The Future of Biofuels: "An Investigation of Science and Policy in the UK/EU"

Payman Moayedi-Araghi

Faculty of Science and Technology

The Future of Biofuels: “An Investigation of Science and Policy in the UK/EU”

Payman Moayedi-Araghi

A thesis submitted in partial fulfilment of the requirements of the University of Westminster for the degree of Doctor of Philosophy

September 2014

AUTHOR'S DECLARATION

I declare that the present work was carried out in accordance with the Guidelines and Regulations of the University of Westminster. The work is original except where indicated by special reference in the text.

The submission as a whole or part is not substantially the same as any that I previously or am currently making, whether in published or unpublished form, for a degree, diploma or similar qualification at any university or similar institution.

Until the outcome of the current application to the University of Westminster is known, the work will not be submitted for any such qualification at another university or similar institution.

Any views expressed in this work are those of the author and in no way represent those of the University of Westminster.

Signed Date

”If the facts don’t fit the theory, change the facts”

Albert Einstein

Abstract

Biofuels were first used, as motor fuel (bioethanol) in 1860 in Germany and soon after, biofuels became the main rival for petroleum. But the abundance and the low price of fossil fuels had severe impact on the use of biofuels. Decades later, in 1970s, the shortage of fossil fuels due to the geopolitical conflicts, and the subsequent rise in the price of crude oil in 2000s, alongside energy security and climate change concerns, once again attracted the attention of governments to the use of biofuels. As a result of investment in biofuel production, the share of biofuels among the total renewable energy sources has increased since the beginning of the new century. The crop-based fuels (the so-called first generation biofuels) were considered as panacea to solve energy problems and environmental concerns. At the same time, research in advanced biofuel production methods, i.e. the second (non-food crops and residues) and the third (algae) generation has increased. However, in 2007-2008, biofuels were blamed for pushing up food prices, failing to meet environmental standards, and destroying natural habitats. As such, the use of first generation biofuels has been controversial. As for the second and the third generation biofuels, there is a need for further technological breakthrough. Currently, they cannot compete with crude oil economically, and are not commercially viable yet. In addition, fracking and the discovery of the new shale gas resources add further complication to this already complicated case.

Although there is vast number of publications on biofuels, and they have been discussed extensively, to date, very little effort has been made to integrate the knowledge to provide new ideas to inform policy. The aim of this study is to investigate, bring together, and analyse the current biofuel science and regulations to provide recommendations for policy-makers in the UK/EU. Therefore, an extensive and critical literature review of the refereed journals, books, relevant publications, and official policy documents was carried out in this study, and views of the experts in three different sectors (academic, governmental, and industrial/private) were collated and analysed. The participants were recruited based on purposive sampling, and the semi-structured qualitative interviewing method was adopted. The participants' views

were analysed in relation to the published literature in order to drive an inclusive and integrated insight to develop novel recommendations for the biofuels agenda and extend the knowledge about this platform.

This thesis suggests that, while the first generation biofuels are problematic, it is likely that they will remain dominant until 2022. The fate of the second generation biofuels is mainly determined by the advances in technology, and this type could become dominant beyond 2022. The potential of algae for the third generation biofuels is being increasingly recognised; however, to date, it is difficult to predict any time period for this method to become a commercial reality.

The future of biofuels is very much related to the price of fossil fuels. If the global supply of fossil fuels continues to be tight, the price of crude oil may go above US$100 per barrel beyond 2030. Increasing crude oil prices is interpreted as increasing demand for biofuels in the future. A robust development in biofuels research and technology, and tighter mandatory policies for biofuel blending is forecasted. But, if shale gas resources are used extensively in the coming years, the price of crude oil may decrease/stay under US$ 100 per barrel and as a result, at least the current level of investment in biofuels technology may be kept. However, a backing away from investing in biofuels and re-focusing on other climate mitigation methods beyond 2030 is also possible but very unlikely.

Based on the results of this study, there is no single, simple and generic solution for the issues surrounding biofuels. In this context, a range of recommendations are provided, a major one is for the UK/EU policy makers to push for the establishment of an international biofuels governing body, supported by the UN, to oversee sustained global biofuels production and consumption.

Acknowledgement

This dissertation marks the end of a long journey. On this journey, I saw many shifts and turns, ups and downs, and hopes and fears. I saw a revolution, I saw a war, I saw a hopeless generation, I lost classmates, I lost friends...but I never lost my vision. I left my homeland, I started again and I knew this long journey would come to an end. Today is the day. This journey would not have been possible without the support, faith and guidance of kind people around me, to only some of whom it is possible to give particular mention here:

I would like to express the most sincere gratitude to my Director of Studies, Professor Tajalli Keshavarz, who has been a true friend in the final years of this journey. He supported me, guided me, encouraged me, gave me freedom and courage and not to mention his unsurpassed knowledge.

I would like to extend my gratitude to Dr. Sharron McEldowney, Professor Damien Ridge and Dr. Marie Polly, for their invaluable advice, guidance and friendship during all these years.

I would also like to thank my true friends, for their undeniable support and priceless encouragement throughout.

Last, but by no means least, I would like to thank my wife, Roxana, for her support and great patience at all times. My parents, brother, in laws, aunts and uncles have given me their precious encouragement throughout, for which my mere expression of thanks likewise does not suffice.

Table of Content **Page**

Table of Content **Page**

Table of Content | **Page**

Table of Content **Page**

Table of Figures

Page

Table of Figures

Table of Tables

List of Abbreviations

ABE:	Acetone–butanol–ethanol fermentation
ABO:	Algal Biomass Organization
bbls:	Billion barrels
bblsoe:	Billion barrels oil equivalent
bboe:	Billion barrel of oil equivalent
BGS:	British Geological Survey (UK)
Bio-SNG:	Bio Synthetic Natural Gas
BtL:	Biomass to liquid
CAP:	Common Agricultural Policy (EU)
CBP:	Consolidated bioprocessing
CHP:	Combined heat and power
CNG:	Compressed Natural Gas
CO_2e/kWh:	CO_2 equivalent per kilowatt-hour
CtL:	Coal to liquids
DDGS:	Dried Distillers Grains and Solubles
DECC:	Department of Energy and Climate Change (UK)
DfT:	Department of Transport (UK)
DME:	Dimethyl ether
DOE:	US Department of Energy
EABA:	European Algae Biomass Association
EIA:	US Energy Information Agency
EISA:	Energy Independence and Security Act (USA)
EJ:	Exajoule; (1 EJ = 10^{18} J)
EOR:	Enhanced Oil Recovery
EPA:	Environmental protection agency (USA)
EROI:	Energy return on investment
ETBE:	Ethyl tertiary butyl ether
FAME:	Fatty Acid Methyl Esters
FAO:	UN Food Agency
FQD:	Fuel Quality Directive (EU)
FT:	Fischer–Tropsch
Gasohol:	A fuel consisting of a blend of ethanol and unleaded petrol
Gb:	Gigabarrels, 1 billion barrels
GBEP:	Global BioEnergy Partnership
GHG:	Green house gas
GoBiGas:	Göteburg Biomass Gasification Project (Sweden)
GtOE:	Gigatonne of oil equivalent
GtL:	Gas to liquids
ha:	Hectare
IATA:	International Air Transport Association
IBF:	U.N. International Biofuels Forum
IEA:	U.N. International Energy Agency
ILUC:	Indirect land use change
IMF:	International Monetary Fund
IPCC:	Intergovernmental Panel on Climate Change
IRENA:	International Renewable Energy Agency
kbls/d:	kilo-barrels per day
LCA:	Life Cycle Assessment
Le:	Litre of ethanol
LNG:	Liquid Natural Gas
LUC:	Land use change
Lw:	Litre of water

mmbls/d:	million barrels per day
MTBE:	Methyl tert butyl ether
Mtoe:	million tonnes of oil equivalents
Mtpa:	million tonnes per annum
MW:	Megawatt, one million (10^6) watts
MWh:	Megawatt hour (10^6 wh)
NPP:	Net primary production
NFFO:	Renewable Non-Fossil Fuel Obligation (UK)
NGL:	Natural gas liquids
NNFCC:	National Non-Food Crops Centre (UK)
NRMM:	Non-Road Mobile Machinery (UK)
OCF:	Oil cost factor
OECD:	Organisation for Economic Co-operation and Development
OPEC:	Organisation of the Petroleum Exporting Countries
PBR:	Photo-bioreactor
PPO:	Pure plant oil
Proalcool:	Brazil's National Alcohol Program
PVO:	Pure vegetable oil
RCEP:	Royal Commission on Environmental Pollution (UK)
RED:	Renewable Energy Directive (EU)
RFA:	Renewable Fuels Agency (UK)
RFS:	Renewable Fuel Standard (USA)
RO:	Renewables Obligation (UK)
RTFC:	Renewable Transport Fuel Certificates (EU)
RTFO:	Renewable Transport Fuel Obligation (UK)
SNG:	Synthetic Natural Gas
SPS:	Single Payment Scheme (EU)
SVO:	Straight vegetable oils
Syngas:	Synthetic gas
TAG:	Triacylglycerol lipid molecule
TAME:	Tert-amyl methyl ether
Tbls:	Trillion barrels , i.e. 10^{12} barrels
Tcf:	Trillion cubic feet
TOE:	Tonnes of Oil Equivalent
TWh:	Terawatt hour, 10^{12} watt-hours
UCO:	Used cooking oil
UNICA:	Brazilian Sugarcane Industry Association
USGS:	US Geological Survey (USA)
VAT:	Value-added tax
WCED:	World Commission report on Environment and Development
WEO:	World Energy Outlook
WF:	Water footprint
WPA:	World Petroleum Assessment
WVO:	Waste vegetable oils

Code of Ethics

Part of this study is interviewing experts for the data collection process. The interviews will be carried out based on ethical guidelines. The participants' rights, including the right to be well informed about the purpose of the study, the right to freely decide whether to participate in and the right to withdraw at any time are recognised. The collected data is accurate without fabrications, fraudulent materials and omissions. The information obtained through interviews is not disclosed to other bodies, and only been used for the purpose of this study. The consent is formalized through a written/ or a recorded verbal agreement, including the rights for disclosing the name and views of participants for this study purposes. A sample of consent form and list of questions are available in Appendix F.

Chapter One

Introduction

Chapter One: Introduction

The term biofuel normally refers to biological material for energy and covers liquid, gas and solid fuels produced from biomass. Biomass is biological material derived from living, or recently living organisms and in the context of biomass for energy is often used to mean plant base material. Production and consumption of biofuels have been increased radically in the past 14 years, driven mainly by governments' policies aimed at reducing dependence on imported crude oil and lowering greenhouse gases emissions.

In this chapter, the purpose and the significance of this dissertation are discussed, then the hypothesis, aims and objectives are described followed by the background of the biofuel industry and the structure of the dissertation.

1.1 Purpose of the study

The biofuel industry should provide a net energy gain, have environmental benefits and be economically competitive with alternative resources, in order to establish its place as a feasible alternative to fossil fuels. It also needs to be producible in large quantities without reducing food supplies or having negative effects on other important agricultural and natural ecosystems. These are the challenges that governments face across the world. There is an urgent need to define a robust future policy for biofuels in the UK/EU, considering the international context, the history, the current regulations, the impacts on the society, the environment and both advantages and limitations of biofuels.

1.2 Significance of the study

This dissertation will provide a novel analysis of long term projections for biofuel production and consumption in the EU/UK and will discuss the arguments for and against the biofuel agenda. Recommendations will be presented on achieving the aims and effective directives for the future of biofuels in the EU/UK.

1.3 Primary research questions

The primary questions are: Is biofuel the main answer to the concerns for energy security and environment protection for the next decades? Do the current regulations provide a robust model for a sustainable renewable energy source for the future? What changes should be made?

1.4 Hypothesis

Current policy for biofuels in the UK/ EU is not sufficient to fulfil future needs and must be improved radically in response to the integrated global policies.

1.5 Aims and objectives

The overall aim of this research project is to investigate the current and future role of biofuel technologies and policies in the UK/EU. To address this aim; these objectives need to be followed:

- Comprehensive review of published literature to establish the current situation in terms of science and policy for biofuels in selected key countries.
- Investigate the extent of current policies on biofuels in the EU/UK and their implications.
- Assess economic costs, regulatory structure, carbon neutrality, adverse effects and technical feasibility of biofuel production.
- Collect and assess the views of key experts from the business/private industry, governments and academic sector.
- Analyse the collected data and provide suggestions for the UK/EU policy makers and regulatory bodies to provide achievable and effective regulations for decades ahead.

