Memo to the Environmental Commissioner of Ontario regarding the

LIFECYCLE ANALYSIS OF ETHANOL IN GASOLINE

Appendix B to the ECO's
Greenhouse Gas Progress Report 2016

(S&T)[2] Consultants Inc.

Memo

To: Environmental Commissioner of Ontario

From: Don O'Connor

Date: 2016-09-05

Re: Ethanol GHG Emissions in Ontario Transportation Sector

The Environmental Commissioner of Ontario (ECO) is the province's environmental watchdog, an independent officer of the Legislature. The Province of Ontario is considering the increased use of ethanol in the gasoline pool as part of their Climate Action Plan. The ECO is reviewing the use of ethanol in gasoline and has raised a number of issues with respect to the lifecycle analysis of ethanol and gasoline in Ontario. This memo addresses the issues raised by the ECO.

GHGenius and Lifecycle Analysis

The GHGenius model is based on the 1998 version of Dr. Mark Delucchi's Lifecycle Emissions Model (LEM). GHGenius is capable of analyzing the energy balance and emissions of many contaminants associated with the production and use of traditional and alternative transportation fuels.

GHGenius is capable of estimating life cycle emissions of the primary greenhouse gases and the criteria pollutants from combustion and process sources. The specific gases that are included in the model include:

- Carbon dioxide (CO_2),
- Methane (CH_4),
- Nitrous oxide (N_2O),
- Chlorofluorocarbons (CFC-12),
- Hydro fluorocarbons (HFC-134a),
- The CO_2-equivalent of all of the contaminants above.
- Carbon monoxide (CO),
- Nitrogen oxides (NOx),
- Non-methane organic compounds (NMOCs), weighted by their ozone forming potential,
- Sulphur dioxide (SO_2),
- Total particulate matter.

The model is capable of analyzing the emissions from conventional and alternative fuelled internal combustion engines or fuel cells for light duty vehicles, for class 3-7 medium-duty trucks, for class 8 heavy-duty trucks, for urban buses and for a combination of buses and trucks, for light duty battery powered electric vehicles, and for marine vessels. There are over 200 vehicle and fuel combinations possible with the model.

GHGenius can predict emissions for past, present and future years through to 2050 using historical data or correlations for changes in energy and process parameters with time that are stored in the model. The fuel cycle segments considered in the model are as follows:

- Vehicle Operation

  Emissions associated with the use of the fuel in the vehicle. Includes all greenhouse gases.

- Fuel Dispensing at the Retail Level

  Emissions associated with the transfer of the fuel at a service station from storage into the vehicles. Includes electricity for pumping, fugitive emissions and spills.

- Fuel Storage and Distribution at all Stages

  Emissions associated with storage and handling of fuel products at terminals, bulk plants and service stations. Includes storage emissions, electricity for pumping, space heating and lighting.

- Fuel Production (as in production from raw materials)

  Direct and indirect emissions associated with conversion of the feedstock into a saleable fuel product. Includes process emissions, combustion emissions for process heat/steam, electricity generation, fugitive emissions and emissions from the life cycle of chemicals used for fuel production cycles.

- Feedstock Transport

  Direct and indirect emissions from transport of feedstock, including pumping, compression, leaks, fugitive emissions, and transportation from point of origin to the fuel refining plant. Import/export, transport distances and the modes of transport are considered. Includes energy and emissions associated with the transportation infrastructure construction and maintenance (trucks, trains, ships, pipelines, etc.)

- Feedstock Production and Recovery

  Direct and indirect emissions from recovery and processing of the raw feedstock, including fugitive emissions from storage, handling, upstream processing prior to transmission, and mining.

- Feedstock Upgrading

  Direct and indirect emissions from the upgrading of bitumen to synthetic crude oil at a standalone facility, including fugitive emissions.

- Fertilizer Manufacture

  Direct and indirect life cycle emissions from fertilizers, and pesticides used for feedstock production, including raw material recovery, transport and manufacturing of chemicals. This is not included if there is no fertilizer associated with the fuel pathway.

- Land use changes and cultivation associated with biomass derived fuels

  Emissions associated with the change in the land use in cultivation of crops, including N_2O from application of fertilizer, changes in soil carbon and biomass, methane emissions from soil and energy used for land cultivation.

