FIELD TO FURNACE – A SOCIAL COST-BENEFIT ANALYSIS OF GROWING SWITCHGRASS ON INACTIVE AND UNDERUSED FARMLAND IN NOVA SCOTIA FOR THE RESIDENTIAL HEATING MARKET

by

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The undersigned hereby certify that they have read and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled "FIELD TO FURNACE – A SOCIAL COST-BENEFIT ANALYSIS OF GROWING SWITCHGRASS ON INACTIVE AND UNDERUSED FARMLAND IN NOVA SCOTIA FOR THE RESIDENTIAL HEATING MARKET" by Ryan Duff in partial fulfilment of the requirements for the degree of Master of Development Economics.

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DEDICATION PAGE

This work is dedicated to my late Grandmother, Hilda Duff. I miss you everyday.

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ABSTRACT

Energy crops may present an opportunity to reduce Nova Scotia's Greenhouse Gas emissions by offsetting fossil fuel use and provide economic benefits for farmers. They have also received government policy support. To investigate this opportunity, I conduct a partial social cost-benefit analysis using non-equity weighted monetary valuation of growing switchgrass on inactive and underused farmland in Nova Scotia for local residential heating.

The private net benefit for farmers, processors and consumers is estimated between $24.9 million and $209.9 million. I estimate that the external net benefit to society from the potential reduction in GHG emissions (at $50/tonne CO_2E) ranges from $11.3 million to $72.2 million. This must be taken with caution as the analysis does not account for the entire ecological footprint of the project. While a net benefit to society is suggested, the paper also points to a need for more research surrounding the life-cycle emissions of energy crops.

LIST OF ABBREVIATIONS USED

ALIP	Agricultural Land Identification Project
CO_2	Carbon Dioxide
CO_2E	Carbon Dioxide Equivalents
COMFIT	Community Feed-In Tarrif
G	Gram
GHG	Greenhouse Gas
GJ	Gigajoule
GWh	Gigawatt Hour
Ha	Hectare
HANPP	Human Appropriation of Net Primary Productivity
K	Potassium
Kg	Kilogram
KWh	Kilowatt Hour
Km^2	Kilometer-squared
M^2	Meter-squared
N	Nitrogen
NPP	Net Primary Productivity
NPV	Net Present Value
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs
P	Phosphorous
REAP-Canada	Resource Efficient Agricultural Production Canada
T	Tonne

GLOSSARY

Carbon Dioxide Equivalent	A unit of measurement for various types of GHGs, equiating them to how much global warming that much carbon dioxide would cause.
Disc	A type of plow that uses disc blades for quick, shallow plowing.
Greenhouse Gas	Gases that trap heat when in the atmosphere, such as carbon dioxide and methane. Measured in carbon dioxide equivalents (CO_2E).
Hectare	There are 100 hectares in a square kilometer.
Harrow	Agricultural tool with metal teeth that is used to level land, break up sod, clear weeds, etc.
Lime	A soil additive made from ground up limestone or chalk that reduces soil acidity.
Mow Conditioner	Agricultural machinery that cuts the grass, as well as crushing it to promote faster drying.
Pellet	Small cylinder made of densified material such as wood or grass.
Plow (plough)	Used to make long trenches for planting.
Switchgrass	A type of tall grass native to North America that grows in large clumps.
Tedding	Spreading grass for drying.

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CHAPTER 1 - INTRODUCTION

1.1 People, Energy and Consequences

When people lived in nomadic hunter-gatherer societies, the only energy they required was that to feed themselves and little more. As humanity evolved and became stationary, building structures, growing and breeding food, more energy was required for each person. Now, humanity is using energy at levels never experienced before, fuelled by the historical abundance of easily accessible, cheap and energy-dense fossil fuels. It should come as no surprise then that fossil fuels are still the driving force of the world economy. But while these fossil fuels have allowed for countless advances in human society, they have not come without a cost. By taking hundreds of millions of years' worth of stored carbon from underground and releasing it into the atmosphere in just over a century, we have increased the atmospheric concentration of carbon dioxide to climate-altering levels, a development that could have untold consequences for life as we and other species know it here on Earth.

But energy is required for life, and modern society demands a lot of it every day. So it follows then that we must find a way to generate and consume that energy in ways that emit little or no carbon dioxide and other greenhouse gases into the atmosphere, becoming carbon-neutral or carbon-negative in the process. Unfortunately, no single renewable energy source or technology with the potential to be carbon-neutral or –negative can commercially provide all of the energy that modern societies demand under current conditions. Rather, it will likely be a portfolio of renewable energy sources such as wind, solar, hydro, geo-thermal and biomass in conjunction with an overall reduction in energy consumption through improved efficiency that is necessary to sufficiently displace fossil fuels to the point where catastrophic climate change can be avoided.

Thanks to the increased attention and understanding afforded to climate change, interest and investments in renewable energy are growing at an accelerating pace. Globally, investment in renewable energy (including power and fuels) increased 17% in 2011 to an all-time high of $257 Billion (Frankfurt School of Finance and Management, 2012). While this is encouraging, it will be essential to have investments of even greater magnitude in renewable energy and energy efficiency initiatives if we are to move away from fossil fuels as society's main source of energy. Despite being greater than the $223 Billion spent on new fossil fuel power generation (that figure does not include transportation fuel), we still have a long way to go before our energy is generated and consumed sustainably. In Nova Scotia for example, roughly 57% of our electricity is still generated by burning coal, and 20% from natural gas (Nova Scotia Power Inc., 2012a).

Developing a portfolio of commercially feasible renewable energy sources on such a grand scale is a challenge that has never been attempted before, and will not be simple, quick or inexpensive to achieve, as evidenced by the relatively modest advances in the share of renewable energy gained with such large investments. Yet, despite the difficulties, it is essential that each of the options for generating renewable energy be studied, improved upon and implemented in the most beneficial manner possible. In pursuit of this goal, this paper will examine using a switchgrass (*Panicum Virgatum)* crop to make pellets, a form of solid biomass for space heating energy in particular, using Nova Scotia as the geographic context.

1.2 Agri-Biomass As An Energy Source

In the context of energy, biomass refers to organic matter that is used as a fuel or energy source, especially in a power station for the generation of electricity (Oxford Dictionaries, 2012). It is one source of energy that, if managed properly, should be considered as a primary component in any renewable energy portfolio aimed at reducing greenhouse gas (GHG) emissions. This is due to its potential to be carbon neutral or negative, as well as its potential for commercial success. While greenhouse gases are released when the biomass is combusted in either electricity or direct heat generation, the difference is that the carbon which underpins the GHGs was absorbed from the atmosphere while the biomass was growing, some of which becomes fixed or sequestered in the soil (Girouard et al., 1999) and thus helps to reduce atmospheric GHG concentrations. With fossil fuels, millions of years' worth of carbon that was stored safely underground is being taken and put into the atmosphere, while using biomass simply recycles the carbon that is already there.

Biomass as a source of energy is very versatile, as it can come in a number of forms and can be used for energy in a number of ways. For example, biomass can be used to make transportation fuel like ethanol or biodiesel, space and water heating fuel from wood or grass pellets, or electricity fuel from larger briquettes, which can also be made from wood or grass. Of these uses, biomass for space heating makes sense for a number of reasons. Space heating consumes the second-most energy in Nova Scotia, much of which is provided by fuel oil (a crude oil derivative) and fossil fuel-generated electricity (Hughes, 2007). Thus, it may make more sense to use biomass for direct heat applications, replacing oil furnaces and electricity for heat, due to the superior conversion efficiency, rather than losing energy in additional conversions.

Biomass material can be harvested from a number of different sources, including forestry, forestry waste and agri-biomass, which can come from agricultural waste or purpose-grown energy crops, the subject of this paper. Purpose-grown energy crops are a form of agriculture, and are planted, maintained and harvested similar to food crops. Once harvested, the biomass is then processed into a variety of energy products for a variety of uses, like those previously mentioned.

A number of species can be used for energy crops in Nova Scotia, both woody (trees) and herbaceous (grasses). Some woody examples include a number of varieties of willow (genus *Salix*), alder (genus *Alnus*) and poplar (genus *Populus*), while grasses include reed canary grass (*Phalaris arundinacea*), elephant grass (*Miscanthus giganteus*), timothy-grass (*Phleum pretense*) and switchgrass. Any of these species may be used as an energy crop, and each has strengths and weaknesses that have received significant research attention in recent years from organizations such as Resource Efficient Agricultural Production (REAP) Canada (www.reap-canada.com), Nova Scotia Agricultural College (www.nsac.ca), as well as provincial agriculture departments. The United States has also been conducting considerable research in energy crops, for example a 10-year program researching switchgrass as a "model" dedicated energy crop (McLaughlin & Kszos, 2005). The main goal of that research is to maximize the productivity of the crop by increasing yields and reducing costs, as well as to determine the ecological costs and benefits of using energy crops in order to determine best practices and maximize the overall benefit.

Unfortunately, energy crops have a number of issues that must be addressed if they are to be used at any significant scale and avoid causing more problems than they solve. Because they are a form of agriculture, they often compete for the same land as food crops, or require new land to be deforested, or converted from its current state. As Searchinger et al. (2008) point out, due to land-use change, using biomass for energy could actually result in a warming effect through an increase in GHG emissions. That is, if we simply clear-cut areas of forest in order to grow energy crops, the loss of that GHG absorption and fixation could result in a net increase in GHGs, including any emission reductions achieved via offsetting fossil fuel use. In order to fully understand the impacts of a biomass project and avoid causing harm, a full life-cycle assessment (LCA) would ideally be performed for each project, or group of new projects (Searchinger et al., 2008). However, as Field et al. (2008) argue, that abandoned farmland represents the best opportunity to grow energy crops without a net increase in GHGs, since the land is already cleared and is likely to be easily re-established as productive cropland.

1.3 A Rural Opportunity

There has generally been a trend toward fewer, larger farms, leading to a large supply of farmland that is currently unused or underused. In 1998, Nova Scotia had an estimated 25,000 hectares (abbreviated ha) of inactive farmland, concentrated in the counties of Pictou, Inverness, Colchester and Cumberland (CBCL Limited, 2008). In reality this figure was likely higher, as land that was being used but only marginally would not have been included as "inactive". Other more recent studies have identified even more land. For example, Kungi (2011) looked at land available for grass production and determined that in addition to the 25,000 hectares identified as inactive, much of the land identified as active in that study was actually only being maintained (bushcut) and not actively farmed. Thus, Kungi estimated the amount of land available for energy crop (grasses) production in Nova Scotia without impacting food production would be closer to 60,000 hectares (Kungi, 2011).

Inactive and underused farmland may present a number of opportunities, not only in terms of environmental impacts, but also in terms of helping rural communities economically. As the number of farms has declined and the industry became more consolidated, opportunities for individual, often smaller-scale farmers have declined to the point where many have stopped farming altogether, contributing to the economic struggle of the rural communities that have relied on them for generations (Sparling et al., 2005).

Using inactive and underused farmland to grow energy crops could represent an opportunity to use biomass to potentially reduce greenhouse gas emissions. The farmers that would be growing the energy crops, including those with currently inactive or underused land and the communities that rely on them, could benefit from the additional economic activity, and society could benefit as well if there is indeed a reduction in GHG emissions. To investigate these issues, this paper will use a partial social cost-benefit analysis using non-equity weighted monetary valuation[1] to quantify the private and external costs and benefits, and determine the net benefit to society of growing

[1] This implies that monetary gains are of equivalent value to everyone. Greater need is not accounted for.

switchgrass on inactive and underused farmland in Nova Scotia to produce pellets for the local residential heating market.

1.4 Research Objectives and Social Cost-Benefit Analysis

In determining the net benefit to society of growing switchgrass for the local heating market, the study will seek to answer three core questions:

1. Does a business case exist to profitably use inactive and underused farmland in Nova Scotia to grow switchgrass as an energy crop, and would this result in savings for consumers?
2. Would this practice result in a reduction in GHG emissions, measured in CO_2 equivalents, providing an external net benefit to society, measured in monetary terms?
3. Is it in society's best interests to grow switchgrass as an energy crop in Nova Scotia?

The answers to these questions are essential in determining the social net benefit of switchgrass as an energy crop. The term "net benefit" is used to describe the sum of costs and benefits expressed in monetary terms, and could be positive (a benefit) or negative (a cost). The goal of calculating the social net benefit is to arrive at a single metric for the effect a project has on society as a whole. This is divided into the private net benefit, which is addressed by the first core question, and the external net benefit, which is addressed by the second core question. The third core question combined the two to estimate the effect on society.

The prospect of profitability and consumer savings addressed in the first core question is important to determine if this project would produce a private net benefit, and thus be advisable for private individuals to undertake, as well as for policy consideration by government. Many rural communities in Nova Scotia are struggling economically, which includes those that once relied on agriculture. Should this study suggest a strong business case for growing energy crops on currently inactive or underused farmland, there could be large economic implications for farmers and their communities. Three groups will be examined to determine the private net benefit; farmers, processors and consumers. But while the private net benefit is an important part of the social net benefit equation, we also must consider how the project will affect others, and indeed society as a whole.

The second core question will be used to estimate the external net benefit of switchgrass as an energy crop. The main purpose of using biomass for energy is to improve social well-being by potentially reducing greenhouse gas emissions and being part of the movement to a new low-carbon energy supply mix in order to help avoid catastrophic climate change. This means that when a tonne of GHG emissions is foregone, everyone benefits, not only those directly involved with the project. By quantifying the change in GHG emissions resulting from using switchgrass for space heating and assigning a monetary value to those emissions, we can estimate the external net benefit. The concept of assigning monetary costs to a tonne of GHG emissions will be discussed further later in the paper. This should not be taken to suggest that GHG emissions are the only environmental issue that is important, and indeed other issues such as biodiversity and water quality should be included in a full social cost benefit analysis. However, for the purposes of this paper, only GHG emissions are quantified.

Once the private and external net benefits have been quantified and expressed in monetary terms, they can be added together to determine the social net benefit. In doing so, a number of scenarios could occur. A switchgrass-for-energy project could have both a private and external positive benefit, which would be the ideal case. Alternatively, it could have both a private and external cost, in which case there would be no argument for the project to move forward. However, if there is a private benefit and a social cost, or vice versa, the two must be compared. Even if the project would result in a private loss, it is possible there will be social benefits that outweigh the private loss. In this case, it might then be advisable for the public sector to play a role, in the form of subsidies or some other support, to improve the economics for proponents and ensure that the project does move forward, enhancing societal well-being. Although it will not be covered in this paper, the social net benefits of any project must be compared to other appropriate projects to determine the best possible use of public resources. The private benefit, external cost scenario is likely to be the most controversial, as the good of the many must then be weighed against the good of the few.

1.5 Thesis Outline

The paper will begin with an introduction to energy crops, including an explanation of what they are, how they are grown and processed, how they are used, and environmental considerations that must be taken into account when assessing their use. While brief, the section also includes additional reading on a number of environmental issues. The paper then moves to the analysis of the social costs and benefits, which includes those both private and external. Private costs and benefits are estimated for farmers, processors and consumers, while external costs and benefits examine the GHG impacts of the project.

Finally, the paper finishes with a discussion of the additional costs and benefits that were not included in the analysis but that should be in further research, as well as a discussion of energy crop developments in Nova Scotia before concluding.

CHAPTER 2 - ENERGY CROPS EXPLAINED

This chapter will serve to introduce the reader to the subject of energy crops. It will start by explaining what energy crops are in general, including a brief discussion of the various species that can be used and the various energy products that can be made from energy crops. An essential aspect of energy crops is the accompanying environmental issues in addition to GHG externalities that must be considered with any energy crop initiative, which will conclude the chapter.

2.1 What Are Energy Crops?

As the name implies, energy crops are crops grown for the purpose of using them for energy instead of food. Because plants collect and store energy from the sun as they grow, energy crops are another method of harnessing solar energy. These crops are being considered as a source of energy because they have the potential to offset GHG emissions when they displace fossil fuel use, if they are managed properly (Samson et al., 2008a). It is important to remember that the opportunity cost of the land being used, i.e. its natural state, must be included in any analysis.

As the crops grow, they remove carbon dioxide (CO_2) from the atmosphere through photosynthesis. Of the CO_2 absorbed, some is released back into the air, some carbon (C) is sequestered in the soil the crops are growing in, and some remains in the plant as biomass (Adler, Grosso, & Parton, 2007). When the biomass is ultimately combusted to generate energy, GHGs are released back into the air. However, since the CO_2 was absorbed from the air in the first place, it's possible that energy crops result in a carbon-neutral or –negative cycle. The full life cycle emissions will depend on a number of factors, such as production practices and what land the crop was planted on. However, if the crop is managed in a sustainable way, GHG emission reductions could be realized (Samson et al., 2008a).

Many species of energy crops are planted, maintained and harvested similar to traditional food crops, and some can even use the same equipment as food crops. In fact, "first-generation" energy crops were largely traditional crops such as maize, sugarcane and oil palm seeds (Parrish & Fike, 2009). Once harvested, the crop is processed into one of a number of energy products, such as liquid transportation fuel (ethanol or biodiesel) or solid fuel for heating applications or electricity generation.

While first-generation energy crops were largely traditional food crops, second-generation energy crops have utilized higher-yielding species that are not used for food and can be grown on more marginal land, meaning there could be less competition and impact on food supply (Parrish & Fike, 2009). Nonetheless, it is still possible that economic factors may come into play that cause energy crops to compete with food crops regardless, which would further suggest that active management of the industry is required.

There is a great deal of variation within these second-generation energy crops as far as species that can be used, and also in the products and end uses that each species can be grown and used for. The result is a number of combinations of species and end products, each with its own unique supply chain. While one supply chain may be profitable with a net reduction in emissions, another could be profitable with a net increase in emissions, another could be unprofitable with a net reduction, and so on. This makes it important to take a systems view and look at the entire supply chain of each source individually, rather than assume that what is true for one type is true for another. This will be affected by a number of factors unique to the area the crop will be grown in, such as climate, soil, distance to processing, distance to end market, etc.

