Alan Bryce
Blue Fuel Energy Corporation
100 – 9800 McDonald Park Road
Sidney, BC V8L 5W5 Canada
www.bluefuelenergy.com
C 250.888.5951
T 250.655.0330
F 250.483.1577

10-ALT-01

2010-11 Investment Plan

Response public comments for the Alternative and

Renewable Fuel and Vehicle Technology Program

FY 2010-11

GHG EMISSIONS OF BLUE FUEL METHANOL PRODUCTION PROCESS

Prepared For:

Blue Fuel Energy Corporation
100-9800 McDonald Park Road
Sidney, BC, Canada
V8L 5W5

Prepared By

(S&T)^2 Consultants Inc.
11657 Summit Crescent
Delta, BC
Canada, V4E 2Z2

Date: March 18, 2010

EXECUTIVE SUMMARY

Blue Fuel Energy Corporation is developing a novel process for the production of methanol or DME (dimethyl ether). The process combines hydrogen produced via electrolysis of water with carbon dioxide from an industrial production process to produce methanol or DME.

The produced methanol or DME can be used to replace fossil fuel derived methanol or DME and therefore has the potential to result in products with a lower carbon footprint than the products currently on the market.

This work will focus on the lifecycle analysis of the production of methanol from the Blue Fuel process, as there are significant existing markets for methanol, including fuel markets in some countries.

The concept of life-cycle assessment (LCA) emerged in the late 1980's from competition among manufacturers attempting to persuade users about the superiority of one product choice over another. As more comparative studies were released with conflicting claims, it became evident that different approaches were being taken related to the key elements in the LCA analysis:

- boundary conditions (the "reach" or "extent" of the product system);
- data sources (actual vs. modeled); and
- definition of the functional unit.

LCA considers the entire life cycle stages of a product or service, including: extraction and acquisition of all relevant raw materials, energy inputs and outputs, material production and manufacturing, use or delivery, end-of-life treatment, and disposal or recovery. This systematic overview of the product "system" provides perspective on the potential differences in environmental burden between life cycle stages or individual processes.

The GHGenius lifecycle model has been developed for Natural Resources Canada over the past ten years. It 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. The model has been developed using the principles established by the ISO 14000 series.

GHGenius is capable of estimating life cycle emissions of the primary greenhouse gases and the criteria pollutants from combustion 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 GHG emissions from the Blue Fuel methanol production process are expected to be heavily influenced by the emissions from the hydrogen production so it is important for the model to have significant flexibility in the type of electric power that is used in the process.

For this work, the existing biomass to methanol pathway in GHGenius has been modified to be able to model the Blue Fuel methanol process. This approach has been taken because the Blue Fuel process conceptually is similar to the use of biomass as a feedstock, carbon dioxide is essentially removed from the atmosphere for the production of the fuel and then is returned to the atmosphere when the fuel is combusted to release it's energy.

The process parameters used for modelling have been supplied by Blue Fuel and are based on a preliminary engineering analysis. The process has not been optimized with respect to energy efficiency nor has the process been demonstrated on a significant commercial scale before. The results can be easily updated with the model as the process moves through the engineering process.

A special GHGenius model has been developed to project the lifecycle energy balance, GHG and CAC emissions. The model is flexible and it can model a wide range of types of electric power that would be used in the process. A number of scenarios have been evaluated and it is apparent that the source of electrical energy that is used in the process strongly influences all of the results.

The overall primary energy balance of the process is strongly influenced by how the electric power is produced. The results from the four scenarios that have been evaluated are summarized in the following table.

Table ES- 1 Energy Balance Summary

Fuel	Methanol			
Feedstock	CO_2, H_2			
Power Source	Wind	BC Grid	Alberta Grid	Natural Gas
	Joules Consumed/Joule Delivered			
Fuel dispensing	0.0039	0.0039	0.0039	0.0039
Fuel distribution, storage	0.0222	0.0222	0.0222	0.0222
Fuel production	1.8316	1.9457	4.3354	3.8827
Feedstock transmission	0.0000	0.0000	0.0000	0.0000
Feedstock recovery	0.0000	0.0000	0.0000	0.0000
Ag. chemical manufacture	0.0000	0.0000	0.0000	0.0000
Co-product credits	0.0000	0.0000	0.0000	0.0000
Total	**1.8577**	**1.9718**	**4.3615**	**3.9088**
Net Energy Ratio (J delivered/J consumed)	**0.5383**	**0.5071**	**0.2293**	**0.2558**

The wind power scenario is closest to a secondary energy balance where the energy required to produce the energy is not include. This is the best measure of the efficiency of the process itself and in this case is influenced mostly by the efficiency of hydrogen production from electrolysis. When other sources of electricity are considered the overall energy efficiency drops considerably. The natural gas scenario is not as efficient as just producing the methanol directly from natural gas and thus it can be expected that this route would have higher GHG emissions than the direct natural gas to methanol route (and probably less attractive economics).

The GHG emissions from the process are related to the energy consumption and reflect both the quantity of energy used and the carbon intensity of the different energy sources. In the following table, the GHG emissions of the four scenarios considered are compared. The lifecycle GHG emissions are attractive when Wind Power or the BC Grid power are used but if Alberta power or natural gas derived power were used, the emissions are higher than they are for gasoline or methanol produced from natural gas.

Table ES- 2 GHG Emission Summary

Fuel	Methanol			
Feedstock	CO_2, H_2			
	Wind	BC Grid	Alberta Grid	Natural Gas
	g CO_2eq/GJ			
Fuel dispensing	40	40	40	40
Fuel distribution and storage	1,687	1,687	1,687	1,687
Fuel production	10,631	28,038	412,920	215,296
Feedstock transmission	0	0	0	0
Feedstock recovery	0	0	0	0
Land-use changes, cultivation	0	0	0	0
Fertilizer manufacture	0	0	0	0
Gas leaks and flares	0	0	0	0
CO_2, H_2S removed from NG	0	0	0	0
Emissions displaced	0	0	0	0
Total	12,359	29,766	414,648	217,024
Combustion emissions	1,911	1,911	1,911	1,911
Grand Total	14,271	31,670	416,559	218,935
% Change	-84.3	-65.1	+359	+141

The modelling results from the scenarios considered are not that different from other electricity based transportation fuels such as electric vehicles or fuel cells power by electrolytic hydrogen. In some locations in Canada, these pathways produce better GHG emissions than gasoline and in other regions; there is little or no benefit.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Blue Fuel Energy Corporation is developing a novel process for the production of methanol or DME (dimethyl ether). The process combines hydrogen produced via electrolysis of water with carbon dioxide from an industrial production process to produce methanol or DME.

The produced methanol or DME can be used to replace fossil fuel derived methanol or DME and therefore has the potential to result in products with a lower carbon footprint than the products currently on the market.

This work will focus on the lifecycle analysis of the production of methanol from the Blue Fuel process, as there are significant existing markets for methanol, including fuel markets in some countries.

1.1 LIFECYCLE ANALYSIS

The concept of life-cycle assessment emerged in the late 1980's from competition among manufacturers attempting to persuade users about the superiority of one product choice over another. As more comparative studies were released with conflicting claims, it became evident that different approaches were being taken related to the key elements in the LCA analysis:

- boundary conditions (the "reach" or "extent" of the product system);
- data sources (actual vs. modeled); and
- definition of the functional unit.

In order to address these issues and to standardize LCA methodologies and streamline the international marketplace, the International Standards Organization (ISO) has developed a series of international LCA standards and technical reports under its ISO 14000 Environmental Management series. In 1997-2000, ISO developed a set of four standards that established the principles and framework for LCA (ISO 14040:1997) and the requirements for the different phases of LCA (ISO 14041-14043).

By 2006, these LCA standards were consolidated and replaced by two current standards: one for LCA principles (ISO 14040:2006); and one for LCA requirements and guidelines (ISO 14044:2006).

The ISO 14040:2006 standard describes the principles and framework for life cycle assessment including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements. ISO 14040:2006 covers life cycle assessment (LCA) studies and life cycle inventory (LCI) studies. It does not describe the LCA technique in detail, nor does it specify methodologies for the individual phases of the LCA. The intended application of LCA or LCI results is considered during definition of the goal and scope, but the application itself is outside the scope of this International Standard.

It is useful to consider seven basic principles in the design and development of life cycle assessments as a measure of environmental performance. The seven principles outlined below are the basis of ISO Standard 14040:2006:

- Life Cycle Perspective (the entire stages of a product or service);
- Environmental Focus (addresses environmental aspects);
- Relative Approach and Functional Unit (analysis is relative to a functional unit);

- Iterative Approach (phased approach with continuous improvement)
- Transparency (clarity is key to properly interpret results)
- Comprehensiveness (considers all attributes and aspects)
- Priority of Scientific Approach (preference for scientific-based decisions)

1.1.1 Life Cycle Perspective

LCA considers the entire life cycle stages of a product or service, including: extraction and acquisition of all relevant raw materials, energy inputs and outputs, material production and manufacturing, use or delivery, end-of-life treatment, and disposal or recovery. This systematic overview of the product “system” provides perspective on the potential differences in environmental burden between life cycle stages or individual processes.

1.1.2 Environmental Focus

The primary focus of a LCA is on the environmental aspects and impacts of a product system. Environmental aspects are elements of an activity, product, or service that cause or can cause an environmental impact through interaction with the environment. Some examples of environmental aspects are: air emissions, water consumption, releases to water, land contamination, and use of natural resources. Economic and social aspects are typically outside the scope of an LCA, although it is possible to model some of these elements. Other tools may be combined with LCA for more extensive analysis.

1.1.3 Relative Approach and Functional Unit

LCA is a relative analytical approach, which is structured on the basis of a functional unit of product or service. The functional unit defines what is being studied and the life cycle inventory (LCI) is developed relative to one functional unit. An example of a functional unit is a light-duty gasoline vehicle driving an average distance (with other details of time, geography, trip characteristics, and potential fuels added). All subsequent analyses are then developed relative to that functional unit since all inputs and outputs in the LCI and consequently the LCIA profile are related to the functional unit.

An LCA does not attempt to develop an absolute inventory of environmental aspects (e.g. air emissions inventory) integrated over an organizational unit, such as a nation, region, sector, or technology group.

1.1.4 Iterative Approach

LCA is an iterative analytical approach. The individual phases of an LCA (Goal and Scope Definition; Inventory Analysis; Impact Assessment; and Interpretation) are all influenced by, and use the results from, the other phases. The iterative approach within and between phases contributes to a more comprehensive analysis and higher quality results.

1.1.5 Transparency

The value of an LCA depends on the degree of transparency provided in the analysis (for example: the system description, data sources, assumptions and key decisions). The principle of transparency allows users to understand the inherent uncertainty is the analysis and properly interpret the results.

1.1.6 Comprehensiveness

A well-designed LCA considers all stages of the product system (the “reach”) and all attributes or aspects of the natural environment, human health, and resources. Tradeoffs between alternative product system stages and between environmental aspects in different media can be identified and assessed.

1.1.7 Priority of Scientific Approach

It is preferable to make decisions from an LCA analysis based on technical or science reasoning, rather than from social or economic sciences. Where scientific approaches cannot be established, consensual international agreement (e.g. international conventions) can be used. The power of the technical or scientific approach lies in the proper attribution of facts to sources and the potential reproducibility of these facts under scientific conditions. While the scientific approach is typically more objective than economic or social values, it does not preclude the use economic or social values for informing LCA decisions.

1.2 GHGENIUS

The GHGenius lifecycle model has been developed for Natural Resources Canada over the past ten years. It 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. The model has been developed using the principles established by the ISO 14000 series.

GHGenius is capable of estimating life cycle emissions of the primary greenhouse gases and the criteria pollutants from combustion 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, and for light duty battery powered electric vehicles. There are over 200 vehicle and fuel combinations possible with the model.

