Advanced Biofuels

A Public Deliberation

Preface

This project received support from the following organizations:

Genome Canada, Genome Quebec and Genome Aberta through: the Genozymes for Bioproducts and Bioprocesses project

Genozymes for Bioproducts and Bioprocesses
Genozymes for Bioproducts and Bioprocesses is a scientific project located primarily at Concordia University, Montreal, Quebec.

The project is interested in the transition of our fossil-fuel based economy to a bioeconomy based on converting plant material into fuel, chemicals and other materials. Plant cell walls are an abundant, renewable, biological resource made up of polymers of sugar and other compounds that are collectively called ***lignocellulose***. Project researchers are identifying and producing the proteins (enzymes) involved in the process that converts lignocellulose into simple sugars. These sugars are the basic building blocks of **advanced lignocellulosic biofuels** (sometimes refered to as 2^{nd} generation biofuels) and biochemicals. The project aims to turn agricultural straws, forestry residue and urban waste into useful products and fuel.

The project includes the study of 'science and society' issues through the Genozymes-GE3LS component. This sub-project includes engaging the Canadian public in a conversation about the promises and challenges they see associated with using lignocellulosic biomass (an advanced biofuel feedstock) as a key source of chemicals and fuels in the future.

The research team
The Genozymes-GE3LS research team authored this document. The Genozymes-GE3LS team designs and tests methods to support public involvement in social and environmental issues relating to biotechnology, genomics and **bioenergy**.

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The Purpose of this Event

The purpose of this event is to engage people like you in a broad dialogue about the promises and challenges of **advanced biofuels**. This discussion is important because:

1. Energy and fossil-fuel usage are important issues of our time;
2. Governments worldwide are seeking sustainable energy sources such as **biofuels**;
3. Some argue that the production of 1st genertion biofuels like grain ethanol is not a sustainable practice;
4. Canada is now poised to enter a new phase of biofuel production with a focus on advanced biofuel production facilities;
5. Broad public dialogue over the need for advanced biofuels in Canada is lacking.

The event will seek your views on the need for advanced biofuels in Canada. If a need exists then your views will be sought on how to offer more socially acceptable biofuels based on the conversion of lignocellulosic biomass.

The Purpose of this Booklet

This booklet is meant to provide background information to support public deliberation on the promises and challenges of advanced biofuels. It contains perspectives on biofuels collected from academic literature, the media, various government agencies, organization websites and interviews. While it includes a wide variety of opinions, it is not an exhaustive collection of all possible perspectives. The hope is that it will stimulate discussion and reflection. The material in this booklet may be new to you, however, there will be plenty of time to ask questions and discuss its content at the event.

The Importance of Deliberative Democratic Discussion

People in our society are concerned about the development and regulation of science and technology. Discussion of these concerns is shifting from telling people what they need to know about science and technology to discovering that all citizens are sources of information and therefore have important views to contribute on policy. Here we aim to do both: inform and seek advice. Canadian policies on advanced biofuels are currently undetermined so public awareness is key at this time. Our goal is to understand the public's interests more clearly by drawing on people from many different backgrounds, and with many different opinions, needs and expectations. By using the knowledge, insight and advice of an educated citizenry to inform policy, we can make decisions that reflect social realities and add to the trust we can put in the outcomes of these processes.

Words and their meaning

A word can have multiple interpretations and meanings. To avoid confusion, in this booklet:

1st generation biofuels refers to ethanol made from plant-derived sugars and starches (including food crops), and biodiesel made from waste greases and plant oils.

Advanced biofuels refers to new liquid biofuels not made from materials used to make 1st generation biofuels. They are sometimes called 2nd generation biofuels.

Advanced lignocellulosic biofuels refers to new biofuels made from plant cell walls (lignocellulose) as opposed to municipal solid waste or algae.

Further definitions of terms are included in the glossary

Table of contents

Introduction

The problems of **greenhouse gas** emissions through the use of fossil fuels, accumulating nuclear waste, and dependence on fluctuating, unstable foreign fuel sources are driving a search for new forms of globally sustainable fuel. Many industrialized nations are investing in renewable resources and seeking to transform fossil-fuel based economies into renewable bio-economies.

Bioproducts such as **biofuels**, **bioenergy**, biochemicals and bioplastics will form the basis of such an economy. Many emerging technologies, such as **biocatalysis**, fermentation and green technology, can contribute to the transformation of renewable 'feedstocks' (plants, animal by-products, microbes and organic residues) into these bioproducts. However, many social and environmental questions remain.

Lignocellulosic biomass (fibrous, woody and generally inedible portions of plants) can, for example, be decomposed into simple 5- and 6-carbon sugars by physical and chemical pre-treatment and/or by exposure to enzymes from biomass-degrading microorganisms. These sugars are the basic blocks required to build advanced biofuels and biochemicals.

Biofuels form one part of a global interest in bioenergy, which is the production of heat, power and liquid fuels (e.g. biofuels) from solid, liquid or gaseous biomass. Certain types of biofuels produced from food crops, such as corn, soybean, sugar cane and palm oil (1st generation), are seen as environmentally unsustainable. Some link them to negative societal impacts, such as concerns over spikes in global food prices, widened inequities, and the displacement of vulnerable peoples in developing nations. 'Second generation' or **advanced biofuels** – produced from non-food cellulosic sources such as urban and organic waste and underutilised agricultural straws – promise greater sustainability.

The use of lignocellulosic biomass, however, is currently limited by high costs, and environmental, economic and social unknowns. Biotechnology holds promise as a tool to overcome process inefficiencies. Genome research enables trait analysis, selection and engineering of potential feedstock plants. It also facilitates the analysis and modification of enzymes – from yeast, fungi and the gut microbia of wood-feeding termites – to increase the efficiency of the breakdown and conversion of sugars into ethanol, other fuels and bioproducts for industrial processes.

Canada is poised to enter into a new phase of energy production with a focus on **advanced lignocellulosic biofuels**. This is despite several environmental and social issues linked to 1st generation biofuels such as grain ethanol that remain outstanding. What public views exist on the promises and challenges of advanced biofuels in Canada is as yet unclear. There is a need for the public to weight in with their support and/or resistance to regulatory measures, government policies and current levels of public knowledge underpinning the development of advanced biofuels.

> "There is a need for the public to weight in with their support and/or resistance to the development of advanced biofuels."

Some governing bodies already take public involvement seriously, holding focus groups, online consultations and community dialogue sessions on bioenergy topics. While this is a good start, the scope of issues addressed through these efforts is limited and there is concern that public voices are not being heard on a wide range of issues surrounding novel biotechnologies. The appropriate form of public involvement should include serious reflection on how decisions are made, what scope of issues should be addressed, and who should be involved in decision making. Informed deliberation happens when citizens understand each others' views and work together to suggest how to shape a common future.

With this in mind, this booklet is organized to provide a general introduction to Canada's energy picture, the science of biofuels and the complex social and cultural issues surrounding biofuel development. We hope that by respecting the differences among us, a diversity of other perspectives will be introduced by you, the participants.

Section 2
Canada's Energy Picture

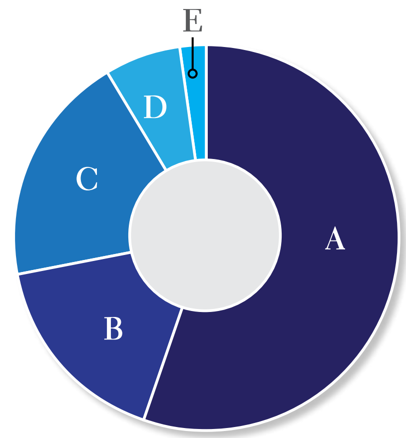
The energy industry is an important economic engine in Canada. Canada produces an overall surplus of energy commodities and exports substantial volumes of energy in the form of crude oil, natural gas, coal and electricity (see Table 2.1 and Figure 2.1). Among countries with crude oil reserves, Canada ranks second globally. On the world stage, Canada is a significant player in global energy trade due largely to its proximity to and trade with the U.S. Although the U.S. has traditionally provided the biggest market for Canada's energy exports, Asian countries are seeking greater access to Canada's natural energy resources as well.

Table 2.1 : Canada's rank in world energy

Rank	Endowment	Reference Year
5th	Primary Energy Production	2007
7th	Primary Energy Consumption	2007
2nd	Crude Oil Reserves	2009
6th	Crude Oil Production	2009
10th	Crude Oil Consumption	2009
20th	Natural Gas Reserves	2009
3rd	Natural Gas Production	2008
8th	Natural Gas Consumption	2008
13th	Coal Reserves	2009
13th	Coal Production	2009
19th	Coal Consumption	2009
5th	Uranium Reserves	2007
2nd	Uranium Production	2009
7th	Electricity Generation Capacity	2007
6th	Electricity Generation	2008
7th	Nuclear	2009
3rd	Hydro	2009
13th	Wind	2008
8th	Biomass	2008
7th	Electricity Consumption	2007

Sources:
Coal Reserves: BP Statistical Review of World Energy. Uranium Reserves and Production: World Nuclear Association. All others: Energy Information Administration

Figure 2.1: Canada's Energy Exports, 2010



		%
A	Crude Oil	55.4
B	Natural Gas	16.7
C	Petroleum and Coal Products	19.2
D	Coal and Bituminous Substances	6.4
E	Electricity	2.2
Total		100

Source: StatsCan, adapted from Centre for Energy report "Canadian Leadership in Energy"

Canada's Energy Production and Consumption

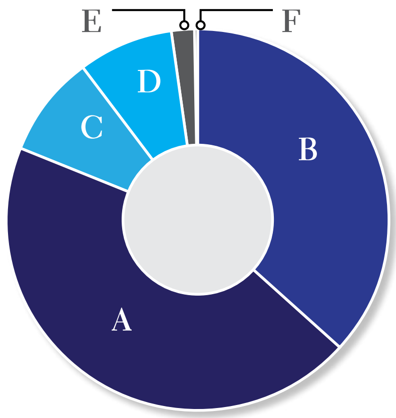
Estimates for Canadian production and consumption of energy vary depending on the source of information and methods of estimation. According to the Energy Information Administration (EIA) – the official source of energy statistics for the U.S. government – the percentage breakdown of energy production in Canada in 2009 and energy consumption in 2008 is as given in Figure 2.2. The top two energy ressources produced in 2009 are crude oil at 44.3% and natural gas at 36.8%. The EIA estimates that petroleum comprised the largest source of energy consumed in 2008 at 31.3% followed by natural gas at 24.8% of overall energy consumption (see Figure 2.2). Non-hydro renewable energy sources (which include biofuels) made up 0.2% of total production in 2009 while consumption of renewable energy made up 0.8% of toal consumption in 2008.

