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Money to Burn

ASSESSING THE COSTS AND BENEFITS OF CANADA'S STRATEGY FOR VEHICLE BIOFUELS

Douglas Auld and Ross McKitrick

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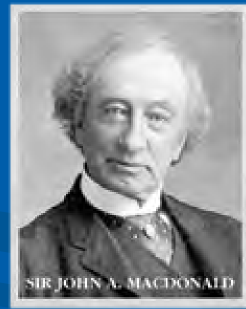
True North in Canadian Public Policy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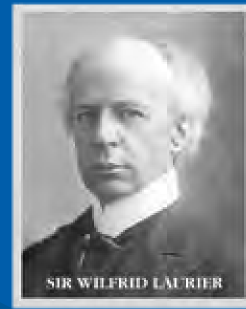
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Executive Summary

Since the turn of the century, biofuels production in the US and Canada has soared more than 8-fold, driven by extremely favourable government support programs. In 2006, the new Conservative government announced its intention to radically accelerate and broaden the existing ethanol support system, beginning a major intrusion into the transportation fuel market.

The government's stated goal was to reduce the emissions of greenhouse gasses (GHG) associated with climate change. In this report we investigate, first, whether this is likely to have been achieved, and second, whether the policy yielded benefits commensurate with the costs.

Over the 2008–2012 interval, allowing for very optimistic assumptions about the efficacy of reducing GHG from ethanol blending, we estimate that federal government biofuel initiatives cost Canadians between $3.00 and $3.50 for every dollar of social and environmental benefits achieved. Consequently the policy has failed to deliver value to Canadian taxpayers.

Determining whether use of biofuels reduces GHG emissions is difficult because many ethanol production processes are so energy-intensive that they actually increase overall GHG emissions compared to use of conventional gasoline. Obviously if there are no GHG reductions, the cost per tonne of reductions is effectively infinite. So throughout our analysis we make assumptions that are maximally favourable to the possibility that biofuels do yield net GHG reduction in order to estimate the most optimistic possible benefit-cost ratio.

Canada's biofuels policies impose costs in a variety of ways, from direct government support for biofuels research and subsidies to producers, to market-distorting biofuels mandates, to increased costs for agricultural products and harm done to other industries that employ many Canadians. In economic terms, for a policy to be socially beneficial, the cost per tonne of greenhouse gas reduction policies should be at or below the conventional estimates of the "social cost of carbon". By that measure, Canada's biofuel support programs have been a dismal failure.

Notwithstanding the fact that since 2008, there have been significant improvements in the technology to manufacture ethanol, therefore improving its GHG effectiveness, any reduction in GHG achieved by blending ethanol and gasoline continues to yield negative net social benefits. On a per-tonne basis, we estimate that the cost per tonne of CO_2 equivalent reduction from production and use of corn ethanol ranges from $400 to $3300 per tonne, and that from cellulosic ethanol is about $142 per tonne. This far exceeds the conventionally-estimated benefits of CO_2 reduction of between $0 and $50 per tonne.

The most obvious recommendation to emerge from this analysis is the need to phase out the major components of current transportation biofuel policy on the grounds that the costs far exceed the social benefits and there are no realistic prospects for this situation to change. If the government's goal is to support the development of renewable fuels that have at least a theoretical potential to replace gasoline on a cost-competitive basis, a case can be made for limiting public research and development funds to cellulosic ethanol.

Sommaire

Depuis le début du siècle, la production de biocarburants a été multipliée par plus de huit fois au Canada et aux États-Unis, soutenue par des programmes d'aide gouvernementaux puissamment incitatifs. En 2006, le gouvernement conservateur nouvellement élu annonçait son intention d'accélérer et d'élargir grandement le programme de soutien existant à l'éthanol, une intrusion considérable dans le marché du carburant de transport.

L'intention déclarée du gouvernement était de réduire les émissions de gaz à effet de serre (GES) pour combattre le réchauffement climatique. Dans ce rapport, nous examinons tout d'abord si les objectifs ont été atteints et, ensuite, si la politique a entraîné des bénéfices ayant une commune mesure avec les coûts.

Au cours de la période allant de 2008 à 2012, en posant des hypothèses très optimistes quant aux impacts des carburants à l'éthanol sur la réduction des GES, nous estimons que chaque dollar de bénéfice social ou environnemental généré par les programmes du gouvernement fédéral en matière de biocarburants a coûté aux Canadiens entre trois et trois dollars cinquante. Par conséquent, la politique n'a pas livré la marchandise aux contribuables du pays.

Il est difficile de déterminer si l'utilisation des biocarburants réduit les émissions, car nombreux sont les processus de production de l'éthanol qui sont si voraces en énergie qu'ils accroissent en réalité l'ensemble des émissions produites par rapport à l'utilisation traditionnelle de l'essence. Évidemment, dans le cas où le remplacement de l'essence par l'éthanol n'entraînerait aucune réduction des GES, le coût par tonne de toute réduction progresserait en fait à l'infini. Par conséquent, tout au long de notre analyse, nous posons les hypothèses les plus optimistes possible relativement à l'impact des biocarburants sur la réduction nette des GES. Cela nous permet de produire les estimations les plus favorables quant au ratio des avantages-coûts.

Les politiques en matière de biocarburants au Canada imposent des coûts de diverses façons, depuis le soutien direct du gouvernement pour la recherche et les subventions aux producteurs de biocarburants, jusqu'aux objectifs pour ce secteur qui sont de nature à fausser le marché, en passant par l'augmentation des coûts pour les produits agricoles et les dommages causés à d'autres industries qui emploient de nombreux Canadiens. En termes économiques, pour qu'une politique soit socialement bénéfique, elle doit viser un coût par tonne de réduction des émissions qui ne dépasse pas les estimations traditionnelles du « coût social du carbone ». Selon ce critère, les programmes d'aide gouvernementaux en matière de biocarburants ont échoué lamentablement.