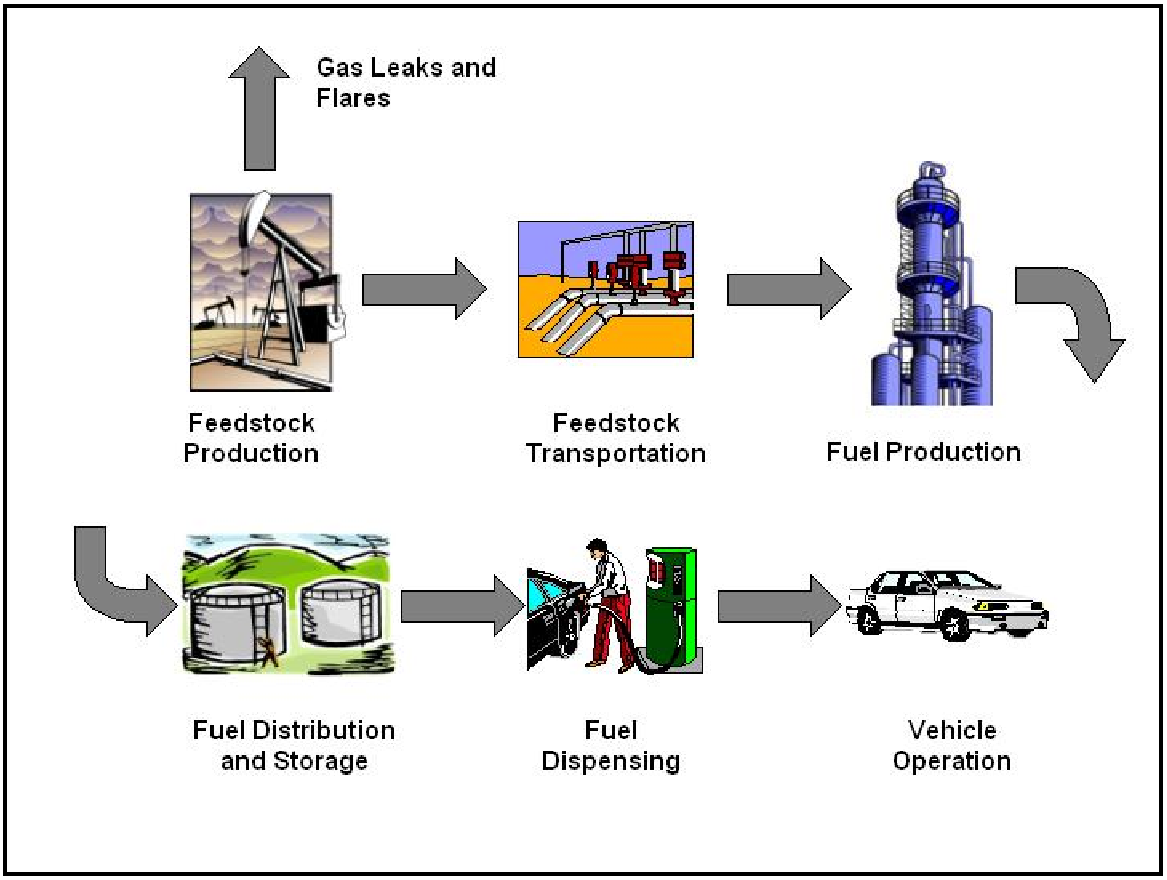
GHGenius can predict emissions for past, present and future years through to 2050 using historical data or correlations for changes in energy and process parameters with time that are stored in the model. The fuel cycle segments considered in the model are as follows:

- 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.
- 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.

The main lifecycle stages for crude oil based gasoline or diesel fuel are shown in the following figure.

Figure 1-1 Lifecycle Stages



1.3 SCOPE OF WORK

The GHG emissions from the Blue Fuel methanol production process are expected to be heavily influenced by the emissions from the hydrogen production so it is important for the model to have significant flexibility in the type of electric power that is used in the process.

For this work, the existing biomass to methanol pathway in GHGenius has been modified to be able to model the Blue Fuel methanol process. This approach has been taken because the Blue Fuel process conceptually is similar to the use of biomass as a feedstock, carbon dioxide is essentially removed from the atmosphere for the production of the fuel and then is returned to the atmosphere when the fuel is combusted to release it's energy.

The converted model (GHGenius 3.16c) has been set up to include all of the Blue Fuel specific process and location data. The model has all of the flexibility and tools in the standard GHGenius model. In addition, it has the flexibility of being able to specify the electric power mix that is used to drive the plant. This special model is not being shared with the general public.

The process parameters used for modelling have been supplied by Blue Fuel and are based on a preliminary engineering analysis. The process has not been optimized with respect to energy efficiency nor has the process been demonstrated on a significant commercial scale before. The results can be easily updated with the model as the process moves through the engineering process.

This report describes the modelled process and the results for a number of scenarios of power mix.

2. REFERENCE FUELS

An important principle in lifecycle analysis is that of using a relative approach, the emissions for a product or a process are presented relative to the emissions of a comparable product or process. Methanol, when used as a fuel is most often used to supplement or replace gasoline in spark ignited engines. Gasoline production and use is therefore the most appropriate reference fuel for comparing the Blue Fuel methanol to. Methanol has also been used in heavy-duty engines on a demonstration basis so a diesel fuel reference case has also been considered for some of the analyses.

If Blue Fuel were to produce DME then the most appropriate reference fuel would be diesel fuel, as DME has excellent combustion properties when use in a compression ignition engine.

2.1 GASOLINE

The GHG emissions for gasoline will depend on a number of factors including, the crude oil slate being refined, the refinery configuration, and the location, which influences the emissions associated with the distribution of the products that are produced. The results for three gasoline scenarios in the year 2010 are shown in the following table. All of the results are derived from the default values in GHGenius 3.16c. These cases were described in more detail in the recent report on the development of "Provincial Models" ((S&T)[2] Consultants, 2009).

Table 2-1 Lifecycle GHG Emissions for Gasoline

	Canada Average	Western Canadian Average	BC Average
	g CO_2 eq/GJ		
Fuel dispensing	109	198	20
Fuel distribution and storage	465	639	405
Fuel production	12,349	11,780	11,622
Feedstock transmission	1,030	228	81
Feedstock recovery	8,414	12,368	11,990
Land-use changes, cultivation	205	427	427
Fertilizer manufacture	0	0	0
Gas leaks and flares	1,848	2,582	2,582
CO_2, H_2S removed from NG	0	0	0
Emissions displaced	-122	-222	-198
Total	24,298	28,001	26,929
Combustion	63,778	63,778	63,778
Grand Total	88,076	91,779	90,707

The emissions form gasoline production in western Canada are higher than the national average because of the significant quantities of bitumen derived crude oil refined in this region.

The emissions for the gasoline system could increase or decrease in the future. Increasing quantities of bitumen derived gasoline will have a tendency to increase emissions, whereas efficiency improvements in refining and oil production systems could decrease emissions.

Given that over 70% of the emissions of gasoline are from the vehicle, the potential for large changes in lifecycle GHG emissions are relatively small.

2.2 Diesel Fuel

The results for the three diesel fuel scenarios are shown in the following table. All of the results are derived from the default values in GHGenius. These cases were described in more detail in the recent report on the development of "Provincial Models" ((S&T)[2] Consultants, 2009).

Table 2-2 Lifecycle GHG Emissions for Diesel

	Canada Average	Western Canadian Average	BC Average
	g CO_2 eq/GJ		
Fuel dispensing	112	203	20
Fuel distribution and storage	477	653	414
Fuel production	8,436	8,063	7,954
Feedstock transmission	1,049	233	83
Feedstock recovery	8,717	12,639	12,253
Land-use changes, cultivation	212	427	427
Fertilizer manufacture	0	0	0
Gas leaks and flares	1,805	2,577	2,577
CO_2, H_2S removed from NG	0	0	0
Emissions displaced	-127	-222	-198
Total	20,681	24,574	23,531
Combustion	70,276	70,276	70,276
Grand Total	90,957	94,850	93,807

On an energy basis, the GHG emissions from diesel fuel are slightly higher than they are for gasoline. However, when the higher efficiency of the diesel engine is considered then the GHG emissions on a per distance travelled or per unit of work delivered are lower than the gasoline emissions.

3. BLUE FUEL PRODUCTION PROCESS

Blue Fuel Energy has developed a process and project for producing methanol from electrical energy, water, and recycled CO_2 from the Spectra Energy operated Pine River gas plant in the Peace Region of northern BC. Hydrogen is to be produced through the electrolysis of water and reacted with CO_2 to produce methanol, a product that is easily shippable through existing transportation methods.

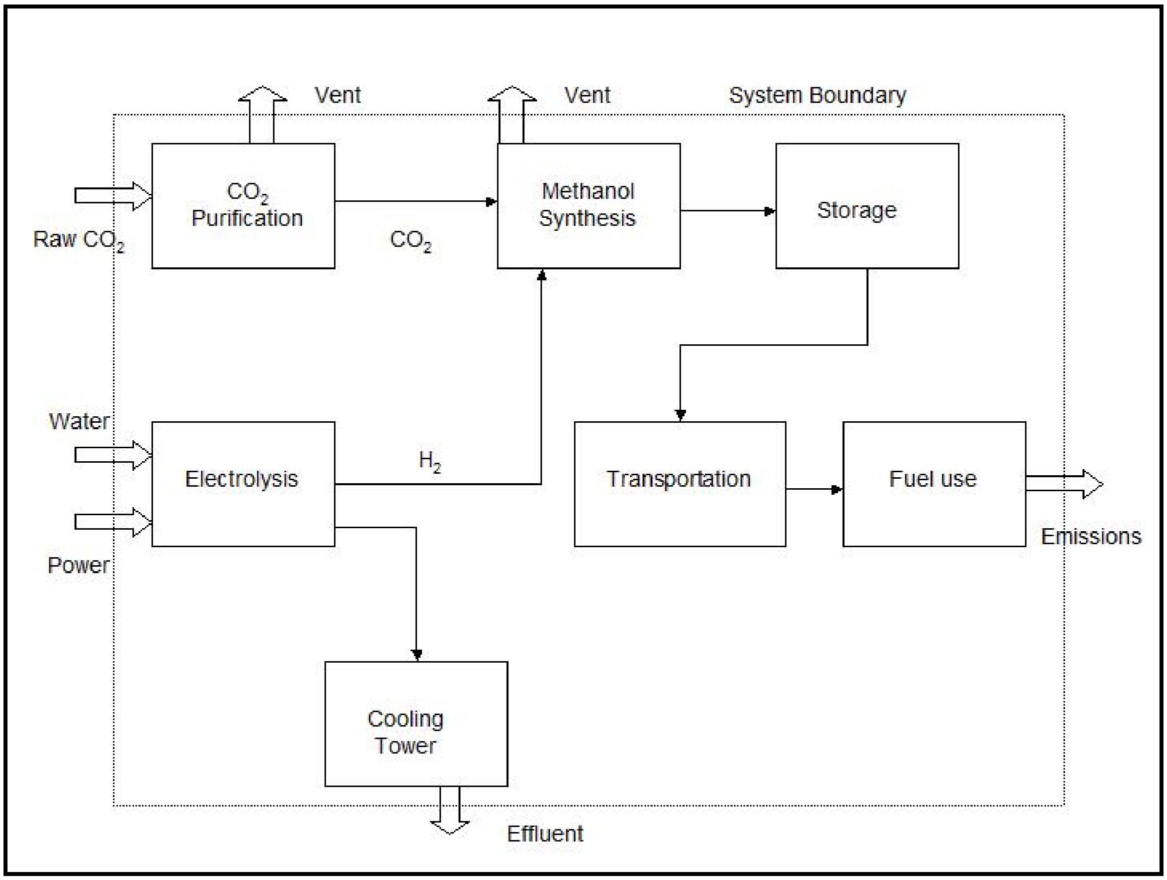
A simplified process equation is as follows:

Water + Electricity → Hydrogen + Oxygen

Hydrogen + CO_2 → Methanol + Water

A simplified process schematic is shown in the following figure.

Figure 3-1 Blue Fuel Production Process



Benefits of producing methanol from green power near the Pine River gas plant include:

- Production of a commercial product in close proximity to a large existing hydroelectric dam and potential wind resource. The wind resource estimates in the Peace region far exceed local energy requirements and the distance from suitably sized markets make electrical transmission expensive; however Blue Fuel discussions with BC Hydro indicate that the hydroelectric dam would be able to absorb power fluctuations from a large wind farm and provide a stable power supply to a future methanol or DME plant.

• Unlike other gas plants located further to the east, the Pine River plant is relatively far from any substantial oil fields that might provide attractive down well sequestration opportunities to enhance oil recovery. Blue Fuel provides an opportunity to actively recycle these “stranded” CO_2 emissions. Recent environmental legislation is providing financial incentives for the reduction of CO_2 emissions, which would be realized by the Pine River gas plant.

• Enhanced sulphur recovery, which would be required to purify the CO_2 prior to its use in the methanol plant would allow a capacity increase at the Pine River plant, which is presently limited to a sulphur production rate of 2000 TPD without significant upgrades to improve the overall sulphur capture efficiency.

• Close proximity to a rail spur.

