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# Wood-Ethanol for Climate Change Mitigation in Canada

**Peter J. Graham,* David J. Gregg, and John N. Saddler**

*Canadian Forest Service, Natural Resources Canada, 580 Booth St., Ottawa, Ontario, Canada, K1A 0E4; E-mail: pegraham@nrcan.gc.ca*

## Abstract

The impetus for this paper is Canada's commitment under the United Nations Framework Convention on Climate Change to reduce national greenhouse gas emissions as well as reducing our dependency on fossil fuels. Wood-based ethanol offers an excellent opportunity for greenhouse gas mitigation due to market potential, an ability to offset significant emissions from the transportation sector, a reduction of emissions from $CO_2$-intensive waste-management systems, and carbon sequestration in afforested plantations. While there are technological and economic barriers to overcome, using wood-biomass as a source of ethanol can be an economically viable tool for reducing greenhouse gas levels in the atmosphere. This paper examines the costs and mitigation potential of the production of ethanol from biomass supplied from industrial wood waste as well as from trees harvested from afforested land.

**Index Entries:** Ethanol; greenhouse gas; afforestation; wood waste; economics.

## Introduction

Wood-ethanol's contributions to mitigating climate change include its use as a substitute for fossil fuels and as an octane-boosting gasoline additive. Also, the wood-biomass to be used as feedstock for ethanol production can itself be useful in reducing net emissions of greenhouse gases: afforestation increases the size of the terrestrial carbon sink and the use of industrial wood waste replaces other carbon-dioxide-intensive management methods such as landfill and incineration. Clearly, the production of ethanol from wood-biomass merits serious consideration.

The impetus for this paper comes from two related issues: (1) climate change and the international commitment to its mitigation and (2) the importance of the reduction of our dependency on fossil fuels for energy. Reducing

*Author to whom all correspondence and reprint requests should be addressed.

our dependency on fossil fuels, of which there is an essentially finite supply, would reduce the impact of sudden and major fluctuations in oil and gas prices on consumers. The incentive for mitigating climate change through the reduction of greenhouse gas (GHG) emissions is to avoid the resulting economic, social, and environmental impacts of potential damages.

## Climate Change Mitigation Measures

As mentioned above, ethanol production can positively impact climate change mitigation through both the forestry sector's carbon sink enhancement and the transportation and energy sectors' emissions reduction. A brief examination of these measures follows.

### *Forestry Measures: Sequestering Carbon*

A terrestrial carbon sink such as a forest effectively captures and disposes of atmospheric carbon dioxide ($CO_2$) by converting it, through photosynthesis, into carbon. The carbon is stored as biomass in four carbon pools *(1)*: above-ground biomass; dead organic matter; below-ground biomass; and soil organic carbon. Above-ground biomass consists of tree stems, branches, and foliage. Below-ground biomass refers to root biomass; dead organic matter is mostly leaf litter and woody debris; and soil organic carbon consists of microbiotic organisms in the soil. The success of forestry measures to sequester carbon must examine their effects on each of these carbon pools.

Afforestation is defined by the United Nations Framework Convention on Climate Change as the direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding, and/or the human-induced promotion of natural seed sources (Article 3.3 of the Kyoto Protocol). So, through planting fast-growing trees on marginal farmland, for example, afforestation can increase the size of the terrestrial carbon sink, which in turn reduces atmospheric GHG levels. As there is a finite amount of land available, this benefit is relatively short-lived if the trees are just left standing. However, the opportunity for long-term reductions lies in the use of the afforested biomass as a source of wood-biomass for energy conversion. By using carbon-sequestering tree plantations as feedstock for ethanol production, emissions from the production and combustion of fossil fuels can be offset within the transportation and energy sectors.

### *Transportation and Energy Sector Measures: Reducing Emissions*

Terrestrial sinks keep carbon locked up and out of our atmosphere. However, in order to reduce the level of atmospheric GHGs in the long term, we must reduce our emissions of them in the first place. The transportation sector is the largest source of anthropogenic GHG emissions in Canada, followed by the industry and energy sectors *(2)*. Emissions from these sectors can be reduced through a number of actions, including the use of renewable energy, the displacement of fossil fuel use, and improving the efficiency of energy consumption.

