# GHG EMISSION REDUCTIONS FROM WORLD BIOFUEL PRODUCTION AND USE

Prepared For:

**Global Renewable Fuels Alliance**
2 St. Clair Avenue West
Suite 2100
Toronto, ON M4V 1L5
Canada

Prepared By

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

Date: November 23, 2009

# EXECUTIVE SUMMARY

As environmental awareness increases, governments, industries and businesses have started to assess how their activities affect the environment. Society has become concerned about the issues of natural resource depletion and environmental degradation. The environmental performance of products and processes has become a key operational issue, which is why many organizations are investigating ways to minimize their effects on the environment. Many have found it advantageous to explore ways to improve their environmental performance, while improving their efficiency, reducing costs and developing a “green marketing” advantage. One useful tool is called life cycle assessment (LCA). This concept considers the entire life cycle of a product.

Life cycle assessment is a "cradle-to-grave" (or “well to wheels”) approach for assessing industrial systems. "Cradle-to-grave" begins with the gathering of raw materials from the earth to create the product and ends at the point when all materials are returned to the earth. An LCA evaluates all stages of a product's life from the perspective that they are interdependent, meaning that one operation leads to the next. LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle, often including impacts not considered in more traditional analyses (e.g., raw material extraction, material transportation, ultimate product disposal, etc.). By including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product selection.

Specifically, LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by:

- Compiling an inventory of relevant energy and material inputs and environmental releases;
- Evaluating the potential environmental impacts associated with identified inputs and releases;
- Interpreting the results to help make better-informed decisions.

The term "life cycle" refers to the major activities in the course of the product's life span from its manufacture, use, maintenance, and final disposal; including the raw material acquisition required to manufacture the product.

The objective of this project was to estimate the global GHG emissions reduction achieved through the production and use of biofuels.

The approach that has been used to document the production of biofuels in the world for each of the major producing countries and the feedstocks used in each country. This volume is then combined with an estimate of the GHG emissions associated with the production of that fuel in that country and these emissions are compared to the emissions that are avoided from the displaced petroleum products. These estimates were developed using LCA models and LCA studies on biofuel production around the world.

World biofuel production has now surpassed 100 billion litres of annual production. After accounting for energy contents, this is displacing 1.15 million barrels of crude oil derived petroleum products per day. If all of the biofuel were produced in one country, that country would effectively be the world’s 24th largest crude oil producer, after Qatar but ahead of Indonesia.

The production and use of this crude oil and the fuels produced from it creates about 215 million tonnes of GHG emissions annually.

The world ethanol production of 73.7 billion litres in 2009 is estimated to reduce GHG emissions by 87.6 million tonnes. Most of this reduction is experienced in Brazil and the United States due to their high levels of ethanol production and use. The emission reductions achieved with fuel ethanol is about the same as the total GHG emissions for Austria in 2007 (88.0 million tonnes) (UNFCCC).

The forecast world biodiesel production of 16.4 billion litres is calculated to result in a reduction of GHG emissions of 35.9 million tonnes. For comparison, the GHG emission reductions provided by biodiesel is greater than the 2007 GHG emissions reported for Croatia (32.4 million tonnes).

The combined biofuels GHG emission reduction is 123.5 million tonnes, an average reduction of about 57% compared to the emissions that would have occurred from the production and use of equivalent quantities of petroleum fuels. This is almost equal to the national GHG emissions of Belgium (131.3 million tonnes) or Greece (131.8 million tonnes). It is also almost the combined GHG emissions from the following Annex 1 parties, Monaco, Liechtenstein, Iceland, Latvia, Luxembourg, Slovenia, Estonia, Lithuania, and Croatia (129.6 million tonnes).

The average per capita GHG emission for the Annex 1 countries is about 14 tonnes/person per year. The biofuel GHG emission reductions are therefore equal to the combined output of about 8.8 million people.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# 1. INTRODUCTION

As environmental awareness increases, governments, industries and businesses have started to assess how their activities affect the environment. Society has become concerned about the issues of natural resource depletion and environmental degradation. The environmental performance of products and processes has become a key operational issue, which is why many organizations are investigating ways to minimize their effects on the environment. Many have found it advantageous to explore ways to improve their environmental performance, while improving their efficiency, reducing costs and developing a “green marketing” advantage. One useful tool is called life cycle assessment (LCA). This concept considers the entire life cycle of a product.

