THE ADDITION OF ETHANOL FROM WHEAT TO GHGENIUS

Prepared For:

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EXECUTIVE SUMMARY

Under the Kyoto Protocol, Canada committed to reduce GHG emissions by 6% from 1990 levels by the period 2008 to 2012. Transportation represents the single largest source of Canada's GHG emissions, accounting for 27 per cent of the total. Transportation emissions arise from all sectors of the commercial economy and are inherent to the movement of people and goods for social and recreational activities. Hence, measures to reduce emissions from the transportation sector must be considered very carefully and respect the ramifications of such measures on the economy and peoples day-to-day activities. Emissions from transportation are growing faster than the average for all emissions and are forecast to exceed 1990 levels by 26 per cent in 2010 and 42 per cent by 2020.

The use of ethanol blended gasoline as a transportation fuels that are partially manufactured from agricultural materials is receiving increased attention. The Climate Change Plan for Canada released in November 2002 set a goal of having 35% of Canada's gasoline contain 10% ethanol by 2010. The greenhouse gas emissions from the production and use of ethanol derived from corn and from lignocellulosic materials has been studied in the Canadian context (Levelton 1999, 1999b). Widespread use of ethanol in Canada would probably result in some of this ethanol being produced from wheat rather than corn or lignocellulose. Policy and decision-makers require data and information on the potential impact of ethanol fuels on greenhouse gas emissions in Canada so that they can make informed decisions regarding the development of these fuels.

The production of ethanol from wheat is practiced commercially on a small scale in Western Canada. In addition to the Federal goal of increasing ethanol production, there are also proposals and actions to significantly expand ethanol production in Saskatchewan and Manitoba. The objective of this work is to:

1. Add the wheat to ethanol upstream fuel cycle to the NRCan GHGenius model. The ethanol that is produced could be used wherever ethanol from corn is used so all of those full fuel cycles will be added to the model.
2. While the GHGenius model calculates the greenhouse gas emission credits for co-products, the calculation of energy credits for the co-products is not currently included in the model. This improved functionality has been added to the model.

The energy balance of wheat ethanol is slightly less positive than that of corn ethanol, 0.69 vs. 0.65 BTU's consumed per BTU of ethanol produced. This is due to higher energy consumption in the ethanol plant related to the higher level of DDG produced, more fertilizer energy required as a result of the higher protein content of wheat compared to corn. These higher energy usage rates are partially offset by less energy required for harvesting and transportation and higher credits for the higher protein DDG produced.

The GHG emission reduction for wheat ethanol depends on where the ethanol is produced. Manitoba with it's high proportion of hydro electricity produces a larger reduction in GHG emissions than ethanol produced from corn in Ontario but if the wheat ethanol is produced in Saskatchewan the GHG emissions are higher than they are for Ontario corn ethanol. The results for a blend of 10% ethanol in gasoline for these three cases are summarized in the following table.

Table ES-1 GHG Reductions E10 - 2002

	Gasoline	E10	E10	E10
		Ontario	Saskatchewan	Manitoba
Feedstock		Corn	Wheat	Wheat
Vehicle operation	340.2	337.7	337.7	337.7
C in end-use fuel from CO_2 in air	0.0	-23.9	-23.9	-23.9
Net Vehicle Operation	340.2	313.8	313.8	313.8
Fuel dispensing	0.5	0.5	0.5	0.5
Fuel storage and distribution	6.6	6.6	6.6	6.6
Fuel production	66.0	73.4	77.2	73.4
Feedstock transport	1.0	1.5	1.2	1.2
Feedstock and fertilizer production	46.1	48.2	49.4	49.4
Land use changes and cultivation	0.0	3.8	7.3	7.3
CH_4 and CO_2 leaks and flares	14.0	12.9	12.9	12.9
Emissions displaced by co-products	0.0	-11.5	-17.2	-17.2
Sub total (fuel cycle)	474.3	449.3	451.7	447.9
% Changes (fuel cycle)	2.8	-2.6	-2.1	-2.9
Vehicle assembly and transport	8.5	8.5	8.5	8.5
Materials in vehicles	42.8	42.7	42.7	42.7
Grand total	525.6	500.5	502.9	499.1
% Changes to RFG (grand total)	0.0	-4.8	-4.3	-5.0

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1. INTRODUCTION

1.1 BACKGROUND

Under the Kyoto Protocol, Canada committed to reduce GHG emissions by 6% from 1990 levels by the period 2008 to 2012. Transportation represents the single largest source of Canada's GHG emissions, accounting for 27 per cent of the total. Transportation emissions arise from all sectors of the commercial economy and are inherent to the movement of people and goods for social and recreational activities. Hence, measures to reduce emissions from the transportation sector must be considered very carefully and respect the ramifications of such measures on the economy and peoples' day-to-day activities. Emissions from transportation are growing faster than the average for all emissions and are forecast to exceed 1990 levels by 26 per cent in 2010 and 42 per cent by 2020.

The use of ethanol blended gasoline as a transportation fuels that are partially manufactured from agricultural materials is receiving increased attention. The Climate Change Plan for Canada released in November 2002 set a goal of having 35% of Canada's gasoline contain 10% ethanol by 2010. The greenhouse gas emissions from the production and use of ethanol derived from corn and from lignocellulosic materials has been studied in the Canadian context (Levelton 1999, 1999b). Widespread use of ethanol in Canada would probably result in some of this ethanol being produced from wheat rather than corn or lignocellulose. Policy and decision-makers require data and information on the potential impact of ethanol fuels on greenhouse gas emissions in Canada so that they can make informed decisions regarding the development of these fuels.

There have been a few published studies of full cycle greenhouse gas emissions from the manufacture and use of ethanol from wheat but these have been done in a European context (Concawe). The results from these studies have also varied widely, as the results are very sensitive to inputs, land use assumptions and methodology. It is therefore important to have a publicly accessible Canadian study that uses the best data available and applies sound scientific methodology to provide a basis for informed public policy decisions.

1.2 STUDY OBJECTIVES

The production of ethanol from wheat is practiced commercially on a small scale in Western Canada. In addition to the Federal goal of increasing ethanol production, there are also proposals and actions to significantly expand ethanol production in Saskatchewan and Manitoba. The objective of this work is to:

1. Add the wheat to ethanol upstream fuel cycle to the NRCan GHGenius model. The ethanol that is produced could be used wherever ethanol from corn is used so all of those full fuel cycles will be added to the model.
2. While the GHGenius model calculates the greenhouse gas emission credits for co-products, the calculation of energy credits for the co-products is not currently included in the model. They must be calculated manually "off sheet" at the present time. It is proposed to add these calculations to sheet I of the model.

The ethanol fuel may be used for both light duty and heavy-duty applications so the full cycle results for sheets AC, AD, Cost LDV, Cost HDV, Summary LDV, and Summary HDV will include both light duty and heavy duty results. Sheets K and I will also be modified to include the new fuel cycle. All of the existing functionality of the model will be retained.

2. WHEAT PRODUCTION

2.1 OVERVIEW

Canadian wheat production has averaged 24.7 million tonnes per year between 1997 and 2001 (Agriculture and Agri-Food Canada). A number of classes of wheat make up this total and this is summarized in the following table.

