Economic and Environmental Impacts of Biofuel Policy in Canada: An Application of Input-Output Modelling

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ABSTRACT

The government of Canada has committed that Canada's total GHG emissions be reduced by 17 percent of 2005 levels by 2020. To achieve this, the federal government of Canada announced its renewable fuels strategy in 2007, which introduced mandated requirements for the use of ethanol and biodiesel. The Federal government has also introduced several initiatives by setting new emissions standards for heavy-duty vehicles, and phase in regulations for the generation of electricity from coal by 2015. These regulations required 2% renewable content in diesel fuel and heating distillate oil by 2012, for a total production of approximately 600 million litres of biodiesel per year. In addition, renewable content standards for gasoline were targeted at 5% by 2010. This represents approximately 2.1 billion litres of ethanol being required per year according to the Canadian Renewable Fuels Association. With this backdrop, the study aims at estimating the macroeconomic impacts of the ethanol and biodiesel sectors in Canada using an Input-Output model. Biofuel sectors including ethanol, biodiesel and corresponding by-products have been incorporated into the 2008 Input-Output Model of Canada. Simulation exercises have also been attempted to reach the mandates using a modified Leontief model. Results show that the macroeconomic impact of the ethanol sector leads to an increase in industrial output, GDP and employment. Further, the agriculture sector is affected because of feedstock use in the biofuel sector. Mining and manufacturing industries also show a considerable impact.

RÉSUMÉ

Le gouvernement canadien s'est engagé à réduite de 17 pourcent par rapport au niveau de 2005 l'émission de gaz à effet de serre pour l'an 2020. Pour atteindre cet objectif, le gouvernement canadien a annoncé sa stratégie d'énergie renouvelable qui a introduit des exigences supplémentaires pour l'usage d'éthanol et de biodiésel dans les carburants fossiles. Ainsi, le gouvernement fédéral introduit des initiatives comme la mise au point de nouveaux standards d'émission pour les véhicules lourds et, depuis 2005, introduit de nouveaux règlements entourant la génération d'électricité à partir du charbon. Ces règlements exigent que le diesel et l'huile de chauffage contienne 2 pour cent de biocarburants, créant ainsi une demande en biodiésel d'environ 600 millions de litres par an. De plus, les standards de contenu de biocarburants dans l'essence ont été ciblés à 5% à partir de 2010, ce qui représente environ 2.1 milliards de litres d'éthanol par année selon l'Association Canadienne de Carburants Renouvelables (ACCR). Dans ce contexte, cette étude estime les impacts macroéconomiques des secteurs de l'éthanol et du biodiésel au Canada en utilisant un modèle d'entrées-sorties. Les secteurs bio-carburants a été intégrés au modèle entrées-sorties à partir de l'an 2008. Les exercices de simulation ont également utilisé un modèle Leontief modifié afin d'atteindre les objectifs. Les résultats démontrent que l'impact macroéconomique du secteur des biocarburants fait augmenter la production industrielle, le PIB et l'emploi. De plus, le secteur agricole est affecté de par l'usage du secteur des biocarburants de grain initialement utilisé pour l'alimentation animale. Les industries minières et manufacturières sont également touchées par ces nouvelles politiques.

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CHAPTER 1

BACKGROUND AND INTRODUCTION

1.1 INTRODUCTION

The competition for land resources is increasing worldwide. This increased competition is the result of rising demand for food production for a growing population and the demand for the non-agricultural uses, such as plant oils for the cosmetics industry and timber for the construction sector. In addition, concern about climate change have increased the demand for land to be used to produce biomass feedstocks for power and heat (European Biofuels 2014).

There is an increasing environmental cost for using fossil fuels. Alternatives to fossil fuels, such as biofuels, can be a potential way to increase sustainability. Energy conservation and efficiency can be achieved at the same time (Dale et al. 2014) and if energy sources are of high-quality, this can benefit society and human-beings globally (Lambert et al. 2014). In both developed and developing countries, economic benefits may be achieved from the production of biofuels. Also, the energy security can be improved by the production of biofuels (Sims et al. 2010). The pollution of air and water associated with petroleum refineries will continue to create GHG emissions in the future. Thus, both economic benefits and ethical considerations should provide encouragement to explore environmentally friendly alternative energy sources, including biofuels (Buyx and Tait 2011). However, there are also concerns about using land for non-food uses which create debates.

Since fossil fuels are not a renewable energy sources, the global demand for renewable biologically produced fuels should become stronger as sources of fossil fuels dry up (Borowitzka and Moheimani 2013). This is why ethanol and biodiesel, as renewable fuels, are again being considered as clean-burning alternatives that reduce greenhouse gas emissions that lead to global warming. (Kim et al. 2010, P.1).

Biofuels, including ethanol and biodiesel, are fuels derived from biomass feedstocks. Since they are produced from plants or animal fats that harness the power of the sun, they are considered renewable fuels. Ethanol and biodiesel are organic non-toxic fuels that burn cleaner than fossil fuels and contribute to reducing pollution and the emission of greenhouse gases (A. C. Hansen et al. 2006). Using biofuels can diversify energy supply, and, in turn, help our environment and economies.

Ethanol can be made from different agricultural crops such as wheat, corn, and sugar cane through a fermentation process. Ethanol is the most widely used biofuel. After being blended with gasoline at appropriate levels, ethanol becomes an important, viable alternative to unleaded gasoline. That is high-octane with high oxygen content. This characteristic allows the automobile engine to combust its fuel more completely. The desirable result is fewer harmful emissions.

Biodiesel is a sustainable substitute for mineral diesel and is made from biological materials such as vegetable oil or animal fats. After a chemical process named transesterification, a reaction between the fat or oil reacts and methanol synthesized from natural gas occurs (Laan et al. 2009). For a better chemical reaction, a catalyst can be used to produce biodiesel and its main by-product, glycerin (Yang et al. 2012). Other by-products are generated at the same time such as fatty acids, fertilizer and oilseed meal. The glycerine and oilseed meal are the valuable by-products. These by-products are sold to the cosmetics and food manufacturing industries. Glycerin is mainly used in foods and sweets processing and is considered safe by the US Food and Drug Administration (Bruso 2015). The range of variation for the energy content of biodiesel is between 88 per cent and 99 per cent of the energy content of standard mineral diesel, depending on the feedstock and esterification process used (Laan et al. 2009). Biodiesel substitutes for fossil (mineral) diesel is either at a blended rate (normally 5% or 20%) or pure. Brassicas (mainly rapeseed, canola, and camelina), soybean, palm and Jatropha are the main oilseed crops used for fuel production (Laan et al. 2009). Algae is another possible feedstock with high oil content although this microalgal feedstock is currently only at the research and demonstration stage (Laan et al. 2009). Waste vegetable oil and animal or fish oil by-products are used for biodiesel production as well.

Biofuel production worldwide has been increasing since 2000. It is reported that the production grew from 16 billion litres in 2000 to more than 100 billion litres in 2011 (International Energy Agency 2012). Currently, nearly 3% of total on-road fuel energy use comes from biofuels although in some countries biofuel account for higher shares. Nearly 21% of Brazil's road transport fuel demand in 2008 was met by biofuels. In the European Union (EU) and US, the percent share was 3% and 4% in 2008, respectively. Biofuels can have a variety of feedstocks, including biological plants (e.g. Miscanthus, Jatropha, and Short Rotation Coppice), wastes (e.g. cooking oils, and municipal solid wastes.), agricultural and forestry residues (straw, corn stover, etc), and new potential feedstocks, for instance, algae (European Biofuels 2014).

In Canada, half of the bioethanol production is in three provinces: Saskatchewan, Manitoba, and Ontario. In 2013, Canada produced enough fuel ethanol additive to supply 523 million gallons of final product (Renewable Fuels Association 2013). The major ethanol production feedstock in Canada is corn. However, in Western Canada, the major feedstock is wheat. Canada is actually importing biofuels because of the demand for grain by the livestock sector and to satisfy export markets. The U.S. exported 621.5 million gallons of ethanol

(Farmgateblog) in 2013, the third-highest annual amount in history. Canada imported 52% of the total ethanol produced in the U.S. (Renewable Fuel Association 2014).

The prices and availability of biodiesel feedstocks are the determining factors for production. Given the Canadian agricultural production, canola is the oilseed feedstock with the greatest potential. The main competitors are rendered animal fats and oils (tallow and yellow grease), and soybean oil. In the future, the growing market for sustainable energy from the European Union (EU) can reasonably be expected to generate a potential demand for biodiesel exports from Canada (Evans and Dessureault 2013).

1.2 PROBLEM STATEMENT AND OBJECTIVES

Public policy-makers have considered the sustainability of biofuels to be a positive part of a broader interest in sustainable energy. The European Union has emphasised the importance of promoting sustainable renewable energy alternatives (European Commission 2008). The United Nations has developed a framework for decision-makers to encourage sustainable bioenergy production (Larson 2007). The US outlined a "roadmap" for bioenergy and biomass production in the US (Biomass Research and Development Technical Advisory Committee 2007). In 2007, the federal government of Canada announced a policy for the use of ethanol and biodiesel. The policy is designed to create a demand for biofuels, which produce lower GHG emissions than fossil fuels. The federal government is also committed to providing new Canadian biofuels facilities with a budget of $2.2 billion for operating and capital support. Canada's total GHG emissions is forecast to be reduced by 17 percent of 2005 levels by 2020 (Canadian Renewable Fuel Association 2014). Lowering carbon emissions has become imperative. Therefore, the Federal government has introduced three major initiatives: 1)

Passenger automobile and light truck GHG emissions regulations setting new emissions standards for 2011-2016 model-year vehicles; 2) Heavy-duty vehicle emissions regulations that are intended to restrict emissions from heavy-duty vehicles, in alignment with similar regulations being developed in the US; and 3) Regulations on coal-fired electricity generation have been proposed. In order to reduce GHG emissions, new Renewable Fuels Regulations (RFR) require 2% renewable content in diesel fuel and distillate oil for heating. The rules became effective on July 1, 2011 with the first compliance period ending on December 31, 2012. Initially, an implementation exemption until December 31, 2012 was given to the eastern part of Canada. But on May 18, 2013, regulations extended the exemption until June 30, 2013. The fuels sold in Newfoundland and Labrador have been given a permanent exemption for renewable content. The exemption was given in order to decrease the cost for Canadians that use oil to heat their homes (Government of Canada 2013). These fuels include diesel fuel and heating distillate oil as well as the renewable content in heating distillate oil. Also, temporary exemptions for renewable content in diesel fuel and heating distillate oil have been extended until June 30, 2013. This temporary exemptions only cover the fuels sold in Quebec and all Atlantic provinces which need more time to install biodiesel blending infrastructure (Evans and Dessureault 2013). In addition, renewable content mandates for gasoline were targeted at five percent starting on September 1, 2010.

Based on the RFR, the 2% renewable fuel mandate would generate a 500 million litres of biodiesel demand per year. In 2011, the Canadian government amended the RFR to require an average 2% renewable energy in diesel fuel and heating oil. This commitment will require approximately 600 million litres of biodiesel production per year (Farm Credit Canada 2007). On the other hand, for the mandate for gasoline targeted at 5% starting on September 1, 2010, according to the Canadian Renewable Fuels Association, this would requires approximately 2.1 billion litres of ethanol supply per year. The Regulations will require fuel producers and importers to only import fuels having a minimum 5% ethanol and 2% biodiesel blended with gasoline and diesel (Government of Canada 2010). The reduction of GHG emissions by 62 percent with ethanol and up to 99 percent with biodiesel is expected to be achieved compared to fossil fuels which reduce GHG emissions of approximately four million tonnes. The more biofuels get used in Canada, the more fossil fuels can be conserved or exported to meet the international market demand for energy. Not only is the natural petroleum supply in Canada extended, but Canada's reputation as a responsible producer and supplier of energy can also be advanced (Canadian Renewable Fuel Association 2014). The above mandates of 600 million litres of biodiesel and 2.1 billion litres of ethanol required per year are expected to have effects on the Canadian economy. Given this backdrop, the purpose of this study is to estimate the macroeconomic impacts of the ethanol and biodiesel sectors in Canada using an Input-Output model.

1.3 ORGANIZATION OF THE STUDY

The following is the outline of the thesis. Chapter 2 reviews the relevant literature concerning biofuels in developed as well as developing countries. This is followed by a global overview of biofuels in Chapter 3. This chapter presents the consumption, production, import and export situations for ethanol and biodiesel around the world. The mandates worldwide and the current and future development trends for biofuels are also discussed. Chapter 4 consists of describing the Input-Output methodology used in the study as well as the preparation of the biofuel sector in the Canadian Input-Output Model. We incorporate four industries and eight commodities in our Canadian Input-Output Model. Chapter 5 illustrates the data preparation of the biofuel sectors in the Use and Make matrices. Chapter 6 presents the analysis, results and discussions. In Chapter 7, six simulations are presented. The conclusion and policy recommendations are presented in Chapter 8.

CHAPTER 2

LITREATURE REVIEW

With the increasing concern about the global warming, governments from different countries have taken initiatives to reduce the greenhouse gas emissions. To promote an interest in biofuels and set national biofuel mandates is one of the major actions of government. In consequence of this background of interest, and the resulting need for supporting analysis, many studies have been conducted in the biofuels area. The literature reviewed in the following pages covers different economic models used in biofuel area for both developing and developed countries. In addition, Canadian biofuel studies using Input-Output analysis have been elaborated at the end of the literature review.

2.1 BIOFUEL STUDIES WORLDWIDE USING VARIOUS METHODOLOGICAL APPROACHES

In the biofuel area, in addition to Input-Output analysis, other researchers use Computable General Equilibrium Models (CGE), Life Cycle Assessment (LCA), or Cost/Benefit Analysis (CBA) for estimation. Other studies have combined or compared the different methodological approaches used for analysis.

2.1.1 Computable General Equilibrium Model in Biofuel Study

In developing countries, research projects have been conducted to estimate the impacts of biofuels on the economy and to investigate the feasibility of biofuel production. The development of a biofuels industry may not only reduce poverty by boosting the economy (Arndt et al. 2010) but also may be an alternative energy source and so alleviate electricity shortages

(Scaramucci et al. 2006). One study used a recursive dynamic computable general equilibrium model for Tanzania to investigate the feasibility of biofuel production and to estimate their impacts on the economy (Arndt et al. 2012). Results show that with the engagement and improvement of the productivity of smallholder farmers, poverty can be reduced in developing countries such as Tanzania. Ethanol produced from cassava is more profitable than with other feedstocks. The conclusion has been reach that the establishment of a biofuels industry supported by public investments can enhance the development of other industries.

Argentina is one of the biggest biodiesel producer and exporter in the world. The major production feedstock in Argentina is soybean (Timilsina et al. 2013). There, a study using a computable general equilibrium approach carried out simulations on international demand and supply for biofuels and their feedstocks. The impacts of the local government biofuel policy were estimated at the same time. The simulations results report that Argentina's GDP and social benefits would be increased because of the increases in prices for biofuels and feedstocks. However, GNP of the country and social benefits would suffer small losses. The reason is because part of biodiesel and feedstock have been transferred from exports to domestic market which has lower benefits. In addition, the increase of the export tax also reduces the GDP and social benefits.

In developed countries, many studies are focused on the impacts of biofuel policy to the economy. In a European study, a farm-detailed CGE model has been used to estimate the consequences of the European biofuel policy on the farm sector (Gohin 2008). Primary results show that domestic production of biodiesel is sufficient to meet the market demand. In addition, the livestock sectors are never negatively influenced. In a US study, the impacts of the biofuel policy from partial and general equilibrium perspectives have been assessed (Tyner and

Taheripour 2008). Results of the study show that the link between energy and agricultural markets that has now come into being is of great importance. The linkage has profound impacts on the global agricultural sector.

Another paper investigates the economic effects of augmenting production capacity of operating biofuel plants in Andalusia using a computable general equilibrium model. The changes in the economic sector's activity in macroeconomic variables related to biofuel plants has been calculated. Results indicate that with the achievement of the ‘‘Plan Andaluz de Sostenibilidad Energética (PASENER)” target, the economy can create 167,975 jobs lasting one year and increase the GDP by 9.82%.

A European study aims to estimate economic and environmental impacts of introducing a biofuel sector into the economy. The discussion is focusing on the feasibility of implementing an advanced biofuels program in the European Union (De Lucia and Bartlett 2014). The objective of the policy is to achieve a 20% reduction in GHG emissions using 20% of renewable fuels by the year 2020. Results from the simulation exercise using a CGE model show that oilseed production will be increased. In addition, there will be a decrease in sectoral GDP in several other areas. In Eastern Europe specifically, oil and electricity prices would decrease. The results indicate the 20% GHG emissions reduction target could not be met. The suggestion from this study is that an improvement of the production technology of the second generation biofuels (such as lignocellulosic biomass) is required.

In addition to individual-based country studies, a Global Computable General Equilibrium Model has been used to estimate how biofuel production impacts global agricultural markets (Birur et al. 2008), international trade, and environmental impacts in terms of land-use change and GHGs emissions (Birur 2010). The more specific study has been conducted to look at the impacts of biofuel mandates for the livestock industry around the world. The study mainly focused on economic impacts estimation in the US, the EU, and Brazil (Taheripour et al. 2011).

A study has been conducted using the Global CGE Model to investigate the economic and environmental impacts of regional and international mandate policies. The mandate policies aim to increase renewable energy production and consumption (Taheripour et al. 2010). The study explicitly introduces Dried Distillers Grains with Solubles (DDGS) and biodiesel by-products (BDBP) into a worldwide CGE model with the argument that most of the studies have overestimated the effects of biofuels because they did not consider the importance of their by-products. Results show that, in a model considering by-products, prices change less due to the mandate policies. Last but not least, results also demonstrate that the incorporation of DDGS by assuming producers use DDGs in the production process as a substitute mainly for corn, can significantly change the land use impacts of the biofuel mandate policies.

2.1.2 Life Cycle Assessment in Biofuel Study

Life Cycle Analysis has become a popular tool for policy use, especially in the field of bioenergy (Angell and Klassen 1999). This technique offer a quantitative approach to estimate environmental impacts of technologies, products and services (Herrmann et al. 2014). It can be used to support the decision maker to understand and improve processes or answer environmental impact questions. The ability to calculate greenhouse gas savings or to improve processes has facilitated its use in meeting targets, choosing energy sources, and implementing policies by helping assess possible results of policy decisions (Schneider 1989). A number of studies (such as Larson (2006) and Spatari et al. (2005)) use LCA to estimate the biofuels' impacts on the transport sector. Some of them (such as Von Blottnitz and Curran (2007) and Liska et al. (2009)) focus on the environmental impacts' perspective considering GHG emissions. With the development of the biofuel industry, more and more studies focus on the potential second generation biofuel feedstocks such as lignocellulosic biomass (Singh et al. 2010) and microalgae using LCA (Lardon et al. 2009).

Two studies from Brazil have used the Life Cycle Assessment to estimate the economic and environmental impacts of biofuels. The sugarcane industry in Brazil has been considered promising for the production of advanced fuels and bio-based products (Souza and Seabra 2014). However, the large volume of fossil fuel required for cultivation and transportation needs a diesel replacement to reduce the negative environmental effects. The authors of the study performed a stochastic estimation of the environmental and economic consequences of the integrated supply of sugarcane bioethanol and soybean biodiesel, in comparison with the conventional sugarcane-to-ethanol process. Results indicate that the integrated system can contribute to the ethanol environmental performance.

The other study performed an economic assessment and carbon emissions analysis on ethanol from sugarcane and on an emerging process where sugarcane bagasse[1] is additionally used to produced ethanol (Wang et al. 2014). The combined conventional (sugarcane) plus lignocellulosic (sugarcane bagasse) ethanol pathway is found to be less economically favorable than the conventional ethanol pathway. The reason is the high cost of lignocellulosic ethanol production. GHG emissions savings against gasoline for both the traditional ethanol and the lignocellulosic ethanol pathways would increase with technological developments. The results show that using sugarcane bagasse for generating electricity is more favorable than ethanol before the lignocellulosic ethanol from sugarcane bagasse can be commercialized.

[1] Bagasse is sugarcane fiber waste left after milling process.

2.1.3 Cost and Benefit Analysis in Biofuel

A number of economic cost-benefit studies consider biodiesel and fuel ethanol production and attempt to determine the net impact of new economic activity on society. For biodiesel studies, we have a Canadian study looking at the impacts on the Ontario economy of removing the provincial fuel tax from biodiesel (Ontario Ministry of Agriculture and Food 2002) as well as a UK study looking at energy alternatives, global warming, and socio-economic costs and benefits (Mortimer et al. 2003). For ethanol studies, a Canadian report uses CBA to estimate three types of ethanol plants using different types of feedstocks and assesses internal rates of return with and without tax subsidies (Natural Resources Canada 2003).

Using the Cost and Benefit Analysis (CBA), a research paper reviewed the costs of biofuel policy in Thailand in 2011 (Bell et al. 2011). Both production and environmental costs and benefits are estimated. The results of the paper indicate that domestic biofuel production is 317 million dollars more expensive than importing the same amount of fossil fuels. An environmental benefits of 4.04 dollar per capita in 2011 was generated from GHG savings and losses. This result suggests that although biofuels are somewhat costly in the short term, their domestic production can conserve the capital in Thai economy instead of sending them outside of the country.

2.1.4 Other Studies in Biofuel

A study integrates material based Life Cycle Analysis (LCA) with welfare economic Cost Benefit Analysis (CBA) to estimate resource and environmental effects as well as social welfare effects of introducing biofuels in the Danish road transport sector (Møller et al. 2014). The integrated method focuses on fossil energy consumption, CO_2 emissions and total economic welfare changes within the life cycle flow chain including both production of biomass and subsequent conversion into biofuel and combustion in vehicles. The combination method is applied to the production of diesel from oilseed rape, first generation ethanol from wheat and second generation ethanol from straw. Results show that, under the backdrop of commercialization, supply and demand of all three biofuels lead to the expected large savings on fossil fuel and reductions in GHG emissions.

As tax credits for biofuels are likely to be a temporary policy, it is important that the production cost of biofuels be lower if they are to compete with fossil fuels. A study has been conducted to analyze projected production costs for different types of biofuels in Europe for 2015 and 2020 (Festel et al. 2014). Results show that second generation biofuels are most likely to achieve competitive production cost mid- to long-term when the impacts from technological learning and production scale, as well as crude oil prices, are considered.

In addition, a Canadian study aims to assess the economics of biofuel plants and to estimate the production, consumption and prices of this fuel ($(S\&T)^2$ Consultants Inc. 2004a). The biodiesel and ethanol industry status and performance in Canada, US and Europe are discussed. Feedstocks, costs and revenues, business structure and income taxes, market development as well as the assessment of policy tools are included. The work also quantified the financial as well as the non-financial impacts of biofuels including biodiesel and ethanol. The results are used to construct a template-like analytical system for various models of ownership structure to help estimate the economic benefits of the biofuel industry across Canada.

2.2 BIOFUEL STUDIES WORLDWIDE USING INPUT-OUTPUT ANALYSIS

Numerous studies have been carried out to estimate the economic effects of biofuel production in terms of industrial output and employment. However, studies using an Input-

Output modelling framework are much fewer in number, where ethanol studies take the lead compared to the biodiesel. In earlier explorations in the biofuel area conducted in developed countries a comparison was made with developing countries. In the developed countries, national policies for promoting biofuels are mainly focused on concerns of energy security and global warming.

The development of the Input-Output Model, resulted in models such as the Food and Agricultural Policy Simulator (FAPSIM) (Vogel et al. 2003), Impact Analysis for Planning (IMPLAN) (Schlosser et al. 2008), Ecologically-Based Life Cycle Assessment (Eco-LCA) (Baral and Bakshi 2010), and the Regional Input-Output Modeling System (RIMS II) (Herreras Martínez et al. 2013). The work has been conducted to assess the economic impacts of biofuels in the context of increasing biofuels production and consumption, including both traditional and second generation biofuels technologies. The accuracy of the I-O model is discussed by Schlosser et al. (2008).

One large-scale econometric model of the US agricultural sector maintained by the USDA's Economic Research Service (ERS) is the Food and Agricultural Policy Simulator (FAPSIM). "The model accounts for the price and substitution effects on corn and soybean markets from increasing demand for ethanol and biodiesel" (Vogel et al. 2003, P.1). The economic impacts of applying the Renewable Fuels Standard have been estimated by using "land-constrained" and "land-unconstrained" scenarios to build constraints. The application of the RFS would enhance new output and increase employment. For these two scenarios, applying the RFS creates a direct positive influence on corn and soy mills.