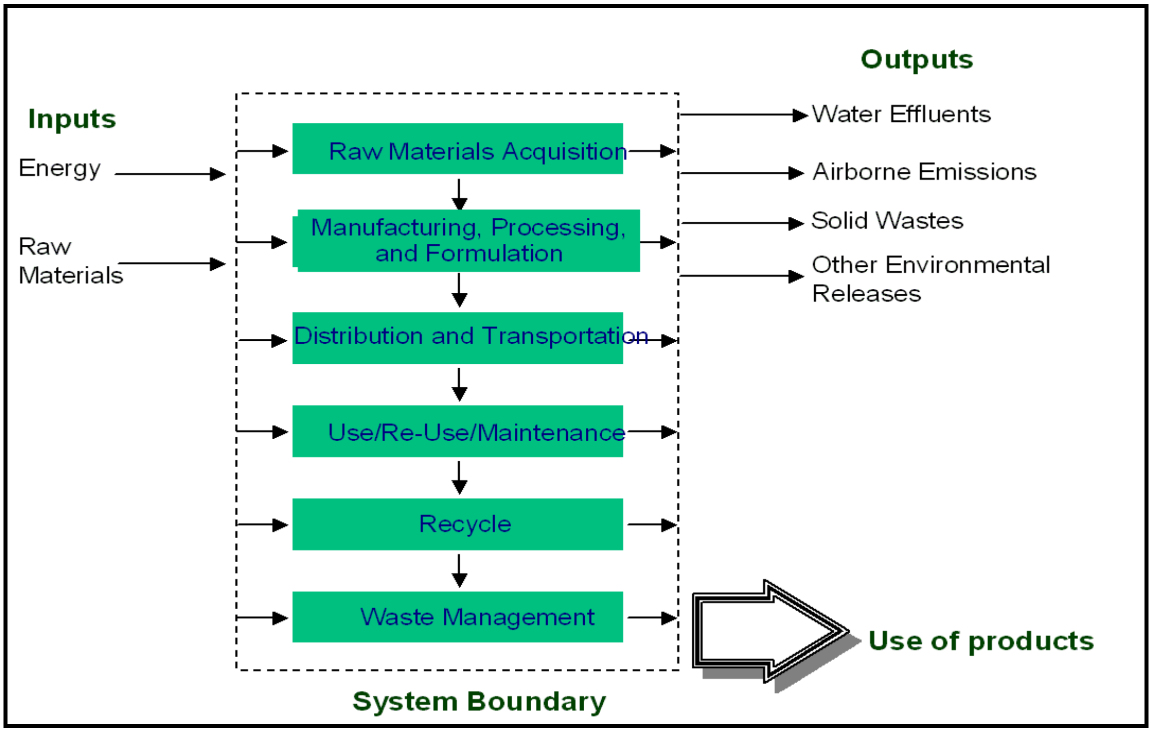
Life cycle assessment is a "cradle-to-grave" (or “well to wheels”) approach for assessing industrial systems. "Cradle-to-grave" begins with the gathering of raw materials from the earth to create the product and ends at the point when all materials are returned to the earth. An LCA evaluates all stages of a product's life from the perspective that they are interdependent, meaning that one operation leads to the next. LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle, often including impacts not considered in more traditional analyses (e.g., raw material extraction, material transportation, ultimate product disposal, etc.). By including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product selection.

Specifically, LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by:

- Compiling an inventory of relevant energy and material inputs and environmental releases;
- Evaluating the potential environmental impacts associated with identified inputs and releases;
- Interpreting the results to help make better informed decisions.