Table 2-1 Canadian Wheat Production by Variety

Class	Typical Protein Level (%)	Average Million Tonnes
Canadian Western Red Spring	13.2	15.4
Canadian Western Extra Strong	12.2	0.6
Canadian Prairie Spring Red	11.5	1.8
Canadian Western Red Winter	11.3	0.3
Canadian Prairie Spring White	11.2	0.4
Canadian Western Soft White	10.5	0.15
Canadian Western Amber Durum	12.8	4.7
Eastern Canadian		1.4
Total		24.75

Ethanol producers convert the starch in wheat to ethanol and look for classes and varieties that have a lower protein content and thus a higher starch content. The wheat classes that are of most interest are Canadian Prairie Spring (Red and White), Canadian Western Red Winter and Canadian Western Soft White.

Canada Prairie Spring Red Wheat (CPS-R) has been developed to allow Canadian farmers to compete with American hard red winter wheat in markets that do not require the high protein and strong gluten of CWRS wheat for the products that they produce. These include hearth breads such as French bread, flat breads such as pita, and crackers.

CPS-R production is estimated by Agriculture and Agri-Food Canada (AAFC) to have averaged about 1.8 Mt between 1997 and 2001. Exports of CPS-R wheat have averaged 353,000 tonnes over the past five years, about 20% of production, with the major markets being countries that tend to use wheat for the production of flat breads or noodles. The major domestic use of CPS-R wheat is for feeding livestock, largely hogs, in western Canada.

CPS-R wheat is priced lower than CWRS wheat, and it does not receive protein premiums. Over the past 5 years, on-farm Canadian Wheat Board (CWB) returns for No.1 CPS-R have averaged about 25% lower than for No.1 CWRS with 13.5% protein. It yields about 20-30% higher than CWRS, largely offsetting the lower price.

Canada Western Red Winter Wheat (CWRW) is the only winter wheat grown on the Prairies. It is grown only on a small area, with production averaging just 311,000 tonnes between 1997 and 2001. Production is rising, particularly on the eastern Prairies, and it reached 441,000 tonnes in 2001, with almost 50% grown in Manitoba. The popularity of CWRW is increasing, as it provides several important benefits. On average, winter wheat yield is 23% higher than spring wheat. It often escapes infection by serious pests such as Fusarium Head Blight and the orange wheat blossom midge. It offers workload displacement, and promotes conservation tillage practices.

Average protein content of CWRW is similar to CPS-R, averaging 11.3%. Exports have averaged only 58,000 tonnes over the past 5-years. Domestically, the major use of CWRW is for feed.

Canada Prairie Spring White wheat (CPS-W) varieties were developed by Canadian wheat breeders largely in response to demand from the Asian noodle market, which traditionally imported Australian Standard White wheat for noodle production. Average protein content is slightly lower than CPS-R wheat, with the 5-year average being 11.2%. The white seed coat produces a flour with fewer visible bran specks, and with a whiter colour at high extraction rates, compared to a red wheat.

Production of CPS-W is estimated by AAFC, to have averaged about 0.4 Mt over the past 5-years. Exports of CPS-W have averaged almost 300,000 tonnes between 1996-1997 and 2000-2001, relatively little is milled domestically, and the slightly higher protein CPS-R wheat is preferred for livestock feeding.

Canada Western Soft White Spring Wheat (CWSWS) is the only soft wheat grown on the Prairies. It has a soft kernel and low protein. Most is grown under irrigation, in southern Alberta, since dryland production can result in excessively high protein content if rainfall is not adequate. It can be used for flat breads, but it is largely used for the production of cookies, pastries, biscuits and crackers.

Due to low prices, production has been declining, as alternative crops could be more profitably grown on the irrigated land. The 1997 to 2001 average has been about 150,000 tonnes, but this fell to only 72,600 tonnes in 2001. As a result, most CWSWS is now used domestically in western Canada for the production of cake and pastry flour.

All of the wheat classes that are of interest to ethanol producers are lower protein, higher starch and higher yielding the Canadian Western Red Spring wheat. A larger domestic market for these classes should lead to higher production of these classes through the substitution of land for these wheats with land used for CWRS. This would result in an increase in wheat produced and a slight decrease in wheat available for export.

The five year (1998-2002) average supply and disposition for all wheat in Canada is shown in the following table. Increasing the Food and Industrial uses of wheat by one million tonnes for ethanol would reduce exports by approximately 700,000 tonnes (~4%) if the classes of wheat suitable for ethanol production displaced CWRS acreage. The one million tonnes of wheat would increase the domestic market for wheat by over 30% and produce 370 million litres of ethanol.

Table 2-2 Wheat Supply and Disposition

Year	Land Harvested	Production	Food & Industrial Usage	Feed, Waste & Dockage	Exports
	1000 Hectares	1000 tonnes	1000 tonnes	1000 tonnes	1000 tonnes
1997-1998	11,407	24,280	2,665	4,416	19,366
1998-1999	10,678	24,082	2,864	4,152	14,723
1999-2000	10,367	26,900	2,938	4,635	18,312
2000-2001	10,963	26,804	3,015	3,728	17,110
2001-2002	10,585	20,568	3,083	3,523	16,207
Average	10,800	24,527	2,913	4,091	17,144

2.2 WHEAT PRODUCTION PRACTICES

Wheat can be grown in different soil types (brown, dark brown, black) and different production methods (conventional tillage, minimum tillage, zero tillage). The variety of combinations available makes it more complex to determine average values for the inputs of wheat production. To help simplify matters it will be assumed that higher yielding, lower protein wheat is the feedstock for the ethanol plants. It will be assumed that the yield of the wheat is 2.69 tonnes/hectare (40 bushels/acre). This can be considered conservative since the average yield for CPS wheats between 1989 and 1998 was 3.0 tonnes/hectare (44.7 bushels/acre) (Manitoba Rural Adaptation Council). The lower value accounts for the fact that some of the lower quality CWRS wheat is likely to be used for ethanol production along with the CPS varieties.

The primary energy consumption during wheat production is for tractor fuel for the various field operations and for fertilizer production. Depending on the tillage system used there will be cultivator operations, seeding, fertilizing, spraying, and combining operations that will use diesel fuel. Data was obtained from Agriculture and Agri-Food Canada (Wall) on the energy consumption for growing wheat at four test sites over a three year period. The test sites included brown, dark brown and black soils. The tests data was obtained from a variable rate fertilizer trial. There were a total of 726 data sets and a subset of 328 of those were selected that provided a yield between 2000 kg/ha and 3900 kg/ha with the average yield being 2,686 kg/ha (the assumed yield for modeling). The energy, fertilizer and yield data from this subset is shown in the following table.