1.6 History and background

Long before the discovery of crude oil by Edwin Drake in 1859, ethanol was used for lamp oil and cooking but first official use of ethanol as a motor fuel was in 1860, when the German inventor Nicholas Otto constructed the internal combustion engine in his "Ottocycle," and used ethanol as fuel

(Songstad et al., 2009). Twenty five years later, in 1885, the first car to run on petrol was made by the German engineer Karl Benz, while in 1896, Henry Ford's first car ran on ethanol (Fullwiki, 2010) and in 1900 Rudolf Diesel used peanut oil in internal combustion engines (Shay, 1993). In 1899, first bioethanol facility in Japan was build in Hokkaido (Koizumi, 2013) and soon bioethanol became a main rival for petroleum. In the early 1900s, there was a competition between petroleum and ethanol industries. On April 26, 1906, The New York Times published an article showing interest in ethanol as a fuel for cars (NYtimes, 1906) and eight months later, a comparative fuel test was done by the Bay State Automobile Association in the USA. Three cars using petrol, kerosene and alcohol reached Boston from New York without any problem and approved that kerosene and alcohol were perfectly practical for car use (NYtimes, 1907). In 1925, France, Germany, Brazil and other countries implemented a "mandatory blending" law which required retailers to blend in large volumes of alcohol with all petrol sold (Fullwiki, 2010). A few years later, US followed the same pattern (Blanco, 2006) (Appendices A and B). Since then, periodically crude oil has been through short supply. The search for alternative energy sources emerged in the 1930s and 1940s using vegetable oils (Pousa et al., 2007). This gave a sense of energy independency to those countries producing oil crops. With the end of World War II, once again low cost and availability of crude oil made it the dominant energy source until the 1970s. The Arab oil embargo of 1973 sent world oil prices skyrocketing with a consequent interest in ethanol production throughout the world. In 1975, Brazil introduced the National Alcohol Program, “Proalcool”, focusing on the production of ethanol from sugarcanes (Colares, 2008). In 1978, the International Energy Agency (IEA) initiated a “Bioenergy Agreement” with the aim of cooperation between countries that had bioenergy national programmes (Wright, 2006). In the late 1990s, environmental awareness and the increasing concern about the reduction of the world’s non-renewable energy sources brought new eagerness in the search for biofuels (Pousa et al., 2007). However, in spite of the long history of bioethanol, the use of butanol as a biofuel was only reported in 2005, when a car toured across the United States, using this alcohol instead of petrol. Although consumption was almost 9% higher, emissions of CO, hydrocarbons, and NO_x decreased several fold (Dürre, 2007). Since the turn of the new century, the global production of biofuels has increased dramatically. Between 2000 and 2013, bioethanol production registered an increase from 16.9 to 88.0 billion litres while biodiesel grew from 0.8 to 24.7 billion litres in the same period (Fig1.1) (Sorda et al., 2010; REN21, 2010; GRFA, 2014; RFA, 2014);

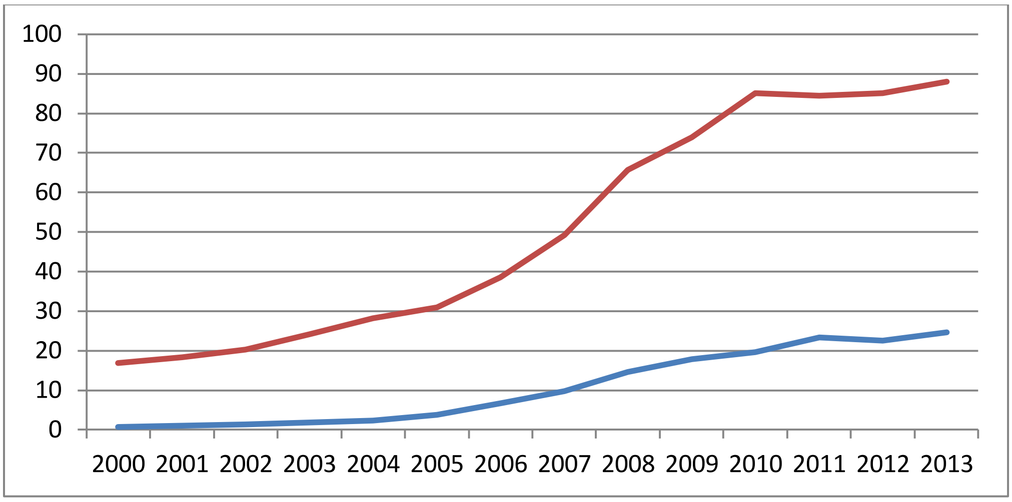


Fig.1.1 World annual bioethanol (red line) and biodiesel (blue line) production, 2000–2013 in billion litres, adapted from (Sorda et al., 2010; REN21, 2010; GRFA, 2014; RFA, 2014)

In the beginning of the 21st century, almost 140 years after the use of bioethanol as a motor fuel for the first time, biofuels became the panacea to treat the problems of energy shortages and climate change. However, increasing public concerns about the impact on food prices and supplies related to the diversion of feedstocks for their production made a backlash that threatened biofuel industry. In order to overcome these issues, the second generation of biofuels has been developed (Cherubini, 2010), which offers the outlook of higher yield and significantly reduced greenhouse gases (GHGs) emissions compared to most first generation biofuels. Although promising, second generation technology is costly and huge efforts have been made to reduce the cost. In this situation, the algae has emerged as a feedstock which produces lipids (oil) at a rate considerably higher than agriculture crops (Weyer et al., 2010). The potential of algae as a biofuel feedstock was investigated relatively recently but the concept of using algae as a source of fuel is very old. In the early 1950s, methane gas was produced from algae (Sheehan et al., 1998). Even before that, during World War II, algae was used by German scientists as a source of protein on a large scale in open ponds (Demirbas, 2010). The energy crisis of the 1970s restored the concept of using algae as a fuel (Sheehan et al., 1998) and perhaps the most comprehensive study of algae as a resource for energy was the “Aquatic Species Program (ASP)”- 1978 to 1996- conducted by the US National Renewable Energy Laboratory (NREL). The aim of the program was to produce billions of gallons of lipids for less than the cost of soy oil (Tyson, 2005). Algal research has been further developed in recent years and on January 7, 2009, in Hawaii, a Boeing 727 carried out a test flight of bio-jet fuel, that included 2.5% derived from algae oil (Benemann, 2009). This test proved the technical possibility of algal biofuels and this was exactly what aviation industry was looking for. A few months before, on May 29, 2008, the Algal Biomass Organization (ABO) was formed in the US, with the aim of promoting the development of transportation and power generation fuels as well as other non-energy applications for algae biomass (Ghelfi, 2008). Boeing was a co-founder and the International Air Transport Association (IATA) was among the first of the aviation-related members to join ABO (Millikin, 2008). One year later, on June 5, 2009, the European Algae Biomass Association (EABA) was officially launched in Italy, aiming to reach Industrial-scale production of bioenergy from algae by 2020 (Kovalyova, 2009). In recent years, the policy makers in both sides of the Atlantic have passed a few legislations to encourage the use of algal fuels. Article 89 of the DIRECTIVE 2009/28/EC of the European parliament urges member states to encourage investment in research and development of biofuels, including algae (OJ, 2009). In the US, revised climate legislation (S. 1733) defined algae-based fuel as "advanced" biofuels under the Federal Renewable Fuels Standard (RFS) programme, making them equal to cellulosic ethanol and other fuels made from non-food biomass (Rickman, 2009). On September 28, 2010, the US House of Representatives passed “The Algae-based Renewable Fuel Promotion Act”, which is called H.R. 4168 (H.Res, 2010). Based on this Act, the Internal Revenue Code of 1986 was amended to expand the definition of cellulosic biofuel to include algae-based biofuel for the purposes of cellulosic biofuel producer credit and the special allowance for cellulosic biofuel plant property (H.Res, 2010).

1.7 The structure of the dissertation

The next chapter (Chapter 2) describes the method used for this study. Chapters 3-6 are devoted to literature review as follows: Chapter 3 draws the global policies, regulations and mandates for biofuel, Chapter 4 considers the history and current situation of biofuel production and consumption in the UK, Chapter 5 reviews the science and technology of biofuel industry and describes the limitations and advantages of various production technologies, and Chapter 6 reviews and assesses environmental and socio-economic impacts and risks associated with the biofuel production and consumption. Chapter 7 compares biofuel and fossil fuel technologies and forecasts the future of both industries and chapter 8 summarises the interviews with experts and the essences of their views are discussed. Chapters 9 and 10 are dedicated to the final discussion and conclusion and recommendations and chapters 11 and 12 are for the References and the Appendices.

Chapter Two

Methods

Chapter Two: Methods

This chapter describes the research methods used in this study. To assess the possible outlook for biofuel science and policies in the UK/EU, this research used critical review of published articles and policy documents. Then semi-structured qualitative interviews were used to elicit views with a purposive sample of participants from three different sectors. The data collection, data analysis methods, the participants and the interview procedure are described in detail in this chapter.

2.1 Data Collection

A literature review of books, journals, papers and official policy documents was carried out. Online databases such as BioOne, Web of Science, Web of Knowledge, University of Westminster's library, WFL publisher, Worldwide Science and Google scholar were used with key words such as: "biofuels, biofuel AND history, biofuels AND regulations, biofuels AND directives, biofuels AND food, biofuels AND biorefinery, biofuels AND ethanol, biofuels AND algae, biofuels AND generations". This resulted in almost 500 of relevant articles and the references provided in each article were also examined. More than 250 appropriate articles (published from 1906 to 2014) and policy documents (published from 2000 to 2013) were selected and examined. The data extracted from publications are categorised and analysed in chapters 3-7. This study also tries to enhance the understanding of the issues by obtaining an up-to-date picture of the views of stakeholders, in different sectors, which are not necessarily reflected in the scientific journals. Previous analyses of biofuels policies and their impacts potentially missed important cross-sectorial interactions that exist within the biofuels policy landscape. Therefore, this study seeks to fill that gap by interviewing key stakeholders.

2.2 Participants

A group of 300 stakeholders from the environment and energy industries, regulatory bodies, universities and research institutes, and governments around the world were approached and at the end, twenty-eight participants were recruited by purposive sampling to provide a broad sample of experts both in different sectors and countries. The participants held different positions in different sectors including academic, governmental and industrial/private sectors, but their views were not necessarily assumed to be representative for their "sector" as a whole.

2.3 Semi-structured interview procedure

In total, twenty eight in-depth semi-structured interviews were carried out with participants from 11 countries as shown in Table 2.1. The full list of participants, the interview questions and the interview transcripts are shown in Appendices C, D and E.

Country	Number of Participants	Sector		
		Academics	Governmental	Industrial/Business
USA	7	5	1	1
UK	5	2	1	2
Belgium	4	2	1	1
Sweden	3	1	1	1
Austria	1	-	1	-
Finland	2	1	-	1
Germany	1	1	-	-
Brazil	1	1	-	-
Ireland	1	-	1	-
Italy	1	-	-	1
Iran	2	2	-	-
TOTAL	**28**	**15**	**6**	**7**

Table 2.1: Participants from different countries and sectors

The interviews were carried out in person, over the phone (approximately 30-40 minutes) or by emails. In each case, the voice or print records have been kept and archived and a consent email/signed consent form, from each participant has been attained, to show their consent for their interviews to be used in this study (Appendix F). Each participant had time to ask any questions before the interview and signing the consent form.

Three topics served as the starting point for the interviews;

- The future of biofuels and forecasting scenarios for different generations
- The environmental impacts of biofuels
- The global regulations/mandates and governments' support for boosting the biofuel industry.