Environmental Impact of Canada's Energy Industry

Petroleum, natural gas and coal account for about two-thirds of Canada's energy mix. These energy sources are finite (i.e. not renewable), carbon intensive, polluting, and their extraction is becoming more challenging and costly in both economic and environmental terms. Most **greenhouse gas** emissions result from the burning of petroleum products, natural gas and coal. Carbon dioxide is one of the greenhouse gases that contribute to the **greenhouse effect**. Figure 2.3 depicts the breakdown of carbon dioxide emissions by fuel source for 2009 and shows that petroleum emitted the highest percentage at 50.2%. Figure 2.4 depicts carbon dioxide emissions by sector in 2008 and shows that the industrial

Figure 2.2: Canada's Energy Production (2009) and Consumption (2008)

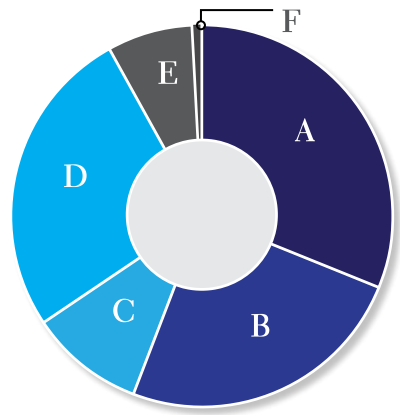
2009 Canadian Energy Primary Production



		%
A	Crude Oil	44.3
B	Natural Gas	36.8
C	Coal	8.8
D	Hydro	7.9
E	Nuclear	1.9
F	Other Renewables	0.2
Total		100

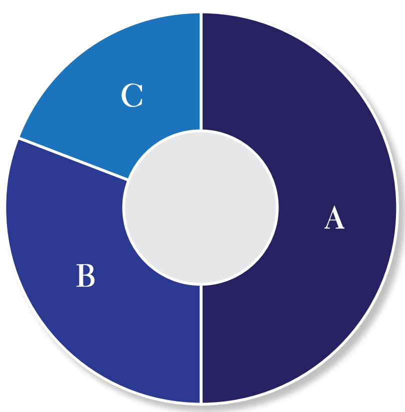
Source: Energy Information Administration, adapted from Centre for Energy report "Canadian Leadership in Energy"

2008 Canadian Energy Primary Consumption



		%
A	Crude Oil	31.3
B	Natural Gas	24.8
C	Coal	9.6
D	Hydro	26.4
E	Nuclear	7.1
F	Other Renewables	0.8
Total		100

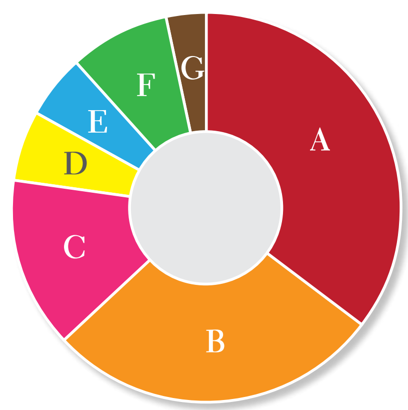
Figure 2.3: Canadian carbon dioxide emissions by source, 2009



		%
A	Petroleum	50.2
B	Natural Gas	30.9
C	Coal	18.9
Total		100

Source: Energy Information Administration, adapted from Centre for Energy report "Canadian Leadership in Energy"

Figure 2.4: Canadian carbon dioxide emissions by sector, 2008



		%
A	Industrial	35.5
B	Transportation	27.5
C	Electricity Generation	14.2
D	Residential	5.9
E	Commercial/Institutionnal	5.2
F	Agricultural	8.4
G	Waste	3.2
Total		100

Source: Environment Canada, adapted from Centre for Energy report "Canadian Leadership in Energy" sector has the highest rate at 35.5% followed by the transportation sector at 27.5%. These estimates also vary depending on the source of information – the estimates used in the figures are from the EIA and Environment Canada.

In the worldwide debate over energy production and use, three interrelated and yet sometimes conflicting concerns surface:

1) global loss of sustainable food production and human habitat due to climate change;

2) increasing greenhouse gas emission that cause climate change and environmental instability;

3) the economic consequences of not being energy self-sufficient (energy security) as world energy consumption and fossil fuel demand increase.

Fossil fuels used in transportation and heating are major greenhouse gas emitters. Hence, government policies are now favouring less carbon-intensive sources of energy. Simply put, there is a desire for sustainable, carbon neutral, renewable and more efficient approaches to future energy production.

Canada's Renewable Energy Future

Canada has a vast and exceptionally diversified mix of renewable-energy resources, including **hydro power**, **solar energy**, **wind energy**, **biomass** (includes biofuels) and **tidal or wave power**. Canada has the third-largest renewable energy capacity (hydro, solar, wind, biofuel and tidal) in the world. Between 2003 and 2011, 126 foreign companies established **Greenfield investment** projects in Canada to invest in the renewable energy sector. Global biofuel demand and production is expected to increase due to higher prices of crude oil and refined petroleum products.

The blending of ethanol with gasoline is one way to reduce the environmental impact of fossil fuels. Ethanol can replace other more hazardous compounds used for octane enhancement in gasoline. This blending reduces harmful engine emissions, the usage and importation of petroleum and refinery products, and net greenhouse gas emissions. Due to its physical properties, however, ethanol (pure and unblended) is not suitable for use in Canada's current petroleum infrastructure – it is not compatible with pipelines, storage tanks, service pumps, etc. that are used to deliver retail gas. Retrofitting of these structures would be required if pure ethanol is to be made as widely available to consumers. Currently, ethanol blended with gasoline in concentrations up to 10% is available to consumers at service pumps.

When it comes to biofuels specifically, Canada has a federal mandate of a 5% **renewable fuel** content (i.e. gasoline must be blended with bioethanol), which came into effect in 2010 (see Section 7). Consumption of biofuels (all renewable biofuels combined, including biodiesel and bioethanol) by the transportation sector made up 1.1% of total transportation fuel used in 2009 and is projected to triple to 3.3% by 2035 as estimated by Canada's National Energy Board. Targeted policies and incentives that range from tax credits and education programs to market-stimulating regulations are needed if biofuel production is to be increased.

Environmental Sustainability of Biofuels

It is important to state that biofuels are desired because they are renewable (i.e. not finite). Such renewable fuel sources have the potential to reduce greenhouse gas emissions when used to replace fossil fuels. Biofuel can help reduce carbon dioxide emissions provided that the **biomass feedstock** is sustainably produced and managed; the conversion process uses little energy; and the source of energy used in conversion is renewable or low-emiting. Ideally, the sustainable provision of energy should meet present energy needs without compromising the ability of future generations to meet their energy needs.

Biofuel production carries a host of challenges. For one, it also creates greenhouse gas emissions, such as emissions from fertilizer use, that are not sources of emission for fossil fuels. In Canadian biofuel production, however, the net effect is that biofuels emit fewer greenhouse gases overall than petroleum, gasoline and diesel. While biofuel does release carbon dioxide when consumed, the carbon dioxide released is part of the carbon cycle and is recaptured by the growth of new biomass feedstock. Again, this cancelling out of carbon dioxide emissions depends on whether the production of biomass and its conversion into biofuel are sustainable, which varies depending on the biomass feedstock chosen and the **conversion technology** used (i.e. how biomass is converted to sugars and then to ethanol).

Ideally, the **conversion process** should yield more energy (output) than the energy used to grow, harvest, transport and convert the biomass into fuel (input). Many factors need to be considered to determine the sustainability of a biofuel. For example, some argue it is better to use marginalized lands and previously cleared lands to grow **biomass energy** crops rather than clearing intact forests to grow these crops as the latter would result in a carbon negative environmental impact that will take decades to cancel out. It is important to note that in Canada no land has been cleared for the production of grain ethanol (1st generation) biofuels.

Other benefits of using biofuels include the production of biomass feedstocks that offer new markets for agricultural producers, local employment opportunities at the cultivation and processing stages as well as regional economic development through the trade of ethanol biofuel.

Do Advanced Biofuels Have a Place in Canada's Future?

Canada is currently self-sufficient in energy and should not need to import energy from foreign sources. However, with the government mandate to meet biofuel blending targets (i.e. gasoline must be mixed with 5% of bioethanol), biofuel consumption has increased beyond our current production capacity, necessitating importation of bioethanol from the U.S.

Our energy prices are also influenced by world demand so rising energy costs are problematic. Canadian biofuels have to be cost competitive with fossil fuels or market demand will be small (i.e. biofuel must be as cheap or cheaper to produce as fossil fuel). For now, world demand for fossil fuel energy continues to grow at a much greater rate than can be significantly affected by biofuel production alone. In order to make significant impacts in reducing greenhouse gas emission, other mitigating strategies will have to be put in place. One strategy is the substitution or blending of fossil fuels with biofuels as mentioned earlier.

> "it may become both socially and economically unacceptable to use food crops for biofuel production"

Given that the production of grain ethanol — a 1st generation biofuel — from a food crop like corn is a source of concern for some and that the global demand for food is rising, it may well become both socially and economically unacceptable to use such food crops for biofuel production. This increases the attractiveness of producing advanced biofuel from non-food feedstocks (i.e. agricultural and forestry residues, etc.).

It is hoped that using genomics and advanced biotechnologies to convert lignocellulosic materials grown in non-cropland areas (i.e. marginal land that cannot be used for food crops) to biofuel will lead to a production system that is sustainable and minimizes the impact on food prices and the environment (see textbox in Section 3).

There are several unknowns that need to be considered. For instance, an increase in advanced biofuel production from a policy perspective may require government policy interventions and subsidies that target lignocellulosic biofuels specifically, perhaps at the expense of other options. These interventions would need to be responsible and reflect the values of a variety of stakeholders and the emerging bioenergy industry (see Section 8). There is uncertainty surrounding the sustainability of large scale production of lignocellulosic biofuel feedstocks as well as its effect on land and water resource availability (see Section 6). There are also questions over the high cost of advanced biofuels and the level of public knowledge on biofuel-related issues.

