# BACKGROUND STUDY TO REVIEW AND ASSESS KNOWN PRINCIPLES & CURRENT INFORMATION ON BIOFUEL PRODUCTION UNDER IRRIGATED CONDITIONS

For: Agriculture and Agri-Food Canada
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## Executive Summary

Biofuels, including ethanol and biodiesel, provided 2.7% of all fuel used for road transportation in 2010, and global biofuel production has been rising steadily. Worldwide, ethanol production was 18% higher in 2010 than in 2009 and biodiesel production increased by 12%. The United States dominates world ethanol production (51 billion litres in 2011) and became a net exporter for the first time in 2010. Over 40% of the corn crop in the United States is used to produce this ethanol. Brazil is also a major ethanol producer (32 billion litres in 2011) and uses sugarcane as feedstock. Canada is a small player on the world stage with a capacity of producing 1.8 billion litres of ethanol annually. Over 60% of this ethanol is produced in Ontario using corn. Globally, biodiesel production is dominated by Germany, Brazil, Argentina and France using primarily rapeseed and soybean crops for feedstocks. Each country produces between 2 and 3 billion litres annually. Canada produced 0.1-0.2 billion litres of biodiesel in 2010 with British Columbia, Ontario and Quebec roughly sharing 80% of the country's total.

Biofuel production worldwide is a result of government mandates and subsidies. The economics of biofuel production varies between crops and regions and is difficult to assess. Processing costs are lowest for ethanol made from sugarcane and highest for oil crops made into biodiesel due to the high price of the feedstocks. Biodiesel made from crops is not currently profitable without government incentives. The economics of ethanol from corn sits somewhere between the two and is strongly affected by feedstock price, processing method and marketability of by-products.

The amount of energy required to turn a crop into fuel relative to the amount of energy generated by the fuel, is one measure of biofuel sustainability. Wide variations in this energy ratio exist depending on the energy used to convert crop to fuel and the amount of credit given to by-product generation. The highest values come from ethanol produced from sugarcane which is estimated to generate about 8 times more energy than is required to produce it. This compares to between 1.4 to 2.4 times for corn or wheat. Greenhouse gases emitted during feedstock generation including land use change, nitrogen fertilizer production and use, fuel extraction, distribution, delivery and use of the finished fuel by the consumer are also an important measure of the sustainability of biofuel use. These values are compared to baseline gasoline or diesel emissions, and greenhouse gas emission reduction (or creation) is estimated for each crop to fuel cycle. As with the energy ratio, there is wide variation in this value. Ethanol from agricultural residues and switchgrass has the highest reported values with greenhouse gases reduced by over 100% compared to baseline gasoline.

The complete environmental impacts of biofuel production, including water use and contamination, and soil erosion, are rarely included in assessments of biofuel feedstock crop sustainability. Worldwide less than 2% of major feedstock crops are irrigated. In the United States about 15% of the corn used for ethanol production is irrigated and for each litre of ethanol produced, 5 to 2138 litres of water are used for corn irrigation and processing. Almost 70% of this water comes from the Ogallala aquifer. In the long term, such a level of groundwater use for ethanol production is not sustainable in the United States. By 2030, water consumed in the

expected production of biofuels is projected to account for nearly half of the total amount of water consumed in the production of all energy fuels.

No biofuel crops are currently irrigated in Canada.  Irrigation can more than double crop yields when water is limiting and, if infrastructure is already in place, it may help to develop a reliable source of biofuel crops in some areas. The price of water would have to be accounted for in any cost-benefit analysis. Where there is currently no irrigation infrastructure, the investment in off- and on-farm irrigation infrastructure and the cost of operating irrigation equipment are almost certainly not cost effective for producing biofuel feedstock. The authors feel that currently there are limited opportunities for biofuel production under irrigation in Canada. Further research into breeding and agronomics of biofuel crops, sustainable management methodologies, development of processing technologies and a policy framework for sustainable biofuel production practices would be valuable for future biofuel expansion in Canada.

# 1.0 Introduction

Biofuels provided 2.7% of all global fuel for road transportation in 2010; an increase from 2% in 2009, according to the Renewable Energy Policy Network (Ren21 2011). Most biofuel is used for road transport, with a limited amount in the marine transport sector. Interest is growing in the use of bio-oil as a potential fuel for aviation but it is still at the pilot stage. Biofuel production and use are being driven by government mandates, investments and subsidies. A summary of the mandates in some of the key fuel consuming nations and in each Canadian province are found in Appendix A. Biofuel alternatives to fossil fuels for transportation largely consist of ethanol and biodiesel.

## *1.1 Ethanol*

The addition of ethanol to gasoline increases the fuel octane rating and results in cleaner, more complete combustion. Ethanol has about 66% the energy of gasoline, and a blending rate of up to 10% ethanol does not require any engine modification (USDE 2012).

Bioethanol, the most widely used liquid biofuel, is produced mainly by first generation technologies. Sugars are converted directly to ethanol from crops like sugarcane or sugar beets, or indirectly through hydrolysis of starch from crops such as corn, wheat, potatoes, or cassava. Recent breakthroughs in cellulosic conversion, or advanced biofuel technologies, promise a wider range of feedstocks for ethanol production such as agricultural residues, perennial grasses (switchgrass, Miscanthus) or woody materials.

An important by-product of ethanol from sugarcane is bagasse, the fibre left over after the juice has been squeezed from the stalks. It can be used as a fuel source to heat and power sugar mills and ethanol plants and also as biomass for cellulosic ethanol production. Bioethanol produced from cereals creates the by-product distillers grains with solubles (DGS), a valuable, high-protein animal feed. It can be sold in its wet form (WDGS) to local cattle feedlots and dairies although it spoils quickly. The product can also be dried (DDGS) and sold as a high-protein ingredient for cattle, swine, poultry, or fish feed. For every 100 kg corn processed, 30 kg of DGS is produced as well as 30 kg of $CO_2$ which is used in the food and beverage industry (Hussain et al. 2011). Other by-products of this production process include brewer’s yeast, fertilizers and weed control products (Amaizeingly Green 2012).

## *1.2 Biodiesel*

Biodiesel has similar energy density and viscosity to regular diesel but a heating value that is 12% lower. (Canakci 2006). It is a clean burning fuel which can be used in any diesel engine with few or no modifications although at blends higher than 5% engine service life can be reduced.

Biodiesel can be made through a chemical process called transesterification whereby the glycerine is removed from used cooking oils, animal fats or vegetable oil. In principle, any vegetable oil can be used, with rapeseed being the primary source material in Europe, soya oil in South America and the USA, and palm oil in Southeast Asia. Plant oils vary in their fatty acid composition and therefore in their suitability, particularly in winter months, for use as biodiesel. Cold filter plugging point (CFPP), an estimate for the lowest temperature that a fuel will give trouble free flow, is 5˚ C and -12˚ C for biodiesel made from palm oil and rapeseed, respectively. From the CFPP value, biodiesel usage can be restricted to a limited time frame (e.g. summer) according to the climate.

During the extraction of vegetable oils, rape or soya meal is produced as a by-product. Either of these can be used as a high-protein feed for livestock. Every 100 kg of rapeseed produces roughly 57 kg of rape grist and 43 kg of rapeseed oil, while 100 kg of soybean produces around 80 kg of grist and 20 kg of oil. Separate markets exist for glycerine, primarily in the pharmaceutical industry, although currently the market is oversupplied and prices are low.

## 2.0 Biofuel Production: The Global Picture

The rapid increase in biofuel production that began in 2000, continued through 2010 (Figure 1). Global ethanol production was 86 billion litres in 2010, 18% more than in 2009 and biodiesel production rose to 19 billion litres, a 12% increase from 2009 (Shrank and Farahmand 2011).

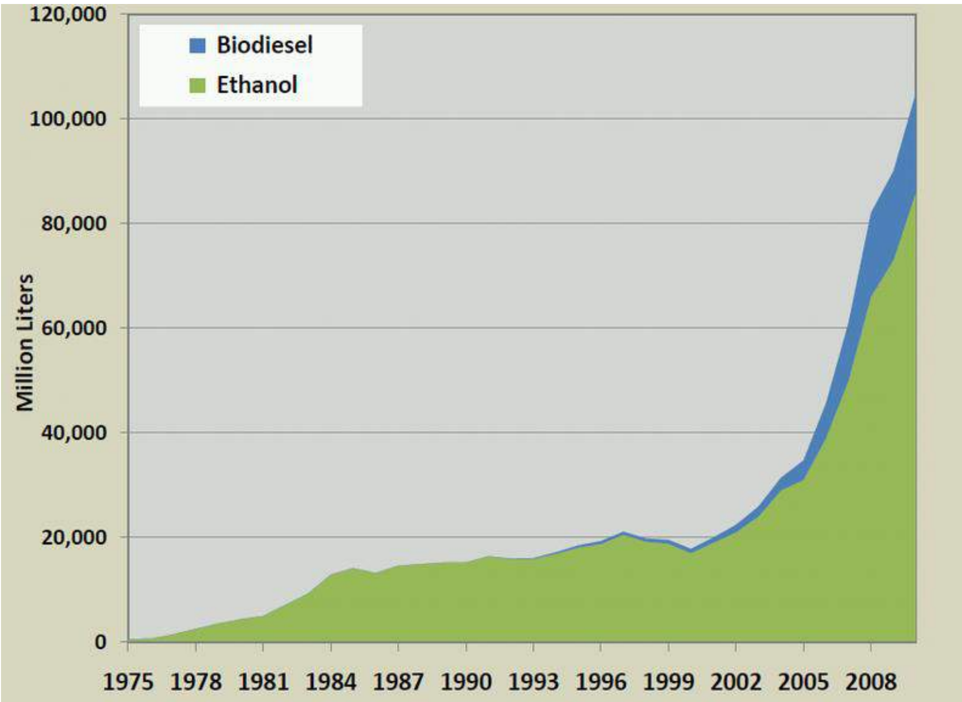



**Figure 1:** Global bioethanol and biodiesel production 1975-2010. (Shrank and Farahmand 2011)

### *2.1. Bioethanol*

The United States and Brazil remained the two largest producers of bioethanol in 2010 with 49 and 28 billion litres respectively (Table 1). Ethanol production in the United States accounts for more than half of the world total and production has more than tripled over the last 5 years from 18 billion litres in 2005 to an expected 51 billion litres in 2011. After several years as a net importer of ethanol, the United States became a net exporter in 2010, sending a record 1.3 billion litres of fuel ethanol overseas, mainly to Canada, Jamaica, the Netherlands, the United Arab Emirates, and Brazil (Ren21 2011). The United States has 204 ethanol plants in 29 states, almost all of which use corn as a feedstock (RFA 2012). The long-standing U.S. system of subsidy and import tariff protection for local producers of bioethanol expired on December 31, 2011 and may have negative repercussions for domestic ethanol production.

**Table 1:** Ethanol production and major feedstock by country

| Country | Ethanol Production (millions of litres) | | Feedstock crop (proportion of total ethanol production, if known) |
|---|---|---|---|
| | **2010 (unless specified)** | **2011 (estimated)** | |
| United States[1] | 49,210 | 51,100 | Corn (100%) |
| Brazil[2] | 28,000 | 32,500 | Sugarcane (100%) |
| China[3] | 2128 | 2217 | Corn (80%)<br>Wheat and rice (20%) |
| India[4] | 1435 | 1934 | Sugarcane molasses (100%) |
| Canada[5] | 1200 | 1351 to 1800[5a] | Corn (74%)<br>Wheat(26%) |
| Germany[6] | 1042 | 1100 | Wheat and rye (major Feedstocks)<br>Barley, maize and triticale (minor feedstocks) |
| France[7] | 805-1150(2009) | NA | Sugar beet (major feedstock)<br>Wheat, maize (minor feedstocks) |
| Thailand[8] | 426 | 528 | Sugar molasses (80%)<br>Tapioca (20%) |
| Columbia[9] | 302 (2009) | NA | Sugarcane (100%) |
| Australia[10] | 203 (2009) | NA | Waste wheat starch (50%)<br>Sugarcane (18%)<br>Sorghum (27%) |
| **World[11]** | **85800** | **88700[12]** | |

1.Urbanchuk 2011; 2. Barros 2010 and REN21 2011; 3. Scott and Junyang 2011 4. Aradhey 2011; 5. Dessureault 2011; 5a: KD Communications 2011 6. Licht 2012; 7. Henard 2010 and Biofuels Platform 2010; 8. Preechajarn and Prasertsri 2011; 9. Pinzon 2009; 10. Darby 2010. 11. Ren21 2011. 12.GRFA 2011

Brazil's ethanol production increased more than 7% in 2010 and accounted for nearly one-third of the global total. Long the world's leading ethanol exporter, Brazil continued to lose international market share to the United States, particularly in its traditional markets in Europe. Adverse weather conditions hampered global harvesting of sugarcane, pushing up prices and making subsidized U.S. corn-based ethanol cheaper in international markets (Ren21 2011). As of 2011, Brazil had 441 bioethanol refineries and between 40 and 50% of car fuel was consumed as bioethanol (Barros 2010). The *flex-fuel* car, developed in 2003, allows consumers to freely choose between gasoline and hydrated ethanol (E100) and gas stations offer both gasoline (actually a mixture of 75 % gasoline and 25 % ethanol) and ethanol (100%) (Barros 2010).

China produced 2 billion litres of bioethanol in 2010 and remained Asia's largest ethanol producer, followed by India and Thailand. China's five ethanol plants use grain (corn and wheat) and tuber (cassava) for ethanol production. Due to China's rising food prices, the government stopped approval of new fuel ethanol plants and fell short of reaching its production target in the 2005-2010 period (Scott and Junyang 2011). Over the past few years, China has been actively experimenting with non-grain feedstocks such as cassava and sweet sorghum for ethanol production. Reportedly, for the next five year plan (2011-2015), the government has set a target for non-fossil energy consumption at 11.4%, an increase of 3.1% from 2010. Compared with other renewable energy sources, biofuel is expected to play a minor part in China's diversified energy policy because of lack of sustainable supply of feedstocks and appropriate technology (Scott and Junyang 2011).

Production of ethanol in India, all from sugarcane, reached a high in 2007 at 2.4 billion litres, dropped to 1.1billion litres in 2009 and has gradually been working its way back up to a forecast of 2.1 billion litres in 2012 (Aradhey 2011). The Indian government mandated the use of 5% ethanol (E5) blend in petrol in some states and territories in 2003 and expanded the plan to the entire country in 2008. The target is somewhat successful in years of surplus sugar production, and unfilled when sugar production declines (Aradhey 2011). However, with an outlook of bumper sugarcane and sugar production in 2011/12, the government is likely to renew its focus and strongly implement the mandatory E5 ethanol blend. There is limited scope to bringing additional area under water intensive sugarcane cultivation and alternate crops for ethanol production such as sweet sorghum, sugar beets or sweet potatoes are under experimentation.