These topics were derived from the literature review. The first couple of interviews served as pilot interviews to test the coverage of the selected topics. As the first couple of interviews developed, more questions asked to cover the areas, which had not been considered in the initial three topics. The future of the crude oil market and discovery of new shale gas resources were among these new series of questions. A summary of the research method is illustrated in Fig. 2.1:

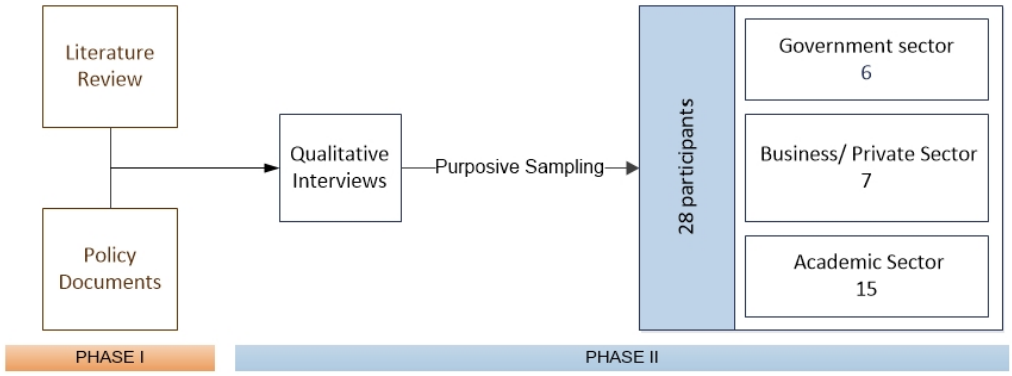


Fig. 2.1: A summary of the research method

2.4 Data analysis

A professional transcription agency transcribed the interviews and all the interview transcripts were read several times in order to become completely familiar with the data. Then the interview transcripts were coded using the WEFT software, and then thematically analysed. The data extracted from the interviews is categorised in chapter 8. Then the themes from the interviews were compared to the themes from the literature review. Analysis of the data extracted from both literature review and the interviews is discussed and conclusions drawn (Chapters 9 and 10) to help reach a realistic novel approach to the future regulations in the UK/EU.

Chapter Three

Global Biofuel Policies

Chapter Three: Global picture and current policies, regulations and directives

The growing concerns with global climate change and the shortage of fossil fuels have directed the attention of policy makers across the world towards biofuels. To date, 62 countries have set mandates or targets to blend biofuel with other transportation fuels (RFA, 2014). The aim of most governments in developed and developing countries is to reduce their entire dependence on foreign crude oil and increase the ability to control their own future economic security by increasing the availability of domestic fuel supplies. The increase in biofuel production requires governmental support, although the nature of the support varies from country to country. Currently most parts of North and South America, Europe and some parts of Asia have advanced biofuel production programmes (Fig 3.1).

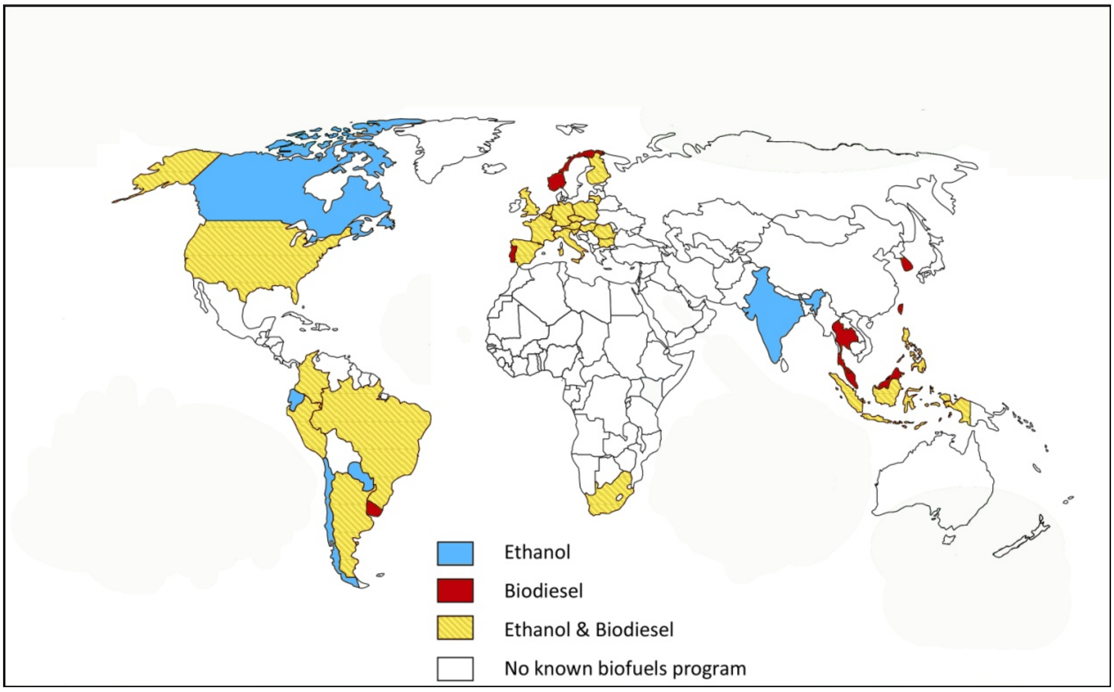


Fig 3.1: Global picture of biofuel programs, adapted from (PINTO, 2011)

As a result of the vast production plans, the share of biofuels among the total renewable energy sources has been increased since the beginning of the new century. However, in 2012, global biofuels production recorded the first decline since 2000 (-0.4%), mainly due to a decline in the US (-4.3%) production (BP, 2013).

According to the data from the US Energy Information Administration (EIA), in 2011, the United States, Brazil and the European Union combined represented 87.5% of the world biofuel production and 89% consumption. In the same year, the US shares of the world biofuel production and consumption amounted to 51% and 49%, respectively (EIA, 2013) (Table 3.1);

World biofuel production and consumption 2011 (million litres per day)		
Country/Area	**Production**	**Consumption**
North America	159.768	150.462
Central & South America	82.545	67.241
Europe	39.820	54.664
Africa	0.126	0.207
Asia & Oceania	18.789	16.282
Eurasia & Middle East	0.599	0.493
World (total)	301.647	289.349

Table 3.1: World Biofuel Production and Consumption 2011 (million litres per day), based on data released by EIA (EIA, 2013)

In recent years, many countries have introduced and adopted biofuel policies in order to reduce energy dependence and reduce green house gas emissions. Some of these policies have been successful and some have not, depending on the countries' geographical, economical and agricultural conditions. In this chapter, the global biofuel policies across the world are discussed in order to draw some conclusions on the affectivity of global biofuel policies in different countries.

3.1. North America

In North America, both USA and Canada have established biofuel programmes.

3.1.1. Canada

Producing biofuel in Canada from agriculture and forestry feedstock is not a new idea. Commercial production of ethanol has grown slowly since its early days in the 1970s in two small facilities in Ontario and one larger plant in Quebec. In 1995, the production capacity of ethanol reached to 60 million litres per year and increased to 238 million litres per year by 2000. The rapid expansion to about 1.8 billion litres by 2011 coincided with a significant investment and excess of federal and provincial policies that promoted ethanol production and consumption as fuel (Le Roy and Klein, 2012). The main driving force has been the reduction of greenhouse gases associated with the transport fuel (Mabee and Saddler, 2010). According to the Act Bill C-33, since 2010, a 5% renewable content in petrol (E5) (Sorda et al., 2010), has been mandated. In Canada, there are different provincial mandates, with different ethanol requirements. As a result, the common standard is E10 (a blend of 10% ethanol and 90% petrol) (Le Roy and Klein, 2012) (Appendix G).

The biofuel industry is not financially viable without governmental support and it has been promoted by Canadian federal government through consumption mandates, tax exemptions and direct incentive policies (Nersesian, 2008). For example, the federal government excise petrol tax of $0.10 per litre has not been imposed on the ethanol contained in the petrol-ethanol blend. But even with these incentives, the agricultural and forest residues could only provide part of Canada's transportation fuel demand. It is reported (Mabee and Saddler, 2010) that under moderate scenarios, energy crops might be able to provide an additional 12% of Canada's transport fuel demand at the most. Therefore, Canada needs to import ethanol to meet the domestic demand and net ethanol imports have risen to almost half a billion litres per annum in recent years (Fig. 3.2).

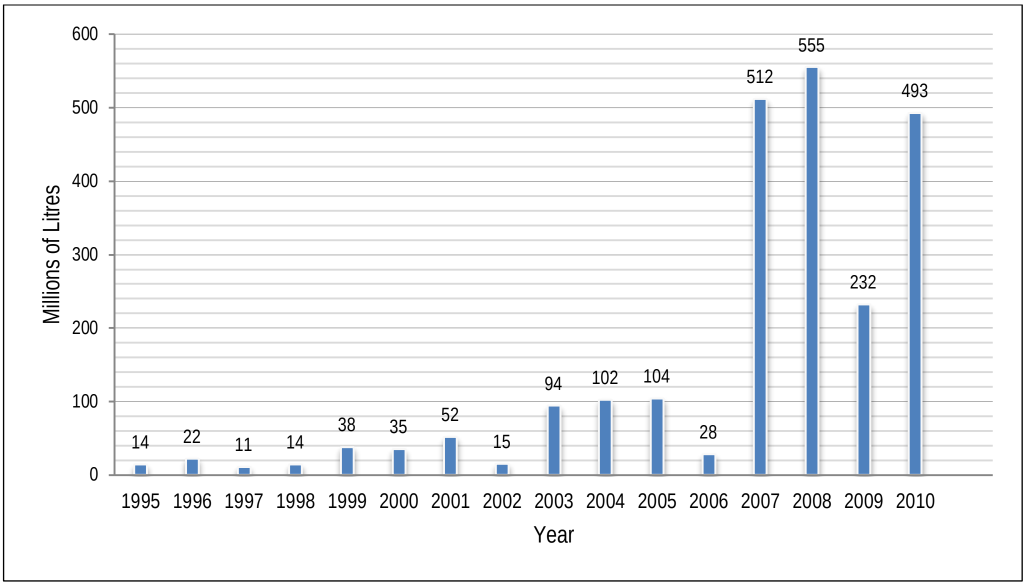


Fig. 3.2: Canadian ethanol imports in millions of litres, 1995–2010 , adapted from (Le Roy and Klein, 2012)

Currently, the main feedstocks for ethanol production are corn in eastern Canada and wheat in the western part of the country (Sorda et al., 2010) but interest in using second generation biofuels has been growing (Mabee and Saddler, 2010). It is estimated that Canada has between 64 to 561 million dry tonnes of lignocellulosic biomass, which might be used (Gronowska et al., 2009). The variation in estimates comes from the differences in the number of biomass categories, economic considerations, assumptions about energy crop yields and land areas. Despite these figures, the logistics and financial issues of lignocellulosic biofuels have not been resolved yet, and currently there are no commercial scale second generation biofuel facilities. However, the Canadian government has shown its commitment to inspiring potential producers for investment on second generation biofuels by "NextGen Biofuels Fund" which is used to help second and third generation biofuel projects once the projects demonstrate commercial potentials (SDTC, 2013).

Although Canada with its long winters and short summers is not the ideal place to breed algae for biofuel production, there have been some investments in algae research in Canada in recent years. In September 2010, it was reported (Brenhouse, 2010) that a new strain of algae has been found in marine environments across the Atlantic provinces of Canada that appears capable of producing oil at a rate 60 times greater than other types of algae being used for biofuel production. The Canadian government is hopeful that a combined usage of lignocellulosic biomass and algal fuel could raise biofuel production to well above domestic requirements.

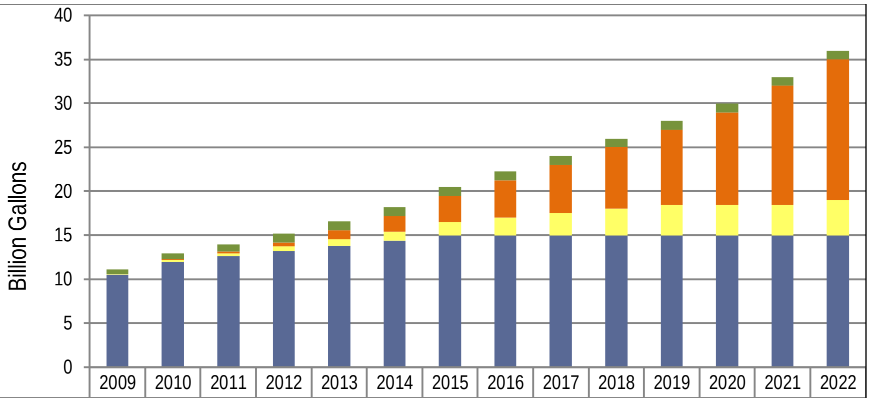
3.1.2. United States

United States is the world's largest bioethanol producer, utilising mainly maize as a feedstock. There is continuing interest in expanding biofuel production and the guiding principle has been a reduction in the country's dependency on fossil oil. The use of ethanol is subsidised and a tax credit is provided to fuel suppliers who blend ethanol into the fuel they sell. Biodiesel has also been subsidised using a similar mechanism (Meyer et al., 2012). The federal corn ethanol blender's tax credit was equal to US$ 0.45/gallon (US$ 0.12/litres) before it expired on December 31st, 2011; fuel blenders receive an additional state-level subsidy, which averages US$ 0.07/gallon (US$ 0.02/litres) and takes the form of a tax credit in most states. Also biodiesel blenders enjoy a tax credit of US$1 per gallon (US$ 0.26/litres) of biodiesel blended with regular diesel (Rajcaniova et al., 2013).