Wood is a renewable resource and the carbon emitted in its conversion to energy is assumed to be fully sequestered by the next rotation of trees, resulting in zero net emissions (under current carbon accounting methodologies). Fossil fuels, on the other hand, are non-renewable and therefore the amount combusted adds to atmospheric GHG levels. Using biomass from tree plantations to produce ethanol provides the added benefit of the one-time gain in carbon uptake from initial afforestation. Net emissions can be further reduced through the use of wood waste that would have been incinerated or put into landfills, and through the displacement of fossil fuels that would have been burned to provide the energy previously. Fossil fuel displacement will also be increased through technological innovations that will make biomass-fuel conversion more efficient. Estimates of emission savings from fossil fuel displacement currently range from 1.7 to 9.0 tonnes of carbon per hectare per year depending on forest type, discount rates, energy conversion efficiency, and the particular fossil fuel being displaced *(3,4)*. The establishment of plantations and the operation of biomass systems will also result in an increase in employment, with most of the jobs created in rural areas.

In conclusion, GHG mitigation would be realized most effectively through the combination of sink-enhancement and source-oriented measures. A system of renewable energy production that would use biomass from afforested land as feedstock would displace the use of fossil fuels in energy production while increasing the terrestrial carbon sink. Wood-ethanol production, which potentially involves all of these elements, is an excellent step toward mitigating climate change.

## Mitigative Potential of Wood-Ethanol

In this section, the ethanol industry's potential to reduce atmospheric GHG levels will be discussed: its technical challenges, its supply of wood-biomass, and its markets and incentives.

The production of ethanol from cellulosic materials is increasing internationally, with production plants being established in the United States, Canada, and Sweden. Production and use of ethanol, as an alternative transportation fuel or as an octane booster, help reduce GHG emissions from road vehicles and can promote sustainable development and management of forests and forest industries through waste minimization. This presents a two-fold environmental advantage as it has been realized that stabilisation of atmospheric GHG concentrations requires both reduction of fossil fuel consumption and preservation and enhancement of carbon sinks and reservoirs, such as forests *(5)*.

### *Wood-Ethanol Technologies*

The technology for converting grain to ethanol has been around for some time. The impetus for developing wood-ethanol conversion processes stems from the availability of low-cost wood residues and, more recently, the desire to reduce GHG emissions. Ethanol is derived from sugars present in lignocellulosic materials such as agricultural, hardwood, and softwood residues. However, owing to the different structural and chemical compositions of these three materials, different processes have been developed to deal with the different forestry feedstocks. Softwoods have greater lignin content than hardwoods or agricultural residues, and it is the lignin that initially hinders the processing of the sugars into ethanol.

There are a number of wood-based ethanol processes, each at different stages of development. While the technology and configuration of each process may vary the conversion of wood-biomass to ethanol involves the following basic steps: pretreatment of feedstock, hydrolysis, fermentation, and ethanol recovery. A report by McCloy and O'Connor *(6)* examined the current technologies with a key requirement being their ability to deal with softwood residues, the dominant feedstock in Canada.

Iogen Corporation, with the assistance of the Canadian federal government and a partnership with Petro-Canada Corporation, has constructed an industrial-scale demonstration plant in Ottawa, Ontario to convert lignocellulosics to ethanol. Iogen uses an enzymatic process designed initially to process agricultural and hardwood wastes. A co-product of the process is lignin, which can then be used as starting material in other processes or as a fuel to produce steam or electricity.

Acid hydrolysis is a process that has been known for over 100 years, but was abandoned due to the lower production costs of petrochemical-derived ethanol. Currently, high capital and operating costs limit the development of industrial scale facilities. There are at least three different acid hydrolysis processes in use or in development *(6)*. Another promising process involves the gasification of wood. While it is currently in the early stages of development, the gasification process may prove to be an effective and efficient technology. The gasification process has the advantage that many of its technological components are currently used at industrial scales in other energy applications. Also, in theory, gasification is able to handle a wide range of feedstock types, including softwoods.

