GHG EMISSION REDUCTIONS FROM WORLD BIOFUEL PRODUCTION AND USE - 2015

Prepared For:

Global Renewable Fuels Alliance
151 Bloor Street W, Suite 455
Toronto, Ontario
M5S 1S4
Canada

Prepared By

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

Date: November 26, 2015

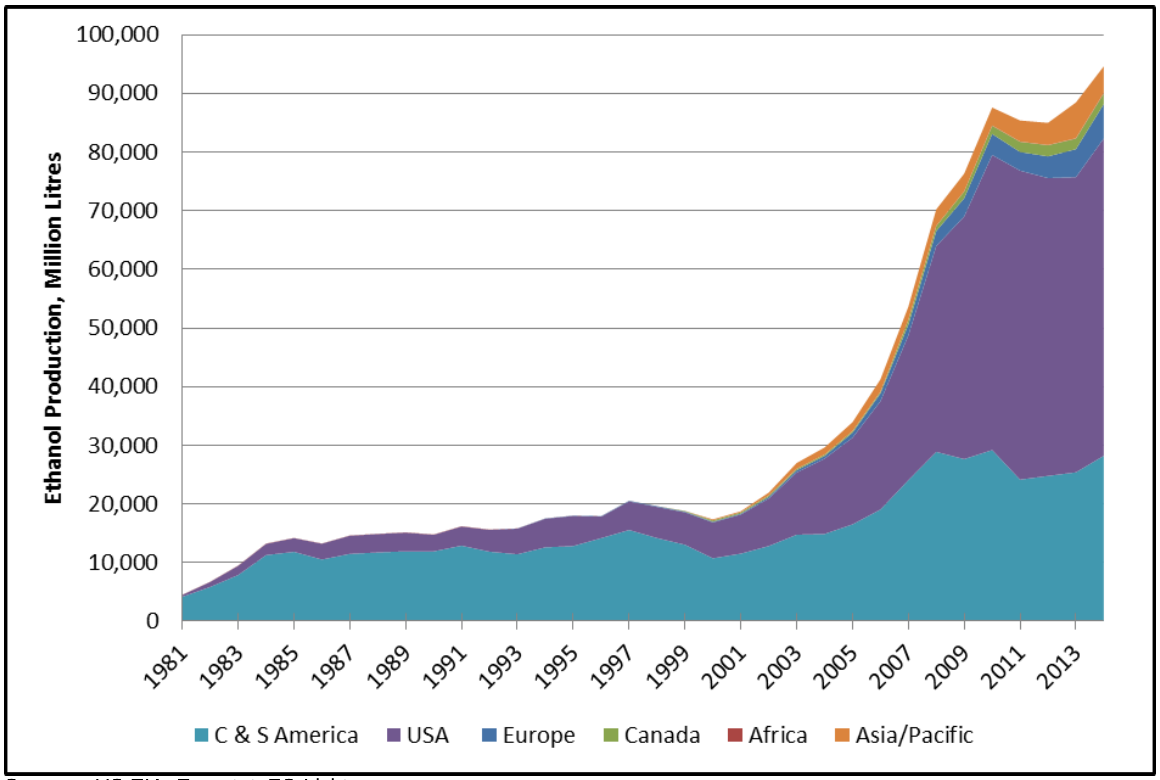
EXECUTIVE SUMMARY

The objective of this project was to estimate the global GHG emissions reduction achieved through the production and use of biofuels. This work was first undertaken in 2009 and much has changed since then: biofuel production levels are higher, biofuel production processes have become more efficient and more is known about the GHG emissions of fossil fuel systems.

The approach that has been used is similar to the 2009 approach; first the production of biofuels for each of the major producing countries and the feedstocks used in each country is documented. This volume is then combined with revised estimates 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.

Fuel ethanol is currently produced in more than 50 countries from a variety of sugar and starch based feedstocks. The production of fuel ethanol has increased more than threefold over the past decade as shown in the following figure.

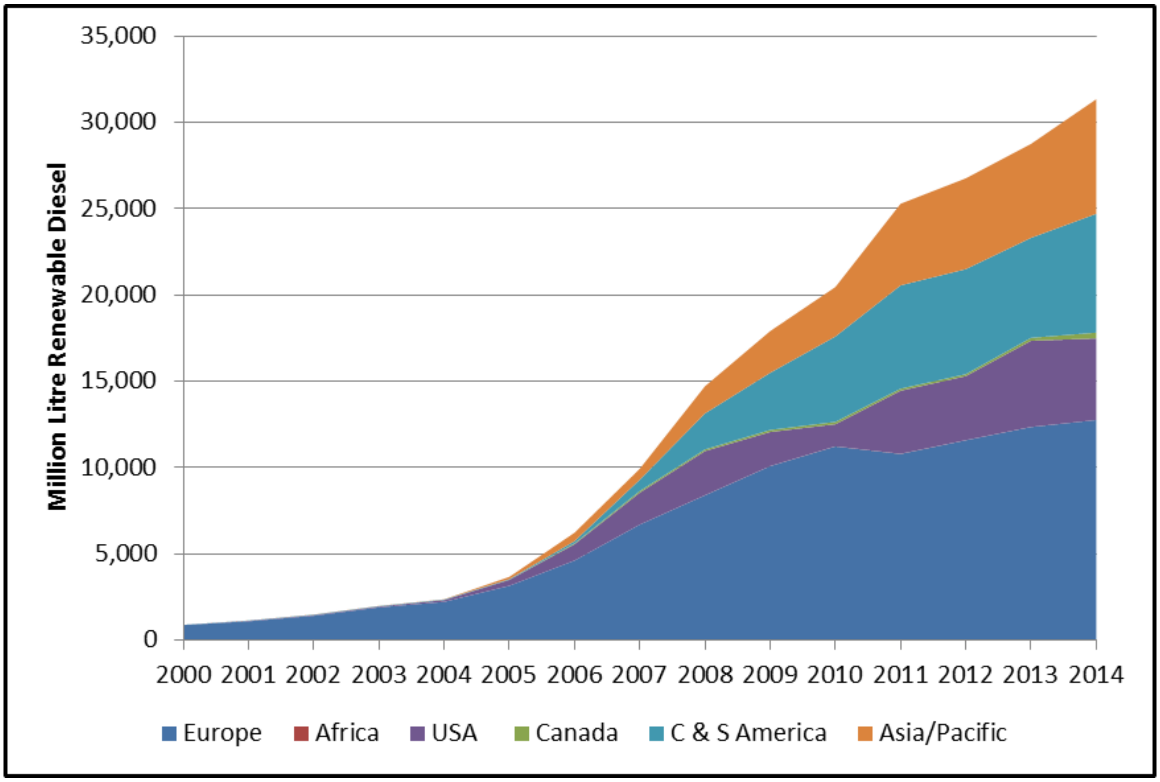
Figure ES- 1 Global Fuel Ethanol Production



Sources: US EIA, Eurostat, FO Lichts.

World biodiesel production has increased tenfold during the past decade as shown in the following figure. Biodiesel is produced commercially in approximately 60 countries around the world.

Figure ES- 2 Global Biodiesel Production



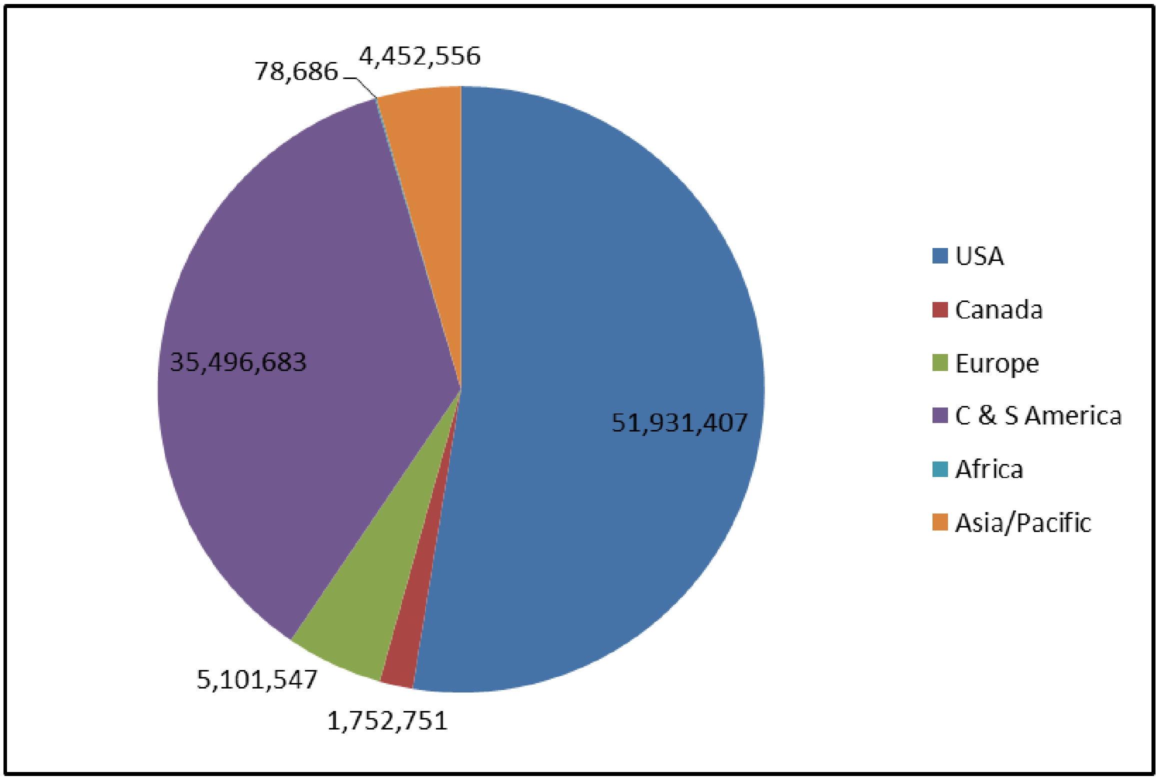
Sources: US EIA, Eurostat, FO Lichts.