Historically, the US government's support for biofuels started with the fuel excise tax exemption- the Energy Tax Act of 1978- which officially defined "gasohol" as a blend of petrol with at least 10% non fossil fuel ethanol by volume (Nersesian, 2008). Since then, a range of policies has been implemented to promote bioenergy, including the Surface Transportation Assistance Act of 1983, the Tax Reform Act of 1984/86, the Omnibus Budget Reconciliation Act of 1990, the Energy Policy Act of 1992 (Nersesian, 2008), the Biomass Research and Development Act of 2000 , the Farm Bill of 2002, the Energy Policy Act of 2005 and finally the Energy Independence and Security Act of 2007 (EISA) (FAO, 2008). Based on EISA 2007-which also called the Renewable Fuels Standard (RFS1)- it is expected that until 2022, 1.6 billion tons of biomass will be harvested each year (Pimentel et al., 2009) with a total of 36 billion gallons (136.275 billion litres) of renewable fuels will be produced in the United States (FAO, 2008). However, according to the Interagency Working Group report, “Growing America’s Fuel” (DOE, 2010), reaching the 36 billion gallons per year goal by 2022 is unlikely unless a greater integration of efforts occurs. According to this report, the US government should:

- Support the existing biofuels industry,
- Accelerate the commercial and sustainable establishment of the advanced biofuels industry,
- Utilise the best skill, and expertise across many US Federal departments,
- Support feedstock research, minimize transaction costs and create wealth for farms and rural communities, and
- Improve technologies and public-private partnerships (IWG, 2009).

In July 2010, the updated Renewable Fuel Standard (RFS2) went into effect. Based on RFS2, cellulosic biofuel production in the US is expected to surge to 16 billion gallons (60.56 billion litres) in 2022 while conventional (first generation) biofuels remains almost the same (around 15 billion gallon or 56.78 billion litres). Also the total contribution of advanced biofuels, derived from cellulose, hemicellulose, lignin, sugar, waste material, biogas and algae- would not be less than 21 billion gallons (79.49 billion litres) by 2022 (Fig. 3.3) (Klein, 2012).



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Biodiesel	0.5	0.65	0.8	1	1	1	1	1	1	1	1	1	1	1
Cellulosic Biofuels	0	0.1	0.25	0.5	1	1.75	3	4.25	5.5	7	8.5	10.5	13.5	16
Non-Cellulosic Biofuels	0.1	0.2	0.3	0.5	0.75	1	1.5	2	2.5	3	3.5	3.5	3.5	4
Conventional Biofuels	10.5	12	12.6	13.2	13.8	14.4	15	15	15	15	15	15	15	15

Fig. 3.3: The US biofuel requirements by 2022, adapted from (Klein, 2012)

3.2. Central and South America

3.2.1. Brazil

Brazil has the most developed and integrated biofuels programme in the world. Brazil has shown to the entire world an impressive energetic matrix with almost 44% renewable resources (of which 13.5% is derived from sugarcane) (Soccol et al., 2010). The land area of Brazil is around 851 million hectares, of which 54% are preserved. From the land available for agriculture (340 million hectares), only 0.9% is occupied by sugarcane as an energy crop, showing a great expansion potential. It is predicted that the bioethanol production in Brazil may triplicate by 2020, compared to 2010 figures (27.5 billion litres to 70 billion litres) (Soccol et al., 2010).

The development of Brazil's ethanol industry dates back to the global oil crisis of the 1970s. In 1975 Brazil introduced the National Alcohol Program- Proalcool- to promote the production of ethanol from sugarcane (Sorda et al., 2010). This was the first major renewable fuels programme in the world.

Brazil was under military rule at the time, and heavily relied on crude oil imports (Doku and Di Falco, 2012). US$5 billion were provided by the government as low interest loans to finance the construction of ethanol production plants and also to purchase ethanol to blend vehicle fuel with a minimum ethanol content of 22% (E22) (Nersesian, 2008). Depending on the alcohol market at the time, petrol companies must add 20–25% of ethanol to fossil petrol (E20-E25). Also, ‘‘the total of value-added tax” (VAT), fuel tax and other taxes on ethanol were about half as much as that applied to petrol (Doku and Di Falco, 2012). The addition of 25% ethanol to petrol reduced the import of 550 million barrels of oil and also reduced the emission of CO_2 by 110 million tonnes (Soccol et al., 2010). In 2000, Brazil removed all direct ethanol subsidies, stopped importing ethanol, and became an exporter. Lack of direct subsidies for ethanol production was one of the reasons that Brazil lost its place as the global leader in ethanol production in the past decade. To inspire the biofuel industry, in February 2012, the Brazilian government once again announced a new US$38 billion in subsidized credit for the ethanol sector with the aim of increasing sugar production and milling industry (BD, 2012). In spite of these efforts, the ethanol industry in Brazil is still struggling. On 2nd December 2013, it was announced (Bloomberg, 2013) that about 20 ethanol mills are about to shut down within two or three years. This is on top of the 50 mills, which have been closed since 2007. It seems that the incentives are not enough to lift the biofuel industry. Brazil was the global leader in ethanol production and consumption until 2005, when the U.S. became the current leader. Ethanol produced in Brazil, though, has proven to be more efficient (Doku and Di Falco, 2012). North-American ethanol is produced mainly from corn, with lower productivity and higher cost. For example, the average ethanol production in the US is 3,200 l/ha/year, while in Brazil this figure is more than twice higher (6,800 l/ha/year.). This is reflected in production costs: US$ 0.20/l in Brazil against US$ 0.47/l in the US, which still strongly subsidises the production of ethanol (La Rovere et al., 2011).

Based on the successful experience of the bioethanol plan, Brazil has started investing in biodiesel, but contrary to ethanol, its economic competitiveness is relatively poor and production is still subsidized (Sorda et al., 2010). Biodiesel has a great potential to be developed. Although the task is even more challenging for biodiesel than for ethanol. The Brazilian government introduced a mandatory biodiesel blend rate of 2% by 2008 and 5% by 2013 (La Rovere et al., 2011) (Fig 3.4)

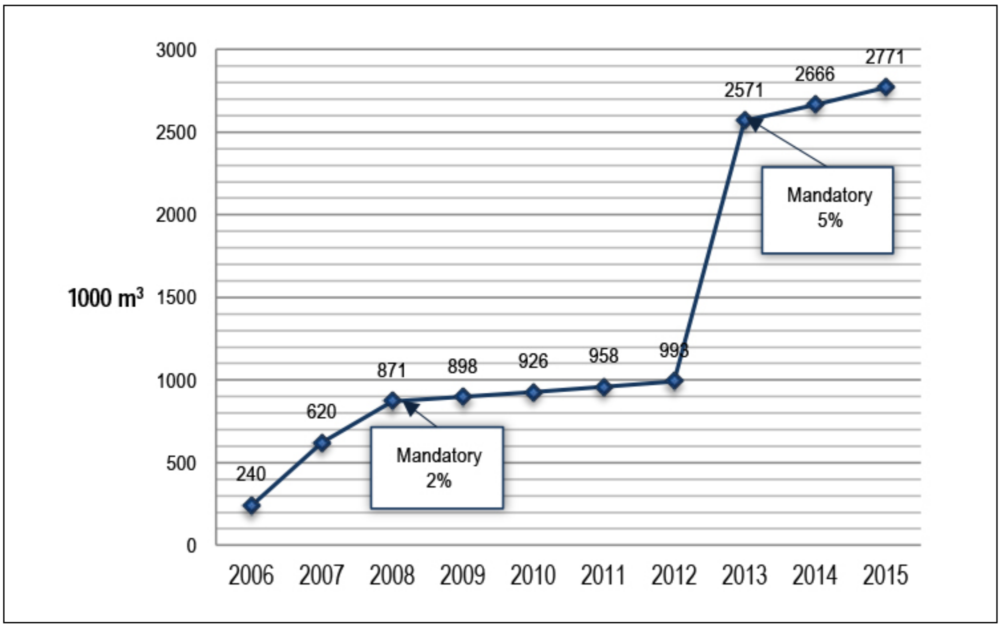


Fig. 3.4: Biodiesel demand forecast in Brazil (1,000 m^3/year): 2006–15 (La Rovere et al., 2011)

Brazil runs an ethanol outreach programme, which started in 1997 focusing on Latin American and African countries. The aim of this programme is to replicate the successful ethanol experience across the world. The funds for the ethanol outreach programme are provided by Brazilian and the US governments. The Brazilian Sugarcane Industry Association (UNICA) has attempted to push ethanol in the rest of Latin America and Africa to promote the use of cane products for sugar, ethanol and electricity around the world (Hitchings, 2010).

Brazil has also started investing in the third generation biofuels since 2012, although in a limited scale. In June 2012, it was announced that the country's first algal biomass plant will be built in the northeast part of Brazil, by an Australian company (SAT, 2012) and to date is still under construction.

3.2.2. Argentina

After Brazil, Argentina has the most developed biofuel programme in South America. The key driver of biofuel markets in Argentina has been the economic development and despite being a relative latecomer to the industry, Argentina is well placed to meet international demands for biofuels, particularly for biodiesel. In 2008, Argentina produced more than 10% of the world's biodiesel (Tomei and Upham, 2009) and this made Argentina the world's third largest biodiesel producer after Germany and the US. There are no agricultural subsidies at either the national or provincial level (Tomei and Upham, 2009). But in order to promote the production, the government has reduced export taxes on the feedstock. Whereas exports of soy oil are subject to export taxes of 32%, biodiesel made in Argentina pays just 14.16% tax, thus reducing the price of local soy oil. However for farmers, it makes no difference if soy oil is sold on domestic or international markets, either way they gain only 66% of the international price (Tomei and Upham, 2009).

3.2.3. Peru

In Peru, in 2002, the government announced their plan to become a leading exporter of ethanol. They planned on building up to twenty distilleries, utilising sugarcane juice as its feedstock (Doku and Di Falco, 2012). They also announced an ambitious plan to bring 240,000 hectares of land into cultivation, in order to export 1.2 billion litres of ethanol per year, in the northern part of the country (Nersesian, 2008). In 2003, the Peruvian government also announced an obligatory blend of biofuels: 2% of biodiesel in diesel fuel from 2009 and 5% from 2011 as well as 7.8% of ethanol in petrol from 2010 (Doku and Di Falco, 2012).

3.2.4. Colombia

In Colombia, according to Law 963, since 2001 the government has mandated a 10% bioethanol blend in cities with populations of over half a million (Sorda et al., 2010). Though the law was promulgated in 2001, actual production of sugarcane-based ethanol began in October 2005, because the country did not yet have the facilities to produce ethanol. As of April 2008, 70% of all petrol sold in Colombia were mixed at a 10% blend level with ethanol (E10) and a tax exemption for ethanol is in place (Doku and Di Falco, 2012). Also in 2009, the government Decree 1135 required that from 2012, 60% of all new vehicles sold in Colombia must support an E85 flexi fuel technology. The government has also announced its plans to cover the entire national demand with up to 25% blend (E25) by 2020. Also, the promotion of biodiesel started in 2004 with Law 939 (Sorda et al., 2010).