These unknowns pose a challenge to public deliberation on the direction of Canada's energy future and on the possible role of advanced biofuels and their associated technology in this future.

Section 3
Biofuels: Understanding the Science and Technology

Bioenergy and Biomass

Bioenergy is energy that has been produced from renewable biological sources (i.e. living or recently living plants and plant-derived materials) and can be used to generate heat, electricity and make transportation fuels. Basically, bioenergy is energy contained in biological organisms or organic matter. Plants obtain bioenergy from photosynthesis while animals obtain it by consuming plants.

Organic matter that may be used to produce energy is known as biomass. Biomass, such as wood, can be burned for heat or used to generate electricity. Biomass can also be converted into industrial chemicals and products such as ethanol. Wood is the most abundantly used biomass energy resource. Other sources include food crops, municipal waste, agricultural and forestry residues as well as grassy and woody plants.

There are 3 Types of Biomass:

Primary biomass resources are produced by photosynthesis and are harvested directly from the land. These include perennial short-rotation woody crops (e.g. willow and poplar) and herbaceous crops (e.g. switchgrass), the seeds of oil crops (e.g. palm oil), and residues resulting from the harvesting of agricultural crops and forest trees (e.g. wheat straw, corn stover, and the tops, limbs and bark from trees).

Secondary biomass resources are left over from the processing of primary biomass resources either physically (e.g. the production of sawdust in mills), chemically (e.g. black liquor from pulping processes) or biologically (e.g. manure production by animals).

Tertiary biomass resources are post-consumer wastes, including animal fats and greases, used vegetable oils, packaging wastes, and construction and demolition debris.

Source: United Nations Foundation (UNF) Bioenergy (2005)

1st Generation and Advanced Lignocellulosic Biofuels

What is unique to biofuel compared to other renewable energy sources, such as wind and hydro power, is that biomass can be converted directly into fuel in liquid form, which allows it to be stored and transported to an end user.

Biomass also allows for the synthesis of a variety of industrial chemicals (e.g. bioplastics and bioadhesives) that would otherwise be derived from fossil fuels — some of which may emit less greenhouse gases then their fossil fuel-derived counterparts. Unique by-products of biofuel production (e.g. livestock feed in the form of **dried distillers grains with solubles**) also represent new forms of revenue.

The two most common types of biofuels in use today are ethanol and biodiesel. Bioethanol is mostly used as a blending agent that is combined with gasoline to increase octane and cut down on carbon monoxide and other smog-causing emissions.

Ethanol is an alcohol – the same alcohol found in beer and wine. Ethanol used as a fuel, however, is modified to make it undrinkable. It is most commonly made by fermenting any biomass high in carbohydrates through a process similar to beer brewing.

Most bioethanol is made from starches and sugars derived from food crops. Food crops like corn and sugarcane are 1st generation feedstocks. However, scientists are developing more economical processes so ethanol can be produced from **cellulose** and **hemicellulose** – the fibrous material that makes up the bulk of most plant matter. These are sometimes called 2nd generation biomass or advanced lignocellulosic biofuel feedstocks, of which there is a global abundance. The transformation of cellulosic feedstocks is linked to advanced biotechnology and genomic research (see text box on Genomics as a Tool).

3rd and 4th Generation Biofuels

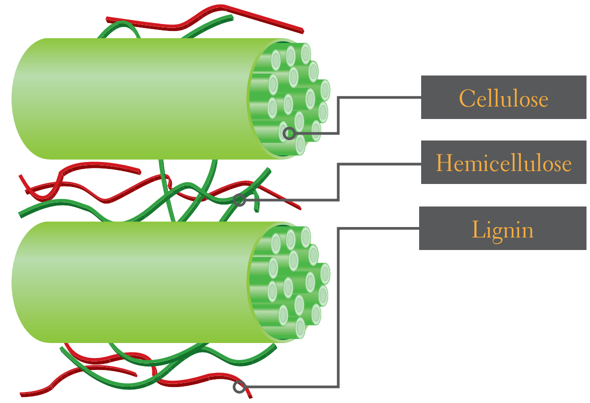
Aside from 1st generation and advanced lignocellulosic biofuels (2nd generation), there are 3rd and 4th waves of advanced biofuels emerging. Research and development into algae-based or 3rd generation biofuels is being conducted in the U.S. and Canada. Microalgae are able to produce 15-300 times more oil for biodiesel production than traditional crops. In comparison to traditional crop plants that are harvested once or twice a year, a key benefit of microalgae is their very short harvesting cycle (1-10 days), which allows for continual harvests with significant increases in yield. However, there are challenges associated with 3rd generation biofuels that need to be addressed, such as the high production costs required to implement the technology that would be used in production.

The 4th generation of biofuels may be created using petroleum-like hydroprocessing or advanced biochemistry. Joule Technology is one company pursuing the development of this technology. Their research suggests that sunlight, waste carbon dioxide and genetically engineered microorganisms could be combined in a 'solar converter' to create fuel. This system, however, is not likely to be fully realized in the near future.

Advanced Feedstocks and Biofuel Production

Biomass feedstocks differ chemically in structure and in their composition of three main components: cellulose, hemicellulose and lignin (see Figure 3.1). Cellulose are long sugar chains made up of 6-carbon sugars. Hemicellulose is the matrix that surrounds the cellulose and is comprised of 5-carbon sugars. The lignin is the cross link between the cellulose and hemicellulose. It is the 'glue' that helps holds the plant cell wall together and is the most difficult component to break down.

Figure 3.1: Lignocellulosic composition of biomass



Source: Adapted from Alonso, M., Wettstein , S., &Dumesic , J. 2012. Bimetallic catalysts for upgrading of biomass to fuels and chemicals.Chem. Soc. Rev.

Food crops such as corn are limited in supply when compared to the abundance of other plant materials on the planet, which can be high in cellulose and hemicellulose. However, the simpler carbohydrates and sugars in food crops such as corn are much easier and cheaper to convert to fuel. The conversion of cellulose and hemicellulose used to make advanced biofuel requires higher temperatures and more chemicals to breakdown the sugars in these materials (depending on the conversion process used). This is expensive. We lack effective, energy efficient ways to convert these materials to fuel. There is currently no commercial scale production system for advanced lignocellulosic biofuels. In other words, the development of conversion processes has not reached a point where it can produce these biofuels at low enough costs for economic gains.

There are two main conversion methods for biomass feedstocks: biochemical and thermochemical.

Genomics as a Tool

Genomics explores how genes interact with each other and their environment, and the role they play in the functioning of living organisms. Genomics is a tool that can facilitate environmentally sound biofuel production by, for example, examining the genetic make-up of possible biomass feedstock options to determine how to maximize efficient fuel production yet minimize environmental impact and energy expenditure. Analysis and modification of enzymes from yeast, fungi and the gut microbia of wood-feeding termites may help increase the efficiency of the breakdown and biochemical conversion process of biomass into ethanol.

Genomics contributes to the development of sustainable biofuel systems when applied to non-edible biomass feedstocks in the production of advanced lignocellulosic biofuels. The research relies on continual financial investment and governments are currently investing in the research and development phases of these advances. Supported by government policies, breakthroughs in science and biotechnologies could facilitate a steady increase in sustainable biofuel production while minimizing the impact on the environment.

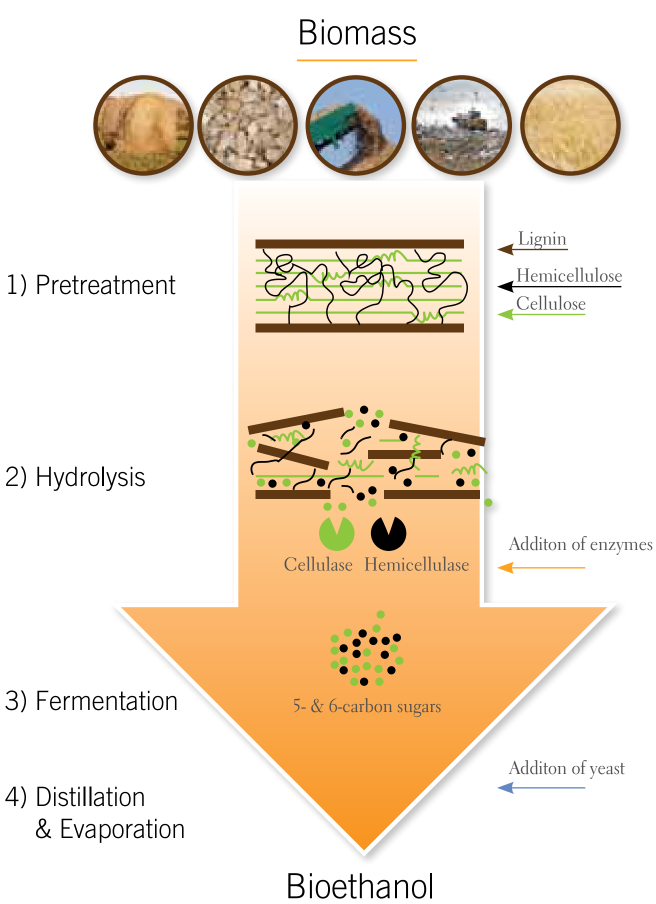
Biochemical conversion process

The biochemical conversion process involves the use of enzymes which can accelerate the breaking down of biomass into sugars. The biochemical conversion method is currently used in the production of ethanol from starch derived from corn crops. It is a 1st generation production process.

The four steps in the conversion of biomass into ethanol are (see Figure 3.2):

1) Pretreatment: the goal of pre-treatment is to expose the chains of sugar (i.e. cellulose portion of the biomass feedstock) to enzymes for hydrolysis. Pre-treatment can be chemical, thermal or biological.
2) Hydrolysis: with the use of water, the sugar chain components or polysaccharide (cellulose and hemicellulose) components of the biomass are broken down into simple sugars by enzymes.
3) Fermentation: the 6-carbon sugars and 5-carbon sugars obtained from the hydrolysis step are then fermented into ethanol using yeast (Saccharomyces cerevisiae).
4) Distillation and evaporation: The final step of the bioconversion process is distillation where the fermented ethanol and water are exposed to heat. This stage represents an energy intensive and expensive step in ethanol production.