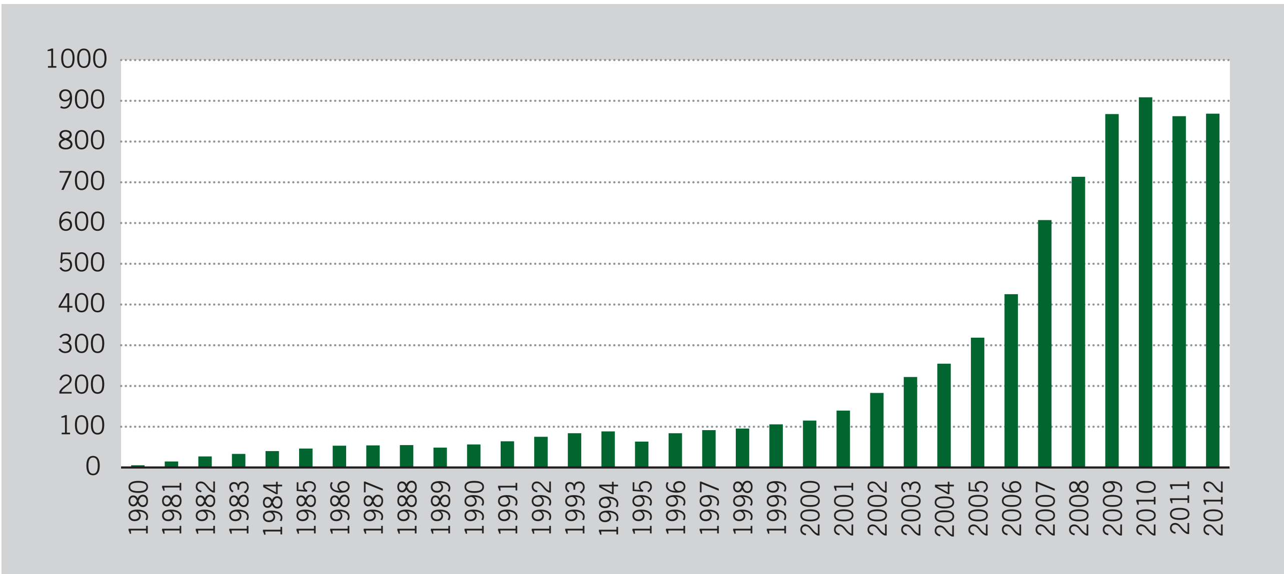
En dépit du fait que depuis 2008, la technologie permettant de produire de l'éthanol s'est améliorée de façon importante et qu'elle est donc devenue moins génératrice de GES, toute réduction obtenue en combinant l'éthanol et l'essence continue d'entraîner des bénéfices sociaux nets négatifs. Nous estimons qu'une réduction d'une tonne d'équivalent CO2 produit par la fabrication et l'utilisation de l'éthanol de maïs coûte entre 400 $ à 3 300 $, tandis qu'elle coûte 142 $ environ pour l'éthanol cellulosique. Ces sommes dépassent largement les estimations classiques des bénéfices attribuables aux réductions d'équivalent CO2, qui varient entre zéro et 50 $ la tonne.

Les recommandations les plus évidentes qui ressortent de cette analyse consistent à demander de mettre un terme aux principales composantes de la politique actuelle sur le biocarburant de transport en raison du fait que les coûts dépassent de beaucoup les bénéfices sociaux, alors qu'aucun retournement de la situation n'est envisageable de façon réaliste. Si le but du gouvernement est de soutenir le développement des énergies renouvelables ayant au moins le potentiel théorique de remplacer l'essence en répondant à des impératifs concurrentiels, alors il est tout à fait justifié de limiter la recherche et les fonds publics destinés à l'éthanol cellulosique.

Introduction

Government support for biofuels takes many forms. Programs, mandates, and financial support are in place in Canada and around the world, supporting biofuel research, production, and consumption. The use of biofuels to power vehicles is not new, but the massive level of current production is. Chart 1 shows total US production of vehicle ethanol from 1980 to 2012.

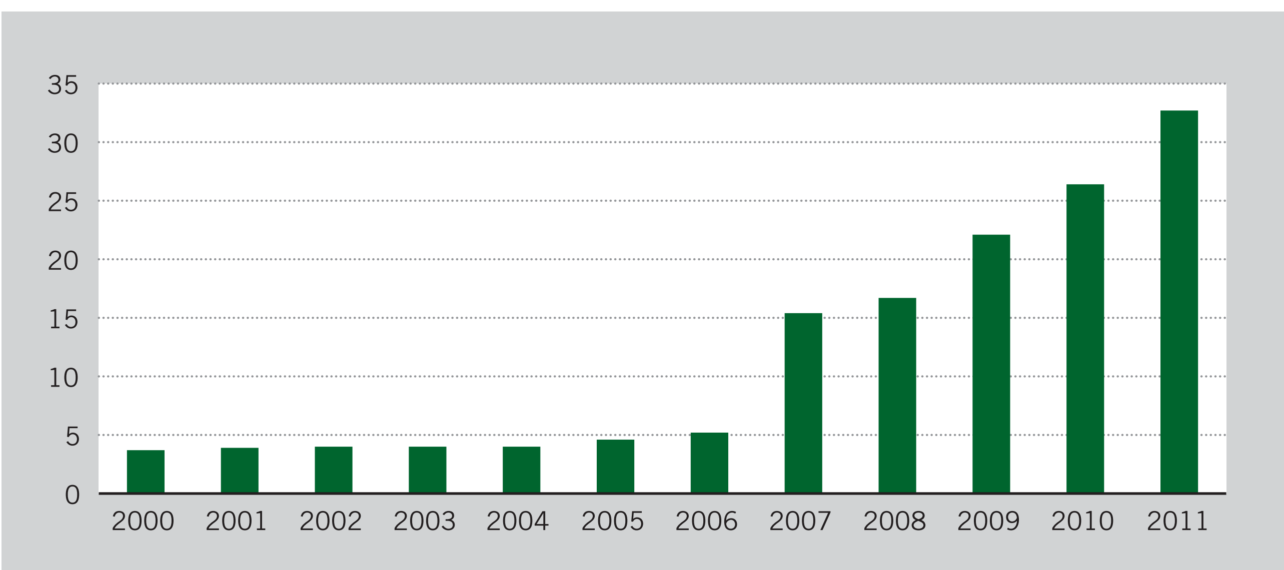
CHART 1: Total production of fuel ethanol in the US, 1980–2012, thousand barrels per day



Source: US Energy Information Administration, May 2014, *Monthly Energy Review.*

Production in the mid-1980s was steady at just over 40,000 barrels per day (bpd), but took off after the turn of the century, rising almost 8-fold from 115,000 bpd in 2000 to 862,000 bpd in 2011. Canadian production from 2000 to 2011 is shown in chart 2.

CHART 2: Total production of fuel ethanol in Canada, 2000–2011, thousand barrels per day



Source: US Energy Information Administration.

It jumped almost 9-fold over the same period, from 4000 bpd to 33,000 bpd in 2011. In both cases the interval from 2006 to 2009 was particularly influential, coinciding with the implementation of aggressive government support policies.