Most second-generation energy crop species can first be separated into two categories: woody (trees) and herbaceous (grasses). While the forestry industry likely comes to mind when one thinks about woody biomass, some species can also be supplied by short-rotation woody coppice. Short-rotation woody coppice (SRWC) are tree crops grown on agricultural land, which are then harvested and processed into chips, pellets, briquettes or liquid fuels. Coppicing involves cutting back the original growth after the first year, which results in multiple new shoots of growth, and greater biomass yield. Species are chosen based on their ability to produce biomass quickly, due to their fast rates of growth in available soil and climate conditions (Biomass Energy Centre, 2011). The crops are not harvested every year, but rather in cycles ranging from 3 to 5 years.

Some examples of woody species used for SRWC include willow, poplar and alder. While these species will not be discussed in great detail in this paper, they have a number of benefits that could lead to them being used as part of the total energy crop supply. Keoleian and Volk (2005) look at the life-cycle energy, environmental and economic performance of willow in the United States (U.S.), and suggest that due to its "potential for high biomass production in short time periods, ease of vegetative propagation, broad genetic base, and ability to re-sprout after multiple harvests", it can play a significant role in reducing GHG emissions. The authors also compared it to U.S. electricity generation, and found that willow can achieve reductions in GHG emissions, NO_x, SO_2 and particulate emissions of 70 to 98 percent.

In addition to woody species, certain types of herbaceous forage crops, which are types of grasses, are often used as energy crops (Sanderson & Adler, 2008). Forage grasses have traditionally been used to feed livestock (Small, n.d.), however they are now some of the most extensively studied species for energy crop use (Sanderson & Adler, 2008), and hold several advantages over woody energy crops.

Unlike woody energy crops, grasses can be harvested once or twice a year, providing a more consistent income stream without the need to rotate the crop. In addition, they have relatively lower inputs and costs during production, do not require coppicing to increase yields, and have the benefit of farmer experience since they have been grown as forage crops for many years (Sanderson & Adler, 2008). This experience also means much of the equipment used in production of herbaceous energy crops is already available (Sanderson & Adler, 2008). This last point will likely play a large part in the adoption of energy crops by farmers, as it can significantly decrease the initial investment required. Some examples of grass species used for energy crops are switchgrass, the focus of this paper, as well as reed canary grass, elephant grass, alfalfa grass and others.

In many instances, it appears as though switchgrass is becoming the energy crop of choice. In the United States, it has been researched as the "model" energy crop (McLaughlin & Kszos, 2005), while Samson et al. (2008b) found that switchgrass pellets for bioheat were the best choice for fossil fuel displacement in terms of net energy gain. The Samson study included life-cycle emissions from fossil fuels used during production of the crop, as well as the production of nitrogen (N) fertilizer use in switchgrass production, although it did not include the loss of carbon sinks from land use change.

Despite the advantages of grasses over woody species just described, it should not be assumed they are universally better. For example, grasses are not as dense as woody biomass, and tree species may be easier to establish than grass species like switchgrass, which suffers from competition with other plants (Sanderson & Adler, 2008). This means that the economics of grass energy crops are different than that of woody crops, and so they may be best suited for different energy products and locales than woody energy crops. Indeed, an established energy crop industry will likely consist of a number of species, both grasses and woody, with the species of choice depending on the specific characteristics of the region in which they are being grown. This paper does not make direct comparisons of the yield, cost, GHG emissions and so on between species. However, it should be noted that such a comprehensive comparison of species should be completed in order to achieve the greatest benefit and likelihood of financial and ecological success from any energy crop project.

Growing energy crops generally involves three stages; establishment, maintenance and harvesting. The process required for establishing an energy crop depends largely on what the land was previously used for. In order to plant crops, land must first be cleared of trees, shrubs and other plants that may have been growing there. The more grown-in the land is, the more time and energy will be required to prepare the land. In addition, there may be a larger loss of carbon sequestration from more drastic land use change. As Searchinger et al. (2008) point out, clearing forested land in order to grow energy crops may actually result in a warming effect through increased net atmospheric GHG concentrations, negating the benefits to society (and therefore the purpose) of producing energy crops in the first place. However, by using any land for agriculture, it is being prevented from returning to its natural state. Thus, this opportunity cost must be included in the analysis, even if the land was not in its natural state just prior to the crop being planted.

Sanderson and Adler (2008) describe establishment as a critical phase in energy crop production. Certain crops, switchgrass included, can be slow to establish and may become overwhelmed by other plants, causing the crop to fail. Thus, properly preparing the land and caring for the crop are essential to successful establishment, which usually takes one to two seasons.

Once a switchgrass crop is established, maintenance essentially consists of nitrogen fertilizer application, as no herbicides, pesticides, phosphorous (P) or potassium (K) are typically required during production years (Thomas et al., n.d.). There is also minimal work required on the land itself, as energy crops, whether grasses or SRWC, are perennial and grow back each season during their lifespan. That also means no tilling is required, which is a source of carbon dioxide emissions associated with annual crop production.

Once a year, the switchgrass crop is mowed in order to harvest the biomass. Various strategies for harvesting have been explored, each with its own pros and cons, including fall mow and harvest, fall mow and spring harvest, and spring mow and harvest. The main idea behind harvesting in the spring is to reduce the moisture and mineral content (phosphrous, P; potassium, K; chlorine, Cl and others) of the biomass, both of which reduce the efficiency of processing and combustion. If the moisture content is low enough, over-wintering can eliminate the need for additional drying prior to making pellets, reducing costs. The presence of minerals such as P, K and Cl are harmful to combustion equipment and also produce "clinkers", which are like rocks that form from the melted minerals in the biomass. This is a particular problem when burning grasses due to higher mineral content than wood, and has prevented their widespread adoption (Soberg, 2011). By allowing the grass to sit on the field over winter, called over-wintering, much of the moisture and minerals leach back into the soil (REAP-Canada, 2008).

A drawback from leaving the switchgrass in the field over winter is a lower yield that results from the baler leaving more material behind and from pre-harvest decomposition (Adler, et al., 2006). But despite the lower yields, the higher biomass quality and energy density, more efficient combustion and other benefits could make spring harvesting attractive, particularly if improved baler methods are adopted that reduce the amount of material left behind (Adler, et al., 2006). What is not immediately clear is whether leaving that material behind has benefits that outweigh the reduced yield, such as improved soil quality and reduced need for fertilizer, as well as reduced GHG emission reductions, since C enters the atmosphere as it decomposes. Once the material is collected and baled, it is transported to a processor to be densified, unless the farmer processes it themselves.

Biomass for heating applications can come in a number of forms. At one end, it includes fireplaces and wood stoves that use fairly raw, unprocessed material. At the other end are processed, densified products like pellets and briquettes that can be used in pellet furnaces or boilers, such as those from Harman (www.harmanstoves.com) or LST Energy (www.lst-energy.com). The LST furnace is of particular interest to grass pellet producers because of its built-in solution to the clinker issue. That is, it is able to burn higher-ash (mineral content) grasses more efficiently than other furnaces by constantly agitating the ash, preventing clinkers from forming. However, this may result in an increase in particulate emissions that would need to be investigated.

Biomass pellets from either wood or grass are cylindrical in shape, ranging from 6 mm to 10 mm in diameter. The process essentially involves the raw material being dried[2] in a large drier, ground, and compressed into the cylinder shape. This results in a product that burns more efficiently, is more energy-dense and is easier to transport and handle, particularly over long distances.

2.2 Environmental Considerations

Despite all the benefits of energy crops we've discussed so far, they must be monitored and managed properly to avoid causing significant damage themselves. This damage comes in a number of forms. The first of these issues we will discuss is land use change.

The land use change issue is one of the primary motivations for using inactive and underused farmland in this paper. While not guaranteed, Field et al., (2008) argue that using agricultural land that currently sits unused likely presents the best opportunity to

[2] Depending on the moisture content of the raw biomass, some material may not require pre-drying before being densified. This is usually around 10% moisture.

grow large amounts of energy crops with the fewest adverse impacts. This still must be compared against the next best alternative use for that land however, which would likely be to allow a mixed forest to grow back. This will affect the carbon sequestration ability of the land, biodiversity, soil nutrient levels, and so on. The specific impacts will depend on the crop, land and practices being used, as well as the end-use energy product. For example, the impacts from using switchgrass for direct heat will be different than the impacts from making ethanol from corn. The impacts must also be compared to the impacts from other types of energy in order to determine which source has the fewest adverse effects while providing usable energy for society.

Agriculture in general has a number of additional environmental impacts that must be monitored to limit its adverse effects, some of which will be applicable to energy crops, including the use of fertilizer. Fertilizer production is an energy-intensive process, and much of it is derived from petroleum. Thus, the use of large amounts of fertilizer can result in significant GHG emissions and mitigate the positive impacts of displacing fossil fuel use with biomass from energy crops. In addition, introducing significant amounts of nutrients into ecosystems through farm runoff will have adverse effects as well (Wang et al., 2004). For an example of how non-market items such as water quality are incorporated into social cost benefit analysis, see Alcon et al. (2012).

Biodiversity is yet another concern arising from agricultural activities. As most crops are planted as monocultures, this significantly alters the landscape and the species that are able to live there. While a natural forest or grassland will have a wide variety of species, a monoculture will likely lose some of that biodiversity and therefore some of the ecosystem's functionality. Groom, et al., (2007) argue that by using polycultures of native perennial grasses in addition to switchgrass as opposed to monocultures, the crop would be much more conducive to biodiversity. In addition, the authors suggest that the greater diversity of pollinators present would be beneficial for adjacent crops that require those pollinators, providing an additional ecosystem service.

In order to fully understand a project's total impact, issues such as those just described and others would need to be accounted for throughout the life-cycle of what is being produced. This includes not only the impacts from the direct activities themselves, but also from indirect activities such as the production of materials being used. It should also look at the area surrounding the agricultural land and determine how far the impacts are likely to reach. For example, nearby waterways that would be affected by nutrient runoff would need to be included in the analysis, as well as whether the crop could be considered an invasive species.

CHAPTER 3 - SOCIAL COST-BENEFIT ANALYSIS

This study takes the form of a social cost benefit analysis, using the three core questions outlined above as guidance to come to a conclusion on the appropriate course of action with regard to growing switchgrass as an energy crop on inactive and underused farmland in Nova Scotia. The goal of the paper is to paint as realistic a picture as possible. The portions of the study for which there is insufficient data are addressed by either sensitivity analysis, making assumptions or addressing the issue qualitatively. Regardless, this study explores a potentially exciting opportunity for rural communities in Nova Scotia to improve their economic standing while also potentially contributing to the required reduction in greenhouse gas emissions.

This chapter will start by including the economic theory underlying social cost-benefit analysis. It will then move on to discuss the results of the study, beginning with the costs and benefits borne by those directly involved with the project, including farmers, processors and consumers. The chapter will then discuss the external costs and benefits of using switchgrass pellets for residential heat, followed by a comparison of the private and external costs and benefits to determine the social net benefit of the project.

3.1 The Concept and Economic Theory

The primary motivation behind social cost benefit analysis is to extend private cost benefit analysis to account for monetary and non-monetary costs and benefits arising from a certain project that are borne not only by those directly involved with the project, but by society at large. Private costs and benefits such as production costs and revenue form an important part of the analysis, however this does not account for the external costs and benefits. Because these costs and benefits are external to those involved with the project, they are often not reflected in market prices. These are called “externalities”, which were first referred to as we know them today by Arthur Pigou in his 1920 book *The Economics of Welfare* (Cassidy, 2009).

While projects have private costs and benefits that are analysed by the proponent to determine if the venture would be profitable, externalities are often ignored. Thus, social cost benefit analysis presents a more complete picture of the actual impacts of a project than private cost benefit analysis. Climate change is likely one of the most glaring examples of this, since for the most part project proponents who either increase or reduce GHG emissions neither pay the costs nor receive the benefits from those external impacts of the project.

Social cost benefit analysis involves quantifying and comparing both the private net benefit and the external net benefit (Hanley & Spash, 1993). The private net benefit is essentially a traditional private cost benefit analysis, subtracting the private costs from the private benefits. The external net benefit also subtracts the external costs from the external benefits, however due to the nature of the costs and benefits it can be more difficult to quantify. For example, placing a price on a tonne of GHG emissions or placing a value on biodiversity. This is certainly not a clearly defined concept, however it is necessary in social cost benefit analysis in order to compare the external net benefit to the private net benefit, which is how the social net benefit is estimated.

Like private cost-benefit analysis, it is necessary to account for future benefits and report them in a single metric, called Net Present Value (NPV), which will be discussed more in

Section 3.4. This essentially involves estimating how much a future benefit is worth today by applying a discount rate. If a future benefit is worth less, a greater discount rate is applied. For a more detailed discussion of social cost benefit analysis in general, please refer to Hanley and Spash (1993), as well as Almansa and Martínez-Paz (2010) for a discussion of the importance of discount rates.

3.2 Private Costs and Benefits

The first step in performing this study will be to determine the private costs and benefits related to the project, which will be expressed in the form of profitability for farmers and processors (the producers) and in the form of cost savings for consumers from switching heating sources. That is, can producers make money by growing switchgrass as an energy crop? Will they lose money? Is it cheaper to heat your home using switchgrass pellets than light heating oil or electricity? For consumers, cost is the only criteria accounted for here.

There are several assumptions made for this analysis that should not be taken as representing all real-world scenarios. First, for the sake of simplicity, it is assumed here that farmers and processors are separate entities, and that the farmer sells the raw switchgrass to a processor. In actuality, there may be situations where the farmer is also the processor, or perhaps in a co-op relationship, however that will not be addressed here. In a full cost-benefit analysis, the net benefits to suppliers of equipment, materials and labour should also be included, however that is not included in the scope of this analysis due to time limitations.

Another assumption made here is that the processors sell directly to the consumer. This means there is no retail component between processors and consumers, but rather a direct sales model. In reality, while some biomass processing companies do direct to consumer sales[3], biomass pellets can also be purchased in a wide range of retail stores. Let us now move on to quantifying the private costs and benefits, beginning with farmers.

3.2.1 Farmers

Farmers are assumed to be the first step in the production chain for producing energy crops. While there will be seed producers, etc. that would be further up the supply chain, their private net benefit is not accounted for here. For the purposes of this paper, farmers will be assumed to incur costs from establishing, maintaining and harvesting the crop, and receive a benefit from selling the raw product to processors. This does not entirely represent reality, as subsidies that improve the private benefit for farmers are not included. Determining whether growing switchgrass as an energy crop will improve conditions for farmers is one of the primary motivations for this paper, so estimating the private net benefit for farmers should be considered one of the key results. Before discussing the private costs and benefits accruing to farmers, we will first discuss why the well-being of farmers motivates the paper.

Agriculture is a significant economic driver in many regions, including Nova Scotia (Scott & Colman, 2008). It has been estimated that as of August, 2008, the agriculture sector in Nova Scotia directly generated roughly $150 million in taxes, 6,600 person years of employment, as well as an additional 3,700 person years of employment

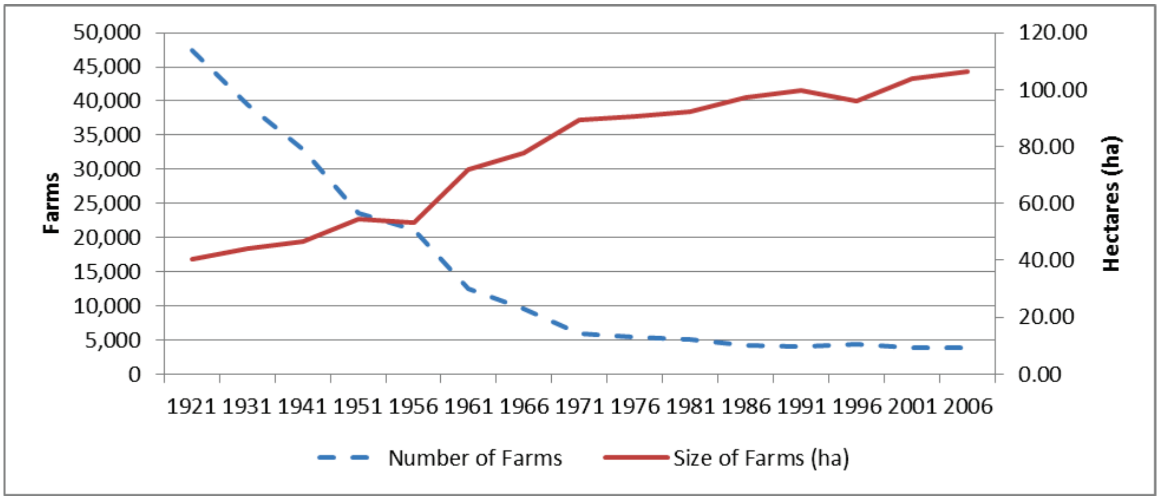
[3] BioEnergy Inc is one such company doing direct sales.

indirectly annually through direct business expenditures of $460 million (Scott & Colman, 2008). This same study estimated that on average, 60% of these expenditures are made within the community in which the farm is located, and 92.5% within the province.

Yet, despite increasing total farm cash receipts, net farm income in Nova Scotia declined by an average of 91% between 1971 and 2008, and has been negative for four of the six years prior to 2008. Other indicators, such as the *expense to income ratio*, *total debt to net farm income ratio* and the *solvency ratio* have all been experiencing negative trends as well (Scott & Colman, 2008).

Over the past number of decades, there has been a marked trend towards fewer, larger industrial farms abroad and in Nova Scotia (Scott, 2008). According to Sparling et al. (2005), this is due largely to globalization in the food supply chain, which means that each farm faces more competition for their products and therefore faces declining prices. This has led to a consolidation of farms in order to achieve economies of scale and keep costs down to remain competitive. Using data from the Census of Agriculture, Scott (2008) shows that in Nova Scotia, the number of farms has declined by 92% since 1921, although the trend has largely stabilized since roughly 1971 (Figure 3.1). She also shows that the average size of a farm, meanwhile, has increased roughly 164% since 1921 (Figure 3.1). While this increase has not plateaued as the decline in the number of farms has, the increase has been slower and steadier for the most part.