Ethanol production in Thailand continues its upward trend from 426 to 528 million litres/y between 2010 and 2011, to an estimated 580 million litres/y in 2012. Another 5 new ethanol plants, all using tapioca as feedstock, will be added to the 19 existing plants (Preechajarn and Prasertsri 2011). Thailand's ethanol exports are estimated to have increased from 49 million litres in 2010 to 70 million litres in 2011. The proportion of tapioca vs sugar molasses used as feedstock varies somewhat between years depending on their relative prices. A bumper crop of sugarcane in 2010/2011 and record tapioca prices made molasses-based ethanol 17% cheaper to produce than tapioca-based ethanol.

In 2009, the European Union mandated a 10% minimum target for renewable energy to be consumed in transport by 2020. E.U. bioethanol production surged by more than 30% in 2010. France and Germany remained the largest European ethanol producers using wheat, rye and sugar beets as major feedstocks. The E.U. imported ethanol in 2011 from the U.S. due to higher costs and production shortfalls in Europe. Output is about 625 million litres short of the 9.27 billion litres that drivers are mandated to use this year according to Bloomberg New Energy Finance (Freedman 2011). At the end of 2011, ethanol in New York Harbor was $0.78 per litre ($2.95/U.S. gal) compared with $0.85 per litre ($3.21/U.S.gal) in Rotterdam.

Africa represents a tiny share of world ethanol production but saw continued rapid growth in production during 2010.World ethanol prices increased by more than 30% in 2010 in the context of a new commodity price spike of ethanol feedstocks, mainly sugar and maize, and firm energy prices. This situation contrasts with 2007/08 where ethanol price movements did not follow commodity price increases and ethanol profit margins were lower (OECD-FAO 2011).

### *2.2. Biodiesel*

The European Union generated 53% of the world's biodiesel in 2010 with rapeseed as the major feedstock (Table 2). Germany was the world's largest biodiesel producer with 2.9 billion litres. Brazil was the second largest producer with 2.5 billion litres, a 50% increase over 2009 and all for national consumption. Argentina was not far behind Brazil at 2.1 billion litres and is projected to increase biodiesel production to 3 billion litres by 2012 due to large investments in the sector (Joseph 2011). Both countries rely heavily on soybean for biodiesel feedstock.

An increasing share of the E.U. supply of biodiesel is being imported, primarily based on soy or palm oil, as tax incentives decline but biofuel mandates remain. Also, the growing capacity of European harbours, often connected to inland waterways, facilitates the import of cheap international biofuels and feedstock. A large amount of recent biodiesel production growth (e.g. Argentina, Indonesia) can be linked to exports to the E.U. (Lamers 2011). Recent EPA analysis shows that biodiesel and renewable diesel produced from palm oil do not meet the minimum 20% lifecycle GHG reduction threshold needed to qualify as renewable fuel under the Renewable Fuel Standard (RFS) program in the United States (EPA 2011b). This may have an impact on global trade in biodiesel.

World biodiesel prices increased in 2010 in a context of rising rapeseed and other vegetable oil prices and high crude oil prices although this price increase is smaller than for ethanol (OECD-FAO 2011).

## 3.0 Biofuel Production: The Canadian Picture

Total annual biofuel production (ethanol plus biodiesel) in Canada is estimated to be between 1.46 and 2.0 billion litres (Table 1). If all ethanol production plants currently in operation are running at 100% capacity, ethanol production would be 1.83 billion litres per year, with 74% of that capacity generated using corn as the feedstock (Tables 3, 4). The remaining capacity comes from wheat (26%) and small amounts of wheat straw and wood waste. Most of Canada's ethanol capacity is located in Ontario (63%) and Saskatchewan (20%) (Table 3). There are currently 14 operational ethanol production plants in Canada, 6 plants under construction or proposed and 4 research plants using cellulosic feedstocks. Of the 'under construction or proposed' plants, 2 will use municipal waste as feedstock and 1 will use agricultural residues (Appendix B). According to Coad and Bristow (2011), from 2005 to 2009, corn imports to Canada remained relatively constant while corn use for ethanol production quadrupled. This suggests that imports of corn play a minimal role in Canada's ethanol industry.

**Table 2:** Biodiesel production and major feedstock by country

| Country | Biodiesel Production (millions of litres) | | Feedstock (proportion of total biodiesel production, if known) |
|---|---|---|---|
| | **2010[1]** | **2011 (estimated)** | |
| Germany | 2900 | | Rapeseed |
| Brazil[2] | 2450 | | Soy bean (80%)<br>Animal tallow (15%)<br>Cotton seed oil (4%) |
| Argentina[3] | 2100 | 2560 | Soybean (100%) |
| France | 2000 | | Rapeseed |
| United States[4] | 1200 | | Soybean (60%)<br>Canola (10%)<br>Recycled grease +<br>Animal fats (20%)<br>(data est. from Biodiesel Magazine Jan 2012) |
| Spain[5] | 1100 | 739 | Imported soy (43%) and palm oil (38%);<br>Animal fats and recycled oils (12%) |
| Italy[6] | 800 | 568 | Imported Rapeseed, soy and palm oil |
| Indonesia[7] | 700 | | Palm oil |
| Thailand[8] | 600 | | Palm oil |
| Canada[9,10] | 110-200 | | Animal fats (60%)[A]<br>Canola oil (14%)<br>Yellow grease (13%) |
| **World** | **19884** | | |

1. REN21 2011; NBB 2012; 2. . Barros 2010 3. Joseph 2011; 4. Urbanchuk 2011 5. Guerrero 2011; 6. Baldi 2011; 7. Slette 2011; 8. Preechajarn and Prasertsri 2010; 9. KD Communications 2011; 10. Dessureault 2011.

**Table 3**: Current and potential ethanol production capacity in Canada

| Province | Current Operational Capacity for Ethanol Production | | Potential Capacity for Ethanol Production* | |
|---|---|---|---|---|
| | **Million litres/year** | **Proportion of total (%)** | **Million litres** | **Proportion of total (%)** |
| Alberta | 42 | 2.4 | 398 | 18.6 |
| Saskatchewan | 345 | 20.2 | 345 | 16.1 |
| Manitoba | 130 | 7.6 | 170 | 8.0 |
| Ontario | 1073 | 62.7 | 1073 | 50.2 |
| Quebec | 120 | 7.0 | 152 | 7.1 |
| **TOTAL** | **1710** | | **2138** | |

*Based on assumption that all proposed production plants are built and run at full capacity. See **Appendix B.**

**Table 4**: Current and potential ethanol capacity by crop in Canada

| Province | Current Capacity for Ethanol Production | | Potential Capacity for Ethanol Production* | |
|---|---|---|---|---|
| | (million litres/year) | | | |
| | **wheat** | **corn** | **wheat** | **corn** |
| Alberta | 42 | | 362 | |
| Saskatchewan | 345 | | 345 | |
| Manitoba^ | 65 | 65 | 65 | 65 |
| Ontario | | 1073 | | 1073 |
| Quebec | | 120 | | 120 |
| **TOTAL** | **452** | **1258** | **772** | **1258** |
| **% of Total Production** | **26%** | **74%** | **36%** | **59%** |

^Assume the Husky plant uses 50% corn and 50% wheat (see Appendix B for details).

Based on 2010 data, gasoline sales in Canada subject to the Renewable Fuel Standard (E5) totalled 42.75 billion litres (Coad and Bristow 2011). This means that 5% or 2.14 billion litres of ethanol is required to meet the RFS. Assuming that all plants are built, Canadian ethanol capacity will rise to 2.1 billion litres in the next few years (Appendix B). This indicates that ethanol imports or additional production capacity will be required to meet the RFS as gasoline demand in Canada grows.

Ontario will continue to dominate ethanol production in the medium term, but Alberta's share will rise from 2 to 19 % of Canadian capacity (Table 3). Corn will account for 59% of the bioethanol feedstock and wheat 36% (Table 4). The remainder will come from the organic components of municipal waste and wheat straw.

The newer wheat bioethanol plants have more flexibility built-in as the pipes are larger and allow the use of other feedstocks, such as corn, when wheat feedstock may be too expensive. For example, Husky Energy's wheat-based bioethanol plant in Minnedosa, Manitoba uses corn when wheat feedstock is unavailable or too expensive. Husky Energy has agreed that 80% of the feedstock used to produce bioethanol will come from Manitoba producers. The agreement is with the Manitoba government and expires in 2017.

Canada's limited ethanol production capacity, both in the short and medium term suggests that Canada's entry into the global bioethanol market is still quite distant (Dessureault 2011).

The capacity of biodiesel production plants in Canada is 260 million litres with British Columbia, Ontario and Quebec roughly sharing 80% of the total capacity (Table 5). It is difficult to ascertain the proportion of feedstocks used in biodiesel production from the data given by the plants because almost 50% of the capacity is said to come from multi-feedstocks which are a mixture of vegetable or cooking oils and animal fats (Table 6).

**Table 5**: Current and potential biodiesel production capacity in Canada

| Province | Current Operational Capacity of Biodiesel Production | | Potential Operational Capacity of Biodiesel Production* | |
|---|---|---|---|---|
| | Million litres | Proportion of total (%) | Million litres | Proportion of total (%) |
| British Columbia | 61 | 23 | 61 | 5.8 |
| Alberta | | 0 | 463$^{+}$ | 43.7 |
| Saskatchewan | 20 | 7.7 | 20 | 1.9 |
| Manitoba | 33 | 1.3 | 33 | 3.1 |
| Ontario | 81 | 31.1 | 378 | 35.7 |
| Quebec | 65 | 25.0 | 105 | 9.9 |
| **TOTAL** | **260** | | **1060** | |

* Based on assumption that all proposed production plants are built. $^{+}$Does not include 2 plants 'on-hold' that total 256 million litres in annual capacity. See Appendix B.

**Table 6:** Current and potential biodiesel production capacity by feedstock in Canada

| Province | Current Capacity for Biodiesel Production by Feedstock (million litres/year) | | | | Potential Capacity* for Biodiesel Production by Feedstock (million litres/year) | | |
|---|---|---|---|---|---|---|---|
| | **Canola** | **Multi-feedstock** | **Grease/oil** | **Canola** | **Multi-feedstock** | **Soybean** | **Grease/oil** |
| British Columbia | | | 61 | | | | 61 |
| Alberta | | | | 397 | 66 | | |
| Saskatchewan | 20 | | | 20 | | | |
| Manitoba | 33 | | | 33 | | | |
| Ontario | | 66 | 15 | | 193 | 170 | 15 |
| Quebec | | 55 | 10 | | 95 | | 10 |
| **TOTAL** | **53** | **121** | **86** | **450** | **354** | **170** | **86** |
| **% of Total Production** | **20%** | **47%** | **33%** | **42%** | **33%** | **16%** | **8%** |

*Based on assumption that all proposed production plants are built and run at full capacity. See Appendix B.

According to Dessureault (2011), the share of biodiesel production from tallow (animal fats) is currently 60%. The proportion of biodiesel produced from canola oil in 2012 is forecast to rise to 42% from an estimated 20 % share in 2011. The share of biodiesel produced from yellow grease is forecast to fall to 8% in 2012 from 2011 levels of nearly 33%. A new soybean plant in Ontario will produce 16% of Canada's biodiesel capacity.

There are 12 operational biodiesel plants located in Canada with another 9 proposed or under construction and 2 currently 'on hold' due to financial issues. (Appendix B). If all plants are built, the biodiesel production capacity will increase to almost 1.1 billion litres (Table 5). This is double the amount required to meet the B2 mandate (Statistics Canada 2010). This expansion is happening predominantly in Ontario and Alberta.

The federal government program, ecoEnergy provided eligible producers of renewable alternatives to gasoline with up to $.10/L of eligible sales for the first year in the program. Due to the less-established nature of the industry, producers of renewable alternatives to diesel were eligible for an incentive of up to $.26/L of eligible sales for the first year in the program. Funding for this program is now fully allocated (NRCAN 2012).

## 4.0 Fuel Yields of Feedstock for Biofuel Production

The amount of energy produced by a unit of biofuel compared to the amount of fossil-fuel energy required to produce that unit, is equal to the energy ratio. Biofuel production from crops has two major energy inputs:

- production of the feedstock crop
- extraction of ethanol or biodiesel from the crop.

Feedstock production requires energy inputs to plant, harvest, dry and transport the crop, including the energy required to produce fertilizer, pesticides and irrigation water and often the farm machinery itself. For corn production, energy inputs due to fertilizer are often half the total production inputs. Energy inputs vary with yields, tillage practices, soil texture, amount of chemicals applied to the crop, chemical production methods, and amount of water used for irrigation. For example, most of the ammonia plants in Canada recover a higher percentage of process-generated emissions than producers in other countries, which reduces the energy required to produce N fertilizer (NRCan 2007). Canadian corn producers use less nitrogen fertilizer than do U.S. producers because they use more manure. This also results in a smaller energy input and better fuel yield (Coad and Bristow 2011).

The greatest energy input for corn ethanol production is during the extraction process at the ethanol plant (Figure 2). This amount varies depending on the technology used, installation date, and fuel and electricity sources used (Coad and Bristow 2011). For instance, an ethanol plant that uses conventional fossil fuel power for thermal energy and electricity requires considerably more energy inputs than a plant that utilizes biomass for energy. In the case of corn, stover can be used to generate energy and may represent up to a 40% savings in energy inputs (USDA 2010). In Brazil, bagasse, is used to fuel ethanol plants making them very energy efficient and contributing to the high energy use ratio for sugarcane. The proportion of energy used to convert sugarcane to ethanol at the plant is only about 10% of total energy inputs (relative to over 60% for corn) (Macedo et al 2008).

By-products generated during ethanol production are also often included in the calculation of the energy ratio as "credits". In the case of ethanol production from corn, a by-product credit is given for the heat used to prepare dry DGG. Including this credit raises the energy ratio from 1.4 to over 1.9.

Energy ratios vary widely within and between crops (Table 7). Sugarcane has the highest energy ratio, producing an output of energy that is about 800% greater than input energy. Other crops used for ethanol production have energy ratios between 1.1 and 2.4 or produce 10 to 140% more energy than is required for inputs. Biodiesel crops have somewhat high energy ratios although, with the exception of palm oil, the fuel yield/ha is generally much lower than for the ethanol crops. The amount of ethanol produced per hectare is related to the amount of starch or sugar in the crop and crop yield. Wheat and triticale have the lowest ethanol yield with less than 2000 litres/ha estimated by McLeod et al. (2010). Sugarcane and sugar beets have the highest yields although there is a very large variation in the latter.