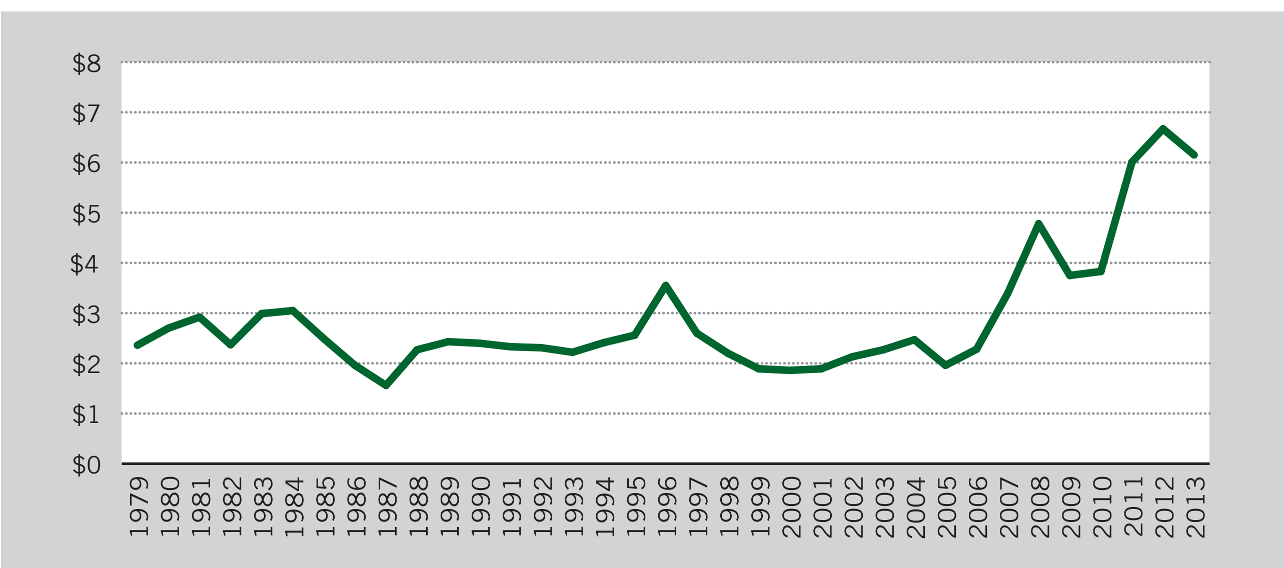
A few relatively minor policies preceded the post-2006 intervention. In the 1980s, ethanol was used in the US to boost the oxygen content of gasoline as a way to achieve required reductions in carbon monoxide exhaust emissions (Rask 2004). But a more widely-used oxygenating additive at the time was methyl tertiary butyl ether (MTBE), which was derived from natural gas. This changed in 2005 when the US government removed the oxygenate requirement for reformulated gasoline and replaced it with a renewable fuels mandate, leading to a switch away from MTBE towards ethanol as the main fuel additive. This switch was in part motivated by fears that MTBE might be a carcinogen, leading many states to ban it outright, though the US Environmental Protection Agency does not endorse that claim.[1]

In 2006, the new Conservative government announced its intention radically to accelerate the existing ethanol support programs.

In Canada the blending of biofuels in gasoline was promoted by eliminating the excise tax on the ethanol portion, and by 1987 there were approximately 250 service stations in the West offering ethanol-blended fuels ((S&T)[2] Consultants 2004). A few stations in Ontario and Quebec provided ethanol-blended fuel in the early 1990s. In 1994, as part of the nascent biomass incentive program, the federal government provided additional incentives for ethanol and biodiesel production. This was followed by several provincial governments putting their toes in the ethanol support pool. By the time the Liberal government launched the Ethanol Expansion Program in 2003, incentives for ethanol to be blended with gasoline had been put in place in several provinces.

In 2006, the new Conservative government announced its intention radically to accelerate the existing ethanol support programs and broaden them significantly. As chart 2 shows, this had an enormous effect on production, possibly larger than the government itself intended. Policies introduced at the same time in the US (chiefly the 2007 *Energy Security and Independence Act*) as well as the European Union also caused a rapid increase in biofuels production. This coincided with a doubling in the price of corn (chart 3), leading to widespread and continuing concerns that poor households in developing countries were being directly harmed by biofuels policies in wealthy countries (for an example see Wise 2012).

CHART 3: Price of corn 1979–2013, US$/bushel



Source: University of Illinois.

While defenders of the biofuels industry have argued that many other factors contributed to the price rise (such as income growth in Asia, rising energy costs, and market speculation), recent and ongoing empirical work has failed to find they play nearly as big a role as biofuels policy (Wright 2014). In addition to concluding that "The [grain] price jumps since 2005 are best explained by the new policies causing a sustained surge in the demand for biofuels" (75), Wright (2014) also argues that US and EU biofuels policy effectively doubled the real price paid by the world's landless poor for their dominant calorie staples.

It is conceivable that ethanol blending actually raises overall emissions of conventional air contaminants.

This report provides a critical overview of biofuels policy in Canada, focusing on the environmental costs and benefits. We enumerate, as best we are able, the range of federal and provincial support policies and their costs (direct and indirect). We also provide calculations on the potential environmental benefits of ethanol production. Whether greenhouse gases (GHGs) are reduced by blending ethanol in the fuel supply is debatable, as we will show. The beneficial effect on conventional air contaminants is also small at best. Rask (2004) showed that cars built after the 1988 model year exhibited no reduction in carbon monoxide or hydrocarbon emissions as a result of using ethanol-blended fuels. Considering that biofuels are less efficient and cars need to burn more to travel the same distance compared to regular gasoline, it is conceivable that ethanol blending actually raises overall emissions of conventional air contaminants. In that sense we cannot provide conventional cost-benefit calculations, since there do not seem to be any reliable environmental benefits. However, some independent research does find that ethanol, under certain conditions, results in lower GHG emissions than gasoline. Taking these estimates at face value, we nonetheless find that biofuels policy is an extraordinarily costly approach to GHG reduction, and yields a net welfare loss for Canada under plausible assumptions, when both direct and indirect costs and benefits are considered.

Canadian Biofuel Policy: An Overview

Table 1 summarizes biofuel programs established by the federal government in the last decade.

TABLE 1: Federal biofuels support policies since 2007

Program Name	Budget and Administering Agency	Instrument Type	Goals/Details
EcoEnergy for Biofuels Overview	$1.5 billion NRCan	Production subsidy, capacity subsidy	Subsidies of up to $0.26/L for renewable alternatives to vehicle fuels
ecoAGRICULTURE Biofuels Capital Initiative	$200 million Agriculture and Agri-Food Canada	Loans (repayable contributions)	Encourages producer equity/ownership in bio-fuel facilities. Helps fund projects that use agricultural feedstock to produce bio-fuels
Agricultural Bio-products Innovation Program (ABIP)	$145 million Agriculture and Agri-Food Canada	Grants	Seeks to mobilize research networks focused on developing technologies for agricultural biomass conversion

Program Name	Budget and Administering Agency	Instrument Type	Goals/Details
Agri-Opportunities Program	$134 million Agriculture and Agri-Food Canada	Loans (repayable contributions)	Accelerate the commercialization of new agricultural products. Program closed in 2011.
NextGen Biofuels Fund	$500 million Sustainable Development Technology Canada	Loans (repayable contributions)	Increase production capacity of 2nd generation biofuels. Program closed in 2011.
Biofuels Opportunities for Producers Initiative	$20 million Agriculture and Agri-Food Canada	Direct payment	Provides financial assistance to develop bio-fuel feasibility. Program closed in 2008.

Table 2 provides a similar listing of provincial biofuel policies and programs. We will address, in this paper, only those policies and programs affecting the vehicle fuel market in Canada.