- Carbon in Fuel from Air

  Carbon dioxide emissions credit arising from use of a renewable carbon source that obtains carbon from the air.

- Leaks and flaring of greenhouse gases associated with production of oil and gas

Fugitive hydrocarbon emissions and flaring emissions associated with oil and gas production.

- Emissions displaced by co-products of alternative fuels

    Emissions displaced by co-products of various pathways. System expansion is used to determine displacement ratios for co-products from biomass pathways.

- Vehicle assembly and transport

    Emissions associated with the manufacture and transport of the vehicle to the point of sale, amortized over the life of the vehicle.

- Materials used in the vehicles

    Emissions from the manufacture of the materials used to manufacture the vehicle, amortized over the life of the vehicle. Includes lube oil production and losses from air conditioning systems.

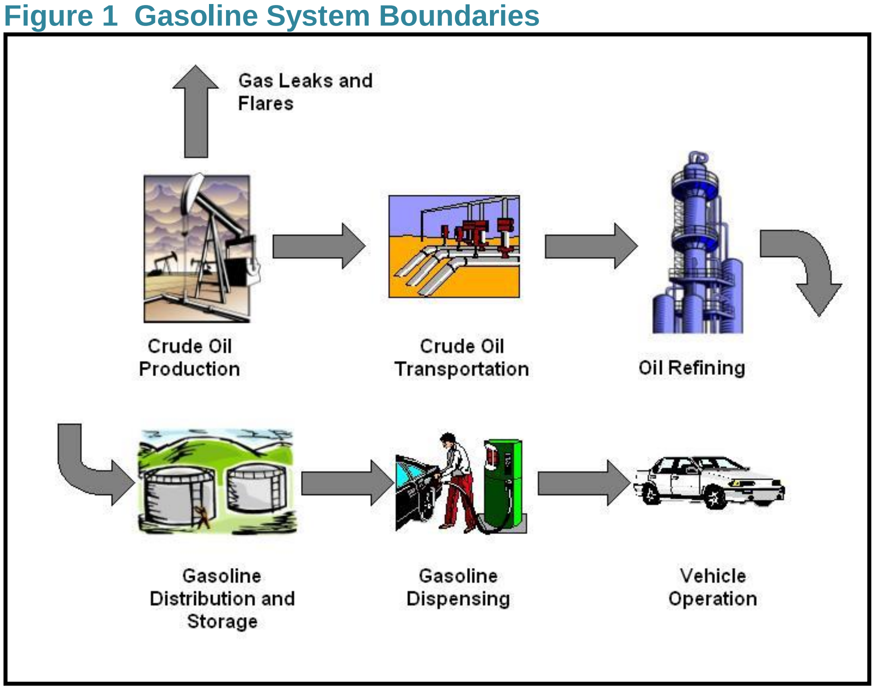
GHGenius 4.03a is fully documented in two volumes of manual that are available on the GHGenius website www.ghgenius.ca.

For this modelling work, the model has been set to Ontario. The year is 2016 and the 2007 IPCC GWPs are selected.

Gasoline Emissions

The lifecycle system boundaries for gasoline are shown in the following figure. All emission sources from the well to the fuel combustion are considered. Ontario gasoline is produced mostly from crude oil produced in Western Canada.