## *Wood-Biomass Supply for Ethanol Production*

The supply of wood-biomass for bioenergy production relies on two main sources from the forest sector: afforested land, and industrial wood waste. (Another potential source not covered in this paper is forestry residue left over at logging sites and log sorting areas.) The availability and costs of supply from afforestation and wood waste, as well as afforestation's productivity, are important factors, as they limit the scale and economic potential of wood-based bioenergy and its contribution to GHG reduction.

### Supply from Afforestation

The supply of biomass from afforested lands is a function of the amount of land available, the productivity of that land, the growth and yield of the species planted, and the costs associated with all of these factors.

The physical availability of suitable land is fairly easy to estimate given government statistics on land and agriculture. These estimates are not the primary concern, because it is the cost of land, or economic availability, which restricts the potential scale of afforestation, not its physical availability *(7–10)*.

How much wood-biomass can be produced on afforested land depends on the site productivity, the species planted, and the management regime used. In an afforestation program, site productivity depends on the quality of the land that the landowner is willing to lease for tree planting. Fast-growing species are preferred; the rotations must be short, but with high enough yields to minimize costs. For instance, if the requirements of these site-specific management regimes are met, hybrid poplar plantations on marginal farmland may provide economically viable sources of wood-biomass for energy production. The distance from the plantations to the conversion facility and the cost of leasing the land are key factors in the economics of wood-biomass supply. The cost of transportation can restrict the economic supply of afforested biomass to within a 50 km radius of a wood-ethanol production facility *(10)*. The opportunity cost of converting highly productive farmland to tree plantations result in higher leasing rates for more productive land.

### Supply from Industrial Wood Waste

The wood waste discussed in this paper is limited to wood processing residues, which mainly consist of sawmill and pulpmill residues. The availability of such wood waste relates explicitly to uncertain annual harvest and allowable cut levels. Waste/input ratios also vary by tree species, log condition, type of processing, and end product. Residue supply is expected to decrease due to developments in technology and process efficiencies that tend to reduce the amount of waste from the various processing stages. In addition to decreased residue production, an increase in competition from other secondary processing industries, such as medium-density fiberboard, is expected and will continue to reduce the availability of inexpensive wood residues *(11–14)*.

There are currently millions of tonnes of industrial wood wastes that are being incinerated or dumped into landfills; these wastes are often given free-of-charge to those willing to bear the expense of transporting it. However, with the development of secondary industries that use wood residues in their production processes, these residues are taking on a value greater than the cost, to the mill, of disposal. The demand for mill residues depends on the type of waste (e.g., bark, chips, or sawdust) and the distance of the residues from the secondary industries. Whitewood chips and sawdust are the most valuable due to demand from medium-density fiberboard and other engineered wood product industries. They are also preferred, in the context of this paper, due to their relative ethanol conversion rates. A decrease in the availability of wood waste due to more efficient processing, combined with an increase in the number of secondary wood-processing industries and bioenergy systems, will result in an increase in the value of the wood waste.

As a result of this increase in the value of wood waste, the demand for biomass from fast-growing plantations will increase. Thus, although the economic balance may change to favor one over the other, both afforestation and wood waste are important sources of the supply of wood-biomass for bioenergy production. The scale of a commercial wood-ethanol production facility will depend on the economics of supply and the capacity of existing transportation infrastructure in the supply area.

## *Markets and Incentives for Ethanol Production*

The main source of information on markets and incentives for ethanol production in Canada is the McCloy and O'Connor report *(6)*. In it, the current and projected ethanol markets are discussed along with a number of incentive mechanisms that may assist the industry's growth in Canada. Comparisons to the United States are made due to the current level of development of the ethanol industry in that country.