3.3. Asia

3.3.1. China

China is the largest ethanol producer in Asia and the third largest producer of ethanol in the world. The driving force for ethanol production in China is the country’s need for energy. Up to 2008, 61% of rural household energy came from traditional use of biomass such as livestock manure or direct burning of woods (Hu and Phillips, 2011). Currently, China is the largest and fastest growing economy in the world with high-energy consumption, which is likely to continue for some decades. This rising demand has turned China into a net energy importer. In order to reduce its reliance on fossil fuels for sustainable economic growth, China has invested in renewable energy, and biofuel industry has gradually become one of the nation's priorities to sustain the energy sources (Hu and Phillips, 2011). However the renewable energy economy is not yet cost-competitive with the fossil energy economy so its development is very much dependent upon government support (Ma et al., 2010). The Chinese government has tax exemptions for fuel ethanol, 5% from consumption tax, and 17% from VAT (Doku and Di Falco, 2012).

In China, the primary feedstock for ethanol is maize but wheat also is used in the newest biofuel plants (Ma et al., 2010). China is the world's second largest producer of corn after the US, but due to its high price, the attention now has been switched to non-grain crops such as cassava, sweet sorghum and sweet potatoes (Sorda et al., 2010). China's Ethanol Promotion Program was launched in 2002 and the plan is to boost renewable energy as a share of total primary energy consumption to 15% by 2020 (Sorda et al., 2010). Biofuels are expected to play an important role in the achievements of these targets. Ethanol production should correspond to 15 million tonnes by 2020 (DEFRA, April 2008) while biodiesel consumption is projected to reach to 2 million tonnes by 2020 (Sorda et al., 2010). In China, there are no national standards in terms of biodiesel and no direct subsidies are currently granted. A target of 11.4% for renewable energy consumption by 2015 has been set (EBTP, 2012b). Until very recently the biofuel industry had been reliant on first generation technology, but now there is growing interest in advanced biofuels (second and third generations). China has started pilot scale research on the second generation biofuels since 2010 with a total capacity for 280,500 tonnes bioethanol production each year (Zheng, 2013). The results of a recent survey released by "Research and Markets" group also show that the biofuels market in China will grow at an annual rate of 16.88% by 2017, and the third generation biofuels represent an increasing share of this growth (R&M, 2013).

But in spite of all these efforts, the advanced biofuel technology is still considered as relatively immature (Zheng, 2013).

3.3.2. India

After China, the second largest producer of ethanol in Asia is India. In 2002, the Indian government decreed that ethanol blending with fuel must be mandatory in four of the federally ruled areas, and nine states, from 2003. The main feedstock used for ethanol production is sugarcane molasses (Doku and Di Falco, 2012). The policy has been successful and in 2006, India accounted for 4% of global bioethanol production from sugar cane and new plans for increasing ethanol production was announced (EBTP, 2012b). The "National Policy on Biofuels" was also set in September 2008 aimed to meet 20% share of biodiesel demand by 2017 (Richardson, 2009). Apart from sugar cane, using jatropha (*Jathropha podagrica*) as a feedstock is now common. For many years, remote communities in India have used Jatropha oil as an alternative to diesel fuel and now jatropha is being considered for as an energy crop in 19 Indian states offering a combination of available marginal land, socio-economic benefits and growing conditions (EBTP, 2012b).

3.3.3. Indonesia

In Indonesia, the main drivers of biofuel policies are creating jobs, improving economy and living standards (Zhou and Thomson, 2009). It is estimated (Wicke et al., 2011) that enough land would be available in the country for further biofuel production, at least until 2020, without further forest losses or the replacement of other agricultural production. Biofuels are scheduled to account for 3% and 5% of Indonesia's total energy mix, in 2015 and 2025 respectively. By 2025, it is predicted that ethanol will replace 15% of the petrol consumed and biodiesel will replace 20% of the diesel consumed.

3.3.4. Iran

Iran is one of the top crude oil and natural gas producers in the world. Despite Iran's diversity of terrain and climate, only 12% of the total land is utilized for crops. Agricultural residues are not commonly used for energy but crop residues and sugar cane bagasse, wheat, rice, barley and corn are the most favourable bioethanol production sources (Najafi et al., 2009). The Iranian government is paying considerable attention for biofuels and has invested in pilot plant scales in the past decade (Yahyaee et al., 2013). The key drivers for Iranian government involvement in biofuel production is reducing the country's reliance on fossil fuels, providing the opportunity to use the fossil resources in more value-added products and employment opportunities in rural areas (Avami, 2012). Iran's first biodiesel plant was built in the central province of Isfahan on 28th February 2013 at the cost of over US$12 million, funded by the government (PressTV, 2013). At the same year (2013) Iran also launched an ambitious third generation biofuel project for 10 hectares scale up of microalgae based biodiesel and bioethanol in the Persian Gulf "Knowledge Village", in Bushehr province of Iran (Moazami, 2013). Also it is reported that with 17.86 million tons of annual crops wasted in Iran, 5 billion litres of bioethanol could be produced annually (Ghobadian, 2012).

3.3.5. Malaysia

In Malaysia, there is very little ethanol production, but production of biodiesel using palm oil as the feedstock is a developed industry (Zhou and Thomson, 2009). Malaysia accounts for 41% of world palm oil production and is the biggest palm oil exporter with 14.21 million tonnes which accounted for almost half of the total exportation of palm oil in the world (Ong et al., 2011). A 5% biodiesel (B5) mandate programme was successfully launched in 2011 in the central regions of Malaysia, and the Malaysian government started planning for a pilot B10 program, which is expected to be fully implemented in late 2014. Currently there are 11 active biodiesel plants in the country with the total annual capacity of 1.65 million tonnes per year (Yusoff et al., 2013).

3.3.6. Thailand

In 2000, Thailand's government became interested in ethanol due to high prices of crude oil and low prices for feedstock commodities. The Thai government started the ''Gasohol'' program, using sugarcane molasses as a feedstock, with aiming to raise ethanol production (Zhou and Thomson, 2009). Tax privileges have been granted including an 8 year corporate tax holiday and duty exemptions on machinery imports (Doku and Di Falco, 2012).

Currently 5% ethanol blend is used as transport fuel but the government is also promoting E20 and E85 blends through subsidies that keep prices lower than that of petrol (Richardson, 2009). In Thailand, biofuel production is calculated to be US$ 317 million more expensive than importing the same amount of petroleum (Bell et al., 2011) but domestic production allows almost all of the money to stay within the country.

3.3.7. Japan

Japan is the world's largest importer of natural gas, second largest importer of coal and the third largest net importer of oil. Japan relied on oil imports to meet about 42 percent of its energy needs in 2010 (EIA, 2013). Therefore, energy security is a main driving force for the Japanese government to promote biofuel programmes. Environmental concerns and the need to promote rural development are also other reasons for investment in the biofuel industry. For Japanese government reducing the cost of ethanol production is vital to increase its domestic production, but in the short term, it is not easy. To date, ten bioethanol production projects are operating. However, it is difficult for most of these facilities to boost their production levels due to the shortage of suitable land and limited feedstock (Koizumi, 2013).

3.4. Australia

Although Australia is a low-cost producer of sugar, it has relatively limited biofuel production (Nersesian, 2008). Australia began developing its sugarcane-based ethanol sector in 2000 (Doku and Di Falco, 2012) and the federal government introduced an excise tax exemption for biofuels in diesel and petrol cars. Australia produces less than 5% of its energy from biomass (mainly sugar, wood processing and paper manufacturing industries). The production of second generation biofuel is currently in the development phase. Three major bioethanol facilities are currently in operation with a total capacity of 170 million litres per year, planned to be double in the next few years (Yusaf et al., 2011). After July 1st 2015, the excise tax discount of 50% will be implemented (Cuevas-Cubria, 2009) and ethanol will receive a subsidy of 12.97 cents a litre relative to petrol, assuming the energy content of ethanol is 68% that of petrol. In Australia, biodiesel is currently most commonly sold in a 5% biodiesel and 95% diesel blend (B5). The research on biofuel production has been hugely intensified by governments AU$ 5.1 billion budget allocated for the "Clean Energy Initiative" for supporting new renewable energy technologies, including biofuels, over the coming decade (Puri et al., 2012).

3.5. Africa

In general, there is a lack of a coherent biofuel development strategy in Africa despite the increase in the price of petroleum-based fuels, uncertainties exist regarding future oil reserves as well as the climate change concerns. But several African countries are making efforts to introduce biofuel specific policies and there are very few operational commercial biofuel systems in operation.

Since 1980, Zimbabwe pioneered the production of fuel ethanol for blending with petrol in Africa although actual production stood at only 22.7 million litres in 2004 (Amigun et al., 2011). Zimbabwe's fuel blending target is 10% for both diesel and ethanol by 2017, but as of April 2012, a comprehensive biofuel policy had not yet been formulated (Duvenage et al., 2013).

Malawi has very favourable economic conditions for ethanol due to government policy to reduce the volume of imported fossil fuels. However, although Malawi's national energy policy was approved in 2003, and in the policy, ethanol blending is mandatory, a supportive legislation is yet to be passed by parliament (Jumbe et al., 2009). The total ethanol production in Malawi is about 30 million litres and Malawi has sustained the 10% alcohol blend in petrol (Amigun et al., 2011).

Mauritius started producing and shipping bioethanol to the EU in 2004. Other commercial ethanol plants also exist in countries such as Mozambique, Tanzania, Zambia, Kenya, Angola, Swaziland, Egypt, Ethiopia and Uganda (Amigun et al., 2011).

South Africa and Ghana have developed specific biofuel strategies with specific targets. For example, the Government of Ghana has set a target of substituting 20% of national gas and oil consumption with biodiesel by 2015, and 30% of national kerosene consumption is to be replaced with Jatropha oil by 2015. (Jumbe et al., 2009). The South African government introduced a blending requirement of 2% and 8% for biodiesel and bioethanol, respectively. These targets were proposed to be maintained until 2020 (Sparks and Ortmann, 2011). In terms of biodiesel development, the situation is the same. Most of the countries in Africa except South Africa, Mozambique and Zimbabwe are still in the first stage of biodiesel development. The South Africa's biodiesel market is mainly characterised by several small and medium-scale producers while Zimbabwe recently inaugurated Africa's first ever commercial biodiesel plant. The first biodiesel plant in Mozambique was erected in Matola, in 2007 as a result of the mandate from the Mozambique government (Amigun et al., 2011).

3.6. Europe

The EU is currently the world's third producer and consumer of biofuels, after the United States and Brazil. In 2011, 14.5 billion litres of biofuel were produced in the EU, of which more than 10 billion litres (69%) were biodiesel (Fig. 3.5) (EIA, 2013):

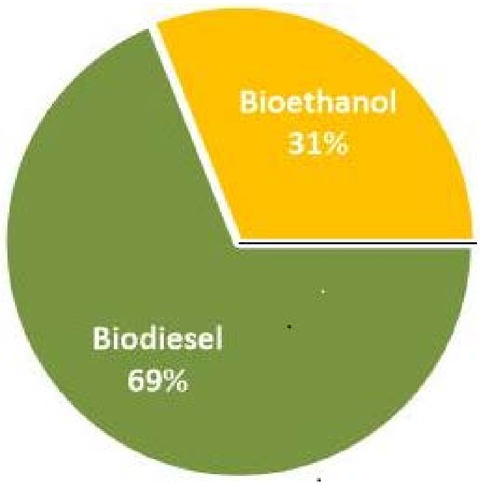


Fig. 3.5: EU-27 biofuel production 2011, based on the data from (EIA, 2013)

Currently, the main part of the EU's biofuel production and consumption are concentrated in a few member states of which Germany and France are two leading producers (Wiesenthal et al., 2009). Germany leads the European biodiesel market, accounting for about 30% of EU biodiesel production, and

France remains the leading ethanol producer, with 24% of total EU ethanol production (EIA, 2013). Table 3.2 shows the EU-27 countries' biofuels production in 2011 (Million Litres Per Day) (EIA, 2013);

Country/Area	Bioethanol	Biodiesel	Total
Austria	0.397	0.986	1.383
Belgium	1.033	1.383	2.416
Bulgaria	0	0.064	0.064
Cypress	0	0.016	0.016
Czech Rep.	0.302	0.652	0.954
Denmark	0.016	0.429	0.445
Estonia	0	0.008	0.008
Finland	0.032	0.636	0.668
France	2.767	5.406	8.173
Germany	2.115	8.268	10.383
Greece	0	0.318	0.318
Hungary	0.477	0.445	0.922
Ireland	0.032	0.143	0.175
Italy	0.159	1.781	1.940
Latvia	0.016	0.143	0.159
Lithuania	0.047	0.254	0.301
Luxembourg	0	0	0
Malta	0	0	0
Netherlands	0.636	1.526	2.162
Poland	0.461	1.193	1.654
Portugal	0	0.875	0.875
Romania	0.047	0.254	0.301
Slovakia	0.350	0.159	0.509
Slovenia	0	0.047	0.047
Spain	1.272	1.908	3.18
Sweden	0.541	0.795	1.336
UK	0.795	0.636	1.431
EU-27	11.495	28.325	39.820