3.1 SYSTEM BOUNDARIES

The system that is being analyzed starts with the collection and purification of waste stack gases from the gas plant and ends with the combustion of the methanol as a fuel. All of the process inputs are considered on a full lifecycle basis. The energy and emissions embedded in the transportation infrastructure, rail cars, trucks, pipelines, etc., is included in the analysis but the energy and emissions embedded in the fuel production plants is not included. Previous work has shown that these emissions are quite small ((S&T)^2 Consultants Inc., 2006).

3.2 MASS BALANCE

NORAM has prepared independent mass and energy balances based upon a target DME production rate of 300,000 tonnes per year (TPY), chosen by Blue Fuel Energy. The production of methanol instead of DME requires only minor modifications to the mass and energy balance. The plant would produce 417,500 tonnes per year of methanol based on the mass balance developed by NORAM. NORAM assumed that:

• Sufficient water resources are available. Due to electrical inefficiencies, the electrolysis process will require a substantial cooling water supply. The methanol production process from CO_2 and H_2 will also require cooling water and steam supplies.

• Constant electrical supply is available. Some of the unit operations involved in methanol production would be negatively affected by large swings in process duty, which would impact the overall system efficiency. In a purely wind-powered methanol production facility, significant hydrogen and CO_2 storage may be required to stabilize the process.

• Product shipment by rail once per week. It has been assumed that rail shipment would occur once per week; adequate storage has been provided for 10-days of production.

• 8,000 hours/year plant operation. This operating time has been used to provide plant downtime for equipment maintenance. This is believed to be quite conservative given the nature of the equipment and the number of electrolyzers, which reduces the amount of capacity that is likely to be offline at any given time.

There are five main parts to the process:

1. CO_2 purification from Pine River gas plant.
2. Hydrogen production through electrolysis.
3. Gas compression and storage (hydrogen, CO_2).
4. Methanol production from H_2 and CO_2 feeds.
5. Water management & utilities (steam, cooling water, wastewater treatment).

The overall mass balance for the process is summarized in the following table; additional water is required for the utilities and produced as wastewater in the process. As these don't have a direct impact on the energy balance or GHG emissions, they are omitted from the table for clarity.

Table 3-1 Mass Balance – Blue Fuel Process

	Input	Output
Water, tonnes/hr	88.0	
CO_2, tonnes/hr	71.8	
Methanol, tonnes/hr		52.2

Normalized data is required for GHGenius and that is summarized in the following table.

Table 3-2 Normalized Mass Balance– Blue Fuel Process

	Input	Output
Water, kg	1.33	
CO_2, kg	1.09	
Methanol, litres		1.0

3.3 Energy Balance

Electrical energy is required for the production of hydrogen and for various utilities, and thermal energy is required for process utilities. Some of the utility load can be satisfied from thermal energy recycled from the process but some additional energy will be required to balance the system. It is assumed that this additional thermal energy is supplied by natural gas.

Table 3-3 Energy Balance– Blue Fuel Process

	Input	Output
Electricity, MW	550	
Natural gas, GJ/hr	165	
Methanol, tonnes/hr		52.2

The normalized energy balance information is summarized in the following table. More than 90% of the process energy requirements are supplied by the electricity. The data in the following table has been confirmed by NORAM.

Table 3-4 Normalized Energy Balance– Blue Fuel Process

	Input	Output
Electricity, kWh	8.32	
Electricity, kj	29,952	
Natural gas, litres	66.0	
Natural gas, kj	2,498	
Methanol, litres		1.0

This information is entered on the Input Sheet, column N, rows 229 to 234 in GHGenius. Different system performance can be modelled by changing the power and natural gas use on this input sheet. The modified pathway for the Blue Fuel process has been identified in the model will the light green background.

3.4 PROCESS EMISSIONS

It has been assumed that the process emissions are similar to those from a natural gas to methanol production system. The process emissions include small amounts of methane and N_2O and result in a small amount of process related GHG emissions. There is significant uncertainty regarding these emissions and the assumptions may be conservative.

3.5 PRODUCT DISTRIBUTION

For the purposes of this lifecycle assessment, it will be assumed that the methanol is shipped by rail from Ft. St. John to Vancouver, a distance of 1,200 km. In addition, it is assumed that the product is moved by truck a distance of 80 km from the fuel distribution terminal to the retail service station.

3.6 PRODUCT USE

In GHGenius methanol can be used in blends of gasoline, as a neat fuel in diesel engines, and as a fuel for hydrogen production. Low level and high-level methanol blends were used in Canada in the 1980's (low level blends) and 1990's (M85) but the fuels have not been used commercially in Canada since about 1998. Methanol use as a fuel in diesel engines was demonstrated in transit buses and in class 8 trucks in the 1980's but was never used commercially in Canada.

The GHG emission performance of M85 in flex fuel vehicles and M100 in diesel engines is evaluated later in the report. The exhaust emission data in the model is based on the relative performance in the earlier demonstration work. The energy efficiency of the methanol fuels is also based on the relative performance of the earlier demonstration work, but the model projects the current relative performance based on the performance trends established in the 1990's. The exhaust emissions and energy efficiency results can be strongly influenced by the engine design parameters and the overall tuning philosophy of the vehicle manufacturer, but since there are no current commercial vehicles offered for M85 or M100 the only reasonable approach is to use the historical data.

4. MODELLING SCENARIOS AND RESULTS

The energy requirement data showed that the electrical energy inputs dominate the overall energy requirements. The overall system performance, both in terms of lifecycle energy balance, GHG emissions, and criteria air contaminant (CAC) emissions will therefore be dominated by how the electricity is produced. The special version of GHGenius that has been developed for this work has a large degree of flexibility in assessing different sources of electricity for use in the production process. Users can choose the power mix based on the average regional power mixes, for example, BC or Alberta, or the user can specify a specific type of electric power generation, such as natural gas fired turbines. The model will then calculate the primary energy balance, the GHG emissions performance, and the CAC emissions for the scenario.

The results for a number of scenarios are presented below.

4.1 WIND POWER

The initial Blue Fuel plant is expected to be located in the Peace River region of British Columbia. This is due to the availability of relatively concentrated CO_2 exhaust streams from gas plants in the region and the large wind potential that exists in the region. Thus, the initial concept is to utilize electric power that is generated by wind turbines. Due to the intermittent nature of wind power, it is expected that the project would be tied into the provincial grid so that the large hydroelectric reservoir capacity could be used to regulate the power supply to the plant.

In GHGenius, the GHG emissions for electric power production do include SF_6 emissions from power switch gear and a small amount of N_2O emissions related to corona discharge from power transmission, therefore there is no GHG emission free electric power in the model but wind power is very close with a carbon intensity of 1,471 g CO_2eq/GJ of electric power delivered.

4.1.1 Lifecycle Energy Balance

The model also assumes that wind power is 100% energy efficient. A similar assumption is made for hydro electricity. This is of course not true but it is not possible to assign an energy value to the wind or water that is not transformed into mechanical energy by the turbines. The overall lifecycle primary energy balance for the production of methanol from the Blue Fuel system is compared in the following table to the energy balance for methanol produced by natural gas and to gasoline produced from crude oil. The natural gas methanol is assumed to be produced offshore and transported to the market by ocean tanker.

Table 4-1 Energy Balance – Wind Scenario

Fuel	Gasoline (Low S)	Methanol	Methanol
Feedstock	Crude oil	NG	CO_2, H_2
	Joules Consumed/Joule Delivered		
Fuel dispensing	0.0019	0.0039	0.0039
Fuel distribution, storage	0.0086	0.0419	0.0222
Fuel production	0.1619	0.3902	1.8316
Feedstock transmission	0.0025	0.0037	0.0000
Feedstock recovery	0.1797	0.0763	0.0000
Ag. chemical manufacture	0.0000	0.0000	0.0000
Co-product credits	-0.0030	0.0000	0.0000
Total	**0.3517**	**0.5161**	**1.8577**
Net Energy Ratio (J delivered/J consumed)	**2.8436**	**1.9375**	**0.5383**

There are a number of ways of presenting energy balance information and there are usually issues with most of them, particularly when the production systems can be very different. For gasoline and methanol produced from natural gas the energy balance information in the previous table does not include the energy imbedded in the feedstock, it only counts the additional energy put into the system to convert the feedstock energy into a more useful form of energy. For the Blue Fuel methanol process there is no energy embedded in the feedstocks (Water and CO_2) and thus the comparison is not made in the same basis. To compare the processes on the same basis a 1.0 would have to be added to the fuel production values for gasoline and NG methanol. However, even if this is done the energy efficiency of the Blue Fuel process is not as high as the production of methanol from natural gas or the production of gasoline from crude oil.

4.1.2 GHG Emissions

The lifecycle GHG emissions from the three fuels for this scenario are shown in the following table on the basis of the emissions to produce the fuel plus the emissions that would arise from the combustion of the fuels assuming the same combustion efficiency per unit of energy.

Table 4-2 GHG Emissions – Wind Scenario

Fuel	Gasoline (Low S)	Methanol	Methanol
Feedstock	Crude oil	NG	CO_2, H_2
	g CO_2eq/GJ		
Fuel dispensing	20	40	40
Fuel distribution and storage	405	3,299	1,687
Fuel production	11,622	7,768	10,631
Feedstock transmission	81	209	0
Feedstock recovery	11,990	4,144	0
Land-use changes, cultivation	427	0	0
Fertilizer manufacture	0	0	0
Gas leaks and flares	2,582	854	0
CO_2, H_2S removed from NG	0	868	0
Emissions displaced	-198	0	0
Total	26,929	17,182	12,359
Combustion emissions	63,778	59,014	1,911
Grand Total	90,707	76,196	14,271
% Change		-16.0	-84.3

Both of the methanol fuels results in lower overall GHG emissions than gasoline. While the GHG emissions for the wind energy system are only slightly lower than the NG methanol when only the production emissions are considered, the GHG emission profile of the Blue Fuel process is significantly better than the traditional natural gas based methanol when the combustion emissions are factored in and the benefit of removing the CO_2, that would have otherwise been emitted to the air in the Blue Fuel process, is considered. Most of the GHG emissions from the Blue Fuel process, when wind power is used for the electric power, are related to the natural gas used in the process. There may be opportunities for increased waste heat utilization for the process (and thus lower natural gas consumption) when final engineering and design is completed.

4.1.2.1 M85 Vehicles

The GHG emissions can also be presented based on distance travelled as the functional unit rather than just using a unit of energy. This approach has the advantage in that that includes any differences in the combustion or conversion efficiency of the fuel in the vehicle. In GHGenius, E85 and M85 vehicles are slightly more efficient that gasoline powered vehicles. M85 denotes 85% methanol by volume but on an energy basis, 25% of the energy (and thus the emissions) is provided by the gasoline. In the following table the lifecycle emission results are presented for gasoline, M85 from natural gas, and M85 from the Blue Fuel process.

Table 4-3 Lifecycle GHG Emissions Light Duty Vehicles – Wind Energy

General fuel	Gasoline	Methanol	Methanol
Fuel spec	RFG30ppm S	M85	Blue Fuel M85
Production process energy	Crude oil	Natural Gas	Wind Energy
	g CO_2eq/km		
Vehicle operation	211.4	190.0	190.0
C in end-use fuel from CO_2 in air	0.0	0.0	-134.6
Net Vehicle Operation	211.4	190.0	55.5
Fuel dispensing	0.1	0.1	0.1
Fuel storage and distribution	1.3	8.1	4.3
Fuel production	38.5	27.5	34.2
Feedstock transport	0.3	0.6	0.1
Feedstock and fertilizer production	41.2	19.6	9.6
Land use changes and cultivation	0.0	0.0	0.3
CH_4 and CO_2 leaks and flares	8.6	6.1	2.1
Emissions displaced by co-products	-0.7	-0.2	-0.2
Sub total (fuel cycle)	300.7	251.9	106.0
% changes (fuel cycle)	0.0	-16.2	-64.9
Vehicle assembly and transport	*4.5*	*4.5*	*4.5*
Materials in vehicles	*27.5*	*27.7*	*27.7*
Grand total	332.7	284.1	138.2
% changes to RFG (grand total)	0.0	-14.6	-58.5

The use of M85 blended with methanol from the Blue Fuel process results in significant GHG emission reductions when the process uses wind electricity as the source of energy. The reduction is about four times larger than the reduction provided by methanol produced from natural gas.

4.1.2.2 M100 HD Vehicles

The results for the use of methanol in heavy-duty engines are shown in the following table. Methanol is not an ideal fuel for use in compression ignition engines as it has a high-octane value but a low Cetane value. The engines were modified to utilize a glow plug to enhance ignition and unlike M85 in spark ignited engines, where an increase in combustion efficiency is found, the M100 engines have a lower efficiency than engines operated on diesel fuel.