The GHG emission reductions from fuel ethanol in 2014 are shown in the following table. The Americas have experienced the greatest reductions in GHG emissions from the production and use of fuel ethanol.

Table ES- 1 Fuel Ethanol GHG Emission Reductions

Region	2014 Million Litres	2014 GJ Bioenergy	GHG Reduction kg CO_2eq/GJ	GHG Reduction tonnes
USA	54,126.0	1,146,388,680	45.3	51,931,407
Canada	1,800.0	38,124,000	46.0	1,752,751
Europe	5,471.0	115,875,780	44.0	5,101,547
C & S America	28,826.2	610,538,068	58.1	35,496,683
Africa	76.6	1,622,382	48.5	78,686
Asia/Pacific	4,339.0	91,900,020	48.5	4,452,556
World	94,638.8	2,004,448,930	49.3	98,813,630

Figure ES- 3 Fuel Ethanol GHG Emission Reductions 2014

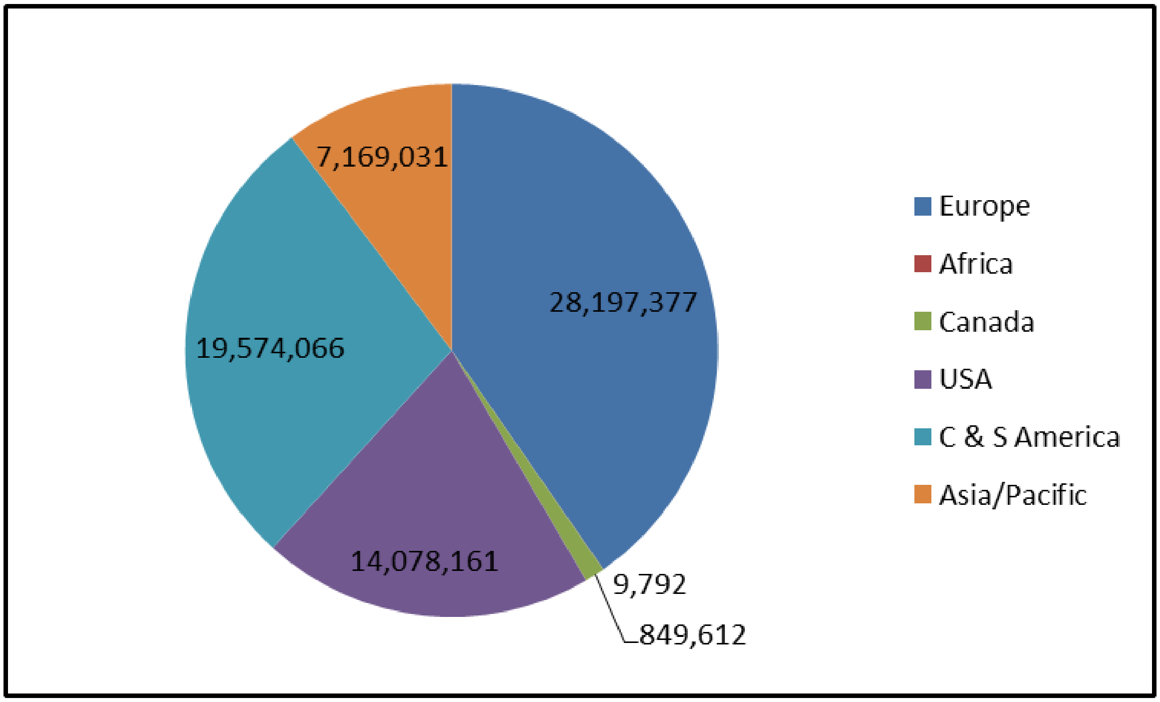


The GHG emission reductions resulting from the production and use of biodiesel are summarized in the following table. The greatest reductions have occurred in the EU were the greatest volume of biodiesel is produced and used. In each region the GHG emission reductions are weighted according to the estimated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

Table ES- 2 Biodiesel GHG Emission Reductions

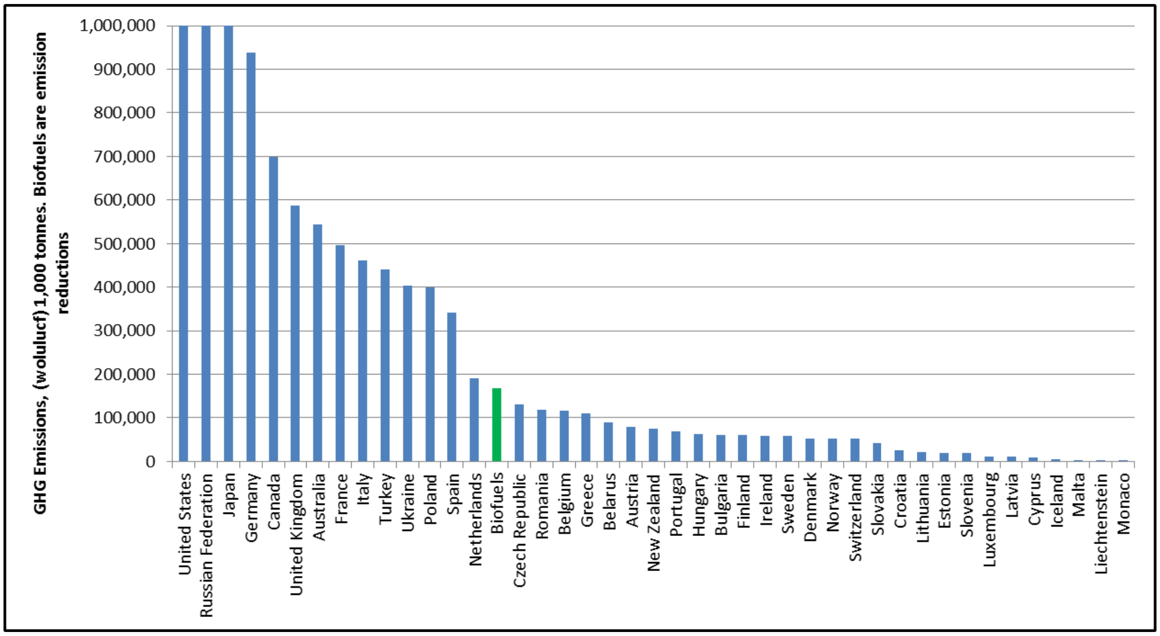
Region	2014	2014	GHG Reduction	GHG Reduction
	Million Litres	GJ Bioenergy	kg CO_2eq/GJ	tonnes
USA	4,727.7	155,068,023	90.8	14,078,161
Canada	290.0	9,512,000	89.3	849,612
Europe	12,361.3	405,449,306	69.5	28,197,377
C & S America	7,233.1	237,247,033	82.5	19,574,066
Africa	3.5	114,800	85.3	9,792
Asia/Pacific	6,721.0	220,449,912	32.5	7,169,031
World	31,336.6	1,027,841,074	68.0	69,878,039

Figure ES- 4 Biodiesel GHG Emission Reductions 2014



The total GHG emission reductions from biofuels forecast for 2014 are 168,690,000 tonnes. Only 14 UNFCCC Annex 1 countries have emissions greater than this value. The GHG emissions in 28 Annex 1 countries are lower than this value. The following figure compares the emission reductions from biofuels to the national GHG emissions (without land use, land use change, and forestry) from Annex 1 countries for the year 2012. The large emitters, the US at 6,487,847 thousand tonnes, the Russian federation at 2,297,152 thousand tonnes, and Japan at 1,343,137 thousand tonnes, are truncated in the figure for clarity.

Figure ES- 5 Biofuel Reduction Comparison to National GHG Emissions



While the GHG emission reductions delivered by biofuels are substantial, there is still room for growth in the sector. Forecasts for business as usual are reviewed and the GHG emission reductions in 2030 are calculated from these forecasts. A high penetration scenario, where 15% ethanol is used in the developed world markets is also considered.

The production scenario for 2030 has been developed from the 2014 production data and slightly more conservative growth rates than those used by BP in their 2035 Energy Outlook. The average growth rate is 2.77%. The same mix of feedstock is used in each region and no improvement in the carbon intensity of the biofuel feedstock or production or increase in the carbon intensity of the petroleum products is assumed, although historical we see reductions in biofuel carbon intensity and increases in petroleum carbon intensity over time. The ethanol production and GHG emission reductions are shown in the following table.