Table 3.2: EU-27 Biofuels production in 2011 (Million Litres Per Day), based on data released by EIA (EIA, 2013)

The main feedstock used for biodiesel is rapeseed, but sunflower oil and soybean oil have also been used. For ethanol production, the main feedstock are sugar beet and cereals (FAO, 2008). The main driver for biofuel in the European Union (EU) has been a commitment to cut greenhouse gas emissions (Nersesian, 2008) and the biggest incentive to promote biofuel production and utilization in the European countries (Koizumi, 2013) was provided by the “KYOTO TREATY”. The Kyoto treaty was adopted on 11 December 1997 and entered into force in 2005 (Capros et al., 2011). The protocol sets binding targets for 37 industrialised countries and the European community for reducing GHG emissions. The targets amount to an average reduction in emissions of 5% against 1990 levels over the five-year period, 2008–2012. In 2005 the EC concluded that the EU was well on its way to meet the Kyoto targets, but progress also required thorough implementation of EU legislation, further domestic measures and the use of flexible mechanisms (Capros et al., 2011). In April 2009 the European Parliament endorsed a minimum binding target of 10% for the renewable in transport by 2020 as part of the EU Renewable Energy Directive (Directive 2009/28/EC)- or RED- on renewable energy. RED’s goals, which are also known as the “20-20-20 targets”, are intended to ensure that the EU meets its pledges made at Kyoto and to set the stage for further global negotiations. The target, which originally stated that 10% of transport fuel should be met by biofuels, was later changed to “10% of the energy in transport must be sourced from renewable resources” (Amezaga et al., 2010). However, this target is expected to be met mainly (some 90%) by the use of biofuels rather than the use of electricity or hydrogen (Capros et al., 2011). The directive also specified a minimum 35% reduction in GHG emissions to be achieved by biofuels during their life cycle, a target that is meant to increase to at least 50% starting from 2017 (Sorda et al., 2010). The Renewable Energy Directive was discussed within a legislative package also containing the Fuel Quality Directive (FQD) (Directive 2009/30). This directive sets technical specifications for fuels, together with a target for the reduction of life cycle greenhouse gas emissions (Wiesenthal et al., 2009). The history of biofuels policy in Europe is relatively short and before Directive 2009/28/EC, biofuel legislation consisted of just a few main directives, which have dealt with differing aspects of the biofuels production chain. The directive on the Taxation of Energy Products (2003) for example, allowed Member States to exempt biofuels from being taxed as an incentive for the development of biofuels or The Promotional Directive (2003) provided for the promotion of a biofuels market in the EU. According to this directive ‘‘Member States shall achieve a 2% share of renewable fuels by the end of 2005 and a 5.75% share by the end of 2010’’ (Doku and Di Falco, 2012). This was followed by the Renewable Energy Directive (RED) (2009/28/EC) that sets out a target of 10% for all forms of transport to be from renewable sources by 2020 (UKPIA, 2013). On September 11th, 2013, the European Parliament amended the 2009 EU’s Renewable Energy Directive (RED) and the 2009 Fuel Quality Directive (FQD). The key points of the amendments:

- Retains the current target of 10% renewable fuels by 2020.
- Sets the target of 7.5% renewable fuels in petrol by 2020.
- Sets a limit of 7.0% for the extent to which food-derived fuels could contribute to the 10% target (also applies to “other energy crops grown on land”).
- Sets separate targets for the use of second and third generation biofuels at 0.5% by 2016 and 2.5% by 2020.
- Requires the EU to develop by June 30, 2016, data and methodology to take ILUC into account, and to report this to the Parliament by December 31, 2017 (Europarl, 2013)

Table 3.3 shows the main tools, which are/have been used to promote biofuels in the EU:

Year/code	Directive
1992/CAP	Common Agricultural Policy
1998/70/EC	Fuel Quality Directive I
2003/17/EC	Fuel Quality Directive II
2003/30/EC	Biofuels Promotional Directive
2003/96/EC	Energy Taxation Directive
2008/ adopted in the sitting of 17th December	EU Climate and Energy Package
2009/30/EC	Fuel Quality Directive (FQD)
2009/28/EC	Renewable Energy Directive (RED)
2013/ adopted on September 11th 2013	Amendments on RED and FQD

Table 3.3: The main directives to promote biofuels in the EU, adapted from (Amezaga et al., 2010) and (Europarl, 2013)

However, in spite of all these efforts, these directives were not exactly a success story: only Germany, Austria and Sweden reached the 2% target in 2005 (Epure, 2011) and the figures showed that meeting the 2010 target for most EU countries was impossible (Fig 3.6) (Eurostat, 2011).

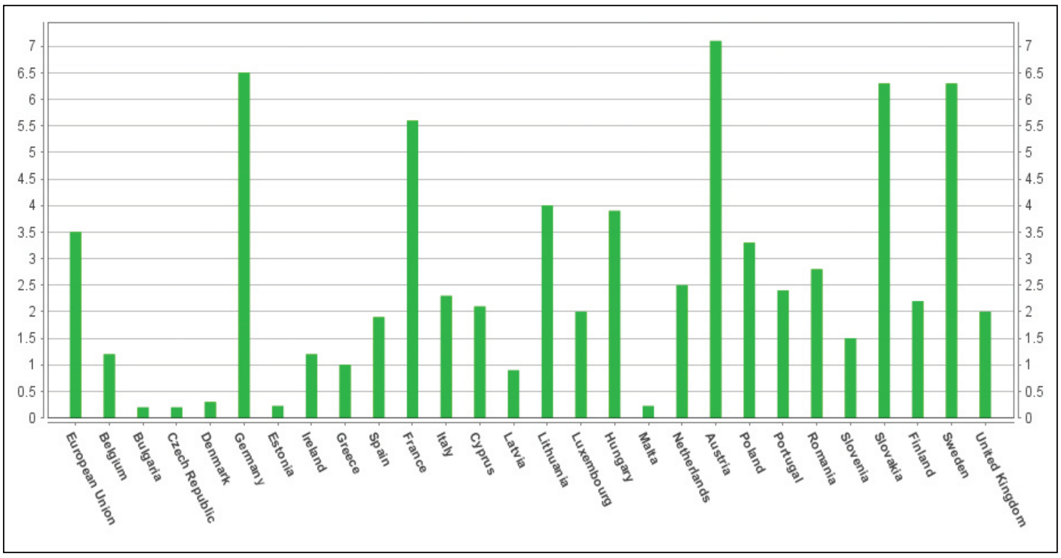


Fig. 3.6: Renewable energy percentage in fuel consumption of transport in the EU (Eurostat, 2011)

In July 2009, the German government approved a revision of its mandatory biofuel targets. The overall mandatory biofuels share in the transport sector will be held at 6.25% from 2010 until 2014 (Sorda et al., 2010). From 2015 onwards, the biofuel quotas will be determined on the basis of GHG emission reductions. Germany is the first country in the EU to propose biofuel quotas based on GHG emission savings (Sorda et al., 2010). Later on European Commission followed and set an 80% reduction of carbon emissions in transport for 2050 (compared to 1990 level) and a 70% reduction in the use of oil (Linares and Pérez-Arriaga, 2013).

Tax exemptions for biofuels have been vital in promoting biofuels in the EU. However, a trend of Member States switching from tax exemption schemes to obligation schemes can currently be observed. Biofuels in Europe have also, until recently been supported through agricultural policies. This support, established within the Common Agricultural Policy (CAP), was available through two instruments. Firstly, the Energy Crop Scheme which began in 2004 provided a direct subsidy of up to 45€/ha for farmers within the EU. Secondly, energy crops could also be grown on Set-aside land. In the EU, the set-aside accounted for 10% of a farmer's land and could not be used for production under EU agricultural law. The CAP reform in 1992 allowed the production of non-food crops on set-aside land without losing the subsidy. The abolishment of compulsory set-aside came into force shortly afterwards and the Energy Crop Scheme was terminated in 2010. Therefore, currently there is no direct incentive for the production of biomass available in the EU (Amezaga et al., 2010).

3.7. Summary of global biofuel policies

A summary of the main global policies supporting the biofuel production is shown in Table 3.4:

Country/ Area	Policy information	Methods of support
Australia	–Began developing sugarcane sector in 2000, due to financial difficulties –Bioethanol produced from grain and sugar cane molasses	–Federal government: excise tax exemption for biofuels in diesel and petrol –Capital subsidies for new or expanded capacity for biofuel production –State government: certain states have regional level support
Brazil	–Global leader in ethanol production and consumption until 2005 –Brazilian ethanol production is more efficient than other countries (e.g., U.S.) –Successful biofuel programme (the National Fuel Alcohol Programme, or Proalcool), created in 1975 –Most ethanol derived from sugarcane	–Minor tax reductions and ethanol, petrol blending provisions used –Depending on the alcohol market at the time, petrol companies must add 20–25% of ethanol to fossil petrol –The total value-added tax (VAT), fuel tax and other taxes on ethanol is only about half as much as that applied to petrol
China	– Launched its fuel ethanol programme in 2000 in order to improve the fuel supply situation in view of rapidly growing demand for transportation fuels	– Tax exemptions for ethanol: 5% from consumption tax, 17% from VAT
Colombia	– Since 2006 , the use of 10% ethanol in fuel in cities with populations larger than 500,000 inhabitants has been mandatory – Due to lack of facilities to produce ethanol, production of sugarcane- based ethanol began in October 2005	– Because Colombian ethanol production is not enough to cover a 10% ethanol blend nationwide, in mid 2008, the government announced that it would ease blending requirements in areas not sufficiently supplied with ethanol –Tax exemption for ethanol is in place
EU	– The Directive on the Taxation of Energy Products, the Promotional Directive created by the European Commission in 2003 and Renewable Energy Directive (RED) – Main biofuel producers are Germany and France –Main driver for biofuel has been a commitment to cut greenhouse gas emissions	–Direct subsidy of up to 45€/ha for farmers was available between 2004 to 2010 –No direct incentive available since 2010 –A trend of Member States switching from tax exemption schemes to obligation schemes can currently be observed
India	–In 2002, the Indian government decreed that four of the federally ruled areas, and nine states, must sell (E5) from January1, 2003, by law –main feedstock used is sugar cane molasses	– An excise tax reduction for E5, the obligation to blend all petrol with 5% ethanol in certain regions since January 2003 and government regulation of the ethanol selling price on the basis of ethanol production costs – In 2004, obligation suspended due to drought – The blending mandate was amended, stating ''that the 5% ethanol blended petrol shall be supplied in identified areas if: (a) the indigenous price of ethanol offered for ethanol blended petrol programme is comparable to the indigenous ethanol industry (b) the indigenous delivery price of ethanol offered for the ethanol blended petrol programme at a particular place is

Country/ Area	Policy information	Methods of support
		comparable to the import parity price of petrol at that location; and (c) there is adequate supply of ethanol
Peru	– 2002: government of Peru stated that it planned to become a leading exporter of ethanol – Planned to use sugarcane juice as feedstock	– In 2003, the Peruvian government created the ‘‘Law of Promotion of the biofuels market’’ – Regulations used include ‘‘an obligatory blend of biofuels: 2% of biodiesel in diesel from 2009 and five per cent from 2011 as well as 7.8% of ethanol in petrol from 2010’’
Thailand	– 2000: Thailand’s government became interested in ethanol due to high oil prices (which they mostly imported), high energy prices, and low prices for feedstock commodities (i.e., sugar and cassava) – Sugarcane molasses mostly used as feedstock	– Finance Ministry planned to waive the excise tax on gasohol in order to promote the ethanol market, and also planned to contribute to the Energy Conservation Fund, and the State Oil Fund –Tax privileges including duty exemptions on machinery imports and an 8 year tax holiday for corporations
USA	– Current global leader in ethanol production; mainly maize used as feedstock – Ethanol industry began to expand in early 1980s – The Clean Air Act and the Reformulated Petrol Programme were created in the 1990s, ‘‘which mandate the use of cleaner burning fuels by requiring minimum oxygen levels in petrol in US cities with high air pollution’’	– Both federal and state level tax reductions for fuel ethanol; most important one is a federal tax credit (which was valid until 2010), which is US$0.52/gallon of pure ethanol – ‘‘Ethanol–petrol blends consisting of 7.7% or 5.7% alcohol have received a prorated exemption;’’income tax credits exist for alcohol fuels, there are ‘‘federal incentives for the production of clean-fuel led vehicles that use (E-85)fuels and the Federal Bioenergy Programme and USDA programmes to promote the industrial use of selected agricultural commodities in the production of biofuels’’

Table 3.4 : Biofuel policies in selected countries, adapted from (Doku and Di Falco, 2012)

3.8. Discussion: Policy for biofuels, trends and drivers

A brief look at the global policies reveals that across the world, the key drivers for governmental involvement in the biofuel industry vary from country to country. While environmental concerns are the main drivers for the development of biofuels within Europe, energy security is the number one reason for the USA.