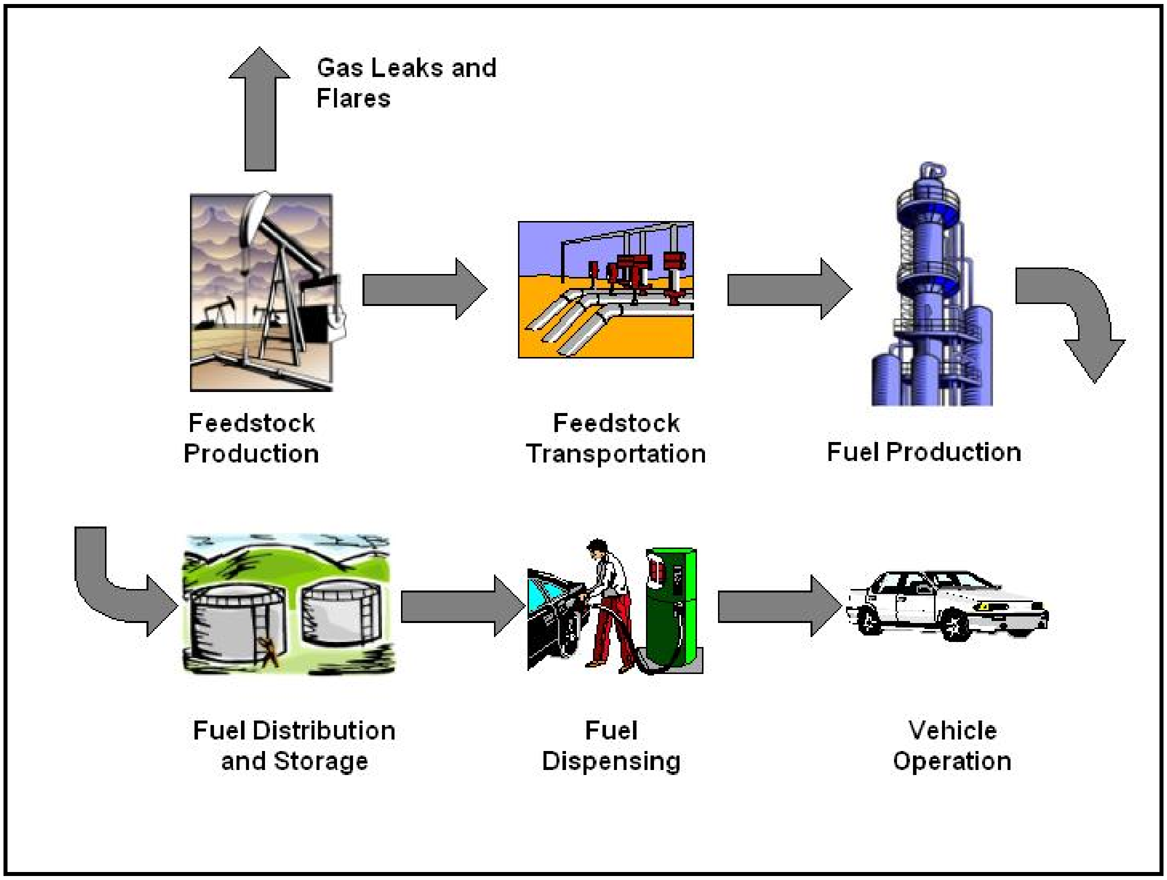
The term "life cycle" refers to the major activities in the course of the product's life span from its manufacture, use, maintenance, and final disposal; including the raw material acquisition required to manufacture the product. The following figure illustrates the typical life cycle stages that can be considered in an LCA and the quantified inputs and outputs.

**Figure 1-1 Life Cycle Stages**



When transportation fuels are being considered then the system boundary for undertaking a typical LCA is similar to that shown in the following figure.

**Figure 1-2 Transportation Fuel Life Cycle Stages**



## 1.1 SCOPE OF WORK

The objective of this project was to estimate the global GHG emissions reduction achieved through the production and use of biofuels.

The approach that has been used to document the production of biofuels in the world for each of the major producing countries and the feedstocks used in each country. This volume is then combined with an estimate of the GHG emissions associated with the production of that fuel in that country and these emissions are compared to the emissions that are avoided from the displaced petroleum products. These estimates were developed using LCA models and LCA studies on biofuel production around the world.

The GHG emission estimates used for this work do not include any indirect emissions. Indirect emissions are possible future emissions arising from an expansion of current activities; they are forecast by looking at the emissions on a marginal or incremental basis. There are several reasons for not including them in this work.

1. There have been no credible assessments undertaken for the indirect effects of petroleum fuels. Biofuels can only be compared to petroleum fuels if the system boundaries are the same.

2. The estimates of indirect effects of biofuels that have been done suffer from a lack of transparency; it is not possible to independently analyze and verify the estimates produced to date.
3. A lack of data on what might happen and the impacts of these changes require a large number of assumptions to be made during the estimation process.

All three of these issues are inconsistent with the principles of lifecycle analysis established by the International Standards Organization 14040 standard for lifecycle assessment. 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)

The three critical principles that are not currently followed in indirect analyses are briefly expanded on below.

### 1.1.1 Relative Approach and Functional Unit

LCA is a relative analytical approach (one system is compared to another), 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.

### 1.1.2 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.

### 1.1.3 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.

## 1.2 LIFE CYCLE ASSESSMENT MODELS

LCA work involves the collection and utilization of large amounts of data and thus is ideally suited to the use of computer models to assist with the inventorying and analysis of the data.

Due to the complexity of the systems being modelled, no LCA model can yet perfectly model transportation fuels.

In North America, two models are widely used for the analysis of transportation fuels:

- GREET. A model developed by Argonne National Laboratory in the United States, and
- GHGenius. A model developed by Natural Resources Canada, which has data for both Canada and the United States. This model also has much greater flexibility for modelling different types of crude oil production and many more types of alternative fuels.

The results produced by GREET and GHGenius are similar when the models are run for the same regions, same fuels and similar inputs are used. The GHG emissions associated with biofuels production are a function not only what is done but in many cases where it is done. The GHGenius model is best suited to modelling transportation fuels in North America, as it has the most extensive set of feedstocks and fuels available and a good set of input factors for all regions of North America.