Figure 3.2: Biochemical conversion of biomass to bioethanol



Source: Adapted from Dashtban, M. et al. *Int J Biol Sci* 2009; 5(6):578-595.

Thermochemical Conversion Process

Unlike the biochemical method that separates each portion of the biomass, the thermochemical method subjects the entire biomass including the lignin portion to heat which decomposes it altogether. There are two types of thermochemical conversion processes – gasification and pyrolysis.

In gasification, the first stage involves the partial combustion of the biomass feedstock using extreme heating temperatures of up to 700ºC. This process produces synthesis gas (syngas), carbon monoxide and hydrogen. The syngas is then cleaned of its impurities such as tar and ash and converted into a variety of liquid fuels – this method is called the Fischer–Tropsch process. The major issue with the gasification process is that the biomass must have 20% or less moisture content to begin with. This means that all biomass feedstocks used in this process must be dried first, which raises production costs.

In pyrolysis, the process again uses heat (450ºC – 600ºC) without the presence of oxygen which converts the biomass feedstock into bio-oil, which can be further refined into biofuels. The key advantage of this process is that it can convert the biomass into a liquid form, which reduces storage and transportation costs.

Section 4
Transitioning to Advanced Biofuels

First generation biofuel production utilises feedstocks such as sugarcane, wheat grain and corn to produce ethanol. Canadian bioethanol is made mainly from corn although some biofuel also comes from wheat. An estimate of 30% of the annual corn production and 4% of the annual wheat production in Canada were used to produce 1.83 billion litres of bioethanol in late 2010.

The first wave of biofuel production can be deemed 'successful' for many reasons: conversion technologies work on a commercial scale, biofuel facilities contribute positively to the Canadian economy, biorefinery facilities exist and feedstock availability is considered abundant in Canada. Government recognition, acceptance and promotion through policy regulations and incentives have also been established.

The Move to Advanced Biofuels

Despite the gains made with 1st generation biofuels, there is growing realisation that biofuel production using food crops can be environmentally unsustainable due to its water requirements and the implications of fertilizer and pesticide use coupled with the reality that rich agricultural land is essential to cultivate these feedstocks for bioenergy rather than food production.

There is concern that the utilization of 1st generation food-based feedstocks may contribute to increases in future global food prices, market volatility and land use change, which points to a potential need for a transition towards a more sustainable biofuel production process. Proponents of alternative non-food feedstocks for advanced lignocellulosic biofuel production believe it may represent a more viable option.

Feedstock Choices for Advanced Lignocellulosic Biofuels

Feedstock choice is a crucial component of sustainable biofuel production. The feedstocks used to produce ethanol from lignocellulosic materials are deemed as advanced (or in some cases 2nd generation) if they are non-edible sources, contain cellulose and typically fall under one of the three following categories:

1. Agricultural residues. This refers to parts of the plant that are not removed with the primary food or fibre product (e.g. the leaves or stalks of the corn crop also called corn stover).

2. Forest residues (hardwood and softwood). This incorporates residues from the logging industry, the forest floor and mill processing residues.

3. Energy crops. These are non-food crops grown primarily to be harvested for energy and include herbaceous crops such as switchgrass and wood energy crops such as short rotation coppice, poplar and willow.

Each biomass feedstock option has different percentages of cellulose, hemicellulose and lignin. Biomass feedstocks with low lignin content are more favourable. A lower lignin content helps the conversion process as the enzymes used for digestion have an easier time getting through to the sugar-containing cellulose and hemicellulose components (see Table 4.1). The high cost of using enzymes is one challenge that scientists are trying to surmount by developing biotechnologies that use up less energy and costs less to produce high yields of cheaper ethanol.

Environmental Impact Based on Feedstock Choice

Each feedstock option will have its own specific set of environmental implications from its cultivation to its removal processes.

Agricultural residues such as corn stover are the underutilized material (i.e. the leaves and stalks) of the corn crop. Currently, the leaves and stalks are left on the land to combat **soil erosion** by acting as a safeguard, protecting the plant from the wind. The removal of corn stover from the land to use as a biofuel feedstock will impact soil retention, organic matter content, nutrient availability and compaction. One solution is to adjust the removal rate based on site-specific criteria to maximise soil quality by leaving a certain amount of corn stover on the land.

The benefits of using forest residues are twofold. Its cultivation does not compete for land or food production and residues are currently inexpensive to harvest as production cost and inputs are low. The removal of forest residues from the forest floor may have negative effects on the levels of biodiversity. Thus, it is vital that removal practices adhere to sustainable practices and environmental guidelines.

Energy crops such as perennial grasses are fast growing plants. Switchgrass (Panicum virgatum) is a promising feedstock choice for biofuels due to its low lignin content and its potential to maintain biodiversity and soil quality. Switchgrass, which is more resistant to pests, can be cultivated on marginalized land (abandoned agricultural land or land with poor soil quality). The availability and location of these feedstock sources are important elements to consider when transiting away from food based sources.

Table 4.1: Composition of biomass feedstocks and corresponding ethanol yield

Biomass Feedstock	Cellulose %	Hemicellulose %	Lignin %	Ethanol yield*
Agricultural Residues (corn stover)	37.9	24.5	19.8	113
Softwood Forest Residues (coniferous)	42.8	20.4	26.4	82**
Hardwood Forest Residues (deciduous)	41.7	23.8	25.9	82**
Energy crops (switchgrass)	22-36	13-27	11-25	97

*Estimated theoretical yields- gallons per dry ton, Schnepf, R (2010).
**This estimated ethanol yield relates specifically to forest thinnings

Source: US Department of Energy, Biomass feedstock composition and property database

Environmental Challenges of Advanced Lignocellulosic Biofuels

Some arguments over negative effects and experiences from 1st generation biofuel production in Brazil highlights the need for careful planning and assessments prior to commercial scale production. Clearing forested land in Brazil to cultivate food crop-based feedstocks facilitated indirect land use change whereby lands for pasture and food production were forced into direct competition with each other.

At present, the environmental impacts of advanced lignocellulosic feedstocks (dedicated energy crops) are projected from small scale project level research and are not based on expansive land areas, making it difficult to determine the full benefits or negative impacts of advanced lignocellulosic biofuels. The cultivation and harvesting of advanced energy crops are considered less resource intensive (i.e. uses less water, fertilizer and pesticides) but their impact on soil after their removal remains difficult to predict. Land use for biofuel production is a pertinent issue (see Section 6). Land availability and suitability vary across the globe. Selecting potential feedstock options must take into account current land use statistics as a means of gauging the future prospects for cellulosic biofuel feedstocks. Marginal or idle lands are strong contenders for consideration as they are characterized by poor soil quality that is deemed unsuitable for food production anyway. This choice will avoid competition for land with crops grown for food. However, finding the right energy crop that will produce high yields consistently, requires low inputs and is non-invasive will prove challenging.

> "Targets for cellulosic based biofuels in Canada have yet to be introduced and are consequently not well defined"

Policy Challenges Facing Advanced Lignocellulosic Biofuels

Transitioning towards an increased use of advanced lignocellulosic biofuels has recently been encouraged through industrial investments and governmental incentives. Biofuel blending targets (i.e. blending gasoline with a renewable energy source) have been implemented by governments worldwide (including Canada) to combat climate change and greenhouse gas emissions. Regulated fuel blends ensure that transportation fuel is mixed with a percentage of a renewable energy source, namely biofuels. These percentage-based mandates (see Section 7) aim to increase the retail availability of renewable fuels to consumers.

Unlike the U.S. and Europe, targets for cellulosic based biofuels in Canada have yet to be introduced and are consequently not well defined. Currently, the targets set for biofuel production do not specify or distinguish between the use of various food based (1st generation) versus non-food based (advanced lignocellulosic) feedstocks. They also fail to take into account the broader implications of the production and use of food-quality feedstock versus other organic waste sources as feedstock materials.

Climate Change Challenges of Advanced Lignocellulosic Biofuels

Regardless of the blending targets in place, climate change will affect the cultivation of biofuel feedstocks through its effect on global land and water availability. The impact will be especially relevant to those feedstocks that come from agriculture (i.e. agricultural residue) as increases in temperature will influence cultivation conditions (potentialy in a positive manner) and water requirements of agricultural crops – the extent of which is difficult to predict. Therefore, the promise of cellulosic biofuels as a solution to diversify Canada's energy supply and reduce greenhouse gas emissions remains a challenge filled with uncertainty.

Navigating the challenges to advanced lignocellulosic biofuel production will be informed by the experiences gained from 1st generation biofuel production when it comes to land use, water use and biodiversity concerns (see Section 6). Currently, the development of approaches to advanced lignocellulosic biofuel production is occurring amidst the emergence of a myriad of potential feedstocks, novel and complex conversion processes, multiple governance assessment frameworks, and diverse political, economic, ethical and environmental considerations. The transition to advanced lignocellulosic biofuels could involve the use of a mix of options from both advanced lignocellulosic (2nd generation) and 1st generation feedstocks (e.g. a mixture of corn stover, agricultural residues and energy crops) to meet blending targets so that an over reliance on one feedstock group alone does not occur. Consideration for the environmental parameters that accompany each feedstock option must also be factored in as different options are associated with different environmental impacts to different degrees.

Section 5
Contemporary and Historical Challenges

Almost a century ago, an economy based on renewable resources was the norm rather than the exception. Fuel ethanol production from corn began to hit its stride in North America after the oil price spike of 1979. This development was initially driven by the desire to reduce dependence on oil but later evolved to include (1) the need to replace lead and other hazardous compounds as octane enhancers for gasoline, (2) concerns about air quality problems and especially carbon monoxide in urban air in winter, (3) concerns about greenhouse gas emissions and (4) a desire to increase grain prices for farmers and reduce government subsidies to support farm income. Mohawk Oil began producing fuel-grade ethanol in Manitoba and blending it into gasoline in 1981. The Canadian Renewable Fuels Association was created in 1984. The timeline presented in the appendix is an outline of important events related to biofuel policy and regulation in Canada with an emphasis on biofuels and developments since 2000 (see timeline in appendix).