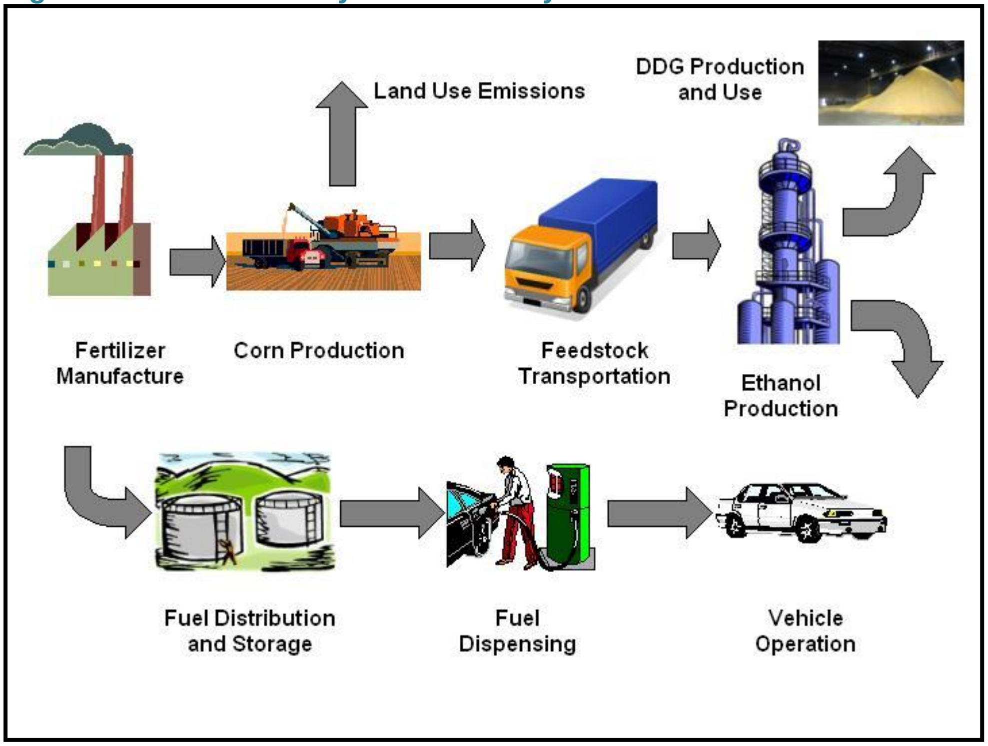
Figure 1 Gasoline System Boundaries



Ethanol Emissions

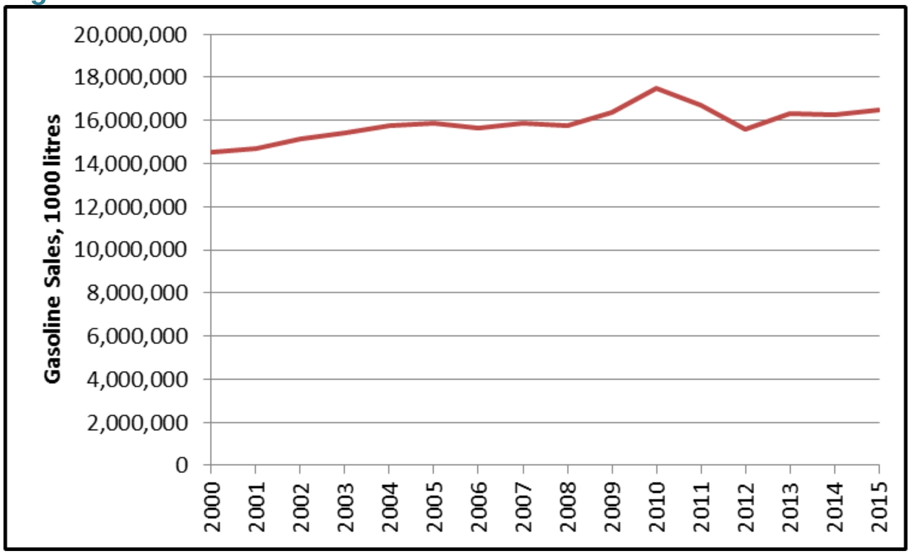
Corn ethanol is one of the pathways in GHGenius. The system boundary for the corn ethanol pathway is shown in the following figure. It is the same basic system boundary as used for gasoline. All of the direct emissions from the field to the combustion of the fuel are included.

Figure 2 Corn Ethanol System Boundary



Gasoline sales in Ontario are just over 16 billion litres per year as shown in the following figure. The trend line increase is about 120 million litres per year over the past 15 years.

Figure 3 Ontario Gasoline Sales



1. GHGenius 4.03 Results

GHGenius 4.03a was released in March 2013 and is the most recent public version of the model. While a slightly revised version of the model was developed with support from NRCan it was not released to the public. The GHG emissions for gasoline and corn ethanol from 4.03a are shown in the following table.