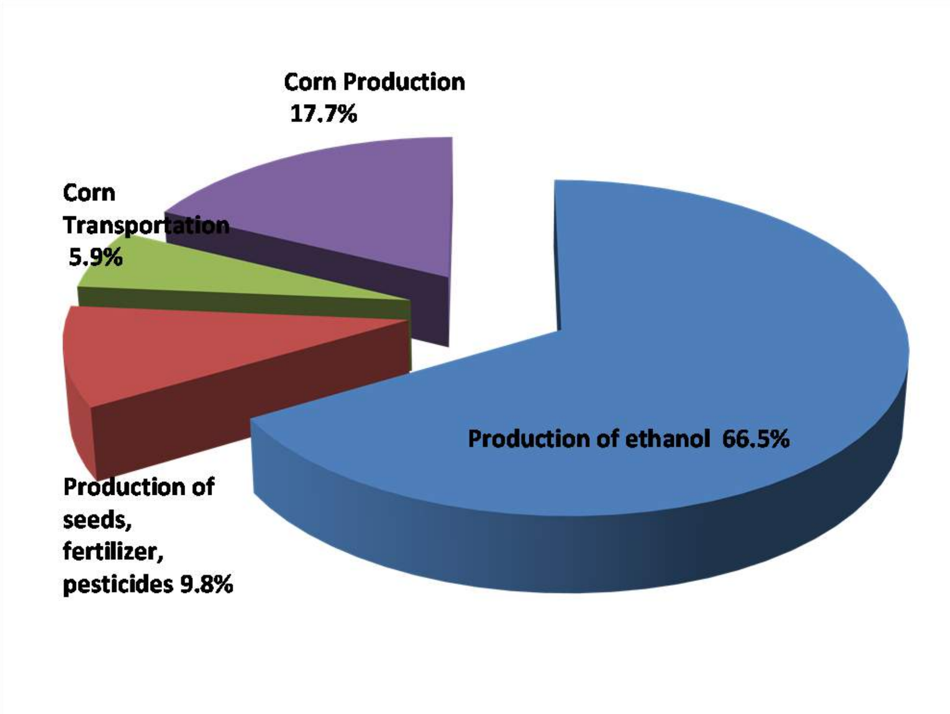



**Figure 2:** Proportion of energy used for production of ethanol from corn grown in Ontario From: Hussain et al. (2011)

Older studies often show higher energy requirements to produce feedstocks and convert them to ethanol. The largest energy components for corn production are nitrogen and direct energy for fuel and electricity. According to USDA (2010) nitrogen use has declined by about 20% since the mid-90s. Similarly, all direct energy components have declined by about 50% since the mid-90s. Together, the nitrogen and direct energy reductions result in a 30% decline in the energy required to produce a tonne of corn. Almost 85% of Canada's biofuel capacity has come into service since 2005 and Canada's ethanol plants use modern, energy-efficient technologies.

Models of energy requirements of biofuels in the future show continued growth in energy efficiency resulting in higher energy ratios.

**Table 7:** Energy ratios and fuel yields for various feedstock crops. *High number includes by-product generation

| Biofuel type | Energy Ratio | Conversion Rate | Biofuel yield | Country | Reference |
|---|---|---|---|---|---|
| ***Ethanol*** | *Output energy/input energy* | *Litres ethanol/t dry grain or crop* | *Litres/ha* | | |
| Corn | 1.7 – 2.4* | 400 | 3600-4000 | Ontario, Canada | Hussain et al 2011 |
| Corn | 1.4-1.9* | 417 | 3300<br>6900-7500(from grain +stover) | U.S.<br>Kansas, U.S. | USDA 2010b<br>Propheter 2010 |
| Wheat | 1.1-2.1 | 370-386 | 1000-3000<br>1657 | E.U.<br>Canada | De Vries et al 2010; EUBIA 2007<br>McLeod et al 2010 |
| Triticale | | 368 | 1757 | Canada | McLeod et al 2010 |
| Sugar beet | 1.5-2.1 | 94 | 3400-8000 | E.U. | De Vries et al 2010; USDA 2006<br>EUBIA 2007 |
| Sugarcane | 8-9.3 | 70 -83 | 4900 - 6767 | Brazil | De Vries et al 2010<br>Ecofys 2007; USDA 2006; Brazil Institute 2007 |
| Cassava | .85-1.11 | 330 (dry cassava chips)<br>150 (fresh roots) | 1500-6000 | Africa | Papong and Malukul 2010; EcoFys 2007 |
| Agricultural residues | | 110-270<br>310-400(theoretical) | | Canada<br>U.S. | Mabee and Saddler 2010<br>GenSolutions 2007 |
| **Wood Residues** | | 120-300 | | Canada | Mabee and Saddler 2010 |
| Switch grass | | 98-115<br>203-222(theoretical) | 2,534–3,720 | U.S. | Vogel et al 2010 |
| Miscanthus | | | 3963 | Kansas, U.S. | Propheter 2010 |
| ***Biodiesel*** | | ***Litres biodiesel/t dry grain or crop*** | | | |
| Rapeseed | 2.0-2.5 | 470 | 711-1000 | E.U. | De Vries et al 2010; Hofman 2003<br>Brown 2006 |
| Canola | 2.1-2.4<br>4.5 | 470 | 676-900 (calc) | Canada | Smith 2007<br>CRFA 2010 |
| Soybean | 2-3.6<br>2.1-2.4 | | 460-520<br>(419 calc) | U.S.<br>Canada | De Vries et al 2010<br>Smith et al 2007; Hofman 2003<br>Brown 2006 |
| Palm oil | 4 | | 4800-5675 | Malaysia-World | De Vries et al 2010; Brown 2006<br>Pahl 2005 |
| Jatropha | 1.4-6.0 | | 1818 | World | Pahl 2005 |

## 5.0 Greenhouse Gas Emissions Reduction

Greenhouse gas (GHG) emission assessments are related to the full fuel lifecycle from feedstock generation or extraction through the distribution and delivery and use of the finished fuel by the ultimate consumer. Mass values for all greenhouse gases are adjusted to account for their relative global warming potential. Direct and indirect emissions, including significant emissions from land use changes are part of the calculation. The resulting Life Cycle Assessment (LCA) value is the percentage increase or decrease in GHG emissions compared to a baseline of gasoline or diesel fuel, as is appropriate.

In the United States, the Energy Independence and Security Act (2007) established specific greenhouse gas emission thresholds for each of four types of renewable fuels:

- 20% reduction in lifecycle GHG emissions for any renewable fuel produced at new facilities (those constructed after enactment),
- 50% reduction in order to be classified as biomass-based diesel or advanced biofuel,
- 60% reduction in order to be classified as cellulosic biofuel.

In the EU, biofuels must have GHG emissions savings of at least 35% once the Renewable Energy Directive (RED) is implemented through national legislation (Flach et al. 2010). Starting in 2017, the GHG emission savings has to be 50%. For biofuels produced in installations for which production starts in 2017 and onwards, the GHG savings must be 60%.

Assessment of greenhouse gases emitted during the life cycle analysis is very complex and involves dozens of factors (Appendix C). The LCA value differs depending on the type of feedstock, conversion technologies, and end-use technologies. Regional differences can be significant with respect to land use and biomass production patterns. (S&T)[2] (2011) compared biodiesel GHG emissions in Canada, the U.K. and concluded that biodiesel produced in Canada is far more effective at reducing GHG than in the U.K. This was due, in large part, to greater use of ammonium-based fertilizers in Canada vs nitrate-based fertilizers in the United Kingdom (UK). The latter have higher GHG emissions during fertilizer production. Reference energy systems also vary in their GHG emissions. For example, natural gas-generated electricity has a GHG emission factor of around 400 g $CO_2$-eq/kWh (110 g $CO_2$-eq/MJ) compared with 990 g $CO_2$-eq/kWh (240 g $CO_2$-eq/MJ) for coal-based electricity (Bird et al 2011.). LCA values will also change as technologies become more energy efficient and as our understanding of greenhouse gas emissions from agricultural soils improves. In their assessment of GHG emissions from the cultivation of a wide range of crops in Sweden (SLU 2011), the authors point out that direct nitrous oxide emissions from soil account for more than half of the greenhouse gas emissions from crop cultivation. However there are huge uncertainties in the estimation of $N_2O$ emissions. For example GHG emissions from winter wheat cultivation varied from 10 to 42 g $CO_2$eq/MJ.

The wide variation in GHG emission reductions reported in Table 8 reflects the complexity of the analysis described above. Even for any one feedstock converted to ethanol using the same technology, there is a large degree of uncertainty. There is a trend however, with corn having a smaller effect on GHG emission reduction than corn stover, sugarcane or switchgrass. For biodiesel feedstocks, waste vegetable or animal oils have the highest levels of GHG emission reduction. Scientific studies on indirect land use change prepared for the European Commission concluded that biodiesel from E.U. rapeseed, Asian palm oil and South American soybean all emit more carbon dioxide than conventional diesel when their indirect emissions are taken into account (European Commission 2010). With countries now setting biofuel standards based on GHG emission reductions, less variable data will be required in the future.

**Table 8:** Percentage change of GHG emissions during the life cycle of biofuel feedstocks

| **Crop Feedstock** | **Conversion Method (if known)** | **Amount GHG emissions are reduced (-) or raised (+)** | **Reference** |
|---|---|---|---|
| ***Ethanol*** | | *%* | |
| Corn | Coal Dry Mill | +13 to +34 | EPA 2009 |
| Corn | Natural Gas Dry Mill | -16 to +5 | EPA 2009 |
| Corn | Best Case Natural Gas Dry Mill | -39 to -18 | EPA 2009 |
| Corn | Biomass Dry Mill with Combined Heat and Power | -47 to -26 | EPA 2009 |
| Corn Stover | | -115 | EPA 2009 |
| Sugar beet | | -52 | Flach et al. 2010 |
| Sugarcane | | -80 to -26 | EPA 2009; Flach et al. 2010; Macedo et al 2008 |
| Switchgrass | | -128 | EPA 2009 |
| ***Biodiesel*** | | | |
| Soy bean | | -31 to 4 | EPA 2009<br>Flach et al. 2010 |
| Rapeseed | | -38 | Flach et al. 2010 |
| Sunflower | | -51 | Flach et al. 2010 |
| Palm oil | | -19 | Flach et al. 2010 |
| Palm oil | methane capture at oil mill | -56 | Flach et al. 2010 |
| Waste vegetable or animal oils | | -83 | Flach et al 2010 |

Several LCA studies have examined other environmental aspects, including local air pollution, acidification, eutrophication, ozone depletion and land use (reviewed by Cherubini 2009). These studies conclude that most bioenergy crops lead to increased negative environmental impacts through the intensive use of water, fertilizers and pesticides which may cause water scarcity and contamination of water and soil resources. Therefore, it should always be acknowledged that a positive impact on GHG emissions may carry a cost in other environmental areas. A careful analysis is needed to understand the trade-offs for every crop and region.

## 6.0 Water Use for Biofuel Production

Water scarcity is already a problem in many parts of the world. Water use has been growing globally at more than twice the rate of population increase in the last century, and an increasing number of regions are reaching the limit at which reliable water services can be delivered. Approximately 1.2 billion people live in river basins with absolute water scarcity, where water resource development has exceeded sustainable limits (Molden et al 2007). Contamination of water supplies by agricultural, municipal and industrial effluents further limits water consumption. Climate change is also projected to have a significant impact on water availability. It is generally agreed that climate variability and the frequency of extreme weather events will increase even in the near term in all regions. Reserves of water in mountain glaciers are declining, thus affecting river flows and water availability during growing seasons (IPCC 2007). By 2020, water use is expected to increase by 40%, and 17% more water will be required for food production to meet population needs (Palaniappan and Gleick 2009).

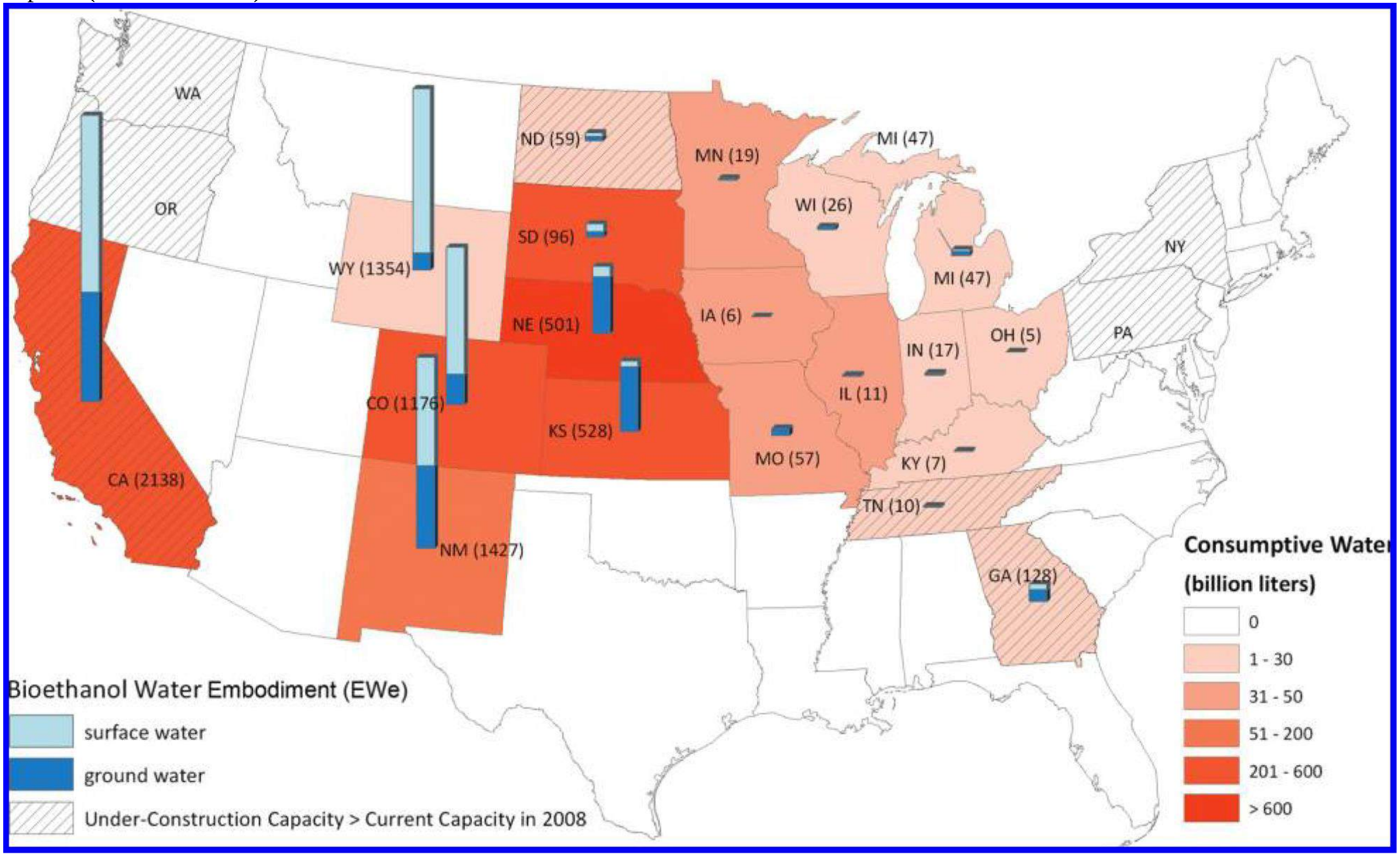
The implications of increasing biofuel production on water supply must be considered. A large-scale expansion of energy crop production will likely change evapotranspiration appropriation for energy depending on the previous land use. In some countries this could lead to further deterioration of an already stressed water situation (Berndes 2002). India and China have already exploited most of their available natural water resources for agriculture and expansion into large scale irrigated biofuel crop production is unlikely using current crops and technologies. In contrast, Sub-Saharan Africa and Latin America have enormous potential for irrigation expansion (Muller et al. 2008). De Fraiture et al (2008) estimated that 1.7% of the total irrigation water used worldwide is currently devoted to biofuel crops. If 20% of liquid transport needs are to be met by biofuels, this would rise to 5%.