### Markets

Currently in Canada, about 175 ML of ethanol are being produced from grain. No industrial wood-ethanol plants are presently operational. Total ethanol production represents only 0.5% of the 35 GL of gasoline sold in Canada each year, and only 5% of the potential market if all gasoline was blended with 10% ethanol. The wholesale price of ethanol is estimated at 40 cents per liter in Alberta and 43 cents in British Columbia, including federal and provincial tax incentives *(6)*. The wholesale price of gasoline is approx 21 cents per liter.

Ethanol is used by gasoline companies in six provinces and the Yukon Territory. Some companies, such as Mohawk Oil, use it for its clean-burning properties to address a particular market niche, while other companies, such as Petro-Canada, use it for its octane-boosting properties. However, ethanol must compete with other octane-boosting agents such as MMT (methylcyclopentadienyl manganese tricarbonyl) and MTBE (methyl tertiary butyl ether), currently used by refiners. In light of the current health and environmental concerns related to the use of MMT and MTBE (discussed in the following pages), ethanol presents an attractive and effective alternative to these additives, as well as contributing to the reduction of harmful emissions from gasoline combustion. These benefits, combined with relatively low costs, indicate the opportunity for the ethanol industry to take a larger share of the fuel additive market and increase its share of the transportation fuels market as well.

An examination of US ethanol markets provides an indication of the potential for growth in the Canadian industry given appropriate incentives.

The US currently produces about 6.5 GL/yr of ethanol from 42 production facilities. Almost all US gasoline retailers use ethanol for at least part of the year. Domestic US consumption accounts for approx 5.2 GL.

With annual gasoline consumption of 450 GL, and most of the ethanol used in 10% blends, ethanol is used in approx 12% of the gasoline sold in the US.

The potential short-term growth in the US ethanol market will depend mostly on changes in state legislation to favor ethanol use. Also, an increase in production of E85 vehicles (vehicles that run on 85% ethanol blends) will increase demand. Studies looking at the role of ethanol in climate change mitigation scenarios project an annual demand of 36 GL by 2015 *(15)*, or 145 GL by 2020 *(16)*. These projections assume the success of research and development programs in reducing the cost of ethanol production, and a substantial increase in the sales of E85 vehicles. The US Department of Energy *(17)* projects the production of cellulose-based ethanol to be between 20 and 28 GL by 2010.

### Incentives

Health and environmental concerns are leading incentives to reduce GHG and other noxious gas emissions. Ethanol can play an important part in these reductions.

As previously mentioned, MMT and MTBE are currently widely used instead of ethanol as octane-boosting agents in gasoline. The manganese component of MMT is a known neurotoxin at high exposure levels, but current research on the effects of low-level exposure is inconclusive. (The Canadian government imposed a ban on the interprovincial trade of MMT, but this was later rescinded due to the threat of legal challenge by manufacturers and provincial concerns.) MTBE is a more expensive octane booster than MMT but has the added benefits of lowering carbon monoxide (CO) and volatile organic compound emissions (VOCs). However, MTBE has been linked to groundwater contamination in the US and is a significant source of GHG emissions, as it is a by-product of the natural gas industry.

The combustion of gasoline releases VOCs, nitrogen oxides ($NO_x$), CO, and particulate matter (PM). The combination of VOCs and $NO_x$ with sunlight results in the formation of low-level ozone, the main component of smog. CO is a deadly poison and the inhalation of fine particulate matter ($PM_{2.5}$) is a serious health concern. In 1990, Health Canada and Environment Canada estimated that 13% of all $PM_{2.5}$ emissions in Canada were from the transportation sector. A blend of 10% ethanol in gasoline has the potential to reduce VOCs by up to 10%, and reduce CO emissions by 8–30%. The use of ethanol-blended gasoline has the potential to significantly reduce particulate emissions, although this claim has yet to be fully substantiated with data *(6)*. If blended at the refinery, as opposed to "splash blending" outside the refinery, ethanol-blended gasoline can reduce $NO_x$ emissions as well, thus further reducing the potential for smog.