In the US, many regional studies have been conducted using the Input-Output Model. In order to connect the important economic factors of modern ethanol production, and compile an

Input-Output system of regional economies with a modern ethanol production plant, a study that illustrates procedures to estimate the economic benefits of the ethanol output in Iowa is this one: (Swenson and Eathington 2006). Another important objective of the study was to manipulate the investor capital flows for the prototypical plant. The result demonstrates the localized economic impacts of various levels of domestic investment. With a properly specified and applied Input-Output Models, the study could come up with regional economic impact summaries which are understandable and reasonable to clarify the net augmentation of regional ethanol production.

One study looks at the economic impacts in Minnesota of producing and using soy diesel blended at 2% and 5% with petroleum diesel using the IMPLAN model (Minnesota Department of Agriculture 2002). The direct, indirect and induced effects on the Minnesota economy would be $212 million annually for 2% blends and $527 million for 5% blends. However, the study does not analyse the financial feasibility or consumer effects of soybean production although it includes detailed production, consumption, and price information for fuel and soybeans. Another study estimates the economic impact of producing and using soy diesel blends in Kentucky instead of Minnesota (Bowman 2003). The environmental impacts of using soy diesel are also explored. The report appears to advocate state mandating of the use of soy diesel as the impetus for production. Results of the study show that 2%, 5%, and 20% soy diesel blends would contribute $234 million, $571 million, and $2.16 billion dollars total output respectively. The jobs created are 1,240, 3,020, and 10,600 for 2%, 5%, and 20% soy diesel blends respectively.

In 2012, a report outlined the development and current situation of the ethanol industry, specifically for Iowa. The work detailed the various economic and financial consequences of the ethanol industry within the state. The domestic economy, corn and land prices, and distributional ownership patterns were estimated (Hart et al. 2012). The IMPLAN Input-Output economic modeling software was utilized in the analysis for the ethanol industry in Iowa. The modelling results show that the prototypical 100 million gallon per year ethanol plant generates over US$300 million of benefits and creates 52 full-time equivalent jobs which is equivalent to US$4.2 million labour income. Considering direct, indirect, and induced effects, the full operation would contribute 234 jobs and US$12 million of labour income to the representative rural Iowa counties.

With the exploration of the advanced biofuels feedstock, a study aimed at assessing the direct, indirect, and induced effects on the economy associated with the establishment of wood-based bioenergy facilities in Mississippi has been conducted (Joshi et al. 2012). The IMPLAN 2010 data set has been used in the Input-Output Model of the Mississippi economy. The study considered three potential wood-based biofuel plants, including wood pellets, bio-oil, and methanol-based gasoline. Results of this study indicate that the operation of the three facilities would create 9,189 jobs and US$121 million of industrial output to the local economy in total. The methanol-based gasoline plant has the most significant economic impact due to its relatively lower unit cost compared to the other types of plants. This kind of plant would utilize the highest volumes of woody biomass for an equal amount of industrial output in the Mississippi economy.

To estimate the desirability and trade-offs for using alternative fuels, a tiered hybrid Ecologically-Based Life Cycle Assessment (Eco-LCA) model which is developed by compiling data on production processes and their supporting ecosystem services with the economy-scale Eco-LCA model has been conducted for biofuels (Baral and Bakshi 2009). Results from Input-Output hybrid life-cycle assessment (IOHLCA) show that energy returns on investment or net energy on corn-based biofuels are lower compared to fossil fuels. However, the study shows that less work from ecosystems is required for biofuels compared to fossil fuels. From a global warming perspective, biofuels can greatly reduce GHG emissions compared to fossil fuels. Field-to-wheel emissions of methane would be lower in using biofuels however, renewable transportation fuels lead to an increase of emissions of "PM10, nitrous oxide, nitrogen oxides (NO_x) as well as nutrients such as nitrogen and phosphorous" (Nanaki and Koroneos 2012, P.1). A similar study illustrates the use of a thermodynamically extended Input-Output Model of the US economy. The extended model can obtain sector-specific energy to money ratios that can be used instead of a single ratio (Baral and Bakshi 2010). The energy analysis was conducted using a hybrid approach and compared with traditional energy analyses. As a result, gasoline is more efficient than corn ethanol even though corn ethanol is found to be less competitive than gasoline but more sustainable.

In Australia, a study has been conducted to investigate the economic and employment consequences of introducing a new sugarcane-based biofuel industry (Malik et al. 2014). The study investigated the case of a future bio-refining industry in Australia by introducing Brazil's alcohol refining technology into the Australian IO table using a hybrid IO-LCA (Input-Output life cycle assessment) approach. The study developed and tested an analytical and a numerical approach for re-balancing an IO table augmented with rows and columns representing large new biofuel industries. Results show that after quantifying changes in economic output and employment in the Australian economy, a future biofuel industry will be employment-positive for Australia.

In the European Union, biofuels play a unique role in European energy policy. There are two reasons to advocate the promotion of biofuel. The first is to promote the sustainable use of natural resources and to reduce greenhouse gas emissions originating from transport activities. The second is to reduce dependence on imported oil and thus enhance security of the European energy supply (Neuwahl et al. 2008). The paper estimates the employment effects in an Input-Output model considering bottom-up technology to specify biofuel activities linked to partial equilibrium models for the agricultural and energy sectors. The calculations in the study refer the 2020 target which was set by the Renewable Energy Roadmap. The results lead to the conclusion that the 10-15% blend rate of biofuels could be achieved without an offset in net employment. In 2007, the direct and indirect effects on the Croatian economy from biodiesel production was estimated using Input-Output analysis (Kulišić et al. 2007). An Input-Output table has been modified to incorporate biodiesel into the system. Results show that a significant positive net impact on the Croatian economy can be captured due to biodiesel production despite the high level of subsidies required for growing rapeseed as the feedstock.

Some of the studies have introduced Input-Output analysis into the biofuel supply chains area. Cruz Jr et al. (2009) present a multi-time-stage Input-Output-based model to promote the dynamics of renewable energy supply chains. The conclusions are that not only physical linkages between processes and information flows, but also behavioral responses among sectors with regard to deficits and surpluses of relevant products, resources or emissions, have influenced the dynamics of bioenergy systems. In addition, the policy or market-based strategies can control the dynamic systems and decrease uncertainty in production. Another study illustrates the blueprint of cellulosic ethanol supply chains under economic, environmental, and social objectives (You et al. 2012). A multi-objective mixed-integer linear programming model (mo-MILP) which covers the primary characteristics of cellulosic ethanol supply chains and Aspen Plus models for bio-refineries with various production methods are built. The model is integrated with Life Cycle

Assessment (LCA) and Economic Input-Output (EIO) through a multi-objective optimization system considering the economic, environmental, and social criteria. The modelling results demonstrate that enhancing the conversion technologies is the most significant method to overcome the difficulties in commercializing cellulosic ethanol.

Developing countries consider renewable fuels as a potential way to provide energy alternatives, increase income and create jobs. The flourishing of the biofuel industry can also contribute to poverty relief, rural development, a decrease in oil imports and an increase in exports of biofuel by-products. In this case, increasing biofuel programs and studies have been conducted in developing countries.

An Input-Output Model using mixed technologies was constructed to allow the representation of sectors with different technologies producing the same products in Brazil (Cunha and Scaramucci 2006). The objective of the study is to estimate the socioeconomic impacts of an extensive expansion of bioethanol production in Brazil using the extended Input-Output Model with mixed technologies. The direct, indirect and induced effects have been calculated based on the shock of an ethanol production increase of nearly 800%. The results indicate that GDP has increased by 11.4%, which equals approximately all of the economy in the Northeast region of Brazil. In addition, it would also create more than 5 million jobs. In 2013, a similar study estimated the socioeconomic impacts in terms of value added, imports and employment of sugarcane-ethanol production in Northeast Brazil (Herreras Martínez et al. 2013). Three scenarios projected for 2020 have been analysed using an extended inter-regional Input-Output Model. The first is a business-as-usual scenario which projects current practices; the second scenario (A) considers more efficient agricultural practices and an increase in processing efficiency, and the third scenario (B) expands the sector into new areas. The study indicates that the large reduction in employment due to the replacement of manual harvesting by mechanical harvesting can be offset by additional production and indirect effects. The total employment in Northeast Brazil by 2020 increases by 10% in scenario A and 126% in scenario B. The indirect effects of sugarcane production in the Northeast region are large compared to the rest of Brazil due to the import of inputs from these regions.

To release energy demand pressure, Asian countries (China in particular) have taken action to launch aggressive biofuel programs. Actually, if we count the EU as a whole, China is currently the fourth largest net producer of biofuels in the world. A study using the mixed-unit Input-Output life cycle assessment to analyse energy, economic, and environmental effects of seven categories of biodiesel feedstocks in China has been conducted (Liang et al. 2013). In the short term, feedstocks such as Jatropha seed, castor seed, waste cooking oil, and waste extraction oil are preferred for biodiesel production. The result shows that these four feedstocks have positive net energy yields and positive net economic benefits for biodiesel production. In the long run, Algae are expected to be more competitive because they require less arable land.

In Thailand, the socioeconomic impacts of biofuels production have been estimated using Input-Output analysis (Silalertruksa et al. 2012). The biofuels considered in the study are ethanol from cassava, molasses and sugarcane ethanol as well as palm biodiesel. Results from the study indicate that producing biofuels need about 10 times more workers than fossil fuels per energy content. The ethanol production in Thailand in the year 2022 would create 238,700-382,400 jobs and 150 million dollars GDP.

A study designed to assess the economic impacts of ethanol production for an E10[2] policy in nine Association of Southeast Asian Nations (ASEAN) countries (except Brunei) and minimizing CO_2 emissions has been conducted (Kunimitsu et al. 2013). Two self-sufficient

[2] E10, a fuel mixture of 10% ethanol and 90% gasoline.

ethanol production policies, including self-efficiency within each country and within the ASEAN region under a production quota, were considered. An optimization model and the Inter-regional Input-Output Table, which is estimated from the GTAP-7 database (Global Trade Analysis Project, ver. 7), are used for policy assessment. Results indicate that the E10 policy under the scheme of a regional production quota causes about 20% more environmental and economic impacts than self-sufficient production within each country. In addition, neighbouring countries including Singapore, Japan, China and the USA show production increases through ethanol plant construction and annual production, even if they are assumed not to increase production in this study. Furthermore, the increase of annual ethanol production also increases agricultural production. This benefits the agricultural sector with more than half of all induced production.

2.3 CANADIAN BIOFUEL STUDIES USING INPUT-OUTPUT ANALYSIS

Existing studies on Canadian biofuels are few, and tend to focus on the technical potential for commercial advantages (Heath 1989), policies and programs to stimulate biofuel production (Walburger 2006), or their contribution to greenhouse gas emissions reduction strategies (Coxworth 2003). More recent studies focus on the sustainability of biofuel production (Gupta and Verma 2015), production technology selection (Ziolkowska 2014), and second generation biofuel feedstocks (Zhu et al. 2014). Here we are capturing several sources of literature which aim to estimate the economic impacts using Input-Output analysis. Thomassin et al. (1992) estimated the macroeconomic consequences on the Canadian economy of a Jerusalem artichoke based ethanol industry. Results of the study demonstrate that Jerusalem artichoke could be used as the feedstock for ethanol production. Macroeconomic impacts have been estimated in western Canada for an ethanol plant with a production capacity of 100 million litres per year. This plant would enhance industrial output by $154 million, increase GDP at factor cost by $50 million, and generate 1,365 jobs. Similarly, a study using the Input-Output Model of the Canadian economy estimated the macroeconomic impact of building a large-scale fuel ethanol plant (Thomassin and Baker 2000). The plant uses corn as the feedstock and has a capacity of 200ML per year. The direct, indirect and induced effects of constructing and operating a large-scale fuel ethanol plant have been estimated. The impact on corn and barley production and the price of corn which has an increasing demand as a feedstock are calculated at the same time. Results show that the macroeconomic impact of the operation of this plant increases $328.6 million of industrial output, generates $84.2 million more in GDP and creates 1,390 jobs.

Another Canadian study estimates the macroeconomic impacts of ethanol production using the 2003 Input-Output table (Mukhopadhyay and Thomassin 2011). Two new industries (i.e., Ethanol and E10) and four commodities (i.e., Ethanol, E10, DDG and CO_2) are introduced into the system after necessary modifications to the Input-Output table. Results demonstrate that the macroeconomic impacts of the ethanol sector contribute to GDP at factor cost, industrial output as well as employment.

The literature on biofuel until now attempts to estimate various economic impacts using Input-Output Models or its extended approach. The existing gap in this literatures is that none of them use the Input-Output Model (except for Mukhopadhyay and Thomassin (2011) who have introduced ethanol and E10 into the economy) to properly introduce the new industry and new commodity set up for biofuel sectors including ethanol, E10, biodiesel and B5 in the economic system. In our study, efforts have been made towards that goal. The study prepares Ethanol, E10, Biodiesel and B5 as four new industries and eight commodities (i.e., Ethanol, E10, DDG, CO_2, Biodiesel, B5, Glycerin and Canola meal) in an existing Input-Output Model of Canada for the year 2008. In addition, the study has also assessed the impacts of these new industries.

CHAPTER 3

GLOBAL BIOFUELS OVERVIEW

Current global concerns about the sustainability of fossil fuels, increasing environmental costs, as well as energy security have been the major causes for various countries to look for alternative energy sources. In developed countries, national policies to promote biofuels are mainly justified by concerns over energy security and GHG emissions, while in developing countries, biofuels are considered as a potential way to increase energy diversity, income, and employment. Any increase in the size of the biofuel industry can also contribute to poverty relief, rural development, decrease oil imports and increase exports of biofuel by-products. In this chapter, we present a global status report for biofuels, including feedstock availability and sustainability, the production and consumption of biofuels and the mandates and planned targets for biofuels worldwide.

3.1 THE AVAILABILITY, EFFICIENCY AND SUSTAINABILITY OF BIOFUELS FEEDSTOCKS

With feedstocks in all regions, biofuels which have good performance in combustion engines for transportation and are compatible with current fuel distribution infrastructures, have attracted wide attention (United Nations Conference on Trade and Development 2009). In countries where a biofuel industry is established, feedstocks such as corn, wheat, sugar cane and oil seeds are widely used to produce biofuels. These crops are usually the most important in the country (Elbehri et al. 2013). They are typically called conventional biofuel feedstocks. In the U.S., corn is the major crop and serves as the feedstock for most of the domestic ethanol production due to its abundance and relative ease of conversion to ethanol. Only small amounts of wheat and sugarcane are used compared to corn. In order to ensure sufficient supply in livestock feed, human food, and export markets, the US Renewable Fuel Standard set a quota to limit the production of ethanol from grains to 15 billion gallons (US Department of Energy 2014). A study from the UFOP (Union for the Promotion of Oil and Protein Plants) indicates that 90 percent of the feedstock used to produce biodiesel in winter is rapeseed (Davis 2014). In Europe, especially in Germany, rapeseed oil is the most common feedstock for biodiesel production, wheras the culivation of sugarcane as the sugar sourse is paramount in Brazil. The Portuguese settlers exported sugarcane as one of the first commodities to Europe (Schmitz et al. 2011). In the late twenties and early thirties of the twentieth century, sugarcane ethanol was already used as a fuel in Brazil following the introduction of the automobile. Brazil is the largest sugarcane producer (625 million tons of sugarcane in 2011) in the world followed by India and China (Rocha et al. 2012). The availability of free sugars in the cane juice and molasses, by-products of the sugar industries, make sugarcane an excellent source for the production of first generation ethanol. Malaysia is the world's second largest supplier of palm oil after Indonesia (Abdullah et al. 2009). The two countries account for approximately 85% of the world’s total production. However, with an increasing future demand and concerns about the sustainability of many conventional biofuels, there has evolved an exploratory interest in advanced feedstocks including lignocellulosic and dedicated feedstocks (e.g. cereal straw, bagasse, forest residues, wastes, and purpose-grown energy crops such as vegetative grasses and short rotation forests) (Sims et al. 2010). The major benefits of the second-generation biofuels are that they can consume waste residues and make use of abandoned land. Therefore, potential renewable energy could help to stimulate rural development. However, if the production of the second-generation biofuels crops compete with food crops for available land, the biofuels coming from these crops will become unsustainable. Thus, their sustainability will depend on whether the criterias like minimum lifecycle GHG reductions, including the land use change and social standards are followed (Eisentraut 2010). Even though many of the technical and economic challenges have been overcome, second-generation biofuels are still not in full commercial deployment. However, various pilot and demonstration plants have been built or are under construction for research and development in many countries. North America, Europe and a few other countries (e.g. China, Brazil, Thailand and India) are the major pioneers of these second-generation biofuels.

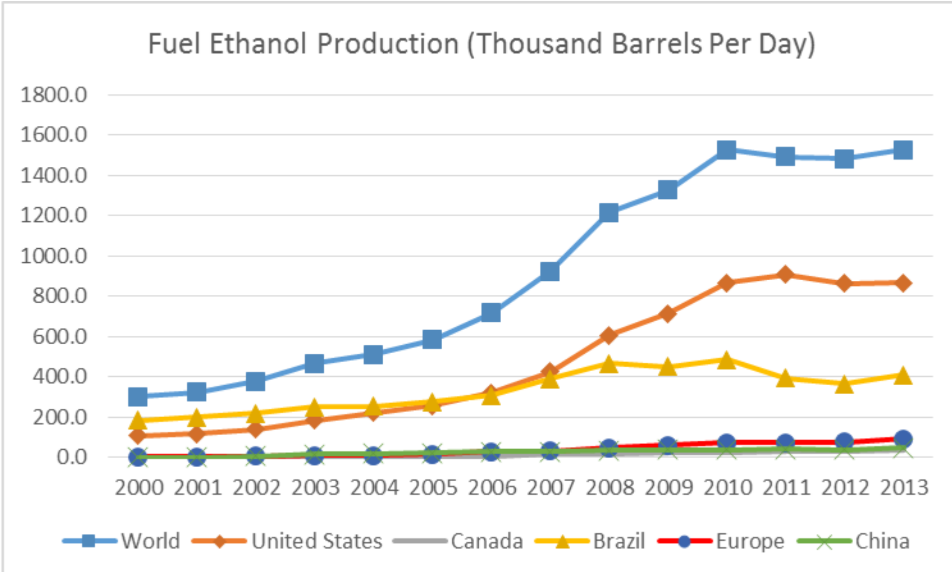
Sugarcane is the most efficient crop among the commercialized feedstocks (in terms of yield per unit of land). However, the sustainability of sugarcane largely depends on water availability (Elbehri et al. 2013, Moraes et al. 2014). Palm oil is by far the most efficient source for biodiesel next to sugarcane, far exceeding alternatives such as rapeseed, soybeans or sunflowers.

3.2 GLOBAL BIOFUEL PRODUCTION AND CONSUMPTION

Biofuel production has been growing smoothly over the last decade aroind the world. It has expanded from 16 billion litres in 2000 to around 110 billion litres in 2013. In the road transportation energy sector, around 3.5% of the total fuel requirements are fulfilled by biofuels globally. Some countries have more developed biofuel industries, like Brazil, where biofuels reach almost 25% of road transportation energy demand today (International Energy Agency 2013).

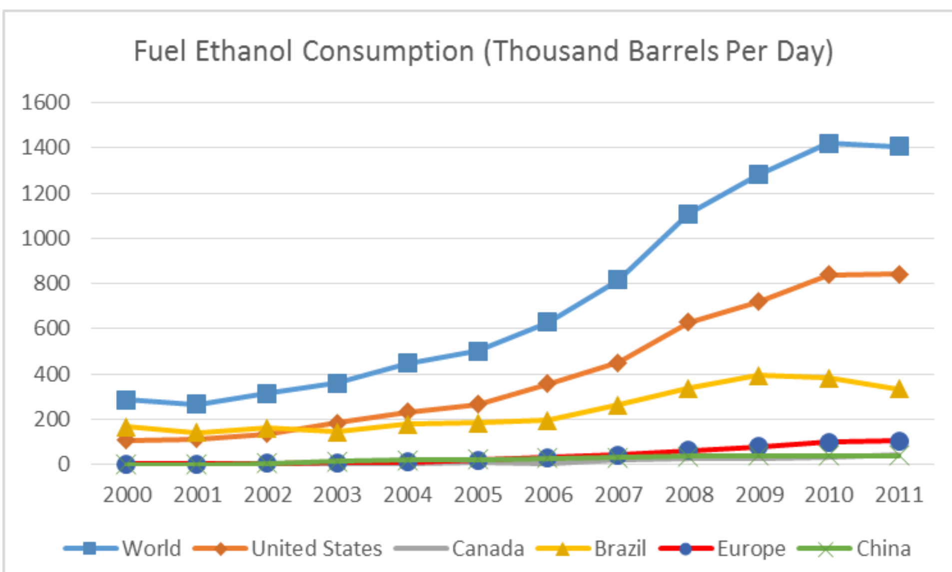
We have selected five major biofuel producing and consuming countries and regions to show the world trend of biofuel supply and demand. The fuel ethanol production and consumption are shown in Figure 1 and Figure 2. The biodiesel production and consumption are presented in Figure 3 and Figure 4. Due to the limited production and consumption of biofuels in Canada, that country's data cannot be clearly seen in the figures. We show the details we do have in Figure 6 right after the biofuel plant locations in Figure 5. The total fuel ethanol production in 2013 was 23,429 million gallons (Renewable Fuels Association 2013). Brazil and the US are still the leaders of global bioethanol production and consumption. The percentage of US and Brazil bioethanol production as a fraction of the total world ethanol production is 57% and 27% respectively. Europe still dominates the biodiesel market with the production of 178 thousand barrels per day and the consumption of 240 thousand barrels per day in 2011. The US biodiesel industry had a billion gallon production in 2011 for the first time. According to the EPA (Environmental Protection Agency), production was more than 1.1 billion gallons in 2012 and a 1.8 billion gallons target was set for 2013 (Tenaska Commodities 2014). Under the Federal Renewable Fuel Standard, the total production of the industry exceeded the biodiesel requirement for the year 2013. The production in 2013 was enough to meet most of the biofuel demand. In ten years, the international trade in ethanol is expected to have made a significant advance. The majority of business among countries will be Brazil exports to the US and EU (European Biofuels 2014).