Canadian Biofuel Production: A Global Context

Among global producers of biofuels, the U.S. and Brazil lead the way (see Table 5.1). Estimates show that Brazil and the U.S. accounted for 87% of global biofuel production in 2008, which was mainly driven by government support through subsidies and incentive-based programs. International trade in biofuel is expected to grow rapidly over the next decade, mainly with exports from Brazil to the U.S. and Europe. Some forecast that biofuel production will grow at an annual rate of 5% from 2009-2018. Significant growth is also predicted in India and China. This prediction is echoed by the Organisation for Economic Co-operation and Development (OECD) and the United Nations' Food and Agricultural Organization (UN FAO) food agency, which projected that global ethanol production will double between 2007 and 2017.

Table 5.1: Global biofuel production

Bioethanol production in 2008 (million litres)	
United States	36,300
Brazil	24,497
China	2,448
Canada	870
Germany	730
France	578
Spain	578
Australia	164
United Kingdom	153

Source: Bacovsky et al, 2009, DEFRA 2010

The global use of biofuels and their policies seek to: 1) diversify the current use of finite energy sources, enabling greater energy security; 2) reduce levels of greenhouse gas emissions; and 3) enhance rural development. The nature of biofuel policies worldwide is complex due to the range of areas they may directly or indirectly impact, such as land use, the promotion of certain feedstocks and levels of public awareness of biofuel. Despite these complexities, the emergeance of biofuel has succeeded in heightening international awareness and promoting shared global responsibilities to decrease the levels of greenhouse gas emissions. Ultimately, this has resulted in the establishment of legislative instruments such as blending targets, subsidies, grants and import tariffs.

Canada's limited biofuel production capacity suggests that Canada's entry into the global bioethanol market is still far from being realized. In an effort to lower greenhouse gas emissions, a federal mandate is in effect that will increase Canadian biofuel consumption (see Section 7). Based on the trend of net national sales of gasoline used for road motor vehicles, the present production capacity of biofuel is not expected to meet Canadian biofuel demand. Thus, imports of biofuels to Canada are expected to grow in 2011 and 2012.

Challenges to Biofuel Production

Public support for renewable energy (i.e. wind, solar, hydro and biofuels) in Canada continues to grow. To realize a different energy future, however, broad public support or critique is important. This input is crucial to the establishment of new bioenergy projects and the appropriate facilitation of both regulatory measures and the government policies that underpin them.

At present, biofuel production in Canada is mainly driven by Canadian provinces implementing new government blending targets. In 2011, Ontario alone is estimated to account for 62% of current domestic biofuel production. The provinces of Manitoba, Saskatchewan and Alberta combined are estimated to account for 29% of domestic biofuel production capacity. Quebec is estimated to account for 9% of current domestic biofuel production capacity. For the location of biofuel refinery plants in Canada, see Figure 5.1.

There are various challenges to biofuel production in Canada that need to be considered. For one, the food versus fuel debate is a relevant issue for Canadians as most biofuels in Canada are produced using food crops (in 1st generation biofuel production). In 2011, it is estimated that 78% of the production of domestic biofuel will be derived from corn, 21% from wheat and 1% from non-food feedstocks (used in advanced biofuels) such as agricultural residue and lignocellulosic material. In 2012, forecasts predict a shift in these numbers to 67% corn, 31% wheat and 2% from non-food feedstock

It has been suggested that advanced lignocellulosic biofuel production may reduce greenhouse gas emissions, maintain levels of biodiversity and be less water intensive during the cultivation of feedstocks. These arguments are based on research into feedstocks from agricultural waste, forestry residues and specific energy crops such as switchgrass. Despite some initial data, forecasting the future of advanced biofuels under Canadian conditions is challenging (see Section 6). For now, the use of 1st generation feedstocks is perceived by some to have negative social, ethical and environmental effects. Failure to recognize and address these impacts could hinder the possible progress of large scale commercialisation of advanced lignocellulosic biofuels.

Figure 5.1: Map of biofuel refinery plants and feedstocks used in Canada (Data as of November 4, 2010)

Source: Canadian Renewable Fuels Association
MMly: Million litres per year

Transitioning to advanced lignocellulosic biofuel production will most certainly build on the experiences gained from 1st generation biofuel production. Similar issues of land use, water use and impact on biodiversity will need to be considered.

Lessons Learnt From 1st Generation Biofuels

There are a variety of economic, environmental, ethical and policy implications associated with the production of 1st generation biofuels. These issues can be broken down into the following 6 categories: land, water. sustainability, social impacts, economics and ethics. Although resource requirements will vary depending on the feedstock used, some argue that 1st generation biofuel production is a serious deviation away from sustainable practices.

First generation biofuels which utilise food-based feedstocks, such as sugarcane, wheat and corn, are therefore under increasing criticism as the environmental implications of their production pose barriers to achieving sustainable development. Brazil is a case in point. With over 30 years of experience in the biofuel industry, Brazil has attained a high level of technological expertise and experience in biofuel development and production. The production of biofuel from sugarcane has proven to be economically affordable and profitable for Brazil with 45% of their total energy demands being met by renewable sources. Although biofuels have contributed to the socio-economic development of Brazil, associated jobs generally require low skill levels and are non-permanent positions. Brazil has also received negative attention due to patterns of deforestation and land use. A study published in the *Proceedings of the National Academy of Sciences* suggest that the expansion of biofuel production in Brazil won't directly lead to more deforestation but will indirectly do so as it takes over land previously used for cattle ranching.

Section 6
Questions Facing Advanced Lignocellulosic Biofuels

There are various environmental, social, economic and ethical considerations to take into account when deciding if advanced lignocellulosic biofuel production is an appropriate and sustainable energy resource that should be pursued in Canada, as well as, what considerations should go into its development if pursued. This section contrasts some of the potential benefits and challenges associated with the production of 1st generation biofuels compared to advanced lignocellulosic biofuels.

Environmental Impact

Land Resources

1st Generation Biofuels

The production of 1st generation biofuel feedstocks requires a lot of land (four times more land is needed to fuel an automobile than to feed one person) and competes with land allocated to food crops, forests and urbanization. One consequence of this large need for land has been the conversion of natural ecosystems, such as forests, into energy-crop plantations. This changes the habitat and food sources available to the indigenous wildlife. Environmentalists have expressed their concern over the destruction of forests as a result of the rapid expansion of biofuel feedstock agriculture, especially in the tropics. According to some researchers, the net effect of land use change (from rainforests, peatlands, savannas or grasslands to energy food crops used to produce biofuel) is the increase of carbon dioxide emissions for decades or centuries more relative to fossil fuel use.

Growing 1st generation biofuel feedstock also affects soil quality. Intensive **monoculture plantations** required for 1st generation biofuel production reduces the diversity of vegetation, and exhausts the **nitrogen** in the soil, making it insufficiently fertile over time to supply enough nutrients to the plants. To counteract this effect, the natural levels of nitrogen in these lands have to be replaced with synthetic fertilizers – the production of which requires energy-intensive processes. For instance, in the U.S., the production of corn – the most common food crop used for biofuels – requires more nitrogen than any other crop.

Land use change (both direct and indirect) remains one of the greatest issues of biofuel production. Indirect land use change occurs when a biofuel crop replaces a food crop. Monitoring difficulties make it hard to predict the exact impact of indirect land use change. As such, this 'wild card' remains a prominent concern associated with biofuel production.

Advanced Lignocellulosic Biofuels

Feedstocks for advanced lignocellulosic biofuels moves away from food crops and is instead produced from cellulosic biomass (see Section 3). These include forestry crops, perennial grasses and residues from the wood industry, forest and agriculture, which are likely to be less stressful on the environment than the production of 1st generation biofuel feedstocks. The production of next-generation feedstocks is generally expected to result in fewer overall greenhouse gas emissions, fewer direct air pollutant emissions, less of an adverse impact on soil quality and health, lower water demand and less adverse impacts on water quality compared to conventional corn or soybean production.

In the case of advanced lignocellulosic biofuels, the extensive root systems associated with perennial crops are thought to minimize the loss of nitrogen due to soil runoff, which in turn reduces the need for fertilizers to replace lost nitrogen. Ultimately, this process would result in less water pollution from crop field runoff. The extensive root systems of these non-food crops also improve the transfer of atmospheric carbon into soil biomass through photosynthesis, which reduces the amount of carbon dioxide in the atmosphere.

Perennials or woody species minimize **soil carbon depletion** and control soil erosion compared with annual food crops. High diversity mixtures of grassland species can also provide greater bioenergy yields and reductions in greenhouse gas emissions than 1st generation biofuel production systems. Furthermore, cellulosic crops can be genetically modified to be more resistant to pests, diseases and **abiotic stress** (e.g. drought). Cellulosic biomass, however, can be invasive (i.e. spread like weeds), which would threaten other species and could result in a destabilizing effect on the areas they colonize (negative impact on wildlife habitats and biodiversity). The production of certain next-generation feedstocks is also expected to have a greater impact on land use and biodiversity. For example, if excessive amounts of forest thinnings are removed, changes in land structure, habitat fragmentation, wildlife disturbances and introduction of non-native plants.

Water resources

1st Generation Biofuels

Production programs for 1st generation biofuels also require more water by several orders of magnitude than is needed for domestic and industrial use, which puts a strain on water supplies. For example, in some regions of Arizona in the U.S., groundwater is being pumped 10 times faster than the natural recharge potential of the aquifers to irrigate corn acreages. The production of 1st generation biofuels can also cause water pollution from fertilizer and pesticide runoff from crop fields and effluents from production facilities and biorefineries.

Advanced Lignocellulosic Biofuels

Although advanced lignocellulosic feedstocks result in less water pollution due to less fertilizer use compared to 1st generation feedstocks, the water usage in biofuel refineries is more than that used in oil refineries – even for advanced lignocellulosic biofuels. Refineries used for 1st generation biofuel production consume 4 gallons of water per gallon of ethanol produced while water use in petroleum refining is about 1.5 gallons per gallon of oil. In the production of advanced lignocellulosic biofuels, the use of water in the refineries is 2 gallons per gallon of biofuel produced, which is still higher than oil refineries. Cellulosic ethanol biorefineries for advanced lignocellulosic biofuels, however, are expected to result in lower total greenhouse gas emissions than conventional ethanol biorefineries and to produce less water and solid wastes.