When production cycles involve activities outside of North America it is often difficult to find good quality data to use in the modelling. In these cases, the data sets need to be reviewed with some care. For this work, information from other sources has also been utilized because emissions are expected to be different than they are in North America.

The GHGenius model has been developed for Natural Resources Canada over the past eight years by S&T Squared Consultants Inc. It is based on the 1998 version of Dr. Mark Delucchi’s Life Cycle Emissions Model (LEM). GHGenius is capable of analyzing the emissions of many contaminants associated with the production and use of traditional and alternative transportation fuels.

GHGenius is capable of estimating life cycle emissions of the primary greenhouse gases and the criteria pollutants from combustion 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.
- 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.

### 1.3 STRENGTHS AND WEAKNESSES OF LIFE CYCLE ANALYSES

Life cycle assessment is a useful tool for comparing on a functional unit basis, the relative environmental performance (based on a specific set of metrics) of different feedstock/fuel pathways. However, LCA should be utilized along with other information in the decision making process. Decision-makers should be aware of both the strengths and limitations of LCA. In order to more completely understand the implications on the environment (and economy) of fuel production (e.g., scale of production issues, impacts on ecosystem and human health) LCA results should be augmented with those of other modeling systems, economic and market analyses or perhaps, integrated modeling systems could be developed in the future as well as decision makers' good judgment.

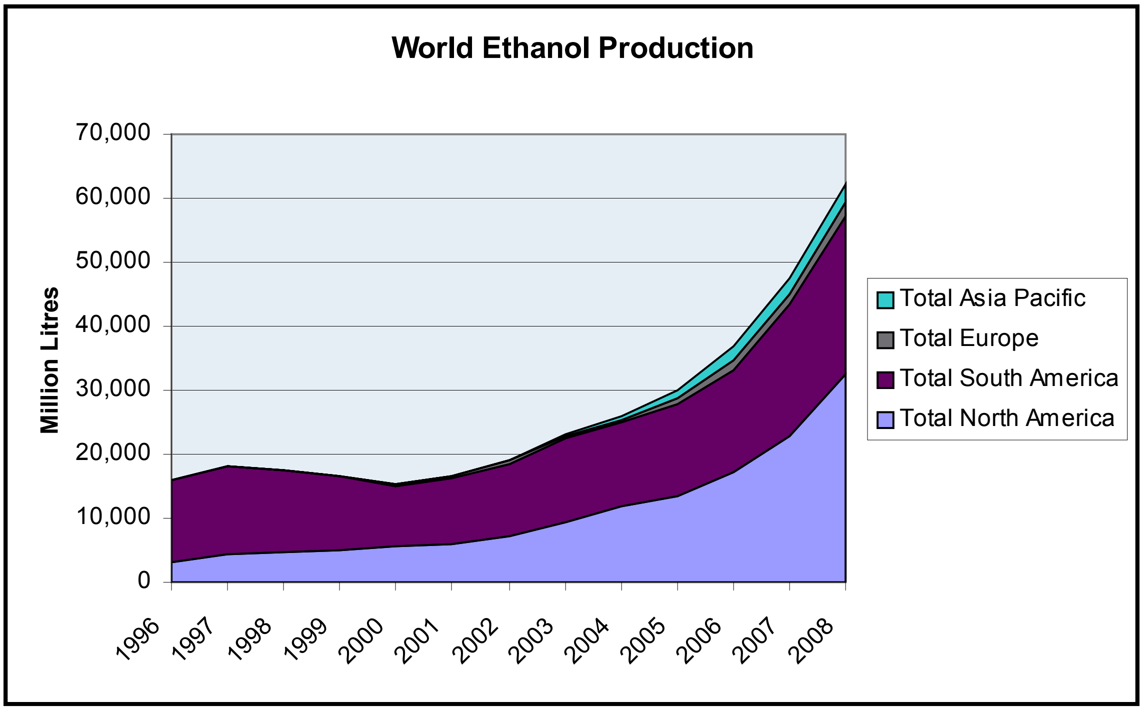
# 2. GLOBAL BIOFUEL PRODUCTION

Information on global biofuel production has been obtained from F.O. Lichts. F.O. Lichts is an Agra Informa company, they provide global information for a number of agricultural and energy sectors including the fuel ethanol and biodiesel sectors. They are world leaders in their industry.

## 2.1 FUEL ETHANOL PRODUCTION

Fuel ethanol is currently produced in more than 15 countries from a variety of sugar and starch based feedstocks. The production of fuel ethanol has been increasing rapidly over the past decade as shown in the following figure.

**Figure 2-1 Fuel Ethanol Production**



Source: BP Statistical Review of World Energy. 2009.