Table 2-3 Energy and Test Data for Wheat

	Metric Units
Average Yield Results	2.69 tonnes/hectare
Nitrogen	67 kg/hectare
Phosphorus	31 kg/hectare
Potash	0 kg/hectare
Sulphur	0 kg/hectare
Fuel	1,129 MJ/hectare
Fuel, Litres Diesel Equivalent	29 litres/hectare
Chemicals	230 MJ/hectare

The modeling assumptions for the wheat are shown in the following table. The pesticide value provides the same energy requirements as the previous table. The fertilizer requirements are typical of the recommendations found in wheat production guides published by Manitoba and Saskatchewan Agriculture departments (Saskatchewan Agriculture and Food, Manitoba Agriculture). Some of this nitrogen is supplied by manure. Desjardins (2001) calculated N2O emissions for agriculture as part of Canada's national GHG inventory. The N2O emissions from manure in Western Canada were estimated to be 25.9% of the emissions from synthetic nitrogen fertilizers. On this basis, it is estimated that on average 20% of the nitrogen for wheat production is supplied by manure and 80% by synthetic fertilizers. The substitution of manure for synthetic fertilizer will slightly reduce greenhouse gas emissions since less energy is required for fertilizer production. The N_2O emissions are similar for both types of nitrogen fertilizer.

Table 2-4 Assumed Agronomic Data for Wheat

	English Units		Metric Units
Yield assumption	40 bu/acre		2.69 tonnes/hectare
Nitrogen, total	60 lb/acre	1.5 lb/bu	67 kg/hectare
Nitrogen, synthetic	48 lb/acre	1.2 lb/bu	53.6 kg/hectare
Nitrogen, manure	12 lb/acre	0.3 lb/bu	13.4 kg/hectare
Phosphorus	30 lb/acre	0.75 lb/bu	33 kg/hectare
Potash	0 lb/acre	0 lb/bu	0 kg/hectare
Sulphur	0 lb/acre	0 lb/bu	0 kg/hectare
Fuel, Diesel Equivalent	3.11 USG/acre	0.0779 USG/bu	29 litres/hectare
Pesticides	0.8 lb/acre	0.02 lb/bu	4.35 kg/hectare
Seed	110 lb/acre	2.75 lb/bu	123 kg/hectare

The annual improvement rates used in the model will be the same percentages as for corn in the model. There are some recommendations found in the literature that use lower amounts of nitrogen fertilizer but these are for crop rotation where wheat follows a fallow year. The amount of summer fallow is declining in western Canada. One of the disadvantages of this practice is that it releases soil carbon to the atmosphere.

2.3 EMISSIONS FROM LAND USE

Greenhouse gas emissions from land use arise from changes in soil carbon content because of cultivation and emissions of N_2O from the application of fertilizer and small emissions of methane and carbon dioxide directly from the soil.

The change in soil carbon for the three Prairie Provinces has been estimated using the Century model (Smith). Manitoba and Saskatchewan are estimated to be increasing soil carbon with their current practices and Alberta soil carbon is declining. The weighted average (according to wheat production) is estimated to be an increase of 6.42 kg SOC/ha/year. This value has been incorporated into the model.

The other factors that are required by the model to calculate the greenhouse gas emissions from land use as they apply to wheat production are shown in the following table. The model generally follows IPCC guidelines for emission estimating. There are two differences that have been used so that the emissions more closely follow the Canadian inventory as developed by Desjardins et al. Both of these changes increase the emissions from land use and cultivation. The first is the use of one emission factor for all forms of synthetic nitrogen fertilizer. Desjardins estimates that this leads to a 63% increase in N_2O emissions over the IPCC practice of different factors for different synthetic fertilizers. The second change is a reduction in the amount of nitrogen lost through leaching. In the model this leaching increases the carbon sequestered in increased biomass growth, by reducing the leaching less carbon is sequestered and the emissions attributed to land use changes for all biomass increases. Both of these variations from IPCC guidelines increase the emissions associated with biomass pathways and make the results of the model more conservative.

Table 2-5 Factors Relating to Land Use Emissions

Parameter	Value
N content of plant (fraction of dry mass)	0.0125
Ratio of N fixed by plant to total N content of plant	0.0
Ratio of plant-N derived by biological fixation to total N content of plant	0.0
N displaced per gram of excess N produced by biological fixation	1.0
Ratio of total biomass weight to weight of crop or product harvested	2.2
Of total residue (incl. roots) available, fraction left in the field (as opposed to burned or marketed)	0.95
N-N2O/N-input (synthetic or animal-manure N), direct or "on-site" emissions, in base year 1990	0.011
N-N2O/N-input (biologically fixed or crop-residue-N), direct or "on-site" emissions, in base year 1990	0.013
Synthetic or manure N lost offsite through drainage or runoff, fraction of N applied, in base year 1990	0.15
Biologically fixed or crop-residue N lost offsite through drainage or runoff, fraction of N applied, in base year 1990	0.0
Of N lost offsite, fraction that fertilizes terrestrial ecosystems	0.4
Of N lost offsite, fraction that fertilizes freshwater ecosystems (remainder fertilizes marine systems)	0.15
N-N2O/N-fertilizer-offsite	0.025
Annual percentage change in on-site emission rate, and offsite N leaching rate for synthetic and animal manure fertilizer	-0.5
Annual percentage change in on-site emission rate, and offsite N leaching rate for biologically fixed and crop-residue N	0
g-N-N2O (soil)/ha/yr, due to cultivation of high-organic soils (histosols), independent of fertilizer rate	5000
Histosol soil fraction of total area under cultivation	0.0002
N-NOx/N-fertilizer (synthetic or manure) applied	0.04
NH3-N+NOx-N per kg N for synthetic	0.1
NH3-N+NOx-N per kg N for manure	0.2
N2O-N per kg (NH3-N+NOx-N) emitted	0.01
g-CO2 (soil)/g-N-fertilizer (synthetic or manure)	0
g-CH4 (soil)/kg-N-fertilizer (synthetic or manure)	0.10
Change in harvest yield (%/year)	1.0
Post-harvest losses (fraction of harvest yield)	0.02
Acreage fraction fertilized with synthetic fertilizer	1.0

2.4 TRANSPORTATION RELATED EMISSIONS

The wheat will be transported by truck from the farms to the ethanol plants. The wheat ethanol plants are anticipated to be 80 to 100 million litres in annual capacity. This will require approximately 100,000 hectares of land. The land surrounding the plant will grow other crops as well as wheat; if 15% of the surrounding land provides feedstock to the plant then the average trucking distance to the plant will be 32 km (20 miles).