Table 1 GHG Emissions Ontario Gasoline and Ethanol – GHGenius 4.03a

Fuel	Gasoline	Ethanol
Feedstock	Crude Oil	Corn
	g CO_2eq/GJ (HHV)	
Fuel dispensing	66	104
Fuel distribution and storage	397	1,388
Fuel production	10,209	24,190
Feedstock transmission	716	3,500
Feedstock recovery	5,143	5,685
Feedstock upgrading	1,828	0
Land-use changes, cultivation	102	26,184
Fertilizer manufacture	0	4,826
Gas leaks and flares	3,736	0
CO_2, H_2S removed from NG	0	0
Emissions displaced - co-products	-59	-18,054
Sub Total	22,137	47,822
Gasoline Combustion	63,978	2,175
Lifecycle Emissions	86,115	49,997
CI, g CO_2eq/MJ	86.1	50.0
% Reduction		41.9

2. GHGenius 5.0 Beta 2 Results

GHGenius 5.0 Beta 2 is a development version of GHGenius. It has about 75 updates to version 4.03a that have been developed for other work that has been done by $(S\&T)^2$ Consultants Inc. These updates include new pathways, new regions (data for the EU has been added), updated data series, additional output data, new model features and flexibility.

One of the changes is that the short lived gases, carbon monoxide and unburned hydrocarbons are now assumed to be fully oxidized to carbon dioxide. This is consistent with IPCC methodology. This has the impact of increasing GHG emissions of gasoline and fuels burned in a spark ignited engine, which has relatively high CO emissions. The GHG emissions for gasoline and ethanol using this version of the model are shown in the following table.

The gasoline production emissions are lower with the new version primarily due to changes in crude oil supply to the Ontario refineries. This is due to a reduction of imported crude oil with the reversal of Line 9 and greater availability of light crude oil from Western Canada due to advances in drilling technology. The combustion emissions increase due to the inclusion of the short lived gases carbon monoxide and unburned hydrocarbons.

The ethanol emissions decrease primarily due to new data on farm energy use and lower chemical usage in the ethanol plants.

Table 2 GHG Emissions Ontario Gasoline and Ethanol – GHGenius 5.0

Fuel	Gasoline	Ethanol
Feedstock	Crude Oil	Corn
	g CO_2eq/GJ (HHV)	
Fuel dispensing	152	238
Fuel distribution and storage	579	1,580
Fuel production	9,942	22,015
Feedstock transmission	371	3,373
Feedstock recovery	5,487	3,213
Feedstock upgrading	1,594	0
Land-use changes, cultivation	85	26,126
Fertilizer manufacture	0	4,998
Gas leaks and flares	3,093	0
CO_2, H_2S removed from NG	0	0
Emissions displaced - co-products	-64	-16,430
Sub Total	20,879	45,114
Gasoline Combustion	70,595	2,142
Lifecycle Emissions	91,474	47,256
CI, g CO_2eq/MJ	91.5	47.3
% Reduction		48.3

3. Per Litre Emission Reductions

The previous two tables compare ethanol and gasoline on an energy equivalent basis. However there is a significant body of information that suggest that ethanol in gasoline has a small positive effect on the combustion efficiency. In GHGenius this is modelled as a 1% increase in fuel efficiency with a 10% ethanol blend.

The emission reductions per litre of ethanol consumed are calculated by the model. The following table compares the result for the two versions.

Table 3 Emission Reductions per Litre Ethanol

Model version	Emission Reduction, kg CO_2eq/litre
GHGenius 4.03a	1.09
GHGenius 5.0 Beta 2	1.29

The GHG emission reduction projected with the latest version of GHGenius is almost 20% larger than it is with the earlier version of the model, primarily with the better accounting of the short lived gases.

Ethanol is currently blended in Ontario gasoline at a rate of about 7%. The current ethanol consumption is 1.12 billion litres per year. The emission reduction currently being achieved is 1.2 megatonnes CO_2eq using version 4.03a or 1.44 megatonnes CO_2eq using version 5.0 of GHGenius.

If the ethanol blend rate is increased to either 10 or 15% by volume the emission reductions will increase and these are summarized in the following table.