TABLE 2: Major provincial biofuels support policies

Province	Programs	Highlights
Alberta	Ethanol blend target	5% as of 2011 Life Cycle must demonstrate 25% less GHG than gasoline
	Bioenergy credit program for 2^{nd} generation biofuels	Between 9 and 14 cents per litre of biofuel
	Biogas program	Sliding scale of $0.06 to $0.017 per kwh
British Columbia	Ethanol blend target	5%
	Biodiesel	3% in 2010 and 4% afterward
	Bio Energy Network	$25M support for biomass facilities
	Liquid Biofuel program	$10M for liquid biofuel facilities
	Innovative Clean Energy	Support pre-commercial technology not specific to biofuels
Manitoba	Ethanol blend target	8.5%
	Production Incentive	$0.20 per litre declining to $0.10 until December 2015

Province	Programs	Highlights
Ontario	Ethanol blend target	5%
	Ontario Biofuel Growth Fund	$32.5 M capital assistance; up to $0.10 per litre $60.5M 2007–17 for operating assistance up to $0.11 per litre No longer taking applications as of 2012
	Independent retailers support	$16M to support independent retailers selling blends
	R&D program	$7.5 Million
	Biogas	Guaranteed FIT
Quebec	Production incentive	$0.185 per litre for 10 years to ethanol producers if oil falls below $65 per barrel. 2006 to 2018
	Green Technology Demonstration Program	Support technology to reduce GHG in fuels, improve energy efficiency
	Enerkem	Capital and other support for cellulosic ethanol for company founded in 2002.
Saskatchewan	Ethanol blend target	7.5%
	Go Green Strategy	Promotes environmentally friendly transportation
	Biofuel Grants Program	$80 M total
Atlantic Canada	Atlantic Bioenergy Task Force	NS tax credit on biodiesel

Source: United States (2012), Canada (2012), United States Department of Agriculture.

A quick glance at the array of programs indicates that most are exclusively focused on vehicle fuel, primarily ethanol, accompanied by emerging developments in cellulosic ethanol and a token commitment to biodiesel for transportation. There is a complex array of programs with substantial duplication between the federal and provincial levels, as well as inconsistencies across provinces. For instance, fuel retailers on the prairies must contend with the fact that the ethanol mandate is 5 percent in Alberta, 7.5 percent in Saskatchewan, and 8.5 percent in Manitoba, breaking these regions up into smaller boutique fuel markets based on arbitrary ethanol content targets. These inconsistencies hamper trade in fuels and lead to higher retail prices than are necessary. The differing mandates and subsidy programs may also lead to production facilities being located in areas not well suited to ethanol production.

According to the Canadian Renewable Fuels Association, there are ethanol refining facilities in five provinces. In principle, before it began implementing its own ethanol policies the federal government should have worked with provinces to harmonize provincial mandates, eliminate inter-provincial trade barriers, and eliminate beggar-thy-neighbour investment incentives. However, given the lead provinces have in developing provincial regulations, the ability of the federal government to do any of this now is doubtful.

With this background, we turn now to examine the primary argument advanced by governments to justify the production subsidies and mandates for the consumption of biofuel-blended gasoline: reducing greenhouse gas (GHG) emissions and criterion air contaminants (CACs).

Effects on Various Forms of Emissions

The introduction of mandates for blended fuel and the payment of significant financial incentives for the industry by the new Conservative government in 2006 marked the beginning of a major intrusion into the transportation fuel market. What was the rationale behind the accelerated interest in biofuels? In the Speech from the Throne opening the 2nd session of Parliament in 2007, the new Conservative government squarely tied biofuels policies to their commitment to a 20 percent reduction in GHGs by 2020. The following year, the November 19, 2008 Speech from the Throne stated:

> Our Government has committed to reducing Canada's total greenhouse gas emissions by 20 percent by 2020. . . . to meet the challenge posed by climate change, we will also need to make greater use of technologies that do not emit greenhouse gases. Our Government will set an objective that 90 percent of Canada's electricity needs be provided by non-emitting sources such as hydro, nuclear, clean coal or wind power by 2020. In support of this ambitious national goal, our Government will continue to provide support for biofuels, wind and other energy alternatives. (Government of Canada, 2008)

Finally in a section regarding industry sector support, the Speech noted, “The agricultural sector will benefit from our Government's promotion of biofuels”.

The difficulty with assessing the cost of GHG emissions from biofuels is that it is impossible to say whether they reduce emissions at all.

Providing support for the agricultural sector was thus a secondary goal, against the primary one of reducing GHG emissions. Ethanol was seen at the time as a mechanism for reducing GHGs because the source for ethanol is plant material rather than fossil petroleum. In principle, when corn is converted to ethanol and then burned, the carbon released is fully offset by the carbon sequestered when the plant grew a few months earlier, so there is no net change in the atmospheric concentration of CO_2. When petroleum is burned, carbon is released that was stored millions of years earlier, leading to a net increase in the current atmospheric CO_2 content. Forcing refineries to blend ethanol in gasoline therefore reduces the total effect on atmospheric CO_2 levels from using gasoline.

That is the theory, at any rate, but there are serious practical difficulties that put the putative benefits into some doubt.

- Life cycle emissions: While corn, as a raw material, yields no net CO2 emissions when it is burned, the process by which corn is converted to ethanol is energy-intensive. The corn itself does not yield enough energy both to run the ethanol-making process and to sell the remainder on the market for enough to make the process profitable. So ethanol manufacturers need to use conventional energy sources to produce the ethanol, as well as the farming and transportation work required to get the ethanol to market. Some of these conventional energy sources are major sources of GHGs, such as, for instance, an ethanol plant drawing power from a coal-fired electricity grid. Taking into account the energy needs during ethanol production reduces the net benefit of using ethanol in place of gasoline.

- Lower BTU content: A gallon of ethanol contains 33 percent less energy than a gallon of gasoline (Martinot 2010). A 95 percent gasoline blend takes a car a shorter distance than a 100 percent gasoline blend – namely about 98 percent as far. As a result, to drive the same distance the driver needs to use 2 percent more of the blended fuel compared to the unblended fuel, so we cannot say that the reduction in gasoline use is 5 percent, since it is offset by the increased consumption of the blend needed to go the same distance. In fact the reduction works out only to about 3.4 percent.

Both these issues need to be analysed using a life-cycle analysis (LCA) framework. Detailed LCAs have been done by, among others, the US Department of Energy Argonne National Laboratory and the US Environmental Protection Agency (EPA), plus many others. A review of all the studies and estimates of GHG emissions from biofuels and comparisons with gasoline and diesel fuel would constitute a short book in itself. Table 3 presents the results from a 2009 survey by the US Environmental Protection Agency.