Table ES- 3 Forecast GHG Emission Reductions – Ethanol 2030

Region	2014 Production	Growth rate	2030 Production	2030 GHG Emission Reductions
	Million Litres		Million Litres	tonnes
USA	54,126	2.0%	74,303	71,290,693
Canada	1,800	2.0%	2,471	2,406,151
Europe	5,471	2.0%	7,511	7,003,331
C & S America	28,826	3.5%	49,984	61,550,753
Africa	77	25.0%	2,721	2,795,471
Asia/Pacific	4,339	5.0%	9,471	9,719,371
World	94,639	2.8%	146,461	154,765,770

The biodiesel forecast GHG emission reductions are shown in the following table. The total growth rate for the biodiesel is higher because of the different distribution of production regions.

Table ES- 4 Forecast GHG Emission Reductions – Biodiesel 2030

Region	2014 Production	Growth rate	2030 Production	2030 GHG Emission Reductions
	Million Litres		Million Litres	tonnes
USA	4,728	2.0%	6,490	19,326,298
Canada	290	2.0%	398	1,166,335
Europe	12,361	2.0%	16,969	38,708,957
C & S America	7,233	3.5%	12,542	33,941,158
Africa	4	25.0%	124	347,897
Asia/Pacific	6,721	5.0%	14,671	15,649,096
World	31,337	3.1%	51,194	109,139,741

For this business as usual case the GHG emission reductions from biofuel production and use increase from 168.9 million tonnes per year in 2014 to 263.9 million tonnes in 2030. This is a 56% increase in the GHG emission reductions.

One of the limiting factors in the growth of ethanol in the developed world is the 10% ethanol "blend wall". Fifteen percent ethanol has been demonstrated in North America and has been approved by the US EPA for all post 2001 vehicles. This scenario considers that E15 will be the fuel in the US, Canada, and Europe by 2030. To accommodate this we have increased the growth rate from 2% per year to 3% per year in these three regions and from 3.5% to 4% in Central and South America as US exports would be expected to decrease under this scenario and that market would be filled by production from the other Americas regions.

Table ES- 5 Forecast GHG Emission Reductions – High Level Ethanol 2030

Region	2014 Production	Growth rate	2030 Production	2030 GHG Emission Reductions
	Million Litres		Million Litres	tonnes
USA	54,126	3.0%	86,856	83,334,664
Canada	1,800	3.0%	2,888	2,812,651
Europe	5,471	3.0%	8,779	8,186,485
C & S America	28,826	4.0%	53,991	66,484,622
Africa	77	25.0%	2,721	2,795,471
Asia/Pacific	4,339	5.0%	9,471	9,719,371
World	94,639	2.8%	164,706	173,333,264

This scenario increases the GHG emission reductions by a further 19 million tonnes in 2030.

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.

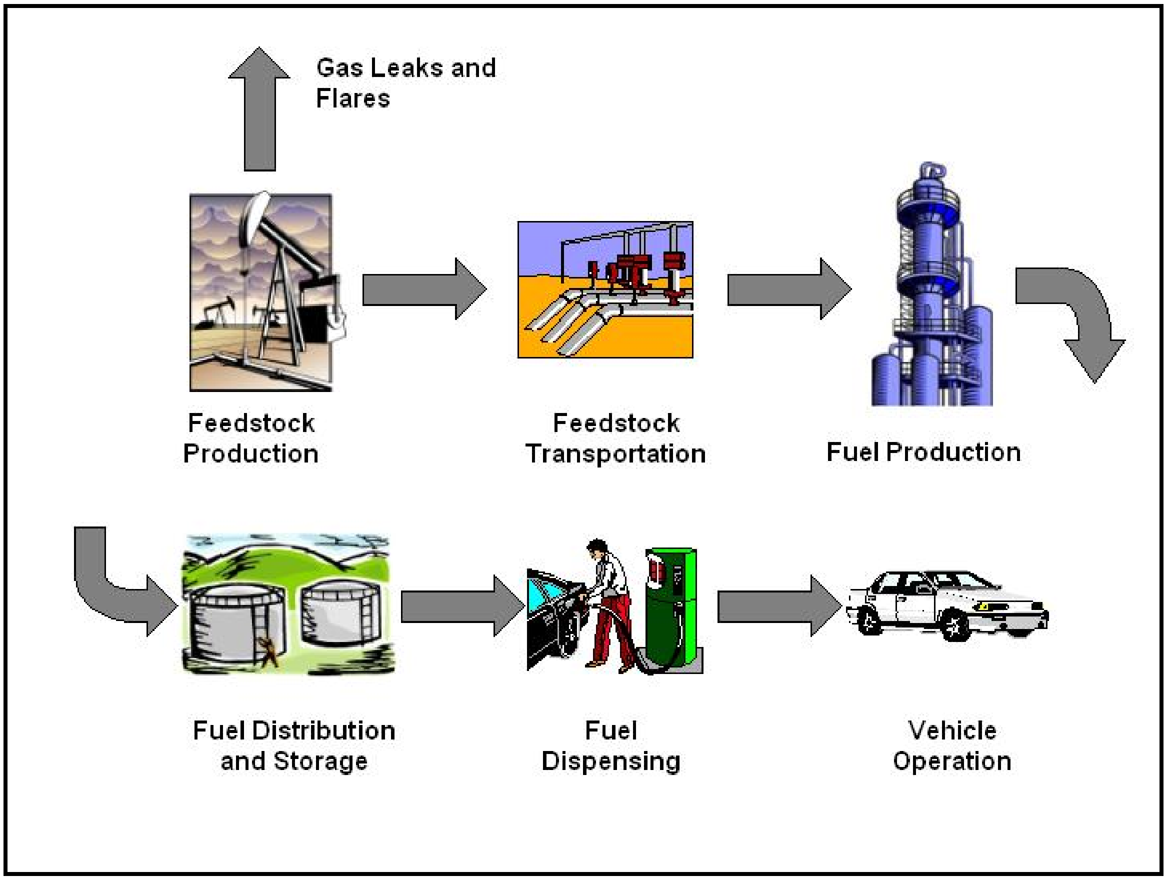
Specifically, LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by:

- 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.

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 1-1 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. This work was first undertaken in 2009 and much has changed since then, biofuel production levels are higher, biofuel production processes have become more efficient and more is known about the GHG emissions of fossil fuel systems.

The approach that has been used is similar to the 2009 approach; first the production of biofuels in the world for each of the major producing countries and the feedstocks used in each country is documented. This volume is then combined with revised estimates 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. Some recent LCAs of biofuels have included predicted emissions from theoretical indirect land use changes (ILUCs). However, there are several reasons for not including indirect emissions in this work.

1. There have been no credible assessments undertaken for the indirect effects of gasoline and diesel production. 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 generally suffer from a lack of transparency; it is often 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.
4. The ILUC models currently used don't properly include the more than 200 million ha of underutilized agricultural land in the world. Faced with increased demand, the models convert pasture and forests to agricultural land rather than utilize the available agricultural land.
5. As the ILUC models have been improved and refined, the ILUC emission estimates have generally been reduced. The first estimates of ILUC emissions in 2008 suggested that emissions were more than 100 g/MJ, while recent estimates have emissions less than 20 g/MJ, even with the known deficiencies in the models.
6. Recent evidence (Babcock & Iqbal, 2014) shows that most of the increased crop production has come from better utilization of the existing agricultural land rather than from the conversion of pasture and forests to agricultural land. The ILUC models do not reflect this intensification of production but rather project that most of the increased production is die to extensification of agricultural production.
7. Some economists (Rajagopal, 2015) have argued that ILUC emission penalties are an ineffective means to deal with leakage from systems and are not widely supported in the economics literature, and that other policies are available with better risk-reward profiles.

All 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 system providing the same product or service), 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 in 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 $(S\&T)^2$ Consultants Inc., which has data for Canada, the United States, Europe, Mexico, and India. 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 of 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.

The GHGenius model has been developed over the past fifteen 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.

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

- Vehicle Operation
  Emissions associated with the use of the fuel in the vehicle. Includes all greenhouse gases.
- Fuel Dispensing at the Retail Level
  Emissions associated with the transfer of the fuel at a service station from storage into the vehicles. Includes electricity for pumping, fugitive emissions, and spills.
- Fuel Storage and Distribution at all Stages
  Emissions associated with storage and handling of fuel products at terminals, bulk plants and service stations. Includes storage emissions, electricity for pumping, space heating, and lighting.
- Fuel Production (as in production from raw materials)
  Direct and indirect emissions associated with conversion of the feedstock into a saleable fuel product. Includes process emissions, combustion emissions for process heat/steam, electricity generation, fugitive emissions, and emissions from the life cycle of chemicals used for fuel production cycles.
- Feedstock Transport
  Direct and indirect emissions from transport of feedstock, including pumping, compression, leaks, fugitive emissions, and transportation from point of origin to the fuel refining plant. Import/export, transport distances, and the modes of transport are considered. Includes energy and emissions associated with the transportation infrastructure construction and maintenance (trucks, trains, ships, pipelines, etc.)
- Feedstock Production and Recovery
  Direct and indirect emissions from recovery and processing of the raw feedstock, including fugitive emissions from storage, handling, upstream processing prior to transmission, and mining.
- Feedstock Upgrading
  Direct and indirect emissions from the upgrading of bitumen to synthetic crude oil at a standalone facility, including fugitive emissions.
- Fertilizer Manufacture
  Direct and indirect life cycle emissions from fertilizers, and pesticides used for feedstock production, including raw material recovery, transport, and manufacturing of chemicals. This is not included if there is no fertilizer associated with the fuel pathway.
- Land use changes and cultivation associated with biomass derived fuels

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

- Carbon in Fuel from Air
  Carbon dioxide emissions credit arising from use of a renewable carbon source that obtains carbon from the air.
- Leaks and flaring of greenhouse gases associated with production of oil and gas
  Fugitive hydrocarbon emissions and flaring emissions associated with oil and gas production.
- Emissions displaced by co-products of alternative fuels
  Emissions displaced by co-products of various pathways. System expansion is used to determine displacement ratios for co-products from biomass pathways.
- Vehicle assembly and transport
  Emissions associated with the manufacture and transport of the vehicle to the point of sale, amortized over the life of the vehicle.
- Materials used in the vehicles
  Emissions from the manufacture of the materials used to manufacture the vehicle, amortized over the life of the vehicle. Includes lube oil production and losses from air conditioning systems.