Figure 3.1: Number and Size of Farms in Nova Scotia



Source: Adapted from GPI Atlantic, http://www.gpiatlantic.org/pdf/agriculture/landcapacity.pdf

There is no denying that agriculture plays an essential role in vibrant, healthy rural communities. And while it has been argued that increased scale is beneficial since it reduces production costs, the scale argument would be more convincing if either net farm income was rising, food prices were decreasing, or both. However, the opposite is true. Although farms receive less for their product and net farm income is declining, savings have not been passed on to the consumer in the form of reduced food prices, which have actually been rising (Mitchell, 2008).

Under this project, farmers would be growing a switchgrass crop using the process described in Chapter 2, which involves establishment, maintenance and harvesting. They then sell the raw switchgrass to processors, who sell switchgrass pellets to consumers. The private net benefit for individual farmers will be equal to the revenue they receive for the product, minus the costs to grow that product. This is done first on a per hectare basis, and then aggregated to the provincial level. Production costs will be discussed first, followed by revenues. Private net benefits are estimated in Section 3.2.4.

3.2.1.1 Costs of Production, Farming

Similar to traditional crops, the costs associated with growing switchgrass are accrued during establishment, maintenance and harvest. To quantify these costs, figures were taken from three studies; Thomas et al. (n.d.), Kungi (2011) and a study by REAP-Canada (2008) for the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) that used a case study of Nott Farms in Ontario. Given the wide range of scenarios that exist with a venture as complex as agriculture, having multiple estimates can give one a greater sense of reality when comparing. The cost estimates presented in the three papers rely on different assumptions and circumstances. However, comparing them is meant to give a greater sense of the costs that can be incurred and where savings can be had than simply presenting a single estimate.

Thomas et al., (n.d.) describe two scenarios with estimated costs of producing switchgrass in Nova Scotia. The first scenario is one in which the land needed to be cleared of rocks and have lime applied to the soil (Scenario 1), while the second scenario is one in which neither was needed, with lower fertilizer prices as well (Scenario 2). While it is likely that at least some of the land will require lime and rock picking, it is unlikely that all of it will. The costs were estimated based on the experience of the authors, as well as interviews with farmers. Table 3.1 presents the cost items exactly as they appear in Thomas et al., expressed on a per hectare basis[4].

[4] Thomas et al. (n.d.) expressed their estimates on a per acre basis, and there are 2.47105381 acres/hectare.

Table 3.1 Costs of Producing Switchgrass per Hectare, Thomas et al (n.d.)

Establishment Year		
Activity	Scenario 1[5]	Scenario 2[6]
Herbicide (Round-up 1.5 L/acres @ $11/litre)	$40.77	$40.77
Ploughing, 5 furrow (2.5 acre/hour @ $80/hour)	$79.07	$79.07
Disc, 14 foot disc (8.0 acre/hour @ $90/hour)	$44.48	$44.48
Harrowing, 14 foot S-tyne (8.0 acre/hour @ $80/hour)	$24.71	$24.71
Rock Picking	$54.36	$0.00
Land Level	$22.24	$22.24
Lime (3 tonne/acre @ 27.43/tonne plus trucking & spreading costs)	$247.11	$0.00
Fertilizer (250 lbs/acre of 12-24-24)	$360.77	$185.33
Seed	$148.26	$148.26
Planting and Rolling	$39.54	$49.42
Total	$1,061.32	$594.29
Production Years		
Fertilizer (150 lbs/acre of 34-0-0)	$143.32	$84.02
Mow conditioner (6.0 acres/hour @ $90/hour)	$37.07	$37.07
Tedding (10 acres/hour @ $64/hour)	$16.06	$16.06
Racking	$29.65	$29.65
Round Baler (5 acres/hour @ $100/hour)	$98.84	$98.84
Hauling and Unloading	$49.42	$49.42
Total	$374.36	$315.06
Ten-year average cost per hectare	$443.06	$342.98
Yield in oven-dried tonnes per hectare	7.41	8.65
Ten-year average cost per tonne of switchgrass	$59.79	$39.65

In general, establishment costs consist of the cost of preparing the land for planting, and planting the crop itself. The intention is to give the crop that will be planted the best chance of a successful establishment, since there is a certain amount of risk involved at this stage. For example, switchgrass has a reputation for being difficult or slow to establish itself, although Parrish and Fike (2010) argue this can be mitigated with proper attention to seeding and other factors at the outset, such as seed dormancy. In discussing

[5] Scenario 1 represents land that requires rock picking and lime, where fertilizer costs are $1250/tonne in the establishment year and $775/tonne in production years.

[6] Scenario 2 requires neither rock picking nor lime and fertilizer costs of $625/tonne in the establishment year and $500/tonne in production years. The yield is larger because the land is of naturally higher quality. Meant to be demonstrative.

the key factors in increasing the likelihood of success in establishing a switchgrass crop, the Thomas study suggests the omission of fertilizer during planting, as well as controlling weeds to minimize competition for the switchgrass seedlings.

Although the Thomas study suggests not fertilizing during planting, these are included in the cost of establishment in their estimates. The Nott Farms case study from Ontario (REAP-Canada, 2008) does not include the cost of fertilizer in the establishment year, with only nitrogen applied in production years. Removing the cost of fertilizer during the establishment year from the estimates of Thomas et al results in establishment costs of $700.55/ha in Scenario 1, and $408.96/ha in Scenario 2.

Another variation surfaces in the Nott Farms study (REAP-Canada, 2008) when discussing collection and transport of the raw material. The study suggests that using a bulk transporting system instead of baling could save 52% on harvesting costs[7]. In terms of transport costs, which are a portion of harvesting costs, transporting bulk switchgrass to the processor instead of bales can save between 27% and 35%[8]. Table 3.2 details the cost estimates per hectare from the REAP study. Scenario 1 presents the costs for producing and shipping baled switchgrass, while Scenario 2 presents the costs for producing and shipping bulk switchgrass. The goal of the Nott Farms study was to examine switchgrass commercialization strategies and identify areas where cost savings can be found to make it more economically viable (REAP-Canada, 2008).

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[7] Using bulk instead of bales was said to reduce harvesting costs from $20.32/tonne to $9.84/tonne.
[8] The study included $16.02 per oven-dried tonne (ODT) for conventional switchgrass bales, $14.20/tonne for high-density switchgrass bales, and $10.42/tonne for ground switchgrass.

Table 3.2 Costs of Producing Switchgrass per Hectare, Nott Farms

Establishment Year		
Activity		Scenario 1 & 2
Land Rental		$383.01
Cultivation		$74.10
Stone Picking		$7.41
Seed		$132.20
Seeding		$29.64
Packing		$29.64
Herbicide - burndown and broadleaf control		$132.20
Herbicide - Application (2x)		$34.58
Clipping (2x)		$34.58
1st-year operating loan @ 6%		$51.44
Total		$908.80
Production Years		
Activity	Scenario 1	Scenario 2
Fertilizer - 50 kg N/ha 46-0-0	$60.00	$60.00
Custom Work (Fertilizer Application)	$6.00	$6.00
Land Rental	$383.01	$383.01
Mowing	$48.80	$49.40
Baling	$153.85	$0.00
Stacking	$29.04	$0.00
Storing	$45.00	$45.00
Hauling	$144.18	$93.78
Merging	$0.00	$18.53
Bulk Harvesting	$0.00	$45.00
Transport to storage	$0.00	$25.00
Total	$869.88	$725.72
Ten-year average cost per hectare	$782.89	$744.03
Yield in oven-dried tonnes per hectare	9.00	9.00
Ten-year average cost per tonne of switchgrass	$86.99	$82.67

One of the main differences between the two studies is that the REAP study included the cost of land in their estimates, while the Thomas study does not. The cost of land is proving to be a significant cost driver in Ontario (REAP-Canada, 2008), and would likely be the same in Nova Scotia. While some cases will not require land to be purchased if the current owner of the land is the proponent of a switchgrass energy crop, this cost will be included in the analysis to provide a conservative estimate. In any case, even if the land owner is not required to pay a monetary cost for the land, there will be an opportunity cost of what they could alternatively sell the land for. For ease of comparison, and to illustrate the importance of paying close attention to underlying assumptions and practices, Table 3.3 presents the establishment and production year costs per hectare from each of the studies as they originally appear.

Table 3.3 Comparison of Cost Estimates

	Establishment Year	
	Scenario 1	Scenario 2
Thomas Study	$1,061.32	$594.29
Nott Farms	$908.80	$908.80
	Production Years	
	Scenario 1	Scenario 2
Thomas Study	$374.36	$315.06
Nott Farms	$869.88	$725.72

Note that the scenarios in each study include different cost items, and so are not directly comparable. Table 3.3 is meant to show how the inclusion of different items can alter how the costs are presented, and so must be paid careful attention. Clearly, one could come to quite different conclusions about the economic viability of growing switchgrass if these estimates are assumed to be equal with respect to assumptions and circumstances. For example, Scenario 2 during the establishment year in the Thomas study does not include rock picking or land costs, but it does include fertilizer. Attempting to detail in the text what the differences are between the studies in each scenario could become quite cumbersome and confusing. To simplify matters, let us now look to Table 3.4 for a summary of what costs are included in each case.

Table 3.4 Comparison of Cost Items Included

	Establishment Year		Production Years	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2
Thomas Study	Herbicide	Herbicide	Fertilizer	No Difference
	Ploughing, 5 furrow	Ploughing, 5 furrow	Mow conditioner	
	Disc, 14 foot disc	Disc, 14 foot disc	Tedding	
	Harrowing, 14 foot S-tyne	Harrowing, 14 foot S-tyne	Racking	
	Land Leveling	Land Level ing	Round Baler	
	Fertilizer	Fertilizer	Hauling and Unloading	
	Seed	Seed		
	Planting and Rolling	Planting and Rolling		
	Lime			
	Rock Picking			
Nott Farms	Land Rental	No Difference	Fertilizer	Fertilizer
	Cultivation		Custom Work (Fertilizer Application)	Custom Work (Fertilizer Application)
	Stone Picking		Land Rental	Land Rental
	Seed		Mowing	Mowing
	Seeding		Storing	Storing
	Packing		Hauling	Hauling
	Herbicide - burndown and broadleaf control		Baling	Merging
	Herbicide - Application (2x)		Stacking	Bulk Harvesting
	Clipping (2x)			Transport to storage
	1st-year operating loan @ 6%			

The costs included in Table 3.4 should be compared both vertically and horizontally within the same time period. That is, for the establishment year, the two scenarios within a study should be compared (horizontally), as well as the differences between the studies (vertically). For a description of each activity, please refer to the Glossary at the beginning of the paper. To summarize, the difference between scenarios in the establishment year for the Thomas study is the requirement for rock picking and lime, while there is no difference for the Nott Farms study. Between studies, rather than compare each individual item, we will assume that similar activities in farming have simply been given differing titles, and focus on the main differences. The Nott Farms study includes land rent and an operating loan, which neither scenario in the Thomas study does, as well as stone (rock) picking, which Scenario 2 in the Thomas study does not. The Thomas study includes lime and fertilizer in Scenario 1 and only fertilizer in Scenario 2, which the Nott Farms study does not.

For production years, there is no difference between scenarios in the Thomas study[9]. For the Nott Farms study, Scenario 1 includes baling and stacking, where Scenario 2 includes merging, bulk harvesting and transport to storage. Between studies, the main difference seems to be the harvesting method of bales versus bulk, as well as the cost of land. While both studies include hauling, these costs are much lower in the Thomas study, even compared to bulk transport. At this time, it is not clear which assumptions the Thomas study relied on to estimate the cost of hauling, however this would be necessary to do a true comparison between the two.

It should be clear at this point that the underlying assumptions in a study can greatly influence the figures reported. For further comparison, the Kungi (2011) study also includes cost estimates for producing energy grasses. Table 3.5 details the costs reported in the Kungi study, which examined the cost of grass production as livestock feed at a farm in West Hants, Nova Scotia.

[9] Note that the cost of fertilizer is included in both scenarios, however the cost is lower in Scenario 2.

Table 3.5 Costs of Producing Switchgrass per Hectare, Kungi (2011)

Establishment Year		Production Years	
Activity	Cost	Activity	Cost
Plow	$58.37	Fertilize	$12.90
2 × Disc	$65.04	Mow	$32.32
Land Level	$31.58	Bale (3 acres per hour)	$64.62
Fertilize	$12.90	Haul	$99.06
Seed	$31.48	Fertilizer	$74.13
Mow Weeds	$35.41	1/3 cost to spread ashes	$32.12
Fertilizer	$185.33	Land rent	$370.66
Grass Seed	$207.57		
Land Rent	$370.66		
Total	$998.33	Total	$685.82
Ten-year average cost per hectare			$717.07
Yield in tonnes per hectare			7.41
Ten-year average cost per tonne of switchgrass			$96.77

The cost of establishment per hectare in the Kungi study is $998.31, while for the Nott Farms study it is $908.80. Both of these studies include the cost of land in the estimate, however Kungi includes fertilizer where Nott Farms does not. Additionally, while Nott Farms includes the cost of rock picking, Kungi does not. The Thomas study estimated establishment year cost per hectare of $1,061.32, however this included fertilizer at a higher cost, rock picking and lime, and did not include the cost of land. While the different fertilizers used among the three studies could affect the yields, there is not enough information immediately available to determine whether that is indeed the case. What is clear from looking at Tables 3.3 and 3.5 is that the three studies do have similar cost estimates for establishment under certain scenarios, while the costs of production have larger differences.

For production years, Kungi estimates costs of $685.82 per hectare, while the Nott Farms study estimates $869.88 for the baling scenario, and the Thomas study estimates $374.36

not including land costs. If the same land costs applied to Kungi are applied to Thomas, we get an estimate of $745.02.

In estimating the private net benefit associated with farming switchgrass, it will be necessary to decide on a model to estimate the costs of production per hectare. Given the range of items included in each model and the costs assigned to similar items, there is certainly a lot to choose from. While some comparisons and analysis of the differences between the three studies were performed in this section, this was simply meant to introduce the information that would be drawn from in order to construct a custom model that is judged to be representative of the costs, taking multiple sources of information into account. It also served to demonstrate the range of estimates that have been made surrounding costs, and how they vary with underlying assumptions.

In order to construct the custom, standardized model, a number of decisions had to be made about which costs to include and which ones to omit. Ideally, sensitivity analyses would have been conducted around each item, however for a paper of this scope that simply was not practical. The result is a model which is based primarily on the model from Thomas et al (n.d.), with adjustments. This includes removing the cost of fertilizer and adding the cost of an operating loan from the Nott Farms study in the establishment year, and including the cost of land in both the establishment year and production years. The base model to be adjusted could have come from any of the papers, however Thomas et al. (n.d.) was chosen first because it uses Nova Scotia as the geographic context, and also because of a connection with REAP-Canada, from which information was used for other portions of this study. The results of the custom model are detailed in Table 3.6.

Table 3.6 Costs of Producing Switchgrass per Hectare per Year, Custom Model

Establishment Year (Year 1)	
Cost of land	$370.66
Rock Picking	$54.36
Land Level	$22.24
Herbicide (Round-up 1.5 L/acre @ $11/litre)	$40.77
Ploughing, 5 furrow (2.5 acre/hour @ $80/hour)	$79.07
Harrowing, 14 foot S-tyne (8.0 acre/hour @ $80/hour)	$24.71
Disc, 14 foot disc (8.0 acre/hour @ $90/hour)	$44.48
Lime (3 tonne/acre @ 27.43/tonne plus trucking & spreading)	$247.11
Seed, planting and rolling	$187.80
1st-year operating loan	$51.44
Total	$1,122.64
Production Years (Years 2-10)	
Fertilizer (150 lbs/acre of 34-0-0@775/tonne plus spreading)	$143.32
Mow conditioner (6.0 acres/hour @ $90/hour)	$37.07
Tedding (10 acres/hour @ $64/hour)	$16.06
Racking	$29.65
Round Baler (5 acres/hour @ $100/hour)	$98.84
Hauling and Unloading	$49.42
Cost of Land	$370.66
Total	$745.02
Ten-year average cost per hectare	$782.78

For an individual farm, the total cost of production will depend largely on the size of the farm and the yields for that site. So, while certain items will cost roughly the same, individual farms will have different cost structures based on the particular characteristics of that farm. For the purposes of this paper however, it was necessary to use a model such as this in order to come to some sort of conclusion about farmers' private profitability from growing switchgrass. Putting these costs on a per tonne of output basis is also beneficial, which depends on yields per hectare.

Yields are an essential part of any farming operation, and refer to the amount of output received for a given amount of land, which we are defining as oven-dried tonnes per hectare[10]. In reality, output will vary by county, indeed by farm, depending upon a large number of dynamic factors, such as soil conditions, rainfall and other climate and site-specific characteristics. The yield of switchgrass will likely be different in Colchester County than it will in Cape Breton County, and so on. Unfortunately, data at this level of detail is not currently available, so assumptions will be made with regard to yields, with an average yield being used for the province, based on existing literature. This is likely the most prudent approach, since yields can be linked to costs. For example, in Thomas et al (n.d.), incurring the additional expense of adding lime to the soil improves the yield in comparison to when it is not. Similarly, when the cost of land is taken into account, land with higher yields will likely have higher market value than marginal land.