Only 1% of the sugarcane crop in Brazil (approximately 40,000 ha) is irrigated and the proportion that is used for ethanol production is uncertain (Laclau 2009). According to Aquastat, (FAO 2003) the major feedstock crops in Germany and France (wheat, sugar beet and rapeseed) are not irrigated. It is possible that some of the maize, used as a minor feedstock in France, is irrigated but it is not possible to determine how much. In Canada, corn, wheat and canola used for biofuel production are not presently irrigated (Hussain et al 2011; B. Beres personal communication[1]). In India, sugarcane is mostly grown under full control irrigation and a litre of ethanol produced from this sugarcane requires 3,500 liters of irrigation water (de Fraiture and Berndes 2009).

In the United States about 15% of the corn crop used for biofuels is irrigated and the National Research Council (2008), warned that corn ethanol production increases may significantly impact water quality and availability. A study of the water used for irrigation and during processing, to produce ethanol from corn in the United States (Chiu et al. 2009), calculated embodied water in ethanol (EWe). EWe is defined as the sum of water used to irrigate corn for feedstock production (WIR) plus process water consumed within biorefineries (WP), divided by total ethanol production within a state. EWe is presented in liters of water per liter of ethanol ($L\ L^{-1}$). Naturally occurring, direct precipitation to corn fields was not included in WIR

[1] Brian Beres, Cereal Agronomist, AAFC, Lethbridge Alberta

**Figure 3:** Water use for corn production in the United States in 2007. The foreground bar shows water used per litre of ethanol with surface and ground water indicated by colour. Background colour of each state indicates TCW and reflects local and regional ethanol impacts (Chiu et al 2009).



to isolate purely anthropogenic water consumption induced by corn ethanol production. Each state's total consumptive water use (TCW) was defined as the sum of WP and WIR of the state attributable to its bioethanol production.

EWe varied widely between states from 5 to 2138 L per liter of ethanol depending on regional irrigation practices (Figure 3). As a general trend, the EWe increased from east to west and from the Midwest to the southwest regions of the U.S. Also evident from Figure 3 is the large proportion of groundwater withdrawn to produce ethanol. The TCW of South Dakota, Nebraska, Wyoming, Colorado, Kansas, Oklahoma, New Mexico, and Texas, which cover the Ogallala aquifer, amounted to 2.4 trillion liters in 2007, of which 68% was supplied from groundwater. In 2008, the TCW in these states was 4.5 trillion liters or about 18% of the estimated annual depletion rate of the entire Ogallala aquifer in 2000 (Chiu 2009). This indicates that continued use of irrigated corn to produce ethanol in these states may have significant impact on the largest fossil water reservoir in the U.S.

The predictions of future water use to grow biofuel crops in the United States are alarming. Total domestic freshwater consumption, driven mainly by population growth, is expected to increase by nearly 7% between 2005 and 2030. Water consumed for energy production is expected to increase by nearly 70%, and water consumed for biofuels (biodiesel and ethanol) production is expected to increase by almost 250% (Elcock 2010). This rise assumes that future government mandates for biofuel production (139 billion litres of renewable fuels/y of which 60 billion are cellulosic) are met. By 2030, water consumed in the production of biofuels is projected to account for nearly half of the total amount of water consumed in the production of all energy fuels. Most of this is for irrigation, and the West North Central Region (the 'corn belt') is projected to consume most of this water in 2030. The proportion of irrigation water which went to biofuels in the United States was about 3% in 2005 (Service 2009). This is projected to rise to 20% in 2030 under current government biofuel mandates.

Feedstock processing requires as much as 10 litres of water per litre of biofuel produced, and is small relative to crop needs. However, processing plants located near urban areas will often compete with cities for scarce and expensive water (de Fraiture and Berndes 2009). For example, a typical biofuel facility might produce 100 million gallons of ethanol a year and use as much water as a town of 5000 people (Service 2009). Although this amount of water is not a lot on a national scale, it could certainly strain local resources in some regions.

Research into crops with low water requirements is ongoing. For example, jatropha was promoted in India as water efficient and suitable for arid and semiarid regions. However, although jatropha persisted on arid and infertile soil, oil yields were too low under such marginal growing conditions, to make it a viable source of biodiesel (World Bank 2010). Irrigation increases yields but defeats the purpose of finding a drought resistant feedstock. In addition, irrigation made jatropha more susceptible to pests. Cellulosic feedstocks such as switchgrass and woody perennials also have low water requirements although they too grow better with irrigation and fertilization.

In summary, water use for biofuel production needs to be evaluated at different scales (state or province vs national), for each type of bioenergy source and the site-specific conditions in which they are grown (UNEP 2011). Maximizing the beneficial consumptive water use across a range of agricultural management regimes, from rainfed to irrigated crops is critical to sustainable biofuel production. UNEP (2011) suggests that in order to understand the use of, and impact on, water resources, a life cycle inventory (LCI), accounting for blue and green water use as well as pollution impacts should be carried out on bioenergy crops. This inventory has to be put in the context of the resource base in question and must consider the pressures on the water resource from all competing users.

## 7.0 Land Area and Grain Used for Biofuel Feedstocks

The International Energy Agency estimates that 30 million hectares or 2% of the world's total arable area is used for biofuel feedstock production (IEA 2011) (Table 9). The same report anticipates that by 2050, that proportion will rise to 6%.

**Table 9:** Amount and area of crops used for biofuel feedstock

| Country | Crop | Amount used for ethanol | Year | Area (% total or crop land area) | Reference |
|---|---|---|---|---|---|
| | | Million tonnes | | Million hectares | |
| World | All | | 2006<br>2011(e)<br>2050(f) | 14 (1% total arable)<br>30 (2% total arable)<br>100 (6% total arable) | IEA 2011 |
| | | 3% world's grain supply | 2010 | | REN21 2011 |
| Brazil | Sugarcane | 296 | 2009 | 4.0 (47%of sugarcane) | Barros 2010; FAO Stat 2009,2010 |
| | | 318 | 2010 | 4.3 (48% of sugarcane) | |
| E. U. | Cereals | 9 | 2010 | | Flach et al 2010 |
| | Sugar beets | 10 | 2010 | 0.24 | |
| | Rapeseed | 17 | 2009-2011 | 4-5 (60-75% total rapeseed crop) | Knight 2010; USDA 2011b; Flach et al 2010 |
| | Wheat | | 2008 | 0.5 | Flach et al 2010 |
| | Wheat | | 2013 (f) | 1.5 | Flach et al 2010 |
| Germany | All biofuel crops | | 2010 | (16 % total arable) | Lyddon 2011 |
| U.S. | Corn | 117 | 2010 | 12.2 (31% total corn) | Urbanchuk 2011 |
| | Corn | 127 | 2011(e) | 13.8 (40 % total corn) | USDA 2011a, 2012 |
| Canada | Corn | 2.1 | 2009 | 0.23(21% total corn) | Dessureault 2011 |
| | | 2.3 | 2010 | 0.26(26% total corn) | Dessureault 2011 |
| | | 2.6 | 2011(e) | 0.26(26% total corn) | Dessureault 2011 |
| | Wheat | .65-.71 | 2010 (e) | 0.26-0.28(3%total wheat) | Dessureault 2011 |
| Ontario | Corn | 2.8 | 2011 | 0.28 | KD Communications 2011 |

F=forecast; e=estimate

In Brazil, almost half of the sugar cane grown is used for ethanol although this is a very small proportion (1- 2%) of total agricultural land. In Germany, it is estimated that 16% of the arable land is used to produce all biofuels. The USDA (2012) estimates that over 40% of the area used for corn in the U.S. is directed into ethanol production. This represents about 3% of total farm land.

It is estimated that ethanol production in Canada currently uses about 26% of the corn and 3% of the wheat growing areas (Dessureault 2011). If all ethanol plants were running at full current capacity these numbers would rise to 30 and 6% respectively (Table 10). Wheat area could rise to 10% of the total area used for wheat in Canada if all proposed plants are completed and run at full capacity. The calculation of corn area required is based on the Canadian average yield of 9 tonnes/ha. If the average for Ontario is used (10.1 tonnes/ha), the amount of land would decline by about 30,000 ha and to about 26% of total corn area used.

Wheat feedstock used for ethanol theoretically uses more land than corn because of its lower crop yield (2.9 t/ha on average) and lower ethanol yield. However, as discussed below, wheat yields can be considerably higher under ideal conditions and irrigation and this would reduce the amount of land required.

Canola yields up to 900 litres/ha and Alberta's future biodiesel production would therefore require about 0.44 million ha of canola (from Table 5). This is roughly 4% of the total land used for canola in Canada.

**Table 10**. Crops used and land required for each crop used to produce ethanol in Canada at current and potential operational capacity (Assuming all ethanol plants running at 100% capacity)

| Province | Land Currently Required* (hectares) | | Land Required at Potential Production Capacity (hectares) | |
|---|---|---|---|---|
| | wheat | corn | wheat | corn |
| Alberta | 38,600 | | 333,000 | |
| Saskatchewan | 317,000 | | 317000 | |
| Manitoba^ | 59,800 | 18,000 | 59,800 | 18,000 |
| Ontario | | 298,000 | | 298,000 |
| Quebec | | 33,000 | | 33,000 |
| **TOTAL** | **415,400** | **349,000** | **709,800** | **349,000** |
| **% of Total Wheat or Corn Area in Canada** | **6%** | **30%** | **10%** | **30%** |

*1 tonne corn produces 400 litres ethanol. Average yield 9 t/ha (AAFC 2012); 1 tonne wheat produces 375 litres ethanol. Average yield 2.9 t/ha (AAFC 2012). ^Assume the Husky plant uses 50% corn and 50% wheat.

## 8.0 Land Use Change Due to Biofuel Expansion

As farmers react to price changes for commodities they can produce on their farms, adjustments in land-use decisions can be complex. Not only do land use decisions by individual farmers reflect the relative productivity of farmland for specific crops, but price expectations differ from one operator to the next, and decisions change from year-to-year as new expectations are formed (Wallander et al 2011).

In Canada, the expansion of biofuel production to date has been accommodated without land-use changes because of improvements in seed, better agricultural practices, continued growth in crop yields, technological improvements in ethanol production, and the introduction of new crops for ethanol production (Coad and Bristow 2011). In the future however, if proposed biofuel plants are built, increased areas of wheat and canola will be necessary.

In the United States, area planted to corn rose from 29.3 to 32.2 million hectares between 2000 and 2009 with much of the change occurring between 2006 and 2008 (USDA, National Agricultural Statistics Service, 2010). A study by Wallander et al (2011) showed that the largest source for new corn area was farms that grew primarily soybeans in 2006. However, there has not been a net decrease in soybean area. Reduced area planted to other crops such as cotton, a shift from uncultivated hay to cropland, and the expansion of double cropping (consecutively producing two crops of either like or unlike commodities on the same land within the same year) allowed soybean area to be maintained and corn area to expand (Wallander et al 2011). Increased conversion of hay or pasture to crop production, or an increase in area which is double-cropped and uses more inputs, may accelerate nutrient runoff and soil erosion. The proportion of shifts from relatively low-input crops to high-input crops (e.g., wheat to corn) or from one high-input crop to another (e.g., cotton to corn), will have environmental consequences. In 2011, the area planted to corn was estimated to be 37 million hectares, an additional increase of 13.5% in area over 2009 (USDA, National Agricultural Statistics Service, 2011). Much emphasis is put on the increases seen in corn yields over the last few decades, to provide the same fuel output on less agricultural land. However, average corn yields in the United States have fallen over the last three years from 10.3 t/ha in 2009, to 9.6 t/ha in 2010, 9.2 t/ha in 2011 (USDA 2011), possibly due to poor growing season conditions. Reduced average yields may also be a result of expanding production into areas less suited for corn or use of faster maturing corn types to allow for double cropping with soybeans. Seasonal variability and climate change will continue play a major role in corn feedstock supply in the United States.

More intensive management associated with increased crop yields may have environmental consequences. Increased nitrogen application may result in increased direct $N_2O$ emissions, and more intensive farming practices may result in increased erosion and decreased soil carbon sequestration. There is a limit to how much of the continuing increase in biofuel production can take place without land use change if corn, wheat and canola are the main feedstocks. Potential tradeoffs between use of land and use of other inputs to increase production must be acknowledged and incorporated into a comprehensive analysis (Marshall et al 2011).

Lignocellulosic feedstocks such as switchgrass or hybrid poplar can be grown on marginal lands not currently in use in productive agriculture. Mabee et al. (2006) estimated there are 5.3 million hectares available in Canada for such energy crops. Although cellulosic feedstocks such as perennial grasses can be grown with fewer inputs than a crop such as corn, yields can be improved through the use of fertilizer, and added nutrients will be applied if increased revenues outweigh the costs (Marshall et al 2011).

Several governments have taken steps to identify idle, underutilized, marginal or abandoned land and to allocate it for commercial biofuel production. In Indonesia, for example, the Department of Agriculture has reported that there are approximately 27 million hectares of “unproductive forest lands” that could be offered to investors and converted into plantations (Cotula et al 2008). However, there are likely to be major obstacles to commercial production of biofuels on marginal lands, and overuse of marginal land can result in long-term or permanent ecological damage such as salinization. Use of these lands also has social implications. In many cases, the livelihoods of poor and vulnerable groups depend on lands perceived by governments or private operators as marginal (e.g. for crop farming, herding and gathering of wild products). In India, for instance, jatropha is widely planted on “wasteland” that rural people rely on for fuelwood, food, fodder, timber and thatch.