The results from GHGenius are shown in the following table.

Table 4-4 Lifecycle GHG Emissions Heavy-Duty Vehicles – Wind Energy

General fuel	Diesel Fuel	Methanol	Methanol
Fuel spec	15 PPM S	M100	Blue Fuel M100
Production process energy	Crude oil	Natural Gas	Wind Energy
	g CO_2eq/km		
Vehicle operation	1,078.3	996.9	996.9
C in end-use fuel from CO_2 in air	0.0	0.0	-970.2
Net Vehicle Operation	1,078.3	996.9	26.7
Fuel dispensing	0.3	0.6	0.6
Fuel storage and distribution	6.4	53.0	27.1
Fuel production	122.0	124.7	170.7
Feedstock transport	1.3	3.4	0.0
Feedstock and fertilizer production	194.6	66.5	0.0
Land use changes and cultivation	0.0	0.0	0.0
CH_4 and CO_2 leaks and flares	39.5	27.6	0.0
Emissions displaced by co-products	-3.0	0.0	0.0
Sub total (fuel cycle)	1,439.4	1,272.8	225.2
% changes (fuel cycle)	--	-11.6	-84.4
Vehicle assembly and transport	*8.6*	*10.4*	*10.4*
Materials in vehicles	*30.7*	*35.8*	*35.8*
Grand total	1,478.6	1,319.0	271.4
% changes to Diesel Fuel (grand total)		-10.8	-81.6

The GHG emission reduction for this application of methanol is small when the methanol is produced from natural gas, but is quite significant when using methanol from a wind energy driven Blue Fuel plant.

4.1.3 CAC Emissions

In addition to calculating the GHG emissions from the production and use of various fuels, GHGenius can also report the criteria air contaminant (CAC) emissions for the fuels for each stage of the lifecycle. These emissions are dependent on the engine application as well as the fuel production process.

4.1.3.1 M85 Vehicles

The CAC emissions for the light duty M85 vehicles are summarized in the following table. The vehicle emissions (operation and manufacturing the vehicles) are the same for both sources of methanol but the fuel production emissions are generally lower for the Blue Fuel process when wind energy is the source of the electric power.

Table 4-5 Lifecycle CAC Emissions Light Duty Vehicles – Wind Energy

General fuel	Gasoline	Methanol	Methanol
Fuel spec	RFG30ppm S	M85	Blue Fuel M85
Production process energy	Crude oil	Natural Gas	Wind Energy
	g CO_2eq/km		
CO_2 (not including other pollutants)			
Vehicle Operation	207.6	186.4	51.9
Upstream	77.2	54.4	42.8
Vehicle Material & Assembly	31.0	31.2	31.2
Total	315.8	272.1	125.9
% total CO_2-Equiv.	94.9	95.8	91.1
CH_4			
Vehicle Operation	0.021	0.013	0.013
Upstream	0.436	0.251	0.139
Vehicle Material & Assembly	0.032	0.033	0.033
Total	0.490	0.297	0.185
% total CO_2-Equiv.	3.683	2.611	3.344
N_2O			
Vehicle Operation	0.011	0.011	0.011
Upstream	0.004	0.004	0.014
Vehicle Material & Assembly	0.001	0.001	0.001
Total	0.015	0.015	0.026
% total CO_2-Equiv.	1.385	1.606	5.533
Total CO_2 Equiv.	**332.7**	**284.1**	**138.2**
CFCs + HFCs			
Vehicle Operation	0.002	0.002	0.002
Upstream	0.000	0.000	0.000
Vehicle Material & Assembly	0.000	0.000	0.000
Total	0.002	0.002	0.002
CO			
Vehicle Operation	10.861	7.620	7.620
Upstream	0.051	0.066	0.027
Vehicle Material & Assembly	0.017	0.017	0.017
Total	10.929	7.703	7.664
NOx			
Vehicle Operation	0.218	0.202	0.202
Upstream	0.185	0.244	0.095
Vehicle Material & Assembly	0.048	0.048	0.048
Total	0.451	0.495	0.345
VOC-Ozone weighted			
Vehicle Operation	0.244	0.125	0.125
Upstream	0.106	0.060	0.070
Vehicle Material & Assembly	0.018	0.019	0.019
Total	0.369	0.203	0.213
SOx			
Vehicle Operation	0.018	0.016	0.016
Upstream	0.124	0.053	0.033
Vehicle Material & Assembly	0.068	0.069	0.069
Total	0.210	0.138	0.119
PM			
Vehicle Operation	0.014	0.008	0.008
Upstream	0.022	0.018	0.008
Vehicle Material & Assembly	0.031	0.032	0.032
Total	0.068	0.058	0.047

4.1.3.2 M100 HD Vehicles

The CAC emissions for the use of M100 in heavy-duty vehicles are shown in the following table. There is a lot of similarity in the directional results for this application compared to the light duty use of M85.

Table 4-6 Lifecycle CAC Emissions Heavy-Duty Vehicles – Wind Energy

General fuel	Diesel	Methanol	Methanol
Fuel spec	15 ppm S	M100	Blue Fuel M100
Production process energy	Crude oil	Natural Gas	Wind Energy
	g CO_2eq/km		
CO_2 (not including other pollutants)			
Vehicle Operation	1,063.0	981.5	11.3
Upstream	308.1	245.2	166.0
Vehicle Material & Assembly	38.0	44.7	44.7
Total	1,409.1	1,271.4	221.9
% total CO2-Equiv.	95.3	96.4	81.8
CH_4			
Vehicle Operation	0.067	0.067	0.067
Upstream	1.939	0.995	0.230
Vehicle Material & Assembly	0.038	0.046	0.046
Total	2.043	1.108	0.342
% total CO2-Equiv.	3.5	2.1	3.2
N_2O			
Vehicle Operation	0.046	0.046	0.046
Upstream	0.015	0.019	0.090
Vehicle Material & Assembly	0.001	0.001	0.001
Total	0.062	0.067	0.137
% total CO_2-Equiv.	1.2	1.5	15.1
Total CO_2 Equiv.	**1,478.6**	**1,319.0**	**271.4**
CFCs + HFCs			
Vehicle Operation	0.001	0.001	0.001
Upstream	0.000	0.000	0.000
Vehicle Material & Assembly	0.000	0.000	0.000
Total	0.001	0.001	0.001
CO			
Vehicle Operation	0.184	0.240	0.240
Upstream	0.207	0.366	0.138
Vehicle Material & Assembly	0.100	0.121	0.121
Total	0.492	0.727	0.499
NOx			
Vehicle Operation	0.401	0.201	0.201
Upstream	0.774	1.366	0.428
Vehicle Material & Assembly	0.065	0.079	0.079
Total	1.240	1.647	0.708
VOC-Ozone weighted			
Vehicle Operation	0.111	0.206	0.206
Upstream	0.152	0.235	0.161
Vehicle Material & Assembly	0.034	0.041	0.041
Total	0.297	0.482	0.408
SOx			
Vehicle Operation	0.075	0.075	0.075
Upstream	0.545	0.158	0.032
Vehicle Material & Assembly	0.091	0.110	0.110
Total	0.711	0.343	0.216

PM			
Vehicle Operation	0.020	0.004	0.004
Upstream	0.085	0.088	0.020
Vehicle Material & Assembly	0.047	0.057	0.057
Total	0.151	0.149	0.080

4.2 BC POWER GRID

In order to investigate the sensitivity of the emissions performance of the process to the source of electricity several alternative sources of electric power have been considered. The choice of electric power can be made by the user on the Input sheet in cell N236 by using the drop down menu in that cell.

The BC power grid is mostly hydro electric (90%), with some biomass power (6%), some fossil (~4% natural gas), and less than 1% wind at the present time. It has a total carbon intensity of 11,048 g CO_2eq/GJ of electricity delivered.

4.2.1 Lifecycle Energy Balance

The results of the energy balance calculations are shown in the following table. These results are based on the primary energy values and thus they include the energy required to produce the energy actually used at a plant site.

Table 4-7 Energy Balance – BC Grid Scenario

Fuel	Gasoline (Low S)	Methanol	Methanol
Feedstock	Crude oil	NG	CO_2, H_2
	Joules Consumed/Joule Delivered		
Fuel dispensing	0.0019	0.0039	0.0039
Fuel distribution, storage	0.0086	0.0419	0.0222
Fuel production	0.1619	0.3902	1.9457
Feedstock transmission	0.0025	0.0037	0.0000
Feedstock recovery	0.1797	0.0763	0.0000
Ag. chemical manufacture	0.0000	0.0000	0.0000
Co-product credits	-0.0030	0.0000	0.0000
Total	**0.3517**	**0.5161**	**1.9718**
Net Energy Ratio (J delivered/J consumed)	**2.8436**	**1.9375**	**0.5071**

The energy balance numbers for the BC grid scenario are not quite as attractive as for the wind power scenario because about 10% of the power is coming from thermal power sources which have a lower generation efficiency than the assumed 100% value for wind and hydro power.

4.2.2 GHG Emissions

The GHG emissions from the three fuels for this scenario are shown in the following table based on the emissions to produce the fuel plus the emissions that would arise from the combustion of the fuels assuming the same combustion efficiency.

Table 4-8 GHG Emissions – BC Grid Scenario

Fuel	Gasoline (Low S)	Methanol	Methanol
Feedstock	Crude oil	NG	CO_2, H_2
	g CO_2eq/GJ		
Fuel dispensing	20	40	40
Fuel distribution and storage	405	3,299	1,687
Fuel production	11,622	7,768	28,038
Feedstock transmission	81	209	0
Feedstock recovery	11,990	4,144	0
Land-use changes, cultivation	427	0	0
Fertilizer manufacture	0	0	0
Gas leaks and flares	2,582	854	0
CO_2, H_2S removed from NG	0	868	0
Emissions displaced	-198	0	0
Total	26,929	17,182	29,766
Combustion emissions	63,778	59,014	1,911
Grand Total	90,707	76,196	31,670
% Change		-16.0	-65.1

While the GHG emissions for the Blue Fuel process are now higher than in the wind power scenario, the resulting methanol fuel still has a better emissions profile that methanol produced from natural gas or for gasoline.

4.2.2.1 M85 Vehicles

The GHG emissions can also be presented based on distance travelled as the functional unit rather than just using a unit of energy. This approach has the advantage in that that includes any differences in the combustion or conversion efficiency of the fuel in the vehicle. In GHGenius, E85 and M85 vehicles are slightly more efficient that gasoline powered vehicles. In the following table the lifecycle emission results are presented for gasoline, M85 from natural gas and M85 from the Blue Fuel process.

Table 4-9 Lifecycle GHG Emissions Light Duty Vehicles – BC Grid

General fuel	Gasoline	Methanol	Methanol
Fuel spec	RFG30ppm S	M85	Blue Fuel M85
Production process energy	Crude oil	Natural Gas	Wind Energy
	g CO_2eq/km		
Vehicle operation	211.4	190.0	190.0
C in end-use fuel from CO_2 in air	0.0	0.0	-134.6
Net Vehicle Operation	211.4	190.0	55.5
Fuel dispensing	0.1	0.1	0.1
Fuel storage and distribution	1.3	8.1	4.3
Fuel production	38.5	27.5	75.1
Feedstock transport	0.3	0.6	0.1
Feedstock and fertilizer production	41.2	19.6	9.6
Land use changes and cultivation	0.0	0.0	0.3
CH_4 and CO_2 leaks and flares	8.6	6.1	2.1
Emissions displaced by co-products	-0.7	-0.2	-0.2
Sub total (fuel cycle)	300.7	251.9	146.8
% changes (fuel cycle)	0.0	-16.2	-51.3
Vehicle assembly and transport	*4.5*	*4.5*	*4.5*
Materials in vehicles	*27.5*	*27.7*	*27.7*
Grand total	332.7	284.1	179.1
% changes to RFG (grand total)	0.0	-14.6	-46.2

4.2.2.2 M100 HD Vehicles

The results for the M100 vehicles using the BC grid as the source of power are shown in the following table. As with the M85 light duty vehicles, there are still significant reductions in GHG emissions but not as great as with the wind power alternative.