Figure 1: Fuel Ethanol Production (Thousand Barrels Per Day)



Sources: U.S. Energy Information Administration, 2014
http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=79&pid=79&aid=1
Renewable Fuels Association[3], Ethanol Industry Outlook 2008-2013 reports. Available at www.ethanolrfa.org/pages/annual-industry-outlook

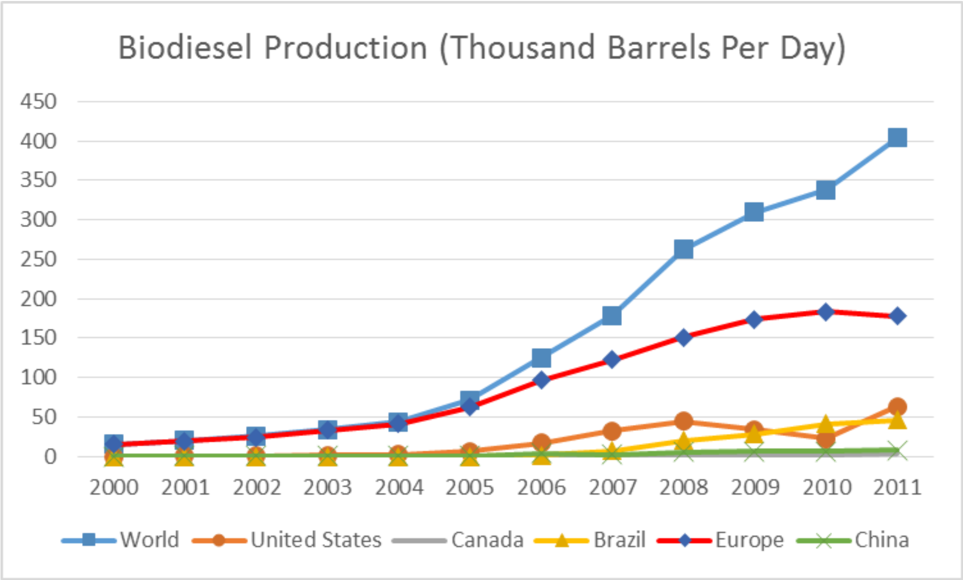
Figure 2: Fuel Ethanol Consumption (Thousand Barrels Per Day)



Source: U.S. Energy Information Administration, 2014
http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=79&pid=79&aid=1

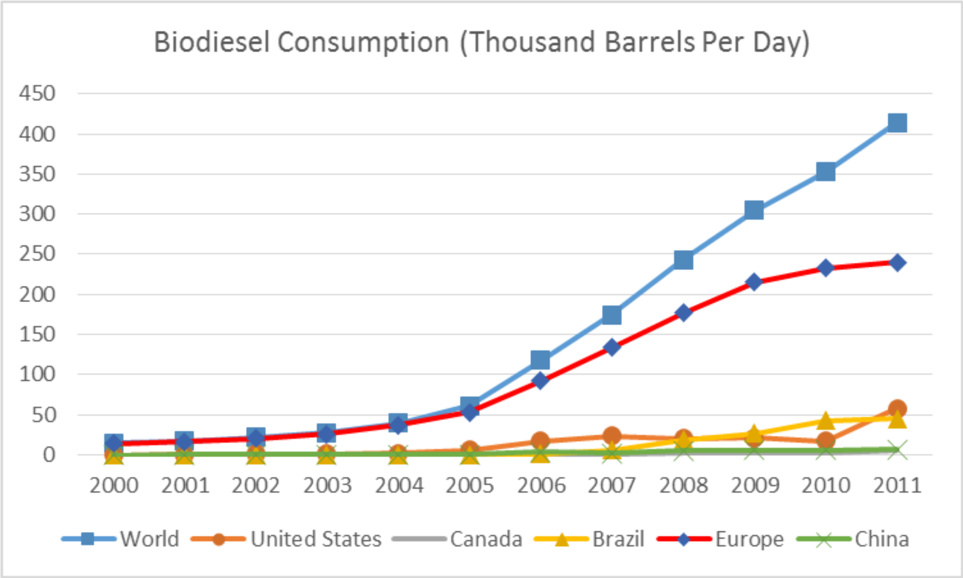
[3]Ethanol production data for the year 2012 and 2013 has taken from Renewable Fuels Association

Figure 3: Biodiesel Production (Thousand Barrels Per Day)



Source: U.S. Energy Information Administration, 2014
http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=79&pid=79&aid=1

Figure 4: Biodiesel Consumption (Thousand Barrels Per Day)

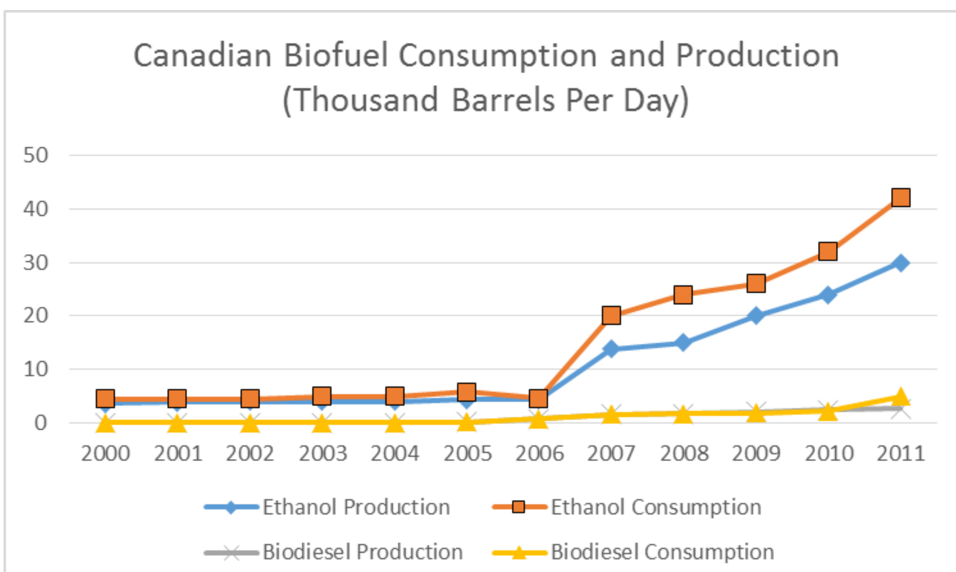


Source: U.S. Energy Information Administration, 2014
http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=79&pid=79&aid=1

Figure 5: Canadian Biofuel Plant Locations, 2014

Source: Canadian Renewable Fuels Association, 2014

Figure 6: Canadian Biofuel Consumption and Production (Thousand Barrels Per Day)



Source: U.S. Energy Information Administration, 2014
http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=79&pid=79&aid=1

Canada only accounted for 2% in the global bioethanol production market in 2013. However, the bioethanol production in Canada has increased from 212 million litres in 2006 to 1,785 million litres in 2013 (Evans and Dessureault 2013). In the same year, Ontario, Saskatchewan, and Manitoba will reach around 86 percent of Canada's overall ethanol production. Almost a quarter of Canada's gasoline sales are expected in British Columbia and Alberta but only 4 percent of the 2013 national ethanol production are from these provinces. The biofuel plants locations are presented in Figure 5. The detailed information of ethanol and biodiesel plants can be found in Appendix 1. The main feedstocks for ethanol production are corn and wheat. However, second generation ethanol from wood waste and municipal solid waste is under research and development. Biodiesel production increases from 48 million litres in 2006 to 646 million litres in 2013. Western Canada leads the biodiesel production growth with the area's abundance of canola production. Most of the plants are using multi-feedstocks including animal fats and vegetable oils in biodiesel production. The growth of biodiesel production is limited by the inability to sustain low cost feedstocks in the future.

The demand for biofuels in Canada is higher than the supply due to government policy incentives. The fuel ethanol consumption in Canada increased from 760 million litres in 2006 to 2,770 million litres in 2013 and biodiesel consumption increased from 57 million litres in 2006 to 713 million litres in 2013.

The limited biofuels production in Canada suggests that Canada will not play as a leader in the global ethanol market in the near future. The co-products of ethanol production export have been increasing. The biofuels trade between Canada and the US shows the most economical trade strategy. No tariff has been required on renewable fuels that are produced in the US and imported into Canada according to the North American Free Trade Agreement

(NAFTA) (Sorda et al. 2010). However, a tariff has been implemented on ethanol imported from other countries to Canada ($0.05 per litre). Brazil is an example. Almost all ethanol imported to Canada has come from the US in recent years. Canada, unlike the US, cannot meet its blend targets by producing biofuels on its own. In the short run, Canada will continue to import the shortfall (Evans and Dessureault 2014).

However, the biodiesel international trade cannot meet the expectation of significant increases due to technical issues, the high trade demand in palm oil, and policies regarding anti-dumping duties. In addition, the major consuming countries are increasing their domestic production levels to reduce biodiesel imports.

3.3 BIOFUEL MANDATES

With increasing demand and supply for biofuels globally, many countries have set up different mandates (targets) based for their own situations. By 2020, Canada is expected to reach a global "peak oil" production level (Kharecha and Hansen 2008). In August 2013, a map was prepared by the Global Renewable Fuels Alliance GRFA to indicate current mandates worldwide (Global Renewable Fuels Alliance 2013). In December 2013, the Biofuels Digest posted 2014 biofuel mandates around the world (Biofuels Digest 2014). The biofuel mandate tables for Canada and worldwide are presented in Table 1 and 2. Nowadays Paraguay has the highest mandates for ethanol usage in the world (24%) followed by Brazil at 20%. Costa Rica has the highest biodiesel mandates at 20%. India's target is to implement the E20 and B20 by 2017. The European Union targets 10% of the transport fuel of every EU country come from biofuels on 2020. In addition, the global civil aviation industry is now preparing for replacement of up to 6% of aviation fuels and lubricants with bio-based alternatives by 2020. Furthermore, the US military's current target is 50% renewable energy by 2020. This goal will be a pressure point to drive a North American increase of biofuel production and consumption (Nosowitz 2010).

The biofuel mandates and production incentives stimulate the bio-refining industry in Canada. The environmental strategy from the federal government contributes to funding for research and development in biofuels (Mabee and Saddler 2010). Renewable fuel standards were implemented in 2010 as part of the Canadian Environmental Protection Act, Bill C-33. The documented mandate is 5% renewable content in gasoline and 2% in diesel fuel and heating oil[1]. In some provinces, separate mandates for renewable fuel content have been enacted. For ethanol blended with gasoline, they range from 5% (British Columbia, Alberta, Manitoba and Ontario) to 8.5% (Saskatchewan) (Mabee 2013). For diesel, the blend rates range between 2% (Alberta, Manitoba, and Saskatchewan) and 4% (British Columbia) (Evans and Dessureault 2014). The actual blend rate for fuel ethanol increases from 2% in 2006 to 6.1% in 2013 (Evans and Dessureault 2013). The blend rate of diesel on-road use increases from 0.2% in 2006 to 2.3% in 2013.[4]

In conclusion, ethanol is still the leader of global biofuel production, and the US dominates world biofuel production for both ethanol and biodiesel. The increasing demand from the transportation sector drives the development of the biofuels industry. Biofuel production and consumption will still be significantly affected by government policies and subsidies. The government of many countries starts to emphasize their biofuel policies to broader ideas of bioenergy and bio-economy instead of only biofuels.

[1] The Government of Canada Biofuels Bill Receives Royal Assent, published in EcoAction on the 26th of June 2008 and available at http://www.ecoaction.gc.ca/news-nouvelles/20080626-eng.cfm. Data also reported in Rajagopal and Zilberman (2007) and Steenblick (2007), as the announcement of the proposed Bill came in December 2006.

Table 1: Biofuel Mandates Across Canada, 2014

Biofuel Mandates Across Canada, 2014		
	Ethanol	Biodiesel
Federal	5%	2%
British Columbia	5%	4%
Alberta	5%	2%
Saskatchewan	8.5%	2%
Manitoba	5%	2%
Ontario	5%	2-4%*

*Depending on greenhouse gas emission reductions

Source: United States Department of Agriculture, 2014

Table 2: Global Biofuel Mandates and Targets in 2014

Global Biofuel Mandates and Targets in 2014			
	Ethanol	Biodiesel	Targets
Angola	10%		
Argentina	5%	10%	
Australia(New South Wales)	4%	2%	E10
Brazil	20%	5%	
Canada	5%	2%	
Chile			E5, B5
China	10% in 9 provinces		E10, B10 by 2020
Columbia	8%		E10
Costa Rica	7%	20%	
Ecuador		5%	B10
Ethiopia	5%		
European Union	5.75%	5.75%	E10 , B10 by 2020
Fiji			E10, B5
India	5%		E20, B20 by 2017
Indonesia	3%	10%	
Jamaica	10%		
Kenya	10% in Kisumu		
Malawi	10%		
Malaysia		5%	
Mexico	2% in Guadalajara		E2 to expand to Mexico City and Monterrey
Mozambique	10%		
Nigeria			E10
Panama	5%		E10
Paraguay	24%	1%	
Peru	7.80%	2%	B5
Philippines	10%	2%	
South Africa	10%		
South Korea		2.50%	
Sudan	5%		
Taiwan		1%	Examining E3 Mandate
Thailand		5%	
USA	Renewable Fuel (e.g. Ethanol/Biodiesel) target of 136 billion litres by 2022		
Uruguay		2%	E5
Vietnam	5%		
Zambia			E10, B5
Zimbabwe	10%		E20

Sources: Global Renewable Fuels Alliance, Biofuels Digest

CHAPTER 4

METHODOLOGICAL FRAMEWORK

4.1 THE INPUT-OUTPUT MODEL

The original Input-Output Model was developed by Leontief based on a transaction table in which each industry produces only one commodity and each commodity is produced by one industry (Thomassin and Baker 2000). It is currently used by countries such as the US, China and India. This is called the square table and since the beginning Input-Output square tables have been used as an international standard for the majority of countries.

One of the main purpose of this study is to illustrate the commodity flow from one sector to another with the help of 2008 transaction matrix for Canada. The Canadian Input-Output Tables are rectangular instead of square as the number of commodities is greater than that of the industries (Statistics Canada 2014a). This characteristic of the rectangular model provides more information than what would be achieved with a square table. In the Input-Output accounting framework, not only the flow of commodities used in the production process and the output of commodities produced by the industrial sectors in the economy, but also the consumption of commodities by final demand categories, are tracked (Thomassin et al. 1992). Commodities are goods and services sold in the market while industries refer to groups of establishments that engage in the same economic activity.

The Input-Output framework contains five matrices: (a) intermediate demand matrix, U, (b) primary inputs, YI, (c) the market share matrix, V, (d) a final demand matrix, F, and (e) a primary inputs matrix going into final demand categories, YF (Table 3). The values of the intermediate plus primary inputs used by industries in producing their outputs can be represented by the “Use” matrix (U and YI). The vector g’ is the total cost to produce each industry’s output in the economy. The values of goods produced by each industry are represented by the “Make” matrix (V). The vector q’ is the total value of each commodity produced. The sum for each row in the V matrix account for the total value of each industry’s output (g). The important assumption of the I-O model is that the total cost of an industry’s production must be equal to the total value of the products produced by that industry which means g’ must be equal to g. Similarly, the total value of commodities in demand must be equal to the total value of commodities supplied which means q equals to q’.

Within this accounting framework, a number of relationships can be utilized to assess the economic impacts of a change in the product demand. The total value of a commodity’s output is equal to the sum of the value of the intermediate and final demands for that commodity and is illustrated in the first relationship (Miller and Blair 2009):

$$q = Ui + Fi \tag{1}$$

The second relationship is that the total value of output for each industry is equal to the value of each of its produced commodities:

$$g = Vi \tag{2}$$

Assuming that current inputs that are used by each industry are proportional to the produced output:

$$U = B\hat{g} \tag{3}$$

Where B is a NC * NI matrix of technical coefficients relating inputs to output.

In addition, assuming that the demand for commodities produced in the economy is allocated to industries in fixed market shares:

$$V = D\hat{q} \tag{4}$$

Where D is a NI*NC matrix of market share coefficients.

Solving the above equations by substituting Equation 2 with Equation 4, 1 and 3, gives the result:

$$g = D\ (Bg + Fi) \tag{5}$$

Rewriting Equation 5:

$$g = (I - DB)^{-1}\ DFi \tag{6}$$

Where I is a NI*NI identity matrix.

The matrix $(I - DB)^{-1}$ D defines the impact matrix which estimates the direct and indirect effects of a change in final demand for commodities. The derived model above does not consider leakages in the economy which may occur when using imports, government production and inventory withdrawals to supply commodities for intermediate and final demands. In the 2008 I-O table, only import leakage is not considered in the given model. The assumption is that the leakage is in fixed proportion to domestic commodity demand. This assumption is integrated into the model in equation 7:

$$g = [I - D\ (I-\hat{U})\ B]^{-1}\ D\ (I-\hat{U})\ f \tag{7}$$

Where:

$\hat{U}$ = a NC * NC diagonal matrix of coefficients whose elements are a ratio of imports to commodity used;

f = a NC * 1 vector of the values of final demand excluding exports, re-exports, imports, government production and withdrawals from inventory.

The matrix $[I - D\ (I-\hat{U})\ B]^{-1}$, named as the inverse matrix equals to the $(I-A)^{-1}$ matrix in the simple Leontief model, except with secondary production. When the inverse matrix is postmultiplied by D, the matrix $[I - D (I-\hat{U}) B]^{-1} D (I-\hat{U})$ is the impact matrix which can assess the direct plus indirect impacts of changes in the demand for commodities.

With this Input-Output Model of the Canadian economy developed, it can be used to estimate how ethanol and biodiesel production impact the Canadian economy. This model can be used to estimate a number of important indicators such as Gross Domestic Product, industrial output, and employment levels. The Canadian rectangular Input-Output table is presented in Table 3.

Table 3: The Input-Output Table

	Commodities	Industries	Final Demand	Total
COMMODITIES		U	F	q
INDUSTRIES	V			g
PRIMARY INPUTS		YI	YF	
TOTAL	q'	g'		

U — the intermediate input matrix by industry
YI — the primary input matrix by industry
V — the make or output matrix
F — the final demand matrix
YF — the primary inputs going into final demand

where:

NC = number of commodities;
NI = number of industries;
NY = number of primary inputs;
NF = number of final demand categories;
V = a $NI \times NC$ order matrix showing the value of gross domestic output of industries by commodities;
U = a $NC \times NI$ order matrix showing the value of commodities used by industries as current inputs;
F = a $NC \times NF$ order matrix showing the value of commodities used by the final demand categories;
YI = a $NY \times NI$ order matrix showing the value of primary inputs used by industries;
YF = a $NY \times NF$ order matrix showing the value of primary inputs used in final demand categories;
q = a $NC \times 1$ vector showing the values of total commodity outputs; and
g = a $NI \times 1$ vector showing the values of total industrial outputs.

Source: Miller and Blair (2009).

4.2 THE MODIFIED INPUT-OUTPUT MODEL

In this section, the aggregation of the 2008 Input-Output Model is presented. This aggregation is the primary task in the design and elaboration of a Canadian I-O model with a biofuel sector. Second, the elements introduced in the system are ethanol, biodiesel, E10 and B5 and their main by-products including DDG, CO_2, glycerin and canola meal[5].

The Input-Output Tables we used for 2008 are prepared by Statistics Canada. Agriculture and Agri-Food Canada modified the tables with the addition of detailed agriculture sectors. In the modified table, there are 25 agricultural commodities and 18 industries. The Input-Output Accounts are prepared and balanced at the most detailed level that is the "Worksheet" (W) level, which included 300 and 282 industries for the year 2007 and 2008, respectively. The number of goods and services as well as primary inputs decreased from 727 in 2007 to 713 in 2008. In the final demand, 172 categories of them are for the year 2007 and 168 categories are for the year 2008. Finally the Worksheet (W) level data are aggregated for consistency into Link (L), Medium (M), and Small (S) levels to cover the time period under consideration (Statistics Canada 2014a).

To simplify the work, 697 commodities have been aggregated into 137 including 25 detail agricultural commodities based on the modified worksheet level. Diesel and petroleum commodities have also been taken into account at the disaggregated level. The remainder of the commodities were aggregated based on the medium level of aggregation for the Canadian I-O table where 16 primary inputs are aggregated into 11 categories. Similarly, the aggregation scheme of the detailed agricultural sector, and diesel and petroleum sectors, which used to aggregate the commodities, has also been applied to achieve industry aggregation. The 282 industries have been aggregated into 87 categories, and final demand to 7 categories from 168 which include private consumption, investment, change in stock, government expenditure, export, re-export and import.

[5] For details, see next chapter.

Therefore, the Use matrix has 137 commodities and 87 industries, 11 primary inputs and 7 final demand categories, and the Make matrix is composed of 87 industries and 137 commodities.

To take the biofuel sectors into account, the Make and Use matrices of 2008 have been extended to 145 commodities and 91 industries. The new 8 commodities are ethanol, biodiesel, E10, B5, DDG, CO_2, glycerin and canola meal. The 4 new industries are ethanol, biodiesel, E10 and B5. The major inputs and final demand categories remain the same. With the incorporation of biofuel sectors, the model is ready to include the biofuel inputs and outputs data which is detail presented in Chapter 5.

CHAPTER 5

DATA PREPARATIONS OF THE BIOFUEL SECTOR IN USE AND MAKE MATRICES

In this chapter, we discuss the preparation of the data for the four biofuels industries and their corresponding eight new commodities and how the numbers take their place in the Use and Make matrices for Canada. Data includes the detailed cost of production for ethanol and biodiesel in 2008. These I-O tables are organized as to include biofuel production including ethanol and biodiesel for the year 2008 at the national level.

5.1 ETHANOL PRODUCTION CAPACITY AND COST STRUCTURE IN 2008

5.1.1 Ethanol Production Capacity in 2008

The total operating capacity for ethanol production in 2008 was 1,183 million litres. In this study, we only consider plants that existed and were operated "at equilibrium" at that time: which means we exclude plants under construction, demonstration plant and plants that underwent expansion in 2008. The descriptive information of the ethanol production capacity is mainly obtained from the Canadian Renewable Fuels Association and then adjusted according to company website (http://www.huskyenergy.ca/) and the Canada Biofuels annual report published in 2009 (Evans and Dessureault 2009). From Table 4 below, we can see that the main feedstocks are corn and wheat. We found six plants using corn to produce 696 million litres of ethanol. These plants were mainly located in Ontario. There were five plants using wheat as the feedstock to produce 357 million litres ethanol and most of them were located in Saskatchewan. The Husky

Energy plant in Manitoba used both wheat and corn as the feedstock. Of the 130 million litres capacity of that plant, 25% of the product originated from wheat and 75% from corn.

Table 4: *Canadian Fuel Ethanol Production Capacity in 2008*

Canadian Fuel Ethanol Production Capacity in 2008				
Company	Location	Start date	Capacity(ML/year)	Feedstock(s)
GreenField	Chatham, Ont.	1989	150	corn
GreenField	Tiverton, Ont.	1989	26	corn
Suncor Energy	St Clair, Ont.	2006	200	corn
Collingwood Ethanol	Collingwood, Ont.	2007	50	corn
IGPC Ethanol	Aylmer, Ont.	2008	150	corn
GreenField	Varennes, Que.	2007	120	corn
Husky Energy	Minnedosa, Man.	2007	130	wheat&corn
Permolex	Red Deer, Alta	1996	40	Wheat
Pound-Maker Agventures	Lanigan, Sask.	1991	12	wheat
NorAmera BioEnergy	Weyburn, Sask.	2005	25	wheat
Husky Energy	Lloydminster, Sask.	2006	130	wheat
Terra Grain Fuels	Belle Plaine, Sask.	2008	150	wheat
Total operating capacity:			**1183**	

Source: Canadian Renewable Fuels Association (www.greenfuels.org) and company website (http://www.huskyenergy.ca/)

5.1.2 Ethanol Cost Structure in 2008

5.1.2.1 Ethanol price

In Canada, a fixed formula basis is generally used to price Ethanol including a small discount to wholesale (rack) gasoline plus tax incentives as usual ((S&T)2 Consultants Inc. 2004b). In 2008, most plants were located in Ontario and Saskatchewan, although other plants were located in Quebec, Manitoba and Alberta. The rack price of gasoline is calculated based on the average of monthly wholesale (rack) prices for regular gasoline in 2008. We gathered the rack prices from major cities[6] and averaged them to a provincial basis. The discount rate (interest rate) is calculated according to the average of monthly rates for Canada in 2008 reported by The International Monetary Fund. The selling prices of ethanol for related provinces in 2008 are listed in Table 5. So calculated, the average selling price of ethanol in 2008 was 105.08 cents per litre.

Table 5: Selling Price of Ethanol in 2008

Selling Price of Ethanol in 2008 (Cents/L)						
	Gasoline Rack Price	Federal Tax	GST	Provincial Tax	Discount	Selling Price
Ont.	75.311	10	5%	14.7	-0.03	104.25
Que.	73.508	10	5%	15.2+7.5% sales tax	-0.03	110.57
Man.	77.783	10	5%	11.5	-0.03	103.64
Alta.	77.150	10	5%	9	-0.03	100.48
Sask.	77.125	10	5%	15	-0.03	106.45
Average						105.08

Source: Gasoline rack prices from Natural Resources Canada, discount rates from International Monetary Fund

5.1.2.2 Estimation of total revenue for ethanol sector in 2008

The by-products resulting from making ethanol depend on the inputs used in producing the ethanol. Since the main feedstocks in our study are corn and wheat, we have considered that Distillers' Dried Grains (DDG) and the Carbon dioxide (CO_2) will be the by-products in our model. In this case, the estimation of total revenue for the ethanol sector includes the total value of ethanol production, the CO_2 value and the DDG value where DDG is used as a high protein and energy animal feed.

During the estimation, we calculated the DDG produced from wheat-based ethanol and corn-based ethanol separately. The former resulted in 38% of DDG and the latter 32% ((S&T)2

[6] The main cities used as a reference basis are: Calgary, Edmonton, Hamilton, London, Montreal, Nanticoke, Ottawa, Quebec, Regina, Sarnia, Sault Ste Marie, Thunder Bay, Toronto and Winnipeg.

Consultants Inc. 2004b). Our calculations showed that 0.397 million tons DDG came from wheat and 0.595 million tons came from corn. The price of DDG from wheat was 160.45 \$/t and from corn was 126.07 \$/t (Mukhopadhyay and Thomassin 2011). The total DDG value was thus 138.64 million dollars.

The CO_2 price averaged 17.5 \$/t (it ranged between 10 \$/t and 25 \$/t) ((S&T)2 Consultants Inc. 2004b). In 2008, the corn-based plant produced 70 million litres (or 0.5511 million tonnes) of CO_2. The estimate we adopted is 0.089 m^{-3} CO_2 released per litre of ethanol production (Mukhopadhyay and Thomassin 2011). Therefore, the CO_2 value in 2008 for ethanol production was 9.65 million dollars. CO_2 is used as a refrigerant, in carbonated beverages, to help in a more rapid growth of vegetable crops in greenhouses, and to flush oil wells. In this study, we have considered the CO_2 as mainly used for food and beverage manufacturing. Table 6 presents the total revenue of ethanol production in 2008.