The global production data for the year 2008 and estimates for 2009 provided by F.O. Lichts are summarized in the following table. The data is mostly consistent with the information available from BP. The primary feedstock used in each region has been provided by F.O. Lichts.

**Table 2-1 Global Fuel Ethanol Production**

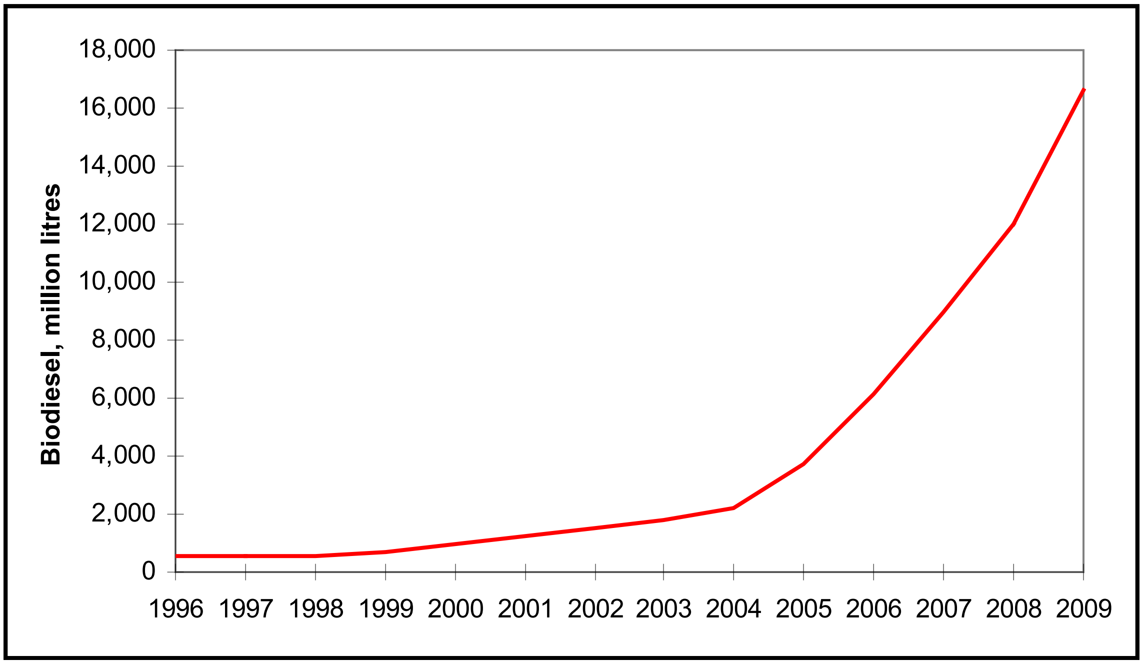
| Country or Region | 2008 | 2009 | Primary Feedstock |
|---|---|---|---|
| | Million Litres | | |
| USA | 34,968 | 39,700 | Corn |
| Brazil | 24,200 | 24,900 | Sugarcane |
| EU | 2,803 | 3,935 | Beet/grain |
| China | 1,900 | 2,050 | Corn |
| Canada | 950 | 1,100 | Corn |
| Other | 436 | 936 | Sugarcane |
| Thailand | 322 | 450 | Sugarcane |
| Colombia | 258 | 315 | Sugarcane |
| Australia | 131 | 215 | Sugar/grain |
| India | 60 | 150 | Sugarcane |
| Total | 66,028 | 73,751 | |

Corn and sugarcane feedstocks dominate world ethanol production. Other grains and sugar beets are used in some locations.

## 2.2 BIODIESEL PRODUCTION

World biodiesel production has also been increasing rapidly during the past decade as shown in the following figure.

**Figure 2-2 World Biodiesel Production**



Biodiesel production has also been obtained from F.O. Lichts. That information is presented in the following table. The estimates of feedstocks utilized are a combination of F.O. Lichts information and our estimates.

**Table 2-2 World Biodiesel Production**

| Region | Million Litres | Feedstocks |
|---|---:|---|
| EU | 9,848 | Rapeseed (50%), soyoil (40%), palm (5%) and tallow (5%) |
| U.S.A | 1,682 | Soy (40%), tallow (20%), canola (20%), palm (20%) |
| Brazil | 1,386 | Soy (80%), tallow (10%), other veg oils (10%) |
| Argentina | 1,250 | Soy |
| Thailand | 614 | Palm |
| Malaysia | 284 | Palm |
| Colombia | 205 | Palm |
| China | 191 | Waste veg oils |
| South Korea | 182 | Palm (33%), soy (33%), waste veg oils (33%) |
| Indonesia | 170 | Palm |
| Singapore | 124 | Palm |
| Philippines | 108 | Coconut |
| Canada | 102 | Tallow |
| O. S. America | 63 | Palm |
| O. Europe | 58 | Rapeseed |
| Australia | 57 | Tallow |
| Taiwan | 43 | Palm (33%), soy (33%), waste veg oils (33%) |
| O. N & C Am | 38 | Palm |
| India | 23 | Waste veg oil |
| O. Oceania | 6 | Waste veg oil |
| O. Asia | 5 | Waste veg oil |
| World | 16,436 | |

## 2.3 SUMMARY

World biofuel production has now surpassed 100 billion litres of annual production. After accounting for energy contents, this is displacing 1.15 million barrels of crude oil derived products per day. If all of the biofuel were produced in one country, that country would be the world's 24th largest crude oil producer, after Qatar but ahead of Indonesia.