Table 4-10 Lifecycle GHG Emissions Heavy-Duty Vehicles – BC Grid

General fuel	Diesel Fuel	Methanol	Methanol
Fuel spec	15 PPM S	M100	Blue Fuel M100
Production process energy	Crude oil	Natural Gas	Wind Energy
		g CO_2eq/km	
Vehicle operation	1,078.3	996.9	996.9
C in end-use fuel from CO_2 in air	0.0	0.0	-970.2
Net Vehicle Operation	1,078.3	996.9	26.7
Fuel dispensing	0.3	0.6	0.6
Fuel storage and distribution	6.4	53.0	27.1
Fuel production	122.0	124.7	450.2
Feedstock transport	1.3	3.4	0.0
Feedstock and fertilizer production	194.6	66.5	0.0
Land use changes and cultivation	0.0	0.0	0.0
CH_4 and CO_2 leaks and flares	39.5	27.6	0.0
Emissions displaced by co-products	-3.0	0.0	0.0
Sub total (fuel cycle)	1,439.4	1,272.8	504.7
% changes (fuel cycle)	--	-11.6	-64.9
Vehicle assembly and transport	*8.6*	*10.4*	*10.4*
Materials in vehicles	*30.7*	*35.8*	*35.8*
Grand total	1,478.6	1,319.0	550.9
% changes to Diesel Fuel (grand total)		-10.8	-62.7

4.2.3 CAC Emissions

In addition to calculating the GHG emissions from the production and use of various fuels, GHGenius can also report the criteria contaminant emissions for the fuels for each stage of the lifecycle.

4.2.3.1 M85 Vehicles

The CAC emissions for the light duty M85 vehicles are summarized in the following table.

Table 4-11 Lifecycle CAC Emissions Light Duty Vehicles – BC Grid

General fuel	Gasoline	Methanol	Methanol
Fuel spec	RFG30ppm S	M85	Blue Fuel M85
Production process energy	Crude oil	Natural Gas	BC Grid
		g CO_2eq/km	
CO_2 (not including other pollutants)			
Vehicle Operation	207.6	186.4	51.9
Upstream	77.2	54.4	73.8
Vehicle Material & Assembly	31.0	31.2	31.2
Total	315.8	272.1	157.0
% total CO_2-Equiv.	94.9	95.8	87.6
CH_4			
Vehicle Operation	0.021	0.013	0.013
Upstream	0.436	0.251	0.491
Vehicle Material & Assembly	0.032	0.033	0.033
Total	0.490	0.297	0.537
% total CO_2-Equiv.	3.683	2.611	7.496
N_2O			
Vehicle Operation	0.011	0.011	0.011
Upstream	0.004	0.004	0.018
Vehicle Material & Assembly	0.001	0.001	0.001
Total	0.015	0.015	0.029
% total CO_2-Equiv.	1.385	1.606	4.867
Total CO_2 Equiv.	**332.7**	**284.1**	**179.0**
CFCs + HFCs			
Vehicle Operation	0.002	0.002	0.002
Upstream	0.000	0.000	0.000
Vehicle Material & Assembly	0.000	0.000	0.000
Total	0.002	0.002	0.002
CO			
Vehicle Operation	10.861	7.620	7.620
Upstream	0.051	0.066	0.032
Vehicle Material & Assembly	0.017	0.017	0.017
Total	10.929	7.703	7.670
NOx			
Vehicle Operation	0.218	0.202	0.202
Upstream	0.185	0.244	0.107
Vehicle Material & Assembly	0.048	0.048	0.048
Total	0.451	0.495	0.357
VOC-Ozone weighted			
Vehicle Operation	0.244	0.125	0.125
Upstream	0.106	0.060	0.070
Vehicle Material & Assembly	0.018	0.019	0.019
Total	0.369	0.203	0.213
SOx			
Vehicle Operation	0.018	0.016	0.016
Upstream	0.124	0.053	0.035
Vehicle Material & Assembly	0.068	0.069	0.069
Total	0.210	0.138	0.120
PM			
Vehicle Operation	0.014	0.008	0.008
Upstream	0.022	0.018	0.008
Vehicle Material & Assembly	0.031	0.032	0.032
Total	0.068	0.058	0.048

4.2.3.2 *M100 HD Vehicles*

The CAC emission results are shown in the following table for the BC grid power mix and the heavy-duty vehicle application. As with the light duty case, the CAC emissions with the Blue Fuel process are considerably better than with diesel fuel or natural gas produced methanol.

Table 4-12 Lifecycle CAC Emissions Heavy-Duty Vehicles – BC Grid

General fuel	Diesel	Methanol	Methanol
Fuel spec	15 ppm S	M100	Blue Fuel M100
Production process energy	Crude oil	Natural Gas	BC Grid
	g CO_2eq/km		
CO_2 (not including other pollutants)			
Vehicle Operation	1,063.0	981.5	11.3
Upstream	308.1	245.2	377.8
Vehicle Material & Assembly	38.0	44.7	44.7
Total	1,409.1	1,271.4	433.8
% total CO2-Equiv.	95.3	96.4	78.8
CH_4			
Vehicle Operation	0.067	0.067	0.067
Upstream	1.939	0.995	2.638
Vehicle Material & Assembly	0.038	0.046	0.046
Total	2.043	1.108	2.750
% total CO2-Equiv.	3.5	2.1	12.5
N_2O			
Vehicle Operation	0.046	0.046	0.046
Upstream	0.015	0.019	0.115
Vehicle Material & Assembly	0.001	0.001	0.001
Total	0.062	0.067	0.162
% total CO_2-Equiv.	1.2	1.5	8.8
Total CO_2 Equiv.	**1,478.6**	**1,319.0**	**550.9**
CFCs + HFCs			
Vehicle Operation	0.001	0.001	0.001
Upstream	0.000	0.000	0.000
Vehicle Material & Assembly	0.000	0.000	0.000
Total	0.001	0.001	0.001
CO			
Vehicle Operation	0.184	0.240	0.240
Upstream	0.207	0.366	0.138
Vehicle Material & Assembly	0.100	0.121	0.121
Total	0.492	0.727	0.499
NOx			
Vehicle Operation	0.401	0.201	0.201
Upstream	0.774	1.366	0.428
Vehicle Material & Assembly	0.065	0.079	0.079
Total	1.240	1.647	0.708
VOC-Ozone weighted			
Vehicle Operation	0.111	0.206	0.206
Upstream	0.152	0.235	0.161
Vehicle Material & Assembly	0.034	0.041	0.041
Total	0.297	0.482	0.408
SOx			
Vehicle Operation	0.075	0.075	0.075
Upstream	0.545	0.158	0.032
Vehicle Material & Assembly	0.091	0.110	0.110
Total	0.711	0.343	0.216

PM			
Vehicle Operation	0.020	0.004	0.004
Upstream	0.085	0.088	0.020
Vehicle Material & Assembly	0.047	0.057	0.057
Total	0.151	0.149	0.080

4.3 ALBERTA POWER GRID

The issue with the BC power mix is that BC is currently an importer of electricity and thus extra load in the province is met through increased efficiency of the existing load or imported power. Details on the source of imported power are not readily available and the source does vary as prices change but some power is imported from Alberta and thus an estimate of the emissions from the process using the Alberta power mix is appropriate.

The Alberta power is more than 90% thermal power, with coal making up almost 60% of the mix, high efficiency sources like wind and hydro only make up about 6% of the Alberta power mix. It has a carbon intensity of 241,200 g CO_2eq/GJ delivered.

4.3.1 Lifecycle Energy Balance

The overall lifecycle energy balance for the production of methanol from the Blue Fuel system is compared in the following table to the energy balance for methanol produced by natural gas and to gasoline produced from crude oil. The natural gas methanol is assumed to be produced offshore and transported to the market by ocean tanker.

Table 4-13 Energy Balance – Alberta Grid Scenario

Fuel	Gasoline (Low S)	Methanol	Methanol
Feedstock	Crude oil	NG	CO_2, H_2
	Joules Consumed/Joule Delivered		
Fuel dispensing	0.0019	0.0039	0.0039
Fuel distribution, storage	0.0086	0.0419	0.0222
Fuel production	0.1619	0.3902	4.3354
Feedstock transmission	0.0025	0.0037	0.0000
Feedstock recovery	0.1797	0.0763	0.0000
Ag. chemical manufacture	0.0000	0.0000	0.0000
Co-product credits	-0.0030	0.0000	0.0000
Total	**0.3517**	**0.5161**	**4.3615**
Net Energy Ratio (J delivered/J consumed)	**2.8436**	**1.9375**	**0.2293**

The lower efficiency (as a result of the higher proportion of thermal power) of the Alberta power system is apparent in this table, as the overall lifecycle energy efficiency is much lower than the two previous scenarios.

4.3.2 GHG Emissions

The GHG emissions from the three fuels for this scenario are shown in the following table based on the emissions to produce the fuel plus the emissions that would arise from the combustion of the fuels assuming the same combustion efficiency.

Table 4-14 GHG Emissions – Alberta Grid Scenario

Fuel	Gasoline (Low S)	Methanol	Methanol
Feedstock	Crude oil	NG	CO_2, H_2
	g CO_2eq/GJ		
Fuel dispensing	20	40	40
Fuel distribution and storage	405	3,299	1,687
Fuel production	11,622	7,768	412,920
Feedstock transmission	81	209	0
Feedstock recovery	11,990	4,144	0
Land-use changes, cultivation	427	0	0
Fertilizer manufacture	0	0	0
Gas leaks and flares	2,582	854	0
CO_2, H_2S removed from NG	0	868	0
Emissions displaced	-198	0	0
Total	26,929	17,182	414,648
Combustion emissions	63,778	59,014	1,911
Grand Total	90,707	76,196	416,559
% Change		-16.0	+359

This mix of electric power increases the GHG emissions dramatically. The process would result in GHG emissions that are much higher the natural gas produced methanol or the gasoline system.

4.3.2.1 M85 Vehicles

The GHG emissions can also be presented based on distance travelled as the functional unit rather than just using a unit of energy. This approach has the advantage in that that includes any differences in the combustion or conversion efficiency of the fuel in the vehicle. In GHGenius, E85 and M85 vehicles are slightly more efficient that gasoline powered vehicles. In the following table the lifecycle emission results are presented for gasoline, M85 from natural gas and M85 from the Blue Fuel process using electricity from the Alberta grid. As expected from the previous table there is a significant increase in GHG emissions.

Table 4-15 Lifecycle GHG Emissions Light Duty Vehicles – Alberta Grid

General fuel	Gasoline	Methanol	Methanol
Fuel spec	RFG30ppm S	M85	Blue Fuel M85
Production process energy	Crude oil	Natural Gas	Alberta Grid
	g CO_2eq/km		
Vehicle operation	211.4	190.0	190.0
C in end-use fuel from CO_2 in air	0.0	0.0	-134.6
Net Vehicle Operation	211.4	190.0	55.5
Fuel dispensing	0.1	0.1	0.1
Fuel storage and distribution	1.3	8.1	4.3
Fuel production	38.5	27.5	978.4
Feedstock transport	0.3	0.6	0.1
Feedstock and fertilizer production	41.2	19.6	9.6
Land use changes and cultivation	0.0	0.0	0.3
CH_4 and CO_2 leaks and flares	8.6	6.1	2.1
Emissions displaced by co-products	-0.7	-0.2	-0.2
Sub total (fuel cycle)	300.7	251.9	1,050.1
% changes (fuel cycle)	0.0	-16.2	248.2
Vehicle assembly and transport	*4.5*	*4.5*	*4.5*
Materials in vehicles	*27.5*	*27.7*	*27.7*
Grand total	332.7	284.1	1,082.4
% changes to RFG (grand total)	0.0	-14.6	224.4

4.3.2.2 M100 HD Vehicles

When the fuel is used in heavy-duty vehicles the emissions results are not attractive as shown in the following table.

Table 4-16 Lifecycle GHG Emissions Heavy-Duty Vehicles-Alberta Grid

General fuel	Diesel Fuel	Methanol	Methanol
Fuel spec	15 PPM S	M100	Blue Fuel M100
Production process energy	Crude oil	Natural Gas	Alberta Grid
		g CO_2eq/km	
Vehicle operation	1,078.3	996.9	996.9
C in end-use fuel from CO_2 in air	0.0	0.0	-970.2
Net Vehicle Operation	1,078.3	996.9	26.7
Fuel dispensing	0.3	0.6	0.6
Fuel storage and distribution	6.4	53.0	27.1
Fuel production	122.0	124.7	6,629.9
Feedstock transport	1.3	3.4	0.0
Feedstock and fertilizer production	194.6	66.5	0.0
Land use changes and cultivation	0.0	0.0	0.0
CH_4 and CO_2 leaks and flares	39.5	27.6	0.0
Emissions displaced by co-products	-3.0	0.0	0.0
Sub total (fuel cycle)	1,439.4	1,272.8	6,684.4
% changes (fuel cycle)	--	-11.6	364.4
Vehicle assembly and transport	*8.6*	*10.4*	*10.4*
Materials in vehicles	*30.7*	*35.8*	*35.8*
Grand total	1,478.6	1,319.0	6,730.6
% changes to Diesel Fuel (grand total)		-10.8	355.2

4.3.3 CAC Emissions

In addition to calculating the GHG emissions from the production and use of various fuels, GHGenius can also report the criteria contaminant emissions for the fuels for each stage of the lifecycle.