A number of incentive mechanisms exist in both Canada and the US that should lead to an increase in the production of ethanol. First, the US will be discussed; there, these mechanisms include legislation to stimulate demand, tax reduction on ethanol-blended gasoline to stimulate production, and the provision of guaranteed loans for capital costs to reduce risk.

Table 1
Summary of Canadian Incentive Programs *(6,18,19)*

| Province | Incentive | Conditions |
|---|---|---|
| Quebec | 19.76 cents per liter ethanol | Not yet proclaimed (as of 1999) |
| Ontario | 14.7 cents per liter ethanol | |
| Manitoba | 2.5 cents per liter of fuel containing a minimum of 10% ethanol | Ethanol produced in Manitoba from Canadian biomass (grain or wood) |
| Saskatchewan | 1.5 cents per liter of fuel containing a minimum of 10% ethanol, plus 4.5 cents per liter of ethanol infrastructure incentive | Not yet proclaimed (as of 2002) |
| Alberta | 9.0 cents per liter ethanol | |
| British Columbia | 11.0–15.0 cents per liter fuel | Applies to blends containing a minimum 85% ethanol |

Legislation requiring minimum oxygen content levels in gasoline has been passed in a number of states to deal with air quality problems, specifically to reduce CO levels in the winter and ground-level ozone in the summer. Minnesota has been very effective at increasing ethanol production in that state by requiring that almost all gasoline sold in the state contain ethanol. The US federal government has offered reduced taxes on ethanol-blended gasoline since the 1970s (prompted by the oil crises), and the incentive is currently at about 21.6 cents per liter (Cdn). Individual states have provided additional incentives (up to 3.25 cents/liter [Cdn] in Alaska) directly to ethanol producers to encourage production in their states. Additional incentives in the form of special loans, property tax assessments, income tax credits, and preferential purchasing policies can assist in the financing of individual projects.

In Canada, there is currently a Federal Excise Tax exemption for ethanol produced from biomass (wood or grain). In addition, a National Biomass Ethanol Program administered by the Farm Credit Corporation provides a line of credit to qualified ethanol manufacturers as a means of rescheduling their long-term debt, thereby reducing risk related to the potential for future increases in taxes and feedstock prices or a decrease in oil prices. However, this program is limited in terms of the ethanol production volumes it can cover *(6)*. Five of the provinces have incentive programs for ethanol production as summarized in Table 1. Two large grain-ethanol plants have been financed in Ontario and Quebec through the provision of agreements that guarantee the level of tax incentives for a number of years, thereby reducing the level of uncertainty regarding future changes to government policies and programs.

The difference between the level of federal incentives appears to be the main reason why Canada's ethanol industry has not kept pace with the US As McCloy and O'Connor *(6)* point out, "the Canadian fuel industry is much more national in scope than the US industry and prefers single marketing and product programs across the country" (p. 48). For this reason, provincial incentives are not sufficiently effective in developing the ethanol industry. A doubling of federal incentives, combined with financing assistance at the provincial level, would likely result in a rapid increase in investment (most likely from the oil companies themselves) in ethanol production.

To conclude this section, then, wood-ethanol's potential to help mitigate climate change is considerable. Given that 1 L of ethanol contains 65% of the energy of 1 L of pure gasoline, and accounting for relative efficiencies, 1 L of 10% ethanol-blended gasoline replaces 0.8 L of gasoline. The lignin co-product from the wood-ethanol conversion process can be burned to generate power, thereby replacing power generated from natural gas or used as a source material for other (perhaps chemical production) processes. This combined reduction in the use of gasoline and natural gas translates to about 2.7 kg $CO_2$/L of avoided emissions through the production of wood-ethanol. By 2020, ethanol production is estimated to reach 525 ML/yr, resulting in 1.4 Tg of avoided $CO_2$ emissions per year *(6)*. However, the potential GHG reductions from the increased production of ethanol will depend greatly on the development of additional tax incentives and the development of the technology.