The production and use of this oil and the products produced from it creates about 215 million tonnes of GHG emissions annually.

# 3. GHG EMISSIONS

The production and use of transportation fuel accounts for about 20 to 35% of most countries GHG emissions. One of the few options available to immediately reduce these emissions is through the introduction of biofuels into the transportation fuel mix. The quantity of GHG emissions avoided by biofuels is a function of the carbon intensity of the petroleum products produced and the carbon intensity of the biofuels that are used to displace those products.

## 3.1 PETROLEUM FUELS

The carbon intensity of gasoline and diesel fuel will depend on the types of crude oil produced, the efficiency of the refineries used for conversion, and the mix of petroleum products produced. In a recent study of the GHG emissions from a variety of world crude oils, Jacobs Consultancy (AERI, 2009) reported that the GHG emissions for gasoline varied from 99 to 118 g/MJ (LHV) and for diesel fuels the range was 98 to 115 g/MJ. The low end of the ranges have been used to determine the GHG emission reductions for biofuels to be conservative, although a case could be made that the higher emission intensity is associated with the more difficult to extract crude oils and these are more likely to be the marginal sources of production and this the most likely emissions avoided.

Some of the GHG emission data available for fuels was reported on a lower heating value basis and some on a higher heating value basis. For consistency all data has been converted to a higher heating value basis for this work. This has no impact on the results reported. The gasoline and diesel emissions are therefore assumed to be 92 $gCO_2eq/MJ$ (HHV). This is at the low end of the range reported by Jacobs and provides a conservative estimate of the emission reductions achieved by biofuels.

## 3.2 FUEL ETHANOL

Most of the world's ethanol is currently produced from corn or sugarcane and both of these pathways are included in GHGenius. Sugar beet ethanol and grain ethanol are also included in GHGenius but most of the world's production of these kinds of ethanol is located in Europe, and thus European LCA estimates has been used in the roll up of the emission benefits of biofuels. Each of the feedstock types is discussed briefly below.

### 3.2.1 Sugar Cane Ethanol

Brazil is the world's largest producer of sugar cane ethanol. A significant number of LCA studies have been undertaken on Brazilian ethanol. The emissions from some of these are summarized in the following table. It can be seen that there is a relatively small range for the emissions.

**Table 3-1 Sugar Cane Ethanol GHG Emissions**

| Source | GHG Emissions, g $CO_2eq/MJ$ (HHV) |
|---|---:|
| GHGenius | 23 |
| California Air Resources Board | 11 to 24 (average 18) |
| JRC | 12 to 21 |
| EU RED (JRC) | 21 |
| Assumed value for modelling | 20 |
| Emissions avoided | 72 |

The emissions avoided are equivalent to 1.7 kg $CO_2$eq/litre of ethanol produced and used. The emissions from sugar cane ethanol are less sensitive to regional factors since the mills tend to be self reliant for their energy needs and the sugar cane farming inputs are relatively low so the same GHG emission value will be used for all sugar cane ethanol producing regions.

### 3.2.2 Corn Ethanol

The US is the dominant ethanol producer in the world and most of their production is based on corn ethanol. Some corn ethanol is also produced in Canada, China and some European countries. There is some regional variation in the emission estimates for corn ethanol as shown in the following table so different values will be used for different regions.

**Table 3-2 Corn Ethanol GHG Emissions**

| Source | GHG Emissions, g $CO_2$eq/MJ (HHV) |
|---|---:|
| GHGenius US | 56 |
| GHGenius Canada | 44 |
| California Air Resources Board | 50 to 65 (average 60) |
| EU RED | 33 |
| Assumed value for modelling US and China | 56 |
| Emissions avoided US and China | 36 |
| Assumed value for modelling Canada | 44 |
| Emissions avoided US and Canada | 48 |

The emissions avoided range from 0.85 kg $CO_2$eq/l for the US and China to 1.13 kg $CO_2$eq/l for Canada. A large part of the difference in emissions between the corn and sugar cane pathways is driven by the use of bioenergy to fuel the sugar cane ethanol production process and the use of fossil energy in the corn ethanol system.