Landowners will allocate land among competing uses based on the expected net benefits of those uses, and those benefits will vary for each use depending on land quality and location. A landowner seeking to maximize profits will allocate a land parcel to the use that yields the highest expected economic return after the costs of conversion, which can include changes in machinery investments and management practices. Relative expected returns change with market conditions (commodity prices, production costs, population growth, consumer tastes, international trade, and other factors affecting the demand for land in different uses), technological advancements, and weather. The level of uncertainty surrounding future conditions will affect a landowner’s assessment of expected benefits and costs (Marshall et al. 2011).

## 9.0 Summary of Canadian Biofuel Feedstocks

### *9.1Corn*

Corn, the major biofuel crop in Canada, has a relatively high starch content of about 70–72% by mass of the grain kernel (Mabee and Saddler 2010) and yields 400 litres of ethanol per tonne of corn. Average corn crop yields in Canada were reported at 9 metric tonnes per hectare for harvests between 2009 and 2011 (AAFC, 2012) and 10.1 in Ontario in 2011 (OMAFRA 2011). Although using corn to produce ethanol results in energy outputs which are greater than inputs, this number is variable and is dependent on credits given for by-products, which may or may not find a market as supplies increase. In addition, effects of intensive corn crop management on soil fertility and local water quality must be considered.

Ethanol production and cattle feedstock compete directly for corn and there is controversy about how much of recent corn price increases are a result of rising demand for ethanol. Coad and Bristow (2011) reviewed interactions between ethanol demand for corn or wheat, ethanol plants supplying DDGS, and the cost of livestock feeding in Canada. They concluded that ethanol demand for corn influences livestock feed prices in a very complex way and although corn is responsible for some of the price increase, it is thought to play a smaller role than other factors such as the rising cost of fossil fuels.

Genetically modified corn, recently developed by Syngenta, contains an added gene for an enzyme (amylase) that speeds the breakdown of starches into ethanol. Ethanol plants normally have to add the enzyme to corn when making ethanol. The Enogen-branded corn is being grown for the first time commercially on about 5,000 acres on the edge of America's corn belt in Kansas, following its approval by the US Department of Agriculture in 2010 (The Guardian 2011) . In its promotional material Syngenta says it will allow farmers to produce more ethanol from the corn while using less energy and water. Serious concerns about contamination of corn crops not used for ethanol production will no doubt be raised should this crop be grown in Canada.

Use of corn stover as well as grain for ethanol production, results in much higher yields of ethanol per hectare than grain alone (Table 9, Propheter 2010). Producing ethanol from stover will be covered in 'Agricultural Residues' below.

### *9.2.Wheat*

The majority of anticipated ethanol production capacity expansion in the medium term will take place in Alberta and will use wheat as a feedstock. Canadian wheat farmers view ethanol plants as an alternative market for their low-quality feed wheat, which is primarily downgraded hard red spring wheat damaged by early frost, disease or rains during harvest (Coad and Bristow 2011). However, such a supply would be too uncertain for ethanol plants and there is a need for high-yielding, low-protein wheat.

Traditionally, Canadian wheat cultivars were developed to express high protein concentrations for functionality in the production of bread and pasta, extracting price premiums in the marketplace. Starch content of wheat ranges from 56-61% and is inversely related to protein content. In their trial of grains for ethanol production, McLeod et al. (2010) determined that Canada Western Soft White Spring (CWSWS), Canada Prairie Spring Red (CPSR) and Canada Spring Prairie White (CPSW) classes of wheat had the highest starch levels and produced the greatest amount of ethanol (about 380 litres/tonne). Canada Western Red Spring (CWRS) and Canada Western Amber Durum (CWAD) produced the least at about 370 litres of ethanol/tonne.

Soft white spring wheats have become the standard for ethanol production, and most acres of soft wheat are now located in dryland regions of Saskatchewan, instead of the traditional irrigation belt of southern Alberta (Barker 2010). The ethanol plant at Pound-Maker Agventures in Lanigan, Saskatchewan, currently uses more than 85% AC Andrew, a low protein, high starch, high yielding Canada Western Soft White Spring.

The Canadian Grain Commission has taken several steps to modify the current wheat classification system to encourage breeding and production of ethanol and feed wheats. Effective August 2008, the Grain Commission created a new class of wheat, called Canada Western General Purpose (CWGP), and it is removing the kernel visual distinguishability (KVD) requirements for the six minor wheat classes, which include CPS, Red Winter and Soft White wheats. The commission also worked on developing techniques to replace KVD requirements for registering milling wheat varieties by 2010 (Top Crop Manager 2008).

Triticale may be of interest for ethanol production or other biorefinery applications as it is a high yielding cereal that has large seeds with high starch content and low protein accumulation. The perceived limitation for production is later maturity and susceptibility to ergot, but crop maturity of triticale parallels soft white spring wheat and is even preferred when compared to soft white spring types in shorter season environments. Ergot susceptibility has improved with the newer cultivars. The advantage of height is the increase in straw production, which could be a source of biomass, whether for ethanol or other forms of energy. Triticale has been studied for ethanol production and has similar starch content and ethanol production to the top three wheat classes (Beres et al 2010). However, the presence of high concentrations of pentosans in triticale and certain wheat classes can adversely affect the ethanol extraction process through increases in mash and wort viscosities (McLeod et al 2010). Ethanol facilities also have standards related to wheat diseases, such as a maximum tolerance level of *Fusarium* mycotoxins in the sample.

It should be noted that throughout the last few decades of the 20$^{th}$ century, breeders worked to reduce the height of small grain cereals like triticale. This was done to reduce lodging and had the excellent additional effect of shifting biomass from stems to seeds, increasing grain yields. Shifting biomass back into the stems would change it from easily degraded starch into more recalcitrant cellulose and lignin.

Phelps et al (2009) reported wheat and triticale yields increased from about 5.5 tonnes/ha (82 bu/acre) to almost 10 tonnes/ha with irrigation. It is generally too cold to produce winter wheat on the Prairies although climate change may eventually alter this.

Wheat trades internationally and is affected by world food prices. Using wheat for biofuel will depend on market prices and the need for the farmer to find new markets for his/her wheat crop.

## *9.3.Canola*

Canola is the major feedstock crop for biodiesel production in Canada although animal fats and yellow grease currently supply a large portion of plant production needs. Canola will become more important when the current biodiesel plant in Lloyminster, Alberta is completed and if the proposed plant in Vegreville, Alberta goes ahead (Appendix B) as both used oil seed as feedstock. The Vegreville cropping area has a high proportion of seeded hectares sown to canola as well as high average yields and oil content. According to BioStreet, the company building this processing plant, by procuring locally produced feedstock, total lifecycle GHG emissions will remain low when compared to imported feedstock such as soybean and palm oil, and quality will remain high due to the superior cold weather properties of canola. A recent study commissioned by the Canola Council of Canada demonstrates that Canadian canola biodiesel compared to petroleum diesel reduces GHG emissions by 92.5%.

The introduction of new canola hybrids and biotechnological traits, along with improved agronomic practices have allowed Canadian farmers to improve canola yields over the past 15 years, to meet both food and fuel demands. Average canola yields rose 50% from 1.2 to 1.8 tonnes/hectare between 1995 and 2010 (Canola Council of Canada 2012). According to the Canola Council for Canada, Canadian farmers are already growing more than enough canola to fill the demand for both food and fuel. The federal government’s 2% biodiesel mandate would require about one million tonnes (MT) of canola seed annually. Historically, food demand has left enough carryover (ending stocks) of canola seed to fill this biofuel demand. This could however, result in lower canola exports.

## *9.4.Lignocellulosic Feedstocks*

Second generation biofuels are made from lignocellulosic biomass feedstocks using advanced technological processes that convert cellulose, found in plant structural elements such as stalks, leaves, grasses, and even trees, to ethanol. Cellulosic conversion technologies for the production of ethanol offer significant benefits over grain-based production of ethanol, including a higher ethanol yield per hectare from a diverse array of feedstocks and the use of perennial feedstocks that require less intensive management than annual grains. The amount of cellulosic material available for potential use vastly outweighs the amount of available starch based substrate. According to Gronowska et al (2009), there are between 64 and 561 million dry tonnes of biomass available in Canada.

The cost of pre-processing cellulosic material to generate free glucose is much higher than that for conventional feedstock, as both mechanical and thermochemical treatments are often required. Although there is growing interest and investment in lignocellulosic feedstock for ethanol production, the technological advances are proceeding more slowly than expected. Established by the U.S. government in 2007, the mandate for cellulosic biofuel production in 2010 was 100 million gallons, rising to 250 million in 2011 and 500 million in 2012. In late 2010 the Environmental Protection Agency, which has the authority to revise the mandates, reduced the 2011 requirement by 243.4 million gallons to 6.6 million (EPA 2010). In December 2011, the 2012 mandate of 500 million gallons was lowered to 8.65 million gallons (EPA 2011).

There is no mandate for cellulosic biofuels in Canada although there are several plants proposed or under construction, including municipal waste plants in Edmonton and Varennes and several operational demonstration plants. Lignol Energy Corporation, which specializes in cellulosic bioethanol and biorefining has a pilot plant in Burnaby, British Columbia that produces cellulosic bioethanol. In 2010 Lignol signed a research and development agreement with Novozymes, the world's leading producer of industrial enzymes, to make biofuel from wood chips and other forestry residues (Dessureault 2011). The partners aim to develop a process for making biofuel from forestry waste at a cost as low as $0.53/L ($2/ U.S.gallon), a price competitive with gasoline and corn bioethanol at the current United States' market prices. With support from the Government of Canada, Iogen Corporation has built a demonstration plant to convert biomass fibers to bioethanol using enzyme technology. Located in Ottawa, Ontario, the plant can process over 25 tons of wheat straw per week, using enzymes produced in an adjacent facility.

Ontario Power Generation (OPG) is looking to buy two to three million tonnes of biomass annually by 2015, the date at which the Ontario government has mandated an end to burning coal for electricity generation (Dessureault 2011). Biomass is being targeted to replace coal as soon as technical obstacles are overcome. However, a more efficient and condensed solution for the transport and handling of biomass needs to be developed.

### ***9.4.1*** *Agricultural Residues*

Average residues for wheat, barley, and oat, are 1.3, 1.0 and 1.2 tonnes/ha, although higher weights have been recorded for wheat depending upon the harvest method employed (reviewed by Mabee and Saddler 2010). Wheat straw is predominantly comprised of cellulose, and contains on average 35% cellulose by weight. Hemicellulose makes up approximately one quarter of the weight of straw, and the most common type of hemicellulose is xylan. Thus, approximately 60% of straw can be converted to sugars and 394 litres ethanol/dry ton wheat straw produced (GenSolutions

2007). However, ethanol production from five carbon sugars in hemicelluloses is generally much less efficient than conversion of the six carbon sugars in cellulose.

The amount of straw that can be removed and utilized should be based on a number of factors, such as:

- value of straw for soil erosion control;
- equivalent fertilizer value of the nutrients contained within the straw;
- value of the straw for building soil organic matter, soil quality, and soil tilth; and
- value of the straw for soil moisture conservation (Gov. Sask 2006).

It should be assumed that soil conservation requirements will account for 50% or more of the total residues in many areas, and older studies indicate that particularly dry conditions could result in mandating that 100% of residues remain on the field (Mabee and Saddler 2010). Furthermore, a proportion of cereal straw will generally be utilized by farmers for livestock feed. After accounting for the factors of soil conservation, livestock feed and season variation, Bowyer and Stockmann (2001) suggested that between 15% and 40% of the total residue production would be available on average for industrial purposes.

### ***9.4.2**. Switchgrass*

Switchgrass is a perennial grass, native to the prairie region of North America, and has a number of characteristics which are desirable for use as a bioenergy feedstock, including high productivity, persistence and wide adaptation (Coulman et al. submitted). Switchgrass is not currently grown as a crop in Canada although several trials have taken place across the Prairie Provinces and in central Canada with the goal of creating an economically viable energy crop. Switchgrass grows rapidly, thus providing a large amount of energy potential when compared to crop residues and, as a perennial grass, it requires a minimal amount of resources to cultivate. Numerous studies have evaluated nitrogen fertilizer application and harvest management in switchgrass, identifying these management practices as critical to not only crop productivity but also to the long-term stand persistence and greenhouse gas emission or sequestration. (Reviewed by Coulman et al, submitted). However, fewer inputs of fertilizer and less fossil fuels are burned in the seeding of switchgrass than for any cereal crop (GenSolutions 2007). Plant growth promoting rhizobacteria (PGPR), that increase yields and enhance nitrogen use efficiency possibly through nitrogen fixation have been isolated from switchgrass and may explain its low requirements for nitrogen fertilization (Ker et al. submitted 2012).

### ***9.4.3**. Wood*

Hybrid poplar is the target of large breeding programs and plantations for solid wood and pulp and paper production. It can be grown in many regions of the US and Canada but to date the amount of land in industrial plantations is still quite limited (Coulman et al. submitted). Hybrid poplars are cut from twelve to twenty-five years after planting. Fast-growing willows are also being considered for ethanol production and can be harvested in three to ten year cycles. Both crops have excellent potential for simultaneous heat and power generation through burning of wood pellets/biomass, but are not yet good candidates for bioethanol production due to the challenge of efficiently converting woody feedstocks into liquid biofuel.

The wood pellet industry in Canada, especially in the west, has grown at an annual average rate of more than 20% over the last 5 years due to the steady supply of wood residues, and increasing demand from Europe. According to the Canadian Wood Pellet Association, as of 2010, Canada has 33 pellet plants with 2 million tons annual production capacity. In 2010, Canada's pellet plants operated at about 65% capacity, producing about 1.3 million tonnes per year. The province of British Columbia accounts for about 65% of Canadian production and capacity, while, collectively, the provinces of Alberta, Quebec, New Brunswick, Nova Scotia, and New Brunswick account for 35%. Contrary to the United States, where almost all the 800,000 tons of wood pellets produced are consumed domestically, more than 80% of wood pellets manufactured in Canada are exported to Europe (Dessureault 2011).

## 10.0 Economics of Biofuel Production

The baseline for measuring the economics of biofuels is the price of gasoline and diesel. However, these fossil fuels have been heavily subsidized by government. Thus, comparison of biofuel cost per litre with "at the pump" gasoline cost does not constitute a level playing field. In addition, decades of research, much of it paid for with public money, has provided huge advances in technology that make refineries efficient and cost effective. Petro-refineries have had the time to develop full and complex economics; approximately 40% of the profits of a petro-refinery come from non-fuel products although they may make up only about 5% of the refinery output. These include monomers used to make plastics, chemicals for inks, dyes and paints, etc. Such high-value products have not yet been developed for biorefineries although it is safe to assume that there is a similar bioproducts potential. This will substantially change the overall economics of biofuel production.