4.3.3.1 M85 Vehicles

The CAC emissions for the light duty M85 vehicles using fuel produced from the Alberta grid are summarized in the following table

Table 4-17 Lifecycle CAC Emissions Light Duty Vehicles – Alberta Grid

General fuel	Gasoline	Methanol	Methanol
Fuel spec	RFG30ppm S	M85	Blue Fuel M85
Production process energy	Crude oil	Natural Gas	Alberta Grid
		g CO_2eq/km	
CO_2 (not including other pollutants)			
Vehicle Operation	207.634	186.437	51.9
Upstream	77.178	54.448	965.4
Vehicle Material & Assembly	31.018	31.199	31.2
Total	315.831	272.084	1048.5
% total CO_2-Equiv.	94.933	95.782	96.9
CH_4			
Vehicle Operation	0.021	0.013	0.013
Upstream	0.436	0.251	0.944
Vehicle Material & Assembly	0.032	0.033	0.033
Total	0.490	0.297	0.990
% total CO_2-Equiv.	3.683	2.611	2.287
N_2O			
Vehicle Operation	0.011	0.011	0.011
Upstream	0.004	0.004	0.019
Vehicle Material & Assembly	0.001	0.001	0.001
Total	0.015	0.015	0.030
% total CO_2-Equiv.	1.385	1.606	0.839
Total CO_2 Equiv.	332.689	284.064	1,082.4
CFCs + HFCs			
Vehicle Operation	0.002	0.002	0.002
Upstream	0.000	0.000	0.000
Vehicle Material & Assembly	0.000	0.000	0.000
Total	0.002	0.002	0.002
CO			
Vehicle Operation	10.861	7.620	7.620
Upstream	0.051	0.066	0.032
Vehicle Material & Assembly	0.017	0.017	0.017
Total	10.929	7.703	7.670
NOx			
Vehicle Operation	0.218	0.202	0.202
Upstream	0.185	0.244	0.107
Vehicle Material & Assembly	0.048	0.048	0.048
Total	0.451	0.495	0.357
VOC-Ozone weighted			
Vehicle Operation	0.244	0.125	0.125
Upstream	0.106	0.060	0.070
Vehicle Material & Assembly	0.018	0.019	0.019
Total	0.369	0.203	0.213
SOx			
Vehicle Operation	0.018	0.016	0.016
Upstream	0.124	0.053	0.035
Vehicle Material & Assembly	0.068	0.069	0.069
Total	0.210	0.138	0.120
PM			
Vehicle Operation	0.014	0.008	0.008
Upstream	0.022	0.018	0.008
Vehicle Material & Assembly	0.031	0.032	0.032
Total	0.068	0.058	0.047

4.3.3.2 M100 HD Vehicles

The CAC emissions for the M100 heavy-duty vehicle application are shown in the following table.

Table 4-18 Lifecycle CAC Emissions Heavy-Duty Vehicles – Alberta Grid

General fuel	Diesel	Methanol	Methanol
Fuel spec	15 ppm S	M100	Blue Fuel M100
Production process energy	Crude oil	Natural Gas	Wind Energy
		g CO_2eq/km	
CO_2 (not including other pollutants)			
Vehicle Operation	1,063.0	981.5	11.3
Upstream	308.1	245.2	6,477.5
Vehicle Material & Assembly	38.0	44.7	44.7
Total	1,409.1	1,271.4	6,533.6
% total CO2-Equiv.	95.3	96.4	97.1
CH_4			
Vehicle Operation	0.067	0.067	0.067
Upstream	1.939	0.995	5.738
Vehicle Material & Assembly	0.038	0.046	0.046
Total	2.043	1.108	5.851
% total CO2-Equiv.	3.5	2.1	2.2
N_2O			
Vehicle Operation	0.046	0.046	0.046
Upstream	0.015	0.019	0.123
Vehicle Material & Assembly	0.001	0.001	0.001
Total	0.062	0.067	0.170
% total CO_2-Equiv.	1.2	1.5	0.8
Total CO_2 Equiv.	1,478.6	1,319.0	6,730.6
CFCs + HFCs			
Vehicle Operation	0.001	0.001	0.001
Upstream	0.000	0.000	0.000
Vehicle Material & Assembly	0.000	0.000	0.000
Total	0.001	0.001	0.001
CO			
Vehicle Operation	0.184	0.240	0.240
Upstream	0.207	0.366	0.138
Vehicle Material & Assembly	0.100	0.121	0.121
Total	0.492	0.727	0.499
NOx			
Vehicle Operation	0.401	0.201	0.201
Upstream	0.774	1.366	0.428
Vehicle Material & Assembly	0.065	0.079	0.079
Total	1.240	1.647	0.708
VOC-Ozone weighted			
Vehicle Operation	0.111	0.206	0.206
Upstream	0.152	0.235	0.161
Vehicle Material & Assembly	0.034	0.041	0.041
Total	0.297	0.482	0.408
SOx			
Vehicle Operation	0.075	0.075	0.075
Upstream	0.545	0.158	0.032
Vehicle Material & Assembly	0.091	0.110	0.110
Total	0.711	0.343	0.216
PM			

Vehicle Operation	0.020	0.004	0.004
Upstream	0.085	0.088	0.020
Vehicle Material & Assembly	0.047	0.057	0.057
Total	0.151	0.149	0.080

4.4 NATURAL GAS POWER

In many regions of Canada combined cycle natural gas power plants are the marginal supply of electric power so a scenario has been run using natural to produce the electricity. It has been assumed that the efficiency of the natural gas power is 45%.

4.4.1 Lifecycle Energy Balance

The overall lifecycle energy balance for the production of methanol from the Blue Fuel system is compared in the following table to the energy balance for methanol produced by natural gas and to gasoline produced from crude oil. The natural gas methanol is assumed to be produced offshore and transported to the market by ocean tanker.

Table 4-19 Energy Balance – Natural Gas Power Scenario

Fuel	Gasoline (Low S)	Methanol	Methanol
Feedstock	Crude oil	NG	CO_2, H_2
	Joules Consumed/Joule Delivered		
Fuel dispensing	0.0019	0.0039	0.0039
Fuel distribution, storage	0.0086	0.0419	0.0222
Fuel production	0.1619	0.3902	3.8827
Feedstock transmission	0.0025	0.0037	0.0000
Feedstock recovery	0.1797	0.0763	0.0000
Ag. chemical manufacture	0.0000	0.0000	0.0000
Co-product credits	-0.0030	0.0000	0.0000
Total	**0.3517**	**0.5161**	**3.9088**
Net Energy Ratio (J delivered/J consumed)	**2.8436**	**1.9375**	**0.2558**

The system has a higher efficiency than the Alberta grid scenario but the lifecycle energy efficiency is still quite low due to the combination of the efficiency of power production and the electrolysis efficiency.

4.4.2 GHG Emissions

The GHG emissions from the three fuels for this scenario are shown in the following table based on the emissions to produce the fuel plus the emissions that would arise from the combustion of the fuels assuming the same combustion efficiency.

Table 4-20 GHG Emissions – Natural Gas Power Scenario

Fuel	Gasoline (Low S)	Methanol	Methanol
Feedstock	Crude oil	NG	CO_2, H_2
	g CO_2eq/GJ		
Fuel dispensing	20	40	40
Fuel distribution and storage	405	3,299	1,687
Fuel production	11,622	7,768	215,296
Feedstock transmission	81	209	0
Feedstock recovery	11,990	4,144	0
Land-use changes, cultivation	427	0	0
Fertilizer manufacture	0	0	0
Gas leaks and flares	2,582	854	0
CO_2, H_2S removed from NG	0	868	0
Emissions displaced	-198	0	0
Total	26,929	17,182	217,024
Combustion emissions	63,778	59,014	1,911
Grand Total	90,707	76,196	218,935
% Change		-16.0	+141

The GHG emissions using this source of electric power are significantly higher than the direct natural gas to methanol route or from the production and use of gasoline.

4.4.2.1 M85 Vehicles

The GHG emissions can also be presented based on distance travelled as the functional unit rather than just using a unit of energy. This approach has the advantage in that that includes any differences in the combustion or conversion efficiency of the fuel in the vehicle. In GHGenius, E85 and M85 vehicles are slightly more efficient that gasoline powered vehicles. In the following table the lifecycle emission results are presented for gasoline, M85 from natural gas and M85 from the Blue Fuel process.

Table 4-21 Lifecycle GHG Emissions Light Duty Vehicles– Natural Gas Power

General fuel	Gasoline	Methanol	Methanol
Fuel spec	RFG30ppm S	M85	Blue Fuel M85
Production process energy	Crude oil	Natural Gas	Natural Gas Power
	g CO_2eq/km		
Vehicle operation	211.4	190.0	190.0
C in end-use fuel from CO_2 in air	0.0	0.0	-134.6
Net Vehicle Operation	211.4	190.0	55.5
Fuel dispensing	0.1	0.1	0.1
Fuel storage and distribution	1.3	8.1	4.3
Fuel production	38.5	27.5	514.6
Feedstock transport	0.3	0.6	0.1
Feedstock and fertilizer production	41.2	19.6	9.6
Land use changes and cultivation	0.0	0.0	0.3
CH_4 and CO_2 leaks and flares	8.6	6.1	2.1
Emissions displaced by co-products	-0.7	-0.2	-0.2
Sub total (fuel cycle)	300.7	251.9	586.3
% changes (fuel cycle)	0.0	-16.2	94.4
Vehicle assembly and transport	*4.5*	*4.5*	*4.5*
Materials in vehicles	*27.5*	*27.7*	*27.7*
Grand total	332.7	284.1	618.5
% changes to RFG (grand total)	0.0	-14.6	85.9

4.4.2.2 M100 HD Vehicles

Table 4-22 Lifecycle GHG Emissions Heavy-Duty Vehicles– Natural Gas Power

General fuel	Diesel Fuel	Methanol	Methanol
Fuel spec	15 PPM S	M100	Blue Fuel M100
Production process energy	Crude oil	Natural Gas	Natural Gas Power
	g CO_2eq/km		
Vehicle operation	1,078.3	996.9	996.9
C in end-use fuel from CO_2 in air	0.0	0.0	-970.2
Net Vehicle Operation	1,078.3	996.9	26.7
Fuel dispensing	0.3	0.6	0.6
Fuel storage and distribution	6.4	53.0	27.1
Fuel production	122.0	124.7	3,456.8
Feedstock transport	1.3	3.4	0.0
Feedstock and fertilizer production	194.6	66.5	0.0
Land use changes and cultivation	0.0	0.0	0.0
CH_4 and CO_2 leaks and flares	39.5	27.6	0.0
Emissions displaced by co-products	-3.0	0.0	0.0
Sub total (fuel cycle)	1,439.4	1,272.8	3,511.3
% changes (fuel cycle)	--	-11.6	143.9
Vehicle assembly and transport	*8.6*	*10.4*	*10.4*
Materials in vehicles	*30.7*	*35.8*	*35.8*
Grand total	1,478.6	1,319.0	3,557.5
% changes to Diesel Fuel (grand total)		-10.8	140.6

4.4.3 CAC Emissions

In addition to calculating the GHG emissions from the production and use of various fuels, GHGenius can also report the criteria contaminant emissions for the fuels for each stage of the lifecycle.

4.4.3.1 M85 Vehicles

The CAC emissions for the light duty M85 vehicles are summarized in the following table.