### 3.2.3 Sugar Beet Ethanol

Sugar beets are used as a feedstock in Europe and it has been assumed that 50% of the EU ethanol production is produced from sugar beet. The EU RED (JRC, 2008) reports the emissions for sugar beet ethanol range from 23 to 51 g $CO_2$eq/MJ (HHV). An average of 37 g $CO_2$eq/MJ is used and that is equivalent to a reduction of 1.30 kg $CO_2$eq /l of ethanol.

### 3.2.4 Other Grain Ethanol

Other grains, such as wheat and rye, are used to supply most of the rest of the EU ethanol production. The EU RED reports the emissions for wheat ethanol range from 21 to 51 kg $CO_2$eq/MJ (HHV). The average of four scenarios is 38 g $CO_2$eq/MJ and that is used here, that is equivalent to a reduction of 1.27 kg $CO_2$eq /l of ethanol. The 38 g $CO_2$eq/MJ is also the value for wheat ethanol produced in western Canada in GHGenius, although the allocation approach used in the EU calculations is different from the approach used in GHGenius.

## 3.3 BIODIESEL

The GHG emissions from biodiesel production are strongly influenced by the feedstock production stage and those emissions do vary considerably from one feedstock to another. The biodiesel GHG emission factors are summarized below.

### 3.3.1 Rapeseed Biodiesel

Rapeseed biodiesel accounts for more than 30% of the world's biodiesel feedstock according to our estimates. Most of this is produced and used in Europe so we have relied on the EU RED estimates for GHG emission reductions for rapeseed biodiesel. The JRC WTT study presented a range of 27 to 45 g $CO_2$eq/MJ and the EU RED has a default value of 41 g $CO_2$eq/MJ. This will be used here and it produces a GHG emission reduction of 51 g $CO_2$eq/MJ or 1.88 kg $CO_2$eq/litre.

GHGenius produces a larger emission reduction of 2.89 kg $CO_2$eq/litre but this is for a much dryer climate, the use of less GHG emission intensive fertilizer and the use of system expansion rather than allocation by energy.

### 3.3.2 Soy Biodiesel

The EU-RED values for soybean biodiesel range from 30 to 45 g $CO_2$eq/MJ however some of the data used for this analysis is very old. GHGenius produces a result of 30 g $CO_2$eq/MJ and CARB have a value of 24.5 g $CO_2$eq/MJ.

A conservative value of 30 g $CO_2$eq/MJ is used here. This produces an emission reduction of 62 g $CO_2$eq/MJ or 2.39 kg $CO_2$eq/litre.

### 3.3.3 Tallow Biodiesel

Tallow is rendered animal fats. In GHGenius, the emissions for tallow biodiesel range from 1 to 15 g $CO_2$eq/MJ depending on the location. A value of 10 g $CO_2$eq/MJ will be used here. This produces an emission reduction of 82 g $CO_2$eq/MJ or 3.0 kg $CO_2$eq/litre.

### 3.3.4 Palm Biodiesel

The EU-RED has values ranging from 29 to 50 g $CO_2$eq/MJ for palm oil biodiesel. GHGenius produces values of 33 to 45 g $CO_2$eq/MJ depending on the process energy assumptions. An emissions value of 45 g $CO_2$eq/MJ or an emissions reduction of 47 g $CO_2$eq/MJ will be used here. This is equivalent to 1.7 kg $CO_2$eq/litre.

### 3.3.5 Waste Vegetable Oils

The emissions from waste cooking oil in GHGenius are about equal to the co-product credit available from the glycerine so there are no net GHG emissions. The EU-RED value for waste oil biodiesel uses a different allocation method and has a result of 10 g $CO_2$eq/MJ. This value will be used here and it produces an emission reduction of 3.0 kg $CO_2$eq/litre.

# 4. GLOBAL GHG EMISSION REDUCTIONS

The global GHG emission reductions resulting from the production and use of biofuels is simply the product of the quantity of biofuels produce times the emission reduction per litre of biofuel. This information is shown below.

## 4.1 FUEL ETHANOL

The GHG emission reductions from fuel ethanol in 2009 are shown in the following table. The US and Brazil have experienced the greatest reductions in GHG emissions from the production and use of fuel ethanol although Brazil has experience the greatest reduction whereas the US is the largest producer.