The adoption of stronger incentive programs, particularly at the federal government level, would provide the industry with the initial push it requires to justify the high capital cost and risks associated with wood-ethanol production. The potential market growth for ethanol is likely to be maintained due to the general population's level of concern for the environment and due to efforts to meet Canada's Kyoto commitment through reductions in GHG emissions from the transportation sector. Whereas the potential damage resulting from climate change may be perceived by many as not critical enough to require immediate action, the effects of decreased air quality in rapidly growing cities are pushing policy and law makers to demand cleaner sources of transportation fuel.

## Discussion

The use of wood-biomass from afforested lands and industrial wood waste as a feedstock for ethanol production has the potential to be an economically viable tool to reduce greenhouse gas levels in the atmosphere. Afforestation as a supply of wood-biomass for ethanol production has the combined benefit of increasing the terrestrial carbon sink and offsetting the production and combustion of fossil fuels, thereby reducing net atmospheric greenhouse gas levels.

As a forestry measure for mitigating carbon-dioxide emissions through a change in land use, afforestation has a number of potential benefits. The primary benefit is an increase in the size of the terrestrial carbon sink. The use of afforested biomass for renewable energy has the advantage of being emissions-neutral under the Kyoto Protocol, and further greenhouse gas reductions are realised through the displacement of fossil fuels.

There are currently many millions of tonnes of industrial wood waste being disposed of by incineration or in landfills. The conversion of this waste wood into energy products provides an opportunity to avoid these current carbon-dioxide-intensive waste management practices while offsetting emissions from the production and consumption of fossil fuels.

Future reductions in the availability of low-cost wood waste will increase the demand for wood-biomass from fast-growing plantations. The potential for afforestation to meet this demand is limited mainly by the cost and productivity of marginal farmland and its suitability for growing trees.

Considering the conversion of wood-biomass to energy products, wood-ethanol stands out for three main reasons. First, its use as a transportation fuel derived from renewable wood-biomass reduces the net greenhouse gas emissions through the reduced consumption of gasoline, the increase in the terrestrial carbon sink from bioenergy plantations, and the avoided emissions from the incineration and landfilling of wood waste. Second, ethanol has a number of health and environmental benefits, including improving air quality, in addition to mitigating greenhouse gas emissions. The third benefit of ethanol production is that, as it gains a share of the transportation fuel market, the consumer becomes less vulnerable to drastic changes in oil and gas prices (as experienced in the winter of 2000–2001).

To date, most wood-biomass conversion systems burn the lignin co-product for process steam and electricity generation to power the conversion process. If more lucrative markets for the lignin co-product of the wood-ethanol conversion process can be found (within the chemical industry, for example), the economics of production would improve. The use of lignin-based chemicals could replace current petroleum-based chemicals, thereby further reducing the use of fossil fuels.

For the wood-ethanol industry, there remains considerable risk for investors in this new technology due to high capital costs, technological obstacles, and market barriers. In order for the industry to develop, the federal and provincial governments will have to create incentives beyond those that currently exist. Government subsidies aimed at overcoming the risks associated with this new technology can be justified on the basis of carbon gains. An increase in federal incentives in the form of tax concessions on ethanol-blended fuel, combined with provincial incentives designed to help overcome the large capital costs and associated risks, will provide the industry with the necessary boost to get up and running. Government can also help promote the industry through the development of carbon markets in which ethanol producers would be allowed to sell carbon offset credits. In the United States, incentives such as tax benefits, loan guarantees, and regulations have led to the development of a strong ethanol industry. The market potential in the US and Canada is very large and could contribute significantly to economic growth over the next few decades. Canada can gain from a successful ethanol industry not only reduced greenhouse gas emissions, but also an increase in economic activity, particularly in rural areas. To the consumer, the debate over the future availability of fossil fuels is not as much of an issue as the effects of sudden, large jumps in oil and gas prices. Buffering the demand for gasoline through the addition of ethanol in the transportation fuel market will reduce the sensitivity of prices at the pump.

As a "no-regrets" option, the production of ethanol from afforestation and wood waste is economically viable; through both the forestry sector's carbon sink enhancement and the transportation and energy sectors' emissions reduction, ethanol production can help to mitigate climate change.

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