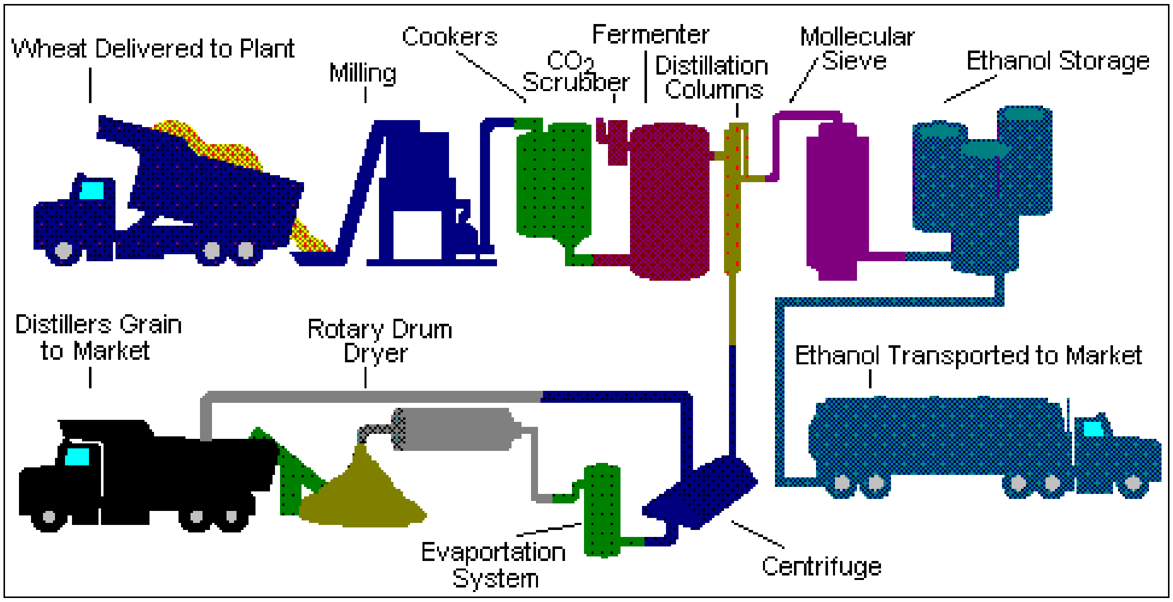
3. WHEAT ETHANOL PRODUCTION

The production of ethanol from wheat is very similar to the production from corn. The wheat has a lower starch content so that the ethanol yield is typically 370 litres/tonne rather than the 400 litres/tonne experienced with corn. This is compensated by the increased production of distillers dried grains of 38% of the feedstock for wheat rather than the 32% typically found with corn. The process and the inputs and outputs are discussed below.

3.1 PROCESS

The process modeled is a dry mill process are shown in the following figure.

Figure 3-1 Wheat Ethanol Process



The major steps in the dry milling process are outlined below.

- Milling: The wheat first passes through hammer mills, which grind it into a fine powder, called meal.
- Liquefaction: The meal is then mixed with water and the enzyme alpha-amylase, and passes through cookers, where the starch is liquefied. Heat is applied at this stage to enable liquefaction. Continuous cookers with a high temperature stage (100-120º C) and a lower temperature holding period (95º C) are used. Lower temperatures can be used with wheat compared to corn.
- Saccharification: The mash from the cookers is cooled and the secondary enzyme (gluco-amylase) is added to convert the liquefied starch to fermentable sugars, a process called saccharification.
- Fermentation: Yeast is added to the mash to ferment the sugars to ethanol and carbon dioxide. Using a continuous process, the fermenting mash is allowed to flow, or cascade, through several fermenters, until the mash leaving the final tank is fully fermented.

- Distillation: The fermented mash, now called "beer", contains about 11-15% ethanol by volume as well as the non-fermentable solids from the corn and the yeast cells. The beer mash is pumped to a continuous flow, multi-column distillation system, where the ethanol is separated from the solids and water. The ethanol leaves the top of the final column at about 96% strength, and the residual mash, called stillage, is recovered from the base of the column and transferred to the co-product processing area.
- Dehydration: The ethanol from the top of the column passes through a patented dehydration system, where the remaining water is removed. The alcohol product at this stage is called anhydrous (pure) ethanol.
- Co-product recovery: Evaporators and gas fired rotary dryers are used to remove the water from the stillage and produce DDGS.

3.2 ENERGY USE

Energy is used in the plant to drive the electric motors, provide steam for the process and to dry the distillers grains (natural gas). There is not a large modern wheat ethanol plant in operation in North America so the energy use data is extrapolated from the latest corn ethanol plants and adjusted for the differences in wheat.

The latest efficient corn dry mills are consuming approximately 1.0 kWh of electricity/USG of ethanol produced (0.265 kWh/litre). Wheat plants in Canada may use slightly more power due to the higher solids content of the wheat mash but that will be partially offset by the fact that cooling water chillers are not required in Western Canada. The electricity consumption used for modeling the wheat to ethanol pathway will be 0.3 kWh/litre (1.13 kWh/USG).

Natural gas is used both to supply steam to the process and to dry the distillers dried grains. The Chippewa Valley Ethanol Company posts its annual natural gas consumption on its web site (www.cvec.com). In 2001, they reported that 33,421 BTU of natural gas/USG of ethanol produced were used. This low value was driven in part by the sale of wet distillers grains but offset in part by the fact that the plant produces some industrial grade ethanol, which has higher energy requirements. New plants are being designed to consume 38,000 to 41,000 BTU/USG of ethanol. It is anticipated that wheat plants will be able to use less steam in the cooking process than corn plants but, because of the higher solids content in the stillage, will use more natural gas in the dryer area of the plant. To be conservative11.98 MJ/litre (43,000 BTU/USG) will be used in the model.

Small amounts of diesel fuel will be used at the plant for front end loaders and similar equipment. The model uses 0.00016 l/litre of ethanol for a corn plant and 10% more diesel fuel will be used for the wheat plant because of the higher quantity of DDG produced and loading DDG is one of the uses of the front end loader. A total of 0.00018 l of diesel fuel/litre of ethanol (0.00018 USG Diesel/USG ethanol) produced is used.

The ethanol plant will use small amounts of caustic soda for cleaning, sulphuric acid for pH adjustment and ammonia for yeast vitality. The amounts modeled for wheat plants are based on engineering estimates. The following table summarizes the ethanol plant inputs.

The corn ethanol plant data in the model was obtained from Commercial Alcohols Inc. in 1999 for a study for Agriculture and Agri-Food Canada (Levelton, 1999). It was based on the actual operating performance of the Chatham, Ontario plant. At that time, the plant was experiencing a number of operating problems that may have been impacting the results. New operating data was obtained for this plant for this update (Shamash), which has now been incorporated into the GHGenius model.

There are some differences between the corn ethanol plant and the wheat plant. The corn plant uses continuous fermentation whereas the wheat plant uses a batch fermentation process. The corn plant generates a portion of its electricity through co-generation whereas the wheat plant purchases all of its electric power. As a result at the corn plant the gas use is higher and the electricity use lower than at the wheat plant.

Table 3-1 Wheat Ethanol Plant Inputs

Parameter	Corn Ethanol		Wheat Ethanol
	Original Model Data	Updated Data	
Ethanol Yield	400 l/tonne	395 l/tonne	370 l/tonne
DDG Yield, dry	286 kg/tonne	295 kg/tonne	350 kg/tonne
Natural gas consumed	13.49 MJ/litre	11.2 MJ/litre	11.98 MJ/litre
Electricity purchased	0.074 kWh/litre	0.1175 kWh/litre	0.30 kWh/litre
Diesel Fuel consumed	0.000115 l/litre ethanol	0.00016 l/litre ethanol	0.00018 l/litre
Caustic soda used	0.045 kg/l	0.0058 kg/l	0.0016 kg/L
Sulphuric acid used	0.047 kg/l	0.011 kg/l	0.0028 kg/l
Ammonia used	0.027 kg/l	0.022 kg/l	0.014 kg/l

The annual rates of improvement for wheat ethanol plants will be the same as for the corn plants in the model.