**Table 4-1 Fuel Ethanol GHG Emission Reductions**

| Country or Region | 2009 | GHG Reduction | GHG Reduction |
|---|---:|---:|---:|
| | Million Litres | kg $CO_2$eq/l | 1,000 tonnes |
| USA | 39,700 | 0.85 | 33,745 |
| Brazil | 24,900 | 1.7 | 42,330 |
| EU | 3,935 | 1.28 | 5,037 |
| China | 2,050 | 0.85 | 1,743 |
| Canada | 1,100 | 1.13 | 1,243 |
| Other | 936 | 1.7 | 1,591 |
| Thailand | 450 | 1.7 | 765 |
| Colombia | 315 | 1.7 | 536 |
| Australia | 215 | 1.5 | 323 |
| India | 150 | 1.7 | 255 |
| Total | 73,751 | | 87,567 |

The emission reduction achieved with fuel ethanol is the same as the total GHG emissions (excluding land use change) for Austria in 2007 (87,958 thousand tonnes) (UNFCCC).

## 4.2 BIODIESEL

The GHG emission reductions resulting from the production and use of biodiesel are summarized in the following table. The greatest reductions have occurred in the EU were the greatest volume of biodiesel is produced and used. In each region the GHG emission reductions are weighted according to the estimated proportion of feedstocks used.

**Table 4-2 Biodiesel GHG Emission Reductions**

| Region | Production | GHG Reduction | GHG Reduction |
|---|---:|---:|---:|
| | Million Litres | kg $CO_2$eq/l | 1,000 tonnes |
| EU | 9,848 | 2.13 | 20,986 |
| U.S.A | 1,682 | 2.40 | 4,030 |
| Brazil | 1,386 | 2.38 | 3,302 |
| Argentina | 1,250 | 2.39 | 2,988 |
| Thailand | 614 | 1.7 | 1,043 |
| Malaysia | 284 | 1.7 | 483 |
| Colombia | 205 | 1.7 | 348 |
| China | 191 | 3 | 573 |
| South Korea | 182 | 2.34 | 425 |
| Indonesia | 170 | 1.7 | 290 |
| Singapore | 124 | 1.7 | 211 |
| Philippines | 108 | 1.7 | 184 |
| Canada | 102 | 3 | 307 |
| O. S. America | 63 | 1.7 | 106 |
| O. Europe | 58 | 1.88 | 109 |
| Australia | 57 | 3 | 170 |
| Taiwan | 43 | 2.34 | 101 |
| O. N & C Am | 38 | 3 | 113 |
| India | 23 | 3 | 68 |
| O. Oceania | 6 | 3 | 17 |
| O. Asia | 5 | 3 | 14 |
| World | 16,436 | | 35,866 |

The GHG emission reductions provided by biodiesel is greater than the 2007 GHG emissions reported for Croatia (32,385 thousand tonnes).

## 4.3 SUMMARY

The total GHG emissions forecast for 2009 are 123,400 thousand tonnes. This is almost equal to the national GHG emissions of Belgium (131,301 thousand tonnes) or Greece (131,854 thousand tonnes). It is almost the combined GHG emissions from the following Annex 1 parties, Monaco, Liechtenstein, Iceland, Latvia, Luxembourg, Slovenia, Estonia, Lithuania, and Croatia (129.6 million tonnes).

The average per capita GHG emission for the Annex 1 countries is about 14 tonnes/person per year. The biofuel GHG emission reductions are therefore equal to the combined output of about 8.8 million people.

# 5. REFERENCES

Alberta Energy Research Institute. 2009. Life Cycle Assessment Comparison of North American and Imported Crudes. http://eipa.alberta.ca/media/39640/life%20cycle%20analysis%20jacobs%20final%20report.pdf

BP. 2009. Statistical Review of World Energy. http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2009_downloads/renewable_table_of_ethanol_production_2009.xls

CARB. 2009. Detailed California-Modified GREET Pathway for Corn Ethanol. http://www.arb.ca.gov/fuels/lcfs/022709lcfs_cornetoh.pdf

CARB. 2009. Detailed California-Modified GREET Pathway for Biodiesel (Esterified Soyoil) from Midwest Soybeans. http://www.arb.ca.gov/fuels/lcfs/022709lcfs_biodiesel.pdf

CARB. 2009. Detailed California-Modified GREET Pathways for Brazilian Sugarcane Ethanol: Average Brazilian Ethanol, With Mechanized Harvesting and Electricity Co-product Credit, With Electricity Co-product Credit. http://www.arb.ca.gov/fuels/lcfs/092309lcfs_cane_etoh.pdf

JRC. 2008. Description and detailed energy and GHG balance of individual pathways. WTT Appendix 2. http://ies.jrc.ec.europa.eu/uploads/media/WTT%20App%202%20v30%20181108.pdf

JRC. 2008. Input data relevant to calculating default GHG emissions from biofuels according to RE Directive Methodology. http://re.jrc.ec.europa.eu/biof/xls/Biofuels%20pathways%20RED%20method%2014Nov2008.xls

UNFCCC. 2009. All Annex I countries - Total emissions excluding LULUCF/LUCF. http://maps.unfccc.int/di/map/