For this work, only the GHG emissions associated with the production and use of the transportation fuel are considered.

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.

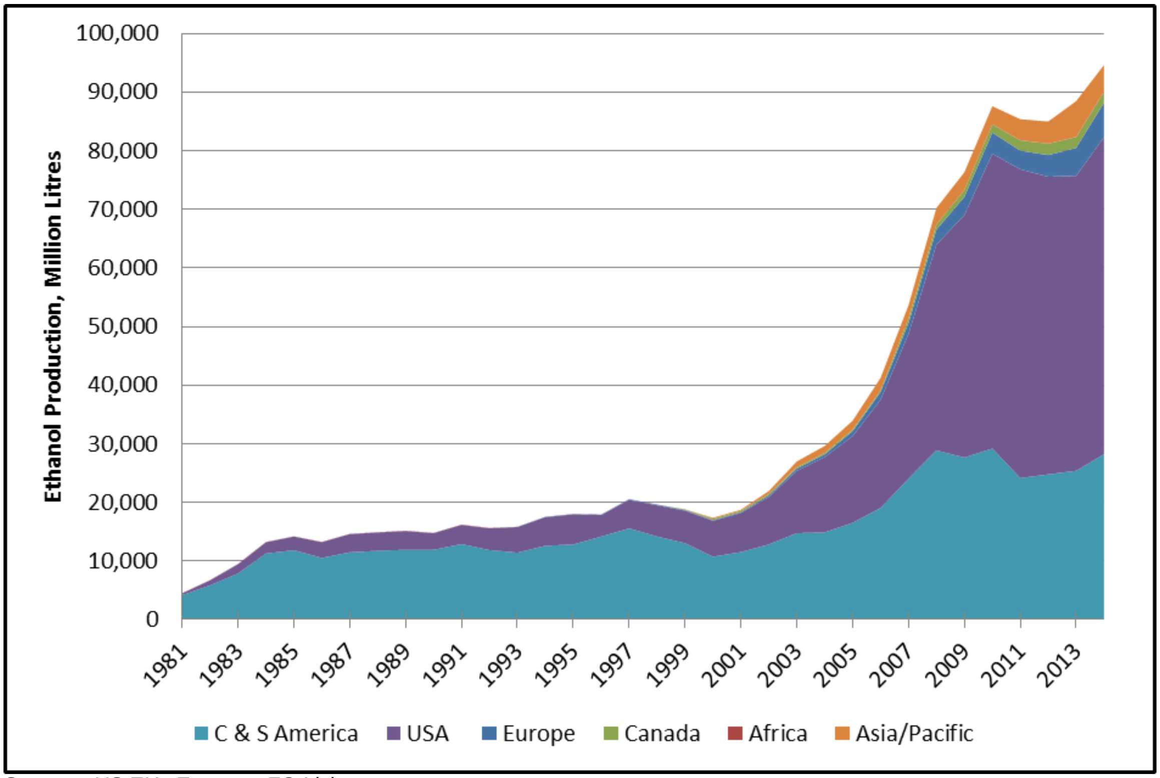
2. GLOBAL BIOFUEL PRODUCTION

Information on global biofuel production has been obtained from a variety of sources. The US Energy Information Administration reports on biofuel production by country up to 2012. The fuel ethanol dataset starts in 1980 and the biodiesel dataset starts in 2000. European data on biofuels production was extracted from Eurostat by country up to 2013. This data was inserted into the EIA data set. F.O. Lichts data on biodiesel and ethanol production was used for 2014 and for 2013 for non-European countries. Some data from the USDA Gain reports was used to fill in data gaps for 2013 and 2014, and finally some 2013 and 2014 values were extrapolated from earlier EIA data when no other source was available.

2.1 FUEL ETHANOL PRODUCTION

Fuel ethanol is currently produced in more than 50 countries from a variety of sugar and starch based feedstocks. The production of fuel ethanol has increased more than threefold over the past decade as shown in the following figure.

Figure 2-1 Global Fuel Ethanol Production



Sources: US EIA, Eurostat, FO Lichts.

The top ten producers for the year 2014 are shown in the following table. The primary feedstock used in each region has been provided by F.O. Lichts. Corn and sugarcane feedstocks dominate world ethanol production. Other grains and sugar beets are used in some locations.

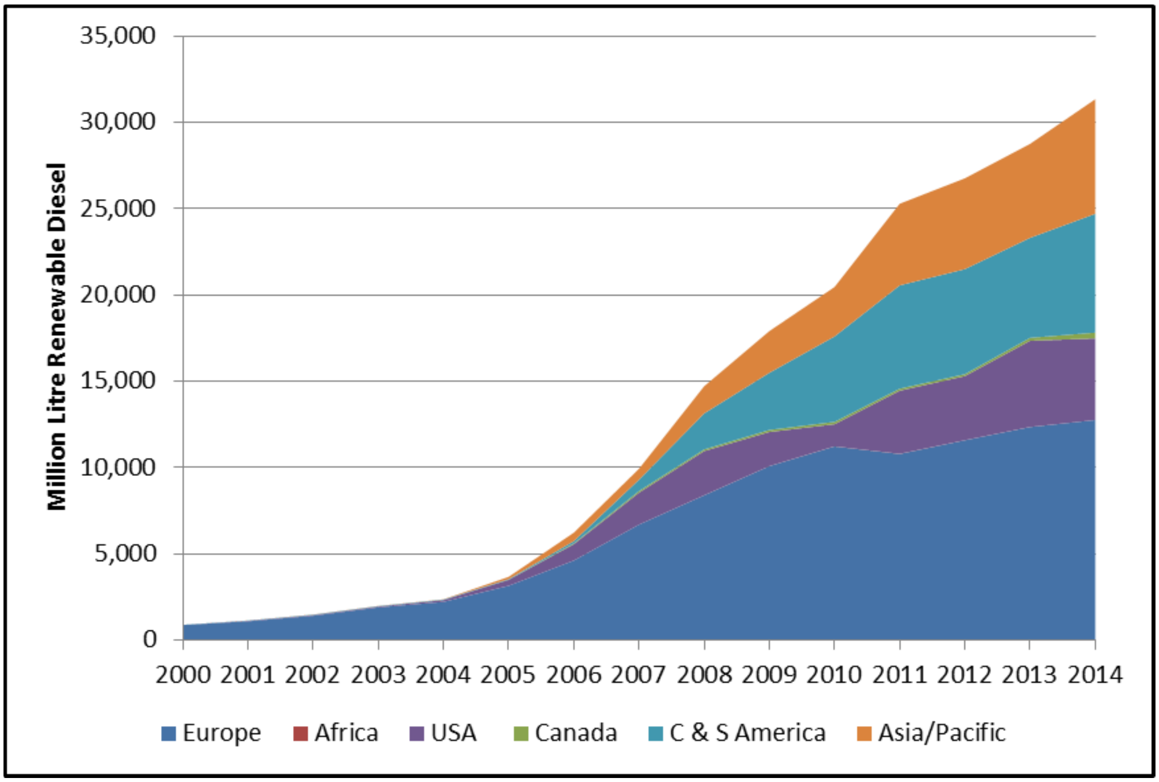
Table 2-1 Top Fuel Ethanol Producers

Country or Region	2013	2014	Primary Feedstock
	Million Litres		
United States	50,341	54,126	Corn
Brazil	23,721	26,328	Sugarcane
China	2,634	2,403	Corn
Canada	1,800	1,800	Corn/wheat
France	904	1,180	Wheat/sugar beet
Thailand	950	1,058	Sugarcane
Germany	723	920	Wheat/sugar beet
United Kingdom	524	760	Wheat/sugar beet
Argentina	475	670	Corn/sugarcane
India	2,063	587	Sugarcane/molasses
Total	88,458	94,639	

2.2 Biodiesel Production

World biodiesel production has increased tenfold during the past decade as shown in the following figure. Biodiesel is produced commercially in approximately 60 countries around the world.

Figure 2-2 Global Biodiesel Production



Sources: US EIA, Eurostat, FO Lichts.

The top ten biodiesel and renewable diesel producing countries in the world in 2014 are shown in the following table.