Sustainability

1st Generation Biofuels

Sustainability certification and labelling represents a variety of interests, such as protection of the local environment, food sovereignty, adequate conditions for labour and biodiversity. Voluntary or mandatory certification schemes have been proposed and established regarding biofuel production. For example, in 2011, the European Union approved the first seven voluntary certification schemes, which are intended to demonstrate that biofuels are produced in a sustainable manner. The Sustainable Biofuels Consensus is an international initiative developed by stakeholders, including farmers, companies, non-governmental organizations, experts, governments and inter-governmental agencies. The principles developed include; (a) respecting international treaties on air quality, water resources, agricultural practices and labor conditions; (b) involving all stakeholders in planning and monitoring; (c) significantly reducing greenhouse gas emissions as compared to fossil fuels; (d) ensuring decent work and the well-being of workers; (e) contributing to the social and economic development of local, rural and indigenous peoples; (f) not impairing food security; (g) avoiding negative impacts on biodiversity and ecosystems; (h) promoting practices that improve soil health and minimize degradation; (i) reducing contamination or depletion of water resources; (j) minimizing air pollution along the supply chain; and (k) not violating any land rights.

In 2011, the Roundtable on Sustainable Biofuels (RSB) launched the RSB Certification System. Biofuel producers that meet these criteria are able to prove to buyers and regulators that their product has been obtained without harming the environment or violating human rights. Several developing countries have labelled these measures as 'green imperialism,' restricting them from profiting from their comparative advantage in natural resources. Some researchers have warned that existing certification schemes for sustainable biofuel production are biased towards industrial-scale producers that have the financial capital and economies of scale to meet sustainability and certification objectives.

An international standard is currently being developed to define the principles, criteria and indicators to be used to assess the economic, environmental and social sustainability of bioenergy and biofuel production chains. The standard is scheduled to be released in 2014 and aims to provide a consistent framework to compare different biofuels as well as biofuels to their fossil fuel counterparts.

Advanced Lignocellulosic Biofuels

The possible environmental impact of advanced lignocellulosic biofuels needs to be evaluated to ensure their sustainability. Some researchers consider that even if advanced lignocellulosic biofuels can be produced from agriculture and forestry residues, this 'waste' is part of a nutrient cycle and play a crucial role in the productivity of agricultural or forestry systems. Losing these nutrients to energy production would mean replacing them with mineral fertilizers and increasing diffuse pollution. Essentially, removing the dead residues from forests could damage biodiversity. All this means that advanced lignocellulosic biofuels should be treated with the same level of caution as 1st generation biofuels and strict sustainability criteria should be developed to guide their production.

Social Impact of Biofuel Production

1st Generation Biofuels

There are concerns that grain ethanol may have negative societal impacts, such as a spike in global food prices, widened inequities and the displacement of vulnerable people in developing nations. The favourable natural conditions, widespread availability of land and low labour costs in tropical countries combined with the fact that sugarcane and oil palm (the most cost-efficient and greenhouse gas-saving crops) grow best in tropical conditions should provide developing countries in tropical regions a comparative advantage in growing biofuel feedstocks. However, to develop these regions, it is also necessary that the value-added stages of biofuel production (processing and refining) also take place there. This infrastructure is not available in many less developed countries, which would then only enable them to export biomass rather than biofuel (i.e. raw materials rather than final products) and result in large foreign companies investing in biofuel production facilities in developing countries with better infrastructure.

Furthermore, researchers have warned about the increasing control that energy corporations are placing on the biofuel industry, affecting small-scale production of feedstocks and forcing small landholders out of the markets and off the land. Biofuels have been presented as a way to provide economic development to small scale farmers. However, the displacement of communities for extractive industrial activities and for conservation has been observed in the past. It is not a stretch, therefore, to consider the potential displacement of subsistence farmers, indigenous communities and other marginalized groups in the course of biofuel development. Moreover, even where economic benefits extend beyond corporations, any benefits will likely be unevenly distributed in rural communities, with small-scale farmers, people with insecure land rights and indigenous peoples potentially being left out or even harmed, particularly by the industrial-scale and plantation-based production of feedstock crops.

Advanced Lignocellulosic Biofuels
Cellulosic feedstocks interfere less with the food economy and might have less negative consequences for the environment. However, they require even more advanced technical processes, higher capital investments and large facilities, thus diminishing the comparative advantage to developing countries to considering to pursue advanced lignocellulosic biofuel production. Scientific research may help in the development of economically feasible advanced lignocellulosic biofuel production systems. Even so, the environmental and social stresses associated with dedicating large geographical areas to the cultivation of cellulosic feedstocks are concerns given the increasing need for land in food production.

Economic Impact of Biofuel Production

1st Generation Biofuels
One of the key economic concerns maintained by some is linked to the diversion of croplands to produce 1st generation biofuel feedstocks, which may have increased the costs of staple foods, like corn and rice. Whether these claims are substantiated or not, this resulted in blame being laid on a combination of biofuel production, globalization in trade and capital flows for food shortages around the world. The rise in food prices was anticipated but it was also expected that the agricultural sector would respond by increasing production, which would have generated more employment and higher wages for the rural poor. However, analysts now acknowledge that landless poor rural and urban consumers are the ones who suffer the most as a result of higher food prices.

> "Some suggest that citizens have a duty to act as good stewards for the environment"

The economic impact of 1st generation biofuel production, however, was not entirely negative. Corn-based ethanol also produces animal feed, known as **dried distillers grains with solubles** (**DDGS**). These by-products could offset the production of equivalent feed, such as soybean meal and their associated greenhouse gas emissions. These by-products are also an important component of the biofuel industry's revenue – around 16% of a corn-based dry milling ethanol plant's revenue comes from DDGS. Therefore, when 1st generation biofuel production is encouraged, the production of these by-products increases and their prices fall. This encourages livestock producers to use more biofuel by-products.

The production of 1st generation biofuels can also stimulate economies. For example, by developing a biofuel industry, Brazil reduced its oil imports by $33 billion in U.S. dollars between 1976 and 1996. The use of biofuel in that country now accounts for more than 40% of the transport fuel market, which has helped Brazil achieve self sufficiency in oil consumption.

Advanced Lignocellulosic Biofuels
Most cellulosic crops used for the production of advanced lignocellulosic biofuels can be grown on marginal or agriculturally degraded lands, and thus may not compete with food production. One of the economic advantages of advanced lignocellulosic biofuels is that for every acre of land committed to biomass-for-energy a much greater quantity of cellulose biomass can be produced. The technological challenge then becomes how to efficiently and economically convert the cellulosic component of waste (crop waste, forestry waste, etc.) into simpler sugars to enable their conversion to biofuel. Currently, cellulosic ethanol is not commercially viable due to high production costs. However, various chemical by-products that are derived from the production of bioethanol are in development and could bolster its commercial viability. The production of bio-based chemicals can form the core or add value to biorefinery operations. In the case of lignin, these include bioproducts and bioplastics, such as polyethylene, PVC and polyester.

Ethical Considerations in Biofuel Production

Ethicists would say that practices associated with fuel production should be fair for all involved. People should be fairly paid for their labour, and costs and benefits should be evenly and fairly distributed. In other words, all the costs associated with the production of advanced lignocellulosic biofuels should not burden one group while another group enjoys all the benefits. The production of any fuel should also respect the rights of all citizens, which includes access to affordable food and water among other things.

1st Generation Biofuels
One ethical concern that is often associated with 1st generation biofuel production is that it uses food crops, which may reduce the overall amount of food available for people and push the cost of food up as supply becomes limited. It may also reduce the amount of land available for other purposes.

Advanced Lignocellulosic Biofuels
Proponents of advanced lignocellulosic biofuels would point out that its production uses only parts of food crops that cannot be used as food (e.g. corn stems and stalks) and non-food crops (e.g. switchgrass), which results in less impact on food production and land use compared to 1st generation biofuels. However, the source of feedstocks for advanced lignocellulosic biofuels may spark ethical concerns for some – for instance, if the non-food source or feedstock is **genetically modified** (**GM**). Some people do not support the use of GM crops (despite the fact that many such crops are already grown in Canada) due to concerns over possible health risks and unintended risks to the environment, including impacts to other organisms and crops.

Another important ethical consideration touches on the environment and sustainability. When considering the environmental impacts of any fuel production, it is important to take into account the effects that these processes may have on the environment over time as well as on citizens living now and future citizens. Some suggest that citizens have a duty to act as good **stewards** for the environment by supporting fuel production that minimizes harm to biodiversity and natural systems. People who support biofuels would point out that advanced lignocellulosic biofuels produce less greenhouse gas emissions than fossil fuels or even 1st generation biofuels. That said, they are still not emission free and may depend in some cases on ethically debated practices like the farming of GM crops.

Section 7
Canadian Policy on Biofuels

This section provides a snapshot of Canadian legislation and programs for bioenergy and biofuels at the federal level as well as for Quebec specifically.

Current Situation

The federal Renewable Fuels Regulation mandates that all gasoline across Canada must contain an average of 5% renewable fuel content (i.e. biofuels). The production of bioethanol in Canada is estimated to be 1,833 million litres in 2012, which is below the federal government's target of 1,900 million litres required to meet the 5% renewable fuels mandate. This necessitates the foreign importation of biofuels to meet the mandate. More than half of all Canadian biofuel production currently takes place in Ontario (62%) while the three provinces of Saskatchewan, Manitoba and Alberta produce 29% combined. Although new projects, such as "waste to biofuels" facilities have been implemented in Alberta and Quebec, Canadian biofuel feedstocks are presently sourced mainly from food crops, namely corn and wheat. The importation of biofuel to meet the current mandate comes from the U.S. where biofuel is mostly derived from food crops as well.

Legislation for Renewable Fuels

The federal Renewable Fuels Regulation mandate came into effect on December 15, 2010. An additional federal mandate requiring 2% renewable fuel content in all diesel fuels was implemented on July 1, 2011. However, eastern Canada has been temporarily exempted from this requirement until December 31, 2012 to provide sufficient time to establish biodiesel blending infrastructure, while Newfoundland and Labrador have been granted a permanent exemption of blending biodiesel.

Currently, there are two provinces whose provincial mandates are higher than the federal 5% renewable fuel blend requirement: in Saskatchewan it is 7.5%, while in Manitoba it is 8.8%. Quebec expects its gasoline to contain 5% renewable fuels by the end of 2012 (see biofuel timeline in appendix).