After reviewing the estimated yields from the Kungi (2011), Thomas (n.d.) and Nott Farms (2008) studies, it appears likely that the switchgrass yield in Nova Scotia will be somewhere between 7.5 and 10 tonnes per hectare. While some studies, such as McLaughlin and Kszos (2005) have found significantly higher average yields, as high as 23 oven-dried tonnes per hectare in areas of the United States, this study will assume the yields presented in the Thomas, Kungi and Nott Farms studies since they are more geographically relevant, and may present a more reasonable estimate. In addition, Thomas et al (n.d.) point out that tests in Ontario and Quebec have been producing yields between 8 and 10 tonnes per hectare. Thus, sensitivity analysis will be performed around the yields in those studies between 7.5 and 10 tonnes per hectare, as well as a lower yield of 5 tonnes per hectare for given costs of production to illustrate the effect yield has on

[10] Tonnes and oven-dried tonnes will be used interchangeably throughout the paper.

the private net benefit for all groups. This occurs through higher revenue per hectare, as well as through lower average production costs.

As shown in Table 3.6, we see estimated establishment and production year costs per hectare of $1,122.64 and $745.02, respectively, which are equal to a ten-year average annual cost of $782.78 per hectare. This ten-year average cost per hectare is then used to calculate the ten-year average costs per tonne for various yields per hectare, which are displayed in Table 3.7.

Table 3.7 Ten-year Average Annual Production Cost per Tonne of Switchgrass

Switchgrass Yield (tonnes/ha)	Ten-year Average Production Cost per Tonne
5	$156.56
7.5	$104.37
9	$86.98
10	$78.28

When costs per hectare are taken as given, the yield per hectare can have a significant effect on the average costs of production per tonne of output. However, it is also possible, indeed likely, that obtaining higher yields leads to higher costs per hectare, which muddies the picture somewhat. An example of this would be the application of more fertilizer. Since it is outside the scope of this paper to estimate the extent to which that is the case, the figures in Table 3.7 will have to suffice for now. In addition to yields, the price per tonne of switchgrass will be an important determinant in whether a switchgrass operation is economically viable, and will be explored further in the next section on private benefits.

To estimate total private net benefits, both total costs and total revenue will be required, which means the costs reported here must be aggregated to the provincial level. This will be done by multiplying the costs per hectare by the total number of hectares being used to produce switchgrass. For provincial private net benefit, the yields are irrelevant, since the costs were originally measured on a per hectare basis and the cost per tonne was only estimated using the cost per hectare.

There have been a number of estimates regarding the amount of land available for growing energy crops without impacting either food production or clearing more forested land. This amounts to land that is already cleared, likely for previous agriculture, that is now sitting unused or underused. First, let us begin with the Agricultural Land Identification Project (ALIP).

The ALIP was completed in 1997, and used geospatial data to identify the amount of farmland being used for various purposes. One of those was inactive farmland, of which the program identified roughly 25,000 hectares. Recall that the problem with this, according to Kungi (2011), is that there is a substantial amount of land that looks as though it is being actively farmed, however it is actually only being kept clear of alders and other species that colonize unmanaged fields for some future purpose, which is called bushcutting. To estimate the amount of land that is actually available for energy crop production, Kungi used the ALIP data as a starting point, and then estimated the amount of additional land that would be available. He did this by using both personal interviews with farmers and a personal, visual assessment of land along highway 215 in West Hants, Nova Scotia. He estimated that in West Hants, there were roughly 2,700 hectares available. He then extrapolated using the same formula for Nova Scotia, leading to an estimate of 60,700 hectares available for energy crops[11]. While it's unlikely that all of this land would be used for energy crops, Kungi's estimate represents a substantial

[11] This is equal to 1.1% of Nova Scotia's land area of 55,491 km^2 or 5,549,100 hectares.

amount of land, and even a portion of it being used for this purpose could produce significant amounts of biomass.

For this study, we will use Kungi's estimate as the high end of available land, to which will be applied various land usage rates to estimate the effect that variable has on aggregated costs and benefits, and thus on private net benefit. At this point yields will not have any effect, since costs were estimated on a per hectare basis. Table 3.8 details the total costs for the province for varying amounts of land used for switchgrass, after which the paper will move to a discussion of the benefits associated with farming switchgrass as an energy crop. This will be compared to the private costs to estimate the private net benefit in Section 3.2.4.

Table 3.8 Total Costs of Production, Nova Scotia

Land Usage Rate	Cost
25%	$11,878,757
50%	$23,757,513
75%	$35,636,270
100%	$47,515,027

3.2.1.2 Revenue (Benefits) Generated, Farming

After discussing the costs in the previous section, this section will discuss the benefits, which we will assume to be the revenue generated from selling the raw material. That is not to say there would not be other benefits, however those would largely be difficult to estimate. It is entirely possible that the farmers have been earning income in other ways while the farmland sat unused or underused, however due to the difficulty in coming up with any sort of realistic estimate for this, no opportunity costs will be deducted from the benefit of growing switchgrass.

Potential revenue will be calculated by first multiplying the expected output in tonnes per hectare by the expected price. This will give us a figure for revenue per hectare, which will then be multiplied by our estimate of the amount of land that we are estimating will be used to grow switchgrass to estimate the total revenue for the province. This means that there are three aspects that must be investigated to calculate revenue; yield, price and available land. Yields and available land were discussed in the previous section, so here we will discuss price.

Two approaches could be considered with regard to estimating price. The first is to use existing estimates as to the price farmers can expect to receive per tonne of their raw material. The second is to use the cost estimates, such as those in Table 3.7, and apply a defined margin to determine what price farmers would need to receive per tonne of raw material in order to make the operation viable. Of course, one must consider that there may be a trickle-down effect in play. That is, farmers will be selling to processors, who sell to consumers. Thus, the price that farmers actually receive for the raw material will depend on the price processors are able to receive for their value-added product from consumers. If processors receive a lower price for their product, they will need to cut costs at some point in their operation, and it is entirely likely that will be in the form of a reduction in the price they are willing to pay for raw material from farmers. If the price farmers receive for the raw material decreases, the likelihood of remaining economically viable is reduced unless the farmers can find other areas to reduce costs, or accept lower margins. For the purposes of this study, we will take our average production costs per tonne of switchgrass and apply a margin of 20% to determine the acceptable price. This is actually more of a demonstrative exercise for farmers' private net benefit, since the cost per tonne was estimated using the cost per hectare. This means that applying a preferred margin to the cost per tonne is essentially the same as applying a preferred margin to the cost per hectare, as revenue per hectare will remain constant, all else equal. The cost per does prove necessary for estimating the private net benefit for the two remaining groups.

According to Kungi (2011), who estimated a yield of 7.41 tonnes per hectare, farmers must receive a price of $106/tonne in order to cover their expenses, including the annualized establishment costs. This is the same as looking at the ten-year average production costs, which includes both the establishment costs and nine years of production, since all of these studies point to at least a 10-year life span for a switchgrass stand. Another study in Ontario by the Western University Research Park, Sarnia-Lambton Campus (Oo et al., 2012) for the Ontario Federation of Agriculture found that the acceptable farm gate price of switchgrass was $137.50/tonne. This is similar to a margin of 20% applied to the roughly $106/tonne costs in Kungi, which would result in an acceptable farm gate price of $127.20. Similarly, using our custom model and the various yields being analysed, we can estimate a range of acceptable farm gate prices per oven-dried tonne of raw switchgrass. The results are presented in Table 3.9.

Table 3.9 Acceptable Farmgate Prices per Tonne of Switchgrass

Switchgrass Yield (tonnes/ha)	Acceptable Price/tonne
5	$187.87
7.5	$125.25
9	$104.37
10	$93.93

Depending on yields, the minimum acceptable price for a tonne of raw switchgrass can vary substantially. Since average production costs are being taken as given on a per hectare basis, the change in the acceptable price is proportional to the change in yield.

Hence, if we were to construct a dynamic model wherein production costs changed with yields, we may find different results. Another factor to consider here is that because the acceptable price per tonne declines by the same proportion as yields are increasing, we are essentially holding revenue per hectare constant. We can find this by multiplying 5 tonnes/ha by $187.87/tonne to get $939.35/ha, and we would find the same result with any other combination of yield and price. The difference is that processors are more likely to pay a lower price for a tonne of switchgrass, meaning farms with higher yields are more likely to be economically viable, and potentially rendering farms with lower yields and higher prices unviable.

In addition, what we calculated here is the minimum acceptable price to maintain a 20% margin. The market will likely set the price per tonne it is willing to pay for switchgrass, which will also depend on substitutes. For those farms that are able to sell for prices which processors are willing to pay, their actual margin may be greater than 20% based on our estimated costs of production. Thus, higher yields would lead to higher revenues per hectare if the price consumers are willing to pay is higher than the minimum acceptable price.

While yields and price are essential components, the total private net benefit will also be determined by the total amount of land used to grow switchgrass in Nova Scotia. Table 3.10 presents the total revenue for Nova Scotia under various land usage rates, which are multiplied by the total amount of available land, 60,700 hectares, and by the amount of revenue per hectare, which we know is $939.35 using only minimum acceptable prices.

Table 3.10 Total Farmer Revenue, Nova Scotia

Land Usage Rate	Revenue
25%	$14,254,636
50%	$28,509,273
75%	$42,763,909
100%	$57,018,545

Under the assumptions made in this paper, the total revenue that could be generated if all available land was used is $57 million. If the more reasonable estimate of 75% of the land is used, revenue would still be a substantial $43 million. However, if government programs aimed at making this more attractive were instituted, without targeting land outside what was identified here, both the land usage rate and the revenue would likely increase. At this point, we now move on to discuss the private costs and benefits accruing to the processors of switchgrass feedstock. Comparing these revenues to production costs, the estimated private net benefit, or profit, ranges from $2.4 million to $9.5 million.

3.2.2 Processors

Processors are an essential component in the biomass supply chain, producing value-added products from raw material, which in this case is sourced from farmers. The processors incur costs when they purchase raw material and process it into a densified product that is used in various energy applications. Pelletizing the biomass has a number of advantages over the raw material, including decreased moisture content, increased energy density and greater homogeneity of chemical composition in the end product than the raw biomass, which are beneficial during combustion and increase combustion efficiency (Sultana et al., 2010), as well as lower private and external[12] transport costs.

For this paper, it is assumed that the processor is selling a grass pellet for residential heating directly to consumers, bypassing the retail market. While at least a portion of

[12] External transport costs refer to costs borne by society in general, such as GHG emissions.

pellet sales occurs in the retail market, it is a starting point in quantifying the full social net benefits associated with replacing existing home heating fuels with grass pellets. We will first discuss the costs associated with processing biomass into energy products, followed by the benefits, which are assumed to be limited to the revenue generated from the sales of switchgrass pellets.

3.2.2.1 Costs of Production, Processing

The cost of producing a tonne of biomass pellets depends on the material being processed, the moisture content and cost of that material, and the capacity of the processing plant. Since in this study we take our material and moisture content as givens, the only variables then are the capacity of the plant and the minimum acceptable farm gate price for switchgrass. We will look at three plant capacities; a smaller, 2 tonne/hour (t/h) plant, a medium-sized 6 t/h plant and a larger, 10 t/h plant. The hourly pellet output is the common unit of comparison, while the annual output will depend on the usage rate, which is the number of hours the plant is being operated annually. We will assume an annual usage rate of 85%, which is the figure Mani et al (2006) use when looking at pellet production costs. This is a reasonable estimate, since it accounts for some downtime with equipment. It is assumed that only one size of plant is distributed across the province to process the available switchgrass, rather than the more likely scenario where there are different plant sizes in different regions, depending on how much switchgrass each region is producing. While necessary for this study due to scope, this type of detailed analysis would be needed to more accurately estimate provincial private net benefit.

In order to estimate the production costs per tonne of pellets, the baseline data from Mani et al (2006) was used. Total production costs were reported as roughly $100/tonne for a 2 t/h plant, $51 for a 6 t/h plant and $41 for a 10 t/h plant in 2004 U.S. dollars, however a detailed breakdown was only given for the 6 t/h plant. In order to obtain usable estimates for this paper for all three plant sizes, a number of conversions and adjustments had to be made. The average cost of production for the 6 t/h plant as reported in Mani et al. (2006), as well as the adjustment steps and the custom production cost model are presented in Table 3.11, with a detailed explanation to follow

Table 3.11: Baseline Costs per Tonne of Pellet Production, 6 tonnes/hour

Operation	2004 US$	2004 CAN$	2012 CAN$	Custom Model
Raw material	$10.00	$13.00	$12.09	$197.76
Transportation	$9.73	$12.65	$11.76	$0.00
Drying operation	$10.30	$13.39	$12.45	$0.00
Hammer mill	$0.95	$1.24	$1.15	$1.15
Pellet mill	$3.31	$4.30	$4.00	$4.00
Pellet cooler	$0.34	$0.44	$0.41	$0.41
Screening	$0.16	$0.21	$0.19	$0.19
Packing	$1.93	$2.51	$2.33	$2.33
Pellet Storage	$0.08	$0.10	$0.10	$0.10
Miscellaneous equipment	$0.76	$0.99	$0.92	$0.92
Personnel cost	$12.74	$16.56	$15.40	$15.40
Land use and building	$0.26	$0.34	$0.31	$0.31
Total cost	$50.56	$75.86	$70.55	$222.58

First, the figures had to be placed in 2004 Canadian dollars by using the average 2004 CAN/US exchange rate of 1.3 (Bank of Canada, 2012). Then, using the Canadian CPI for machinery and equipment, the numbers were converted to 2012 Canadian dollars (Statistics Canada, 2012). This involved multiplying the 2004 figure by 0.93, which means that prices have actually declined since 2004. While it is not immediately clear why this is the case, it is taken as given since the data was reported by Statistics Canada.

Finally, to use the numbers in this analysis, the raw material, transportation and drying figures were replaced. The baseline raw material cost used is the minimum farm gate price that farmers require with a yield of 5 t/ha from Table 3.9. Since a tonne of raw material produces .95 tonnes of pellets, the cost of a tonne of raw material was divided by .95 to find the cost of raw material for a tonne of pellets. Also important is the fact that switchgrass material, compared to other biomass fuels like wood, does not need to be dried before processing since the moisture content is already low enough if it is over-wintered, which is the assumption here. Hauling the raw material to the processor was included under the cost of farming, but we assume the processor pays for transport of the finished product. Thus, the transportation cost is temporarily removed and re-inserted later in the analysis. While different-sized plants would likely have different transportation costs from varying distances to customers, here we assume the same transportation cost for each plant. The transportation cost per kilometer is taken from Mani et al (2006), applied to an distance to customer of 50km later in the analysis, and this cost proves to be substantial[13]. These processing and transportation costs were calculated using sawdust, so switchgrass may have slightly different results. However, this is assumed to provide a reasonable approximation.

Now that we have the detailed cost estimate for the 6 t/h plant in the format we need, we can use the cost ratios from these estimates to complete our estimates for the 2 t/h and 10 t/h plants. Mani et al., (2006) reported the total cost but not the details for each of those plants, however those need to be adjusted to account for our scenario. First, we account for what we know; the raw material and transportation costs remain the same as the 6 t/h

[13] Mani et al (2006) use $9.39/7.5km not including the capital cost of the truck, which is equal to $1.25 per km. If the plant is 100km from the source, this adds $125 per tonne to the cost for the processor.

plant, and the authors detail the personnel cost as $4/tonne ($4.84 in 2012 CDN$) for the 10 t/h plant and $16/tonne ($19.34 CDN$) for the 2 t/h plant. Since we will need to remove the drying cost from the total cost for each of the 2 t/h and 10 t/h plants later but the exact figure was not provided, it had to be estimated by applying the same ratio as the 6 t/h plant for the drying cost over the unknowns, which are the drying costs plus the remaining costs. To estimate the unknowns, we can use the total cost less raw material, transportation and personnel[14], which results in a drying cost to unknowns ratio of 57%.

The drying costs plus remainder for the 2 t/h and 10 t/h plants were $64.27 ($100-$10-$9.73-$16) and $17.27 ($41-$10-$9.73-$4) in 2004 US$, respectively. Thus, 57% are the drying costs, equal to $36.63 and $9.84 for the 2 t/h and 10 t/h plants, respectively. Now, we know the raw material and transportation costs, which are assumed to be the same as the 6 t/h plant, as well as the drying and personnel costs for the 2 t/h and 10 t/h plants. This will allow us to estimate the "remainder" of the costs for each capacity, which will be carried through to the custom model along with the personnel costs, while the raw material and transportation costs will be replaced.

Mani et al., (2006) estimated that the total cost per tonne for the 10 t/h plant is $41 in 2004 US$ or $49.57 in 2012 CDN$. In CDN$, this is estimated to be comprised of $12.09 raw material, $11.76 transportation, $11.90 drying and $4.84 personnel, the first two of which are the same as the 6 t/h plant, while the personnel cost is given in 2004 US$ in Mani et al. (2006) and the drying cost was just estimated. The remainder then is $8.98, which is carried through to the custom model. The custom model cost per tonne of switchgrass pellets produced includes an estimate of the cost of raw material, no

[14] Equal to drying cost/(total cost-raw material-transportation-personnel)

transportation (to be added later) or drying costs, and the personnel and remainder costs estimated by Mani et al (2006). To estimate the cost of raw material, the minimum farm gate price per tonne of raw switchgrass at a yield of 5 tonnes/ha was adjusted to account for the loss in yield in the pelleting process, which was 5% (Jannasch et al., 2001a). The same procedure is repeated for the 2 t/h plant, and the results of the costs per tonne for each plant capacity are presented in Table 3.12.

Table 3.12 Costs per Tonne of Pellet Production, All Plants, 2012 CDN$

Operation	2 t/h	6 t/h	10 t/h
Raw material	$197.76	$197.76	$197.76
Transportation	$0.00	$0.00	$0.00
Drying operation	$0.00	$0.00	$0.00
Personnel cost	$19.34	$15.40	$4.84
Remainder	$33.41	$9.42	$8.98
Total	$250.51	$222.58	$211.57

Going from 2 t/h to 6 t/h produces a drop in production costs of $27.93/tonne (11.1%), while adding the same 4 t/h capacity to the 6 t/h plant reduces costs by only $11.01 (4.9%). Although we assumed here that farmers paid for the transportation to the pellet plant, the processor would still be required to pay for the transport to the customer in most situations. So, the proximity of the pellet plant to its customers will have an impact on how profitable the venture is.