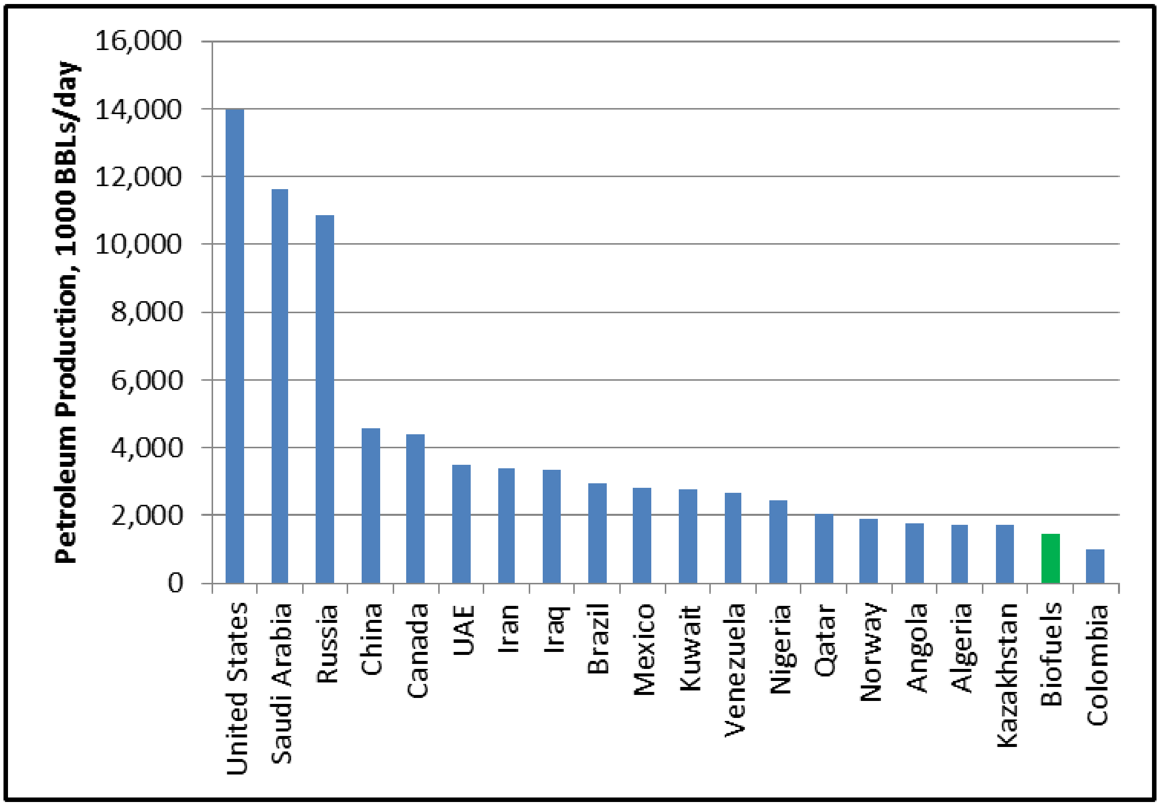
Table 2-2 Top Biodiesel Producers

	2013	2014	Primary Feedstocks
	Million litres		
United States	4,998	4,728	Soy, corn oil, canola oil, used cooking oil
Brazil	2,901	3,401	Soybeans
Germany	3,305	3,390	Rapeseed, used cooking oil
Indonesia	2,203	3,107	Palm
Argentina	2,256	2,881	Soybeans
France	2,386	2,090	Rapeseed
Netherlands	1,505	1,500	Palm, tallow, used cooking oil
Thailand	1,044	1,166	Palm
Spain	800	847	Rapeseed, used cooking oil
Singapore	1,000	800	Tallow, palm, used cooking oil
Total World	28,752	31,337	

2.3 SUMMARY

World biofuel production has now surpassed 120 billion litres of annual production. After accounting for energy contents, this is displacing 1.45 million barrels of crude oil derived petroleum products per day. If all of the biofuel were produced in one country, that country would be the world’s 19th largest crude oil producer, after Kazakhstan but ahead of Columbia. The top 20 oil producers are shown in the following figure.

Figure 2-3 Top 20 Petroleum Producers in 2014



The production and use of this quantity of oil and the products produced from it creates about 275 million tonnes of GHG emissions annually. The production and use of biofuels does have some of its own GHG emissions so the total emission savings is less than this 275 million tonnes and will be discussed in the next section.

3. GHG EMISSIONS – PETROLEUM FUELS

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, the specifications and the mix of petroleum products produced.

The GHGenius model has been used to estimate the GHG emissions for gasoline and diesel fuel. The 100 year 2007 IPCC GWPs have been used for this work, as they are still the most common set of emission factors used. The emissions of carbon monoxide and unburned hydrocarbons have been converted to CO_2 based on their carbon contents in this analysis. The emissions are reported on a lower heating value basis. Slightly different GHG emissions have been used for different regions of the world, the model has detailed emissions for the United States, Canada, Europe, and the emissions for the rest of the world have been estimated from the other values. The results are shown in the following table.

Table 3-1 GHG Emissions Petroleum Fuels – 2007 GWP

Region	Gasoline	Diesel Fuel
	g/MJ (LHV)	
United States	102.0	102.4
Canada	97.7	98.1
Europe	96.4	96.8
Central and South America	95.5	96.3
Africa	94.5	95.3
Asia/Pacific	95.5	96.3

The 2013 GWPs from the IPCC have higher emission factors for methane and can exclude or include climate forcing feedback. The following table shows the gasoline and diesel emissions using the 100 year 2013 GWPs with feedback. These values are slightly higher due to the higher GWP for methane. Using the 2007 GWP is a conservative approach.

Table 3-2 GHG Emissions Petroleum Fuels – 2013 GWP

Region	Gasoline	Diesel Fuel
	g/MJ (LHV)	
United States	103.1	104.3
Canada	98.4	99.6
Europe	97.7	98.8
Central and South America	96.8	98.3
Africa	95.8	97.3
Asia/Pacific	96.8	98.3

4. GHG EMISSIONS – BIOFUELS

The GHG emissions are more complex and varied than the emissions for petroleum fuels. There are different feedstocks used in different parts of the world, different production practices can be used on the same feedstock in different parts of the world, and soil type and climatic conditions can strongly influence the GHG emissions for feedstock production. The GHG emissions for biofuels are also influenced by co-product allocation methods which can have a strong impact on the results. The emissions for the production of ethanol and biodiesel are discussed below.

4.1 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 wheat 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 GHG estimates has been considered in the estimates for these fuels.

The fraction of each feedstock that is used in the various regions is shown in the following table. This data along with the GHG emissions associated with the feedstock and the region will be used to calculate the total GHG emission reductions due to ethanol. The European fractions are from ePure (2015). The other values are estimates from various sources and our calculations.

Table 4-1 Regional Feedstock Use

Region	Corn	Wheat	Sugar Cane	Sugar Beet
United States	1.0	0.0	0.0	0.0
Canada	0.75	0.25	0.0	0.0
Europe	0.42	0.41	0.0	0.17
Central and South America	0.02	0.0	0.98	0.0
Africa	0.5	0.0	0.5	0.0
Asia/Pacific	0.5	0.0	0.5	0.0
World	0.64	0.03	0.32	0.01

Each of the feedstock types is discussed briefly below.

4.1.1 Corn Ethanol

The US is the dominant ethanol producer in the world and most of their production is based on corn. 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. These emissions include the contribution of methane and nitrous oxide from the combustion of the ethanol. The value used for corn ethanol in Europe is higher than the value found in BioGrace and the RED, but that value includes benefits from co-generation and a more favourable treatment of co-products. The use of this value is more conservative.

Table 4-2 Corn Ethanol GHG Emissions

Source	GHG Emissions, g CO_2eq/MJ (LHV)
United States	56.7
Canada	54.8
China	57.1
Europe	52.6

4.1.2 Other Grain Ethanol

Other grains, such as wheat and rye, are used to produce ethanol in the EU and in western Canada. The GHG emissions for wheat ethanol in GHGenius are shown in the following table. The value for Europe is the same as the EU RED default value, except we have removed the extra energy in the regulations and applied a more conservative co-product allocation method.

Table 4-3 Wheat Ethanol GHG Emissions

Source	GHG Emissions, g CO_2eq/MJ (LHV)
Canada	42.5
Europe	55.2

4.1.3 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. These emissions are for Brazilian ethanol used in Brazil. It can be seen that there is a relatively small range for the emissions.

Table 4-4 Sugar Cane Ethanol GHG Emissions

Source	GHG Emissions, g CO_2eq/MJ (LHV)
GHGenius, 50% mechanical harvested	37
California Air Resources Board	34-36
EU RED (JRC), excluding transport	17

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. The GHGenius value of 37 g CO_2eq/MJ will be used.

4.1.4 Sugar Beet Ethanol

Sugar beets are used as a feedstock in Europe. The GHGenius value for sugar beet ethanol in Europe is 56.6 g CO_2eq/MJ (LHV). The EU RED (JRC, 2008) reports the emissions for sugar beet ethanol of 40 g CO_2eq/MJ (LHV). Half of the difference is due to the co-product allocation and the rest is due to different assumptions about farming practices. A value of 45 g CO_2eq/MJ (LHV) is used in this work.