Table 4-23 Lifecycle CAC Emissions Light Duty Vehicles– Natural Gas Power

General fuel	Gasoline	Methanol	Methanol
Fuel spec	RFG30ppm S	M85	Blue Fuel M85
Production process energy	Crude oil	Natural Gas	Natural Gas Power
	g CO_2eq/km		
CO_2 (not including other pollutants)			
Vehicle Operation	207.634	186.437	51.9
Upstream	77.178	54.448	518.6
Vehicle Material & Assembly	31.018	31.199	31.2
Total	315.831	272.084	601.7
% total CO_2-Equiv.	94.933	95.782	97.3
CH_4			
Vehicle Operation	0.021	0.013	0.013
Upstream	0.436	0.251	0.174
Vehicle Material & Assembly	0.032	0.033	0.033
Total	0.490	0.297	0.220
% total CO_2-Equiv.	3.683	2.611	0.889
N_2O			
Vehicle Operation	0.011	0.011	0.011
Upstream	0.004	0.004	0.026
Vehicle Material & Assembly	0.001	0.001	0.001
Total	0.015	0.015	0.038
% total CO_2-Equiv.	1.385	1.606	1.827
Total CO_2 Equiv.	332.689	284.064	618.5
CFCs + HFCs			
Vehicle Operation	0.002	0.002	0.002
Upstream	0.000	0.000	0.000
Vehicle Material & Assembly	0.000	0.000	0.000
Total	0.002	0.002	0.002
CO			
Vehicle Operation	10.861	7.620	7.620
Upstream	0.051	0.066	0.032
Vehicle Material & Assembly	0.017	0.017	0.017
Total	10.929	7.703	7.670
NOx			
Vehicle Operation	0.218	0.202	0.202
Upstream	0.185	0.244	0.107
Vehicle Material & Assembly	0.048	0.048	0.048
Total	0.451	0.495	0.357
VOC-Ozone weighted			
Vehicle Operation	0.244	0.125	0.125
Upstream	0.106	0.060	0.070
Vehicle Material & Assembly	0.018	0.019	0.019
Total	0.369	0.203	0.213
SOx			
Vehicle Operation	0.018	0.016	0.016
Upstream	0.124	0.053	0.035
Vehicle Material & Assembly	0.068	0.069	0.069
Total	0.210	0.138	0.120
PM			
Vehicle Operation	0.014	0.008	0.008
Upstream	0.022	0.018	0.008
Vehicle Material & Assembly	0.031	0.032	0.032
Total	0.068	0.058	0.048

4.4.3.2 M100 HD Vehicles

The CAC emission results for the M100 vehicle and the natural gas power scenario are shown in the following table.

Table 4-24 Lifecycle CAC Emissions Heavy-Duty Vehicles– Natural Gas Power

General fuel	Diesel	Methanol	Methanol
Fuel spec	15 ppm S	M100	Blue Fuel M100
Production process energy	Crude oil	Natural Gas	Natural Gs Power
		g CO_2eq/km	
CO_2 (not including other pollutants)			
Vehicle Operation	1,063.0	981.5	11.3
Upstream	308.1	245.2	3,420.9
Vehicle Material & Assembly	38.0	44.7	44.7
Total	1,409.1	1,271.4	3,477.0
% total CO2-Equiv.	95.3	96.4	97.7
CH_4			
Vehicle Operation	0.067	0.067	0.067
Upstream	1.939	0.995	0.470
Vehicle Material & Assembly	0.038	0.046	0.046
Total	2.043	1.108	0.583
% total CO2-Equiv.	3.5	2.1	0.4
N_2O			
Vehicle Operation	0.046	0.046	0.046
Upstream	0.015	0.019	0.174
Vehicle Material & Assembly	0.001	0.001	0.001
Total	0.062	0.067	0.221
% total CO_2-Equiv.	1.2	1.5	1.9
Total CO_2 Equiv.	1,478.6	1,319.0	3,557.5
CFCs + HFCs			
Vehicle Operation	0.001	0.001	0.001
Upstream	0.000	0.000	0.000
Vehicle Material & Assembly	0.000	0.000	0.000
Total	0.001	0.001	0.001
CO			
Vehicle Operation	0.184	0.240	0.240
Upstream	0.207	0.366	0.138
Vehicle Material & Assembly	0.100	0.121	0.121
Total	0.492	0.727	0.499
NOx			
Vehicle Operation	0.401	0.201	0.201
Upstream	0.774	1.366	0.428
Vehicle Material & Assembly	0.065	0.079	0.079
Total	1.240	1.647	0.708
VOC-Ozone weighted			
Vehicle Operation	0.111	0.206	0.206
Upstream	0.152	0.235	0.161
Vehicle Material & Assembly	0.034	0.041	0.041
Total	0.297	0.482	0.408
SOx			
Vehicle Operation	0.075	0.075	0.075
Upstream	0.545	0.158	0.032
Vehicle Material & Assembly	0.091	0.110	0.110
Total	0.711	0.343	0.216
PM			

Vehicle Operation	0.020	0.004	0.004
Upstream	0.085	0.088	0.020
Vehicle Material & Assembly	0.047	0.057	0.057
Total	0.151	0.149	0.080

5. DISCUSSION

A special GHGenius model has been developed to project the lifecycle energy balance, GHG and CAC emissions. The model is flexible and it can model a wide range of types of electric power that would be used in the process. A number of scenarios have been evaluated and it is apparent that the source of electrical energy that is used in the process strongly influences all of the results.

The overall primary energy balance of the process is strongly influenced by how the electric power is produced. The results from the four scenarios that have been evaluated are summarized in the following table.

Table 5-1 Energy Balance Summary

Fuel	Methanol			
Feedstock	CO_2, H_2			
Power Source	Wind	BC Grid	Alberta Grid	Natural Gas
	Joules Consumed/Joule Delivered			
Fuel dispensing	0.0039	0.0039	0.0039	0.0039
Fuel distribution, storage	0.0222	0.0222	0.0222	0.0222
Fuel production	1.8316	1.9457	4.3354	3.8827
Feedstock transmission	0.0000	0.0000	0.0000	0.0000
Feedstock recovery	0.0000	0.0000	0.0000	0.0000
Ag. chemical manufacture	0.0000	0.0000	0.0000	0.0000
Co-product credits	0.0000	0.0000	0.0000	0.0000
Total	**1.8577**	**1.9718**	**4.3615**	**3.9088**
Net Energy Ratio (J delivered/J consumed)	**0.5383**	**0.5071**	**0.2293**	**0.2558**

The wind power scenario is closest to a secondary energy balance where the energy required to produce the energy is not include. This is the best measure of the efficiency of the process itself and in this case is influenced mostly by the efficiency of hydrogen production from electrolysis. When other sources of electricity are considered the overall energy efficiency drops considerably. The natural gas scenario is not as efficient as just producing the methanol directly from natural gas and thus it can be expected that this route would have higher GHG emissions than the direct natural gas to methanol route (and probably less attractive economics).

The GHG emissions from the process are related to the energy consumption and reflect both the quantity of energy used and the carbon intensity of the different energy sources. In the following table, the GHG emissions of the four scenarios considered are compared. The lifecycle GHG emissions are attractive when Wind Power or the BC Grid power are used but if Alberta power or natural gas derived power were used, the emissions are higher than they are for gasoline or methanol produced from natural gas.

Table 5-2 GHG Emission Summary

Fuel	Methanol			
Feedstock	CO_2, H_2			
	Wind	BC Grid	Alberta Grid	Natural Gas
	g CO_2eq/GJ			
Fuel dispensing	40	40	40	40
Fuel distribution and storage	1,687	1,687	1,687	1,687
Fuel production	10,631	28,038	412,920	215,296
Feedstock transmission	0	0	0	0
Feedstock recovery	0	0	0	0
Land-use changes, cultivation	0	0	0	0
Fertilizer manufacture	0	0	0	0
Gas leaks and flares	0	0	0	0
CO_2, H_2S removed from NG	0	0	0	0
Emissions displaced	0	0	0	0
Total	12,359	29,766	414,648	217,024
Combustion emissions	1,911	1,911	1,911	1,911
Grand Total	14,271	31,670	416,559	218,935
% Change	-84.3	-65.1	+359	+141

The modelling results from the scenarios considered are not that different from other electricity based transportation fuels such as electric vehicles or fuel cells power by electrolytic hydrogen. In some locations in Canada, these pathways produce better GHG emissions than gasoline and in other regions; there is little or no benefit.

References

(S&T)[2] Consultants Inc. 2009. The Development of Provincial Inputs for GHGenius. Prepared for Natural Resources Canada. March 2009. http://www.ghgenius.ca/reports/ProvincialModelsFinalReport.pdf

(S&T)[2] Consultants Inc. 2006. Construction Emissions. March 2006. http://www.ghgenius.ca/reports/ConstructionEmissions.pdf

INDEX TO SHEETS IN THE SPREADSHEET

SUB-LICENCE AGREEMENT FOR GHGENIUS

Sub-licence granted as of September 17, 2004

PLEASE READ THIS SUB-LICENCE AGREEMENT FOR THE USE OF GHGENIUS AND RELATED DOCUMENTATION CAREFULLY BEFORE PRESSING THE "I AGREE" BUTTON BELOW. BY PRESSING "I AGREE", YOU AGREE TO BE BOUND BY THE TERMS OF THIS AGREEMENT. IF YOU DO NOT AGREE TO THE TERMS OF THIS AGREEMENT, PRESS "I DISAGREE", IN WHICH CASE THE APPLICATION WILL CLOSE.

This is a legal agreement between you ("Licensee") and Her Majesty the Queen in Right of Canada ("Canada") as represented by the Minister of Natural Resources Canada ("Licensor"). BY ACCESSING, PRINTING OR USING GHGENIUS, RELATED DOCUMENTATION AND INFORMATION, IT MEANS THAT YOU ARE AGREEING TO BE BOUND BY THE TERMS OF THIS AGREEMENT. IF YOU DO NOT AGREE TO THE TERMS OF THIS AGREEMENT, YOU MUST IMMEDIATELY DISPOSE OF ANY SUCH GHGENIUS, RELATED DOCUMENTATION AND INFORMATION AND ANY DERIVED PRODUCTS.

I WHEREAS GHGenius is used to systematically evaluate the lifecycle energy balances, and emissions of greenhouse gases and common air contaminants of existing and potential transportation fuels. The results from the evaluation can be used for a variety of uses including: comparing the environmental impacts of different fuels on a common basis, improving the environmental performance of fuels by identifying the emissions associated with each stage of the fuel production cycle and making appropriate changes to the production process, identifying shifts in environmental impacts between life cycle stages, quantifying environmental releases from the production and use of transportation fuels.

II AND WHEREAS GHGenius and Related Documentation are hereinafter referred to in this Sub -licence Agreement as "the Material";

III AND WHEREAS the Licensee wishes to obtain the right to use the Material on terms and conditions herein contained;

IV AND WHEREAS Canada represents that it has the authority to grant the rights desired by the Licensee on the terms and conditions herein contained;

V AND WHEREAS the parties are desirous of entering into a sub-licence agreement on the basis herein set forth.

NOW THEREFORE, in consideration of the covenants contained in this Agreement, the parties agree as follows:

1 DEFINITIONS

1.1 "GHGenius" means the entire or any part of the Excel spreadsheet application, including all codes and scripts developed or drafted for that spreadsheet application, if any;

1.2 "Derivative Products" means any product, system, sub-system, device, component, material or software that incorporates, derives from or uses any part of GHGenius;

1.3 "Initial Holders" means the licensors who have signed a licence agreement with Canada for the use of GHGenius and Related Documentation and all other person that may have lawfull ownership title of intellectual property rights in GHGenius and LEM;

1.4 "Intellectual Property Rights" means any intellectual property right recognised by law, including any intellectual property right protected through legislation, such as that governing, but not limited to, copyright and patents;

1.5 "LEM" means the lifecycle emissions model which is the basis model for GHGenius;

1.6 "Licensor" means the Government of Canada, the Minister of Natural Resources and includes any duly authorized officers, representatives, employees and agents.

1.7 "Related Documentation" means the documents, reports and studies with respect to GHGenius posted on this website;

2 SUB-LICENCE GRANT

2.1 Subject to this Agreement, Canada hereby grants to the Licensee a non-exclusive, non-transferable, royalty free sub-licence to use the Material for personal purpose only.

2.2 Canada provides limited personal permission for the Licensee to use the Material. The use of the Material is limited in that you may not:

2.2.1 Use, download or print Material for commercial purposes such as selling, creating course packets or posting information on Web sites.

2.2.2 Make multiple copies, publish or distribute or transmit the Material for public purposes.

2.2.3 Modify, incorporate, translate, adapt, improve, further develop, manufacture in whole or in part the Material.

2.2.4 Transfer or sublicense in whole or in part, the Material or otherwise assign any rights under this Agreement to any third party without the written permission of the Licensor.