Table 6: Estimation of Total Revenue for Ethanol Sector in 2008

Estimation of Total Revenue for Ethanol Sector in 2008	
Ethanol production in 2008(ML)	1183
Ethanol selling price($/L)	1.051
Total value of production in 2008($M)	1243.333
CO2 value($M)	9.650
DDG value($M)	143.358
Total revenue($M)	1396.341

5.1.2.3 Feedstocks

The calculation of feedstock cost is based on the type of feed used in the ethanol plant. Since we have used wheat as the feedstock for plants located in Manitoba, Alberta and Saskatchewan, the average wheat price was 290 dollars per tonne in 2008. For the corn-based ethanol plant located in Ontario, Quebec and Manitoba, the average grain corn price was 198 dollars per tonne (Statistics Canada 2008). Using the conversion of 1 metric tonne of corn produces 400 litres of ethanol, while 1 metric tonne of wheat produces 375 litres of ethanol, to produce 793.5 million litres of ethanol requires 1.98 million tons of corn (Jamieson 2013). The total cost of corn as a feedstock for the ethanol plant was 392.78 million dollars in 2008. To produce 389.5 million litres of ethanol, we need 1.04 million tons wheat. The total cost of wheat as a feedstock was 301.21 million dollars. In summary, the total feedstock cost for ethanol production in 2008 was 694 million dollars.

5.1.2.4 Chemicals

The major ingredients used in producing ethanol are yeasts, enzymes and acids. For a corn ethanol plant, we estimate the enzyme cost to be 1.65 cents per litre, the yeast cost as 0.35 cents per litre and the cost of other chemicals, such as acids at 1.0 cent per litre. The total cost of enzymes, yeast and other chemicals is thus 3.00 cents per litre ((S&T)2 Consultants Inc. 2004b). Additional enzymes may be required for wheat and barley plants to achieve their maximum effectiveness. The cost of enzymes are estimated to be 2.0 cents per litre and other chemicals remain the same as for corn for wheat plants. The total chemical costs for the wheat plant are 3.35 cents per litre ((S&T)2 Consultants Inc. 2004b). Therefore, the total chemical costs for ethanol production in 2008 was calculated to be 36.85 million dollars.

5.1.2.5 Energy

The natural gas usage recommended is 9.8 MJ/litre for a corn ethanol plant. As more wheat needs to be ground to produce an equivalent ethanol output as from corn, thus more DDG will be produced. Thus the total energy consumption for a wheat ethanol plant is higher as compared to that of a corn ethanl plant. We assume that the energy consumption is 12% higher compared to that for corn or 11.0 MJ/litre. The recommendation for electricity usage is 0.24 kWh/litre for corn and 0.27 kWh/litre for wheat ((S&T)2 Consultants Inc. 2004b).

In this case, the total natural gas requirement is 206.37 million m^3 for a corn plant with a capacity of 793.5 million litres and 113.71 million m^3 for a wheat plant with a capacity of 389.5 million litres. The total electricity requirement is 190.44 million kWh for a corn plant and 105.17 million kWh for a wheat plant.

Natural gas prices have already been presented in the biodiesel sector. The electricity prices are calculated based on different levels of power demand and electricity rates differ across provinces as well (Hydro Quebec 2008). The estimation of the energy cost of ethanol production in 2008 is presented in Table 7 which illustrates that the total natural gas cost was 108.04 million dollars and electricity cost was 17.78 million dollars in 2008.

Table 7: Energy cost for ethanol production in 2008

Energy cost for ethanol production in 2008							
	Production	Natural Gas Price	Natural Gas Usage	Natural Gas Cost	Electricity Price	Electricity Usage	Electricity Cost
	ML	¢/m³	million m³	M$	¢/kWh	million kWh	M$
Ont. (corn)	576.00	40.54	149.80	60.73	5.74	138.24	7.93
Que. (corn)	120.00	35.07	31.21	10.95	5.20	28.80	1.50
Man. (corn)	97.50	26.41	25.36	6.70	3.88	23.40	0.91
Man. (wheat)	32.50	26.41	9.49	2.51	3.88	8.78	0.34
Sask. (wheat)	317.00	25.97	92.54	24.03	6.72	85.59	5.75
Alta. (wheat)	40.00	26.77	11.68	3.13	12.53	10.80	1.35
Total	1183.00	-	320.08	108.04	-	295.61	17.78

Sources: Natural gas prices from Statistics Canada, 2008; Electricity prices from Hydro Quebec, 2008; Energy consumption recommendations from (S&T)2 Consultants Inc., 2004.

5.1.2.6 Labour

The labour requirements are a function of plant size. For example some 30 to 40 employees are required for the operation of an Ethanol plant. The operation of plants up to 100 million litres in size can be achieved with 30 employees while 40 employees may be required for plants of 200 million litres per year ((S&T)2 Consultants Inc. 2004b). The average labour cost for one employee is estimated to be $45,000/yr. Employee benefits are set at 15% of the labour costs. The labour costs are assumed to increase by the rate of inflation each year and we have considered the Consumer Price Index as our indicator of the labour cost in 2008. The Consumer Price Indexes of related provinces and the resulting labour costs are presented in Table 8.

Table 8: Total Labour Cost of Ethanol Production

Total labour cost of ethanol production (M$)							
Company	Capacity(ML)	CPI	Unit cost	Benefits	Employees	Labour cost	Labour benefits
GreenField, Ont.	150	113.3	0.051	15%	35	1.784	0.268
GreenField, Ont.	26	113.3	0.051	15%	23	1.173	0.176
Suncor Energy, Ont.	200	113.3	0.051	15%	40	2.039	0.306
Collingwood Ethanol, Ont.	50	113.3	0.051	15%	25	1.275	0.191
IGPC Ethanol, Ont.	150	113.3	0.051	15%	35	1.784	0.268
GreenField, Que.	120	112.7	0.051	15%	32	1.623	0.243
Husky Energy, Man.	130	113.4	0.051	15%	33	1.684	0.253
Permolex, Alta.	40	121.6	0.055	15%	24	1.313	0.197
Pound-Maker Agventures, Sask.	12	115.9	0.052	15%	21	1.095	0.164
NorAmera BioEnergy, Sask.	25	115.9	0.052	15%	23	1.200	0.180
Husky Energy, Sask.	130	115.9	0.052	15%	33	1.721	0.258
Terra Grain Fuels, Sask.	150	115.9	0.052	15%	35	1.825	0.274
Total labour cost of ethanol production (M$)						18.52	2.778

Sources: Consumer price indexes set 2002 = 100, from Statistics Canada, 2008 and labour cost information from (S&T)2 Consultants Inc. report, 2004.

5.1.2.7 Maintenance, water and waste disposal:

We determine the maintenance cost of 0.5 cents per litre based on the information from the (S&T)2 Consultants Inc. report. Therefore, the maintenance cost of ethanol production in 2008 was 5.92 million dollars. The USDA reported costs of 0.36 cents per litre for the cost of water and waste disposal resulting in a cost estimate of 4.26 million dollars.

5.1.2.8 Administrative expenses:

There are many costs covered by administrative expenses, including advertising, office supplies, telephone, licenses and memberships, travel, training, professional services, insurance and local taxes ((S&T)2 Consultants Inc. 2004b). Management costs are also included. In the model, these costs are set at 1.5 cents per litre for the sum of all administrative costs resulting in total administrative costs of 17.75 million dollars in 2008.

5.1.3 Preparation of ethanol commodities and industries in the Canadian I-O structure

In the ethanol industry, we adjusted wheat and corn used in the Food Manufacturing Industry with wheat and corn used as the ethanol feedstock. DDG is the main by-product of ethanol production which is adjusted with the wheat's imputed feed and corn feed sectors used in the Dairy, Cattle, hogs and Poultry Industries based on the following respective percentages of 39%, 38%, 15% and 8% (Farmgateblog 2010). The number deduced is 44% from the wheat imputed feed commodity and 56% from corn feed commodity. The adjustment is based on the distribution of wheat and corn DDG value in 2008. The allocation of CO_2 in our model is based on 87.43% going into the Food Manufacturing Industry and the rest going into the Beverage Industry (Mukhopadhyay and Thomassin 2011). The CO2 has been adjusted with the soft drinks and alcoholic beverages sectors.

The revenue and costs of the sector have also been converted from purchaser's prices into producer's prices through the margin matrix in order to incorporate the ethanol sector into the Input-Output Model[7]. The margin value matrix for ethanol is listed in Table 9.

For the entry of an E10 industry, we need a 90% gasoline to blend with ethanol. The 90% gasoline is assumed to go to the private consumption sector. The necessary adjustment has been

[7] In our model, there are no commodities for gas, storage and pipeline margin. We have adjusted the three margins into wholesale and transport margins by weight.

made in the E10 commodity with service industries to maintain the total output balance. The final cost structure of ethanol production in 2008 is presented in Table 10.

Table 9: Margin Value Matrix for Ethanol

Margin Value Matrix for Ethanol							
	wholesale	retail	transport	gas	storage	pipeline	TOTAL
Wheat	39.95	0.00	30.13	0.00	13.08	0.00	83.16
Corn	15.71	0.00	22.47	0.00	1.28	0.00	39.46
Natural Gas	0.00	0.00	0.00	1.57	0.00	8.50	10.07
Electricity	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chemicals	7.89	0.00	3.39	0.00	0.00	0.00	11.28
Labour	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Labour Benefits	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maintenance	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water and waste disposal	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Operating Surplus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Administrative	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	63.55	0.00	55.99	1.57	14.36	8.50	143.97

Table 10: Cost structure of ethanol production in 2008 (M$)

Cost structure of ethanol production in 2008 (M$)			
	Purchaser	Margin	Producer Price
Feedstock	693.99	122.62	571.37
Wheat	301.21	83.16	218.05
Corn	392.78	39.46	353.32
Natural Gas	107.69	10.07	97.62
Electricity	17.68	0.00	17.68
Chemicals	36.85	11.28	25.57
Labour	18.52	0.00	18.52
Labour Benefits	2.78	0.00	2.78
Taxes	0.52	0.00	0.52
Maintenance	5.90	0.00	5.90
Water and waste disposal	4.25	0.00	4.25
Administrative	17.70	0.00	17.70
Other Operating Surplus	321.85	0.00	321.85
Total	1227.73	143.97	1083.76

5.2 BIODIESEL PRODUCTION CAPACITY AND COST STRUCTURE IN 2008

5.2.1 Biodiesel Production Capacity in 2008

The emergence of a biodiesel industry in Canada has been compared to that of an ethanol industry and was found to be of a smaller scale (Laan et al. 2009). However, the development of biodiesel in Canada is at a very early stage compared to Europe and even the US ((S&T)^2 Consultants Inc. 2004a). Based on the information supplied by the Canadian Renewable Fuels Association and company websites, biodiesel production plants in Canada in 2008 had a capacity of 97 million litres in total with animal fats and canola being the main feedstocks for biodiesel production. There are three plants producing biodiesel using different feedstock. BIOX Corporation had a production capacity of 66 million litres per year which dominated (68.04%) total biodiesel production in 2008. According to personal communication with company officials, we learned that BIOX imported 30% of their feedstock, animal fats, from the US for biodiesel production. The second largest producer in 2008 was Rothsay Biodiesel with a 30 million litre capacity using tallow to produce biodiesel. The only plant that used canola as a feedstock in 2008 was Milligan Bio-tech Inc. Out of 97 million litres of biodiesel production in Canada, the canola-based product amounted to only 1 million litres: the remainder being produced from animal fats. Table 11 illustrates the biodiesel production capacity for Canada in 2008.

Table 11: Canadian Biodiesel Production Capacity in 2008

Canadian Biodiesel Production Capacity in 2008				
Company	Location	Start date	Capacity(ML/year)	Feedstock(s)
BIOX Corporation	Hamilton,Ont.	2006	66	animal fats(30% from US)
Rothsay Biodiesel	Montreal,Que.	2005	30	tallow
Milligan Bio-Tech Inc.	Foam Lake,Sask.	1996	1	canola
Total operating capacity:			**97**	

Source: Canadian Renewable Fuels Association (www.greenfuels.org), company websites and personal communication with company officials in May 2014.

5.2.2 Biodiesel Cost Structure in 2008

5.2.2.1 Diesel and biodiesel pricing

The retail diesel price is the sum of crude oil prices, refining and marketing margins and taxes (Reaney et al. 2006). Based on the plants' locations, the retail diesel price for the three provinces involved in Canada in 2008 are listed in Appendix 2.

Crude Oil Price ($/barrel) / (159 litres) +

Processing Margin (8.35 cents/litre) +

Marketing Margin (7.42 cents/litre) +

Taxes (Federal Excise 4 cents per litre + GST + Provincial)

=Retail Diesel Price

The Canadian crude oil price in 2008 is calculated based on the average monthly prices which were 101.49 Canadian dollar per barrel (Mundi 2008).

There is an economic value for biodiesel attributes since biodiesel has some good properties. The cetane-enhancing additive used in mineral diesel that costs about 0.2 cents per litre can be replaced by biodiesel ($(S\&T)^2$ Consultants Inc. 2004a). The cetane value of vegetable oil diesel and animal fat biodiesel are 0.4 and 1.2 cents per litre, respectively. A lubricity value for biodiesel has been estimated at 2.5 to 5.0, 1.0 to 2.0 and 0.25 to 0.5 cents per litre for B2, B5 and B20, respectively (Reaney et al. 2006). The addition of cold flow improvers ranging in cost from 0.3 to 4.0 cents per litre may be required due to cold weather properties of biodiesel ((S&T)[2] Consultants Inc. 2004a). This property increases the blend propensity of becoming gel in cold weather conditions. The demand for cold flow improvers differs by the feedstock used to produce biodiesel. With the blending levels arise, the demand will increase and vary based on different diesel fuel quality. The cost of blending biodiesel relies on two factors, i.e., where the biodiesel is blended and the blend percentage (B5 or B20) which varies from -1.0 to -3.0 cents per litre (Reaney et al. 2006). These negative values are really like revenues which means savings of using biodiesel instead of diesel. The economic value of biodiesel attributes equals the sum of the cetane value, lubricity value, blending cost and cold weather properties. The economic value of biodiesel attributes of different blends is listed in Table 12. The blending percentage used in this thesis is B5 and B100 (pure biodiesel). Therefore, we have considered the total estimated economic value of biodiesel attributes of B5 to be -1.20 cents per litre and B100 to be -0.13 cents per litre.

Table 12: Economic Value of Biodiesel Attributes of Different Blends

Economic Value of Biodiesel Attributes of Different Blends		
	B100	B5
	cents/liter	cents/liter
Cetane Value	0.4 to 1.2	0.4 to 1.2
Lubricity Value	0.25 to 0.5	1.0 to 2.0
Blending Cost	-1	-2
Cold Weather Properties	-0.3	-1.0 to -2.0
Total	-.65 to 0.4	-1.6 to -0.8

Source: Adapted from (S&T)2 and MNP 2004.

In this paper, we set the price of biodiesel as the cost of diesel plus the federal excise tax of $0.04 per liter and the Canadian fuel taxes for specific provinces, adjusted for biodiesel attributes. The Canadian fuel taxes for gasoline and diesel fuel for specific provinces in 2008 are listed in Appendix 3. The average selling price of biodiesel in 2008 was $1.05 per liter. The calculated selling price of biodiesel in 2008 is listed in Table 13.

Table 13: Selling Price of Biodiesel in 2008

Selling Price of Biodiesel in 2008					
Plant Locations	Retail Diesel Price	B100 Attributes	B5 Attributes	B5	B100
	$/liter	cents/liter	cents/liter	$/liter	$/liter
Hamilton,Ont.	1.02	-0.13	-1.20	1.01	1.02
Montreal,Que.	1.12	-0.13	-1.20	1.11	1.12
Foam Lake,Sask.	1.03	-0.13	-1.20	1.02	1.03

5.2.2.2 Estimation of total revenue for biodiesel sector in 2008

The estimation of total revenue for the biodiesel sector in 2008 includes the revenue of biodiesel made from canola seed and animal fats as well as their by-product revenue. Since we had an output of 97 million liters in 2008, the value of biodiesel production was 102.29 million dollars.

In addition, the meal from crushing the canola as a high protein livestock feed can be used to replace more expensive imported protein meal for dairy and hog rations. Approximately 600 kg of protein meal will be generated per tonne of canola processed (Saville and Villeneuve 2006). This indicates that we would have 1,393.2 tonnes of canola meal after the production process. For the meal selling price, we considered the Saskatchewan market at $180.00 per tonne (Reaney et al. 2006).[8] Therefore, the value of the canola meal in 2008 would be 0.25 million dollars. The main by-product of the biodiesel production procedure is glycerine where 0.079 kg glycerine per litre of biodiesel will be generated from the production process (Dalai et al. 2001). Therefore, we would have 7,663 tonnes of glycerine as the by-product being produced.

[8] Inflation adjusted price of meal plus transportation costs to the selected markets.

When glycerine is marketed as crude glycerine, its price can be set ranging from 11.5 to 16 cents per kilogram (Boyd et al. 2004). We have taken the average price of 13.75 cents per kilogram as the glycerine selling price, thus the value for glycerine would be 1.05 million dollars. To sum up, the estimation of total revenue for a biodiesel sector in 2008 was 103.59 million dollars, which is listed in Table 14.

Table 14: Estimation of Total Revenue for Biodiesel Sector in 2008

Estimation of Total Revenue for Biodiesel Sector in 2008	
Biodiesel production in 2008(ML)	97.00
Biodiesel selling price($/L)	1.05
Total value of production in 2008($M)	102.29
Canola meal value($M)	0.25
Glycerine value($M)	1.05
Total revenue($M)	103.59

5.2.2.3 Feedstock

The cost structure for canola-based biodiesel is calculated by adding up the corresponding costs for oilseed crushing and biodiesel manufacture (Reaney et al. 2006). The cost structure for animal fats-based biodiesel is calculated according to the information obtained ($(S\&T)^2$ Consultants Inc. 2004a).

Biodiesel additive manufacturing can use any grade of canola as the feedstock. Based on information from Milligan Biofuels Inc. (websites and personal communication with company officials), the company mostly uses damaged grade canola, also called off-grade canola, to produce biodiesel. This kind of seed is not suitable for food use, but it still has oil that is good for biodiesel production. The amount of canola seed we need to produce oil is based on the coefficient of 2.322 kg of seed Litre^{-1} of oil (Reaney et al. 2006)[9]. In this case, we have 1 million liters of canola based biodiesel which would use 2,322 tonnes of canola seed. Cold press extruder and oil expeller technology extracting 95% of the oil contained in the seed are used to produce canola from canola seed (Reaney et al. 2006). Since Milligan Biofuels Inc. used off-grade canola seeds to produce biodiesel, the canola seeds selling price is calculated based on the average price of the low-quality seed. The transportation and seed searching costs vary from $10.68 to $35.23 per tonne (Reaney et al. 2006). Therefore, the canola feedstock selling price was $325 per tonne in 2008 based on the calculation from the information obtained. Taken into account the canola usage in 2008 for 2,322 tonne, the canola feedstock cost was $0.75 million dollars.

The largest single cost in plant operation is the purchase of the feedstock. The animal fats costs become the key component of the cost of biodiesel based on our 96 million liters production capacity. The conversion factor we used for the calculation of the animal fats quantity is in accord with the annual biofuels report published in 2009. One liter of animal fats can make 1.1 liters of biodiesel (Evans and Dessureault 2009). The conversion factor gives us an estimation of 87.27 million liters of animal fat usage as the feedstock for biodiesel production. With a rate of conversion of 0.87 kg per liter, we used 75,690 tonnes of animal fat in 2008. The animal fat selling price we considered in this study was $470 per tonne (Albalawi et al. 2011). Thus, the animal fat feedstock cost was 35.57 million dollars.

5.2.2.4 Labour

Both canola crushing and biodiesel manufacture require direct labour which include both operation and maintenance personnel. From the respective government agencies, we came up with the rates for direct labour costs of Employment Insurance, Canada Pension Plan and

[9] Base coefficient calculated as 1000/ (1000*0.415/0.963894), for a standard oil content of 41.5%.

Workman's Compensation. There is a 5.8% holiday pay rate in the direct labour costs as well. Based on the labour cost factor from ((S&T)^2 and MNP 2004) using a base labour cost of $32,000 per worker per year for the biodiesel plant, the per litre cost of direct labour and benefits are .0157 and .002 $ litre^{-1} biodiesel, respectively. Data from the Georgia Oilseed Initiative shows that, for a 700 tonne per day plant, the direct labour cost for a canola crushing plant and benefits are .01 and .0013 $ litre^{-1} biodiesel, respectively (Reaney et al. 2006). Since the biodiesel produced from canola in 2008 was quite limited, the data collection for the labour cost of such a small plant size is difficult. Here we have to use the only reference we found to estimate the labour cost.

The operating labour requirements are a function of the plant size (Independent Business Feasibility Group 2002). The number of employees is 0.335 per million liters of capacity plus 9.3[10]. Therefore, we need 31 people for BIOX Corporation with a 66 million liter capacity and 19 people for Rothsay Biodiesel with a 30 million liter capacity.   Every year the labour costs increase by the inflation rate and we considered the Consumer Price Index as our indicator of the labour cost in 2008. The labour cost indicated in ((S&T)^2 Consultants Inc. 2004a) was $45,000 per person. The Consumer Price Index was 112.7 in Quebec and 113.3 in Ontario on the basis of 2002 as 100 from Statistics Canada. Therefore, the labour cost was $50,715 per person in Quebec and $50,985 per person in Ontario for 2008.

5.2.2.5 Operating Costs

Table 15 presents the operating costs per litre of biodiesel produced to crush and refine the feedstock. More than 75% of the total operating cost is labour and benefits (CPP, EI, WC), natural gas and administrative expenses. The cost of making biodiesel and meal accounts for 40% and 60% of the operating expenses for crushing the oilseed, respectively.

[10] $Y= 0.335 X + 9.3$

Table 15: The Cost of Oilseed Crushing for the Canola plant

The Cost of Oilseed Crushing ($ Litre^{-1} Biodiesel)

Operating Expense	**$ litre^{-1} BD**	**%**
Natural Gas[1]	0.0091	24.1%
Electricity[2]	0.0039	10.2%
Water & Sewer[3]	0.0011	3.0%
Direct labour[4]	0.0100	26.6%
Direct labour Benefits[4]	0.0013	3.4%
Maintenance[5]	0.0015	3.9%
Administrative[6]	0.0100	26.6%
Processing Supplies	0.0009	2.3%
Total Operating Expenses	**$ 0.0377**	**100%**
Fixed Expenses	**$ litre^{-1} BD**	
Depreciation	0.008	
Interest on LTD	0.008	
Total Fixed	**$ 0.016**	

1. Natural gas use rates from Agri-industry Modeling and Analysis Group, 2003. Price from Sask Energy.
2. Electricity use rate from ENVIROCHEM Services Inc, 2005. Price from Sask Power.
3. Water and Sewer use rates from Georgia Oilseed Initiative, 2001.
4. Direct labour and benefits - number of workers from Georgia Oilseed Initiative, 2001. Canada Pension Plan 4.95%, Employment Insurance 1.73%, Workman's Compensation - $1.40/$1000 income, Holiday Pay 5.8%.
5. Maintenance 1% of plant capital cost (S&T)^2 and MNP 2004.
6. Administrative includes office costs, marketing, local tax and insurance.

The operating costs for manufacturing biodiesel include methanol, a catalyst, labour (CPP, EI, WC), repairs, natural gas, electricity, water and sewer expenses, plus interest on any operating loan and/or long-term debt ((S&T)^2 Consultants Inc. 2004a). The cost for using methanol adjusted for freight to arrive at a Saskatchewan price of $0.278 per litre is 0.11 litre litre^{-1} biodiesel. Based on the commercial rate, natural gas is required at 1.4 MJ litre^{-1} of biodiesel and electricity at 0.27 kWh litre^{-1} of biodiesel. Retailers need to pay for biodiesel packaging costs which include capital equipment and containers. The depreciation will be considered in the operating costs. The cost per litre of biodiesel produced at $0.1047 is in the range estimated by Schmidt (2004) at $0.098 and Boyd et al. (2004) at $0.12 (Reaney et al. 2006). In Table 16, we have prepared the cost of biodiesel manufacture for the canola plant.