4.2 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. Six biodiesel feedstocks are considered, rapeseed oil, soy oil, palm oil, distillers corn oil, used cooking oil and tallow. The estimated fractions processed of each feedstock in each region are summarized in the following table.

Table 4-5 Biodiesel Feedstock Fractions

	Rape	Soy	Palm	UCO	Tallow	Corn Oil
Europe	0.58	0.10	0.15	0.10	0.04	0.03
Africa	0.00	0.00	0.00	1.00	0.00	0.00
Canada	0.60	0.00	0.00	0.20	0.15	0.05
USA	0.12	0.53	0.00	0.14	0.10	0.11
C & S America	0.00	0.85	0.05	0.05	0.05	0.00
Asia/Pacific	0.00	0.00	0.60	0.20	0.20	0.00
World	0.25	0.32	0.20	0.12	0.09	0.03

Like ethanol, the co-product allocation approach used has a strong impact on the results. Whereas the co-production allocation used in the RED lowered the GHG emissions for ethanol, the allocation increases the GHG emissions for biodiesel. The biodiesel GHG emission factors are discussed below.

4.2.1 Rapeseed Biodiesel

Rapeseed biodiesel accounts for about 25% of the world's biodiesel feedstock according to our estimates. Most of this is produced and used in Europe, the US, and Canada. The GHG emissions for rapeseed biodiesel in GHGenius are 16.3 g CO_2eq/MJ when European rapeseed is processed, 17.2 g CO_2eq/MJ for the US and only 5.0 g CO_2eq/MJ when Canadian canola is processed. These values are much lower than the 52 g CO_2eq/MJ with the EU RED default values. However, in addition to the co-product allocation issue, the RED default values increase energy and some chemical inputs by 40% and the biodiesel energy use is much too high for normal practice even before the arbitrary 40% increase. We have used the GHGenius values as shown above.

4.2.2 Soy Biodiesel

The EU-RED values for soybean biodiesel is 57 g CO_2eq/MJ however this assumes that soybeans are transported to Europe and crushed there and the allocation approach used puts more of the transportation emissions on the oil. There are also the issues of the 40% of energy use and the high energy use before the increase.

Soy biodiesel produced in the US has emissions of 8.8 g CO_2eq/MJ in GHGenius. In Europe the emissions are similar. This value will be used for all producing regions.

4.2.3 Palm Biodiesel

The EU-RED has values ranging from 37 to 68 g CO_2eq/MJ for palm oil biodiesel depending on the capture of methane from the effluent systems at palm oil mills. Only about 10% of mills have methane capture and would have the low rate. Some palm is grown in drained peat soils and these soils produce very high GHG emissions as the peat oxidizes. These peat emissions can increase the GHG emissions almost an order of magnitude higher than diesel fuel emissions. However only 10 to 20% of the palm is grown on these peat soils, so the palm oil biofuels probably have emissions about the same as petroleum fuels. No GHG emission benefit has been assumed for palm biofuels here.

4.2.4 Used Cooking Oils

The emissions from waste cooking oil in GHGenius range from 5 to 10 g CO_2eq/MJ. The EU-RED value for waste oil biodiesel uses a different allocation method and has a result of 14 g CO_2eq/MJ but this includes the extra processing energy assumed in the default values. A value of 10 g CO_2eq/MJ is used for all regions for used cooking oil.

4.2.5 Tallow Biodiesel

Tallow is rendered animal fats. In GHGenius, the emissions for tallow biodiesel range from 6 to 35 g CO_2eq/MJ depending on the location. The large range is mostly a function of the co-product credit from the meat and bone meal that is also produced from the system. The EU RED uses the same default value for tallow as for used cooking oil. A value of 20 g CO_2eq/MJ for all regions is used for this work.

4.2.6 Distillers Corn Oil

An emerging biodiesel feedstock in the United States and Canada is distillers' corn oil. This is corn oil that is extracted from the dry mill ethanol production process. In GHGenius the emissions are 13.5 g CO_2eq/MJ in the United States and 15.6 g CO_2eq/MJ in Canada. These values are used in the modelling.

5. 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 unit of biofuel. This information is shown below.

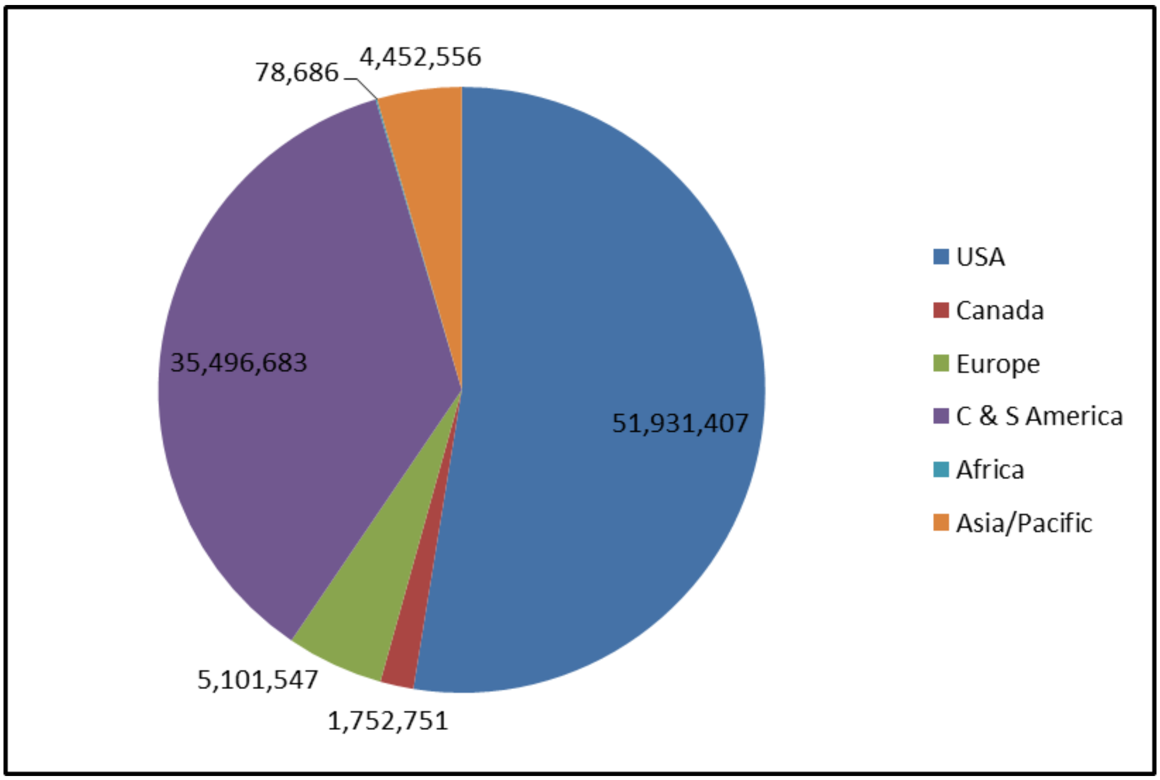
5.1 Fuel Ethanol

The GHG emission reductions from fuel ethanol in 2014 are shown in the following table. The Americas have experienced the greatest reductions in GHG emissions from the production and use of fuel ethanol.

Table 5-1 Fuel Ethanol GHG Emission Reductions

Region	2014	2014	GHG Reduction	GHG Reduction
	Million Litres	GJ Bioenergy	kg CO_2eq/GJ	tonnes
USA	54,126.0	1,146,388,680	45.3	51,931,407
Canada	1,800.0	38,124,000	46.0	1,752,751
Europe	5,471.0	115,875,780	44.0	5,101,547
C & S America	28,826.2	610,538,068	58.1	35,496,683
Africa	76.6	1,622,382	48.5	78,686
Asia/Pacific	4,339.0	91,900,020	48.5	4,452,556
World	94,638.8	2,004,448,930	49.3	98,813,630

Figure 5-1 Fuel Ethanol GHG Emission Reductions 2014



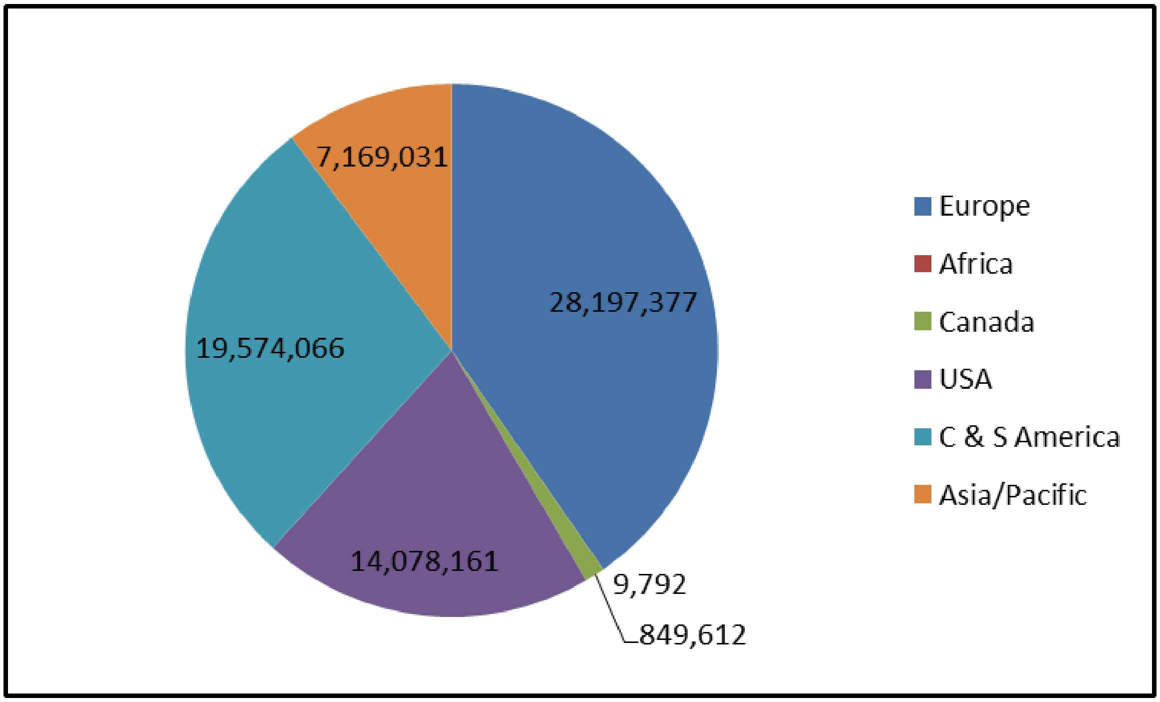
5.2 BIODIESEL

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 5-2 Biodiesel GHG Emission Reductions