TABLE 3: Greenhouse gas reductions or increases from biofuels relative to energy equivalent volume of gasoline

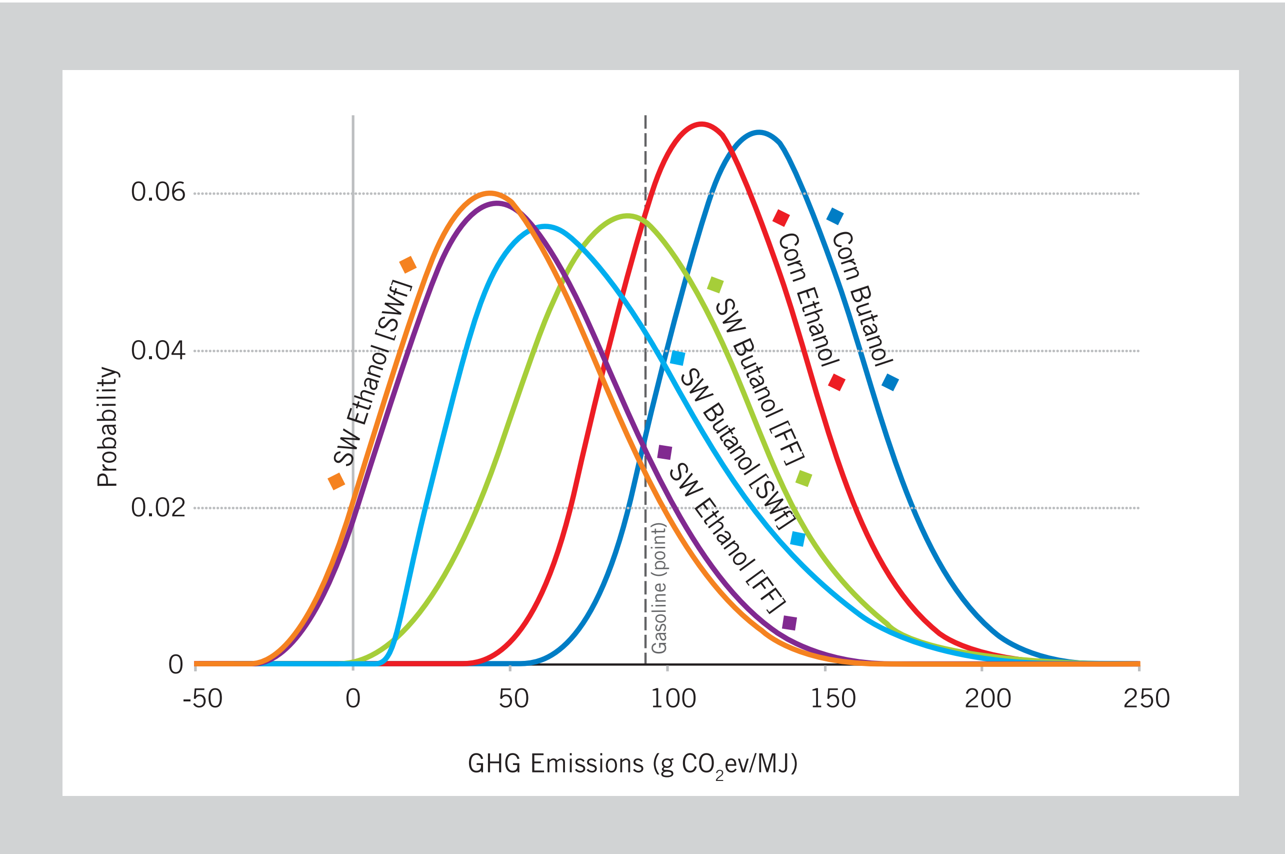
Fuel Pathway	
Corn Ethanol (Natural Gas Dry Mill)	+5%
Corn Ethanol (Best Case Natural Gas Dry Mill)	-18%
Corn Ethanol (Coal Dry Mill)	+34%
Corn Ethanol (Biomass Dry Mill)	-18%
Corn Ethanol (Biomass Dry Mill with Combined Heat and Power)	-26%
Soy-Based Biodiesel	+4%
Waste Grease Biodiesel	-80%
Sugarcane Ethanol	-26%
Switchgrass Ethanol	-124%
Corn Stover Ethanol	-116%

Source: US EPA, 2009, Life Cycle Analysis of Greenhouse Gas Emissions for Renewable Fuels.

It is clear that the results are quite sensitive to the type of biofuel and the manufacturing process used to make the fuel. The two dominant processes, involving natural gas-powered drying and coal-powered drying, both yield more GHG emissions on a life-cycle basis than the (energy-) equivalent amount of gasoline. Some other methods, such as biofuel-powered drying, yield lower emissions, but at a much higher production cost.

A recent and thorough review of the literature on GHG and biofuels was undertaken by the National Research Council in the US (2011). Their review of the literature led to the somewhat disturbing conclusion that, on a comparative life-cycle basis, there is no scientific consensus regarding the GHG emissions from corn-grain ethanol. One of the studies they cited was Mullins, Griffin, and Matthews (2009), whose empirical findings are summarized in chart 4.

CHART 4: Estimates of GHG emissions from different forms of biofuels relative to that from gasoline



Source: Mullins, Griffin, and Matthews (2009).

The benchmark is the vertical dashed line, which shows the emissions of GHG from gasoline in grams CO_2-equivalent per megajoule (g CO_2ev/MJ). The curves show the distributions of estimated emissions from various types of biofuels, with the range indicating the uncertainties. If biofuels were consistently a lower source of emissions then the distributions would all sit to the left of the vertical dashed line, indicating lower emissions per unit of energy. But as is clear, many of the distributions are centered to the right of the benchmark, indicating higher expected GHG emissions than gasoline.

For instance, looking at corn ethanol, we can see GHG emissions range from 50 g CO_2ev/MJ to almost 200 g CO_2ev/MJ, with a mean (at the distribution peak) above that of gasoline. In other words, on a life-cycle basis, the expected emissions per unit of energy from corn ethanol are *higher* than those from gasoline.

Wang, Wu, and Huo (2007) examined GHG emissions and energy use in nine ethanol plants in the US. They found that on a full LCA basis, the effect of using different energy sources for the production of ethanol led to results of GHG emissions that varied considerably. On average, the particular plants they studied showed a reduction in GHG emissions of 15 percent compared to gasoline. In a more recent analysis, Sesmero, Perrin, and Fulginiti (2010) concluded that "on average, plants in our sample may be able to reduce GHG emissions by a maximum of 6 percent." Finally, an examination of the evidence gathered by the International Institute for Sustainable Development (IISD) in 2012 suggests that the range of GHG emissions relative to gasoline is -20 to + 50 percent, a similar range to that shown in Mullins, Griffin, and Matthews (2009).

There are many reasons for such discrepancies. In the case of ethanol, variations in LCA emissions can arise due to the type of fertilizer used to grow the corn, the energy source used to fuel the dry-milling process, the use of a biochemical or thermo-biochemical step in the conversion stage, whether plant oil was utilized as a feedstock (for biodiesel), where the plants were grown, how it was shipped for pressing, and more. Even if all these steps are identified and measured, it is impossible in many cases to state precisely the GHG implications, and a proper analysis must be done in a model that incorporates the probability of an outcome. The actual outcomes are quite sensitive to the underlying assumptions in the LCA model. For example, Coad (2011) argues that, compared to US farmers, Canadian corn producers use more manure than nitrogen and thus less energy to produce ethanol. That may be so but the implications of substituting manure for nitrogen affect GHG emissions since manure is a source of methane. The same author also notes in the context of the LCA modelling that "vehicle emissions are lower because ethanol is a renewable fuel, and the CO_2 emissions from the fuel itself are excluded from the calculation" (16). This questionable assumption will clearly have an impact, in that case skewing the results in favor of ethanol.

Consequently, the difficulty with assessing the cost per tonne of GHG emissions from using biofuels is that it is impossible to say whether, in general, they reduce emissions at all. There is ample evidence that in many cases they do not. Obviously if reductions are zero then the cost per tonne reduced is effectively infinite.