Table 16: The Cost of Biodiesel Manufacture for the Canola plant

The Cost of Biodiesel Manufacture ($ Litre^{-1} Biodiesel)

Operating Expenses	$ litre^{-1} BD	%
Natural Gas[1]	0.0049	4.7%
Electricity[2]	0.0013	1.2%
Methanol[3]	0.0306	29.2%
Direct labour[4]	0.0157	15.0%
Direct labour Benefits[4]	0.0020	1.9%
Maintenance[5]	0.0032	3.1%
Administrative[6]	0.0180	17.2%
Processing Supplies	0.0290	27.7%
Total Operating Expenses	**$ 0.1047**	**100%**
Fixed Costs	**$ litre^{-1} BD**	
Depreciation	0.018	
Interest on LTD	0.018	
Total Fixed	$ 0.036	

1. Natural gas use rates from (S&T)[2] and MNP 2004. Price from Sask Energy.
2. Electricity use rate from Radich, 2003. Price from Sask Power.
3. Methanol prices from Methanex monthly average regional posted contract price adjusted for freight and exchange rate May- 2001 to Feb 2006.
4. Direct labour and benefits - number of workers from (S&T)[2] and MNP 2004. Canada Pension Plan 4.95%, Employment Insurance 1.73%, Workman's Compensation - $1.40/$1000 income, Holiday Pay 5.8%.
5. Maintenance 1% of plant capital cost (S&T)[2] and MNP 2004.
6. Administrative includes office costs, marketing, local tax and insurance.

In general, since the production capacity in 2008 was 1 million litres, the total cost of canola-based biodiesel production was $0.95 million dollars including not only the feedstock cost but also the operating costs.

5.2.2.6 Energy

Both power and heat are required for a biodiesel plant to process and purify their products. The energy and chemical consumption values were taken from the Agri-Industry Modeling Group study of biodiesel production in Tennessee. In general, the energy consumption values match the values used in the greenhouse gas modelling studies previously undertaken for Natural Resources Canada. The Natural Gas requirement is 1.4MJ per liter and the electricity requirement is 0.025 kWh per liter. These energy requirements will be applied to plants of all sizes. It is also assumed from these values that the glycerin is sold as crude glycerine ((S&T)[2] Consultants Inc. 2004a).

In this case, the total natural gas requirement is 2.45 million m^3 for BIOX Corporation with a capacity of 66 million liters and 1.11 million m^3 for Rothsay Biodiesel with a capacity of 30 million liters. The total electricity requirement is 1.65 million kWh for BIOX Corporation and 0.75 million kWh for Rothsay Biodiesel.

Energy prices are volatile and can change dramatically between different regions in Canada. Table 17 shows the natural gas prices (Statistics Canada 2008) for industrial sales by province. Therefore, the cost of natural gas was 0.99 million dollars for BIOX Corporation and 0.39 million dollars for Rothsay Biodiesel. In general, the total natural gas cost for animal fat based biodiesel was 1.385 million dollars.

Table 17: Natural gas, unit price excluding taxes – Industrial sales

Natural Gas Prices	
	2008
	¢/m^3
Ontario	40.54
Quebec	35.07
New Brunswick	38.82
Manitoba	26.41
Saskatchewan	25.97
Alberta	26.77
British Columbia	26.4

Source: Statistics Canada, 2008

Electricity prices are different in different regions of Canada. Prices are regulated and generally uniform in some markets. However, prices are set by the market and they depend on supply and demand in other regions. In Ontario, we have considered the electricity prices for consumers on the regulated price plan (RPP) in 2008 from the Ontario Energy Board. The average RPP price was 5.735 ¢/kWh. Therefore, the cost of electricity in the Ontario plant was 0.095 million dollars. In Quebec, we have taken the electricity price information published by Hydro Quebec into account. Since the monthly electricity consumption of Rothsay Biodiesel was 62,500 kWh, it was classified as a medium power demand company with an average price of 12.42 ¢/kWh including taxes. As a result, the electricity cost for the Quebec plant was 0.093 million dollars. The estimation of the energy cost of biodiesel production in 2008 is presented in Table 18.

Table 18: Energy cost for biodiesel production in 2008

Energy cost for biodiesel production in 2008							
	Production	Natural Gas Price	Natural Gas Usage	Natural Gas Cost	Electricity Price	Electricity Usage	Electricity Cost
	ML	¢/m³	million m³	M$	¢/kWh	million kWh	M$
Hamilton,Ont.	66	40.54	2.45	0.99	5.74	1.65	0.09
Montreal,Que.	30	35.07	1.11	0.39	12.42	0.75	0.09
Foam Lake,Sask.	1	25.97	0.04	0.01	3.88	0.03	0.00
Total	97.00	-	3.60	1.39	-	2.43	0.19

Sources: Natural gas prices from Statistics Canada, 2008; Electricity prices from Hydro Quebec report, 2008; Energy consumption recommendations from $(S\&T)^2$ Consultants Inc. report, 2004.

5.2.2.7 Methanol

Biodiesel plants require the use of methanol, a catalyst and other minor chemicals. Methanol requirements will be considered as 0.12 liters of methanol per liter of biodiesel ($(S\&T)^2$ Consultants Inc. 2004a). In this case, we need 11.52 million liters of methanol to produce 96 million liters of biodiesel. Methanol prices can be volatile and change by location. Since we could not find freight information, we could only apply the price of $0.278 per liter according to the related reference (Reaney et al. 2006). Therefore, the total methanol cost was 3.20 million dollars in 2008.

5.2.2.8 Taxes

The tax estimation is calculated based on Ontario, Quebec and Saskatchewan. The exemptions and incentives will be considered as government subsidies in 2008. The table presented with the biofuel tax exemptions and incentives are in Appendix 4. The taxes we used in the cost of production are calculated according to the tax margin matrix.

5.2.2.9 Maintenance

Biodiesel plants require maintenance much like any other processing facilities. Operating conditions are relatively regular so there should not be any special maintenance concerns. The typical annual maintenance rate will be 1% of the plant capital cost. The plant cost (in million $) is 1.20 times the plant capacity (in million litres) raised to the 0.65 power[11] ($(S\&T)^2$ Consultants Inc. 2004a). Therefore, the maintenance cost for Rothsay Biodiesel was 0.10 million dollars and 0.17 million dollars for BIOX Corporation. The costs of biodiesel manufacture for these two companies are listed in Table 19 and 20.

[11] $Y = 1.2029\ X^{0.6507}$

Table 19: Cost of Biodiesel Manufacture for BIOX Corporation

Table : Cost of Biodiesel Manufacture for BIOX ($ Litre^{-1} Biodiesel)

Operating Expenses	$ litre^{-1} BD	%
Natural Gas[1]	0.0151	12 %
Electricity[2]	0.0014	1 %
Methanol[3]	0.0334	26 %
Direct labour[4]	0.0239	19 %
Direct labour Benefits[4]	0.0030	2 %
Maintenance[5]	0.0026	2 %
Administrative[6]	0.0180	14 %
Processing Supplies	0.0290	23 %
Total Operating Expenses	**$ 0.1264**	**100%**
Fixed Costs	**$ litre^{-1} BD**	
Depreciation	0.018	
Interest on LTD	0.018	
Total Fixed	$ 0.036	

1. Natural gas use rates from (S&T)[2] and MNP 2004. Price from Statistics Canada, 2008
2. Electricity price from Ontario Energy Board.
3. Methanol prices from Methanex monthly average regional posted contract price adjusted for freight and exchange rate May- 2001 to Feb 2006.
4. Direct labour and benefits - number of workers from (S&T)[2] and MNP 2004. Canada Pension Plan 4.95%, Employment Insurance 1.73%, Workman's Compensation - $1.40/$1000 income, Holiday Pay 5.8%.
5. Maintenance 1% of plant capital cost (S&T)[2] and MNP 2004.
6. Administrative includes office costs, marketing, local tax and insurance.

Table 20: Cost of Biodiesel Manufacture for Rothsay Biodiesel

Table: Cost of Biodiesel Manufacture for Rothsay ($ Litre^{-1} Biodiesel)

Operating Expenses	$ litre^{-1} BD	%
Natural Gas[1]	0.0130	10 %
Electricity[2]	0.0031	2 %
Methanol[3]	0.0334	25%
Direct labour[4]	0.0321	24%
Direct labour Benefits[4]	0.0039	3 %
Maintenance[5]	0.0033	2 %
Administrative[6]	0.0180	13%
Processing Supplies	0.0290	21%
Total Operating Expenses	**$ 0.1358**	**100%**
Fixed Costs	**$ litre^{-1} BD**	
Depreciation	0.018	
Interest on LTD	0.018	
Total Fixed	$ 0.036	

1. Natural gas use rates from (S&T)[2] and MNP 2004. Price from Statistics Canada, 2008
2. Electricity price from Hydro Quebec.
3. Methanol prices from Methanex monthly average regional posted contract price adjusted for freight and exchange rate May- 2001 to Feb 2006.
4. Direct labour and benefits - number of workers from (S&T)[2] and MNP 2004. Canada Pension Plan 4.95%, Employment Insurance 1.39%, Workman's Compensation - $1.40/$1000 income, Holiday Pay 5.8%.
5. Maintenance 1% of plant capital cost (S&T)[2] and MNP 2004.
6. Administrative includes office costs, marketing, local tax and insurance.

5.2.3 Preparation of biodiesel commodities and industries in the Canadian I-O structure

Canola and animal fats used as feedstocks for the biodiesel industry have been adjusted with canola used in the Oilseed industry and animal fat and lard used in the Food Manufacturing Industry.

The glycerin by-product can be used as a raw material in the food and beverage, cosmetics and pharmaceuticals industry. To allocate the glycerin in the I-O table, 24% of the glycerin was considered going to the Food Manufacturing Industry, 11% goes to the Beverage and Tobacco Product Manufacturing Industry, 41% goes to the Other Basic Chemical and Manufacturing Industry and 24% goes to the Pharmaceutical and Medicine Manufacturing Industry (Greyt 2011). The glycerin is adjusted with soft drinks, alcoholic beverages, pharmaceuticals and other chemical products sectors.

One kind of high protein livestock feed able to replace more expensive imported protein meal in dairy, cattle, poultry and hog rations is the meal from crushing canola seed (Council 2009). The canola meal is adjusted with other grains and fodder in an imputed feed sector. Since the information about the percentage of canola meal going to other industries is not available, we have distributed the canola meal commodity at a uniform rate of 25% each across the four absorbing industries. Other intermediate inputs of the biodiesel industry, e.g., natural gas, electricity, chemicals, have also been adjusted with the petroleum industry.

The B5 industry uses the production of biodiesel as an input and the total biodiesel production with 95% diesel oil is used by the B5 industry to produce output. The total output of the B5 commodity is mostly being used by the transportation sector (components in the intermediate demand). The disposition of the diesel oil commodity in the Input-Output Model is based on the percentage of the diesel oil going into the transportation sector, the private consumption sector, and other intermediate industries, with the value of diesel oil used for road motor vehicles. In 2008, we had 39,149 million liters net sales of gasoline and 16,555 million liters net sales of diesel oil (Evans and Dessureault 2012). With the selling price of diesel oil in 2008, we can calculate the total value of diesel oil in the transportation sector. This value has been converted from purchaser's price to producer's price using the margin matrix referring to Statistics Canada. We have calculated the coefficients of corresponding commodities and industries. The margins for biodiesel production include wholesale margin, retail margin, transport margin, gas margin, storage margin and pipeline margin. The total margin for diesel oil was 3,911.91 million dollars and the value of the diesel oil in the transportation sector was 13,470.84 million dollars. Therefore, after the aggregation of the transportation sector into intermediate industries, the percentage we distribute in our model is 63% for intermediate transportation industries, 3% for private consumption in the final demand sector, and 34% in other intermediate industries. Instead of allocating the 34% into all other intermediate industries, we choose to allocate these to the service industries.

The same procedure is applied to biodiesel cost of production for the conversion of purchaser's price to producer's price. The margin value for the cost of biodiesel production is presented in Table 21. The final cost structure for biodiesel production in 2008 is listed in Table 22.

Table 21: Margin Value Matrix for Biodiesel

Margin Value Matrix for Biodiesel							
	wholesale	retail	transport	gas	storage	pipeline	TOTAL
Animal Fats	4.21	0.00	1.60	0.00	0.00	0.00	5.81
Canola	0.06	0.00	0.02	0.00	0.01	0.00	0.08
Natural Gas	0.00	0.00	0.00	0.02	0.00	0.11	0.13
Electricity	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Methanol	0.69	0.00	0.30	0.00	0.00	0.00	0.99
Water & Sewer	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Labour	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Labour Benefits	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maintenance	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Processing Supplies	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Administrative	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fixed Expenses	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Operating Surplus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	4.96	0.00	1.91	0.02	0.01	0.11	7.01

Table 22: Cost structure of biodiesel production in 2008 (M$)

Cost structure of biodiesel production in 2008 (M$)			
	Purchaser	Margin	Producer Price
Feedstock	36.32	5.89	30.43
Animal Fats	35.57	5.81	29.76
Canola	0.75	0.08	0.67
Natural Gas	1.40	0.13	1.27
Electricity	0.19	0.00	0.19
Methanol	3.24	0.99	2.25
Water & Sewer	0.00	0.00	0.00
Labour	2.57	0.00	2.57
Labour Benefits	0.32	0.00	0.32
Taxes	0.02	0.00	0.02
Maintenance	0.27	0.00	0.27
Processing Supplies	2.81	0.00	2.81
Administrative	1.75	0.00	1.75
Fixed Expenses	3.51	0.00	3.51
Other Operating Surplus	20.28	0.00	20.28
Total	72.67	7.01	65.66

With regard to the entry of a B5 industry, both the diesel oil commodity and petroleum refinery industry have to be adjusted. In order to adjust the petroleum refinery industry and retail trade industry, the major inputs for biodiesel and B5 have been constructed.

The cost of ethanol and biodiesel production in 2008 has been clearly discussed in this chapter. The macroeconomic impacts of the biofuel industry can be estimated using this model.

CHAPTER 6

RESULTS AND DISCUSSION

In this chapter, we estimate the macroeconomic impact – GDP, employment, output on the Canadian economy in 2008. In addition, the direct and total impacts on industries are also discussed. After this discussion, we could answer the questions such as which industries are influenced when the biofuel sector is introduced into the system and how far the biofuel sector is linked with all the other industries in the economy.

6.1 MACROECONOMIC IMPACTS OF A BIOFUEL SECTOR ON THE CANADIAN ECONOMY

The macroeconomic impacts of the ethanol and biodiesel sectors, including industrial output, GDP and employment are estimated. We multiply the impact matrix with the revised final demand column, to generate the impacts of total output. Since the 2008 Input-Output Model considers withdrawals from inventories or changes in government production leakages, the only leakage we need to take into account is the import leakage. The total industrial output of the Canadian economy for 2008 is 2,261,140 million dollars (Table 23). The contributions from the ethanol and E10 industries are 1,309.21 million dollars and 10,961.45 million dollars respectively. Biodiesel contributes 72.60 million dollars and the number for the B5 industry is 942.17 million dollars. In 2008, the biofuel sector contributed 13,285.43 million dollars which accounted for 0.59% in total industrial output.

The GDP at factor cost is estimated at 1,420,045 million dollars for the Canadian economy in 2008 and in 2008, the biofuel sector contributed 745.46 million dollars which accounted for 0.05% of the total GDP in 2008[12].

The macroeconomics impacts of biofuel sector in employment are estimated as well. The employment data we used is the full-time employment direct jobs multipliers on the basis of the Input-Output worksheet level structure for the year of 2008. After the application of the same aggregation scheme, we multiply the jobs multipliers by the impact matrix to estimate the employment figure which was 16,377,762 persons in 2008. The employment contributions from ethanol and biodiesel industries were 600 and 54 jobs respectively. There were 4,815 jobs created by the E10 industry and 695 jobs by the B5 industry. The contribution from the biofuel sector accounted for 0.04% of the whole Canadian employment market.

[12] We have considered the wages and salaries, supplementary labour income, mixed income and other operating surplus as the GDP value added sectors.

Table 23: Macroeconomic Impacts of Biofuel Sector, 2008 (M$)

Macroeconomic Impacts of Biofuel Sector in Industrial Output, 2008 (M$)		
Total Industrial Output	2261140	% Share
Industrial Output Contribution from Ethanol	1309.21	0.0579%
Industrial Output Contribution from Biodiesel	72.60	0.0032%
Industrial Output Contribution from E10	10961.45	0.4848%
Industrial Output Contribution from B5	942.17	0.0417%
Macroeconomic Impacts of Biofuel Sector in GDP, 2008 (M$)		
Total GDP at Factor Cost	1420045	% Share
Biofuel Contribution in GDP	746.98	0.0526%
Macroeconomic Impacts of Biofuel Sector in Employment, 2008		
Total Employment	16377762	% Share
Employment Contribution from Ethanol	600	0.0037%
Employment Contribution from Biodiesel	4815	0.0294%
Employment Contribution from E10	54	0.0003%
Employment Contribution from B5	695	0.0042%

6.2 DIRECT AND INDIRECT IMPACTS OF A BIOFUEL SECTOR ON THE CANADIAN ECONOMY

One major advantage of the Input-Output Modelling framework is that it can be used to estimate the direct plus indirect impact of changes in the demand for the commodities that are exogenous to the model of that economy. With the introduction of new industries and commodities into the system, we can quantify the economic effects of related policy regulations. The influence of the biofuel sectors for the Canadian economy can be estimated by the adjusted Input-Output Model. In this section, we evaluate the direct impacts of biofuel sectors as well as the total impacts on the industries.

With the initial shock of the Input-Output Model, we obtained the direct impacts of the ethanol, biodiesel, E10 and B5 industries on the economy, which estimate impacts on industries with one unit changes in demand. The direct impacts on industries are captured in the following tables. More detailed tables can be found in Appendix 5.

In Table 24, corn has the highest impact among the industries for the ethanol commodity. The wheat industry holds the second highest direct impacts for ethanol. Since corn and wheat are the main feedstock for ethanol production for the year 2008, it is expected to have important impacts on these two industries. The reason why corn has higher impacts than wheat is because corn accounted for 67% of the feedstock in the year of 2008. "Feedstock requirement of the plants affect the agricultural industries in the aspect of substitution and output allocation with other industries" (Mukhopadhyay and Thomassin 2011, p.2828). With the entry of ethanol into the economic system, mining, manufacturing and service industries also show crucial impacts. These industries in our model are Oil and Gas Extraction, Other Basic Chemical and Manufacturing, Electric Power Generation, Transmission and Distribution, Food Manufacturing, Pesticides, Fertilizer and Other Agricultural Chemical Manufacturing. They are mainly used as inputs in the ethanol production process.

Merely four industries for E10 production have direct impacts, i.e., Petroleum Refineries and Other Petroleum and Coal Products Manufacturing, Ethanol, Wholesale Trade and Transportation Margins. Ethanol is considered as the input of the E10 industry when the biofuel sector of the Input-Output Model is built resulting in direct impacts. The other industries report direct impacts because of some adjustments made in these industries during the model construction. It is assumed that ethanol production would substitute for the demand for the same amount of gasoline.

In Table 25, Animal (excluding Poultry) Slaughtering and Rendering and Meat Processing from Carcasses have the same highest impacts among the industries. The reason is that animal fats accounted for nearly 99% of the feedstock for biodiesel production in 2008. Other top industries are mainly input industries for biodiesel production, such as Oil and Gas Extraction, other basic Chemical and Manufacturing, Wholesale Trade, Services and Electric Power Generation, Transmission and Distribution.

For B5, only five industries have direct impacts. These are Petroleum Refineries and Other Petroleum and Coal Products Manufacturing, Biodiesel, Other Federal Government Services, Wholesale Trade, and Transportation Margins. The reason why Petroleum Refineries and Other Petroleum and Coal Products Manufacturing has the largest impact is that this industry shows big impacts for all fuel related commodities, not only Motor gasoline, but also Aviation fuel, Diesel oil, Light fuel and Heavy fuel. As is the case for Ethanol, Biodiesel is considered as an input of the B5 industry, so the impact is direct. The necessary adjustment has been made on Other Federal Government Services, Wholesale Trade and Transportation Margins during model construction. It is also assumed that the biodiesel production would substitute the demand for the same amount of diesel oil commodity. Since diesel oil is widely used in the wholesale trade and transportation sectors, the impacts are obvious as well.

Table 24: Direct Impacts of Ethanol and E10 on Top Industries

Direct Impacts of Ethanol and E10 on Top Industries		
	Industries	Ethanol
1	Feed grain	0.1769
2	Wheat	0.1759
3	Oil and Gas Extraction	0.0720
4	Wholesale Trade	0.0568
5	Transportation Margins	0.0545
6	Electric Power Generation, Transmission and Distribution	0.0136
7	Administrative and Support Services	0.0079
8	other basic Chemical and Manufacturing	0.0072
9	Professional, Scientific and Technical Services	0.0062
10	Food Manufacturing	0.0023
11	Repair and Maintenance	0.0015
12	Retail Trade	0.0013
13	Pesticides, Fertilizer and Other Agricultural Chemical Manufacturing	0.0010
14	Fabricated Metal Products Manufacturing	0.0010
15	Petroleum Refineries and Other Petroleum and Coal Products Manufacturing	0.0005
	Industries	E10
1	Petroleum Refineries and Other Petroleum and Coal Products Manufacturing	0.7223
2	Ethanol	0.0968
3	Wholesale Trade	0.0024
4	Transportation Margins	0.0004

Table 25: Direct Impacts of Biodiesel and B5 on Top Industries

Direct Impacts of Biodiesel and B5 on Top Industries		
	Industries	Biodiesel
1	Animal (except Poultry) Slaughtering	0.1653
2	Rendering and Meat Processing from Carcasses	0.1653
3	Wholesale Trade	0.0671
4	Administrative and Support Services	0.0404
5	Professional, Scientific and Technical Services	0.0301
6	Transportation Margins	0.0268
7	Oil and Gas Extraction	0.0168
8	other basic Chemical and Manufacturing	0.0109
9	Poultry Processing	0.0099
10	Oilseed	0.0090
11	Repair and Maintenance	0.0079
12	Retail Trade	0.0063
13	Food Manufacturing	0.0037
14	Electric Power Generation, Transmission and Distribution	0.0029
15	Other Transportation	0.0024
	Industries	B5
1	Petroleum Refineries and Other Petroleum and Coal Products Manufacturing	0.9249
2	Biodiesel	0.0491
3	Other Federal Government Services	0.0027
4	Wholesale Trade	0.0020
5	Transportation Margins	0.0002

All subsequent changes resulting from the several rounds of purchases of intermediate outputs are included in total impact (Mukhopadhyay and Thomassin 2011). Both direct and indirect impacts on industries will occur for a one unit change in biofuel demand. The results show that most of the industries have bigger impacts on total impacts than on direct impacts. Total impacts of ethanol and E10, biodiesel and B5 on top industries are listed in Tables 26 and 27 respectively. More detailed impact lists can be referred to in Appendix 6.

Some of the industries have indirect effects only because of the change in ethanol demand, for example, Finance, nsurance, real estate and rental and leasing, Other transportation and Truck transportation industry, etc. Other industries appearing in both direct and total impact lists have higher impacts on the total impacts list. The most prominent total impact of an ethanol sector comes from the Feed grain industry which is the main feedstock used for ethanol production. Other industries having large total effects are trade, finance and insurance, construction and transportation. Some agricultural industries such as Cattle and Support Activities for Forestry have impacts as well. This is because DDG as a by-product of ethanol production has been adjusted with imputed feed wheat and feed corn sectors used in the Dairy, Cattle and Hogs industry. The impacts for the E10 industry is quite similar to ethanol. The largest impacts appear on petroleum refineries and oil and gas extraction sectors. Agricultural industries such as corn and wheat have impacts as well. Other impacts are shared by finance and insurance, transportation and services industries.

In the case of biodiesel total impacts, Animal Slaughtering and Rendering and Meat Processing from Carcasses have the biggest effects. The reason is that animal fats dominated the feedstock for biodiesel production in 2008. The main by-product from the biodiesel production is glycerin which goes to the Food Manufacturing industry. This flow is reported in the impact table as well. Other influenced industries are trade, services and transportation. Agricultural industries such as Cattle, Hogs and Other crops also have impacts. For the B5 industry, petroleum refineries and oil and gas extraction sectors have the greatest impacts. Agricultural industries such as animal slaughtering, rendering and meat processing and cattle have impacts as well. Other impacts are shared by finance and insurance, transportation and services industries.