Table 4 GHG Emission Reductions

Ethanol Blend Rate	Ethanol Volume Blended, billion litres	GHGenius 4.03a	GHGenius 5.0	Change from Current levels (GHGenius 5.0)
			Megatonnes CO_2eq	
7%	1.12	1.22	1.57	-
10%	1.6	1.74	2.25	0.67
15%	2.4	2.62	3.37	1.80

4. High Level Ethanol Blends

Ethanol can be used at higher levels than 10% in gasoline. For many years auto manufacturers produced flexible fuel vehicles (FFV) that could operate on gasoline or any blend of gasoline and ethanol up to 85% ethanol. While these vehicles were initially offered as a special order they were eventually the only fuel option when a particular engine was ordered in a vehicle. The exact number of these vehicles that are on the road in Ontario is not available in the public domain; it is possible to make some estimates based on national and international data.

In a 2015 presentation to the Province of British Columbia the Canadian Vehicle Manufacturers Association (https://engage.gov.bc.ca/climateleadership/files/2015/12/047_-Canadian-Vehicle-Manufacturers-Association.pdf) stated that there were 1.62 million flex fuel vehicles in Canada. Ontario has 35% of the Canadian vehicle registrations according to Statistics Canada which would suggest than there are 560,000 flex fuel vehicles in Ontario (6.7% of vehicles).

The US Department of Energy[1] suggests that there are 20 million FFVs in the United States. This represents 7.7% of vehicle registrations in the US and supports the Ontario estimate made above.

Very few of the Ontario FFVs operate on high level blends as there are only a few stations offering the product in the Province. Three retail chains have offered a few outlets with high level ethanol blends in the past, UPI, MacEwans, and Gales Gas. It is not clear if any of the stations are still offering E85.

[1] http://www.afdc.energy.gov/vehicles/flexible_fuel.html

One of the challenges with the sales of high level blends is that both the Federal and Provincial Governments tax the fuel on a volume basis and not an energy content basis. Since a litre of E85 only contains 70% of the energy of a litre of gasoline this adds over 10 cpl to the cost of the fuel. The benefits to ethanol under a cap and trade program will only be a few cents per litre and are not enough to offset the extra taxation.

The average Ontario vehicle consumes almost 2000 litres of gasoline per year. A FFV operating on E85 would use 2400 litres of ethanol per year if it operated 100% of the time on E85 (and 430 litres of gasoline). The potential market is therefore 1.3 billion litres, twice the current consumption.

The Ontario Climate Change Action Plan includes $100 to $155 million to assist fuel retailers with infrastructure upgrades to sell high blend sustainable biofuels. The start date is 2017/2018. Presumably this covers ethanol and biodiesel fuels. In 2008, the National Renewable Energy Laboratory undertook a survey (http://www.afdc.energy.gov/pdfs/42390.pdf) of the additional costs of installing E85 fueling infrastructure. The range of these costs was expansive: $7,559 to $247,600 for a new tank and $1,736 to $68,000 for an existing tank. We obtained an equipment and installation estimate of $200,000 Canadian for current costs.

There are 12,000 retail stations in Canada which would suggest that 4,000 are in Ontario.

If E85 is added to 200 stations by 2020 and each station sells 200,000 litres/year (based on Minnesota experience, http://mn.gov/commerce-stat/pdfs/e85-fuel-use-2015.pdf) then the ethanol volume in 2020 could be 34 million litres/year. The volume is likely to be very sensitive to pricing. This volume would provide 44,000 tonnes of GHG emission reduction per year.

It must be noted that the “build it and they will come” strategy has never worked for alternative fuels. An expanded infrastructure for higher level blends will need to be accompanied by addressing the taxation issue and having a marketing program to promote the fuel and make potential users aware of the option.

5. US Congressional Budget Office Review of Ethanol Emissions

The Congressional Budget Office released a report in June 2014 entitled “The Renewable Fuel Standard: Issues for 2014 and Beyond”. The report noted that ethanol only has a limited potential for reducing emissions in the near future and that some studies showed that emissions for ethanol production could increase in the future.

The GHG emission reduction calculations undertaken by the EPA for the RFS2 program were very complex and combined results from eight different models in order to arrive at their results. The biofuel calculations were also forecasts of what the industry would look like in 2022. In contrast, the petroleum baseline was frozen at 2005. A large part of the complexity was due to the fact that indirect land use emissions were part of the forecast. The EPA modelling work has been criticized by biofuel proponents and opponents. The EPA work took an incremental approach to calculating the emissions. They shocked their models with an increase in biofuel production and estimated the change in emissions in a number of categories. The baseline results are shown in the following table for a natural gas fired dry mill.