Region	2014	2014	GHG Reduction	GHG Reduction
	Million Litres	GJ Bioenergy	kg CO_2eq/GJ	tonnes
USA	4,727.7	155,068,023	90.8	14,078,161
Canada	290.0	9,512,000	89.3	849,612
Europe	12,361.3	405,449,306	69.5	28,197,377
C & S America	7,233.1	237,247,033	82.5	19,574,066
Africa	3.5	114,800	85.3	9,792
Asia/Pacific	6,721.0	220,449,912	32.5	7,169,031
World	31,336.6	1,027,841,074	68.0	69,878,039

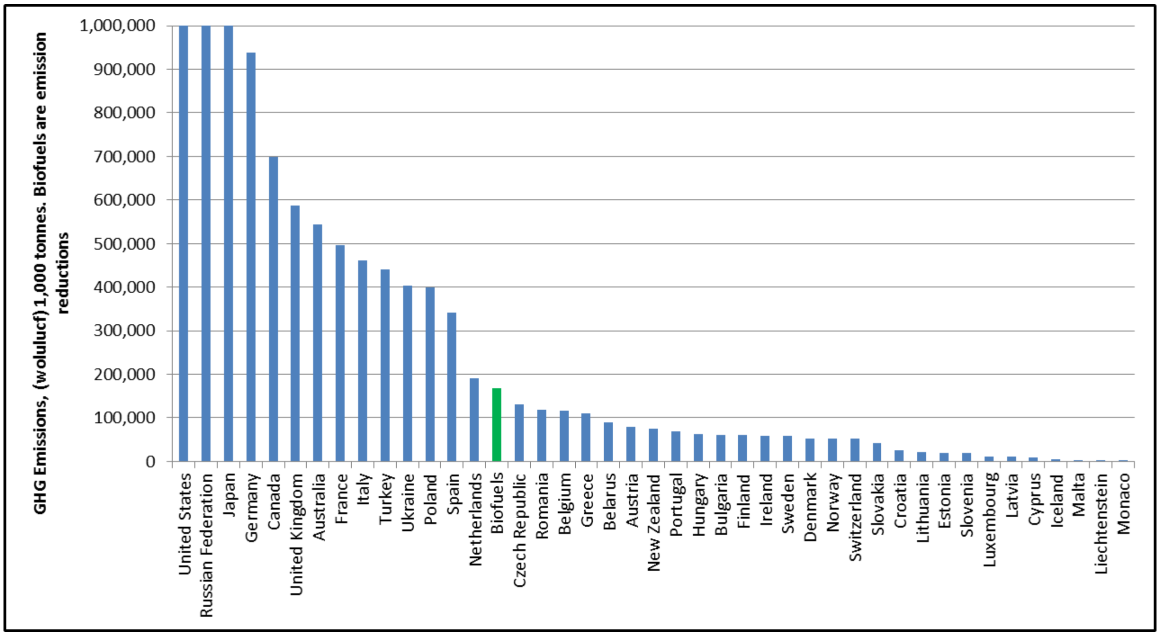
Figure 5-2 Biodiesel GHG Emission Reductions 2014



5.3 SUMMARY

The total GHG emission reductions from biofuels forecast for 2014 are 168,690,000 tonnes. Only 14 UNFCCC Annex 1 countries have emissions greater than this value. The GHG emissions in 28 Annex 1 countries are lower than this value. The following figure compares the emission reductions from biofuels to the national GHG emissions (without land use, land use change, and forestry) from Annex 1 countries for the year 2012. The large emitters, the US at 6,487,847 thousand tonnes, the Russian federation at 2,297,152 thousand tonnes, and Japan at 1,343,137 thousand tonnes, are truncated in the figure for clarity.

Figure 5-3 Biofuel Reduction Comparison to National GHG Emissions



6. Future Opportunities

While the GHG emission reductions delivered by biofuels are substantial, there is still room for growth in the sector. Forecasts for business as usual are reviewed and the GHG emission reductions in 2030 are calculated from these forecasts. A high penetration scenario, where 15% ethanol is used in the developed world markets is also considered.

6.1 Business as Usual

Forecasts are always a challenge especially with relatively new markets. In addition, new regulations on fuel economy of vehicles in the developed world are expected to have a significant impact on the demand for transportation fuels. Several forecast for biofuel production and consumption were reviewed and two of them are discussed below.

6.1.1 OECD Agricultural Outlook 2015-2024

The OECD publishes an agricultural outlook each year and there have been chapters on biofuels in recent publications. The OECD expects global ethanol and biodiesel production to expand to reach, respectively, almost 134.5 and 39 billion litres by 2024. Most of the additional ethanol production is expected to take place in Brazil. The OECD estimates for ethanol production in 2014 are higher than reported here and the ethanol growth rate between 2014 and 2015 is 1.7% per year.

Incentives based on national biofuel policies will continue to influence biodiesel production patterns. Indonesia will surpass the United States and Brazil in the latter years of the outlook period to become the second largest biodiesel producer behind the EU. The forecast growth rate for biodiesel is 2.5% per year. Argentina and Indonesia continue to dominate biodiesel exports, the United States and EU are the only significant importers.

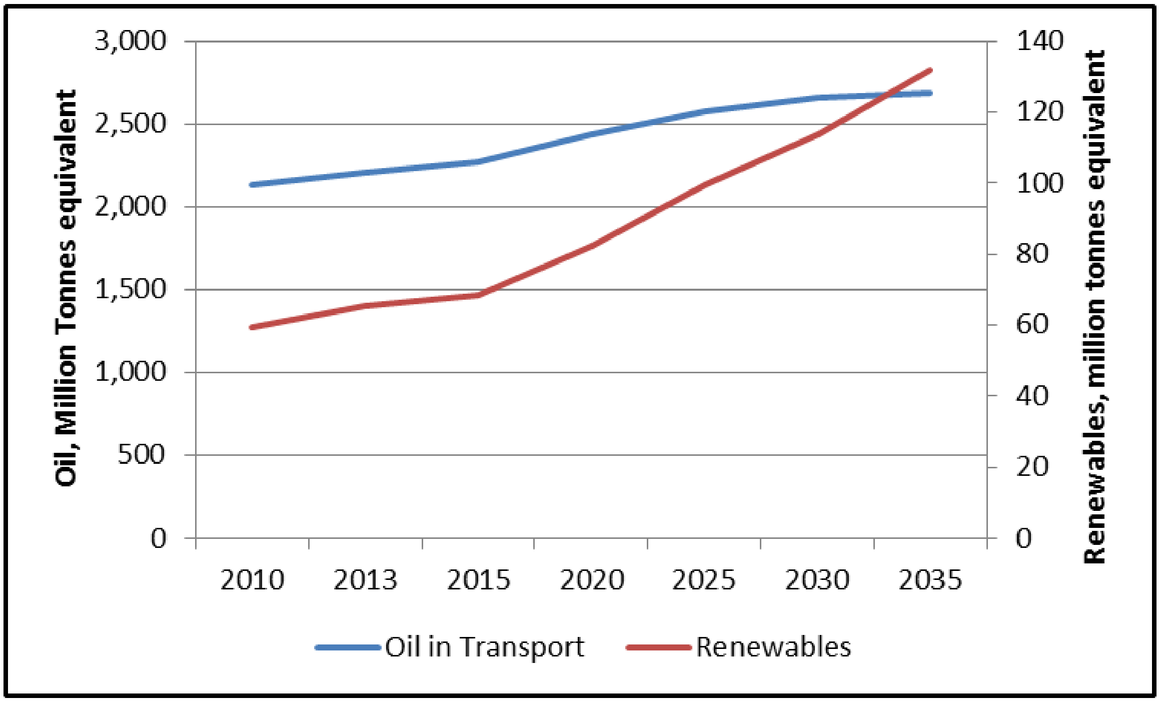
The 2015 OECD forecasts have been lowered from previous years.