Table 26: Total Impacts of Ethanol and E10 on Top Industries

Total Impacts of Ethanol and E10 on Top Industries				
	Industries	Ethanol	Industries	E10
1	Ethanol	1.000	E10	1.000
2	Feed grain	0.185	Petroleum Refineries and Other Petroleum and Coal Products Manufacturing	0.749
3	Wheat	0.180	Oil and Gas Extraction	0.480
4	Oil and Gas Extraction	0.102	Ethanol	0.097
5	Wholesale Trade	0.084	Finance, Insurance, Real Estate and Rental and Leasing	0.042
6	Transportation Margins	0.061	Wholesale Trade	0.023
7	Finance, Insurance, Real Estate and Rental and Leasing	0.045	Administrative and Support Services	0.019
8	Other Transportation	0.033	Support Activities for Mining and Oil and Gas Extraction	0.019
9	Truck Transportation	0.031	Feed grain	0.018
10	Administrative and Support Services	0.030	Wheat	0.018
11	Petroleum Refineries and Other Petroleum and Coal Products Manufacturing	0.029	Operating, Office, Cafeteria and Laboratory Supplies	0.017
12	Electric Power Generation, Transmission and Distribution	0.020	Pipeline Transportation	0.016
13	Operating, Office, Cafeteria and Laboratory Supplies	0.019	Professional, Scientific and Technical Services	0.016
14	Professional, Scientific and Technical Services	0.019	Transportation Margins	0.012
15	other basic Chemical and Manufacturing	0.017	other basic Chemical and Manufacturing	0.010
16	non metalic mineral mining	0.017	Electric Power Generation, Transmission and Distribution	0.010
17	Travel, Entertainment, Advertising and Promotion	0.013	Travel, Entertainment, Advertising and Promotion	0.009
18	Pesticides, Fertilizer and Other Agricultural Chemical Manufacturing	0.011	Other Transportation	0.008
19	Construction	0.009	Construction	0.007
20	Retail Trade	0.008	Truck Transportation	0.007
21	Food Manufacturing	0.007	Retail Trade	0.005
22	Support Activities for Forestry	0.004	Broadcasting and Telecommunications	0.005
23	Cattle	0.003	Repair and Maintenance	0.003

Table 27: Total Impacts of Biodiesel and B5 on Top Industries

Total Impacts of Biodiesel and B5 on Top Industries				
	Industries	Biodiesel	Industries	B5
1	Biodiesel	1.000	B5	1.000
2	Animal (except Poultry) Slaughtering	0.213	Petroleum Refineries and Other Petroleum and Coal Products Manufacturing	0.956
3	Rendering and Meat Processing from Carcasses	0.193	Oil and Gas Extraction	0.605
4	Wholesale Trade	0.097	Finance, Insurance, Real Estate and Rental and Leasing	0.050
5	Cattle	0.087	Biodiesel	0.049
6	Administrative and Support Services	0.073	Administrative and Support Services	0.024
7	Finance, Insurance, Real Estate and Rental and Leasing	0.057	Support Activities for Mining and Oil and Gas Extraction	0.024
8	Food Manufacturing	0.052	Wholesale Trade	0.023
9	Professional, Scientific and Technical Services	0.051	Operating, Office, Cafeteria and Laboratory Supplies	0.021
10	Hogs	0.049	Professional, Scientific and Technical Services	0.020
11	Oil and Gas Extraction	0.042	Pipeline Transportation	0.020
12	Transportation Margins	0.039	other basic Chemical and Manufacturing	0.012
13	Poultry Processing	0.038	Electric Power Generation, Transmission and Distribution	0.011
14	Other Transportation	0.027	Animal (except Poultry) Slaughtering	0.011
15	Other Crops	0.027	Travel, Entertainment, Advertising and Promotion	0.011
16	Travel, Entertainment, Advertising and Promotion	0.024	Rendering and Meat Processing from Carcasses	0.010
17	Petroleum Refineries and Other Petroleum and Coal Products Manufacturing	0.023	Construction	0.009
18	Truck Transportation	0.023	Transportation Margins	0.009
19	Operating, Office, Cafeteria and Laboratory Supplies	0.022	Other Transportation	0.007
20	other basic Chemical and Manufacturing	0.018	Retail Trade	0.007
21	Feed grain	0.017	Broadcasting and Telecommunications	0.006
22	Electric Power Generation, Transmission and Distribution	0.015	Food Manufacturing	0.006
23	Retail Trade	0.015	Truck Transportation	0.006

In conclusion, the sectors that were impacted the greatest were the agriculture sectors because their products are used as feedstock for biofuel production. Among other industries, mining and manufacturing industries also show a considerable impact because of the ethanol and biodiesel entry into the economic system. These sectors products are mainly used as inputs in the ethanol and biodiesel production process. However, since all the available data and model are based on 2008, we have the limitation to obtain the most updated economic impacts.

CHAPTER 7

SIMULATION EXERCISES

The current study undertakes six simulation exercises on biofuel commodities including ethanol, biodiesel, E10 and B5. The reduction in GHG emissions has also been measured from these exercises.

Since the current study considers 2008 as the reference year, it is necessary to check the current status of biofuel consumption and how it affects the economy in terms of industrial output, GDP and employment (for the year 2013). The first exercise is derived on the basis of the demand for ethanol and biodiesel in 2013. We take the economy from 2008 to 2013 using a macro variable (GDP) shock[13]. Instead of applying the actual blend rate for 2013[14], the old blend rate has been increased to 10% for ethanol and 5% for biodiesel since we are trying to estimate the biofuel mandate impacts. In the second exercise, the study estimates the impacts of the increased biofuel blend rates on the economy, for 20% ethanol and for 10% biodiesel on 2013 economy. In the third exercise, the sectoral GDP growth rates (from 2008 to 2013), such as agricultural, mining, manufacturing and services, have been applied to the Canadian economy along with the ethanol blend rate of 10% and biodiesel blend rate of 5% in the system. The fourth simulation exercise was also based on the third simulation except for a higher blend rate for E20 and B10 in the model. Due to the increase in the blend rate, there will be more demand for ethanol and biodiesel. It is expected that the additional ethanol and biodiesel demand cannot be met with the current production. In the short run, the economy has to increase imports but, in the long run, the economy can adjust with the demand. Assuming that the economy can produce 3,106 million liters of ethanol and 567 million liters of biodiesel without imports, many

[13] The GDP cumulative growth rate from 2008 to 2013 has been calculated to be 14% according to The World Bank (2014) data.
[14] The actual blend rates for ethanol and biodiesel are 6% and 3% in 2013.

industries will be affected in the economy. In the last two simulations, the ethanol and biodiesel industries are treated as being exogenous. The ethanol and biodiesel industrial outputs have been fixed in the economy to assess the impact on the rest of the economy and the derivation of final demand.

7.1 SIMULATION 1

In the first simulation, the 2013 economy has been considered as the reference year. The study uses the ethanol blend to 10% and biodiesel blend to 5% in the model. In addition, the cumulative GDP growth of 14% from 2008 to 2013 is also applied in the new model. The data is provided by The World Bank (2014). Results showed that the percent shares of the biofuel sectors in total industrial output, GDP and employment are 2.98%, 0.33% and 0.25% respectively. Table 28 presents the result of this simulation.

The GHG emissions reduction has been estimated using the GHG calculator based on 2013 gasoline consumption (BioFleet 2014). The GHG emissions reduction from using E10 is 9,021,544 tonnes of CO_2 equivalence, which equals the removal of 1,771,500 cars off the road[15]. The GHG emissions reduction from B5 is 5,227,255 tonnes of CO_2 equivalence, which equals the removal of 1,026,441 cars off the road.

12 Emissions are lifecycle CO_2 equivalent using Western Canadian assumptions for all fuels and Wheat as the feedstock for Ethanol. The results are estimates, using assumptions from Natural Resources Canada's GHGenius 3.20a model, NRCan fuel guide and ecoENERGY Fuel Consumption Guide, 2011. 2011 4 Cyl Ford Escape 2wd used for "car off the road" reference vehicle at 5.0926 tonnes CO_2e p.a.

Table 28: Simulation 1

Macroeconomic Impacts of Biofuel Sector in Industrial Output, 2013 (M$)		
Total Industrial Output	2637431	% share
Industrial Output Contribution from Ethanol	4705.85	0.1784%
Industrial Output Contribution from Biodiesel	2246.25	0.0852%
Industrial Output Contribution from E10	41916.52	1.5893%
Industrial Output Contribution from B5	29636.48	1.1237%
Macroeconomic Impacts of Biofuel Sector in GDP, 2013 (M$)		
Total GDP at Factor Cost	1239780	% share
Biofuel Contribution in GDP	4043.89	0.3262%
Macroeconomic Impacts of Biofuel Sector in Employment, 2013		
Total Employment	14753738	% share
Employment Contribution from Ethanol	2024	0.0137%
Employment Contribution from Biodiesel	1168	0.0079%
Employment Contribution from E10	18024	0.1222%
Employment Contribution from B5	15411	0.1045%

7.2 SIMULATION 2

Based on Simulation 1, the study increased the blend rate of ethanol to 20% and biodiesel to 10% and kept the 2013 GDP growth rate at 14%. Results showed that the percent shares of biofuel sectors in total industrial output, GDP and employment are 3.06%, 0.33% and 0.25% respectively. Table 29 presents the results of this simulation.

The GHG emissions reduction has been estimated for Simulation 2 using BioFleet (2014). The GHG emissions reduction from E20 is 18,043,088 tonnes of CO_2 equivalence, which equals the removal of 3,543,001 cars off the road. The GHG emissions reduction from B10 is 10,454,510 tonnes of CO_2 equivalence, which equals the removal of 2,052,882 cars off the road.

Table 29: Simulation 2

Macroeconomic Impacts of Biofuel Sector in Industrial Output, 2013 (M$)		
Total Industrial Output	2755874	% share
Industrial Output Contribution from Ethanol	5122.18	0.1859%
Industrial Output Contribution from Biodiesel	2352.22	0.0854%
Industrial Output Contribution from E20	45709.63	1.6586%
Industrial Output Contribution from B10	31035.00	1.1261%
Macroeconomic Impacts of Biofuel Sector in GDP, 2013 (M$)		
Total GDP at Factor Cost	1299168	% share
Biofuel Contribution in GDP	4345.04	0.3344%
Macroeconomic Impacts of Biofuel Sector in Employment, 2013		
Total Employment	15632926	% share
Employment Contribution from Ethanol	2203	0.0141%
Employment Contribution from Biodiesel	1223	0.0078%
Employment Contribution from E20	19655	0.1257%
Employment Contribution from B10	16138	0.1032%

7.3 SIMULATION 3

The third simulation assumed the blend rate for E10 and B5 and applied the cumulative GDP growth rate based on different categories such as agricultural, mining, manufacturing and services. The data are provided by Statistics Canada (2014b). Results showed that the percent shares of biofuel sectors in total industrial output, GDP and employment are 3.12%, 0.34% and 0.26% respectively. In Table 30, the result is presented.

Table 30: Simulation 3

Macroeconomic Impacts of Biofuel Sector in Industrial Output, 2013 (M$)		
Total Industrial Output	2504646	% share
Industrial Output Contribution from Ethanol	4687.38	0.1871%
Industrial Output Contribution from Biodiesel	2242.37	0.0895%
Industrial Output Contribution from E10	41854.76	1.6711%
Industrial Output Contribution from B5	29586.93	1.1813%

Macroeconomic Impacts of Biofuel Sector in GDP, 2013 (M$)		
Total GDP at Factor Cost	1178117	% share
Biofuel Contribution in GDP	4034.50	0.3425%

Macroeconomic Impacts of Biofuel Sector in Employment, 2013		
Total Employment	14010589	% share
Employment Contribution from Ethanol	2016	0.0144%
Employment Contribution from Biodiesel	1166	0.0083%
Employment Contribution from E10	17998	0.1285%
Employment Contribution from B5	15385	0.1098%

7.4 SIMULATION 4

The fourth simulation is based on the E20 and B10 blending rate along with the sectoral cumulative GDP growth rate to investigate the blend rate impacts. Results showed that the percent shares of biofuel sectors in total industrial output, GDP and employment are 3.33%, 0.37% and 0.28% respectively. The GHG emission reduction calculation is based on the amount of biofuel used. Therefore, the GHG reduction is the same for Simulations 2 & 4, similarly Simulation 1 & 3 are also the same because of the same amount of E10 and B5. Table 31 shows the results.

Table 31: Simulation 4

Macroeconomic Impacts of Biofuel Sector in Industrial Output, 2013 (M$)		
Total Industrial Output	2520673	% share
Industrial Output Contribution from Ethanol	5091.23	0.2020%
Industrial Output Contribution from Biodiesel	2345.72	0.0931%
Industrial Output Contribution from E20	45551.41	1.8071%
Industrial Output Contribution from B10	30951.33	1.2279%
Macroeconomic Impacts of Biofuel Sector in GDP, 2013 (M$)		
Total GDP at Factor Cost	1182116	% share
Biofuel Contribution in GDP	4327.54	0.3661%
Macroeconomic Impacts of Biofuel Sector in Employment, 2013		
Total Employment	14026188	% share
Employment Contribution from Ethanol	2189	0.0156%
Employment Contribution from Biodiesel	1220	0.0087%
Employment Contribution from E20	19587	0.1396%
Employment Contribution from B10	16095	0.1147%

The results for the four simulations are compared in the following table. Based on different assumptions, we have different simulations results. We have selected several macroeconomic factors for estimating impacts. With increasing biofuel demand, the total industrial output, GDP and employment have increased. If Canada can set up a 10% blend rate for ethanol and a 5% blend rate for biodiesel, the economy can be increased to a higher level along with less unemployment. With a higher biofuel blend rate, the contribution of biofuels to industrial output, GDP and employment would be higher. Since the sectoral GDP growth rate is smaller than the general GDP cumulative growth rate, and the biofuel sectors are constant, we have a higher contribution percentage for simulations 3 and 4. The comparison of the simulation exercises is listed in Table 32.

Table 32: Simulation Exercises Comparison

Simulation Exercises Comparison				
Simulation Exercise	Simulation 1	Simulation 2	Simulation 3	Simulation 4
	Biofuel Demand of E10 and B5	Biofuel Demand of E20 and B10	Biofuel Demand of E10 and B5	Biofuel Demand of E20 and B10
Industrial Output				
Contribution from blend ethanol	1.5893%	1.6586%	1.6711%	1.8071%
Contribution from blend biodiesel	1.1237%	1.1261%	1.1813%	1.2279%
GDP at Factor Cost				
Contribution from blend ethanol	0.1080%	0.1124%	0.1135%	0.1231%
Contribution from blend biodiesel	0.0581%	0.0580%	0.0610%	0.0636%
Employment				
Contribution from blend ethanol	0.1222%	0.1257%	0.1285%	0.1396%
Contribution from blend biodiesel	0.1045%	0.1032%	0.1098%	0.1147%
GHG Emission Reduction (in tonnes of CO2 eqivalent)	14,248,799	28,497,599	14,248,799	28,497,599
Equivalence of Cars Removed from the Road	2,797,942	5,595,884	2,797,942	5,595,884

7.5 SIMULATION 5

Canada imported fuel ethanol as well as the corn feedstock from the US. In 2008, 19% of the corn used for ethanol production was imported and over 99% of it was from the US (Evans and Dessureault 2009). In addition, industry statistics suggest that most of the fuel ethanol in Canada was imported from the US, particularly, and the amount of imports was around 70-100 million liters per year for the 2002-2007 period. This simulation exercise has been attempted with a modified Leontief model, to investigate the impact of the exogenously specified ethanol industry and the estimation was based on the 2008 economy. The consumption of 3,106 million liters of fuel ethanol in 2014 has been considered to fix the ethanol final demand exogenously.

The Input-Output Model has been reformulated to carry out this exercise (Eiser and Roberts 2002). Collecting Equation (5) from Chapter 4 we get.

$$g = (DB)\, g + D\, Fi \qquad (8)$$

Considering industrial technology, we have 91 industries and out of this, the 43rd industry will be exogenous (Mukhopadhyay and Thomassin 2011). Equation (8) can be written as

$(1\text{-}a_{11})\ g_1 - a_{12}\ g_2\ \cdots\cdots\ \text{-}a_{1,\,43}\ g_{43}\ \cdots\cdots\ \text{-}a_{1,\,91}\ g_{91} = e_1$

$\text{-}a_{21}\ g_1 + (1\text{-}a_{12})\ g_2\ \cdots\cdots\ \text{-}a_{2,\,43}\ g_{43}\ \cdots\cdots\ \text{-}a_{2,\,91}\ g_{91} = e_2$

$\cdots\cdots\ \cdots\cdots\ \cdots\cdots\ \cdots\cdots$

$\text{-}a_{43}\ g_{43}\ \cdots\cdots\ \cdots\cdots + (1\text{-}a_{43})\ g_{43}\ \cdots\cdots\cdots\cdots\ a_{43}\ g_{91} = e_{43}$

$\cdots\cdots\ \cdots\cdots\ \cdots\cdots\ \cdots\cdots$

$\text{-}a_{91}\ g_{91}\ \cdots\cdots\ \cdots\cdots\ \cdots\cdots\ \cdots\cdots\ \cdots\cdots\ \cdots\cdots + (1\text{-}a_{91})\ g_{91} = e_{91}$

$$\begin{bmatrix} g1 \\ g2 \\ \cdots \\ e43 \\ \cdots \\ g91 \end{bmatrix} = \begin{bmatrix} (1-a11)-a12 & \cdots 0 \cdots & -a1{,}91\ g91 \\ -a21+(1-a22) & \cdots 0 \cdots & -a2{,}91\ g91 \\ \cdots & \cdots & \cdots \\ -a43\ g43 & -1 & -a43{,}91\ g91 \\ \cdots & \cdots & \cdots \\ -a91 & \cdots & +(1-a91) \end{bmatrix}^{-1} \begin{bmatrix} e1+a1{,}43\ g43 \\ e2+a2{,}43\ g43 \\ \cdots \\ -(1-a43)g43 \\ \cdots \\ e91+a91{,}43\ g\ 43 \end{bmatrix} \qquad (9)$$

The sectoral output of 90 industries as well as final demand for the ethanol industry can be obtained from the solution of Equation (9).

Three points are illustrated in the simulation. First, the inverse matrix is different from the traditional Leontief model. Second, one suggestion is that the effects of a change in the gross output of ethanol can be estimated by translating the output effect into derived demand effects on the input and factor suppliers using the vector of direct input coefficients. Finally, by making ethanol exogenous, the final demand for this sector output can be solved endogenously. These results estimated above will ensure that the resulting activity, income and employment levels in the wider economy are consistent with the exogenously specified change in ethanol output (Mukhopadhyay and Thomassin 2011).

Table 33: Impact of Exogenous Ethanol Sector on Industrial Output (% change)

Impact of Exogenous Ethanol Sector on Industrial Output (% change)	
Wheat	7.13%
Feed grain	16.39%
Oil and Gas Extraction	16.12%
Support Activities for Mining and Oil and Gas Extraction	5.55%
Asphalt Paving, Roofing and Saturated Materials Manufacturing	5.25%
Petroleum Refineries and Other Petroleum and Coal Products Manufacturing	35.69%
Petrochemical Manufacturing	3.00%
Pesticides, Fertilizer and Other Agricultural Chemical Manufacturing	2.59%
other basic Chemical and Manufacturing	3.51%
Pipeline Transportation	8.44%

It is observed from this exercise that agricultural sectors such as wheat and feed grain will be affected as wheat and feed grain are the major feedstocks which have been used in ethanol production. The industrial output of Wheat and Feed grain have increased 7.13% and 16.39% respectively. The industrial output of Oil and Gas Extraction and its support activities, chemical industries, as well as the petroleum refineries industry, have been significantly increased.

7.6 SIMULATION 6

The procedure of this simulation exercise is similar to simulation 5 to investigate the impact of an exogenously given biodiesel industry. The consumption of 567 million liters of biodiesel in 2014 has been considered to fix the biodiesel final demand exogenously.

After reformulating the model, we have 91 industries and out of this, the 44th industry will be exogenous. It is observed from this exercise that the Cattle, Hogs, Animal Slaughtering and Rendering and Meat Processing from Carcasses industries are affected. These industries are the major resources of biodiesel production feedstock (animal fats). The industrial output of Cattle, Hogs, Animal Slaughtering and Rendering and Meat Processing from Carcasses have increased 2.41%, 2.78%, 3.86% and 5.84% respectively. The industrial output of Oil and Gas Extraction and its support activities, chemical industries, as well as the petroleum refineries industry, have been significantly increased.

In addition, we have conducted the simulation to fix the demand of 600 million liters biodiesel to support the objective of the study. Since the two percent renewable diesel oil will have a 600 million liters biodiesel demand as we mentioned in the first chapter, we would like to estimate the impact of applying the biodiesel mandate. Table 35 shows the result of this simulation. We can observe the impacts increasing in all sectors.

Table 34: Impact of Exogenous Biodiesel Sector on Industrial Output, Consumption in 2014 (% change)

Impact of Exogenous Biodiesel Sector on Industrial Output (% change)	
Cattle	2.41%
Hogs	2.78%
Oil and Gas Extraction	15.79%
Support Activities for Mining and Oil and Gas Extraction	5.41%
Animal (except Poultry) Slaughtering	3.86%
Rendering and Meat Processing from Carcasses	5.84%
Asphalt Paving, Roofing and Saturated Materials Manufacturing	5.13%
Petroleum Refineries and Other Petroleum and Coal Products Manufacturing	35.29%
Petrochemical Manufacturing	2.86%
other basic Chemical and Manufacturing	3.24%
Pipeline Transportation	8.32%

Table 35: Impact of Exogenous Biodiesel Sector on Industrial Output, 2% Mandate (% change)

Impact of Exogenous Biodiesel Sector on Industrial Output (% change)	
Cattle	2.56%
Hogs	2.95%
Oil and Gas Extraction	16.75%
Support Activities for Mining and Oil and Gas Extraction	5.74%
Animal (except Poultry) Slaughtering	4.10%
Rendering and Meat Processing from Carcasses	6.20%
Asphalt Paving, Roofing and Saturated Materials Manufacturing	5.44%
Petroleum Refineries and Other Petroleum and Coal Products Manufacturing	37.44%
Petrochemical Manufacturing	3.04%
other basic Chemical and Manufacturing	3.44%
Pipeline Transportation	8.83%

CHAPTER 8

CONCLUSION

The main objective of this research was to investigate the macroeconomic impacts of the ethanol and biodiesel sectors in Canada for the year 2008. Four biofuel industries and eight commodities were introduced into the Canadian Input-Output model.

The sectors that were impacted the greatest were the agriculture sectors, especially Feed Grain, Wheat, and the food processing sectors, especially Animal Slaughtering and Rending and Meat Processing, because their products are used as feedstock for biofuel production. Among other industries, mining and manufacturing industries also show a considerable impact because of the ethanol and biodiesel entry into the economic system. These are Oil and Gas Extraction, Other Basic Chemical and Manufacturing, Electric Power Generation, Transmission and Distribution, Food Manufacturing, Pesticides, Fertilizer and Other Agricultural Chemical Manufacturing. These sectors products are mainly used as inputs in the ethanol and biodiesel production process. The industries directly impacted from E10 are Petroleum Refineries and Other Petroleum and Coal Products Manufacturing, Ethanol, Wholesale Trade and Transportation Margins. On the other hand, Petroleum Refineries and Other Petroleum and Coal Products Manufacturing, Biodiesel, Other Federal Government Services, Wholesale Trade and Transportation Margins have a direct impact on the B5 industry. The indirect effects observed from ethanol are Finance, insurance, real estate and renting and leasing, Other transportation and Truck transportation industry and Support Activities for Forestry. Some agricultural industries such as Cattle also have impacts. This is because DDG was included as a by-product of ethanol production and could be used as a feed in the dairy, cattle and hogs industry. It is also found that similar industries are important under indirect effects of E10.

In the case of biodiesel, we found indirect effects on the Food Manufacturing industry because the glycerin is going into this industry and Glycerin is the main by-product of biodiesel production. Other impacted industries are trade, services, and transportation. Agricultural industries such as Cattle, Hogs, and Other crops also have significant impacts. For B5, petroleum refineries and oil and gas extraction sectors have the greatest impacts. Agricultural industries such as animal slaughtering, rendering and meat processing and cattle have considerable impacts as well. Other impacts are shared by finance and insurance, transportation and services industries.

Based on the simulation exercises, it is obvious that if the economy of Canada increases the biofuel mandates, GHG emissions will be mitigated and GDP, industrial output, and employment can be increased. Overall, this research reflects that biofuel has a strong positive impact on the economy. Greater economic, environmental and employment benefits can be achieved by meeting the renewable fuels' strategy made by the federal government of Canada through enhanced biofuel production.

There are few limitations of the study. First of all, the current study considers 2008 Input-Output table instead of recent Input-Output table of 2011. The part of the fact is the availability of the extended I-O table of Agriculture and Agri-food Canada. The detail agriculture sector based extended version of I-O is based on 2008 not prepared for the recent year 2011. Thus, the study has to consider the 2008 table. Second, the study has considered some policy simulation, however, future direction of renewable policy simulation has not been attempted.