If we use the estimate from Mani et al (2006) to calculate the travel cost per kilometer per tonne, we come up with $1.25. So, if the pellet plant is an average of 50 km from their customers, we can add $78.25 to the production costs. This brings us to total production costs of $328.76/tonne for the 2 t/h plant, $300.83/tonne for the 6 t/h plant and $289.82 /tonne for the 10 t/h plant when switchgrass yield is assumed to be 5 t/ha with minimum acceptable farm gate price of $187.87/tonne. Table 3.13 shows the various production costs with different raw material costs, including the cost of transporting pellets 50km. Recall that Table 3.9 presents the minimum acceptable farm gate price for a tonne of raw material.

Table 3.13 Costs per Tonne of Pellet Production, 2 t/h, 6 t/h and 10 t/h Plants.

Switchgrass Yield (tonnes/ha)	2 t/h	6 t/h	10 t/h
5	$328.76	$300.83	$289.82
7.5	$262.84	$234.91	$223.90
9	$240.87	$212.94	$201.93
10	$229.88	$201.95	$190.94

Using an 85% plant capacity usage rate, the 2 t/h plant would produce 14,892 tonnes of switchgrass pellets per year. If we assume that the pellet yield is 95% of the original feedstock input[15], the plant would require roughly 15,675 tonnes of feedstock. Similarly, a 6 t/h plant under the same assumptions would produce 44,676 tonnes of pellets and require roughly 47,027 tonnes of feedstock, while a 10 t/h plant would produce 74,460 tonnes of pellets and require 78,379 tonnes of feedstock. Given available feedstock, the number of plants required to process this feedstock will vary with plant capacity. Table 3.14 presents the total cost per plant to produce the pellets. This will be combined with the total number of plants required to estimate the total provincial costs.

Table 3.14 Cost of Pellet Production per Plant, 2 t/h, 6 t/h and 10 t/h Plant Sizes

Switchgrass Yield (tonnes/ha)	2 t/h	6 t/h	10 t/h
5	$4,895,894	$13,439,881	$21,579,997
7.5	$3,914,233	$10,494,897	$16,671,690
9	$3,587,012	$9,513,236	$15,035,588
10	$3,423,402	$9,022,405	$14,217,537

As the switchgrass yield increases, farmers are able to accept lower prices for the raw material, causing the cost of producing a tonne of switchgrass pellets, and therefore the

[15] Corresponds to the 5% loss in yield during the pelleting process from Jannasch et al. (2001a)

total cost per plant to decline. These figures must then be aggregated to the provincial level to be used in total private net benefit calculations.

In order to aggregate this to the provincial level, some strong assumptions must be made. That is, for ease of calculation, we will assume a standard plant size will be adopted across the province, estimate how many of the plants will be required to process the amount of available raw switchgrass, and multiply the cost per plant by the number of plants required. In reality, there would likely be plants of various sizes located around the province, depending on how much raw material was being produced in certain regions as well as where the switchgrass pellets were being utilized. Table 3.15 presents the number of plants required below[16].

Table 3.15 Number of Plants Required to Grow Available Switchgrass

		Land Usage Rate			
		25%	50%	75%	100%
2 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	4.8	9.7	14.5	19.4
	7.5	7.3	14.5	21.8	29.0
	9	8.7	17.4	26.1	34.9
	10	9.7	19.4	29.0	38.7
6 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	1.6	3.2	4.8	6.5
	7.5	2.4	4.8	7.3	9.7
	9	2.9	5.8	8.7	11.6
	10	3.2	6.5	9.7	12.9
10 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	1.0	1.9	2.9	3.9
	7.5	1.5	2.9	4.4	5.8
	9	1.7	3.5	5.2	7.0
	10	1.9	3.9	5.8	7.7

[16] This is equal to the total amount of switchgrass available divided by the amount of raw material feedstock required by each plant size to produce the switchgrass pellets.

Now that we have estimates of the number of plants that will be required under various circumstances, we can use the costs per plant estimated previously to calculate the total costs for the province, presented in Table 3.16.

Table 3.16 Total Costs of Production for Processors, Nova Scotia

		Land Usage Rate			
		25%	50%	75%	100%
2 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	$23,698,625	$47,397,251	$71,095,876	$94,794,501
	7.5	$28,420,325	$56,840,650	$85,260,975	$113,681,300
	9	$31,253,345	$62,506,689	$93,760,034	$125,013,379
	10	$33,142,025	$66,284,049	$99,426,074	$132,568,098
6 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	$21,684,372	$43,368,745	$65,053,117	$86,737,489
	7.5	$25,399,249	$50,798,497	$76,197,746	$101,596,995
	9	$27,628,174	$55,256,349	$82,884,523	$110,512,698
	10	$29,114,125	$58,228,250	$87,342,375	$116,456,500
10 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	$20,890,574	$41,781,148	$62,671,722	$83,562,295
	7.5	$24,208,612	$48,417,223	$72,625,835	$96,834,446
	9	$26,199,434	$52,398,868	$78,598,302	$104,797,737
	10	$27,526,649	$55,053,298	$82,579,948	$110,106,597

The total costs for the province for various plant sizes under various circumstances can now be compared to the revenue that processors can expect to generate to estimate the private net benefit for processors, which appears in Section 3.2.4. Before doing so however, it should be noted that these figures are estimates only, and have made assumptions around certain costs that would be borne in reality. One such cost is the cost of borrowing capital to finance the construction of the pellet plant, which could be different than the assumptions made in Mani et al. (2006). In addition, when aggregating to the provincial scale, the estimates do not account for partial plants for ease of calculation in determining the amount of pellets that could be produced, since those figures would change if partial plants were accounted for.

3.2.2.2 Revenue (Benefits) Generated, Processing

The first step in determining revenue for processors is finding the price they will be sold at. In a personal communication on July 30, 2012, Mr. Barrie Fiolek, president of BioEnergy Incorporated of Sydney, Nova Scotia explained that a tonne of wood pellets sells for roughly $350. However, for a number of reasons including appearance, less familiarity from the public and a slightly lower heating value[17], grass pellets should be expected to sell for a price somewhat below that. Alternatively, Kungi (2011) estimates the sales price per tonne of grass briquettes to be $225, which he also estimates are cheaper to produce, and thus are able to sell for less than grass pellets. If we take the same approach to determining the sales price per tonne of pellets as we did with the raw biomass, which is to apply a 20% margin to the costs of production per tonne, the sales price will be determined by the capacity of the plant and the price of raw material, which again is affected by yields. Table 3.17 shows the various sales prices to maintain a 20% margin for processors once transportation costs are factored in, assuming the 50 km average distance. The price is equal to the cost of production per tonne of pellets from Table 3.13 multiplied by 1.2.

Table 3.17 Sales Price per Tonne of Switchgrass Pellets

Switchgrass Yield (tonnes/ha)	2 t/h	6 t/h	10 t/h
5	$394.51	$361.00	$347.78
7.5	$315.41	$281.89	$268.68
9	$289.04	$255.53	$242.31
10	$275.86	$242.34	$229.13

Many of these numbers fall into a reasonable range between the cheaper briquettes and the more expensive wood pellets. However, some circumstances would likely make it too

[17] Wood pellets have an energy density of 19.8 GJ/tonne while switchgrass pellets have 19.2 GJ/tonne (Kungi, 2011).

expensive to produce pellets, as evidenced by the highest price of $394.51 for a 2 t/h plant with 5 t/ha yield. Clearly, the economic viability of the processors is closely linked with the ability of farmers to keep the price of raw material under control. However, as yields increase and farmers are able to charge less per tonne of raw material, even the price charged by a 2 t/h processing plant is within a reasonable range. However, looking at the prices, it becomes clear that if a 2 t/h plant wishes to compete with a larger plant, sacrifices will have to be made somewhere. This could come from smaller margins and/or locating closer to customers to reduce transportation costs.

The sales price per tonne is then multiplied by the tonnes of output per plant we defined earlier to find revenue per plant, which is presented in Table 3.18. The assumption here is that the plant only charges the minimum price needed to maintain a 20% margin, which is why total revenue per plant declines as the yield increases. It's likely this would not actually happen, as many plants would take advantage of the cost savings and hold on to at least some of the extra profit being earned, while other would not be able to compete. For this purposes of this paper however, we will assume they will charge the prices presented in Table 3.17 corresponding to the average yield and the plant size.

Table 3.18 Revenue per Plant, 2 t/h, 6 t/h and 10 t/h Plant Sizes

Switchgrass Yield (tonnes/ha)	2 t/h	6 t/h	10 t/h
5	$5,875,072.70	$16,127,857.30	$25,895,996.64
7.5	$4,697,079.07	$12,593,876.40	$20,006,028.49
9	$4,304,414.53	$11,415,882.77	$18,042,705.77
10	$4,108,082.26	$10,826,885.96	$17,061,044.41

This result of revenue per plant declining as yield increases may be surprising, however recall that this is the result of the declining price per tonne with higher yields. Again, the plants wouldn't necessarily charge the minimum price to get a 20% margin, so this result probably would not reflect reality. Since we already know the number of plants that will be present under each combination of yield and land usage for switchgrass from Table 3.15, we can multiply that by the annual revenue per plant to aggregate to the provincial level. These results are presented in Table 3.19.

Table 3.19 Total Annual Revenue for Processors, Nova Scotia

		Land Usage Rate			
		25%	50%	75%	100%
2 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	$28,438,350	$56,876,701	$85,315,051	$113,753,401
	7.5	$34,104,390	$68,208,780	$102,313,170	$136,417,560
	9	$37,504,014	$75,008,027	$112,512,041	$150,016,055
	10	$39,770,430	$79,540,859	$119,311,289	$159,081,718
6 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	$26,021,247	$52,042,494	$78,063,740	$104,084,987
	7.5	$30,479,098	$60,958,197	$91,437,295	$121,916,393
	9	$33,153,809	$66,307,619	$99,461,428	$132,615,237
	10	$34,936,950	$69,873,900	$104,810,850	$139,747,800
10 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	$25,068,689	$50,137,377	$75,206,066	$100,274,754
	7.5	$29,050,334	$58,100,668	$87,151,002	$116,201,335
	9	$31,439,321	$62,878,642	$94,317,963	$125,757,284
	10	$33,031,979	$66,063,958	$99,095,937	$132,127,916

What Table 3.19 shows is that provincial revenue increases with both yield and land usage rate, however land usage rate has a much larger effect. What it also shows is that provincial revenue declines with plant size. This could be a result of the fewer number of larger plants to process the switchgrass, which is overriding the larger revenues for a single large plant versus a smaller one. At this point, we have estimates of total costs and total revenue for processors, which will be compared in Section 3.2.4. Thus, the discussion will now move on to the costs and benefits accruing to consumers from switching to switchgrass pellets.

3.2.3 Consumers

Consumers are the final point in the supply chain, the end users. It is ultimately consumer demand that will drive the entire process. If consumers don't buy switchgrass pellets, then none of it will go forward. Thus, in order for consumers to buy the pellets, they must see a net benefit from doing so. The private benefits to consumers will come from savings in home heating costs over what was previously used, which we will assume to be light heating oil or electricity. Note that the switchgrass is not being used directly for electricity generation, but rather is replacing electricity as a source of home heating.

Costs for consumers in this scenario arise from purchasing not only the pellets themselves, but also the furnaces required to use them for home heating. The cost of the furnace can be offset somewhat however, as Efficiency Nova Scotia (www.efficiencyns.ca) offers rebates for the purchase and installation of the furnaces, as well as removal of electric baseboard heating from the home.

As shown in the previous section, the prices consumers need to pay for pellets to maintain margins for processors, and by extension farmers, will depend on the size of the processing plants and the price paid by the processor for raw material, which depends on the yields of switchgrass. To recap, the minimum prices charged by the processors are detailed in Table 3.17.

According to Hughes (2010), an average home in Nova Scotia uses 70 GJ of energy for space heating. This means that the average home would use 3.65[18] tonnes of switchgrass

[18] Equal to 70 GJ / 19.2 GJ/tonne of switchgrass pellets.

pellets, 1,832 litres of light heating oil or 19,444 KWh of electricity[19], assuming 100% conversion efficiencies.

Depending on the energy source, the actual conversion efficiencies can be quite different. For switchgrass pellets, combustion efficiency has been measured between 82% and 84%, although it could easily be higher as that boiler was not optimized for switchgrass (Samson, Drisdelle, Mulkins, Lapointe, & Duxbury, n.d.). Thus, we will use 84% here. We will look at three oil furncace efficiencies discussed in Hughes (2010), which were Normal (60%), Medium (78%) and High (85%), while electricity will remain at 100% due to the difficulty in estimating transmission losses. Thus, the final fuel requirement for switchgrass pellets is 4.35[20] tonnes, oil may be 3,053, 2,349 or 2,155 litres, and electricity will remain at 19,444 KWh.

We will assume here that the heating source already in place is either electricity or light heating oil, and will be replaced with a pellet furnace burning switchgrass pellets. This ignores the purchase and installation costs of those orignial sources. One barrier to the adoption of grass pellets for space heating has been the formation of clinkers, the solidified minerals that are present in the grass (Kungi, 2011). However, advances have been made to overcome this issue, for example the pellet furnace developed by LST Energy of Pictou County, Nova Scotia (www.lst-energy.com) that was discussed in Chapter 2. In addition to overcoming the clinker problem, LST claims that their furnace also burns more efficiently.

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[19] Recall that switchgrass pellets have 19.2 GJ/tonne, light heating oil has 38.2 GJ/1,000L, and electricity produces .0036 GJ of heat per KWh.
[20] Equal to 3.65/.84.

While a price for this furnace was not immediately available, BioEnergy Inc sells a Harman pellet furnace (www.harmanstoves.com) for $7,800 that will last for 25 years, or $312 per year, which we will use as our estimate. However, Efficiency Nova Scotia has rebate programs that will generally cover up to 50% of the cost of the furnace, as well as additional installation costs for a central air system. So, we will assume that the cost to the homeowner of the furnace will be $3,900, or $156 per year, which will be added to the cost of the pellets. The cost to heat an average 70 GJ home for the year using switchgrass pellets is equal to the price of switchgrass pellets from Table 3.17 multiplied by 4.35 tonnes of pellets required per household, plus the annualized $156 cost for the furnace. The cost under the various circumstances appears in Table 3.20, not including taxes.

Table 3.20 Cost of Heating an Average Household Using Switchgrass Pellets

Switchgrass Yield (tonnes/ha)	2 t/h	6 t/h	10 t/h
5	$1,872.13	$1,726.33	$1,668.86
7.5	$1,528.03	$1,382.24	$1,324.76
9	$1,413.33	$1,267.54	$1,210.07
10	$1,355.98	$1,210.19	$1,152.72

To find the cost for electricity per household, we will take the required KWh and multiply it by the current price for electricity, which is $0.12638 per KWh (Nova Scotia Power Inc., 2012b). Thus, the total cost for heating with electricity is estimated to be $2,457, meaning savings (net benefit) from switching to switchgrass pellets are between $585 and $1,304.

To find the cost for light heating oil per household, we will assume we are replacing a Medium furnace with 78% efficiency, with annual usage of 2,349 litres. Savings will depend on the price per litre, which varies over time across the province. As of August 7, 2012, the price for furnace oil in cents for Halifax was 101.3, Sydney was 98.9, Yarmouth was 105.4, Truro was 99.9, Kentville was 103, and New Glasgow was 101.9, for an average of 101.7 cents per litre (Kent Marketing Services, 2012). At this average price, total annual heating costs would be $2,389, for savings of between $517 and $1,236 when switching to switchgrass pellets. For the province, total savings will also depend on the amount of switchgrass pellets available, which will affect the number of homes that are able to switch, which will be equal to 60,700 hectares * land usage rate * yield / 4.35 tonnes/home. The results are shown in Table 3.21.

Table 3.21 Potential Number of Homes Heated with Switchgrass Pellets

		Land Usage Rate			
		25%	50%	75%	100%
Switchgrass Yield (tonnes/ha)	5	17,443	34,885	52,328	69,770
	7.5	26,164	52,328	78,491	104,655
	9	31,397	62,793	94,190	125,586
	10	34,885	69,770	104,655	139,540

Depending on the yield and land usage, it is estimated that switchgrass pellets grown on inactive and underused farmland could heat anywhere from 17,443 to 139,540 homes in Nova Scotia. From the 2006 Census, Nova Scotia has 376,845 dwellings. If we remove apartments and movable dwellings from this number since it will likely be individual homes we are targeting for the switch, we are left with 293,275 single detached houses and semi-detached/row/duplex dwellings. This means that switchgrass pellets could provide space heating for anywhere from 6% to 48% of the eligible dwellings in Nova Scotia.

The total savings will also depend on the price per tonne of pellets. We can find the total amount saved when switching from either electricity for heat or light heating oil by multiplying the savings from each by the corresponding number of households the switchgrass could heat. For electricity, where savings range from $585 to $1,304, total provincial savings would be between $10.2 million and $182 million, which is a significant range. Switching from light heating oil, where savings range from $517 to $1,236, provincial savings would amount to between $9 million and $172.5 million.

Those replacing electricity with switchgrass pellets save more than those replacing a 78% efficiency oil furnace, however replacing a lower efficiency furnace would result in greater savings. Regardless, it is clear that using switchgrass pellets for space heating instead of light heating oil or electricity results in significant savings for consumers. The next section will compile the information presented for farmers, processors and consumers to estimate the total private net benefit from this project, as well as a more detailed analysis of provincial savings from changing heating sources.

3.2.3 Private Net Benefit

At this point we have estimated the private costs and benefits for farmers, processors and consumers under a range of scenarios. Thus, we can now calculate total private net benefit, which will be equal to the net benefit to farmers, plus the net benefit to processors, plus the net benefit to consumers. The first step then is to combine the cost and benefit information for farmers to estimate their private net benefit.