In Asia, improving trade balances and the expansion of the agriculture sector are the principal forces behind biofuel development. South America's focus is energy security and Africa's reasons are economical (Table 3.5):

Country/Region	Main Drivers					
	Climate Change	Air Quality	Energy Security	Trade	Rural development	Technological progress
Canada	x	x	x	-	-	x
United States	-	x	xxx	x	x	x
EU*	xxx	-	x	x	x	x
Brazil	x	x	xxx		x	x
Argentina	x	x	x	xxx	x	x
Peru	-	-	x	xxx	x	x
Colombia	x	x	x	x	-	x
China	x	x	x	xxx	xxx	-
India	-	-	x	xxx	-	xxx
Indonesia	-	-	-	xx	x	xx
Iran	-	-	x	-	x	x
Malaysia	-	-	-	x	xx	x
Thailand	-	-	x	x	xx	x
Japan	x	x	-	-	x	x
Africa**	x	-	x	xxx	-	-

Table 3.5: Main global drivers for the production of biofuels, adapted from (Sorda et al., 2010)
* EU: 27 member states of the European Union

**Africa: Including South Africa, Zimbabwe, Malawi, Ghana, Mozambique, Tanzania, Zambia Kenya, Angola, Swaziland, Egypt, Mauritius, Ethiopia and Uganda

Across the world, subsidies and tax exemptions have proven to be successful in shaping the biofuel production and consumption, especially in nurturing industries until they become more economically viable. Mandatory blending targets, tax exemptions and subsidies are the main elements widely adopted by governments to boost production and consumption of biofuels across the world (Sorda et al., 2010). However, relatively speaking, the biofuels sector is still in its infancy and needs more political support in order to be able to better compete with traditional fuels. Higher levels of support can be seen in some Asian countries, because the Asian governments have seen biofuels as the answer to many problems, even if private investment is being discouraged by a collapse in oil prices and the global economic crisis (Richardson, 2009).

Indonesia and Malaysia will continue to dominate Asia's biodiesel production, while Thailand, China and India all focus largely on ethanol (Zhou and Thomson, 2009). But the problem in Asia is that a great deal of trial and error seems to be involved and policies are continually being changed due to changes in governments and political instability.

According to researchers who work on biofuel status in Africa (Jumbe et al., 2009), trade policy and investment incentives are still not quite conducive for attracting investments in Africa. It can be concluded that the priority should be given to strengthening local production to satisfy national need and benefits at the local level. As Amigun et al. reported, to date, only a few African countries have implemented effective support policies for biofuel and many countries are still in the process of developing their energy policies. With the exception of South Africa, most polices were formulated without analysis of the impact of biofuels sector development on employment, food security and the environment (Amigun et al., 2011).

In the US and the EU, directives are being implemented to reduce GHG emissions, But the objectives seem ambitious. The previous targets was not exactly a success story for the EU, so in order to achieve the biofuel 2020 objective, the EU seeks to promote biofuels in developing countries in the tropical regions because of high biomass productivity and low production costs (Ponti and Gutierrez, 2009). This is despite the fact that developing countries need to carefully consider the benefits and limitations of biofuels, particularly in relation to the effects on food production.

At present, Brazil is the only country with a credible and profitable biofuel production programme, in which ethanol is able to compete with fossil fuels in a free market. Brazil's success is the result of several elements including the availability of low cost sugarcane and sustained years of governmental support in the past (Sorda et al., 2010). It has climatologic conditions and exceptional availability of land and water for the production of biofuels (Escobar et al., 2009). Considering these points, some argue that without government support (i.e. subsidies and tax exemptions), biofuel production will never survive in other parts of the world. Although in the case of political tensions, higher crude oil prices would make biofuel production relatively cheaper, but the biofuel industry is still far from being able to survive independent of governmental assistance. There are major uncertainties to overcome in the future, but for now, subsidies and tax exemptions have proven to be the most successful elements in biofuel production and consumption.

Chapter Four

Biofuels in the UK

Chapter Four: Biofuels in the UK

In the UK, the key driver for investment in biofuels is the state of the environment (Stern and Treasury, 2007). Meeting the commitment to the Kyoto Protocol, and developing a low carbon economy are key to the UK government targets (BioFRAC, 2006). In this chapter, the previous and current levels of production and consumption of biofuels in the UK are illustrated, the barriers, incentives and opportunities are discussed and the regulations, mandates and relative institutions are introduced.

4.1 History

Historically, the UK has had a delivery program for renewable electricity since 1990, initially the Renewable Non-Fossil Fuel Obligation (NFFO) and then in 2002, the Renewables Obligation (RO) (Mitchell and Connor, 2004), but the actual bioenergy policy in the UK was initiated in 2003 through four documents which are arguably the most important domestic reports in terms of bioenergy policy. In 2003, the UK government published the first “Energy White Paper” for a generation. This report for the first time emphasised the importance of reducing UK CO_2 emissions as a core objective, 60% by 2050, with real progress achieved by 2020. The Energy White Paper covered the options of using biomass to generate heat/power or conversion into liquid fuels for use in road vehicles (Florio and Vandervell, 2013). The report was followed by "Biomass as a Renewable Energy Source" report (also known as RCEP report) in 2004 by the Royal Commission on Environmental Pollution. This set the bio-energy policy agenda in the UK (Slade et al., 2009). Then in 2005, a report was released by an independent commission, the Biomass Task Force, which was a proposal to optimise the contribution of biomass to a range of targets and policies. It was followed by the government's formal response in 2006, called "The Government's Response to the Biomass Task Force Report". This report included the commitment to develop a long term biomass strategy. The report fulfilling this commitment, the UK Biomass Strategy, was published in May 2007 (Slade et al., 2009). In 2008, the Climate Change Act was announced, mandating to cut GHG emissions by 80% by 2050 relative to 1990 levels. Finally there have been Energy Acts 2010 and 2011, establishing the Green Deal in order to implement part of the transition plan prepared by the government (Meeus et al., 2012). But the fact is that the biggest policy changes affecting bio-energy deployment in the UK come not from domestic policy, but from the EU. The EU's commitment to introduce specific and binding targets, along with mechanisms to monitor whether these targets are being met, will force the UK to revisit its strategy for bioenergy, along with its priorities for other renewable sources (Slade et al., 2009). As a member of the EU, the UK is committed to reducing its carbon emissions as initially mandated by the 2003 EU Biofuels Directive that set out a target of 5.75% of transport fuels by 2010. This was followed by the Renewable Energy Directive (RED) that sets out a target of 10% for all forms of transport to be from renewable sources by 2020 (UKPIA, 2013). In order to boost the use of biofuels and other renewable fuels in the transport sector, in November 2005, the UK Government announced that it would introduce the Renewable Transport Fuel Obligation (RTFO) as the first biofuel regulatory reporting scheme in the UK (Upham et al., 2011). In October 2007, UK Parliament approved the RFTO (Florio and Vandervell, 2013) and in 15th April 2008, the RTFO was officially launched (Swinbank et al., 2011) and since then, the scheme has significantly increased the attention of policy makers to biofuels, and established the importance of monitoring and managing the sustainability risks of biofuels in order to increase their GHG benefits (Chalmers and Archer, 2011). Another important document was the Gallagher report, which was released on 7 July 2008. The Gallagher Review was a major study commissioned by the UK Government on the indirect or displacement impacts of biofuels in response to growing concerns about the impacts of biofuels. Based on the findings of this review, the rate of the increase of the UK's target should be limited to 0.5% per annum; targets beyond 5% by volume were only to be applied beyond 2013-2014 if biofuels were shown to be sustainable (RFA, 2008). As a result of publishing this review, in 2009, the RTFO target which was originally 5% by 2010/11, was officially revised to 5% until 2013/2014 (Xynteo, 2011). On 15 December 2011, the RTFO was amended to allow only biofuels to meet the RED carbon and sustainability criteria to count towards the obligation (RTFO, 2013b). From April 2013, the obligation was extended to include fuel consumed by Non-Road Mobile Machinery (NRMM) as well (UKPIA, 2013). The Policy interactions behind the formation of the UK Biofuel Strategy are shown in Fig 4.1.

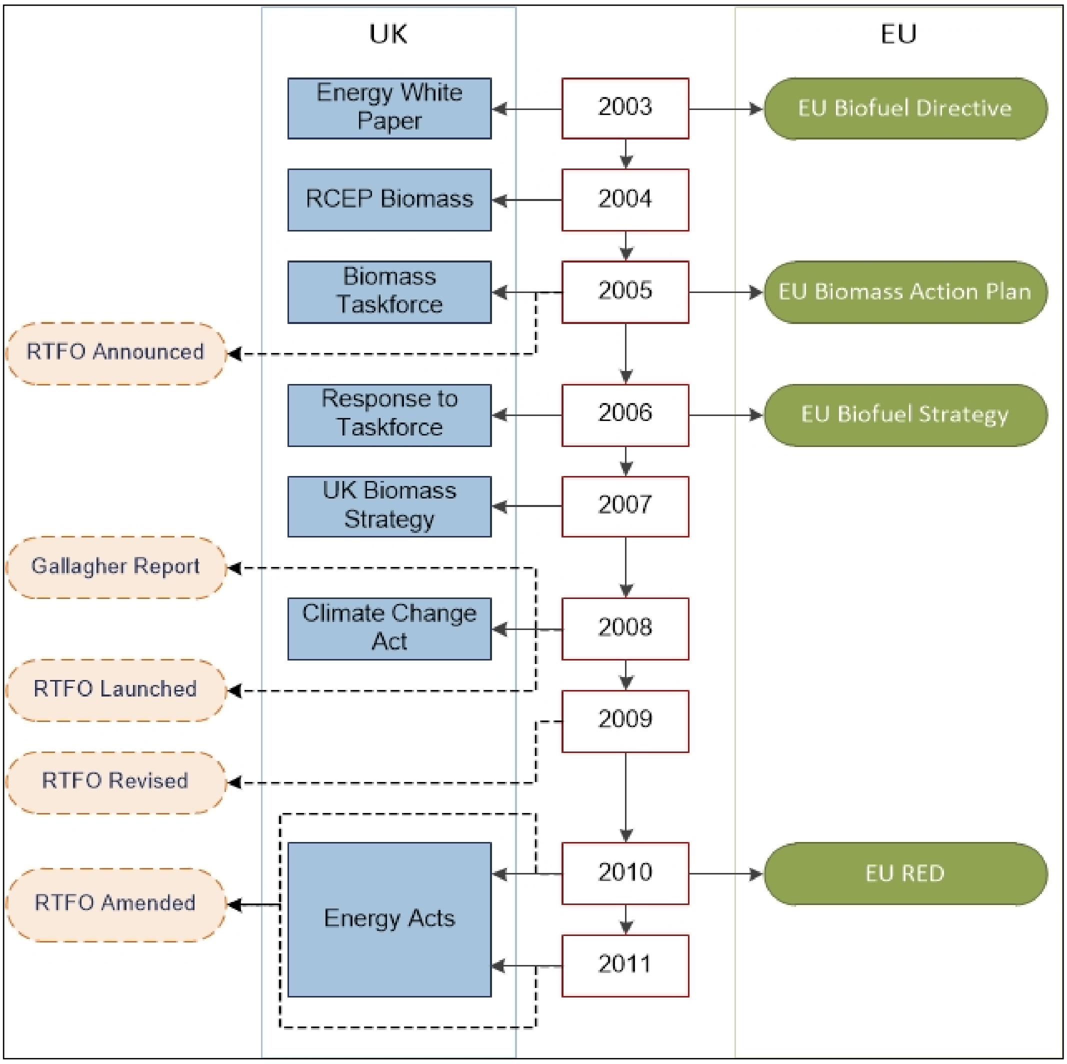


Fig 4.1: Policy interactions leading up to the formation of the UK Biofuel Strategy, adapted from (Slade et al., 2009)