Third, the study has collected several references to prepare the dataset of ethanol and biodiesel and its by-products, not the plant specific primary data.

In Canada, environmental objectives instead of energy security have been the incentive behind the development of policies and programs designed by the federal and provincial government (Evans and Dessureault 2014). To a lesser extent, biofuel policies were also regarded as the way to increase the rural economy and reduce reliance on export markets. In order to stimulate the biofuel industry, the Canadian government is adapting various strategies including investment tax credits, guaranteed prices, exercise tax exemptions, and many subsidies for production, consumption and research and development. Federal and provincial mandates are also established according to their biofuel status (Evans and Dessureault 2014). It is also estimated that the federally mandated blend rates will not increase beyond current levels in the near future.

However, the federal and provincial production incentives for conventional biofuels are scheduled to end in three years according to the Evans and Dessureault (2014) report. The federal and provincial agencies doubt that they will be extended beyond that date. The reason behind this action is that the federal and provincial agencies cannot supply a continuation of production incentives with tightened budgets.

To allow the biofuel industry to make further advancements, the following important economic factors are necessary to be taken into account. First, the cost of biofuel production should be further reduced to promote the industry. On the one hand, the cost can be reduced by increasing plant size and the level of capacity use as large plants can achieve economies of scale. With a fixed input cost, a larger output can lower the cost of biofuel production. Walburger (2006) conducted a study showing that the investment costs per unit of production for ethanol plants were 23% lower than that of plants with half the capacity. Results from this study also showed that a tripling of plant size reduced capital costs by about 40% and operating cost by 15-20% (Mukhopadhyay and Thomassin 2011). Currently, Canada has 15 ethanol refineries and 8 biodiesel refineries which have 1,800 and 400 million liters capacity respectively (Evans and Dessureault 2014). Ethanol refineries are working at 97% capacity, which is almost at full usage. However, the use capacity for biodiesel refineries is only 75%. Thus, the production cost of biodiesel could be lower if we could enhance the use capacity of the refineries. On the other hand, the cost of biofuel production can be decreased with the development of production technology. A study, conducted by Mueller (2010) at the University of Illinois, made a comparison between the dry mill production efficiencies in 2008 and those in 2001. Results showed that thermal energy and electricity use were reduced by 28% and 32% respectively compared to the data in 2001. In addition, since 2001 ethanol yields per bushel processed increased by 5.3%. Research published in Renewable Energy indicated that the energy efficiency of rapeseed biodiesel is low (Van Duren et al. 2015). As a result, replacing diesel with biodiesel from rapeseed is hardly a feasible option unless there are major technological improvements in the production process. Canadian biodiesel plants tended to be smaller compared to ethanol plants and thus were unable to capture economies of scale. The producers in Canada should keep on investing in the latest technologies, retrofitting older facilities and incorporating these technologies into new construction. Consequently, the industry can improve its production efficiency and further enhance the environmental benefits.

Second, biofuel imports should be reduced by increasing domestic production. Canada, unlike the US, does not have sufficient domestic production to meet the federally mandated blend standard only with domestic production which requires Canada to import the balance

(Evans and Dessureault 2014). No tariff on biofuels produced in the US and imported into Canada has been implemented due to the North American Free Trade Agreement (NAFTA). However, for bioethanol imported from other countries, Canada does have a tariff. For example, we have $0.05 per liter tariff for Brazil (Evans and Dessureault 2014, P.10). As a result, all bioethanol imports into Canada have been from the US in recent years. In 2014, 43% of the bioethanol consumption in Canada relies on imports (Evans and Dessureault 2014). In the biodiesel market, because of blender's credit, most biodiesel produced in Canada is exported to the US. There is a $1 per gallon tax credit for pure biodiesel or renewable diesel offered to qualified biodiesel producers or blenders. Most of the product from the two largest biodiesel plants in Canada that ran at full capacity are exported to the US market to take advantage of the high tax credits. On the other hand, the imported biodiesel from the US is needed to meet the federal mandate. Domestic biodiesel faced fierce competition from imports of pure biodiesel. Trade statistics for biodiesel in 2014 suggest that, due to the returning of the blenders' credit, Canada will likely export all domestically produced biodiesel then import biodiesel to meet the federal mandate. However, even if Canada can keep all its biodiesel production to meet the domestic demand, 46% of the biodiesel has to be imported to support domestic consumption. Therefore, ethanol and biodiesel production in Canada cannot meet the domestic demand. Canada is highly dependent on the US in the biofuel market. One major policy suggestion from this study is to increase the domestic biofuel production and decrease the reliance on imports. This will encourage economic development in rural areas and help diversify the risk faced by agricultural producers who depend on export markets.

Third, the government's assistance is needed to promote the advanced (second generation) biofuels, which generally have higher GHG savings. Thus, advanced biofuel production would substantially reduce the cost per ton of CO_2 reduction. The pressure on corn and wheat demand would also decrease since advanced biofuels use non-food feedstocks (Mukhopadhyay and Thomassin 2011). Canada's capacity to produce advanced biofuels is still very limited. Only a few plants have begun full-scale operation, such as Enerkem, which started to produce cellulosic ethanol via treated wood as its feedstock with a 5 million liter capacity in 2012 (Evans and Dessureault 2014). The funding to support the Research and Development of advanced biofuels should be continued. The Canadian Renewable Fuels Association is endorsing a federal policy platform for emerging technologies that exempt cellulosic ethanol from federal and provincial fuel taxes. In Canada, blend mandates and production incentives are major strategies to promote the biofuel industries. In the short term, the blend mandates are not expected to increase because imports have filled a considerable portion of the mandates for ethanol and biodiesel. As a result, both the federal and provincial production incentives should be extended to promote the advanced biofuels for a longer time horizon to commercialize this type of biofuel.

In conclusion, several observations from this study indicate that the economic and environmental value of biofuels and their products can be significant. Future studies can estimate the macroeconomic impacts of advanced biofuels specifically. The international economic impacts of biofuels between Canada and other countries can be explored using global CGE model in the future.

APPENDIX

Appendix 1: Canadian Biofuel Plant Locations in 2014

Ethanol

In million litres per year (Mmly)

	Plant Name	City	Province	Feedstock	Capacity	Status
1	Atlantec Bioenergy Corporation	Cornwall	Prince Edward Island	Energy beets	n/a	Demonstration Facility
2	Enerkem Alberta Biofuels - Edmonton Waste-to-Biofuels Facility	Edmonton	Alberta	Post-sorted municipal solid waste	36 Mmly	Under Construction
3	Enerkem Inc.	Sherbrooke	Quebec	Various feestocks	475,000 Litre/y	Demonstration Facility
4	Enerkem Inc.	Westbury	Quebec	Wood waste	5 Mmly	Demonstration Facility
5	Enerkem Inc.	Varennes	Quebec	Sorted industrial, commercial and institutional waste	38 Mmly	Proposed Demonstration Facility
6	GreenField Ethanol Inc.	Chatham	Ontario	Corn	195 Mmly	Operational
7	GreenField Ethanol Inc.	Johnstown	Ontario	Corn	200 Mmly	Operational
8	GreenField Ethanol Inc.	Tiverton	Ontario	Corn	27 Mmly	Operational
9	GreenField Ethanol Inc.	Varennes	Quebec	Corn	120 Mmly	Operational
10	Growing Power Hairy Hill	Hairy Hill	Alberta	Wheat	40 Mmly	Operational
11	Husky Energy Inc.	Lloydminster	Saskatchewan	Wheat	130 Mmly	Operational
12	Husky Energy Inc.	Minnedosa	Manitoba	Wheat and corn	130 Mmly	Operational
13	IGPC Ethanol Inc.	Aylmer	Ontario	Corn	162 Mmly	Operational
14	Kawartha Ethanol	Havelock	Ontario	Corn	120 Mmly	Operational
15	Mascoma Corporation	Drayton Valley	Alberta	Wood	80 Mmly	Proposed Plant
16	NorAmera BioEnergy Corporation	Weyburn	Saskatchewan	Wheat	25 Mmly	Operational
17	North West Terminal Ltd.	Unity	Saskatchewan	Wheat	25 Mmly	Operational
18	Permolex International, L.P.	Red Deer	Alberta	Wheat, wheat starch, corn, barley, rye & triticale	42 Mmly	Operational
19	Pound-Maker Agventures Ltd.	Lanigan	Saskatchewan	Wheat	15 Mmly	Operational
20	Suncor St. Clair Ethanol Plant	Sarnia	Ontario	corn	400 Mmly	Operational
21	Terra Grain Fuels Inc.	Belle Plaine	Saskatchewan	Wheat	150 Mmly	Operational

Biodiesel

In million litres per year (Mmly)

	Plant Name	City	Province	Feedstock	Capacity	Status
22	Archer Daniels Midland	Lloydminster	Alberta	Canola	265 Mmly	Under Construction
23	BIOX Corporation	Hamilton	Ontario	Multi-feedstock	66 Mmly	Operational
24	City-Farm Biofuel Ltd.	Delta	British Columbia	Recycled oil/tallow	10 Mmly	Operational
25	Consolidated Biofuels Ltd.	Delta	British Columbia	Yellow grease	11 Mmly	Operational
26	FAME Biorefinery	Airdire	Alberta	Canola, camelina, mustard	1 Mmly	Demonstration Facility
27	Great Lakes Biodiesel	Welland	Ontario	Multi-feedstock	170 Mmly	Operational
28	Kyoto Fuels Corp	Lethbridge	Alberta	Multi-feedstock	66 Mmly	Under Construction
29	Methes Energies Canada Inc.	Mississauga	Ontario	Yellow grease	5 Mmly	Operational
30	Methes Energies Canada Inc.	Sombra	Ontario	Multi-feedstock	50 Mmly	Under Construction
31	Milligan Bio-Tech Inc.	Foam Lake	Saskatchewan	Canola	20 Mmly	Operational
32	Noroxel Energy Ltd.	Springfield	Ontario	Yellow grease	5 Mmly	Operational
33	QFI Biodiesel Inc.	St-Jean-d'Iberville	Quebec	Multi-feedstock	5 Mmly	Operational
34	Rothsay Biodiesel	Montreal	Quebec	Multi-feedstock	55 Mmly	Operational

Source: Canadian Renewable Fuel Association

Appendix 2: **Retail Diesel Price in 2008**

Retail Diesel Price in 2008								
Plant Locations	Crude Oil		Processing	Marketing	Federal Excise Tax	GST	Provincial Tax	Retail Diesel Price
	$/barrel	$/liter	$/liter	$/liter	$/liter		cents/liter	$/liter
Hamilton,Ont.	101.49	0.64	0.08	0.07	0.04	5%	14.30	1.02
Montreal,Que.	101.49	0.64	0.08	0.07	0.04	5%	16.2+7.5% sales tax	1.12
Foam Lake,Sask.	101.49	0.64	0.08	0.07	0.04	5%	15.00	1.03

Source: Processing and marketing costs from Ad Hoc Report- MJ Ervin & Associates

Appendix 3: The Canadian Fuel Taxes for Gasoline and Diesel Fuel in 2008

Since January 1, 2008, the rate of Canada's federal goods and services tax (GST) was reduced to 5%. The provincial and municipal taxes vary by province. Based on information from the Ontario Ministry of Finance, the provincial and municipal taxes were 14.7 and 14.3 cents per liter for gasoline and diesel, respectively for Ontario. For Quebec, based on the information supplied by Revenue Quebec, the provincial and municipal taxes were 15.2 and 16.2 cents per liter for gasoline and diesel, respectively. However, there was a 7.5% sales tax applied and an additional local tax in Montreal of 1.5 cents per liter of gasoline (Saville and Villeneuve

2006). In addition, the fuel tax rates for Saskatchewan has not been changed since 2005. Therefore, the provincial and municipal taxes were 15.0 cents per litre for gasoline and diesel.

Canadian Fuel Taxes for Gasoline and Diesel Fuel in 2008		
	Gasoline cents/L	diesel cents/L
Federal Excise Tax	10	4
GST	5%	5%
Provincial and Municipal Taxes		
Quebec	15.2	16.2
Quebec Sales Tax	7.50%	7.50%
Montreal Additional Local Tax	1.5	
Ontario	14.7	14.3
Saskatchewan	15	15
Manitoba	11.5	11.5
Alberta	9	9

Sources: Natural Resources Canada; Revenue Quebec; Ontario Ministry of Finance; Government of Saskatchewan.

Appendix 4: Biofuel Tax Exemptions and Incentives

Biodiesel Tax Exemptions and Incentives(cents/liter)			
Location	Federal Tax	Provincial Tax	Incentives
Ont.	4	14.3	N/A
Que.	4	16.2	N/A
Sask.	4	N/A	N/A

Sources: U.S. Department of Agriculture (2008); provincial tax and biofuel legislation; press releases (Laan et al. 2009).

Ethanol Tax Exemptions and Incentives(cents/liter)			
Location	Federal Tax	Provincial Tax	Incentives
Ont.	10	N/A	N/A
Que.	10	18.5	N/A
Man.	10	2.5	20
Alta.	10	N/A	14
Sask.	10	N/A	N/A

Source: Biofuels annual report, 2009.

Appendix 5: Direct Impacts of Ethanol and E10 on Industries

Direct Impacts of Ethanol and E10 on Industries		
	Industries	Ethanol
1	Feed grain	0.1769
2	Wheat	0.1759
3	Oil and Gas Extraction	0.0720
4	Wholesale Trade	0.0568
5	Transportation Margins	0.0545
6	Electric Power Generation, Transmission and Distribution	0.0136
7	Administrative and Support Services	0.0079
8	other basic Chemical and Manufacturing	0.0072
9	Professional, Scientific and Technical Services	0.0062
10	Food Manufacturing	0.0023
11	Repair and Maintenance	0.0015
12	Retail Trade	0.0013
13	Pesticides, Fertilizer and Other Agricultural Chemical Manufacturing	0.0010
14	Fabricated Metal Products Manufacturing	0.0010
15	Petroleum Refineries and Other Petroleum and Coal Products Manufacturing	0.0005
16	Transportation Equipment Manufacturing	0.0005
17	Other Transportation	0.0005
18	Primary Metal Manufacturing	0.0005
19	Machinery Manufacturing	0.0004
20	Broadcasting and Telecommunications	0.0004
21	Computer and Electronic Product Manufacturing	0.0003
22	Pharmaceutical and Medicine Manufacturing	0.0003
23	Plastics and Rubber Products Manufacturing	0.0003
24	Miscellaneous Manufacturing	0.0003
25	Paper Manufacturing	0.0003
26	Electrical Equipment, Appliance and Component Manufacturing	0.0002
27	Other Provincial and Territorial Government Services	0.0002
28	Wood Product Manufacturing	0.0002
29	Construction	0.0002
30	Finance, Insurance, Real Estate and Rental and Leasing	0.0002
31	Furniture and Related Product Manufacturing	0.0001
32	Beverage and Tobacco Product Manufacturing	0.0001
33	Forestry and Logging	0.0001
	Industries	E10
1	Petroleum Refineries and Other Petroleum and Coal Products Manufacturing	0.7223
2	Ethanol	0.0968
3	Wholesale Trade	0.0024
4	Transportation Margins	0.0004

Direct Impacts of Biodiesel and B5 on Industries

Direct Impacts of Biodiesel and B5 on Industries		
	Industries	Biodiesel
1	Animal (except Poultry) Slaughtering	0.1653
2	Rendering and Meat Processing from Carcasses	0.1653
3	Wholesale Trade	0.0671
4	Administrative and Support Services	0.0404
5	Professional, Scientific and Technical Services	0.0301
6	Transportation Margins	0.0268
7	Oil and Gas Extraction	0.0168
8	other basic Chemical and Manufacturing	0.0109
9	Poultry Processing	0.0099
10	Oilseed	0.0090
11	Repair and Maintenance	0.0079
12	Retail Trade	0.0063
13	Food Manufacturing	0.0037
14	Electric Power Generation, Transmission and Distribution	0.0029
15	Other Transportation	0.0024
16	Broadcasting and Telecommunications	0.0021
17	Fabricated Metal Products Manufacturing	0.0017
18	Pesticides, Fertilizer and Other Agricultural Chemical Manufacturing	0.0015
19	Transportation Equipment Manufacturing	0.0013
20	Primary Metal Manufacturing	0.0013
21	Machinery Manufacturing	0.0009
22	Finance, Insurance, Real Estate and Rental and Leasing	0.0008
23	Petroleum Refineries and Other Petroleum and Coal Products Manufacturing	0.0008
24	Other Provincial and Territorial Government Services	0.0007
25	Computer and Electronic Product Manufacturing	0.0007
26	Construction	0.0007
27	Paper Manufacturing	0.0006
28	Universities and Government Education Services	0.0005
29	Accommodation and Food Services	0.0005
30	Wood Product Manufacturing	0.0005
31	Other Municipal Government Services	0.0005
32	Hospitals and Residential Care Facilities	0.0005
33	Natural Gas Distribution	0.0001
	Industries	B5
1	Petroleum Refineries and Other Petroleum and Coal Products Manufacturing	0.9249
2	Biodiesel	0.0491
3	Other Federal Government Services	0.0027
4	Wholesale Trade	0.0020
5	Transportation Margins	0.0002

Appendix 6: Total Impacts of Ethanol and E10 on Industries

Total Impacts of Ethanol and E10 on Industries				
	Industries	Ethanol	Industries	E10
1	Ethanol	1.000	E10	1.000
2	Feed grain	0.185	Petroleum Refineries and Other Petroleum and Coal Products Manufacturing	0.749
3	Wheat	0.180	Oil and Gas Extraction	0.480
4	Oil and Gas Extraction	0.102	Ethanol	0.097
5	Wholesale Trade	0.084	Finance, Insurance, Real Estate and Rental and Leasing	0.042
6	Transportation Margins	0.061	Wholesale Trade	0.023
7	Finance, Insurance, Real Estate and Rental and Leasing	0.045	Administrative and Support Services	0.019
8	Other Transportation	0.033	Support Activities for Mining and Oil and Gas Extraction	0.019
9	Truck Transportation	0.031	Feed grain	0.018
10	Administrative and Support Services	0.030	Wheat	0.018
11	Petroleum Refineries and Other Petroleum and Coal Products Manufacturing	0.029	Operating, Office, Cafeteria and Laboratory Supplies	0.017
12	Electric Power Generation, Transmission and Distribution	0.020	Pipeline Transportation	0.016
13	Operating, Office, Cafeteria and Laboratory Supplies	0.019	Professional, Scientific and Technical Services	0.016
14	Professional, Scientific and Technical Services	0.019	Transportation Margins	0.012
15	other basic Chemical and Manufacturing	0.017	other basic Chemical and Manufacturing	0.010
16	non metalic mineral mining	0.017	Electric Power Generation, Transmission and Distribution	0.010
17	Travel, Entertainment, Advertising and Promotion	0.013	Travel, Entertainment, Advertising and Promotion	0.009
18	Pesticides, Fertilizer and Other Agricultural Chemical Manufacturing	0.011	Other Transportation	0.008
19	Construction	0.009	Construction	0.007
20	Broadcasting and Telecommunications	0.008	Truck Transportation	0.007
21	Retail Trade	0.008	Retail Trade	0.005
22	Food Manufacturing	0.007	Broadcasting and Telecommunications	0.005
23	Transit and Ground Passenger Transportation	0.006	Repair and Maintenance	0.003
24	Support Activities for Mining and Oil and Gas Extraction	0.005	Asphalt Paving, Roofing and Saturated Materials Manufacturing	0.003
25	Repair and Maintenance	0.004	Food Manufacturing	0.003
26	Fabricated Metal Products Manufacturing	0.004	Publishing Industries, Information Services and Data Processing Services	0.003
27	Machinery Manufacturing	0.004	Primary Metal Manufacturing	0.003
28	Support Activities for Forestry	0.004	Machinery Manufacturing	0.003
29	Primary Metal Manufacturing	0.004	Fabricated Metal Products Manufacturing	0.003
30	Publishing Industries, Information Services and Data Processing Services	0.003	non metalic mineral mining	0.002
31	Plastics and Rubber Products Manufacturing	0.003	Plastics and Rubber Products Manufacturing	0.002
32	Accommodation and Food Services	0.003	Pesticides, Fertilizer and Other Agricultural Chemical Manufacturing	0.002
33	Personal and Laundry Services and Private Households	0.003	Personal and Laundry Services and Private Households	0.002
34	Cattle	0.003	Accommodation and Food Services	0.002
35	Transportation Equipment Manufacturing	0.002	Other Municipal Government Services	0.002

Total Impacts of Biodiesel and B5 on Industries

Total Impacts of Biodiesel and B5 on Industries				
	Industries	Biodiesel	Industries	B5
1	Biodiesel	1.000	B5	1.000
2	Animal (except Poultry) Slaughtering	0.213	Petroleum Refineries and Other Petroleum and Coal Products Manufacturing	0.956
3	Rendering and Meat Processing from Carcasses	0.193	Oil and Gas Extraction	0.605
4	Wholesale Trade	0.097	Finance, Insurance, Real Estate and Rental and Leasing	0.050
5	Cattle	0.087	Biodiesel	0.049
6	Administrative and Support Services	0.073	Administrative and Support Services	0.024
7	Finance, Insurance, Real Estate and Rental and Leasing	0.057	Support Activities for Mining and Oil and Gas Extraction	0.024
8	Food Manufacturing	0.052	Wholesale Trade	0.023
9	Professional, Scientific and Technical Services	0.051	Operating, Office, Cafeteria and Laboratory Supplies	0.021
10	Hogs	0.049	Professional, Scientific and Technical Services	0.020
11	Oil and Gas Extraction	0.042	Pipeline Transportation	0.020
12	Transportation Margins	0.039	other basic Chemical and Manufacturing	0.012
13	Poultry Processing	0.038	Electric Power Generation, Transmission and Distribution	0.011
14	Other Transportation	0.027	Animal (except Poultry) Slaughtering	0.011
15	Other Crops	0.027	Travel, Entertainment, Advertising and Promotion	0.011
16	Travel, Entertainment, Advertising and Promotion	0.024	Rendering and Meat Processing from Carcasses	0.010
17	Petroleum Refineries and Other Petroleum and Coal Products Manufacturing	0.023	Construction	0.009
18	Truck Transportation	0.023	Transportation Margins	0.009
19	Operating, Office, Cafeteria and Laboratory Supplies	0.022	Other Transportation	0.007
20	other basic Chemical and Manufacturing	0.018	Retail Trade	0.007
21	Feed grain	0.017	Broadcasting and Telecommunications	0.006
22	Electric Power Generation, Transmission and Distribution	0.015	Food Manufacturing	0.006
23	Retail Trade	0.015	Truck Transportation	0.006
24	Broadcasting and Telecommunications	0.014	Repair and Maintenance	0.004
25	Poultry and eggs	0.014	Cattle	0.004
26	Repair and Maintenance	0.013	Asphalt Paving, Roofing and Saturated Materials Manufacturing	0.004
27	Oilseed	0.012	Publishing Industries, Information Services and Data Processing Services	0.004
28	Construction	0.010	Primary Metal Manufacturing	0.004
29	Paper Manufacturing	0.008	Other Federal Government Services	0.003
30	Plastics and Rubber Products Manufacturing	0.007	Machinery Manufacturing	0.003
31	Dairy	0.006	Fabricated Metal Products Manufacturing	0.003
32	Publishing Industries, Information Services and Data Processing Services	0.006	Plastics and Rubber Products Manufacturing	0.003
33	Primary Metal Manufacturing	0.006	Hogs	0.002
34	Accommodation and Food Services	0.005	Accommodation and Food Services	0.002
35	non metalic mineral mining	0.005	Personal and Laundry Services and Private Households	0.002

REFERENCES

Abdullah, A., Salamatinia, B., Mootabadi, H., and Bhatia, S. 2009. Current status and policies on biodiesel industry in Malaysia as the world's leading producer of palm oil. *Energy Policy,* 37(12): 5440-48.

Albalawi, A., Batooq, E., Leech, C., Lesmes, N., Majzoub, A., Berruti, F., and Briens, C. 2011. Industrial and Commercial Fats, Oils and Greases. http://www.londonenergysaver.ca/PDFs/Uwo/Industrial_and_commercial_fats_oil_and_greases.pdf (accessed December 9, 2014).

Angell, L. C. and Klassen, R. D. 1999. Integrating environmental issues into the mainstream: an agenda for research in operations management. *Journal of Operations Management,* 17(5): 575-98.

Arndt, C., Benfica, R., Tarp, F., Thurlow, J., and Uaiene, R. 2010. Biofuels, poverty, and growth: a computable general equilibrium analysis of Mozambique. *Environment and Development Economics,* 15(01): 81-105.