3.3 CO-PRODUCTS

Wheat ethanol plants will produce distillers grains and carbon dioxide as co-products. The wheat DDG will be used in animal feed rations and the carbon dioxide will either be vented or if a local market exists it can be collected and marketed.

Wheat DDG is used in the same markets as corn DDG. The wheat DDG does have a higher protein content (38% vs. 30%) so the same displacement ratios cannot be as for corn DDG. The fat content of wheat DDG is lower than corn DDG so its energy content is slightly lower than corn DDG.

The corn DDG displacement ratios that are in the model are that one kg of corn DDG displaces 1.077 kg of corn and 0.823 kg of soymeal. Much of the DDG produced in western Canada is expected to be exported to the United States where it will still displace corn and soymeal. In consideration of the lower energy content and higher protein levels the displacement ratio that has been modeled is that one kg of wheat DDG displaces one kg of corn and 1.04 kg of soymeal.

The model assumes that the carbon dioxide is vented.

4. LIFECYCLE GREENHOUSE GAS EMISSIONS

The GHGenius model calculates the emissions from the energy pathways for the upstream portion of the fuel cycle as well as the use of the ethanol in a variety of conversion systems. The upstream emissions are presented first and then the full cycle emissions are considered for a variety of ways of using the fuel.

4.1 ETHANOL PRODUCTION FROM WHEAT

The GHG emissions for the production of ethanol from wheat based on the parameters outlined in the previous sections are shown in the following tables. In this next table, the results for 2002 are compared to gasoline and are shown for both ethanol production in Saskatchewan and Manitoba. While the emissions are higher for the ethanol pathway when the ethanol is used there will be no carbon dioxide emissions that are counted as per the IPCC guidelines whereas there will be emissions from the gasoline combustion of approximately 63,800 gms/million BTU. The differences between the two provinces are driven by the different electricity generating mixes, Saskatchewan with a high proportion of coal and Manitoba predominately hydropower.

Table 4-1 Wheat Ethanol Greenhouse Gas Emissions- 2002

	Gasoline 150 ppm S	Saskatchewan Ethanol	Manitoba Ethanol
Fuel dispensing	95	150	150
Fuel distribution and storage	1,290	1,561	1,561
Fuel production	12,936	46,287	35,569
Feedstock transmission	194	781	781
Feedstock recovery	9,040	6,631	6,631
Land-use changes, cultivation	0	20,540	20,540
Fertilizer manufacture	0	12,835	12,835
Gas leaks and flares	2,738	0	0
CO_2, H_2S removed from NG	0	0	0
Emissions displaced	0	-48,649	-48,649
Total	26,292	40,137	29,419

By the year 2010 there will some improvement in the efficiency of ethanol production and the gasoline will have a lower sulphur content. There will be more synthetic crude oil processed but the plants will be more efficient. The upstream GHG emissions for 2010 are shown in the following table.

Table 4-2 Wheat Ethanol Greenhouse Gas Emissions-2010

	Gasoline 30 ppm S	Saskatchewan Ethanol	Manitoba Ethanol
Fuel dispensing	112	177	177
Fuel distribution and storage	1,233	1,534	1,534
Fuel production	12,813	44,476	34,205
Feedstock transmission	194	752	752
Feedstock recovery	10,196	6,434	6,434
Land-use changes, cultivation	0	19,479	19,479
Fertilizer manufacture	0	12,034	12,034
Gas leaks and flares	2,596	0	0
CO_2, H_2S removed from NG	0	0	0
Emissions displaced	0	-47,391	-47,391
Total	27,145	39,496	27,226

Both of the previous two tables were calculated using the IPCC guidelines for N_2O emissions from nitrogen fixing crops. The uncertainty of the N_2O emissions from nitrogen fixing crops does not directly impact the production of wheat, it does impact the co-product credits. Wheat DDG displaces some soybean meal in animal rations and soybeans are a nitrogen fixing crop, the wheat DDG credit therefore varies with approach taken in estimating soybean emissions. The Canadian national GHG inventory did not follow IPCC guideline for these N_2O emissions, if the Canadian approach was taken then the co-product credit would be lower than shown in Table 4-2. The results for 2010 using the Canadian approach to N_2O emissions are shown in the following table.

Table 4-3 Wheat Ethanol GHG Emissions-2010, Non IPCC Methodology

	Gasoline 30 ppm S	Saskatchewan Ethanol	Manitoba Ethanol
Fuel dispensing	112	177	177
Fuel distribution and storage	1,233	1,534	1,534
Fuel production	12,813	44,476	34,205
Feedstock transmission	194	752	752
Feedstock recovery	10,196	6,434	6,434
Land-use changes, cultivation	0	19,479	19,479
Fertilizer manufacture	0	12,034	12,034
Gas leaks and flares	2,596	0	0
CO_2, H_2S removed from NG	0	0	0
Emissions displaced	0	-23,569	-23,569
Total	27,145	61,318	51,046

4.2 LOW LEVEL GASOLINE BLENDS

Ethanol is usually used in blends of 5 to 10% with gasoline. There is usually a small (1%) efficiency increase with these fuels and the model accounts for this. The full cycle GHG emissions impact for wheat ethanol in Saskatchewan and Manitoba is shown in the following table. The IPCC methodology is followed for the N_2O emissions. The renewable energy aspect of the ethanol is shown as a credit for the carbon in the fuel that originated from carbon dioxide in air following the IPCC guidelines. The credit is proportional to the effective energy content of the ethanol in the final blend and not the volume of ethanol. The model assumes that E-10 blends provide 1% better energy efficiency than all hydrocarbon gasoline.

Table 4-4 Full Cycle GHG Emissions Wheat Ethanol E-10, 2002

	Gasoline	E10	E10
	150 ppm S	Saskatchewan	Manitoba
Vehicle operation	340.2	337.7	337.7
C in end-use fuel from CO_2 in air	0.0	-23.9	-23.9
Net Vehicle Operation	340.2	313.8	313.8
Fuel dispensing	0.5	0.5	0.5
Fuel storage and distribution	6.6	6.6	6.6
Fuel production	66.0	77.2	73.4
Feedstock transport	1.0	1.2	1.2
Feedstock and fertilizer production	46.1	49.4	49.4
Land use changes and cultivation	0.0	7.3	7.3
CH_4 and CO_2 leaks and flares	14.0	12.9	12.9
Emissions displaced by co-products	0.0	-17.2	-17.2
Sub total (fuel cycle)	474.3	451.7	447.9
% Changes (fuel cycle)	2.8	-2.1	-2.9
Vehicle assembly and transport	8.5	8.5	8.5
Materials in vehicles	42.8	42.7	42.7
Grand total	525.6	502.9	499.1
% Changes to RFG (grand total)	0.0	-4.3	-5.0

The emissions results for the year 2010 are shown in the following table for E10 blends in Saskatchewan and Manitoba. The performance of the E-10 blends improves relative to 2002 due to the increased efficiency of the ethanol plants and the higher gasoline baseline.