6.1.2 BP Energy Outlook 2035

BP publishes annual energy forecasts. These forecasts reflect BPs best effort to describe a “most likely” trajectory of the global energy system, based on their views of likely economic and population growth, as well as developments in policy and technology. The latest forecast was published in February 2015.

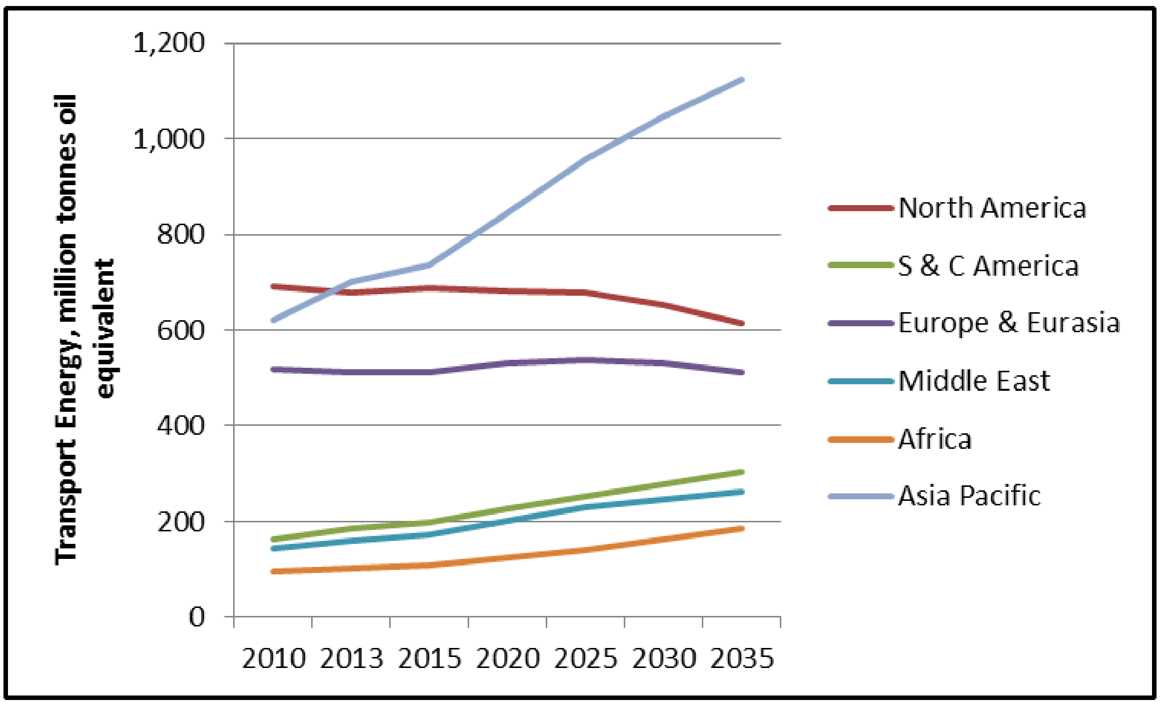
BP forecast a 1.3% growth in liquid fuels for transport and a 3.3% growth in biofuel production. Their forecasts are shown in the following figure.

Figure 6-1 BP Forecast 2035



BP also forecast energy demand on a regional basis and the regional transport demand is shown in the following figure. Reductions in demand in North America and Europe are overshadowed by growth in the rest of the world, especially the Asia Pacific region.

Figure 6-2 BP Forecast Regional Growth



BP forecast the regional biofuel production but does not separate it into ethanol and biodiesel. Their annual growth rates between 2013 and 2030 are shown in the following table.

Table 6-1 BP Forecast Biofuel Growth Rates

Region	2013 Production, million tonnes of oil equivalent	2013-2030 Annual Growth, %
North America	29.5	2.5
S & C America	18.8	3.8
Europe & Eurasia	11.0	2.1
Middle East	0.0	0.0
Africa	0.0	26.7
Asia Pacific	6.1	6.0
Total	65.3	3.3

6.1.3 Forecast GHG Emissions

The production scenario for 2030 has been developed from the 2014 production data and slightly more conservative growth rates than those used by BP. The average growth rate is 2.77%. The same mix of feedstock is used in each region. This means that no cellulosic ethanol has been included in the 2030 ethanol production forecast. Commercial scale cellulosic ethanol plants are now in their first years of production but no peer reviewed GHG emission information from this commercial production is currently available. These cellulosic ethanol process are widely expected to have lower GHG emissions than corn ethanol plants, these additional GHG emissions are not included in the forecasts. Furthermore no improvement in the carbon intensity of the biofuel feedstock or production or increase in the carbon intensity of the petroleum products is assumed; although historical we see reductions in biofuel carbon intensity and increases in petroleum carbon intensity over time. The ethanol production and GHG emission reductions are shown in the following table, they are likely to be very conservation due to the factors mentioned above.

Table 6-2 Forecast GHG Emission Reductions – Ethanol 2030

Region	2014 Production	Growth rate	2030 Production	2030 GHG Emission Reductions
	Million Litres		Million Litres	tonnes
USA	54,126	2.0%	74,303	71,290,693
Canada	1,800	2.0%	2,471	2,406,151
Europe	5,471	2.0%	7,511	7,003,331
C & S America	28,826	3.5%	49,984	61,550,753
Africa	77	25.0%	2,721	2,795,471
Asia/Pacific	4,339	5.0%	9,471	9,719,371
World	94,639	2.8%	146,461	154,765,770

The biodiesel forecast GHG emission reductions are shown in the following table. The total growth rate for the biodiesel is higher because of the different distribution of production regions.

Table 6-3 Forecast GHG Emission Reductions – Biodiesel 2030

Region	2014 Production	Growth rate	2030 Production	2030 GHG Emission Reductions
	Million Litres		Million Litres	tonnes
USA	4,728	2.0%	6,490	19,326,298
Canada	290	2.0%	398	1,166,335
Europe	12,361	2.0%	16,969	38,708,957
C & S America	7,233	3.5%	12,542	33,941,158
Africa	4	25.0%	124	347,897
Asia/Pacific	6,721	5.0%	14,671	15,649,096
World	31,337	3.1%	51,194	109,139,741

For this business as usual case the GHG emission reductions from biofuel production and use increase from 168.9 million tonnes per year in 2014 to 263.9 million tonnes in 2030. This is a 56% increase in the GHG emission reductions.

6.2 HIGHER ETHANOL BLENDS

One of the limiting factors in the growth of ethanol in the developed world is the 10% ethanol "blend wall". Fifteen percent ethanol has been demonstrated in North America and has been approved by the US EPA for all post 2001 vehicles. This scenario considers that E15 will be the fuel in the US, Canada, and Europe by 2030. To accommodate this we have increased the growth rate from 2% per year to 3% per year in these three regions and from 3.5% to 4% in Central and South America as US exports would be expected to decrease under this scenario and that market would be filled by production from the other Americas regions.

Table 6-4 Forecast GHG Emission Reductions – High Level Ethanol 2030

Region	2014 Production	Growth rate	2030 Production	2030 GHG Emission Reductions
	Million Litres		Million Litres	tonnes
USA	54,126	3.0%	86,856	83,334,664
Canada	1,800	3.0%	2,888	2,812,651
Europe	5,471	3.0%	8,779	8,186,485
C & S America	28,826	4.0%	53,991	66,484,622
Africa	77	25.0%	2,721	2,795,471
Asia/Pacific	4,339	5.0%	9,471	9,719,371
World	94,639	2.8%	164,706	173,333,264

This scenario increases the GHG emission reductions by a further 19 million tonnes in the year 2030.

7. References

Babcock, B., Iqbal, Z. 2014. Using Recent Land Use Changes to Validate Land Use Change Models. http://www.card.iastate.edu/publications/dbs/pdffiles/14sr109.pdf

BioGrace. 2015. Version 4. http://www.biograce.net/home

BP. 2015. BP Energy Outlook 2035. http://www.bp.com/energyoutlook

ePure. 2015. Share of Feedstock. http://epure.org/media/1267/share-of-feedstock-used.png

Eurostat. 2015. Supply, transformation and consumption of renewable energies - annual data (nrg_107a). http://ec.europa.eu/eurostat/data/database#

F.O. Lichts. 2015. The World Biodiesel Balance 2015. Vol. 13 No. 15 April 14, 2015.

F.O. Lichts. 2015. The World Ethanol Balance 2015. Vol. 14 No. 4 October 20, 2015.

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

OECD/Food and Agriculture Organization of the United Nations. 2015. OECD-FAO Agricultural Outlook 2015, OECD Publishing, Paris. http://dx.doi.org/10.1787/agr_outlook-2015-en

Rajagopal. 2015. On mitigating emissions leakage under biofuel policies. GCB Bioenergy. http://dx.doi.org/10.1111/gcbb.12262

US EIA. 2015. Total Petroleum and Other Liquids Production 2014. http://www.eia.gov/beta/international/data/browser/#

US Energy Information Administration. 2015. International Energy Statistics. Biofuels Production. http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=79&pid=79&aid=1

USDA. 2014. EU Biofuels Annual 2014. http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_The%20Hague_EU-28_7-3-2014.pdf

USDA. 2015. Gain Reports. http://gain.fas.usda.gov/Lists/Advanced%20Search/AllItems.aspx