Table 5 EPA 2022 Ethanol GHG Emissions

Category	Emissions, g CO_2eq/MJ (LHV)
Domestic Livestock	-3.6
Domestic Farm Inputs and Fert N_2O	7.8
Domestic Rice Methane	-0.2
Tailpipe	0.8
International Rice Methane	2.0
International Livestock	3.3
Domestic Soil Carbon	-3.8
Other (fuel and feedstock transport)	4.0
International Farm Inputs and Fert N2O	6.3
International Land Use Change	30.1
Fuel Production	30.7
Total	77.5

The 2005 gasoline emissions were 93.05 g/MJ (LHV). So the emission reduction was 17% for this configuration of ethanol plant.

The direct emissions for ethanol production are relatively straightforward but because the EPA was required to forecast what those emissions might be in 2020, significant uncertainty was introduced. Before the emission calculations were finalized in 2010, the EPA was made aware that many plants were already using less energy that the 2022 forecast. In 2014 the EPA introduced an "Efficient Producer" program where new plants or plants that had expanded their capacity could supply data that demonstrated that they emissions were lower than the EPA forecast for 2022. To date 63 plants (there are a total of 200 US plants) have been approved by the program. The EPA assumptions and the most recent industry data for NG dry mill ethanol plants are compared in the following table.

Table 6 EPA Assumptions and Current Performance

Parameter	2022 Forecast	Current Performance
Natural gas, BTU/gal (LHV)	28,660	23,948
Electricity , kWh/gal	0.67	0.65
Plant GHG Emissions, g/MJ (LHV)	30.7	26.4

So it is apparent that the EPA forecast for energy use in 2022 was in fact too high and that emissions are about 4 g/MJ below the 2022 forecast with six more years of potential improvements.

The other large source of emissions is the international land use change emissions. With the way that the EPA set up the modelling framework, these are the indirect land use emissions resulting from a drop in US corn exports. The Fapri model was used to estimate the land use change implications of the reduced exports and then the EPA used satellite images to predict what kind of land would be changed in the different regions around the world. The problem with the use of the satellite images is that there are multiple drivers of land use change and the images can't isolate those related to agriculture. They capture normal forestry use and thus the type of land was skewed to a higher portion of forest land and thus higher emissions.

The Fapri model had never been used for this kind of analysis before. The model developers used their best guess of how the world's agriculture system would respond between intensification (higher yield on existing cropland) and extensification (more cropland). The lead model developer has recently admitted that he got it wrong, that the world has responded with much more intensification and with very little land use change. It these emissions are removed from the EPA analysis then the GHG benefits of ethanol become larger and are more in line with those from GHGenius, even though the modelling framework is quite different.

The EPA has previously committed to updating their analysis but has not yet done so.

The other reports that are references in the CBO report that suggest that ethanol could have higher emissions than gasoline all refer to the issue of indirect land use change. Indirect land use emissions are estimated using economic models. The economic models can be sector specific, like the one used by the EPA (partial equilibrium models) or economy wide (general equilibrium models) like the GTAP model used by California. These models were all originally developed for other reasons and not for estimating the land use changes. The models all upset the world's economy by applying an increase in demand for a commodity, which increases the price and then the models find a new equilibrium. The change in production is determined for a range of commodities and that can be translated into a land requirement. To date the forecast changes in land demand have not been observed in the real world. Model developers are aware of the issue and are working to address some of the shortcomings. Some of the reasons include:

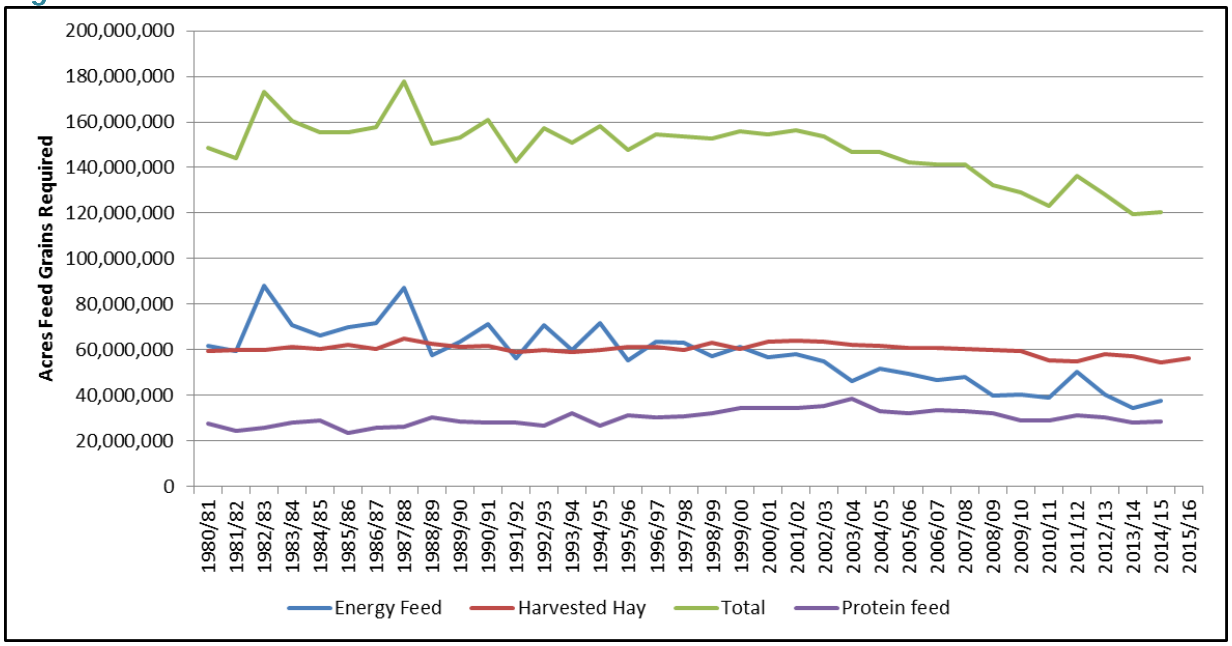
- The models quantify the idle cropland in the world but they are not allowed to access the idle land. Pasture and forest are converted to cropland rather than use the idle land. The available data from FAO suggests that 75% of new harvested crop area comes from existing cropland and only 25% from new cropland.[2]
- The models don't include actions such as double cropping.
- The models are static and don't model the response of a shock over a number of years and there is uncertainty about how to deal with yield response to higher prices.
- The modellers are trying to improve their models by addressing these issues but data availability is always a problem.

Indirect land use change is really addressing the simple question of where does the feedstock come from for increased biofuel production. In our view the answer becomes clearer when you look at the demand for land to produce livestock feed. The USDA has a data series on livestock feed that goes

[2] Increasing global crop harvest frequency: recent trends and future directions. Deepak K Ray and Jonathan A Foley. http://iopscience.iop.org/article/10.1088/1748-9326/8/4/044041/pdf

back to 1975, although the period between 1975 and 1985 is not complete. It is possible to fill in the most significant gaps between 1980 and 1985 so that livestock feed demand between 1980 and 2015 is available. Unfortunately the same data is not available in Canada. The crop yield is known for each of the livestock feeds and thus the demand for land for livestock feed can be calculated. This is shown in the following figure.

Figure 4 Land Demand for Livestock Feed



The demand for US land to produce livestock feed has dropped by 40 million acres since 1980. This is more than the area of land that is used to produce biofuel feedstock in the US. There are many drivers of the this net reduction, population has increased along with per capita meat demand (until recently) but this is offset by higher crop yield, increased feed efficiency, but mostly by changes in the type of meat consumed, with a reduction in beef and an increase in poultry. Poultry feed requirements are about one sixth of the beef requirements per pound of dressed meat.

Biofuel production, rather than requiring an expansion of land for feedstock has used the land that is no longer required for livestock feed production. The indirect land use debate that has been about creating new cropland should have been about what would have happened to the existing cropland if there had not been biofuels. Even if one assumes that the land would have been abandoned (an unlikely response in a free market) and pasture or some kind of forestry replacing crop production, the carbon that might have been sequestered is much less than what the models currently calculate from deforestation.