Table 4-5 Full Cycle GHG Emissions Wheat Ethanol E-10, 2010

	Gasoline	E10	E10
	30 ppm S	Saskatchewan	Manitoba
Vehicle operation	343.2	340.0	340.0
C in end-use fuel from CO_2 in air	0.0	-23.8	-23.8
Net Vehicle Operation	343.2	316.2	316.2
Fuel dispensing	0.6	0.6	0.6
Fuel storage and distribution	6.3	6.3	6.3
Fuel production	65.1	75.6	72.0
Feedstock transport	1.0	1.2	1.2
Feedstock and fertilizer production	51.8	54.2	54.2
Land use changes and cultivation	0.0	6.8	6.8
CH_4 and CO_2 leaks and flares	13.2	12.1	12.1
Emissions displaced by co-products	0.0	-16.7	-16.7
Sub total (fuel cycle)	481.1	456.4	452.8
% Changes (fuel cycle)	2.7	-2.6	-3.3
Vehicle assembly and transport	8.3	8.2	8.2
Materials in vehicles	40.3	40.2	40.2
Grand total	529.7	504.8	501.2
% Changes to RFG (grand total)		-4.7	-5.4

4.3 HIGH LEVEL GASOLINE BLENDS

Flexible fuel vehicles that operate on E85 or gasoline or any fuel in between are available in the marketplace but the fuel is not generally commercially available. The GHG emissions for E85 using ethanol from wheat are shown in the following tables. The assumed energy efficiency of the E-85 fuel is 5% better than gasoline.

Table 4-6 Full Cycle GHG Emissions Wheat Ethanol E-85, 2002

	Gasoline	E85	E85
	150 ppm S	Saskatchewan	Manitoba
Vehicle operation	340.2	315.2	315.2
C in end-use fuel from CO_2 in air	0.0	-256.2	-256.2
Net Vehicle Operation	340.2	59.0	59.0
Fuel dispensing	0.5	0.7	0.7
Fuel storage and distribution	6.6	7.2	7.2
Fuel production	66.0	188.6	147.9
Feedstock transport	1.0	3.2	3.2
Feedstock and fertilizer production	46.1	82.9	82.9
Land use changes and cultivation	0.0	78.0	78.0
CH_4 and CO_2 leaks and flares	14.0	2.7	2.7
Emissions displaced by co-products	0.0	-184.7	-184.7
Sub total (fuel cycle)	474.3	237.5	196.8
% Changes (fuel cycle)	2.8	-48.5	-57.3
Vehicle assembly and transport	8.5	8.6	8.6
Materials in vehicles	42.8	42.8	42.8
Grand total	525.6	288.9	248.2
% Changes to RFG (grand total)	0.0	-45.0	-52.8

Table 4-7 Full Cycle GHG Emissions Wheat Ethanol E-85, 2010

	Gasoline	E85	E85
	30 ppm S	Saskatchewan	Manitoba
Vehicle operation	343.2	310.5	310.5
C in end-use fuel from CO_2 in air	0.0	-250.6	-250.6
Net Vehicle Operation	343.2	59.9	59.9
Fuel dispensing	0.6	0.8	0.8
Fuel storage and distribution	6.3	6.9	6.9
Fuel production	65.1	177.6	139.4
Feedstock transport	1.0	3.0	3.0
Feedstock and fertilizer production	51.8	78.5	78.5
Land use changes and cultivation	0.0	72.3	72.3
CH_4 and CO_2 leaks and flares	13.2	2.5	2.5
Emissions displaced by co-products	0.0	-176.0	-176.0
Sub total (fuel cycle)	481.1	225.4	187.3
% Changes (fuel cycle)	2.7	-51.9	-60.0
Vehicle assembly and transport	8.3	8.3	8.3
Materials in vehicles	40.3	40.4	40.4
Grand total	529.7	274.1	235.9
% Changes to RFG (grand total)		-48.3	-55.5

4.4 E-DIESEL

There is some interest in the use of ethanol with diesel fuels. There are several companies marketing emulsifiers and blending agents to increase the solubility of ethanol in diesel fuels. The ethanol can be used in blends of up to 15% by volume. The GHG results for a 15% ethanol blend in diesel fuel in the year 2002 are shown in the following table. The results shown are for a combined trucks and buses model run.

Table 4-8 Full Cycle GHG Emissions Wheat Ethanol E-Diesel, 2002

	Petroleum Diesel	E-Diesel	E-Diesel
	500 ppm S	Saskatchewan	Manitoba
Vehicle operation	1,703.0	1,701.1	1,701.1
C in end-use fuel from CO2 in air	0.0	-164.4	-164.4
Net Vehicle operation	1,703.0	1,536.7	1,536.7
Fuel dispensing	2.3	2.4	2.4
Fuel storage and distribution	28.0	28.8	28.8
Fuel production	181.0	269.2	244.7
Feedstock transport	4.7	6.0	6.0
Feedstock and fertilizer production	218.5	241.9	241.9
Land use changes and cultivation	0.0	46.9	46.9
CH4 and CO2 leaks and flares	72.6	65.6	65.6
Emissions displaced by co-products	0.0	-111.2	-111.2
Sub total (fuel cycle)	2210.1	2,086.4	2,061.9
% Changes (fuel cycle)	--	-5.6	-6.7
Vehicle assembly and transport	19.2	19.2	19.2
Materials in vehicles	70.7	70.7	70.7
Grand total	2300.0	2,176.3	2,151.8
% Changes (grand total)		-5.4	-6.4

4.5 OTHER ETHANOL PATHWAYS

There are several other ethanol pathways that are included in the GHGenius model. They include;

- Light duty ethanol fuel cell vehicles,
- Ethanol to hydrogen production for use in light and heavy duty fuel cell vehicles, and
- E100 in heavy-duty diesel type engines.

For all of these pathways the ethanol produced from wheat has been added to the model.

4.6 COST EFFECTIVENESS

The cost effectiveness of GHG emission reductions was determined for 2003 and 2010 based on a present value method with a 10% discount rate a 10 year economic vehicle life, and flat retail pricing in year 2003 dollars for fuels and vehicle differential retail costs. The cost effectiveness was calculated both on a tax excluded basis and a tax included basis.

The calculated cost effectiveness for each fuel/vehicle combination takes into account the two dominant cost terms, specifically, the differential fuel price compared to low sulphur gasoline and the differential vehicle purchase price. The differential non-fuel operating and maintenance costs per kilometer between the reference fuel/vehicle and the alternative fuel/vehicle can be considered in the model but have been assumed to be zero in this analysis.

The cost effectiveness calculation sums the vehicle purchase cost and the discounted lifetime operating costs for the alternative fuel and compares that to the costs for the reference vehicle (using low sulphur gasoline). The lifetime GHG emissions are calculated for the alternative fuel and the reference vehicle. If the reference vehicle/fuel provides a reduction in GHG emissions then the cost effectiveness is calculated by dividing the change in vehicle ownership costs by the reduction in GHG emissions. A negative value will indicate that there will be a lifetime savings in ownership costs. This is the most desirable outcome. A positive value indicates that there is a cost to reducing GHG emissions.Small positive values are better than large positive values as they indicate that the option has a lower cost for reducing GHG emissions. All of the calculations can be discounted to the present for vehicles that are purchased in future years.