Revenue per hectare for farmers is estimated to be $939.35, while cost per hectare is estimated to be $782.78, so net benefit per hectare is $156.57, regardless of yield. Here we've held the revenues and costs per hectare constant while allowing the price and costs per tonne to vary. As has been mentioned previously, this will not likely hold true in reality, however it was necessary for the purposes of this paper. What this means is that in the absence of subsidies, for a farmer to earn income of $60,000, they would need roughly 383 hectares. Introducing subsidies in the presence of external net benefits would improve this, and should be advocated if there are indeed external net benefits. Since we know that private net benefit per hectare is $156.57, we can now estimate the provincial private net benefit under the various land usage rates, which are presented in Table 3.22.

Table 3.22 Annual Provincial Private Net Benefit, Farmers

Land Usage Rate	Net Benefit
25%	$2,375,950
50%	$4,751,900
75%	$7,127,849
100%	$9,503,799

We now move on to the private net benefits for processors. Processors were separated into three plants sizes; 2 t/h, 6 t/h and 10 t/h. For these plants, costs and revenues were estimated based on an 85% capacity rate. That is, the plant was operating 24 hours a day for 85% of the year, which equals 7,446 hours. Costs of production and revenue per plant are in Tables 3.14 and 3.18, respectively. Private net benefit per plant is presented in Table 3.23.

Table 3.23 Annual Private Net Benefit per Plant, 2 t/h, 6 t/h and 10 t/h Plant Sizes

Switchgrass Yield (tonnes/ha)	2 t/h	6 t/h	10 t/h
5	$979,179	$2,687,976	$4,315,999
7.5	$782,847	$2,098,979	$3,334,338
9	$717,402	$1,902,647	$3,007,118
10	$684,680	$1,804,481	$2,843,507

These figures must be taken with caution, as the estimation method basically assured a positive net benefit by applying a guaranteed 20% margin. In reality, as was discussed in the section discussing processor revenue, the higher prices required by a smaller plant may not be feasible; meaning competition with a larger plant would be difficult or impossible without cutting into margins or finding savings elsewhere, such as lower transportation costs through locating closer to customers. In addition, private net benefit per plant would not actually decrease with increasing yields, as plants would charge more than the minimum acceptable price.

The only step needed now to find the annual provincial private net benefit for processors is to subtract the costs from revenues. This is presented in Table 3.24. Recall that total annual provincial costs and revenues are in Tables 3.16 and 3.19, respectively.

Table 3.24 Annual Provincial Private Net Benefit, Processors

		Land Usage Rate			
		25%	50%	75%	100%
2 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	$4,739,725	$9,479,450	$14,219,175	$18,958,900
	7.5	$5,684,065	$11,368,130	$17,052,195	$22,736,260
	9	$6,250,669	$12,501,338	$18,752,007	$25,002,676
	10	$6,628,405	$13,256,810	$19,885,215	$26,513,620
6 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	$4,336,874	$8,673,749	$13,010,623	$17,347,498
	7.5	$5,079,850	$10,159,699	$15,239,549	$20,319,399
	9	$5,525,635	$11,051,270	$16,576,905	$22,102,540
	10	$5,822,825	$11,645,650	$17,468,475	$23,291,300
10 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	$4,178,115	$8,356,230	$12,534,344	$16,712,459
	7.5	$4,841,722	$9,683,445	$14,525,167	$19,366,889
	9	$5,239,887	$10,479,774	$15,719,660	$20,959,547
	10	$5,505,330	$11,010,660	$16,515,990	$22,021,319

A paradoxical result we see once again in Table 3.24 is that the total provincial net benefit for processors decreases as the plant size increases. Again, one possible explanation for this is that the larger number of smaller plants required to process the amount of switchgrass available provincially is overriding the larger per plant net benefit enjoyed by the larger plants.

The last group for which the annual provincial private net benefit is required are consumers. Private net benefit for consumers depends on which heating source we assume we are replacing, so at this point we will refine our estimate by predicting who will be replacing their current heating source with switchgrass pellets.

We have shown here that consumers who switch from electric space heating to switchgrass pellets save more than those switching from light heating oil. Thus, economic theory would suggest that these individuals would switch first, since they benefit more. However, viewing Nova Scotia's space heating mix quickly shows that is only possible under certain circumstances, since as of 2009, the proportion of Nova Scotia homes using electricity for heat was 29.5% (NRCan, 2012). This means that of the dwellings we are concerned with, an estimated 86,516 of those use electricity for space heating[21]. So, depending on the number of houses that could be heated using switchgrass pellets, it is possible that all of these and more could switch. We will assume then that consumers are switching from electricity to switchgrass up to 86,516 households, and after that they are switching from light heating oil. That is, if the number of homes that could potentially be heated using switchgrass pellets is less than 86,516, the provincial savings are the same as the figures for savings from switching from electricity. If the number of potential homes is greater than the number of homes using electricity, then the savings per household for the first 86,516 homes is equal to the savings from switching from electricity, while the savings per household for each additional home over 86,516 is equal to the savings from switching from light heating oil. To clarify, the equation for when there are more than 86,516 potential homes is:

[21] Recall that we include only single detached and semi-detached/row/duplex dwelling here, totaling 293,275 dwellings.

Total Provincial Savings = 86,516 * Savings Per Household, Electricity + (Potential Homes Heated with Switchgrass – 86,516)* Savings Per Household, Light Heating Oil

The results of this exercise appear in Table 3.25.

Table 3.25 Annual Provincial Private Net Benefit, Consumers

		Land Usage Rate			
		25%	50%	75%	100%
2 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	$17,791,379	$35,582,759	$53,374,138	$71,165,517
	7.5	$26,687,069	$53,374,138	$80,061,207	$95,987,889
	9	$32,024,483	$64,048,966	$97,780,825	$128,413,404
	10	$35,582,759	$71,165,517	$113,993,583	$150,030,415
6 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	$20,355,431	$40,710,862	$61,066,293	$81,421,724
	7.5	$30,533,147	$61,066,293	$91,599,440	$111,246,048
	9	$36,639,776	$73,279,552	$111,513,168	$146,723,195
	10	$40,710,862	$81,421,724	$129,251,742	$170,374,627
10 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	$21,349,655	$42,699,310	$64,048,966	$85,398,621
	7.5	$32,024,483	$64,048,966	$96,073,448	$117,260,811
	9	$38,429,379	$76,858,759	$116,926,455	$153,940,911
	10	$42,699,310	$85,398,621	$135,266,505	$178,394,311

For consumers, annual provincial private net benefit increases with all three variables, with land usage rate and yield having the same impact, which seems to be larger than the impact from increasing plant sizes. At this point we now have estimates for the private net benefit for each of our three groups under various yields, land usage rates and pellet plant sizes, which corresponds to various amounts of switchgrass pellets being produced. The final step in estimating annual provincial private net benefit from replacing electricity and/or light heating oil with switchgrass pellets is to combine the three. The results are presented in Table 3.26.

Table 3.26 Annual Provincial Private Net Benefit, Total

		Land Usage Rate			
		25%	50%	75%	100%
2 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	$24,907,054	$49,814,108	$74,721,162	$99,628,216
	7.5	$34,747,084	$69,494,167	$104,241,251	$128,227,948
	9	$40,651,101	$81,302,203	$123,660,681	$162,919,879
	10	$44,587,113	$89,174,227	$141,006,647	$186,047,833
6 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	$27,068,255	$54,136,510	$81,204,766	$108,273,021
	7.5	$37,988,946	$75,977,892	$113,966,838	$141,069,246
	9	$44,541,360	$89,082,721	$135,217,922	$178,329,534
	10	$48,909,637	$97,819,274	$153,848,066	$203,169,726
10 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	$27,903,720	$55,807,439	$83,711,159	$111,614,879
	7.5	$39,242,155	$78,484,310	$117,726,464	$146,131,499
	9	$46,045,216	$92,090,432	$139,773,965	$184,404,257
	10	$50,580,590	$101,161,180	$158,910,344	$209,919,429

What these results show us is that under the assumptions and estimates made in this paper, there are significant annual private net benefits for each of the three groups represented, and for the three combined, ranging from $24.9 million to $209.9 million. These net benefits increase with increasing yields, land usage, and pellet plant capacity. However, even the smaller 2 t/h plants are estimated to produce significant private net benefits under these assumptions and estimates. But it should be noted that these are estimates only, and in places have had to rely on strong assumptions, while leaving certain factors out such as smaller plants having to compete with larger plants, which will likely alter these results. Now that we have estimates for the total annual private net benefit, we will move on to a discussion of the external net benefits. Later, in the Social Net Benefit chapter, these annual results will be expressed over the ten-year lifetime of a switchgrass stand.

3.3 External Costs and Benefits

The next step in the analysis is to quantify the external net benefits arising from offsetting fossil fuel use with switchgrass pellets in home space heating. External benefits arise when individuals who are not involved in a specific project, and therefore pay no direct monetary costs, receive a benefit from that project. Since reducing fossil fuel use should[22] help to mitigate climate change through a reduction in GHG emissions, society at large would reap benefits from any project that achieves this goal. Thus, in order to fully understand the costs and benefits of offsetting fossil fuel use, external factors must be taken into account. Enhancing societal well-being through reducing fossil fuel use is the main goal of using biomass pellets instead of fossil fuels, however that is not assured, as was suggested by Searchinger et al. (2008). Thus, an analysis of external net benefits is included in this section, including determining whether the project would actually succeed in a reduction in GHG emissions.

To paint an accurate picture of using switchgrass as an energy crop, two figures must be estimated. The first is the difference between the GHG emissions from combusting switchgrass versus using light heating oil and electricity, and the second is the CO_2 absorbed by the biomass during growth, including the opportunity cost of the next best alternative for a carbon sink, for which we are using a mixed forest. When using switchgrass for heat, the switchgrass absorbs carbon dioxide during growth and emits carbon dioxide and other GHGs during combustion. For fossil fuels, no CO_2 is absorbed during production, however we must account for what happens to the land the switchgrass would otherwise have been grown on. Thus, the second figure is the

[22] The word "should" is used here because not every non-fossil-fuel energy project actually results in a decline in GHG emissions. See Searchinger et al. (2008).

difference between net GHG absorption from the growth of switchgrass and the growth of the natural forest that is assumed to grow in the place of switchgrass.

Given the amount of land that Kungi reports is being bushcut, even though it's not being farmed, it's unlikely that a significant portion of the inactive and underused farmland would actually be allowed to revert to its natural state. However, this paper will assume that is the case, since that would presumably be the best alternative in terms of a carbon sink. In addition, land reverting back to its natural state will do so over time, with the amount of carbon sequestration varying year over year. Rather than try and model this, the paper will assume that the land reverts immediately to its natural state, rather than gradually doing so over time, once again providing a conservative estimate.

Estimating the GHGs emitted during the generation of heat did not prove difficult for this paper, since estimates of life-cycle GHG emissions, measured in carbon dioxide equivalents, (CO_2E) for various fuel sources were available from Samson et al (2008b). The assumption here is that individuals adopting switchgrass pellets as a heating fuel will be displacing either light heating oil or electric heating usage. Estimates from Samson et al (2008b) for the three space heating fuel sources are detailed in Table 3.27 below. It should be noted that when displacing electricity, multiple fuel fossil fuel sources are actually being displaced since Nova Scotia's electricity mix includes coal, natural gas and heavy fuel oil[23].

[23] According to Statistics Canada, CANSIM Tables 127-0007 and 128-0014, Nova Scotia generates 56.75% of its electricity from coal, 19.03% from natural gas and 9% from heavy fuel oil as of 2010. Those figures may currently be different.

Table 3.27 Life-Cycle CO_2E Emissions in kg/GJ

Switchgrass Pellets for heating	8.2
Light Heating Oil	87.9
Natural gas for electricity	121.74
Heavy fuel oil for electricity	281.34
Coal for electricity	298.97

Based on Samson et al. (2008b), life-cycle GHG emissions from switchgrass pellets are significantly below that of other fuels, and should leave no doubt that replacing the fossil fuels listed will provide a reduction in emissions. This information includes the emissions from fossil fuels used in the production, processing and transport of the switchgrass, including nitrogen fertilizer production. What the switchgrass figure does not include is the emissions from land-use change, i.e. the lost carbon sink ability of the next best alternative. This will be explored later in this chapter.

The next step in estimating the external net benefit is to estimate the amount of energy that will be available from switchgrass pellets. This will be done by using estimates of the yield in tonnes per hectare, multiplied by the total number of hectares being used to grow switchgrass, multiplied by the energy content of a tonne of switchgrass pellets, which is 19.2 GJ/tonne (Samson et al., n.d.). A number of assumptions will be made here.

First, since the raw switchgrass will not require drying prior to being pelletized, we will again assume a 1 to .95 processing ratio, meaning a 5% loss of mass during processing (Jannasch, 2001a). That is, the tonnes of switchgrass pellets output is equal to 95% of the raw switchgrass input. Second, the total number of hectares being used will be assumed to be equal to the 60,700 hectares estimated by Kungi (2011), multiplied by a usage rate. Once we have an estimate of the total amount of energy available in GJ, and the life-cycle emissions of CO_2E emissions in kg/GJ, we can estimate the total emissions from using switchgrass. Table 3.28 shows the total amount of switchgrass available in tonnes, the total amount of energy available from that switchgrass, and the total life-cycle GHG emissions from using the switchgrass for heat.

Table 3.28 Amount of Switchgrass and Energy Available, Total Life-Cycle Emissions from using Switchgrass Pellets

		Land Usage Rate			
		25%	50%	75%	100%
Total Switchgrass Available in Tonnes					
Switchgrass Yield (tonnes/ha)	5	75,875	151,750	227,625	303,500
	7.5	113,813	227,625	341,438	455,250
	9	136,575	273,150	409,725	546,300
	10	151,750	303,500	455,250	607,000
Energy Available from Switchgrass Pellets in GJ					
Switchgrass Yield (tonnes/ha)	5	1,383,960	2,767,920	4,151,880	5,535,840
	7.5	2,075,940	4,151,880	6,227,820	8,303,760
	9	2,491,128	4,982,256	7,473,384	9,964,512
	10	2,767,920	5,535,840	8,303,760	11,071,680
Total Life-cycle Emissions from Switchgrass Pellets in tonnes CO_2E					
Switchgrass Yield (tonnes/ha)	5	11,348	22,697	34,045	45,394
	7.5	17,023	34,045	51,068	68,091
	9	20,427	40,854	61,282	81,709
	10	22,697	45,394	68,091	90,788

In calculating the external net benefit, it would not be practical to use each and every estimate shown in the tables. The next step is to estimate the GHG emissions from using fossil fuels to generate the equivalent amount of energy that is available from switchgrass. For light heating oil, this is as simple as multiplying the life-cycle CO_2E emissions by the amount of energy available from switchgrass pellets. Since the emissions are reported in kg/GJ, one must be careful to put this in tonnes/GJ when multiplying by the GJ available. Samson et al (2008b) report life-cycle GHG emissions from light heating oil as 87.9 kg CO_2E/GJ. Table 3.29 presents the amount of light heating oil that could be displaced by using switchgrass pellets, as well as the GHG emissions from that amount of light heating oil.

Table 3.29 Replacing Light Heating Oil

		Land Usage Rate			
		25%	50%	75%	100%
Amount of Light Heating Oil Displaced in Litres					
Switchgrass Yield (tonnes/ha)	5	36,229,319	72,458,639	108,687,958	144,917,277
	7.5	54,343,979	108,687,958	163,031,937	217,375,916
	9	65,212,775	130,425,550	195,638,325	260,851,099
	10	72,458,639	144,917,277	217,375,916	289,834,555
Total Life-cycle Emissions from using Light Heating Oil in tonnes CO_2E					
Switchgrass Yield (tonnes/ha)	5	121,650	243,300	364,950	486,600
	7.5	182,475	364,950	547,425	729,901
	9	218,970	437,940	656,910	875,881
	10	243,300	486,600	729,901	973,201

Performing the same analysis for displacing electricity use requires a few extra steps, since electricity is generated from more than one source. From Statistics Canada, CANSIM Tables 127-0007 and 128-0014, it was calculated that as of 2010, Nova Scotia's electricity fuel mix included 56.75% coal, 19.03% natural has, and 9% heavy fuel oil. It is likely these numbers have since changed due to the province's ambitious renewable electricity program, and that they will continue to change as more renewable energy sources are added to the electricity grid, particularly wind. For the purposes of this analysis however, the 2010 electricity mix will be used.

In order to calculate the GHG emissions from this electricity, the life-cycle emissions of each source from Samson et al (2008b) was used, and the weight of each fuel source was applied to the total amount of energy that would be displaced by switchgrass pellets. From that paper, the life-cycle GHG emissions in kg CO_2E/GJ are 298.97 for coal, 121.74 for natural gas and 281.34 for heavy fuel oil. The assumption is that coal, natural gas and heavy fuel oil are the only fuels that emit GHGs, while the remainder do not, and are thus given a 0 weight. So, the equation for calculating the total emissions from the equivalent energy available from switchgrass (tonnes) is:

Total Emissions = GJ available from switchgrass * (56.75% * 298.97 / 1000 + 19.03% * 121.74 / 1000 + 9% * 281.34 / 1000)

Table 3.30 presents the amount of electricity and GHG emissions that could be displaced by using switchgrass pellets under the 2010 electricity mix for Nova Scotia. Recall that the amount of electricity use displaced by switchgrass pellets will depend on the total number of households that can be heated, and that this number may be larger than the number of houses that use electricity.

Table 3.30 Replacing Electricity Used for Heat

		Land Usage Rate			
		25%	50%	75%	100%
Amount of Electricity Displaced in GWh					
Switchgrass Yield (tonnes/ha)	5	384	769	1,153	1,538
	7.5	577	1,153	1,730	2,307
	9	692	1,384	2,076	2,768
	10	769	1,538	2,307	3,075
Total Life-cycle Emissions from Electricity in tonnes CO_2E					
Switchgrass Yield (tonnes/ha)	5	301,915	603,831	905,746	1,207,661
	7.5	452,873	905,746	1,358,619	1,811,492
	9	543,448	1,086,895	1,630,343	2,173,790
	10	603,831	1,207,661	1,811,492	2,415,322

Of the three heating sources, displacing electricity use for heat has the greatest potential for GHG mitigation, while displacing light heating oil still shows significant benefits. It is not immediately clear whether the GJ of heat provided by 1 KWh takes into account efficiency losses from transporting electricity over distances. That is, if producing .0036 GJ of heat in the home requires 1 KWh, it will require more than 1 KWh to be generated at the power plant. As with other estimates in this paper, we will take the figure as is since it provides a conservative estimate, meaning the GHG emissions savings from replacing electricity could be potentially greater than reported here.