It is nonetheless valuable to know how much the various programs cost. We will go through those calculations now, but when it is time to express them on a per tonne reduced basis we will need to impose an arbitrary assumption about the effectiveness of the program.

Costs of Vehicle Biofuels Programs

Direct Costs of Ethanol

It is clear that both federal and provincial governments see biofuel policy as a means to reduce GHG emissions from vehicle fuel and, secondarily, to provide support for the agriculture/rural sector. As noted earlier, the criteria to support the GHG part of the policy is straightforward: compared to a "business as usual" scenario (no support/intervention in the biofuel sector), over a given period of time we can ask what GHG reductions occurred as a result of the mandated blended vehicle fuel, and whether they come at a low enough cost to make them worthwhile. Referring to the probability distribution in chart 4 above and choosing the mean of the distribution for corn ethanol and the point estimate for gasoline, the result is disappointing from a biofuel policy point of view: there is an increase in GHG emissions over the period. Biofuels policy thus amounts to a subsidy for increased, not decreased emissions.

For the sake of pursuing the analysis further we will refer to the study by Sesmero, Perrin, and Fulginiti (2010) which yielded a much more optimistic estimate of the situation, concluding that GHG emissions from ethanol are 92 grams CO_2 equivalent per Megajoule (g CO_2ev/MJ), a 3 unit reduction from gasoline (which is 95 g CO_2ev/MJ). We can then turn to the question of ascertaining the direct public cost, per tonne, to achieve that reduction.

Even on the most optimistic reading of the evidence, corn ethanol cannot be justified as a GHG mitigation strategy.

The most thorough estimate regarding the total level of public support is provided by Global Subsidies Initiative (2012). Their detailed analysis shows that the direct public support in Canada for ethanol averages between 20 and 24 cents per litre. We will select the lower limit. A litre of ethanol contains 19.6 MJ of energy, so a reduction of 3 g CO_2ev/MJ is equivalent to 60 gms of CO_2ev per litre. A subsidy of 20 cents per 60 grams equals $0.0033 per gram, or **$3300 per tonne**.

Now suppose we assume an extremely optimistic estimate of the GHG benefit from utilizing ethanol, namely 25 g CO_2ev/MJ. In that case, going through the same calculations we find the subsidy declines to about **$400 per tonne**.

By contrast, conventional estimates of the benefits of CO_2 emission reductions (also called the social cost of carbon) are typically well below **$50 per tonne** (Tol 2007). Thus, even on the most optimistic reading of the evidence, corn ethanol cannot be justified as a GHG mitigation strategy.

Direct Costs of Cellulosic Ethanol

There is a concerted effort in Canada, and globally, to commercialize cellulosic ethanol, particularly if the process uses agro-forest waste, municipal waste, and non-food crops grown on marginal land. Not only does this address the concern about diverting food into fuel production, but there is evidence that it yields more GHG reductions per unit of energy compared to ethanol and gasoline. There is currently only one commercial cellulosic ethanol producer in Canada with a capacity of 5 million litres annually (Global Agriculture Information Network 2013). Other refineries in North America are being constructed with considerable support from government. Since it is likely that cellulosic ethanol will replace a portion of ethanol or provide the biofuel for the expansion of blended fuel, the costs of achieving this goal need to be explored.

To estimate the total direct public cost of supporting cellulosic ethanol we have to make two assumptions. The first concerns how much ethanol is likely to be produced in, say, the period 2015 to 2019. There are no formal targets for cellulosic ethanol production in Canada over the next decade. In the US, a target of approximately 16B litres by 2022 has been suggested, which is about one quarter of the current ethanol production level (Today in Energy 2013). We will therefore assume that Canada will work to a target of 1.5 B litres.

The estimated direct government support per litre for cellulosic ethanol in Canada is estimated to be between 32 and 47 cents up to 2010 (Global Subsidies Initiative 2011). We will select the lower subsidy limit of 32 cents and adopt the best-case scenario assumption that cellulosic ethanol emits only 45 g $C0_2$ev/MJ, compared to 95 from gasoline. Substituting cellulosic ethanol for gasoline therefore yields a reduction of 50 g $C0_2$ev/MJ. A litre of cellulosic ethanol contains 30 MJ of energy (Hammerschlag 2006). This translates into 1500 g $C0_2$ev per litre, which translates into a subsidy of $0.32/1500 = $0.000213 per gram or $213 per tonne. Suppose technological advances bring GHG emissions for cellulosic ethanol down to from 45 to 20 g $C0_2$ev/MJ, a possible future target suggested by some researchers. This implies a 75 g $C0_2$ev/MJ reduction in GHG emissions compared to gasoline, which implies a subsidy per tonne of GHG reduction of **$142 per tonne**. Taking this as a feasible lower bound of the implied subsidy cost, it is still well above the typical range of conventional estimates of the social cost of carbon.

Consequently, on a per-tonne basis, even with the most optimistic reading of the evidence, subsidies for corn ethanol and cellulosic ethanol yield GHG emission reductions at a cost many times higher than mainstream estimates of their benefits. And, to reiterate a point made earlier, this unfavourable benefit-cost comparison emerges *after* setting aside the considerable body of evidence that ethanol production actually increases GHG emissions compared to gasoline under reasonable assumptions about how ethanol is produced. Consequently, the case for biofuels subsidies as a climate policy measure appears to be non-existent.

Overall Costs and Benefits: 2008–2012

In this section, we turn to estimating the direct and indirect costs of biofuels policy in the five-year period 2008–12, and we contrast those against conventional estimates of the benefits stemming from the estimated GHG reductions. We choose 2008–12 because the majority of biofuel policies impacting transportation were in effect during this period of time. A complete estimate of all the costs would likely require application of a computable general equilibrium (CGE) model. Such a task is beyond the scope of this paper. For an example of mathematical modelling that examines the interdependency of three biofuel-related markets, see Babcock, Barr, and Carriquiry (2010). Instead we will merely itemize the main costs and benefits separately noting the interdependencies between biofuel markets and other key sectors in the economy.

Economic Costs

A. In the section titled Direct Costs of Ethanol the estimated budgetary expenditures supporting biofuels were used to calculate the cost of reducing GHG by one tonne when comparing gasoline and biofuels. The true cost of this public outlay of funds is actually higher than the dollar value because the marginal cost of public funds is always greater than one. In other words, society loses more than a dollar's worth of real income when governments raise an additional dollar in revenue. Taxes distort prices, driving down returns to sellers and raising costs to buyers. As a result, the tax base shrinks as the tax rate increases, and this base-shrinking represents a reduction in voluntary (mutually-beneficial) transactions. This loss is called the *excess burden* of taxation, and at the margin it is always positive. It must be added to the cost of raising government revenue, and when we do so the resulting quantity is called the *marginal cost of funds* (MCF) for the government. Subsidies from government coffers have to be financed by higher taxes, and these need to be valued at the MCF, not at their nominal value.