The greenhouse gas cost effectiveness calculations have been added for all of the wheat ethanol pathways. The default cost for wheat ethanol has been set at five cents per litre less than corn ethanol. The fact that ethanol produced from wheat in western Canada is less expensive than ethanol produced from corn in Ontario has been shown in several reports for some of the Provinces ((S&T)^2, Saskatchewan) and for the Federal Government ((S&T)^2, NRCan).

The cost effectiveness of transportation options is highly dependent on the assumptions made. The default costs in GHGenius are based on a 1999 forecast of oil prices of $18 /bbl US. More current forecasts are on the order of $25 /bbl US. The wheat ethanol production costs are assumed to be 42 cents per litre and five cents per litre higher at 47 cents per litre for corn ethanol. The return on these ethanol plants is similar to the return for the oil refineries and it should be noted that it might not be possible to finance new ethanol plants at these relatively low rates of returns. No other changes to the cost effectiveness defaults have been made. The cost effectiveness for E10 blends in Manitoba and Saskatchewan compared to E10 from corn ethanol is shown in the following table. The calculations are made for the year 2010 and are discounted to the year 2003 at a 10% rate. This cost effectiveness does not include the existing federal and provincial fuel tax incentives for low level ethanol blends.

Table 4-9 Cost Effectiveness E10 Blends

	Saskatchewan	Manitoba	Ontario
	Wheat	Wheat	Corn
	$/tonne GHG	$/tonne GHG	$/tonne GHG
Year 2010 (not discounted)	73.54	64.22	86.98
Year 2003 (Discounted at 10%)	37.74	32.96	44.64

The cost effectiveness calculations could also be made by including the existing tax incentives for ethanol blends. These tax incentives are 25 cents/litre in Saskatchewan, 24.7 cents/litre in Ontario, and 35 cents/litre in Manitoba. The results of the cost effectiveness calculations on a tax included basis are shown in the following table. The wheat ethanol blends now have a negative cost effectiveness indicating a savings in fuel costs and a reduction in greenhouse gas emissions.

Table 4-10 Cost Effectiveness E10 Blends – Tax Included

	Saskatchewan	Manitoba	Ontario
	Wheat	Wheat	Corn
	$/tonne GHG	$/tonne GHG	$/tonne GHG
Year 2010 (not discounted)	-4.89	-31.67	15.15
Year 2003 (Discounted at 10%)	-2.51	-16.25	7.77

4.7 CRITERIA EMISSIONS

The full cycle criteria emissions are calculated by fuel stage for all of the pathways. Wheat ethanol has been added wherever there was a corn ethanol pathway. The summary for E10 is shown in the following table. Similar information is available in the model for all of the other wheat ethanol pathways.

Table 4-11 Criteria Air Contaminants E10 - 2002

	150 PPM Sulphur Gasoline	E10	E10
		Saskatchewan	Manitoba
CO			
Vehicle Operation	21.252	16.680	16.680
Upstream	0.625	0.488	0.487
Vehicle Material & Assembly	0.116	0.116	0.116
Total	21.993	17.284	17.283
NOx			
Vehicle Operation	0.849	0.725	0.725
Upstream	0.771	0.928	0.920
Vehicle Material & Assembly	0.151	0.151	0.151
Total	1.772	1.804	1.796
VOC-Ozone weighted			
Vehicle Operation	0.686	0.522	0.522
Upstream	0.378	0.381	0.381
Vehicle Material & Assembly	0.034	0.034	0.034
Total	1.098	0.937	0.937
SOx			
Vehicle Operation	0.094	0.059	0.059
Upstream	0.207	0.230	0.213
Vehicle Material & Assembly	0.190	0.189	0.189
Total	0.492	0.478	0.461
PM			
Vehicle Operation	0.056	0.053	0.053
Upstream	0.040	0.044	0.043
Vehicle Material & Assembly	0.205	0.204	0.204
Total	0.300	0.301	0.300

5. ENERGY BALANCE

5.1 MODEL UPDATES

The energy displaced by the co-products is now calculated by the model. The displacements are calculated using the same methodology as the GHG displaced by the co-products. The primary changes in the model are found on sheet I in tables 51.a and 51.c.

5.2 WHEAT ETHANOL

The energy balance for wheat ethanol is different from the energy balance for corn ethanol. The differences are due to the differing requirements for fertilizer and crop production, differences in the processing of wheat compared to corn and different co-product credits. There is some uncertainty surrounding the energy requirements of a wheat ethanol plant since there are no large plants in North America on which to base the inputs. A relatively conservative approach has been taken using 5-10% more energy in the wheat plant than the corn plant. The results from the model are shown in the following table.

Table 5-1 Ethanol Energy Balance - 2002

	Ethanol	Ethanol
	Corn	Wheat
	BTU Consumed/BTU Fuel Delivered	BTU Consumed/BTU Fuel Delivered
Fuel dispensing	0.0028	0.0028
Fuel distribution, storage	0.0126	0.0126
Fuel production	0.5091	0.5561
Feedstock transmission	0.0122	0.0058
Feedstock recovery	0.0998	0.0474
Ag. chemical manufacture	0.1031	0.1899
Co-product Credits	-0.0927	-0.1254
Total	0.65	0.69

The largest difference between corn and wheat is found in the energy used for manufacturing fertilizer. While wheat does require more nitrogen because of the higher protein content, the difference is exaggerated here because in Ontario approximately one third of the nitrogen is supplied by animal manure, which reduces the nitrogen requirements. Some animal manure is used for the nitrogen requirements in western Canada but there are no reliable estimates that quantify the amount. If the corn were grown using all synthetic fertilizer, the energy consumed per unit of energy produced would increase to 0.67.

The energy balance data is sometimes presented as the inverse of that calculated here. In that case, for corn 1.53 BTU's of energy are produced for every BTU consumed and for wheat 1.45 BTU's are produced for every BTU consumed.

In addition, the use of ethanol in low level blends increases the energy efficiency of the engine by approximately 1%. This means that every BTU of ethanol replaces 1.14 BTU's of gasoline. This means that 1.74 BTU's of gasoline are displaced by every BTU of energy used in the corn ethanol pathway and 1.65 BTU's of gasoline are displaced for every BTU consumed in producing ethanol from wheat.

6. COMPARISON TO OTHER PATHWAYS AND STUDIES

The results of the wheat ethanol pathway in GHGenius are briefly compared to corn ethanol in the model and to the results from wheat ethanol studies performed in a European context.

6.1 CORN ETHANOL

The corn ethanol pathway was originally updated for a study performed for Agriculture and Agri-Food Canada in 1999 (Levelton, 1999). The GHGenius model has undergone some changes since that time. The emissions from land use and fertilizer manufacture and use has been updated to follow the IPCC methodology and the calculation of co-products has been changed to eliminate arbitrary allocations and instead utilize a systems expansion approach. For this work the energy consumption at the ethanol plant originally modeled was revisited and update with more current data. In the following table, the results from the 1999 study are compared to the current model results.