The main objective of the 5% renewable fuel content mandated by the federal Renewable Fuels Regulation is to reduce greenhouse gas emissions, with an estimated incremental reduction of about one ton of carbon dioxide equivalent per year. That said, a wide range of estimates exists from various studies concerning the magnitude of benefits of bioethanol in reducing net greenhouse gas emissions and increasing overall fossil energy efficiency. All of these estimates must adjust for inputs used to grow corn, transportation costs, carbon dioxide and nitrous oxide depletion in soil, and credits for by-products which are used for feed and other purposes.

A Canadian example provided in a 2009 analysis by ChemInfo is that substituting 10% ethanol into gasoline in Ontario translates to a 62% reduction in net greenhouse gas emissions, on a per-litre basis (adjusted for feedstock inputs, transportation and associated soil losses). The 62% reduction in turn translates to an annual reduction of 2.3 million tonnes of greenhouse gas emissions – equivalent to the annual emissions from 440,000 cars (about two-thirds of emissions in Ontario).

Federal Programs for Renewable Fuels

The federal government launched a number of programs to encourage the development of a Canadian renewable fuels industry. Such programs have included:

- The **ecoEnergy for Renewable Power Initiative**, a $1.48 billion program aimed at increasing the Canadian supply of clean and renewable energy (from sources such as wind, solar, geothermal, and biofuel, among others) by encouraging the production of 14.3 **terawatt hours** (enough to power about 1 million homes) from renewable energy sources.
- the **Agricultural Bio-products Innovation Program**, a $145 million program that seeks to mobilize research networks that conduct scientific research projects with a specific focus on developing effective and efficient technologies for agricultural biofuel conversion
- the **Biofuels Opportunities for Producers Initiative**, which was designed to aid farmers and rural communities to hire experts to help them develop business proposals and carry out feasibility studies, and other steps needed to increase biofuel production capacity.
- The **ecoAgriculture Biofuels Capital Initiative**, which was a $200 million, four-year program that aided construction or expansion of transportation biofuel production facilities using agricultural waste.
- The **NextGen Biofuels Fund**, which was a $500 million program aimed at increasing the production capacity of 2nd generation biofuels and encouraging investment by the private sector to establish large-scale facilities for the production of next-generation renewable fuels.

Many federal programs that are a part of the renewable fuel strategy expired at the end of March, 2011. The federal government has not yet announced measures to replace the expired programs in the future.

Quebec Biofuel Policies and Programs

Quebec is estimated to account for 9% of current bioethanol production. Quebec currently has in place a temporary refundable tax credit (maximum $0.185 per liter) to be granted for a maximum of 10 years, to corporations that produce renewable fuels and sell the biofuel for use in Quebec. It began in April, 2006 and expires in 2018.

Quebec has in place the Green Technologies Demonstration Program to finance demonstration projects that use innovative technologies and procedures with strong potential for reducing greenhouse gas emissions in Quebec. The program focuses on reducing greenhouse gas emissions by supporting the development of technologies that limit or reduce greenhouse gas emissions; improve energy efficiency to reduce the consumption of fossil fuels; replace fuels and fossil fuels with renewable energy; and contribute to the development of Quebec industry and job creation in the green technology sector.

While some biofuel production from corn feedstock takes place in Quebec, the focus of provincial policies is on the development of cellulosic biofuel. It is Quebec's intention to use wood waste/residue from its forestry industry to grow its biofuel market. This technology seems to be moving closer to commercialization given the joint venture announcement between Enerkem (a Quebec-based gasification and catalysis technology company) and Greenfield Bioethanol (Canada's leading bioethanol producer). Enerkem was founded in 2000 and currently operates two plants in Quebec: a pilot facility in Sherbrooke and a commercial-scale plant in Westbury (see Figure 5.1).

Section 8
Biofuel Stakeholders in Canada

Various groups in Canada have a stake in biofuels and consequently have roles in the funding, research, production or consumption of biofuels. All stakeholders are interconnected. This section presents some of the key stakeholders implicated at every stage of the Canadian biofuels production industry or supply chain (see Figure 8.1).

Citizens

The Canadian public has a stake in every stage of the biofuels process. Canadian citizens pay taxes to the federal and provincial governments. Citizens pay for energy to fuel their cars and homes. All Canadians have an interest in the future of their natural environment, the energy sector and the broader economy.

Government

The Federal government has played an important role in the development of the biofuel sector through production and consumption regulations (e.g. the federal mandate on biofuel blending targets), financial subsidies and the allocation of research funding. Various governmental bodies have an interest in biofuels. Provincial governments have also taken an active role in the development of biofuels. In Quebec, the provincial government subsidizes up to 66% of the cost of adapting infrastructure to facilitate the consumption of biofuels.

Industry

Canadian companies are involved at every stage of biofuel research, production and consumption. Companies, such as the Iogen Corporation, focus on research into the science of biofuels, and the development of industrial processes. Companies, such as GreenField Ethanol, are involved in growing the various crops for biofuels and the processing and production of biofuels. Others, such as Enerkem, are involved in developing the commercial production of cellulosic ethanol. The transportation and heavy machinery industries are the main consumers of biofuels, with ethanol making up an average of 5% of the total volume of gasoline consumed across Canada – this largely due to the government mandate for blending gasoline with bioethanol (see Section 7).

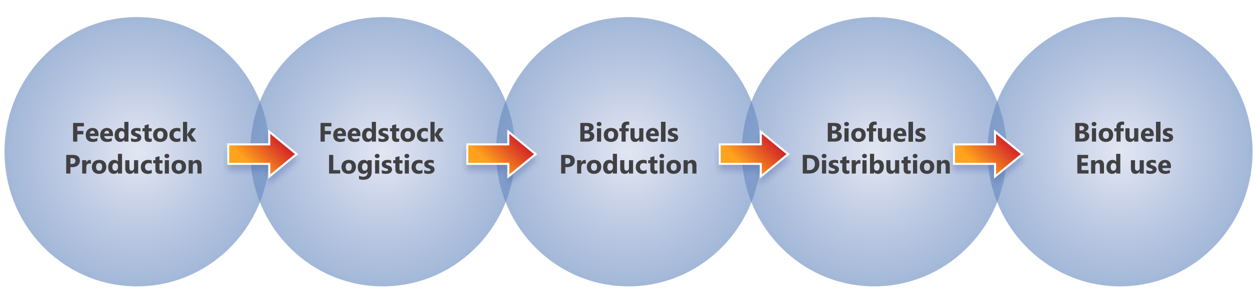
Research Institutions

Universities, colleges and other institutions conduct research into biofuels. At the national level, the NSERC Bioconversion Network supports collaboration between leading researchers from universities and government experts. In Quebec, Concordia University's Centre for Structural and Functional Genomics studies how enzymes found in fungi can be used in the production of biofuels while McGill University's Network for Innovation in Biofuels and Bioproducts conducts interdisciplinary research into biofuel production and policy. These types of institutions receive grants from the federal and provincial governments, while some also enter into partnerships with private companies.

Agricultural Industry

Farming communities are directly involved in the production of biofuel feedstocks, which are predominantly derived from food crops, such as corn and wheat. An increasing demande for crops used in biofuel production would translate to better prices. Government agricultural subsidies for these crops make them an attractive option for farmers. Livestock farmers could also be impacted if animal feed is derived from biofuel by-products.

Figure 8.1: Biofuel supply chain



Source: Adapted from Oak Ridge National Laboratory - Biofuel Supply Chain

Conclusion

Canada has a vast mix of renewable-energy resources and the third-largest renewable energy capacity in the world. Global biofuel production is expected to increase due to higher prices of crude oil and refined petroleum products. However, biofuel (bioethanol and biodiesel) made up only 1.1% of Canada's energy consumption in 2009. With rising concern over greenhouse gas emissions, government policies are expected to favour less carbon-intensive sources of energy. Against this backdrop, there is no better time to deliberate the risks and benefits of biofuel production.

The purpose of this event is to engage people like you in a broad dialogue about the promises and challenges of advanced lignocellulosic biofuels. Engaging the public and collecting your views on these issues will help policy makers and researchers develop socially acceptable policy recommendations to guide the development of this novel technology. For these policies to be responsible, they should reflect the values and beliefs of the Canadian public you represent.

Some of the issues you will discuss during this event may be controversial to some participants, such as the use of advanced biotechnologies in the production of biofuel. Other potentially contentious issues include the impacts that biofuel production may have on rural landscapes and food prices or how to achieve sustainability within the energy sector.

Throughout this event, we will be encouraging respectful dialogue that is informed by a range of different views. It is vital that all participants feel respected and heard, even when their opinions may differ from your own. Ultimately, we are trying to make decisions about what we all agree are socially acceptable policies for advanced lignocellulosic biofuels in Canada. Instead of asserting only your own personal opinions, you will be asked to make decisions and recommendations for all Canadians that are fair and just for everyone.

Some of the issues raised during this event will be highly technical. If you need more information about specific issues raised during your deliberations please ask one of our team members and we will do our best to provide you with that information.

We hope that this deliberative event will be an exciting and worthwhile experience for all participants. We are sincerely grateful for all the time and effort that you have agreed to dedicate to this event.

Links to Further Information

Foreign Affairs and International Trade Canada website, "Energy Security: A Canadian Perspective":
http://www.international.gc.ca/enviro/energy-energie/overview-appercu.aspx?view=d

Regulatory Governance Initiative website, "Timeline – Bioenergy Policy and Regulation in Canada":
http://www.regulatorygovernance.ca/content/timeline-bioenergy-policy-and-regulation-canada

Grain Farmers of Ontario website, "What are the Effects of Biofuels and Bioproducts on the Environment, Crop and Food Prices and World Hunger":
http://gfo.ca/LinkClick.aspx?fileticket=HKfOeU3cHTI%3D&tabid=139

Alberta Agriculture and Rural Development Ministry website, "Farming for Feed, Forage and Fuel"
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/crop12125

Centre for Energy website, "About Energy": http://www.centreforenergy.com/AboutEnergy/

U.S. Energy Information Administration website, Canadian country profile: http://www.eia.gov/countries/cab.cfm?fips=CA

U.S. Department of Agriculture website, Global Agricultural Information Network (GAIN) report on Canadian Biofuels, 2011:
http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Ottawa_Canada_07-05-2011.pdf

The National Academies Press (NAP) website, "Assessing the Sustainability of Biofuels": http://www.nap.edu/openbook.php?record_id=12806&page=117

International Institute for Sustainable Development (IISD) website, "Energy: The global picture and its implications for Canada's role in going forward":
http://www.iisd.org/pdf/2010/banff_dialogue_energy_canada.pdf

International Institute for Sustainable Development (IISD) website, "Biofuels – At What Cost? Government support for ethanol and biodiesel in Canada":
http://www.iisd.org/gsi/sites/default/files/Canadian_biofuels_May_2011.pdf

The World Bank website, "Second-generation biofuels: economics and policies":
http://climatechange.worldbank.org/reports/second-generation-biofuels-economics-and-policies

Appendix: Canadian Biofuels Timeline

1820-1906
Ethanol lamp fuels used but disadvantaged by the tax system while oil industry favoured by subsidies

1906-1940s
Early vehicles use a wide variety of fuels, including ethanol.