   There is a long history of empirical studies to measure the MCF. Jones (2010) found that estimated values for the MCF range between 1.0 and 1.56 for the US, 1.25 to 1.38 for Canada, 1.07 to 1.16 for Sweden, 1.18 for New Zealand, and 1.19 to 1.55 for Australia. While there is a wide range of estimates, ignoring the MCF when considering how to finance biofuel subsidies would be a mistake and lead incorrectly to estimates of a higher net benefit or smaller net cost of biofuel policies. Given our estimate of the support package for biofuels in the years under review, and selecting the lower boundary of the MCF for Canada (1.25), we estimate the true cost of the subsidies and other incentives paid to the biofuel industry in the period 2008 to 2012 to be 1.25 x $ 1.15B (the estimated direct government support for ethanol) which equals **$1.43 billion.**[2]

B. The second negative impact of government intervention in the transportation fuel sector is the loss in income/profit in the fossil fuel sector due to the replacement of gasoline with biofuel. Given the total production of ethanol over the five-year period and knowing that ethanol has 2/3 the energy output of gasoline, approximately 6000 M litres of gasoline were displaced in the period 2008–12. This represents about 4 percent of the total consumption of gasoline, a reduction in sales that occurred only because of a coercive government policy. The most likely place for job reductions is in the refining part of gasoline production. We will suppose that the employment elasticity of output is 0.5, so a 4 percent reduction in output leads to a 2 percent reduction in employment. There are approximately 8500 workers in this sector (MBendi Information Services) so a reduction in employment due to ethanol replacement amounts to about 200 jobs over this period. At an average annual wage of $60,000, this represents a loss of **$12M**. However, these losses are more than made up for by the value of employment gains in the ethanol sector, as we explain below.

C. There is a further negative effect of biofuel policy in the form of the welfare loss shouldered by consumers because of the ethanol mandate-induced rise in the price of corn and food. An earlier study estimated this loss to be $400 million annually (Auld 2008). It would be reasonable to adjust this upward for the 2008–12 period given the increase in disposable income and food purchases but assuming the own-price elasticity is unchanged. This modification yields a cost of **$450M**.

D. Finally, there are losses to the poultry and livestock industry in Canada as a result of the rise in grain prices induced by the demand for ethanol. The loss alone to the livestock industry in Canada is estimated at $120M annually for an overall estimate during the period of **$480M** (Grier, Mussell, and Rajcan 2012).

TOTAL: Adding up the above items yields a total estimated cost of **$2372 million** over the 2008–2012 interval.

Economic and Environmental Benefits

A. The main intended benefit of biofuels policy is a reduction in GHG emissions. To estimate the possible magnitude of this reduction we must take account of the fact that ethanol contains only two-thirds the energy of gasoline. Selecting a GHG emission level for ethanol relative to gasoline is difficult, for the reasons stated above. For our purpose here we will select an estimate from a study that examined, on an LCA basis, the energy and GHG emission level of ethanol from corn produced in Iowa (Sesmero, Perrin, and Fulginiti 2010). Their estimate of GHG emissions from ethanol is 2.3 kg $C0_2$ev/litre, compared to the baseline emissions level of gasoline of 2.9 kg $C0_2$ev/litre. We will also try, for comparison, a substantially more optimistic assumption than that, supposing ethanol to yield only half the GHG emissions per litre compared to gasoline: in other words 1.45 kg versus 2.9 kg per litre.

To obtain the value of the GHG reduction due to the replacement of a quantity of gasoline with ethanol from 2008 to 2012, a market value of the environmental benefit of reduced GHG is required. This can be done two ways. We could use the rather speculative social cost of carbon estimates derived in the economics literature, which typically fall between $0 and $50 but can range as high as $200 depending on assumptions about discounting and climate sensitivity

(Marten 2011). But an alternate, and more objective approach, is to evaluate the cost of abatement through an existing CO_2 trading market, since anyone wanting to offset a tonne of emissions could simply purchase credits in the market and retire them in order to achieve that goal. The EU is the only reasonably functioning carbon market that provides the price in terms of per tonne of CO_2ev. During the 2008 to 2014 period, the price of carbon was as high as 30 euros per tonne to a low in 2014 of 2.8 euros. For our purposes here we select a price of carbon equal to C$20 per tonne.

Between 2008 and 2012, 6.8 B litres of ethanol were produced for use in Canada (Renewable Fuels Association 2013). The net reduction in GHG emissions, denoted ΔGHG, is given by the formula

$$\Delta GHG = 2.3 \times FE - 2.9 \times FG$$

where FE is the ethanol fuel produced (millions of litres), FG is the gasoline that was replaced (a 1:1 switch deflated by 1.3 due to the different energy content), and 2.3 and 2.9 are respectively, the grams of GHG per litre of ethanol and gasoline from Sesmero, Perrin, and Fulginiti (2010). Using FE = 6.8 B this yields

$$\begin{aligned} \Delta GHG &= 2.3 \times 6.8 - 2.9 \times \frac{6.8}{1.3} \\ &= 6.8 \times (2.3\text{-}2.23) \\ &= 0.476, \end{aligned}$$

or a 476,000 tonne *increase* (note: not a decrease), and at a price of $20 per tonne this has a social *cost* of $9.4 million. If we use a much lower (and currently infeasible) figure of 1.45 kg C02ev/litre we estimate a reduction of 5.31 B kg or 5.31 million tonnes, which at $20 per tonne has a value of **$106 million**. Despite being technically infeasible, we will allow this figure to stand as the benefits estimate.

B. The biofuel industry has expanded substantially since 2005/06, creating jobs in the processing/refining, blending, and agriculture sectors. In addition, investments in plants, equipment, and machinery have also increased. While there is no breakdown of the types of jobs and where, a report on the industry stated that “The biofuels industry creates more than 14,000 person-years of employment during construction phase and over 1000 permanent jobs once plants are in operation” (Soberg 2011). Based on this data, we can only estimate that in the 2008–12 period some 1000 to 1800 jobs were created. If the creation of 1400 full time jobs over the period is a reasonable estimate, this would be valued at **$84 million** given an annual average wage of $60,000.

C. A considerable share of the government support for biofuel was the provision of capital grants and no-interest loans for facilities and special depreciation schedules for biofuel capital investment to provide fast write-offs. At the federal level, the C$200 million ecoAGRICULTURE Biofuel Capital (ecoABC) Initiative and the C$20 million Biofuel Opportunities for Producers Incentive (BOPI) are two major granting programs. At the provincial level there are a variety of programs, the largest of which is the Ontario Ethanol Growth Fund (OEGF), which provides C$520 million for operating and construction grants. While there are no current data on the amount of capital construction and support for the 2008–12 period**, $500 million** would be a conservative estimate.

D. The array of government programs to support ethanol production in Canada included payments for research and research related technology development. There are a myriad of federal and provincial programs that direct funds to partnerships, companies, and universities for research and development. At the federal level, the major programs/agencies are National Research Council Canada (NRC), Natural Resources Canada (NRCan), Agriculture and Agri-Food Canada (AAFC), Agricultural Bioproducts Innovation Program (ABIP), Sustainable Development Technology Fund, and Canadian Biomass Innovation Network (CBIN). Two examples at the provincial level are the Ontario Ethanol Growth Fund for Alternative Renewable Fuels Research and Development and the BC Bioenergy Network. There are no consistent and audited data for the 2008 to 2012 period but based on spending up to 2009, a figure **of $100 million** is not unreasonable.