In the future, given that the Nova Scotia government has a goal of 40% electricity generation from renewables by 2020, the benefits from replacing electricity with switchgrass pellets will likely decline over this period. However, it remains to be seen to what extent this goal will be achieved. Also note that the previous two tables do not account for how many homes use each of those heating sources. Thus, switchgrass pellets may not actually be able to displace that much of each fuel. A more detailed household analysis will now be performed to account for this.

At this point we will recall from Section 3.2.4 that economic theory would suggest that those who can save more by switching, those currently using electricity, will do so first, and that there are currently 86,516 households using electricity for space heating that we are concerned with. Also recall Table 3.16 which presents the total number of homes that could potentially have their heat provided by switchgrass pellets. We will make the same assumption here as earlier, which is that the first 86,516 homes to switch will switch from electricity, and the remainder will switch from light heating oil.

Recall that in a year the average house will use 19,444 KWh of electricity for heat, or 70 GJ (Hughes, 2010). Using Nova Scotia's electricity mix and the life-cycle CO_2E emissions per GJ for each source, that's equal to 15.27 tonnes of CO_2E emissions per household using electricity for space heating[24]. The same household using light heating

[24] 70 GJ*((56.75%*298.97 kg CO_2E/GJ + 19.03% * 121.74 kg CO_2E/GJ + 9% * 281.34 kg CO_2E/GJ)/1000) = 15.27.

oil will have 6.15[25] tonnes of CO_2E emissions, while using switchgrass pellets will result in 0.574[26] tonnes of the same emissions. Thus, a household switching from electricity will save 14.7 tonnes of emissions, while a household switching from light heating oil will save 5.58 tonnes of emissions. Now, these figures must be aggregated to the provincial level.

This will be done by using the potential number of households heated using switchgrass pellets[27] as the determinant for direct GHG emission savings. That is, up to the first 86,516 households or fewer will each save 14.7 tonnes of CO_2E emissions, while each household after that will save 5.58 tonnes. The results are presented in Table 3.31.

Table 3.31 Annual Tonnes of CO_2E Emissions Saved During Use from Using Switchgrass Pellets

		Land Usage Rate			
		25%	50%	75%	100%
Switchgrass Yield (tonnes/ha)	5	256,405	512,810	769,216	1,025,621
	7.5	384,608	769,216	1,153,823	1,373,002
	9	461,529	923,059	1,314,604	1,489,797
	10	512,810	1,025,621	1,373,002	1,567,660

The figures presented in Table 3.31 show the amount of GHG emissions that have been saved as a result of burning switchgrass pellets for space heating instead of using electricity or light heating oil. It does not account for the second figure required for estimating the external net benefits, the carbon dioxide absorbed by biomass during growth.

As plants grow, they absorb carbon dioxide from the atmosphere. Some of this is released back to the atmosphere, but some is stored in the plant, including both the visible part of the plant that is sometimes harvested, as well as the roots and the soil the roots are in.

[25] 70 GJ * 87.9 kg CO_2E/GJ / 1000 = 6.15.
[26] 70 GJ * 8.2 kg CO_2E/GJ / 1000 = .574.
[27] These figures are presented in Table 3.21.

Thus, in order to measure the true effect of using energy crops, the carbon sequestration abilities of the land under two scenarios must be included. It is assumed that if the use of fossil fuels is continued, the land that would otherwise have been used to grow switchgrass will revert back to its natural, forested state (also an assumption). What the paper does not account for is what happens to the remaining land that is not being used for switchgrass under the switchgrass scenario. That is, if 75% of the available 60,700 hectares is used for switchgrass, the model does not account for the remaining 25% reverting to its natural state. Rather, the model only addresses the opportunity cost of the land actually being used to grow switchgrass. To present a more accurate picture, the remaining land should be accounted for in future versions of this model.

The amount of carbon dioxide absorbed during the growth of biomass will be estimated by using a tool called Human Appropriation of Net Primary Productivity, or HANPP, which was estimated for Nova Scotia by O'Neill (2005). HANPP refers to the amount of Net Primary Productivity (NPP) which humans claim through forestry, agriculture and other land-use changes (O'Neill, 2005). NPP refers to the amount of carbon that plants fix via photosynthesis throughout the year. Thus, there is a certain amount of carbon fixation that would occur absent human intervention, providing a social benefit. Estimates of NPP for Nova Scotia by O'Neill (2005) for mixed forest and cropland will be used to estimate the difference in the amount of carbon fixation that occurs by allowing inactive farmland to revert to its natural state versus using it for switchgrass. Since there is no estimate for switchgrass in the O'Neill (2005), cropland will be used as an approximation for the carbon sequestration abilities of switchgrass. Also not accounted for here is the varying sequestration under different yields that would occur from more aboveground and belowground biomass per hectare.

This will not be an exact estimate, because it is not certain that even without growing energy crops on the land that it would all revert back to its natural state. According to Kurgi (2011), much of the land is not actually being farmed, but is being cut back and kept clear regardless, possibly for future opportunities. If the biomass that is being bushcut is being burned, this will result in emissions that have not been accounted for.

While a forest will sequester more carbon than cropland on a given plot of land (O'Neill, 2005), there is some evidence that switchgrass is able to sequester a significant amount of carbon itself due to a large, active root system (McLaughlin & Kszos, 2005), much more than traditional crops such as corn (Girouard et al., 1999). So, the carbon sequestration of allowing the land to go back to forest must then be compared to the carbon sequestration abilities of the switchgrass we will be growing since this figure is not included in the life-cycle emissions of 8.2 kg CO_2E/GJ used in previous calculations.

O'Neill (2005) estimates the provincial average NPP for Nova Scotia of forested lands at 284 grams of carbon per square meter per year ((g C/m^2)/year), while the estimate for cropland is 223, in the same units. However, to be useful for the purposes of this paper, the estimates must be coverted to tonnes of carbon dioxide per hectare[28]. Once converted,

[28] Unit conversions: 1,000 g in a kg, 1,000,000 m^2 in a km^2, 1,000 kg in a tonne, and 100 hectares in a km^2.

we find that the NPP of forests is 10.41 tonnes of carbon dioxide per hectare, while cropland is 8.18[29]. Results are presented in Table 3.32.

Table 3.32 Carbon Sequestration Ability of Land Types

	Carbon (tonnes/yr)		Carbon Dioxide (tonnes/yr)[30]		
Land Usage Rate	Forest	Cropland	Forest	Cropland	Difference
25%	42,955	33,729	144,617	113,555	31,062
50%	85,910	67,458	289,233	227,109	62,124
75%	128,865	101,186	433,850	340,664	93,186
100%	171,820	134,915	578,466	454,218	124,248

Now that we have estimates of the total amount of carbon dioxide that will be sequestered when the land is either forested or cropland, and the difference between the two, we can compare this to the life-cycle emissions that are saved when light heating oil and electricity used for heat are replaced with switchgrass pellets. This involves subtracting the difference in annual carbon dioxide absorbed between a forest and cropland[31] from the usage savings in Table 3.31. This means that a positive number represents a net decrease in emissions.

Table 3.33 presents the results, which show that as the yield and amount of land used for switchgrass increases, the GHG savings increase as well. It also appears that yield has more of an effect than the amount of land used, as a doubling of yields results in greater savings than a doubling of land used. It should be cautioned here, however, that increased yields will likely require increased inputs of fertilizer and other chemicals, which will

[29] To convert the estimates, we first divide by 1,000 to get them in kg instead of g, then multiply by 1,000,000 to get them in km^2 instead of m^2, then divide by 1,000 to get them in tonnes per km^2, then divide by 100 to get them in tonnes per hectare.
[30] Weight of carbon is converted to carbon dioxide by multiplying by 3.667.
[31] Note that only some of the carbon dioxide absorbed by the switchgrass will be sequestered. The amount that stays in the aboveground biomass will be combusted, while the amount that goes to the roots and in the soil will for the most part remain sequestered.

affect the life-cycle savings. Both require energy and emissions to produce, and chemicals will reduce the natural carbon sequestration ability of the land.

Table 3.33 Total Annual CO_2E Emissions Saved From Using Switchgrass Pellets (tonnes)

		Usage Rate			
		25%	50%	75%	100%
Switchgrass Yield (tonnes/ha)	5	225,343	450,686	676,029	901,373
	7.5	353,546	707,091	1,060,637	1,248,754
	9	430,467	860,935	1,221,418	1,365,549
	10	481,748	963,497	1,279,816	1,443,412

At this point, it is prudent to remind ourselves of a couple of factors that may impact these results. Firstly, it has been suggested that switchgrass is able to sequester significantly more carbon than traditional crops (McLaughlin & Kszos, 2005). So while cropland was used as a proxy, further iterations should include more stringent measurements of the carbon sequestration of switchgrass to increase the accuracy of the results. In addition, for forested land, these figures do not include the ground vegetation under the trees, since the estimates are made using satellite data. Both of these factors will influence the results in opposite directions, and further research should be done to determine a more accurate measurement of the effect they both have.

Now that the we have estimates of the amount of GHG savings under each scenario, all that remains to estimate the external net benefit is to apply a price per tonne of CO_2E to those figures. So, the figures in Table 3.33 will be given a monetary value to society. Unfortunately, this will not be quite that simple due to the difficulty in estimating the monetary value to society of a foregone tonne of GHG emissions. Thus, we will do as we have done so far in situations of uncertainty and perform a sensitivity analysis.

Tol (2004) analyses the range of estimates that have been made by various authors regarding the value or cost of a tonne of carbon abated (value) or emitted (cost). He finds that the estimates are right-skewed, meaning that most estimates are on the lower end. The mode of the estimates is $2/tonne, the median is $14/tonne and the mean is $93/tonne. Ninety-five percent of the estimates are under $350/tonne. While Tol suggests that the marginal cost is unlikely to exceed $50/tonne using "standard assumptions about discounting and aggregation", the estimates are highly dependent on the discount rate chosen. This practice can be highly arbitrary, considering it amounts to estimating how much one values the future (Almansa & Martínez-Paz, 2010). Thus, the dollar figures used here will be selected based on providing a broad range, including $0, $50, $100, $200 and $300. The selection of these numbers is meant to be demonstrative, considering the remaining uncertainty surround the exact cost of a tonne of carbon.

While it will not be discussed at length in this paper, consideration should also be given to the philosophical and ethical debates that occur surrounding whether it is even possible to place a monetary value on nature. Yet despite the uncertainty and debate, determining the cost of a tonne of carbon is important if it is to be included in the prices for goods and services. That is, if two goods are equal in every way except for the carbon emissions in their production, the one that does less damage will be cheaper. An additional factor that is not accounted for here is the concept that a future tonne of GHG emissions will cause more damage than a current tonne of GHG emissions, which is a very likely possibility. Indeed, if this were the case, then the cost per tonne of emissions would not remain static as we have assumed here, but rather would be dynamic and increase as the marginal damage of a tonne of emissions increases.

At this point, in order to demonstrate the effect that the price of emissions has on the external net benefit, we will provide an example by choosing the combination of a land usage rate of 75% and a yield of 9 tonnes/hectare. The choice of these numbers out of those used in previous estimations was arbitrary, however also necessary to avoid presenting a debilitating amount of estimates in the name of sensitivity. Going forward, when calculating the external net benefit that will be used to estimate the social net benefit, a cost of $50 will be used. Table 3.34 presents the sensitivity analysis around the cost of emissions.

Table 3.34 External Value of Using Switchgrass Pellets Instead of Fossil Fuels

Cost per tonne CO_2E	External Net Benefit
$0	$0
$10	$12,214,181
$50	$61,070,907
$100	$122,141,815
$200	$244,283,630
$300	$366,425,444

Clearly the dollar figure put on these emissions matters a great deal in estimating the value to society of the reductions in emissions detailed in Table 3.33. While it is possible that the marginal damage is actually as high as $300, it is highly unlikely that any jurisdiction adopting a carbon tax would select a value this high. However, even at $10, the value to society of replacing electrical heat and light heating oil with 45,374 hectares growing 9 tonnes/hectare of switchgrass is over $12 million. Now that we have performed a sensitivity analysis around the price of emissions, we will now assume a price of $50/tonne of CO_2E to estimate our external net benefit that will be used in estimating the social net benefit. Essentially, this will involve multiplying each value in Table 3.33 by $50, which appears in Table 3.35.

Table 3.35 Total External Value of CO_2E Emissions Saved

		Land Usage Rate			
		25%	50%	75%	100%
Switchgrass Yield (tonnes/ha)	5	$11,267,158	$22,534,316	$33,801,473	$45,068,631
	7.5	$17,677,287	$35,354,574	$53,031,861	$62,437,686
	9	$21,523,365	$43,046,729	$61,070,907	$68,277,445
	10	$24,087,416	$48,174,833	$63,990,787	$72,170,617

Depending on yield and land usage rates, at an emissions price of $50/tonne our external benefit ranges from $11.3 million to $72.2 million. We now have all of the figures we need to calculate social net benefit, including the total annual private net benefit for our three groups, and the annual external net benefit for society. Thus, the next chapter will combine the two and estimate the social net benefit.

3.4 Social net Benefit

It is now time to combine all of the information we have discussed and estimated thus far, including the annual private net benefit, which is the sum of the private net benefit for farmers, processors and consumers, and the annual external net benefit. The sum of the total annual private net benefit and the annual external net benefit will give us an estimate of the annual social net benefit under the various scenarios of switchgrass yield, land usage rate and pellet plant size. However, there is still one additional step. A switchgrass stand is estimated to last for ten years, meaning we must account for that in estimating the total social net benefit.

To accomplish this, we will find the Net Present Value (NPV) of the sum of annual social net benefits over the 10 years, which will be assumed to remain constant. This involves choosing a discount rate, which is an indicator of how highly future benefits are valued. Our first step, then, is to estimate the annual social net benefit under the various scenarios of switchgrass yield, land usage rate and pellet plant size, which is presented in Table 3.36.

Table 3.36 Annual Social Net Benefit

		Land Usage Rate			
		25%	50%	75%	100%
2 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	$36,174,212	$72,348,424	$108,522,636	$144,696,848
	7.5	$52,424,371	$104,848,742	$157,273,113	$190,665,634
	9	$62,174,466	$124,348,932	$184,731,589	$231,197,324
	10	$68,674,530	$137,349,059	$204,997,434	$258,218,450
6 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	$38,335,413	$76,670,826	$115,006,239	$153,341,652
	7.5	$55,666,233	$111,332,466	$166,998,699	$203,506,932
	9	$66,064,725	$132,129,450	$196,288,830	$246,606,978
	10	$72,997,053	$145,994,107	$217,838,853	$275,340,343
10 t/h Plant Capacity					
Switchgrass Yield (tonnes/ha)	5	$39,170,878	$78,341,755	$117,512,633	$156,683,510
	7.5	$56,919,442	$113,838,884	$170,758,326	$208,569,185
	9	$67,568,581	$135,137,161	$200,844,872	$252,681,702
	10	$74,668,006	$149,336,013	$222,901,131	$282,090,046

As shown in the table, and similar to most other net benefits that have been calculated here, the annual social net benefit increases with switchgrass yield, land usage rate and pellet plant size under the assumptions and information included in this paper. The numbers are positive and significantly large, ranging from $35 million to $271.8 million. Granted, there is certainly information that was not able to be included here, which will be discussed further in Chapter 4, however these figures can serve as a starting point for additional research where the methodology and supporting information can be refined, expanded and improved, leading to more accurate estimates.

These annual estimates must now be expanded to account for the ten-year lifetime of the switchgrass stand. That is not to suggest that the project would stop after 10 years, however the crop must be replanted and thus the process would start anew, with more establishment costs and so forth. Other factors, such as pellet plant construction, would not need to be repeated during that time frame, however, so the results would differ somewhat.

While we will not get into any great detail regarding the discount rate, recall that the choice of discount rate has a significant impact on the calculated NPV, and thus the reported attractiveness of a project (Almansa & Martínez-Paz, 2010). Similar to the price per tonne of emissions, it would not be feasible to do a complete sensitivity analysis around various discount rates and include each of the scenarios we've included thus far for the amount of switchgrass pellets produced. So, we will use a range of discount rates, all three plant sizes, and three combinations of yield and land usage rate to show not only how the discount rate can affect the NPV within each scenario, but then also how changing only the yield or land usage rate affects the NPV. These variables were chosen somewhat arbitrarily from the previous analysis, however they are meant to represent moderate, likely achievable scenarios. Note that the social net benefit in Year 1 is assumed to be 0, as no switchgrass yield is expected. There would actually be a net cost, due to the establishment costs of the crop and pellet plants, however these have been included in the average costs during production years.

Also note that if one cares more about the future than the present, as a parent may care more for their children than they do themselves, the discount rate could be negative. Recall the likelihood that a future tonne of GHG emissions will cause more damage than a current tonne of GHG emissions, meaning the cost per tonne of emissions would increase as the marginal damage of a tonne of emissions increases. However, for this paper we assume a static cost of emissions. With this in mind, the final results of this study are presented in Tables 3.37, which presents three scenarios. Scenario 1 assumes a yield of 7.5 tonnes/ha and a 75% land usage rate, Scenario 2 examines a yield of 9 tonnes/ha on the same amount of land, and Scenario 3 keeps the 9 tonnes/ha yield while reducing the land usage rate to 50%. This serves to show the effect that a change in each variable has on the project NPV over the ten-year lifespan of a switchgrass stand.