Rising costs of biofuel feedstocks in recent years have substantially increased production costs of biofuels. The cost of ethanol production from sugarcane, currently the most economical biofuel feedstock to produce (Table 11), was less than the price of gasoline only one year out of five between 2000 and 2010 (World Bank 2010). In the remaining years, a subsidy would have been needed to make ethanol cost-competitive with gasoline. This means that, without a subsidy, farmers would prefer to sell sugarcane to sugar producers rather than to ethanol manufacturers. This was evident in 2010 when the price of sugar rose rapidly and Brazil, which has a flexible fuel mandate, was forced to reduce the blending proportion of ethanol in gasoline from 25% to 20% (World Bank 2010).

The cellulosic feedstocks in Table 11, (switchgrass and corn stover) have low production costs and high initial investment costs in the two studies reported. This latter value will decline over time as technology improves.

The amount of energy in ethanol is only 66% that of gasoline which means every litre of gasoline replaced requires 1.24 litres of ethanol to produce the same energy. Drivers who fill their tanks with E5 are getting slightly worse mileage than with pure gas and this mileage declines as the proportion of ethanol increases. This makes the economics of ethanol less encouraging.

**Table 11: Costs associated with biofuel production** (FO Lichts 2007; Tao and Aden 2009, Fulton 2010)

| Feedstock | Country | Net Production Cost USD/litre | Total Project Investment* USD/litre |
|---|---|---|---|
| Corn | United States | 0.41-0.79# | 0.77 |
| Sugarcane | Brazil | 0.30 | 0.51 |
| Grain-based | E.U. | 0.58 | NA |
| Beet-based | E.U. | 0.48 | NA |
| Switchgrass^ | United States | 0.27 | .76 |
| Corn stover | United States | 0.39 | 1.10 |
| Soybean | United States | 0.53-0.67 | 0.14 |

*Cost for a 45 MM/gal/y plant depreciated over 20 years. ^From research plots dedicated to switchgrass production in Tennessee (Fulton 2010). # From an informal estimate based on a corn price of USD 7.00/bushel.

Biodiesel economics are more unfavorable than ethanol. Biodiesel feedstock costs alone have generally been higher than petroleum diesel prices. According to Smith et al (2007), at a diesel fuel price of $1/litre, the oilseed oil price could not exceed $539/ton for biodiesel to break even. The current price for diesel is $1.10/ litre and soybean and canola oil prices are over $1100 tonne making biodiesel very expensive to produce from these feedstocks. It is interesting to note however, that although the net production cost of biodiesel from soybean is high, the capital investment for a biodiesel plant, amortized over 20 years, is low (Table 11). The transesterification process is relatively simple and consumes much less energy when compared to distillation of ethanol. Biodiesel contains 88% the amount of energy in diesel fuel so gains a few points relative to ethanol in this regard.

Biofuel economics vary widely with geographic region and potential for local feedstock production. For example, the economics may be favorable in petroleum-importing landlocked or remote areas where transportation costs for imports are high and there are indigenous sources of biofuel feedstocks that can be grown at reasonable costs (World Bank 2010). The economics of exporting surplus feedstocks or biofuels depend on distance to markets as well as production costs and world prices. It should be noted that Table 11 does not include the cost of transporting the feedstock crop to the processing plant. The farmer in Iowa who has five ethanol plants within a 50 km radius of his farm will have much lower transportation costs than a farmer in Southern Alberta who has to drive his crop several hundred kilometers to reach a plant.

Biofuel economics are more favorable where surplus by-products such as molasses are used as feedstocks rather than primary feedstocks. Using wastes as feedstock could also have low costs, although the economics depends directly on the cost of collecting and transporting the wastes to a biofuel manufacturing plant. In addition, wastes often have other markets: waste oils and greases can be sold to rendering companies; waste forestry materials can be made into wood pellets.

## 11.0 Uncertainties in Predicting Future Biofuel Demands

Biofuel demand in Canada and around the world is driven by oil prices, the cost of other transportation energy alternatives (e.g. electric vehicles) and by government policies which mandate biofuel use and provide incentives for production. It is likely that high and volatile food prices and food insecurity predicted for the future will drive the focus away from the use of food crops for biofuels towards non-food crops. The effectiveness of biofuel use in reducing greenhouse gas emissions is also likely to become increasingly important. Policy changes in the E.U. and the U.S. to limit carbon emissions could have a significant impact on the kinds of crops and technology that are used for biofuel production (IFPRI 2012).

In the U.S. corn is the predominant source of ethanol and in some states, a large proportion of that corn is, by necessity, irrigated. Irrigated corn does not have any advantage over rain-fed corn in its yield of ethanol per ton of grain although, as with all irrigated crops, the guaranteed supply of feedstock is critical to the ethanol production plant. Corn production in the U.S. continues to be subsidized and in 2010 corn farmers received $3.5 billion in direct payments or crop insurance premium subsidies (EWG 2011). Significant water use and generous government subsidies currently ensure corn ethanol production in the U.S. If water use is constrained, subsidies decline, food prices rise or policy changes in the U.S. lower acceptable carbon emissions from bioenergy crops, the use of corn-derived ethanol will likely decline. Canadian ethanol derived from corn which does not require irrigation, and generally has lower energy requirements, may have a more optimistic future although the conflict between food and energy will remain.

The yield of canola, the other significant crop for biofuel production in Canada, can be increased through irrigation although production of biodiesel would not be profitable under current market conditions. Canola prices are sufficiently high, and Canadian biodiesel subsidies sufficiently low or non-existent, that the Fame demonstration biodiesel plant in Alberta has recently converted to making canola oil due to 'lack of investment appetite" for producing biodiesel (Oil and Oilseed News 2012). High River-based Western Biodiesel Inc., with 19 million liter/year capacity for biodiesel production closed its doors in 2011 partly because it said the federal government owed it $600,000 in incentives (Chandler 2012).

As fossil fuel supplies diminish in the long term, or are disrupted in the short term by political stability in oil-producing nations, oil prices will become more volatile and more expensive. At the same time, demand for energy in Canada's transportation sector will rise by 1.4% annually (NEB 2011). At a glance, this scenario makes the development of renewable, sustainable fuels that have the added advantage of rejuvenating rural areas, an obvious solution in many regions to meet rising transportation energy needs. Biofuels made from crops have, however, some inherent problems that result in unfavourable economics at our current level of technology. Unlike oil, which is concentrated in one place and generally unaffected by weather, biofuel feedstocks are spread out in a thin layer across a large area, and supply is affected by drought, flooding and pests. They also have a low energy density which means that the large volumes required to produce fuel, are costly to transport to processing plants.

The cost of producing biofuels from crops is generally higher than the selling price, and without government incentives they would not, at current biofuel prices, be profitable. The cost of fuel production is largely due to the cost of feedstocks (corn, sugarcane, wheat, sugar beets, rapeseed, soybean) and their prices naturally follow world food prices. If land and water prices increase significantly in the future, the cost of producing biofuels will also rise. As demand for food rises worldwide, the economics of producing biofuels from crops will be a balance between the ethical issues of using food for fuel and the cost of fossil fuels vs biofuels. In the United States particularly, securing a sufficient supply of energy is a much greater problem than growing enough food. If the balance is tilted in favour of energy, this would have global consequences for food security.

Canada's E5 mandate will require an additional capacity of 700,000 million litres of ethanol per year by 2030, assuming none is imported. This will require ongoing government support which, at least for time being, seems to be stable. World trade in biofuels is also growing and changing dramatically at the moment, and also needs further study to understand potential impacts on Canada's biofuel industry.

Even with uncertainty about future government policies and world trade, it may be possible to create an economically viable biofuel industry in specific regions. For example, a small ethanol plant (20-25 million litre capacity) that is directly linked to a feedlot will have a ready market for its by-product, distiller's grain, and can avoid the high costs of drying and transportation. This would make it less susceptible to volatile food and fuel prices. Development of other valuable by-products would also help to bring down the per litre cost of producing ethanol. For example, Amaizeingly Green Products LP (formerly Collingwood Ethanol LP) a corn ethanol wet mill facility in Collingwood, Ontario has developed a number of value added co-products from corn gluten meal including a corn gluten natural fertilizer, weed control and pet food products. Co-product sales now contribute to a major percentage of the baseline revenue of the facility.

Second-generation technologies—using agricultural residues, forestry products, dedicated energy crops, or municipal and other wastes—or third-generation algae-based technologies could, under certain circumstances, transform the biofuels industry away from one competing for land needed for food production, and thus make a larger contribution to energy security with much smaller adverse effects than today's industry. While second-generation technologies may be more water efficient than currently used feedstocks, algal technologies require large amounts of water as feedstock must be grown in ponds. Crop residues are not without value and a sizable fraction is usually returned to the soil to manage organic matter and soil fertility. Some crop residues are used as animal feed and bedding (maize stover being an example), and, especially in low-income developing countries, they are burned as fuel.

## 12.0 Recommendations for Biofuel Opportunities in Canada under Irrigation

Irrigated crops are not currently used for biofuel production in Canada. Planned expansion of biodiesel production in canola growing areas of Alberta will not use irrigated cropland (Appendix D).

Bioethanol plants in Alberta are also not located near irrigated areas (Appendix D). Although expansion of ethanol production in that province will use wheat as a primary feedstock, two future plants, one proposed (Innisfail) and one under construction (Hairy Hill), are located north of irrigated areas. The high cost of transportation will make it very unlikely that any irrigated wheat will be used as feedstock in these plants.

In Saskatchewan and Manitoba, ethanol plants are located at the edge of irrigated areas, but there is no evidence that irrigated crops are currently used as feedstock. Irrigation can more than double wheat yields when water is limiting and, if infrastructure is already in place, may help to develop a reliable source of biofuel crops in some areas. The price of water would have to be accounted for in any cost-benefit analysis. Where there is currently no irrigation infrastructure, the investment in off- and on-farm irrigation infrastructure and the costs of operating irrigation equipment are almost certainly not cost effective for producing biofuel feedstock.

The bottom line is the price the farmer can get for his crop versus the cost of crop production and transportation. A biofuel production plant offers an alternate market for many crops. Multi-feedstock plants that can utilize crops as well as lower cost materials such as waste oils for biodiesel production, or cellulosic materials for ethanol production, would allow the farmer to obtain a fair price for his crop and reduce the overall price of feedstock to the production plant. The market will determine if an irrigated crop is viable for use as a biofuel.

## 13.0 Research and Technology Transfer Needs for Sustainable Biofuel Production under Irrigation

The authors feel that although there are currently limited opportunities for biofuel production under irrigation in Canada, more research needs to be carried out to develop an economically viable and stable biofuel industry. Further research into breeding and agronomics of biofuel crops, sustainable management methodologies, which may include irrigation, and plant processing technologies and by-product development, would be valuable for future biofuel expansion in Canada. In addition, the potential for genetically engineering the genes of purpose-grown feedstock for production of really high value by-products, such as pharmaceuticals, could be considered. Potential locations for future biofuel plants should also be studied and include long-term economic impacts on the food and fuel sectors, environmental impacts, benefits to the farmers and local communities, and the economics of the plant itself.

Although research and technology into the use of lignocellulosic feedstocks for ethanol is evolving more slowly than anticipated, perennial grasses and woody production systems are increasingly felt to be the future of ethanol production. Low water and fertilizer requirements and the fact they are not a food crop and can be grown on marginal crop lands, are strong advantages.

The development of a national policy framework for sustainable biofuel production practices in Canada is also needed. Such a framework would define acceptable levels of carbon emissions from biofuel production and address implications for water resources (see Section 6.0) and agricultural land use. The policy would need to be refined at provincial, or smaller, scales.

## References


AAFC, 2012. Canada: Grains and Oilseeds Outlook: 2011–12. January 17, 2012, ISSN 1496-967X. Agriculture and Agri-Food Canada (AAFC), Ottawa, Canada. p. 2.

Amaizeingly Green website. http://www.amaizeinglygreen.com/ Accessed March 7, 2012.

Aradhey, A. 2011. India Biofuels Annual. USDA Foreign Agricultural Service. Global Agricultural Information Network. GAIN Report Number IN1159

Baldi, S. 2011. Italy Biofuels Annual. USDA Foreign Agricultural Service. Global Agricultural Information Network. GAIN Report Number IT1160

Barker, B. 2010. Selecting High Cereal Yield Varieties. Top Crop Manager February 2010.

Barros, Sergio. 2010. Brazil Biofuels Annual. USDA Foreign Agricultural Service. Global Agricultural Information Network. GAIN Report Number BR10006

Beres, B.L. Randhawa, H., Eudes, F., Goyal, A., Graf, R.J. et al. 2010. A Pan-Canadian Ethanol Feedstock Study to Benchmark the Relative Performance of Triticale. AAFC Conference Poster

Berndes, G. 2002. Bioenergy and water—the implications of large-scale bioenergy production for water use and supply. Global Environmental Change 12 : 253–271

Biofuels Platform. 2010. http://www.biofuels-platform.ch/en/infos/eu-bioethanol.php

BioStreet. 2012. http://www.biostreetcanada.com/vegreville_energy.php

Bird, N., Cowie, A., Cherubini, F. and Jungmeier, G. 2011. Using a Life Cycle Assessment Approach to Estimate the Net Greenhouse Gas Emissions of Bioenergy. IEA Bioenergy E xExCo

Brazil Institute. 2007. The Global Dynamics of Biofuels. Woodrow Wilson International Center for Scholars

Brown, L. 2006. Plan B 2.0 Rescuing a Planet Under Stress and a Civilization in Trouble NY: W.W. Norton & Co. © 2006 Earth Policy Institute.

Canakci, M. 2006. Combustion characteristics of a turbocharged DI compression ignition engine fueled with petroleum diesel fuels and biodiesel. Bioresource Technology 98: 1167-1175.

Canada Renewable Fuels Association (CRFA). 2010. Growing Beyond Oil Delivering our Energy Future. www.greenfuels.com

Canola Council of Canada. 2011. Canola A Sustainable Source for Food and Fuel. Fact Sheet available at http://www.canolacouncil.org/biodiesel/biodiesel_factsheets.aspx

Chandler, Graham. 2012. Alberta's support for bio-fuels yields an uncertain harvest. Alberta Oil Magazine. April 9, 2012.

Cherubini, F, Birda,N.D., Cowieb, A., Jungmeiera, G., Schlamadingerc,B, Woess-Gallasch, S. 2009. Energy- and greenhouse gas-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations. Resources, Conservation and Recycling 53:434-447

Chui , Y-W., Walseth, B. and Wonsuh, S. 2009. Water Embodied in Bioethanol in the United States. Environ. Sci. Technol. 2009, 43, 2688–2692

Coad, L and Bristow, M.. 2011. Ethanol's Potential Contribution to Canada's Transportation Sector. The Conference Board of Canada. 68 pp

Congressional Budget Office (CBO). 2010. Using biofuel tax credits to achieve energy and environmental policy goals. July 2010. http://www.cbo.gov/publication/25088

Cotula,L. N. Dyer and S. Vermeulen. 2008 Fuelling exclusion? The biofuels boom and poor people's access to land. Published by the International Institute for Environment and Development (IIED) and FAO.