2.2.5 Change or delete propriety notices from Material.

2.2.6 Post or transmit any unlawful, threatening, libelous, defamatory, obscene, scandalous, inflammatory, pornographic or profane material, any propriety information belonging to others or any material that could be deemed as or encourage criminal activity, give rise to civil liability or otherwise violate the

2.2.7 Use the Web site in a manner contrary to any applicable law.

3 PROTECTION OF INITIAL HOLDER(S)

	A	B	C
46		3.1	The original version of GHGenius was based in part on the Lifecycle Emissions Model (LEM) developed by Dr. Mark A. Delucchi. Information on the LEM can be found at Dr. Delucchi's web site (www.its.ucd.edu/faculty/delucchi.htm).
47		3.2	This sub-licence is produced under licences to Canada from Levelton Consultants Ltd. and from S&T Squared Consultants Inc.
48		3.3	The Licensee should assume that everything seen or read on the Material is copyrighted unless otherwise noted.
49		3.4	The Licensee should ensure that Initial Holders, the Licensor or the content originator have given their written permission to the Licensee to allow reproduction of their information.
50		3.5	The name of an Initial Holders shall NOT be used for any purpose without specific prior written authorization of the Initial Holders or the Licensor.
51		3.6	Licensee agrees that title to Intellectual Property Rights in the Material shall at all times remain with the Initial Holders or the Licensor. The Licensee shall have no right, title and interest therein or thereto except as expressly set forth in this Agreement.
52		3.7	The Intellectual Property Rights arising from any modification, improvement, development, adaptation or translation of any part of the GHGenius or from the manufacture of GHGenius or Derivative Products, effected by or for the Initial Holders, the Licensor or the Licensee shall be vested in the Initial Holders or the Licensor or in such person as the Initial Licensors or the Licensor shall decide.
53		3.8	IN NO EVENT SHALL THE INITIAL HOLDERS BE LIABLE FOR ANY CLAIM, OR ANY DIRECT, INDIRECT, SPECIAL OR CONSEQUENTIAL DAMAGES, OR ANY DAMAGES WHATSOEVER (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWSOEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN AN ACTION OF CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF OR IN CONNECTION WITH THE MATERIAL OR THE USEOF THE MATERIAL, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.
54		**4**	**OBLIGATIONS OF THE LICENSEE**
56		4.1	The Licensee shall be responsible for obtaining all that is required to run GHGenius.
57		4.2	The Licensee shall provide the Licensor with complete and accurate contact information including name, organization name, and e-mail address in order to facilitate communication of information relating to the Material.
58		4.3	The Licensee shall not make any statement or representation indicating that the Licensor endorses or approves any recommendation, study, report, product, service or other course of action as a result of the Licensee's use of the Material.
60		**5**	**MAINTENANCE AND SUPPORT**
62		5.1	It is understood and agreed that the Licensor is under no obligation to provide support for installation, conversion, training, technical support, maintenance services, update services, notices of latent defects, or correction of defects for GHGenius.
64		**6**	**DISCLAIMERS, WARRANTY, LIABILITY**
66		6.1	GHGENIUS IS SUB-LICENSED ON AN "AS IS" BASIS AND THE LICENSOR MAKES NO GUARANTEES, REPRESENTATIONS, OR WARRANTIES OF ANY KIND RESPECTING GHGENIUS AND THE MATERIAL, EITHER EXPRESS OR IMPLIED, ARISING BY LAW OR OTHERWISE, INCLUDING BUT NOT LIMITED TO USEFULNESS, NOVELTY, SCOPE, EFFECTIVENESS, COMPLETENESS, ACCURACY, OR FITNESS FOR A PARTICULAR PURPOSE.
67		6.2	The views and opinions on the Material are the views and opinions of the individual author(s) of the documents and do not necessarily state or reflect those of Canada and shall not imply endorsement or credibility of the service, information or product offered.
68		6.3	Reference herein to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favouring by Canada.
69		6.4	The Licensor does not ensure or warrant compatibility with past, current or future versions of your browser or computer to access the Material.
70		6.5	The Licensor shall not be liable in respect of any claim, demand or action, irrespective of the nature of the cause of the claim, demand or action alleging any loss, injury or damages, direct or indirect, which may result from the Licensee's use or possession of GHGenius or any contents on this web site. Canada shall not be liable in any way for loss of revenue or contracts, or any other consequential loss of any kind resulting from any defect in GHGenius.
71		6.6	The Licensor does not assume any legal liability or responsibility if it is determine that the use of GHGenius infringe privately owned rights.
72		6.7	The Licensee shall have no recourse against Canada, whether by way of any suit or action, for any loss, liability, damage or cost that the Licensee may suffer or incur at any time, by reason of the Licensee's possession or use of the Material.
73		6.8	THE LICENSEE SHALL DEFEND AT ITS OWN EXPENSE ANY CLAIM, SUIT OR PROCEEDINGS BROUGHT AGAINST THE LICENSEE, CANADA OR THE LICENSOR, INSOFAR AS IT ARISES FROM LICENSEE'S USE OF THE MATERIAL AND SHALL INDEMNIFY AND HOLD CANADA AND THE LICENSOR
75		**7**	**TERM**
77		7.1	This Agreement is effective as of the date and time of acceptance (Eastern Standard Time) and shall remain in force until terminated as follows:
78			7.1.1 Automatically and without notice, if the Licensee commits or permits a breach of any of its covenants or obligations under this Agreement and the breach is not corrected to the satisfaction of the Minister within ten (10) days after the Minister gives the Licensee notice in writing of the allegation of a breach.
79			7.1.2 Upon written notice of termination at any time, by any Party. Where the notice is sent by the Licensee, such termination shall take effect thirty (30) days after the receipt by Canada of such notice.
80			7.1.3 Upon mutual agreement of the parties.
81			7.1.4 Upon the termination for whatever reason of this Agreement, the Licensee's obligations under section 6 shall survive and the Licensee's rights under section 2 shall immediately cease.
82		7.2	Immediately upon the termination for whatever reason of this Agreement, the Licensee shall delete or destroy all Material acquired under this Agreement immediately and ensure that the Material contained on any media in Licensee's possession has been completely erased or otherwise destroyed.
84		**8**	**DESTRUCTION**
86		8.1	Prior to disposing of any media, Licensee shall ensure that any Material contained on such media has been completely erased of otherwise destroyed.
88		**9**	**GENERAL CONDITIONS**
90		9.1	No member of the House of Commons or the Senate shall be admitted to any share or part of this Sub-licence agreement or to benefit to arise herefrom.
91		9.2	No former public office holder who is not in compliance with the post-employment provisions of the Conflict of Interest and Post-Employment Code for Public Office Holders or the Values and Ethics Code for the Public Service apply, shall derive a direct benefit from this Agreement.
93		**10**	**NOTICES**

	B	C	D	E
95	10.1	All notices, demands and other communications hereunder shall be in writing and shall be deemed to have been duly given if delivered by hand or if sent by first class prepaid mail or facsimile:		
97		To Licensor:		
98		Natural Resources Canada		
99			Office of Energy Efficiency	
100			Derek McCormack	
101			580 Booth St.	
102			Ottawa, Ontario	
103			K1A 0E4	
105		To Licensee:		
107			At the address provided upon registration.	
109	**11**	**APPLICABLE LAW**		
111	11.1	This Agreement shall be construed and enforced in accordance with, and the rights of the Parties shall be governed by, the laws of Ontario and Canada as applicable. The Parties attorn to the jurisdiction of the Superior Court of the Province of Ontario.		
113	**12**	**ENTIRE AGREEMENT**		
115	12.1	This Agreement constitutes the entire agreement between the parties with respect to its subject matter. This Agreement may only be amended in writing, signed by both parties, which expressly states the intention to amend this Agreement.		
117	**13**	**DISPUTE RESOLUTION**		
119	13.1	If a dispute arises concerning this Agreement, the parties shall attempt to resolve the matter first, by negotiation; second, by mediation by a mutually acceptable mediator; and, failing these, the dispute shall be finally settled by binding arbitration in accordance with the rules of the Commercial Arbitration Act (Canada), and judgement upon the award rendered by the arbitrators may be entered in any court having jurisdiction over the matter.		
121	**14**	**ACCEPTANCE OF THE TERMS OF THIS AGREEMENT**		
122				
123	GHGenius Website			
124				
125				
126				
127				
128		A		INDEX TO SHEETS IN THE SPREADSHEET
129		Input		INPUT SHEET FOR RUNNING MODEL
130		Input_Cost		INPUT SHEET FOR ALL COST DATA NEEDED TO CALCULATE COST EFFECTIVENESS
131		Energy Balance		PRIMARY ENERGY BALANCE AND BREAKDOWN OF SECONDARY ENERGY
132		J		COMPLETE FUELCYCLE EMISSIONS FROM ELECTRICITY GENERATION
133		Upstream Results HHV		GRAMS/GJ FUELCYCLE EMISSIONS (HHV), EXCLUDING END USE (CALCULATED RESULTS)
134		Upstream Results LHV		GRAMS/GJ FUELCYCLE EMISSIONS (LHV), EXCLUDING END USE (CALCULATED RESULTS)
135		Lifecycle Results		CO2-EQUIVALENT EMISSIONS, BY VEHICLE/FUEL AND STAGE
136		Lifecycle Results 2		CO2-EQUIVALENT EMISSIONS, BY VEHICLE/FUEL AND STAGE
137		AD		SUMMARY OF PERCENTAGE CHANGES
138		LDV_Summ		LIGHT DUTY VEHICLES: SUMMARY OF GREENHOUSE AND NON-GREENHOUSE GAS EMISSIONS, g/km
139		HDV_Summ		HEAVY DUTY VEHICLES: SUMMARY OF GREENHOUSE AND NON-GREENHOUSE GAS EMISSIONS, g/km
140		CostLDV		COST-EFFECTIVENESS FOR LIGHT-DUTY VEHICLE ALTERNATIVES
141		CostHDV		COST-EFFECTIVENESS FOR HEAVY-DUTY VEHICLE ALTERNATIVES
142		Sensitivity Solver		SENSITIVITY SOLVER
143		Monte Carlo		MONTE CARLO
144		Printing		PRINTING
145		B		TARGET YEAR, COUNTRY, CO2-EQUIVALENCY FACTORS (CEFs)
146		D		ELECTRICITY GENERATION: EFFICIENCY, AND TYPES OF FUEL USED
147		E		CHARACTERISTICS OF FUELS, GASES, AND FEEDSTOCKS
148		F		MISCELLANEOUS FUEL, FEEDSTOCK, AND FUELCYCLE INPUT DATA
149		S		CRUDE OIL PRODUCTION AND OWN USE
150		AA		VENTING AND FLARING OF ASSOCIATED GAS
151		T		U. S. PETROLEUM SUPPLY AND DISPOSITION 1990-2050
152		Z		FLOW OF PETROLEUM (CALCULATION OF TONNE-KM)
153		G		REFINERY ENERGY USE and EMISSIONS
154		R		NATURAL GAS AND NATURAL GAS LIQUIDS SUPPLY AND DISPOSITION
155		Q		COAL MINING AND OWN USE; METHANE FROM COAL MINES
156		P		URANIUM AND NUCLEAR POWER
157		O		ADJUSTMENTS TO CALCULATION OF ENERGY USED TO RECOVER FEEDSTOCKS AND RAIL TRANSIT
158		V		PRODUCTION OF BIOMASS
159		W		FERTILIZER MANUFACTURE, APPLICATION; NUTRIENT LOSS; LAND USE
160		Y		EMISSIONS DISPLACED BY CO PRODUCTS OF FUEL PRODUCTION PROCESSES
161		Sequestration		SEQUESTRATION INPUTS
162		X		PRODUCTION OF ALTERNATIVE FUELS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
163			I		SECONDARY ENERGY-USE INTENSITY AND SECONDARY ENERGY-USE BY TYPE OF FUEL												
164			U		TRANSPORT OF FEEDSTOCKS, FUELS, VEHICLES, ETC.												
165			N		EMISSION FACTORS FOR TRAINS, TANKERS, REFINERIES, METHANOL PLANTS, GAS COMPRESSORS, ETC.												
166			AB		ENERGY USE AND EMISSIONS AT SERVICE STATIONS, INCLUDING ENERGY TO COMPRESS OR LIQUEFY GASEOUS FUELS												
167			C		VEHICULAR ENERGY USE												
168			Exhaust Emissions		MOTOR-VEHICLE EMISSIONS: INPUT DATA AND RESULTS FOR: Western Canada												
169			L		MATERIALS USED IN VEHICLES												
170			M		EMISSIONS FROM VEHICLE ASSEMBLY AND MATERIALS MANUFACTURE; INDIRECT ENERGY USE FOR TRAINS, SHIPS, TRUCKS, ETC.												
171			Defaults		DEFAULT VALUES USED TO INITIATE MODEL INPUT SHEET (**DO NOT INPUT SCENARIO DATA INTO THIS SHEET**)												
172			Macros		MACROS												
173			Glossary		GLOSSARY OF ABBREVIATIONS												