Arndt, C., Pauw, K., and Thurlow, J. 2012. Biofuels and economic development: A computable general equilibrium analysis for Tanzania. *Energy Economics,* 34(6): 1922-30.

Baral, A. and Bakshi, B. R. 2009. Thermodynamic metrics for aggregation of natural resources in life cycle analysis: insight via application to some transportation fuels. *Environmental science & technology,* 44(2): 800-07.

Baral, A. and Bakshi, B. R. 2010. Emergy analysis using US economic input–output models with applications to life cycles of gasoline and corn ethanol. *Ecological modelling,* 221(15): 1807-18.

Bell, D. R., Silalertruksa, T., Gheewala, S. H., and Kamens, R. 2011. The net cost of biofuels in Thailand—An economic analysis. *Energy Policy,* 39(2): 834-43.

BioFleet 2014. GHG Calculator. http://www.biofleet.net/calculate-emissions-mainmenu-58 (accessed December 20, 2014).

Biofuels Digest 2014. Biofuels Mandates Around the World: 2014. http://www.biofuelsdigest.com/bdigest/2013/12/31/biofuels-mandates-around-the-world-2014/ (accessed 09-14, 2014).

Biomass Research and Development Technical Advisory Committee 2007. Roadmap for Bioenergy and Biobased Products in the United States. http://www1.eere.energy.gov/bioenergy/pdfs/obp_roadmapv2_web.pdf (accessed December 26, 2014).

Birur, D., Hertel, T., and Tyner, W. 2008. Impact of biofuel production on world agricultural markets: a computable general equilibrium analysis. *GTAP Work. Pap,* 53.

Birur, D. K. 2010. Global impact of biofuels on agriculture, trade, and environment: A computable general equilibrium analysis. http://docs.lib.purdue.edu/dissertations/AAI3413773/ (accessed December 12, 2014).

Borowitzka, M. A. and Moheimani, N. R. 2013. Sustainable biofuels from algae. *Mitigation and Adaptation Strategies for Global Change,* 18(1): 13-25.

Bowman, K. 2003. Economic Impact of Soy Diesel in Kentucky. *Murray State University*.

Boyd, M., Murray-Hill, A., Schaddelee, K., and Co-op, W. E. 2004. *Biodiesel in British Columbia: Feasibility Study Report Prepared for Eco-Literacy Canada.* WISE Energy Co-op.

Bruso, J. 2015. Foods Containing Glycerin. http://www.livestrong.com/article/333686-foods-containing-glycerin/ (accessed May 25, 2015).

Buyx, A. and Tait, J. 2011. Ethical framework for biofuels. *Science,* 332(6029): 540-41.

Canadian Renewable Fuel Association 2014. Evolution and Growth: From Biofuels To Bioeconomy. http://www.evolutionandgrowth.ca/PDFs/EVO-ENG-total.pdf (accessed September 24, 2014).

Council, C. 2009. Canola Meal Feed Industry Guide. http://www.canolacouncil.org/media/516716/canola_meal_feed_guide_english.pdf (accessed December 9, 2014).

Coxworth, E. 2003. *The role of renewable liquid transportation fuels in Canada's climate action plan.* Saskatchewan Environmental Society and the Climate Action Network Institute Discussion Paper. Saskatoon: Saskatchewan Environmental Society and the Climate Action Network Institute.

Cruz Jr, J. B., Tan, R. R., Culaba, A. B., and Ballacillo, J.-A. 2009. A dynamic input–output model for nascent bioenergy supply chains. *Applied Energy,* 86: S86-S94.

Cunha, M. P. and Scaramucci, J. A. 2006. Bioethanol as basis for regional development in Brazil: an input–output model with mixed technologies. Paper presented at 46th Congress of the European Regional Science Association (ERSA), Volos, Greece, August 30-September 3.

Dalai, A. K., Fund, S. A. D., and Saskatchewan, U. o. 2001. *Production of diesel fuel lubricity additives from various vegetable oils.* Saskatoon: University of Saskatchewan Press.

Dale, B. E., Anderson, J. E., Brown, R. C., Csonka, S., Dale, V. H., Herwick, G., Jackson, R. D., Jordan, N., Kaffka, S., and Kline, K. L. 2014. Take a Closer Look: Biofuels Can Support Environmental, Economic and Social Goals. *Environmental science & technology,* 48(13): 7200-03.

Davis, J. 2014. Rapeseed King of Europe's Biodiesel Feedstock. http://domesticfuel.com/2014/02/27/rapeseed-king-of-europes-biodiesel-feedstock/ (accessed December 2, 2014).

De Lucia, C. and Bartlett, M. 2014. Implementing a biofuel economy in the EU: Lessons from the SUSTOIL project and future perspectives for next generation biofuels. *Renewable and Sustainable Energy Reviews,* 29(0): 22-30.

Eisentraut, A. 2010. *Sustainable production of second-generation biofuels: potential and perspectives in major economies and developing countries.* OECD Publishing.

Eiser, D. and Roberts, D. 2002. The Employment and Output Effects of Changing Patterns of Afforestation in Scotland. *Journal of Agricultural Economics,* 53(1): 65-81.

Elbehri, A., Segerstedt, A., and Liu, P. 2013. *Biofuels and the sustainability challenge: a global assessment of sustainability issues, trends and policies for biofuels and related feedstocks.* Food and Agriculture Organization of the United Nations (FAO).

European Biofuels 2014. Global Biofuels - An Overview. http://www.biofuelstp.eu/global_overview.html (accessed September 14, 2014).

European Commission 2008. Proposal for a Directive of the European Parliament and of the Council on the Promotion of the Use of Energy from Renewable Sources.

http://www.europanels.org/upload/ILUC_EPF_EOS_FEP_FEFPEB_CEI-Bois_Position_Paper.pdf (accessed December 26, 2014).

Evans, B. and Dessureault, D. 2009. Canada Biofuels Annual 2009. GAIN Publication No. CA9037. United States: United States Department of Agriculture.

--- 2012. Canada Biofuels Annual 2012. GAIN Publication No. CA12024. United States: United States Department of Agriculture.

--- 2013. Canada Biofuels Annual 2013. GAIN Publication No.CA13034. United States: United States Department of Agriculture.

--- 2014. Canada Biofuels Annual 2014. GAIN Publication No. CA14109. United States: United States Department of Agriculture.

Farm Credit Canada 2007. Are Biofuels an Idea Whose Time Has Come? https://www.fcc-fac.ca/fcc/agKnowledge/publications/ag-sector-guides/pdfs/understanding-biofuels.pdf (accessed October 7, 2014).

Farmgateblog 2010. Can Feeding DDGS Maximize Livestock Profitability? http://www.farmgateblog.com/article/1185/can-feeding-ddgs-maximize-livestock-profitability (accessed July 23, 2014).

Festel, G., Würmseher, M., Rammer, C., Boles, E., and Bellof, M. 2014. Modelling production cost scenarios for biofuels and fossil fuels in Europe. *Journal of Cleaner Production*, 66(0): 242-53.

Global Renewable Fuels Alliance 2013. Global Biofuel Mandates. http://globalrfa.org/biofuels-map/ (accessed September 14, 2014).

Gohin, A. 2008. Impacts of the European biofuel policy on the farm sector: A general equilibrium assessment. *Applied Economic Perspectives and Policy*, 30(4): 623-41.

Government of Canada 2010. Renewable Fuels Regulations. http://www.gazette.gc.ca/rp-pr/p2/2010/2010-09-01/html/sor-dors189-eng.html (accessed November 17, 2014).

--- 2013. Regulations Amending the Renewable Fuels Regulations. http://www.gazette.gc.ca/rp-pr/p2/2013/2013-11-06/html/sor-dors187-eng.php (accessed May 25, 2015).

Greyt, D. I. W. D. 2011. Introduction on Glycerol as co-product from biodiesel plants. http://supermethanol.eu/uploads/site/Meetings/Final%20Workshop%20Brussels%20December%202011/Wim%20De%20Greyt%20-%20Desmet%20Ballestra%20Group%20-%20Introduction%20on%20glycerol%20as%20co-product%20of%20biodiesel%20production.pdf (accessed September 19, 2014).

Gupta, A. and Verma, J. P. 2015. Sustainable bio-ethanol production from agro-residues: A review. *Renewable and Sustainable Energy Reviews,* 41(0): 550-67.

Hansen, A. C., Gratton, M. R., and Yuan, W. 2006. Diesel engine performance and NOX emissions from oxygenated biofuels and blends with diesel fuel. *Transactions of the ASABE,* 49(3): 589-95.

Hart, C., Otto, D., and Hudak, M. 2012. Economic Impacts of the Ethanol Industry. http://www.cvcia.org/files/CVC-Ethanol-Report-8-9-2012.pdf (accessed October 7, 2014).

Heath, M. 1989. *Towards a Commercial Future: Ethanol & Methanol as Alternative Transportation Fuels.* Calgary, Alberta: University of Calgary Press.

Herreras Martínez, S., van Eijck, J., Pereira da Cunha, M., Guilhoto, J. J. M., Walter, A., and Faaij, A. 2013. Analysis of socio-economic impacts of sustainable sugarcane–ethanol production by means of inter-regional Input–Output analysis: Demonstrated for Northeast Brazil. *Renewable and Sustainable Energy Reviews,* 28(0): 290-316.

Herrmann, I. T., Hauschild, M. Z., Sohn, M. D., and McKone, T. E. 2014. Confronting Uncertainty in Life Cycle Assessment Used for Decision Support. *Journal of Industrial Ecology*, 18(3): 366-79.

Hydro Quebec 2008. Comparison of Electricity Prices in Major North American Cities. https://www.hydro.mb.ca/regulatory_affairs/electric/gra_2012_2013/Appendix_19.pdf (accessed November 12, 2014).

Independent Business Feasibility Group 2002. *The Biodiesel Plant Development Handbook.* Independent Business Feasibility Group.

International Energy Agency 2012. Biofuels for Transport: Technology Roadmap. http://www.iea.org/publications/freepublications/publication/biofuels_roadmap.pdf (accessed September 25, 2014).

--- 2013. About Biofuels. http://www.iea.org/topics/renewables/subtopics/bioenergy/ (accessed November 21, 2014).

Jamieson, C. 2013. Canada's lost Ethanol Opportunity. http://www.dtnprogressivefarmer.com/dtnag/common/link.do;jsessionid=175D3BDB5BF492C3768FE5F817AD5625.agfreejvm1?symbolicName=/ag/blogs/template1&blogHandle=canadamarkets&blogEntryId=8a82c0bc3e43976e013ed3674eb1059b (accessed July 25, 2014).

Joshi, O., Grebner, D. L., Henderson, J. E., Grado, S. C., and Munn, I. A. 2012. Input–Output Modeling of Wood-Based Bioenergy Industries in Mississippi. *Forest Products Journal*, 62(7-8): 528-37.

Kharecha, P. A. and Hansen, J. E. 2008. Implications of “peak oil” for atmospheric CO_2 and climate. *Global Biogeochemical Cycles*, 22(3).

Kim, B., Jeong, J., Shin, S., Lee, D., Kim, S., Yoon, H.-J., and Cho, J. K. 2010. Facile Single-Step Conversion of Macroalgal Polymeric Carbohydrates into Biofuels. *ChemSusChem,* 3(11): 1273-75.

Kulišić, B., Loizou, E., Rozakis, S., and Šegon, V. 2007. Impacts of biodiesel production on Croatian economy. *Energy Policy,* 35(12): 6036-45.

Kunimitsu, Y., Takahashi, K., Furubayashi, T., and Nakata, T. 2013. Economic Ripple Effects of Bioethanol Production in ASEAN Countries: Application of Inter-regional Input-Output Analysis. *JARQ, Japan Agricultural Research Quarterly,* 47(3): 307-17.

Laan, T., Steenblik, R., and Litman, T. A. 2009. *Biofuels--at what Cost?: Government Support for Ethanol and Biodiesel in Canada.* International Institute for Sustainable Development.

Lambert, J. G., Hall, C. A., Balogh, S., Gupta, A., and Arnold, M. 2014. Energy, EROI and quality of life. *Energy Policy,* 64: 153-67.

Lardon, L., Hélias, A., Sialve, B., Steyer, J.-P., and Bernard, O. 2009. Life-Cycle Assessment of Biodiesel Production from Microalgae. *Environmental science & technology,* 43(17): 6475-81.

Larson, E. D. 2006. A review of life-cycle analysis studies on liquid biofuel systems for the transport sector. *Energy for Sustainable Development,* 10(2): 109-26.

Larson, E. D. 2007. *Sustainable bioenergy: A framework for decision makers.* UN-Energy.

Liang, S., Xu, M., and Zhang, T. 2013. Life cycle assessment of biodiesel production in China. *Bioresource Technology,* 129(0): 72-77.

Liska, A. J., Yang, H. S., Bremer, V. R., Klopfenstein, T. J., Walters, D. T., Erickson, G. E., and Cassman, K. G. 2009. Improvements in Life Cycle Energy Efficiency and Greenhouse Gas Emissions of Corn-Ethanol. *Journal of Industrial Ecology,* 13(1): 58-74.

Mabee, W. 2013. Progress in the Canadian biorefining sector. *Biofuels,* 4(4): 437-52.

Mabee, W. E. and Saddler, J. N. 2010. Bioethanol from lignocellulosics: Status and perspectives in Canada. *Bioresource Technology,* 101(13): 4806-13.

Malik, A., Lenzen, M., Ely, R. N., and Dietzenbacher, E. 2014. Simulating the impact of new industries on the economy: The case of biorefining in Australia. *Ecological Economics,* 107(0): 84-93.

Miller, R. E. and Blair, P. D. 2009. *Input-output analysis: foundations and extensions.* Cambridge University Press.

Minnesota Department of Agriculture 2002. Economic Impact of Soy Diesel in Minnesota. http://www.mda.state.mn.us/error404.aspx (accessed January 13, 2014).

Møller, F., Slentø, E., and Frederiksen, P. 2014. Integrated well-to-wheel assessment of biofuels combining energy and emission LCA and welfare economic Cost Benefit Analysis. *Biomass and Bioenergy,* 60(0): 41-49.

Moraes, M. A. F. D., Nassar, A. M., Moura, P., Leal, R. L. V., and Cortez, L. A. B. 2014. Jet biofuels in Brazil: Sustainability challenges. *Renewable and Sustainable Energy Reviews,* 40(0): 716-26.

Mortimer, N., Cormack, P., Elsayed, M., and Horne, R. 2003. Evaluation of the comparative energy, global warming and socio-economic costs and benefits of biodiesel. *Report to the Department for Environment, Food and Rural Affairs Contract Reference No. CSA,* 5982.

Mueller, S. 2010. 2008 National dry mill corn ethanol survey. *Biotechnology Letters,* 32(9): 1261-64.

Mukhopadhyay, K. and Thomassin, P. J. 2011. Macroeconomic effects of the ethanol biofuel sector in Canada. *Biomass and Bioenergy,* 35(7): 2822-38.

Mundi, I. 2008. Crude Oil (petroleum) Monthly Price - Canadian Dollar per Barrel. http://www.indexmundi.com/commodities/?commodity=crude-oil&months=120&currency=cad (accessed July 24, 2014).

Nanaki, E. A. and Koroneos, C. J. 2012. Comparative LCA of the use of biodiesel, diesel and gasoline for transportation. *Journal of Cleaner Production,* 20(1): 14-19.

Natural Resources Canada 2003. Benefit-Cost Analysis of Increasing Ethanol Production. http://www2.nrcan.gc.ca/sr/index-eng.cfm?text=Benefit-Cost%20Analysis%20of%20Increasing%20Ethanol%20Production (accessed December 8, 2014).

Neuwahl, F., Löschel, A., Mongelli, I., and Delgado, L. 2008. Employment impacts of EU biofuels policy: combining bottom-up technology information and sectoral market simulations in an input–output framework. *Ecological Economics,* 68(1): 447-60.

Nosowitz, D. 2010. U.S. Military Aims To Use 50 Percent Renewable Energy Within Ten Years. http://www.popsci.com/technology/article/2010-10/us-military-aims-use-50-renewable-energy-within-ten-years (accessed December 2, 2014).

Ontario Ministry of Agriculture and Food 2002. The Implications of a Biodiesel Industry in Ontario: A report to the Inter-Ministry Task Group on Biodiesel. http://find.gov.on.ca/?searchType=simple&owner=omaf&url=&collection=&offset=0&lang=en&type=ANY&q=biodiesel&search.x=0&search.y=0 (accessed December 8, 2014).

Reaney, M. J. T., Furtan, W. H., and Loutas, P. 2006. *A Critical Cost Benefit Analysis of Oilseed Biodiesel in Canada.* BIOCAP Canada Foundation.

Renewable Fuel Association 2014. U.S. Ethanol Exports Top 620 Million Gallons in 2013 While Imports Fall, DDG Exports Set New Record.

http://www.ethanolrfa.org/news/entry/u.s.-ethanol-exports-top-620-million-gallons-in-2013-while-imports-fall-ddg/ (accessed September 24, 2014).

Renewable Fuels Association 2013. World Fuel Ethanol Production. http://ethanolrfa.org/pages/World-Fuel-Ethanol-Production (accessed September 24, 2014).

Rocha, G., Gonçalves, A., Oliveira, B., Olivares, E., and Rossell, C. 2012. Steam explosion pretreatment reproduction and alkaline delignification reactions performed on a pilot scale with sugarcane bagasse for bioethanol production. *Industrial Crops and Products,* 35(1): 274-79.

(S&T)^2 Consultants Inc., M. N. P. L. 2004a. Economic, Financial, Social Analysis And Public Policies For Biodiesel. http://www.ghgenius.ca/reports/nrcanbiodieselphase1.pdf (accessed October 6, 2014).

--- 2004b. Economic, Financial, Social Analysis And Public Policies For Fuel Ethanol. http://www.ghgenius.ca/reports/NRCanbiofuelsphase2.pdf (accessed October 8, 2014).

Saville, B. A. and Villeneuve, S. 2006. *Economic impact study for a canola-based biodiesel industry in Canada.* BBI Biofuels Canada.

Scaramucci, J. A., Perin, C., Pulino, P., Bordoni, O. F. J. G., da Cunha, M. P., and Cortez, L. A. B. 2006. Energy from sugarcane bagasse under electricity rationing in Brazil: a computable general equilibrium model. *Energy Policy,* 34(9): 986-92.

Schlosser, J. A., Leatherman, J. C., and Peterson, J. M. 2008. Are biofuels revitalizing rural economies? Projected versus actual labor market impacts in the Great Plains. Paper presented at American Agricultural Economics Association Annual Meeting, Orlando, Florida, July.

Schmidt, L. 2004. *Biodiesel vehicle fuel: GHG reductions, air emissions, supply and economic overview.* Climate Change Central.

Schmitz, A., Wilson, N. L., and Moss, C. B. 2011. *The Economics of Alternative Energy Sources and Globalization.* Bentham Science Publishers.

Schneider, S. H. 1989. The greenhouse effect: science and policy. *Science,* 243(4892): 771-81.

Silalertruksa, T., Gheewala, S. H., Hünecke, K., and Fritsche, U. R. 2012. Biofuels and employment effects: Implications for socio-economic development in Thailand. *Biomass and Bioenergy,* 46(0): 409-18.

Sims, R. E. H., Mabee, W., Saddler, J. N., and Taylor, M. 2010. An overview of second generation biofuel technologies. *Bioresource Technology,* 101(6): 1570-80.

Singh, A., Pant, D., Korres, N. E., Nizami, A.-S., Prasad, S., and Murphy, J. D. 2010. Key issues in life cycle assessment of ethanol production from lignocellulosic biomass: Challenges and perspectives. *Bioresource Technology,* 101(13): 5003-12.

Sorda, G., Banse, M., and Kemfert, C. 2010. An overview of biofuel policies across the world. *Energy Policy,* 38(11): 6977-88.

Souza, S. P. and Seabra, J. E. A. 2014. Integrated production of sugarcane ethanol and soybean biodiesel: Environmental and economic implications of fossil diesel displacement. *Energy Conversion and Management,* 87(0): 1170-79.

Spatari, S., Zhang, Y., and MacLean, H. L. 2005. Life Cycle Assessment of Switchgrass- and Corn Stover-Derived Ethanol-Fueled Automobiles. *Environmental science & technology,* 39(24): 9750-58.

Statistics Canada 2014a. Contents of the Input-Output Tables. http://www.statcan.gc.ca/pub/15-201-x/2010001/technote-notetech1-eng.htm (accessed December 3, 2014).

--- 2014b. Table 379-0031 - Gross domestic product (GDP) at basic prices, by North American Industry Classification System (NAICS), annual (dollars), CANSIM (database). http://www5.statcan.gc.ca/cansim/a05?searchTypeByValue=1&lang=eng&id=3790031&pattern=3790031 (accessed December 3, 2014).

Swenson, D. and Eathington, L. 2006. Determining the regional economic values of ethanol production in Iowa considering different levels of local investment. http://www.econ.iastate.edu/research/publications/advancedsearch.asp (accessed November 18, 2014).

Taheripour, F., Hertel, T. W., and Tyner, W. E. 2011. Implications of biofuels mandates for the global livestock industry: a computable general equilibrium analysis. *Agricultural Economics*, 42(3): 325-42.

Taheripour, F., Hertel, T. W., Tyner, W. E., Beckman, J. F., and Birur, D. K. 2010. Biofuels and their by-products: global economic and environmental implications. *Biomass and Bioenergy*, 34(3): 278-89.

Tenaska Commodities 2014. Production Statistics. http://www.biodiesel.org/production/production-statistics (accessed December 1, 2014).

The World Bank 2014. Gross value added at factor cost (current LCU). http://data.worldbank.org/indicator/NY.GDP.FCST.CN?page=1 (accessed December 19, 2014).

Thomassin, P. J. and Baker, L. 2000. Macroeconomic Impact of Establishing a Large-scale Fuel Ethanol Plant on the Canadian Economy. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, 48(1): 67-85.

Thomassin, P. J., Henning, J. C., and Baker, L. 1992. Macroeconomic Impacts of an Agro-Ethanol Industry in Canada. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie,* 40(2): 295-310.

Timilsina, G. R., Chisari, O. O., and Romero, C. A. 2013. Economy-wide impacts of biofuels in Argentina. *Energy Policy,* 55(0): 636-47.

Tyner, W. and Taheripour, F. 2008. Biofuels, policy options, and their implications: Analyses using partial and general equilibrium approaches. *Journal of Agricultural & Food Industrial Organization,* 6(2).

United Nations Conference on Trade and Development 2009. The Biofuels Market: Current Situation and Alternative Scenarios http://unctad.org/en/Docs/ditcbcc20091_en.pdf (accessed December 17, 2014).

US Department of Energy 2014. Ethanol Feedstocks. http://www.afdc.energy.gov/fuels/ethanol_feedstocks.html (accessed December 2, 2014).

Van Duren, I., Voinov, A., Arodudu, O., and Firrisa, M. T. 2015. Where to produce rapeseed biodiesel and why? Mapping European rapeseed energy efficiency. *Renewable Energy,* 74(0): 49-59.

Vogel, S. J., Hanson, K., Price, J. M., and Schluter, G. 2003. Putting bounds on estimating economywide impacts from adopting the renewable fuels standard. *AgBioForum,* 5(3): 101-04.

Von Blottnitz, H. and Curran, M. A. 2007. A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective. *Journal of Cleaner Production,* 15(7): 607-19.

Walburger, A. M. 2006. *Policies to Stimulate Biofuel Production in Canada: Lessons for Europe and the United States.* BIOCAP Canada Foundation.

Wang, L., Quiceno, R., Price, C., Malpas, R., and Woods, J. 2014. Economic and GHG emissions analyses for sugarcane ethanol in Brazil: Looking forward. *Renewable and Sustainable Energy Reviews,* 40(0): 571-82.

Yang, F., Hanna, M., and Sun, R. 2012. Value-added uses for crude glycerol--a byproduct of biodiesel production. *Biotechnology for Biofuels,* 5(1): 13.

You, F., Tao, L., Graziano, D. J., and Snyder, S. W. 2012. Optimal design of sustainable cellulosic biofuel supply chains: Multiobjective optimization coupled with life cycle assessment and input–output analysis. *AIChE Journal,* 58(4): 1157-80.

Zhu, L. D., Hiltunen, E., Antila, E., Zhong, J. J., Yuan, Z. H., and Wang, Z. M. 2014. Microalgal biofuels: Flexible bioenergies for sustainable development. *Renewable and Sustainable Energy Reviews,* 30(0): 1035-46.

Ziolkowska, J. R. 2014. Optimizing biofuels production in an uncertain decision environment: Conventional vs. advanced technologies. *Applied Energy,* 114(0): 366-76.