1970-1980
Oil embargo where ethanol replaces leaded gasoline. Canada adopts regulations to phase out the use of leaded gasoline.

1981-1986
Energy Research and Development in Agriculture and Food (ERDAF) invests $4 M into liquid biofuels research out of $15 M allotted for renewable energy projects.

1990s-2010s
Carbon footprint and biodiversity are concerns. Food vs fuel debate arises around 1st generation, food-based biofuels.

1995
Federal Alternative Fuels Act: 75% of all vehicles operated by federal departments, agencies and crown corporations must be capable of using alternative fuels (e.g. ethanol, methanol, propane gas, natural gas, hydrogen and electricity).

2000
Launch of Biomass for Energy program.

Canada launches Action Plan 2000 on Climate Change. Commits to targeting the transportation sector and increase Canada's ethanol production by 750 million litres.

2001
Manitoba grants a $0.025/L provincial fuel tax reduction for gasoline containing 10% ethanol.

2002
Saskatchewan enacts an ethanol fuel grant regulation for distributors of ethanol-blended fuel.

2003
Ethanol Expansion Program: $1.3 B pledged towards meeting Kyoto Protocol objectives (includes $100 M to expand ethanol production).

2004
Ontario announces a renewable fuels standard (an average of 5% ethanol content in gasoline as of January 2007).

2005
Quebec introduces a variable refundable tax credit for ethanol production (maximum value is $0.185/L).

Ontario Ethanol Growth Fund with 4 initiatives: capital assistance for production facilities; operating grants for producers; assistance to independent fuel blenders to meet new Ontario renewable fuel standard; research and development fund for farmers and businesses.

Saskatchewan implements mandatory minimum renewable fuel content regulations: minimum 1% average ethanol in fuel from Nov 2005 - Jan 2007 (set to increase to 7.5%).

2006
Quebec's Energy Strategy for 2006-2015: 5% target for renewable content in fuel by 2012.

Federal and provincial ministers responsible for renewable fuels set broad parameters for a national strategy with an emphasis on ethanol and biodiesel as well as new technologies (cellulosic ethanol).

Creation of Biofuels Opportunities for Producers Initiative (BOPI) to help agricultural producers. ($10 M)

Launch of Agricultural Cooperative Development Initiative (ag-CDI) to support biofuel and other agricultural cooperatives ($3.25 M over 3 years).

Alberta Bioenergy Strategy: market development program for bioenergy technologies in biodiesel, biogas (methane) and ethanol.

Clean Air Act tabled to reduce greenhouse gases. The bill dies in Parliament and parts are later reintroduced separately.

Government's intent to mandate minimum renewable content in fuels in Canada: annual average of 5% renewable fuel content in gasoline by 2010 and 2% renewable content in diesel and heating oil by 2012 (corresponds to renewable fuels provisions in defunct Clean Air Act). $345 M allotted for federal biofuel initiatives.

2007
Federal budget commits $1.5 B over nine years for renewable fuels. $500 M for large-scale facilities for advanced next-generation biofuels.

Quebec announces financial support for two new cellulosic ethanol demonstration plants in Westbury and Bromptonville. Research chair established at University of Sherbrooke to support the plants.

Saskatchewan Biofuels Investment Opportunity program: 4-year $80 M initiative for ethanol and biodiesel production facilities ($2 million for research and development).

ecoENERGY for Biofuels Initiative: $1.5 B in the 2007 budget for production incentives for renewable alternatives to gasoline and diesel.

NextGen Biofuels Fund: $500 M for large-scale demonstration facilities for 2nd generation biofuels.

2008
Manitoba introduces ethanol production incentives: fuels must contain an average of 5% ethanol for the first quarter of 2008 and 8.5% thereafter.

BC Bioenergy Strategy: $25 M to create BC Bioenergy Network to support cellulosic ethanol, enzymes for bioenergy, biodiesel from algae, energy crops, etc.

BC budget classifies biodiesel and ethanol as alternative motor fuels exempt from provincial fuel taxes.

New Brunswick is the first province to issue a biomass policy to harvest biomass (forest floor residue) for bioenergy production.

2010
Federal Renewable Fuels Regulation mandate came into effect: an average of 5% renewable content (i.e. ethanol) in fuels. Additional federal mandate for 2% renewable content in all diesel fuels implemented on July 1, 2011.

Abiotic stress: negative impact of non-living factors on living organisms.

Advanced biofuels: liquid biofuels that are made from different feedstocks than 1st generation biofuels, including lignocellulose, municipal solid waste, algae and new energy crops. They are typically produced using novel conversion technologies and are sometimes called 2nd generation biofuels.

Advanced lignocellulosic biofuel: liquid biofuels that are made using lignocellulose – a non-food feedstock (e.g. switchgrass) composed of plant cell walls – as opposed to solid municipal waste or algae. It is produced using novel conversion technologies.

Biocatalysis: the use of natural catalysts, such as enzymes, to perform chemical transformations on biomass in the production of biofuels. Both enzymes that have been isolated and enzymes still residing inside living cells may be used for this task.

Biomass feedstock: organic matter that makes up plants is known as biomass. Traditional products derived from biomass include food, feed, fibre and bioenergy. Biomass feedstocks can also be converted into biofuels and bio-based chemicals and materials.

Bioenergy or biomass energy: generation of heat or electrical energy (power) from biomass.

Biofuels: energy carriers that are derived from biomass. They can take the following forms: a) solid biofuel (e.g. wood pellets); b) liquid biofuels (e.g. ethanol, biodiesel); and c) gaseous biofuels (e.g. biogas).

Cellulose: consists of long sugar chains made up of glucose, which is a 6-carbon sugar.

Conversion technologies or conversion processes: processes that use heat, chemicals, enzymes, physical processes or a combination of these to accelerate the process of breaking down biomass feedstocks into bioethanol.

Dried distillers grains with solubles (DDGS): co-product of the distillery industries. This is the dried residue remaining after the starch fraction of corn is fermented to produce ethanol. After complete fermentation, the alcohol is removed by distillation and the remaining fermentation residues are dried and used as livestock feed.

Federal Renewable Fuels Regulation: a Canadian governmental mandate that began in 2010 requiring all petroleum fuels to have at least 5% renewable content. All diesel fuels and heating oils will be required to contain 2% renewable content by 2012.

1st generation biofuels: liquid biofuels that typically include ethanol made from plant-derived sugars and starches (e.g. sugar cane, corn, wheat), and biodiesel made from waste greases or plant oils (e.g. palm oil, canola oil, soy oil).

Genetically modified: the use of modern biotechnology techniques to change the genes of an organism. The process involves the introduction of foreign DNA or synthetic genes into the organism of interest.

Greenfield investment: a form of foreign direct investment where a parent company starts a new venture in a foreign country by constructing new operational facilities from the ground up – it is typically an investment in an area where no previous facilities exist. In addition to building new facilities, most parent companies also create new long-term jobs in the foreign country by hiring new employees.

Greenhouse effect: process by which thermal radiation from a planetary surface is absorbed by atmospheric greenhouse gases, and is re-radiated in all directions. Since part of this re-radiation is back towards the surface and the lower atmosphere, it results in an elevation of the average surface temperature above what it would be in the absence of the gases.

Greenhouse gas: a gas in an atmosphere that absorbs and emits radiation within the thermal infrared range. This process is the fundamental cause of the greenhouse effect. The primary greenhouse gases in the Earth's atmosphere are water vapour, carbon dioxide, methane, nitrous oxide and ozone.

Hemicellulose: part of the matrix that surrounds the cellulose and is comprised of 5-carbon sugars linked together into long chains.

Hydro power: flowing water that creates energy that can be captured and turned into electricity. Also called hydroelectric power.

Lignin: a cross link between the cellulose and hemicellulose. It is a kind of 'glue' that holds the plant cell wall components together, provides structural rigidity and is the most difficult component to break down.

Lignocellulose: plant material composed of cellulose, hemicellulose and lignin. The carbohydrate polymers (cellulose and hemicellulose) are tightly bound to the lignin.

Monoculture plantations: the agricultural practice of growing a single crop or plant species over a wide area and for a large number of consecutive years.

Nitrogen: an element needed in the soil for adequate plant nutrition.

Renewable fuels: fuels produced from renewable resources, including biofuels and fuels that are synthesized from renewable energy sources, such as wind and solar. This is in contrast to non-renewable fuels such as natural gas, petroleum and nuclear energy.

Soil carbon depletion: soil depletion occurs when the components which contribute to fertility are removed and not replaced, in this case carbon.

Soil erosion: a form of soil degradation that supposes loss of soil structure, poor internal drainage, soil acidity problems and loss of organic matter in the soil.

Solar energy: most renewable energy comes either directly or indirectly from the sun. Sunlight or solar energy can be used directly for heating and lighting homes and other buildings, generating electricity, and water heating, solar cooling among other commercial and industrial uses.

Steward: people who act to protect a resource, such as natural resources, and manage that resource in a responsible manner.

Terawatt hours: unit of energy equivalent to one terawatt (1 TW) of power spent for one hour (1 h) of time. Terawatt hours are usually used to measure large amounts of electrical energy, such as in industry and power generation.

Tidal or wave power: thermal energy produced by the ocean using the sun's heat and mechanical energy from the tides and waves. Tides are driven by the gravitational pull of the moon and sun upon the Earth while waves are driven by winds blowing over the ocean's surface.

Wind energy: energy driven by the sun's heat and Earth's rotation. It is captured with wind turbines.