Between 2008–2012, Canada spent between $3.00–3.50 for every one dollar of benefit derived from transportation biofuels.

TOTAL: Adding up the above items yields a total estimated benefit of **$790 million** over the 2008–2012 interval.

Even allowing for a very optimistic calculation of benefits, the costs are three times the benefits ($2372 / $790 = 3). If we zero out the GHG benefits the cost-benefit ratio rises to 3.5. Thus, overall, during the 2008–2012 interval, Government of Canada transportation biofuels policies cost between about $3.00 and $3.50 for every one dollar of benefit.

Conclusions and Recommendations

The support for ethanol as a partial substitute for gasoline in Canada has been very expensive by any test. Notwithstanding the fact that since 2008 there have been significant improvements in the technology to manufacture ethanol, therefore improving the GHG effectiveness of ethanol, any reduction in GHG achieved by blending ethanol and gasoline continues to be costly. On a per-tonne basis, we estimate that the cost per tonne of CO_2 equivalent reduction from production and use of corn ethanol ranges from $400 to $3300 per tonne, and that from cellulosic ethanol is about $142 per tonne. This far exceeds the conventionally-estimated benefits of CO_2 reduction of between $0 and $50 per tonne.

Over the 2008–2012 interval, allowing for very optimistic assumptions about the efficacy of reducing GHG from ethanol blending, we estimate that the federal biofuels policies cost between $3.00 and $3.50 for every dollar of social and environmental benefits. Consequently the policy has failed to deliver value to Canadian taxpayers.

The most obvious recommendation to emerge from this analysis is the need to phase out the major components of current transportation biofuel policy on the grounds that the costs far exceed the social benefits and there are no realistic prospects for this situation to change. If the government's goal is to support the development of renewable fuels that have at least a theoretical potential to replace gasoline on a cost-competitive basis, a case can be made for limiting public research and development funds to cellulosic ethanol.

About the Authors

Douglas Auld is an adjunct professor of economics and finance at the University of Guelph. He has a B.A. (Economics) from Western University, an M.A. (Economics) from the University of Toronto, and a Ph.D. (Public Finance) from the Australian National University. Current research is focused on the political economy of global biofuel production and consumption and distributional aspects of the treatment of pollution policies. He has published articles in *Journal of Political Economy*, *Quarterly Journal of Economics*, *Journal of Public Economics*, *Canadian Journal of Economics* and *Journal of Sustainable Development*.

Ross McKitrick is a Professor of Economics and CME Chair in Sustainable Commerce at the University of Guelph, where he specializes in environmental economics. He has published widely in both economics and physical science journals on pollution policy, climate change, environmental trends, and statistical methods in climate analysis. His book *Economic Analysis of Environmental Policy* was published by the University of Toronto Press in 2010. Professor McKitrick has made many invited academic presentations around the world, and has testified before the US Congress and committees of the Canadian House of Commons and Senate. In 2006 he was one of 12 experts from around the world asked to brief a panel of the US National Academy of Sciences on paleoclimate reconstruction methodology.

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Endnotes

1 See the US Environmental Protection Agency, 2013, *Methyl Tertiary Butyl Ether,* available at http://www.epa.gov/mtbe/faq.htm.

2 Based on the mid-point of the range of estimates for 2008 to 2012 provided by the International Institute for Sustainable Development. See Laan, Litman, and Steenblik, 2009, *Biofuels – At What Cost? Government Support for Ethanol and Biodiesel in Canada,* available at http://www.iisd.org/pdf/2009/biofuels_subsidies_canada.

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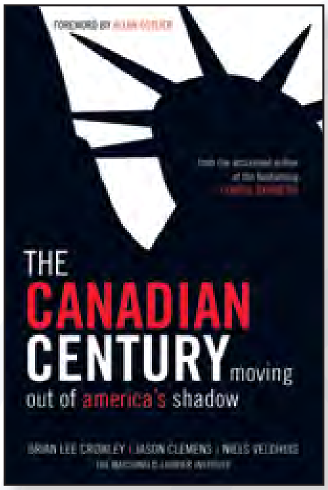

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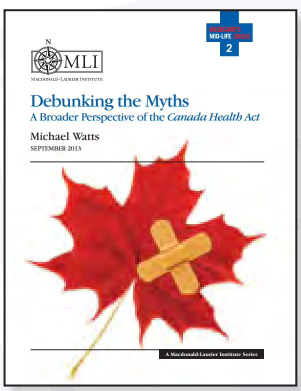

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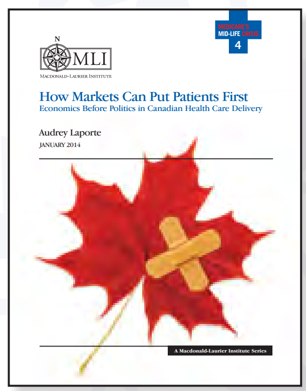

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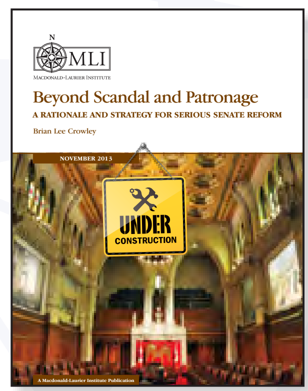

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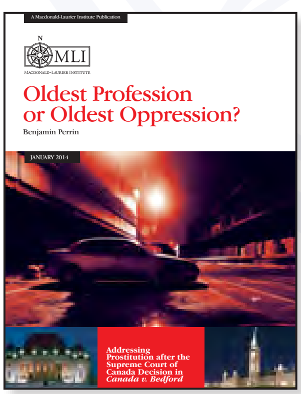

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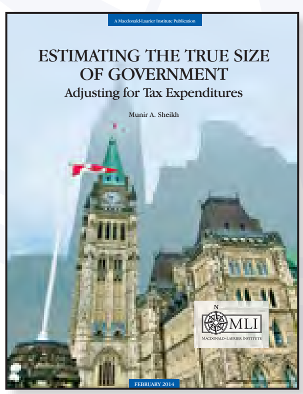

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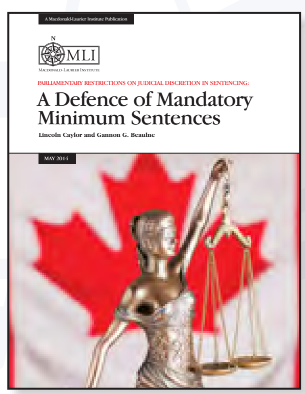

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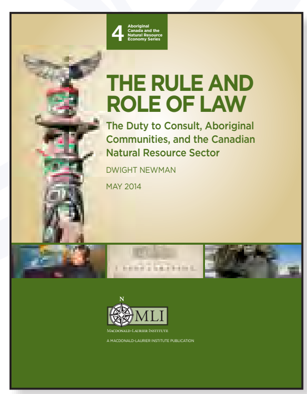

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