Table 6-1 Corn Ethanol Comparison - 2000

	1999 Agriculture Canada Study	Current Model IPCC Methodology	Current Model Non IPCC Methodology
Fuel dispensing	165	150	150
Fuel distribution and storage	1,534	1,570	1,570
Fuel production	38,927	35,889	35,889
Feedstock transmission	1,588	1,663	1,663
Feedstock recovery	8,912	9,099	9,099
Land-use changes, cultivation	908	11,052	11,052
Fertilizer manufacture	6,654	7,105	7,105
Emissions displaced	-12,771	-32,634	-17,423
Total	45,917	33,892	49,104

There have also been some changes to the gasoline pathways in the model. In the 1999 work, the gasoline pathway was optimized for the Ontario refineries. The current model shows a Canadian average value for gasoline. In the following table, the reductions for corn E10 blends are compared.

Table 6-2 GHG Emissions E10 Blends

	1999 Agriculture Canada Study	Current Model IPCC Methodology	Current Model Non IPCC Methodology
Gasoline, g/mile	510.3	524.5	524.5
E10, g/mile	490.6	499.0	505.3
% Reduction	3.9	4.7	3.7

6.2 EUROPEAN WHEAT ETHANOL STUDIES

In Europe, both wheat and sugar beets have been considered as feedstocks for ethanol production. There have been several studies performed on the energy balance and greenhouse gas emissions of producing ethanol from these feedstocks. Concawe summarized the results of studies done by the following authors;

- Gover, M.P. et al (1996) Alternative road transport fuels – a preliminary life-cycle study for the UK. ETSU report R92 volumes 1 & 2. Oxford: Energy Technology Support Unit
- Levy, R.H. (1993) Les biocarburants. Report to the French government based on figures from the Commission Consultative pour la Production des Carburants de Substitution, 1991
- Richards, I.R. (2000) Energy balances in the growth of oilseed rape for biodiesel and of wheat for bioethanol. Report for the British Association of Bio Fuels and Oils (BABFO). Ipswich: Levington Agriculture Ltd
- EU (1994) Application of biologically derived products as fuels or additives in combustion engines. Publication No. EUR 15647 EN. Directorate-General XII Science, Research and Development

These four reports have all used different assumptions about the boundaries of the systems, which make it difficult to compare them to each other as well as to the work presented here. In some cases there is a credit applied for the DDG and in other cases, there is no credit. Some studies assume that the straw is collected and burned to supply the energy for the plant and for other sources and other studies do not consider the straw. The energy balance for the studies is presented and compared to the work here in the following table. In this case, there is a credit for the DDG but not for the straw. If the original authors did not present their data this way then Concawe has made the calculation based on data in the original reports.

Table 6-3 Energy Balance Comparisons

Study	Total Energy Consumed per unit of Energy in the Ethanol Produced	Ratio of Energy Credit for DDG to Energy in Ethanol Produced	Net Ratio after DDG Credit
ETSU	1.07	0.09	0.98
Levy	0.91	0.10	0.81
Levington	0.90	0.00	0.90
EU	1.26	0.23	1.03
Average of Four	1.04	0.10	0.94
This work	0.82	0.13	0.69

In all cases the European studies indicate that the pathways are much more energy intensive than shown in this report. Concawe does note that there are two modern ethanol plants in Sweden and Spain that use much less energy than older technology and that new plants may use the more energy efficient processes.

The data from the Levington (2000) study was reviewed to determine the differences in the assumption and inputs made for the calculations. The productivity of winter wheat in the UK is approximately three times higher than spring wheat yields in western Canada. In spite of this the fertilizer application rates and fuel used for harvesting are very close the data used in this study when calculated on a per unit of wheat produced basis. The large difference in inputs are for the energy used in the ethanol processing. The Levington study used data from the ETSU study, the ethanol plant energy requirement is 50% larger than used for this study, and it appears that they have not considered any energy required for drying the co-products. If the energy required was adjusted to the same rate used here then the energy used per unit of ethanol produced for the Levington study would become 0.69, an even lower value than calculated in this report. This would also partially explain the ETSU results since it was this data that was used by Levington.

The EU study relied heavily on the work of Pimentel for their energy balance data. That data is very old, dating to the 1970's and has been shown by many other authors to be unrepresentative of current practices. It also uses very high energy for the ethanol production stage.

The GHG emissions summary provided by Concawe follows the same patterns as the energy balance but it is not clear if the IPCC methodology has been followed in all cases.

This work provides a more favorable energy balance and a larger reduction in GHG emissions than the European studies found in the literature. The primary reason for this is that the energy required for producing ethanol in this study has been based on estimates from modern ethanol plants whereas the European studies have been based on older ethanol plants where the production of fuel ethanol was not considered in their original designs, as a result they are not very energy efficient. Many of the European studies do not fully credit the DDG co-products and those that do, do not use the system expansion approach to calculating the values of the co-products.

7. SUMMARY

The production of ethanol from wheat has been successfully added to the GHGenius model. The wheat ethanol can be used in all of the energy conversion devices that used in the model including low and high level blends in spark ignited engines, in diesel fuel blends, directly in diesel engines and in fuel cells.

The energy balance of wheat ethanol is slightly less positive than that of corn ethanol, 0.69 vs. 0.65 BTU's consumed per BTU of ethanol produced. This is due to higher energy consumption in the ethanol plant related to the higher level of DDG produced, more fertilizer energy required as a result of the higher protein content of wheat compared to corn. These higher energy usage rates are partially offset by less energy required for harvesting and transportation and higher credits for the higher protein DDG produced.

The GHG emission reduction for wheat ethanol depends on where the ethanol is produced. Manitoba with it's high proportion of hydro electricity produces a larger reduction in GHG emissions than ethanol produced from corn in Ontario but if the wheat ethanol is produced in Saskatchewan the GHG emissions are higher than they are for Ontario corn ethanol. The results for a blend of 10% ethanol in gasoline for these three cases are summarized in the following table.

Table 7-1 GHG Reductions E10 - 2002

	Gasoline	E10	E10	E10
		Ontario	Saskatchewan	Manitoba
Feedstock		Corn	Wheat	Wheat
Vehicle operation	340.2	337.7	337.7	337.7
C in end-use fuel from CO_2 in air	0.0	-23.9	-23.9	-23.9
Net Vehicle Operation	340.2	313.8	313.8	313.8
Fuel dispensing	0.5	0.5	0.5	0.5
Fuel storage and distribution	6.6	6.6	6.6	6.6
Fuel production	66.0	73.4	77.2	73.4
Feedstock transport	1.0	1.5	1.2	1.2
Feedstock and fertilizer production	46.1	48.2	49.4	49.4
Land use changes and cultivation	0.0	3.8	7.3	7.3
CH_4 and CO_2 leaks and flares	14.0	12.9	12.9	12.9
Emissions displaced by co-products	0.0	-11.5	-17.2	-17.2
Sub total (fuel cycle)	474.3	449.3	451.7	447.9
% Changes (fuel cycle)	2.8	-2.6	-2.1	-2.9
Vehicle assembly and transport	8.5	8.5	8.5	8.5
Materials in vehicles	42.8	42.7	42.7	42.7
Grand total	525.6	500.5	502.9	499.1
% Changes to RFG (grand total)	0.0	-4.8	-4.3	-5.0

8. REFERENCES

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