Table 3.37 Net Present Value of Social Net Benefit

Scenario 1: 7.5 tonnes/ha Yield, 75% Land Usage Rate			
Discount Rate	2 t/h Pellet Plant	6 t/h Pellet Plant	10 t/h Pellet Plant
-10%	$2,763,069,788	$2,933,934,821	$2,999,986,226
-1%	$1,503,945,295	$1,596,947,529	$1,632,899,462
0%	$1,415,458,013	$1,502,988,295	$1,536,824,933
1%	$1,333,865,590	$1,416,350,292	$1,448,236,456
3%	$1,188,879,208	$1,262,398,120	$1,290,818,373
6%	$1,009,172,938	$1,071,579,023	$1,095,703,383
10%	$823,399,637	$874,317,716	$894,001,150
Scenario 2: 9 tonnes/ha Yield, 75% Land Usage Rate			
Discount Rate	2 t/h Pellet Plant	6 t/h Pellet Plant	10 t/h Pellet Plant
-10%	$3,245,477,015	$3,448,521,659	$3,528,564,988
-1%	$1,766,520,668	$1,877,038,339	$1,920,606,108
0%	$1,662,584,299	$1,766,599,467	$1,807,603,850
1%	$1,566,746,570	$1,664,765,906	$1,703,406,639
3%	$1,396,446,865	$1,483,811,852	$1,518,252,477
6%	$1,185,365,490	$1,259,524,732	$1,288,759,449
10%	$967,157,836	$1,027,665,495	$1,051,518,548
Scenario 3: 9 tonnes/ha Yield, 50% Land Usage Rate			
Discount Rate	2 t/h Pellet Plant	6 t/h Pellet Plant	10 t/h Pellet Plant
-10%	$2,184,637,747	$2,321,330,625	$2,374,171,920
-1%	$1,189,103,393	$1,263,505,644	$1,292,267,283
0%	$1,119,140,391	$1,189,165,054	$1,216,234,451
1%	$1,054,628,852	$1,120,617,025	$1,146,126,038
2%	$995,064,137	$1,057,325,343	$1,081,393,625
3%	$939,994,497	$998,809,993	$1,021,546,269
4%	$889,014,950	$944,640,653	$966,143,853
6%	$797,908,653	$847,833,832	$867,133,383
10%	$651,025,875	$691,760,593	$707,507,391

Notice that as the discount rate increases, the NPV of the project decreases, as future benefits are valued less and less. Regardless, even with a discount rate of 10%, which is likely high, the NPV of the ten-year project is significantly positive, never less than $651 million, which occurs under the 9 tonnes/ha, 50% land usage rate, 2 t/h pellet plant scenario. In that same scenario, a discount rate of -10% produces an NPV of almost $2.2 billion. It can also be seen that increasing the yield while keeping all other variables the same increases the NPV and vice versa, while the same is true for the land usage rate and the size of the pellet plant. However, let us now look at the proportional changes for each variable.

Increasing the pellet plant size from 2 t/h to 6 t/h (200%) increases the NPV by roughly 6% in every case, while increasing from 6 t/h to 10 t/h (67%) only increases NPV by roughly 2%. Increasing the yield also improves NPV, as an increase from 7.5 tonnes/ha to 9 tonnes/ha (20%) while keeping the other variables constant increases NPV by roughly 17.5%. Similarly, decreasing the land usage rate from 75% to 50% (33%) results in a decrease in NPV of 32.7% in each case. While not exact, the proportional change in NPV is roughly equal to the change in the variable, with the exception of pellet plant size. For a 1% increase in the discount rate, NPV decreases by roughly between 5% and 6%. For example, using 0% instead of -1% increases NPV by 5.88%, 1% instead of 0% by 5.76%, 2% instead of 1% by 5.65%, 3% instead of 2% by 5.53%, and so on.

The goal of this paper has been to determine whether there are net benefits to be had for the various groups in the supply chain and society in general from using switchgrass pellets grown on inactive farmland to replace electricity and light heating oil used for heat. Under the assumptions and estimates made here, it has been that this is in fact the case. Unfortunately, it was not possible to include all relevant costs and benefits. Because of this, a more comprehensive study is recommended that takes into account at least some of the factors that this paper is not able to.

CHAPTER 4 - DISCUSSION

While this paper does not report a single figure for an estimate of the NPV of the project, it does suggest that, under the assumptions and estimates used, it would be positive and in the hundreds of millions of dollars. However, the accuracy of these estimates depends completely on the accuracy of the supporting information used, such as the life-cycle emissions of the various fuels. While this is not a downfall in and of itself, it is recommended that further research around these life-cycle emissions figures is completed to ensure those emissions are completely understood before being used to advocate a particular fossil fuel replacement project.

In order to ensure the accuracy of those estimates, additional costs and benefits that have not been included here should be explored. In light of this, the next section of this chapter briefly explores what some of those costs and benefits may be, and concludes with a brief general discussion of energy crops in Nova Scotia.

4.1 Additional Costs and Benefits Not Quantified

The analysis presented in this paper provides a starting point for estimating the social net benefit of growing switchgrass as an energy crop on inactive and underused farmland. However, costs and benefit that were left out of this paper would be essential for a true, all-encompassing social cost-benefit analysis. This includes both private and external costs and benefits that will briefly be discussed here.

4.1.1 Private

Private costs and benefits included in an analysis such as this should include anyone who is directly affected by the project. This primarily includes monetary costs and benefits, but also extends anyone who experiences direct utility or disutility. Let's begin with farmers.

Many people may feel an increased sense of self-worth when they are employed, especially doing something they enjoy. Thus, a program that increases opportunities for farmers should count among its benefits the increased utility of farmers who are able to farm again, although this would be extremely difficult to measure. Additionally, as the amount of inactive and underused farmland is reduced as switchgrass production increases, companies and individuals who provide goods and services to the farmers would also experience a producer surplus that should be measured. This would include large seed and chemical supply companies, who may or may not exert market power on farmers in order to obtain a greater portion of the benefits.

This concept also extends to processors, as the construction of the plant and use of supplies would result in an increase in benefits from increased economic activity. The same applies to the furnaces that consumers purchase for combusting the pellets. As the switchgrass pellet industry expands, this also would provide taxes for public coffers that would need to be included as well.

There are also private costs that should be measured that have not been. The fuel sources that switchgrass pellets would replace will have a reduction in activity, and a corresponding reduction in total private net benefit and taxes generated from those activities. The extent to which the costs and benefits would be felt is extremely large, and this list is by no means comprehensive. But it should serve to remind the reader that when performing a true cost-benefit analysis, one must go beyond what is immediately obvious and explore the various effects a project can have.

4.1.2 External

External costs and benefits can be non-monetary in nature, and often relate to environmental issues, which were discussed in Section 2.2. The only external factor that this paper quantified was the net GHG emissions, however that is by no means the only factor worth including, and not all emissions were included here. Rather, a true social cost-benefit analysis would include all of the emissions that occurred as a result of this project, as well as the ones that did not occur that otherwise would have. For example, emissions from the production and transport of seed, fertilizer and chemicals, the manufacture and transport of farm equipment, the construction of the pellet plant and the manufacture of materials, the manufacture and transport of the pellet furnace and the materials used, and so on. However, there would also be less mining of coal and extraction of oil, as well as their transport and associated emissions, as well as less manufacture of the equipment required for those activities.

Essentially, a true social cost benefit analysis would include each and every positive and negative impact arising from the project, or at least as many as possible. This type of additional research is recommended before pursuing an energy crop project such as that described here. External costs and benefits are not limited to environmental issues, however.

A significant portion of the energy used in Nova Scotia is derived from fossil fuels, 90% of which is imported from outside the province and outside Canada (Hughes, 2007). By relying on this, the province exposes itself to outside risks that it cannot control, thereby reducing its energy security, which Hughes (2007) describes as "the availability of a regular supply of energy at an affordable price". Thus, the greater percentage of Nova Scotia's energy supply that is sourced locally, particularly from renewable sources, the greater the province's energy security will be. In light of this, it is also recommended that energy security be included as part of future analysis of the costs and benefits of locally-produced energy crops.

4.2 Energy Crops in Nova Scotia

While energy crops are not being used in Nova Scotia on a large scale, there are a number of developments that suggest the industry could expand. For example, it was recently reported that West Nova Agro-Commodities Ltd. of Lawrencetown will receive $1.3 million from the provincial government to build a grass pellet and briquette plant that will be owned by local farmers and landowners (The Chronicle Herald, 2012). In addition, Pro Farm Energy Inc. is currently taking proposals from landowners with underutilized land with the goal of leasing it to grow miscanthus grass that will be used to power a 10 megawatt power plant in Hantsport, Nova Scotia (Power, 2012). The company has issued a request for hundreds of hectares located within 150 km of the power plant. Perennia, an agricultural products research organization, has also been involved with the development of energy crops in Nova Scotia, as has Cape Breton University, which has been conducting a test crop of hybrid willow SRWC.

While it is clear that the industry is developing, there are steps the provincial government could take to accelerate this development. This would be done through the existing Community Feed-in-Tariff (COMFIT) program. According to the Province of Nova Scotia (2012), a "feed-in-tariff" is "a rate per kilowatt hour that small-scale energy producers are guaranteed for a fixed period of time to provide them with enough economic certainty to invest in renewable energy projects." Unfortunately, the program predominantly focuses on the electricity sector as opposed to energy in general. However, in addition to wind, in-stream small-scale tidal and run-of-the-river hydroelectricity, the program does provide incentives for Combined Heat and Power (CHP) biomass.

CHP refers to a power plant that generates electricity from combusting biomass, however it also collects and distributes the waste heat (Province of Nova Scotia, Department of Energy, 2012). This improves the economics of the venture, and energy crops could certainly be used as feedstock for this type of power plant. However, by focusing only on electricity generation, the program is likely missing two opportunities; to reduce fossil fuel use by including residential heating in the program, and to provide additional opportunities for farmers by expanding the energy crop industry. It should be noted that this type of program should only advocate a renewable energy source like energy crops if the evidence from analyses such as this shows that it will actually reduce GHG emissions.

CHAPTER 5 - CONCLUSION

This paper used social cost benefit analysis to answer three core questions; 1) Does a business case exist to profitably use inactive and underused farmland in Nova Scotia to grow switchgrass as an energy crop, and would this result in savings for consumers? 2) Would this practice result in a reduction in GHG emissions, measured in CO_2 equivalents, providing an external net benefit to society, measured in monetary terms? 3) Is it in society's best interests to grow switchgrass as an energy crop in Nova Scotia?

Based on the assumptions and estimates used in this paper, the analysis suggests the answer to the first two questions may be yes for a variety of switchgrass crop yields, usage rates of the total amount of available inactive and underused land, pellet plant sizes and cost estimates per tonne of GHG emissions. However, due to the assumptions and background estimates used, a number of cautions should be noted.

Perhaps most importantly, the reduction in GHG emissions that was found in Section 3.3 relied entirely on the life-cycle emissions figures from Samson et al., (2008b). The analysis behind these figures was not transparent, and they should be used with caution. Thus, while the use of these figures suggests a reduction in GHG emissions, it is recommended that more transparent work be completed on the life-cycle emissions of various energy sources, particularly energy crops, including the loss of the natural state carbon sink. Failure to do so could result in the adoption of policies that exacerbate the issue they were crafted to resolve. This analysis should include all aspects of production, which includes far more components than the simple GHG reduction estimates included here. In addition, further research should include more appropriate measurements of the loss of carbon sequestration ability of the land being used.

The external net benefit estimated here included only GHG emissions, and so only partially represents the true external net benefit. In addition to GHG emissions, there will likely be other external costs such as biodiversity loss and impacts on local water quality that would need to be measured in a full social cost benefit analysis. There would also be impacts from the manufacture of the additional furnaces required to burn the switchgrass, which would be in the tens of thousands.

Similarly, in terms of private net benefit, this analysis included only a portion of supply chain. To estimate the true private net benefit, all stakeholders would need to be included, including suppliers. This would also involve taking a closer look at the market structure, and how stakeholders may be affected by other portions of the supply chain; for example, how seed suppliers affect farmers.

The analysis also guaranteed a positive private net benefit by assuming a 20% margin applied to the costs of production. This ensured the viability of farms and each of the plant sizes, although in reality farms and processing plants with fixed costs would likely have to be a minimum size, accept smaller margins or find cost savings elsewhere to be viable. It would also be extremely difficult for a smaller plant such as one with a 2 t/h capacity to compete with a larger plant due to higher costs. The price required to maintain the 20% margin for the smaller plant was higher than that of the larger plant, so this will depend on consumers' willingness to pay for the product. Because of these issues, while the study does suggest that a switchgrass energy crop grown on inactive and underused farmland may be beneficial for society, it is still unclear whether that is truly the case. With these limitations in mind, the estimates presented in this analysis should be viewed as a starting point for estimating the social net benefit of growing a switchgrass energy crop on inactive and underused farmland.

This inactive and underused land was estimated to total 60,700 hectares, which is equal to 1.1% of Nova Scotia's land area. If all of this land is used, it is estimated to be able to provide enough switchgrass pellets to heat between roughly 70,000 and 140,000 homes. Heating more homes than this would require either higher yields than our maximum 10 t/ha, or more land to be cleared if food production is not to be impacted. If every one of the 293,275 single detached houses and semi-detached/row/duplex dwellings in Nova Scotia were to be heated using switchgrass pellets, with eaching using 70 GJ of energy for heating annually, this would require 1.07 million tonnes of pellets. At a yield of 7.5 t/ha, this would require 142,564 hectares, or 2.6% of Nova Scotia's land area. Recall that 70 GJ of heating energy requires 4.35 tonnes of switchgrass pellets, meaning each household would require .58 hectares or .0058 km^2 to provide the annual heat requirement.

For farmers, the private net benefit is estimated to range from \$2.4 million to \$9.5 million, depending on the amount of land used to grow the crop. Since costs were estimated on a per hectare basis, and revenue was equal to cost plus a 20% margin, yields had no effect on the private net benefit for farmers. Yields did have an effect on the private net benefit for processors however, since the price per tonne of raw material did decrease with increasing yields.

In addition to the yield and the amount of land used to grow switchgrass, the private net benefit for processors also depended on the plant size used throughout the province, which was assumed to be either 2, 6 or 10 tonnes an hour (t/h). For the 2 t/h plant, the private net benefit ranged from $4.7 million to $26.5 million. For the 6 t/h and 10 t/h plants, the range was $4.3 million to $23.3 million and $4.2 million to $22.0 million, respectively. It is suspected that the decreasing private net benefit with increasing plant size is due to the fewer plants needed across the province. On a per plant basis, larger plants had higher private net benefits.

Consumers were the group with the largest estimated private net benefit, which depended on the same factors as processors, including the price paid for pellets, which depended on the price paid for raw material. So, consumer private net benefit depended on switchgrass yield, land usage rate and plant size. However, an additional assumption had to be made to account for the heating source the consumer was switching from. Thus, it was assumed that the first consumers to switch to switchgrass pellets would be those currently using electricity for home heating. Once all of the homes using electricity had switched, the remaining homes would switch from a medium-efficiency oil furnace. For the 2 t/h processing plant, consumer private net benefit ranged from $17.8 million to $150 million. For the 6 t/h and 10 t/h plants, the range was $20.4 million to $170.4 million and $21.3 million to $178.4 million, respectively.

In addition to the private net benefit, the external net benefit was estimated first by determining whether there would be GHG emission savings from using switchgrass pellets instead of electricity and light heating oil, which there were. However, this had to be compared with the carbon sink opportunity cost of using land for energy crops that could be allowed to revert to its natural state, which was assumed to be a mixed forest that would be a larger carbon sink than the switchgrass. However, under the assumptions made and estimates used, which included a cost of GHG emissions of $50/tonne of CO_2E, there was still an external net benefit ranging from $11.3 million to $72.2 million.

Estimating the social net benefit requires combining the private net benefit and the external net benefit under the same circumstances. For example, the private net benefit with a 7.5 t/ha yield, 75% land usage rate, for each plant size, was compared to the external net benefit under the same yield and land usage rate. Thus, when 2 t/h processing plants are used, the annual social net benefit ranges from $36.2 million to $258.2 million. For the 6 t/h and 10 t/h plants, the range is $38.3 million to $275.3 million and $39.2 million to $282.1 million, respectively.

This annual social net benefit was then used to find the Net Present Value (NPV) over the 10-year lifespan of a switchgrass crop for a variety of discount rates, ranging from -10% to 10%. Lower discount rates result in higher NPV values, as a higher value is placed on future benefits. NPV also increases with yield, land usage rate and plant size. In order to restrict the number of figures reported, the effect on NPV of separate changes in switchgrass yield and land usage rates was performed. In all cases, the NPV was quite large. For example, the NPV for the circumstance including 9 t/ha yield, 75% land usage rate and 10 t/h processing plants, the NPV using a -10% discount rate was estimated to be $3.5 billion. Under the same circumstances, a discount rate of 10% resulted in an NPV of $1.05 billion over the 10-year timeframe. Regardless of yield, land usage rate or plant size, increasing the discount rate by 1 percentage point, from -1% to 0% or 0% to 1%, decreased NPV by roughly 5.75%. In future work, it is recommended that a longer timeframe be adopted in estimating NPV to account for changing carbon prices, as the marginal damage from a tonne of GHG emissions increases. This would also account for the longer life of equipment, which would be depreciated over a longer timeframe than the 10 years used here. In this scenario, inflation would also be considered.

To conclude, the analysis performed here suggests a positive social net benefit under a variety of scenarios. However, this was based upon certain assumptions and background estimates, some of which require more research before being relied upon for policy consideration, such as the life-cycle emissions of switchgrass pellets. This was also only a partial analysis, as a number of both private and external costs and benefits were omitted due to the scope of the paper, such as additional members of the supply chain and external costs other than GHG emissions. If switchgrass pellets are to be pursued as a source of residential heat, including when grown on inactive and underused farmland, additional research is needed that encorporates more private and external costs and benefits.

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