Coulman, B., Heaton, E., Lefsrud, M., Levin, D., Neale, D., Singh, J., Smith,D.L.,Whalen, J. (submitted February 2012). Lignocellulosic biofuel feedstocks. Biofpr.

Darby, M. 2010. Australia Biofuels Annual. USDA Foreign Agricultural Service. Global Agricultural Information Network.

De Fraiture, C., M. Giordano, Y. Liao. 2008. Biofuels and implications for agricultural water uses: blue impacts of green energy. *Water Policy* 10(S1), 67–81

De Fraiture, C. And G. Berndes. 2009. Biofuels and water. Pages 139-153 in R.W. Howarth and S. Bringezu (eds.) Biofuels: Environmental Consequences and Interactions with Changing Land Use. Proceedings of the Scientific Committee on Problems of the Environment (SCOPE) International Biofuels Project Rapid Assessment, 22-25 September 2008, Gummersbach Germany. Cornell University, Ithaca NY, USA. (http://cip.cornell.edu/biofuels/)

Dessureault, D. 2011. Canada Biofuels Annual. USDA Foreign Agricultural Service. Global Agricultural Information Network. GAIN Report Number CA11036

De Vries, S. van de Ven, G., van Ittersum, M. Giller, K. 2010 Resource use efficiency and environmental performance of nine major biofuel crops, processed by first-generation conversion techniques. Biomass and BioEnergy 34:588-601

EcoFys. 2007. Bioethanol from Cassava. Ecofys Netherlands BV, Utrecht.

Elcock, D. 2010. Future U.S. Water Consumption: The Role of Energy Production. Journal of the American Water Resources Association (JAWRA) 46(3):447-460. DOI: 10.1111/j.1752-1688.2009.00413x.

Environmental Protection Agency (EPA) 2009. Lifecycle Analysis of Greenhouse Gas Emissions from Renewable Fuels EPA-420-F-09-024, May 2009

Environmental Protection Agency (EPA). 2010. EPA Finalizes Renewable Fuel Standards for 2011. Office of Transportation and Air Quality EPA-420-F-10-056 November 2010 http://www.epa.gov/otaq/fuels/renewablefuels/420f10056.htm Accessed Feb 8, 2012

Environmental Protection Agency (EPA) 2011. EPA Finalizes Renewable Fuel Standards for 2012. Office of Transportation and Air Quality EPA-420-F-11-044 December 2011 http://www.epa.gov/otaq/fuels/renewablefuels/regulations.htm Accessed Feb 8, 2012

Environmental Protection Agency (EPA) 2011b. EPA Issues Notice of Data Availability Concerning Renewable Fuels Produced from Palm Oil Under the RFS Program. Office of Transportation and Air Quality. EPA-420-F-11-046. December 2011.

Environmental Working Group (EWG). 2011. 2011 Farm Subsidy Database. http://farm.ewg.org/progdetail.php?fips=00000&progcode=corn

European Biomass Industry Association (EUBIA). 2007. Bioethanol. http://www.eubia.org/212.0.html Accessed Feb 27, 2012

European Commission. 2010. Report from the Commission on indirect land-use change related to biofuels and bioliquids. Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52010DC0811:EN:HTML:NOT

Flach, B., Lieberz, S., Bendz, D. Dahlbacka, B. and Achilles, D. 2010. E.U. Biofuels Annual. USDA Foreign Agricultural Service. Global Agricultural Information Network. GAIN Report Number NL0019.

FO Lichts. 2007. Ethanol production costs: a worldwide survey, a special study from FO Lichts and Agra CEAS Consulting. Agra Informa, Tunbridge Wells, Kent; 2007.

Fulton, A.D. 2010. Economic Impacts of Production, Storage, Transport, and Conversion of Switchgrass for Cellulosic Ethanol in Tennessee. M.Sc. Thesis. University of Tennessee, Knoxville.

Freedman,J. 2011. E.U. plans probe of U.S. bioethanol imports. http://www.bloomberg.com/news/2011-11-17/eu-plans-probe-of-u-s-bioethanol-imports-threatening-taxes.html

GenSolutions. 2007. Risk Assessment for Bioenergy Manufacturing Facilities in Alberta. Report submitted to Bio-Industrial Technologies Division Director Alberta Agriculture and Food.

Global Renewable Fuels Alliance. 2011. Press Release February 2011.

Government of Saskatchewan. 2006. Best Management Practices when Harvesting Surplus Cereal Straw**.** July 2006 .
http://www.agriculture.gov.sk.ca/Default.aspx?DN=9d0653b7-9839-42e5-9a72-c5f678834165

Gronowska, M., Joshi, S., MacLean, H.L., 2009. A review of US and Canadian biomass supply studies. Bioresources 4:341–369.

The Guardian. 2011. GM corn being developed for fuel instead of food. Accessed Feb 26, 2012 at http://www.guardian.co.uk/environment/2011/aug/15/gm-corn-development-food-fuel/print

Guerrero, M. 2011. Spain Biofuels Annual. USDA Foreign Agricultural Service. Global Agricultural Information Network.GAIN Report Number SP1123

Henard, M-C. 2010. France Biofuels Annual. USDA Foreign Agricultural Service. Global Agricultural Information Network. GAIN Report Number FR9042

Hofman, 2003. Biodiesel fuel. North Dakota State University. AE 1240

Hussain, M.M., Dincer, I and Reddy, B.V. 2011. A comparative life cycle assessment of bio- and conventional fuels in a Canadian province. Intl J. Energy research 35:795-804 DOI: 10.1002/er.1742

International Food Policy Research Institute (IFPRI). 2012. 2011 Global Food Policy Report. IFPRI, Washington, D.C.

International Energy Agency (IEA).2011. Technology Roadmap. Biofuels for Transport. IEA/OECD Available at http://www.iea.org/roadmaps/biofuels.asp

International Panel on Climate Change (IPCC). 2007. Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability. http://www.ipcc.ch/publications_and_data/ar4/wg2/en/contents.html

Joseph, K.2011. Argentina Biofuels Annual. USDA Foreign Agricultural Service. Global Agricultural Information Network. GAIN Report Number – no number

KD Communications. 2011. What are the Effects of Biofuels and Bioproducts on the Environment, Crop and Food Prices and World Hunger? Grain Farmers of Ontario. http://www.greenfuels.org/en/resource-centre.aspx

Ker, K., Seguin, P., Driscoll, B.T. Fyles, J. W., Smith, D.L. Submitted 2012. N dynamics of switchgrass: Effects of inoculation by endophytic plant growth promoting rhizobacteria on establishment year N use efficiency. Biomass and Bioenergy

Knight, B. 2010. Biofuels: Their impact on crop production worldwide. Aspects of Applied Biology 101, 2010

LaClau, J-P. 2009. Growth of the whole root system for a plant crop of sugarcane under rainfed and irrigated environments in Brazil. Field Crops Research 114:351-360.

Lamers, P. 2011. International biodiesel markets. Development in production and trade. German Union for the Promotion of Oils and Protein Plants (UFOP). Berlin, Germany.

Lyddon, C. 2011. Focus on Germany. E.U.'s second largest grain producer features strong organic market and growing biofuels industry. World-grain.com

Mabee, W.E. and Saddler, J.N. 2010. Bioethanol from lignocellulosics: Status and perspectives in Canada. Bioresource Technology 101: 4806–4813

Mabee, W.E., Fraser, E.D.G., McFarlane, P.N., Saddler, J.N., 2006. Canadian biomass reserves for biorefining. Appl. Biochem. Biotechnol. 129, 22–40.

Macedo, I.C., Seabra, J. E.A. and Silva, J.2008..Greenhouse gases emissions in the production and use of ethanol from sugarcane in Brazil: the 2005/06 averages and a prediction for 2020. Biomass and Bioenergy 32: 582-595.

Marshall, E., Caswell, M., Malcolm, S. Motamed, M. Hrubovcak, J., Jones, C and Nickerson, C. 2011. Measuring the indirect land use change associated with increased biofuel feedstock production: a review of modeling efforts: Report to Congress. USDA Administrative Publication No. (AP054) 56 pp, February 2011

McLeod, J. G., May, W. E., Salmon, D. F., Sosulski, K., Thomas, J. B., Brown, P. D. and Vera, C. L. 2010. Changes in ethanol production potential due to species, cultivar and location on the Canadian prairie. Can. J. Plant Sci. 90: 163-171.

Molden D, Frenken K, Barker R, de Fraiture C, Mati B, Svendsen M, Sadoff C, Max Finlayson *C.* 2007. Trends in water and agricultural development. *In* Molden, D. (ed) Water For Food, Water For Life: A Comprehensive Assessment of Water Management in Agriculture. London: Earthscan, and Colombo: International Water Management Institute. Accessed at http://www.iwmi.cgiar.org/Assessment/

Muller, A., J. Schmidhuber, J. Hoogeveen, P. Steduto. 2008. Some insights in the effect of growing bioenergy demand on global food security and natural resources. Water Policy 10 (S1): 83–94.

National Biodiesel Board (NBB) 2012. The Biodiesel Bulletin February 2012. http://www.biodiesel.org/news/bulletin/#1 Accessed Feb 3, 2012.

National Energy Board (NEB). 2011. Canada's Energy Future: Energy Supply and Demand Projections to 2035. An energy market assessment. November 2011. http://www.neb-one.gc.ca/clf-nsi

National Research Council. Water Implications of Biofuels Production in the United States; National Academies Press: Washington, D.C., 2008; pp 19-25.

Natural Resources Canada (NRCAN). 2012. ecoEnergy for Biofuels Program. http://oee.nrcan.gc.ca/transportation/alternative-fuels/programs/10163 Accessed April 26, 2012.

Natural Resources Canada (NRCAN). 2007. Canadian Ammonia Producers - Benchmarking Energy Efficiency and Carbon Dioxide Emissions. http://oee.nrcan.gc.ca/publications/infosource/home/index.cfm?act=online&id=5972&format= PDF&lang=01

Oil and Oilseed News. 2012. Canada's biodiesel plant switched focus to edible canola oil. February 23, 2012. http://entelliprise.com/External/News_full.aspx?DocNumber=3417

Organisation for Economic Co-operation and Development (OECD). 2006. *Agricultural Market Impacts of Future Growth in the Production of Biofuels.* AGR/CA/APM(2005)24/Final, Directorate for Food, Agriculture and Fisheries, Paris: OECD, 2006.

OECD-FAO. 2011. OECD-FAO Agricultural Outlook 2011-2020 http://www.agri-outlook.org/document/0/0,3746,en_36774715_36775671_47877696_1_1_1_1,00.html

OMAFRA. 2011. Ontario Field Crop Report 2011 Corn Seasonal Summary. http://omafra.gov.on.ca/english/crops/field/reports/2011summary-corn.htm

Papong, S. and Malukul, P. 2010. Life-cycle energy and environmental analysis of bioethanol production from cassava in Thailand. Bioresource Technology 101:111-118

Pahl, G. 2005. Biodiesel: Growing a new energy economy. Chelsea Green Publishing Company, White River Junction, Vermont, USA. 281 p.

Palaniappan, M. and Gleick, P. 2009. Peak water. *In*: The World's Water 2008-2009. The Biennial Report on Freshwater Resources. P. H. Gleick with H. Cooley, M. J. Cohen, M.Morikawa,

J. Morrison, and M. Palaniappan. Pacific Institute for Studies in Development, Environment, and Security.

Phelps, S.M. B. Beres, E. Johnson, C. Pozniak, S. Chant. 2009. 2008 Western Canadian Ethanol Feedstock Trial Interim Report – Feb 10, 2009. Western Applied Research Corporation

Pinzon, L. 2009. Columbia Biofuels Annual. USDA Foreign Agricultural Service. Global Agricultural Information Network.

Preechajarn, S. and Prasertsri, P. 2011. Thailand Biofuels Annual. USDA Foreign Agricultural Service. Global Agricultural Information Network. GAIN Report Number TH1088

Propheter, J.L., Staggenborg, S.A., Wu, X and Wan, D. 2010. Performance of Annual and Perennial Biofuel Crops: Yield during the First Two Years. Agronomy Journal 102: 806-814

Prueksakornand, K. and Gheewala, S. 2008. Full Chain Energy Analysis of Biodiesel from *Jatropha curcas L.* in Thailand**.** Environmental Science & Technology 42: 3388-3393.

REN21. 2011. Renewables 2011 Global Status Report Paris: REN21 Secretariat.

Renewable Fuels Association (RFA)2012. Ethanol Industry Overview http://www.ethanolrfa.org/pages/statistics#C

$(S\&T)^2$ Consultants Inc. 2003. The Addition of Ethanol From Wheat to GHGEnius. Office of Energy Efficiency, Natural Resources Canada

$(S\&T)^2$ Consultants Inc. 2010. Lifecycle Analysis Canola Biodiesel. Prepared for the Canola Council of Canada.

$(S\&T)^2$ Consultants Inc. 2011. Biodiesel GHG Emissions, Past, Present and Future: A Report to IEA Bioenergy Task. Report T39-T1a.

Schill, S.2008. Move Over Corn, Wheat's King In Western Canada. Ethanol Producer Magazine.

Scott, R. Junyang, J. 2011. China Biofuels Annual. USDA Foreign Agricultural Service. Global Agricultural Information Network. GAIN Report Number 11039

Service, R. 2009. Another biofuels drawback: the demand for irrigation. Science 326:516-517.

Shrank, S. and Farahmand, F. 2011. Biofuels Gain Momentum. Report for WorldWatch Institute Vital Signs. August 30, 2011. vitalsigns.worldwatch.org

Slette, J. 2011. Indonesia Biofuels Annual. USDA Foreign Agricultural Service. Global Agricultural Information Network. GAIN Report Number ID1134

Smith, M. and Muran, M. 2009.Russia Biofuels Annual. USDA Foreign Agricultural Service. Global Agricultural Information Network. GAIN Report Number RS9036

Smith, E. G., Janzen, H. H. and Newlands, N. K. 2007. Energy balances of biodiesel production from soybean and canola in Canada. Can. J. Plant Sci. **87**: 793–801.

Statistics Canada. 2011. The Supply and Disposition of Refined Petroleum Products in Canada – November 2011.

Swedish University of Agricultural Sciences (SLU). 2011. Greenhouse gas emissions from cultivation of agricultural crops for biofuels and production of biogas from manure. 2011-06-22 Dnr SLU ua 12-4067/08 Revised version

Tao, L. and Aden, A. 2009. The economics of current and future biofuels. In Vitro Cell.Dev.Biol.—Plant (2009) 45:199–217

Top Crop Manager. 2008. Aiming for Ethanol. February 2008. http://www.topcropmanager.com/content/view/1271/38/

United Nations Environment Programme (UNEP). 2011. The Bioenergy and Water Nexus. UNEP, Oeko-Institut and IEA Bioenergy Task 43, 2011.

United States Department of Agriculture (USDA). 2006. The economic feasibility of ethanol production from sugar in the United States**.** Office of Energy Policy and New Uses (OEPNU), Office of the Chief Economist (OCE), U.S. Department of Agriculture (USDA), and Louisiana State University (LSU).

United States Department of Agriculture (USDA). 2007. Major Land Uses. Economic Research Services. United States Department of Agriculture. http://www.ers.usda.gov/data/majorlanduses

United States Department of Agriculture (USDA) 2010a. Office of Chief Economist and World Agricultural Outlook Board. *USDA Agricultural Projections to 2019.* Prepared by the Interagency Agricultural Projections Committee

United States Department of Agriculture (USDA). 2010b. 2008 Energy Balance for the Corn-Ethanol Industry. Agricultural Economic Report 846. 16pp

United States Department of Agriculture, National Agricultural Statistics Service. 2010. Quick Stats Database, Crop Production Summaries, 2010, http://www.nass.usda.gov/QuickStats/index2.jsp.

United States Department of Agriculture, National Agricultural Statistics Service. 2011. U.S. Corn acreage is up in 2011, soybeans slightly down. http://www.nass.usda.gov/Newsroom/2011/06_30_2011.asp

United States Department of Agriculture. 2011a. Corn for Grain Yields USDA-NASS 01-12-12 Available at http://www.usda.gov

United States Department of Agriculture (USDA). 2011b. EU rapeseed output to resume growth in 2011 – just. http://www.agrimoney.com/news/eu-rapeseed-output-to-resume-growth-in-2011---just--3040.html

United States Department of Agriculture (USDA). 2012.World Agriculture Supply and Demand Estimates. World Agricultural Outlook Board. March 9, 2012

United States Department of Energy (USDE). 2012. Advanced Fuels and Advanced Vehicles Data Center. http://www.afdc.energy.gov/afdc/ethanol/ Accessed March 15, 2012.

United States Department of Energy (USDE). 2006. Energy Efficiency and Renewable Energy. 2006.Theoretical Ethanol Yield Calculator. http://www1.eere.energy.gov/biomass/ethanol_yield_calculator.html

United States. Department of Energy, Energy Information Administration. 2010. Annual Energy Outlook. May 2010.

Urbanchuk, J.M. 2011. Contribution of the ethanol industry to the economy of the United States. Renewable Fuels Association. http://www.ethanolrfa.org/ Accessed Feb 3, 2011

Vogel, K.P., Dien, B.S., Jung, H.G., Casler, M.D., Masterson, S.D. and Mitchel, R.B. 2010. Quantifying Actual and Theoretical Ethanol Yields for Switchgrass Strains Using NIRS Analyses Bioenergy Research 4:96-110

Wallander, S. Claassen, R. and Nickerson, C. 2011. The Ethanol Decade: An Expansion of U.S. Corn Production, 2000-09/ EIB-79 Economic Research Service/USDA

World Bank. 2010. Liquid Biofuels: Background Brief for the World Bank Group Energy Sector Strategy. World Bank March 2010. 27 pp

**Appendix A:** Biofuel blending targets and mandates (IEA 2011)

| **Country/Region** | **Current mandate/target** | **Future mandate/target** |
|---|---|---|
| Argentina | E5, B7 | n.a. |
| Brazil | E20-25, B5 | |
| China | E10 (9 provinces) | |
| E.U. | 5.75% biofuels* | 10% renewable energy in transport** |
| India | E5 | E20, B20 (2017) |
| Thailand | B3 | B5 |
| U.S. | 48 billion litres renewable fuel/y of which 0.02 billion is cellulosic | 139 billion litres renewable fuel/y of which 60 billion is cellulosic |
| | | |
| **Canada** | E5 (Newfoundland and Northern Territories exempted); B2 in some provinces | B2 nationwide by 2012 |
| BC | E5 | 3% biodiesel in 2010, 4% in 2011, and 5% in 2012. |
| Alberta | E5, B2 | |
| Saskatchewan | E7.5, B2 | |
| Manitoba | E8.5, B2 | |
| Ontario | E5, B2 | |
| Quebec | | E5*** (2012) B2 (2012) |
| New Brunswick | E5 (target) | |

* *Currently, each member state has set up different targets and mandates. **Lignocellulosic-biofuels, as well as biofuels made from wastes and residues, count twice and renewable electricity 2.5-times towards the target. ***From advanced renewable fuels

**Appendix B:** Ethanol production plants in Canada

| Plant | Province | Feedstock | Capacity (million litres/year) | Status |
|---|---|---|---|---|
| Alberta Ethanol and Biodiesel GP Ltd | Alberta | Wheat | 140 | Proposed |
| Amaizeingly Green Products L.P. | Ontario | Corn | 58 | operational |
| Atlantic Bioenergy | Nova Scotia | Energy beets | Not available | Demonstration |
| CR Fuels | Alberta | Wheat | 140 | Proposed |
| Enerkem Alberta Biofuels-Edmonton Waste-to-Biofuels Facility | Alberta | Municipal solid waste (landfill waste) | 36 | Under construction. Completion date: 2012 |
| Enerkem Inc – Sherbrooke Pilot Plant | Quebec | Various feedstocks | 475,000 litres/t | Demonstration Facility |
| Enerkem Inc. Westbury Commercial-Demonstration Facility | Quebec | Wood waste | 5 | Demonstration |
| Greenfield Ethanol Inc Chatham | Ontario | Corn | 133 | Operational |
| Greenfield Ethanol Inc Johnston | Ontario | Corn | 200 | Operational |
| Greenfield Ethanol Inc Tiverton | Ontario | corn | 3.5 | Research |
| Greenfield Ethanol Inc Varennes | Quebec | corn | 120 | Operational |
| Greenfield-Enerkem Varennes | Quebec | Municipal solid waste | 32 | Funded |
| Growing Power Hairy Hill | Alberta | wheat | 40 | Under construction |
| Husky Energy Inc. Lloydminster | Saskatchewan | wheat | 130 | operational |
| Husky Energy Inc. Minnedosa | Manitoba | Wheat and corn | 130 | operational |
| IGPC Ethanol Inc | Ontario | corn | 162 | operational |
| Iogen Corporation | Ontario | Wheat and barley straw | 2 | Demonstration |
| Kawartha Ethanol Inc. | Ontario | corn | 120 | operational |
| NorAmera BioEnergy Corporation | Saskatchewan | wheat | 25 | operational |
| North West Terminal Ltd. | Saskatchewan | wheat | 25 | operational |
| Permolex International, L.P. | Alberta | wheat | 42 | operational |
| Pound-Maker Agventures | Saskatchewan | wheat | 15 | operational |
| Royal Dutch Shell | Manitoba | Wheat straw (350 t straw/day) | 40 | Under consideration |
| Suncor St. Clair Ethanol Plant | Ontario | Corn | 400 | operational |
| Terra Grain Fuels Inc. | Saskatchewan | wheat | 150 | operational |
| **TOTAL CURRENT CAPACITY** | | | **1710** | |
| **TOTAL POTENTIAL CAPACITY** | | | **2149** | |

| **Appendix B:** Biodiesel Production Plants in Canada**Plant** | **Province** | **Feedstock** | **Capacity (million L/year)** | **Status** |
|---|---|---|---|---|
| Bifrost Bio-Blends Ltd. | Manitoba | canola | 3 | operational |
| Biocardel Quebec Inc. | Quebec | Multi-feedstock | 40 | proposed |
| Bio-Lub Canada.com | Quebec | Yellow grease | 10 | operational |
| BioStreet Canada | Alberta | canola | 237 | On hold |
| BIOX Corporation | Ontario | Multi-feedstock | 66 | operational |
| BIOX Corporation | Ontario | Multi-feedstock | 67 | proposed |
| Canadian Bioenergy Corp-Northern Biodiesel Ltd. Partnership (ADM) | Lloydminster, Alberta | Canola | 265 | Construction start date: spring 2012 |
| City-Farm Biofuel Ltd. | British Columbia | Recycled oil/tallow | 50 | operational |
| Consolidated Biofuels | British Columbia | Yellow grease | 10.9 | operational |
| Drain Brothers Excavating | Ontario | Corn-based syrup | 10 | proposed |
| Eastman Bio-Fuels Ltd. | Manitoba | Canola | 5 | operational |
| FAME Biorefinery | Alberta | Canola, camelina, mustard | 1 | Demonstration (converted back to oil, 2012) |
| Great Lakes Biodiesel | Ontario | Multi-feedstock but primarily soybeans | 170 | Under construction (completion 2012) |
| Kyoto Fuels Corp. | Alberta | Multi-feedstock | 66 | Under construction |
| Methes Energies Canada | Ontario | Yellow grease | 5 | operational |
| Methes Energies Canada | Ontario | Multi-feedstock | 50 | Under construction |
| Milligan Bio-Tech Inc. | Saskatchewan | Canola | 20 | operational |
| Noroxel Energy Ltd. | Ontario | Yellow grease | 10 | operational |
| The Power Alternative | Alberta | canola | 66 | Proposed |
| The Power Alternative | Alberta | canola | 66 | Proposed |
| QFI Biodiesel | Quebec | Multi-feedstock | 10 | operational |
| Rothsay Biodiesel (Maple Leaf Foods) | Quebec | Multi-feedstock | 45 | operational |
| Speedway International Inc. | Manitoba | Canola | 20 | operational |
| Western Biodiesel | Alberta | Multi-feedstock | 19 | Operational but currently on hold |
| **TOTAL CURRENT CAPACITY** | | | 226 | |
| **TOTAL POTENTIAL CAPACITY** | | | 1382 | |

**Appendix C:** Life cycle analysis of crops for biofuels

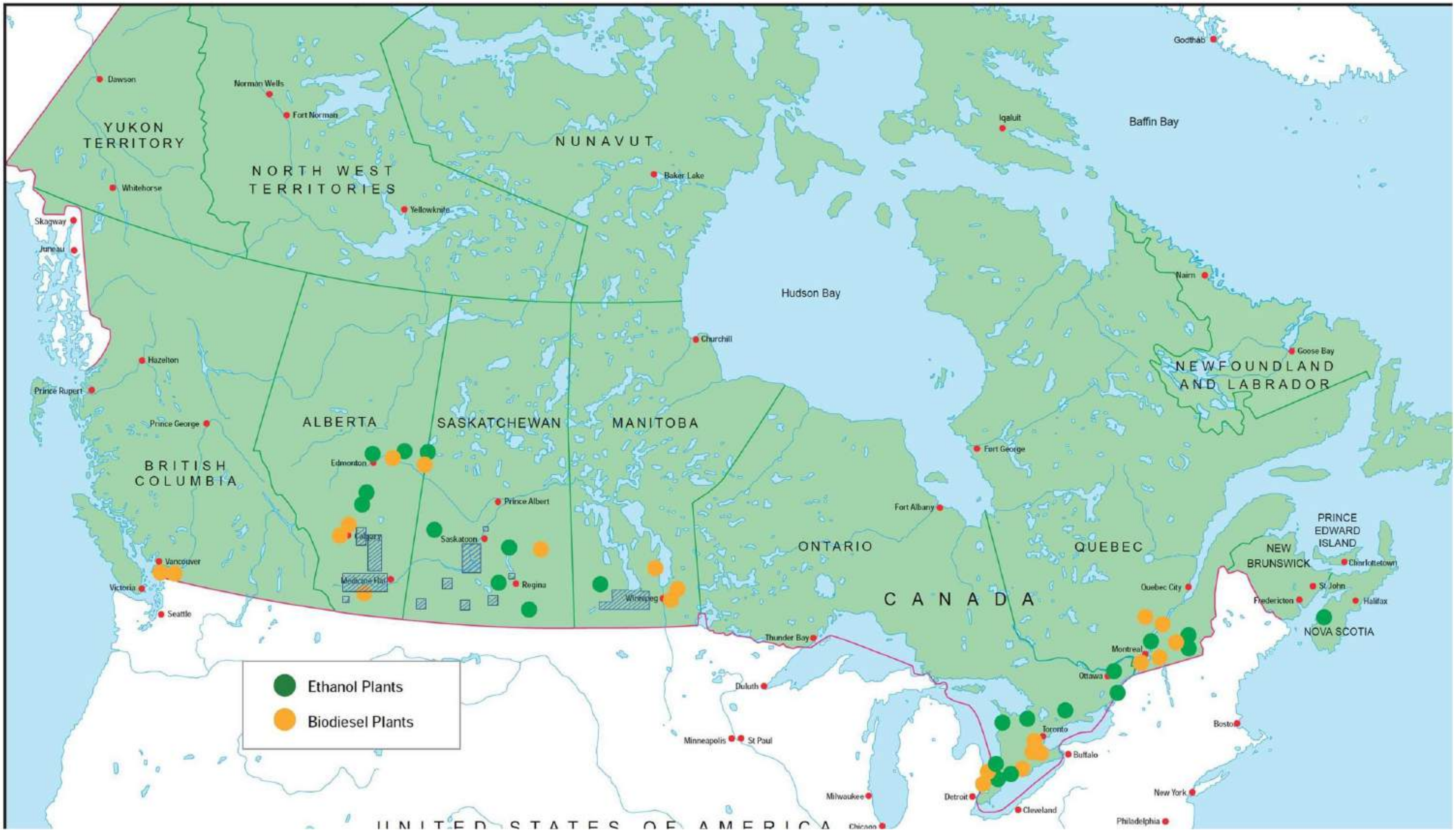
Greenhouse gas emissions from the production and use of transport fuels, biofuels and other bioliquids shall be calculated as:

$$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr} - e_{ee}$$

*E* = Total emissions from the use of the fuel
*eec* = Emissions from the extraction or cultivation of raw materials
*el* = Annualized emissions from carbon stock changes caused by land use change
*ep* = Emissions from processing
*etd* = Emissions from transport and distribution
*eu* = Emissions from the fuel in use
*esca* = Emission savings from soil carbon accumulation via improved agricultural management
*eccs* = Emission savings from carbon capture and geological storage
*eccr* = Emission savings from carbon capture and replacement
*eee* = Emission savings from excess electricity from co-generation

From: SLU 2011

**Appendix D:** Locations of operational and proposed ethanol and biodiesel plants in Canada. Irrigated areas are approximately indicated with blue cross-hatching.




Source: Canadian Renewable Fuels Association