4.2 Current situation

The number of biofuels producers and suppliers has been growing in the UK. This is despite the fact that crude oil, natural gas and nuclear power remain important to the UK energy balance. In 2012, the total primary energy consumption in the UK was 214.3 million tonnes of oil equivalent (mtoe), of which crude oil with around 77 million tonnes, contributed 35.9 %, together with natural gas with around 73 mtoe contributed 34%, coal with 41 mtoe contributed 19% and primary electricity (including nuclear and coal) with 17 mtoe contributed 7.9% of the total primary energy consumption. The bioenergy and waste with 7.79 mtoe, accounted for about 3.6% of total primary energy consumption in the UK (DECC, 2013a) (the total percentage is not equal to 100 due to rounding). The UK is a net importer of energy, with a dependency level of 43%. Fossil fuels are the dominant source, although supply from renewable sources has increased since a decade ago (DECC, 2013a). An important development occurred when the use of coal for electric power generation increased in 2012 to 42.8% (up from 30% in 2011), occupying the top spot among all sources. This is due to the relatively high cost of natural gas in the UK (EIA, 2013). However, the new findings of shale gas reserves in the UK might change the future energy scene. The British Geological Survey have estimated a 40 trillion cubic metres (1,300 trillion cubic feet) of shale gas in the ground in northern England (See chapter 7) (BGS, 2013). Even without considering the Shale gas reserves, the UK continues to produce large amounts of natural gas; in 2012, domestic natural gas production was 1,443.53 billion cubic feet, which was adequate for more than half of domestic consumption (the consumption was 2,757.78 billion cubic feet) (EIA, 2013). Currently the UK biofuel plants with a total capacity of more than 1.5 billion litres per annum are spread in different parts of the country. Table 4.1 provides a breakdown of biofuel production plants in the UK.

In recent years, there has also been considerable interest in the use of algal fuel as feedstock for production of biofuels but hardly any commercial activity exists in downstream processing (Schlarb-Ridley, 2011). In the UK, there are some national projects with the aim of overcoming barriers to the commercialisation of algal biofuel, such as "Intesusal" and "The Algae Biofuels Challenge" (IISD, 2013). The latter, which was the biggest algal fuel project in the UK, was launched in 2008 by the Carbon Trust with the aim of accelerating the move to a low-carbon economy, but had its funding severely cut by 40% in 2010, as part of the major cuts imposed by the UK government due to the financial problems

Company	Location	Capacity (Million Litres)	Year of first operation	Type
Argent Energy Motherwell plant	Motherwell (Scotland)	50.94	2005	biodiesel
Greenenergy Immingham Plant	Immingham	0.23	2006	biodiesel
Harvest Energy	SealSands, Middlesborough	283	2006	biodiesel
British Sugar	Wissington	70	2007	bioethanol
TMO Renewables	Surrey	0 (Project)	2008	Cellulosic Ethanol
Ensus	Wilton	400	2009	bioethanol
Vivergo Fuels	Seltend/Hull	420	2010	bioethanol
Vireol	Grimsby	200	2011	bioethanol
Butamax	Hull	189	2012	bioethanol
Green Biologics	Abingdon	55 tonnes	2012	Biobutanol
Solena/British Airways	East London	0 (Project)	2014	biodiesel

Table 4.1: Breakdown of biofuel production plants in the UK, adapted from (IISD, 2013)

4.3 UK biofuel market overview

In 2013, the market turnover of the UK's biofuel industry was estimated at one billion Euro (IISD, 2013). In 2012/13, UK biodiesel consumption fell to around 520 million litres from previous year's 992 million litres (Fig 4.2). This is mainly because of two factors: the waste fuels (used cooking oil and tallow) to fulfil the obligation, and a shift to ethanol use due to the high availability of cheap US corn ethanol in international markets (Bailey, 2013). The 2012/13 biodiesel levels represented around 2% of total diesel sales by volume (UKPIA, 2013), Fig 4.2:

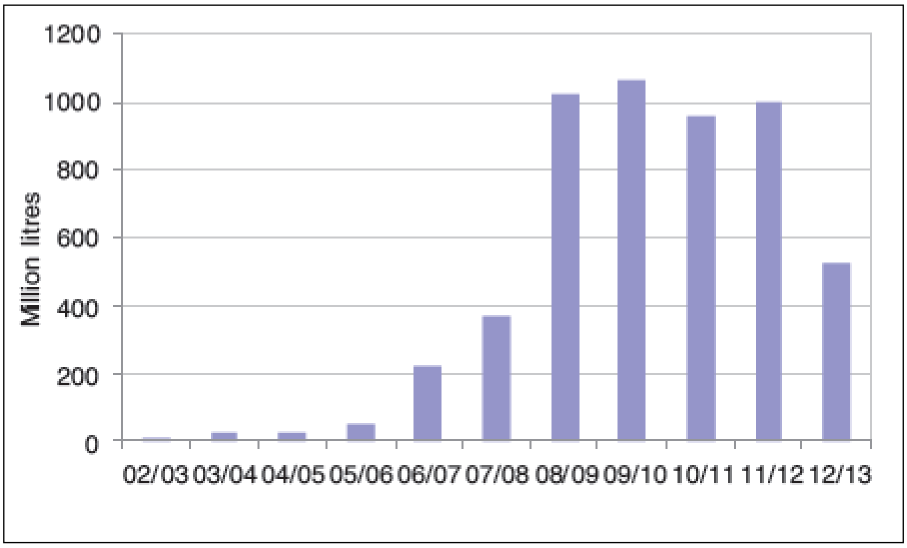


Fig 4.2: UK biodiesel consumptions, (UKPIA, 2013)

Also in 2012/13, UK bioethanol consumption stood at a little under 800 million litres, which represents around 4.2% of all petrol sales by volume (UKPIA, 2013).

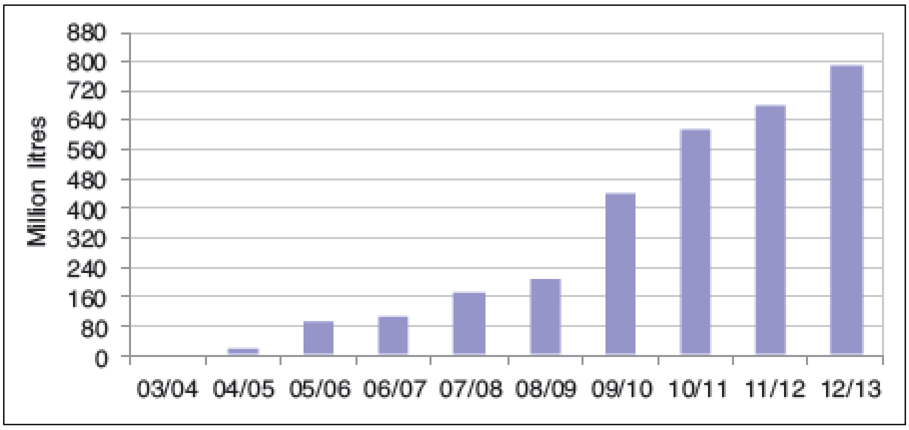


Fig 4.3: UK bioethanol consumptions, (UKPIA, 2013)

Based on Fig 4.2 and Fig 4.3, in 2012-2013, 1.3 billion litres of renewable transport fuel were consumed in the UK, falling by around 300 million litres from previous year's 1.6 billion Litres. This drop is attributed to biodiesel.

Also in the same period, the average carbon savings of 61.2% were reported (RTFO, 2013b). From 1.3 billion litres of renewable fuel, 1.03 billion litres (77%) has been reported to meet the sustainability requirements (RTFO, 2013a) and of which, bioethanol comprised 56% of supply, biodiesel 39% and biomethanol and methyl tertiary butyl ether (MTBE) 5% (RTFO, 2013a), plus a very small volume of biogas, and pure vegetable oil. Figure 4.4 shows the trend in the consumption of bioethanol and biodiesel by calendar year up to 2012, based on percentage by volume of total petrol and diesel consumed. The data shows there has been a marked increase in bioethanol consumption since 2008, while the consumption of biodiesel demonstrates a decrease in 2011 and 2012. The figures also show that of all the biofuel consumed in 2012, 45% was biodiesel and 55% was bioethanol on a volume basis, which shows that in 2012, for the first time the consumption of biodiesel in the UK was lower than the consumption of bioethanol (HMRC, 2013).

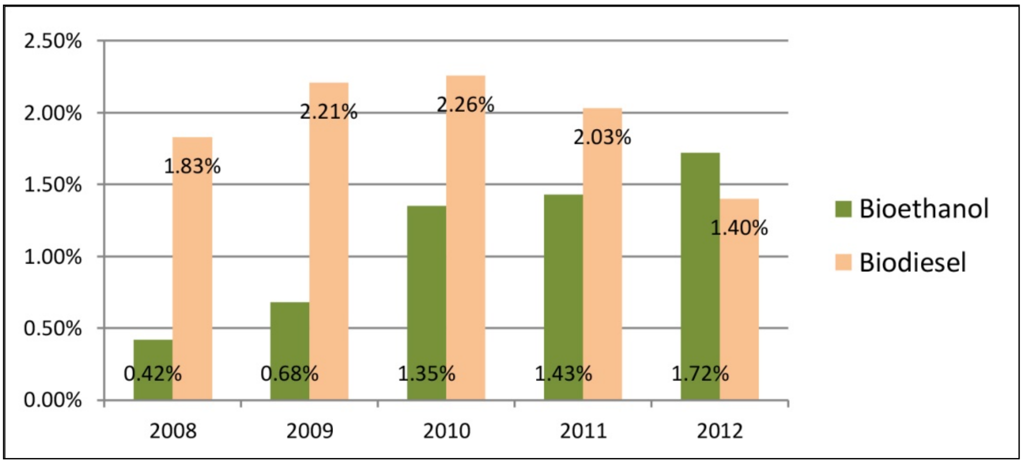


Fig. 4.4: Biofuel consumption in the UK as a percentage of total petrol and diesel consumption, source: (HMRC, 2013)

The figures from HMRC do not, however, reveal what type of feedstocks the biofuels are derived from nor in what mixture strengths the biofuels are consumed. This matters when considering the implications of biofuel consumption because the impact on emissions of various pollutants can depend on how the biofuels are consumed. The effect on emissions can also vary with biofuel feedstock as this defines the chemical structure of the fuel (AQEG, 2011).

4.4 Feedstock

Biofuels can be produced from a variety of sources in different countries. Potential UK grown energy crops include rapeseed which can be converted into biodiesel, and wheat and sugar beet which can be used to produce ethanol by fermentation (Florio and Vandervell, 2013). It is reported that in 2013, 22% of the consumed biofuel in the UK was sourced from UK feedstocks (RTFO, 2013a). This figure is up 5% compared to 2012 (17%) (RTFO, 2013b) and 12% compared to 2011 (10%) (Xynteo, 2011). The main feedstock for biodiesel production is overwhelmingly from used cooking oil (UCO), making up 88% of all biodiesel feedstocks (IISD, 2013). The greenhouse gas balance of biodiesel made from UCO is very good, with 70–75% lower greenhouse gas impact and 50% less total environmental impact than low sulphur petrol (Thornley et al., 2009). The main limitation for UCO is the availability of a suitable and sustainable collectable waste resource. However, in the UK, a national free commercial collection service exists already. The other UK biodiesel feedstocks are soy oil, oilseed rape and other oils such as palm oil and tallow (Kim et al., 2013a). It is important to note the difference in the proportion of these feedstocks today compared to the past. For example in 2009 the proportion was reported as: soy (41%) sourced mainly from the US, followed by oilseed rape (31%) sourced mainly from Germany, palm oil (12%) sourced mainly from

Malaysia and Indonesia and tallow (11%) sourced mainly from the USA and used cooking oil only 4% (Figure 4.5) (AQEG, 2011).

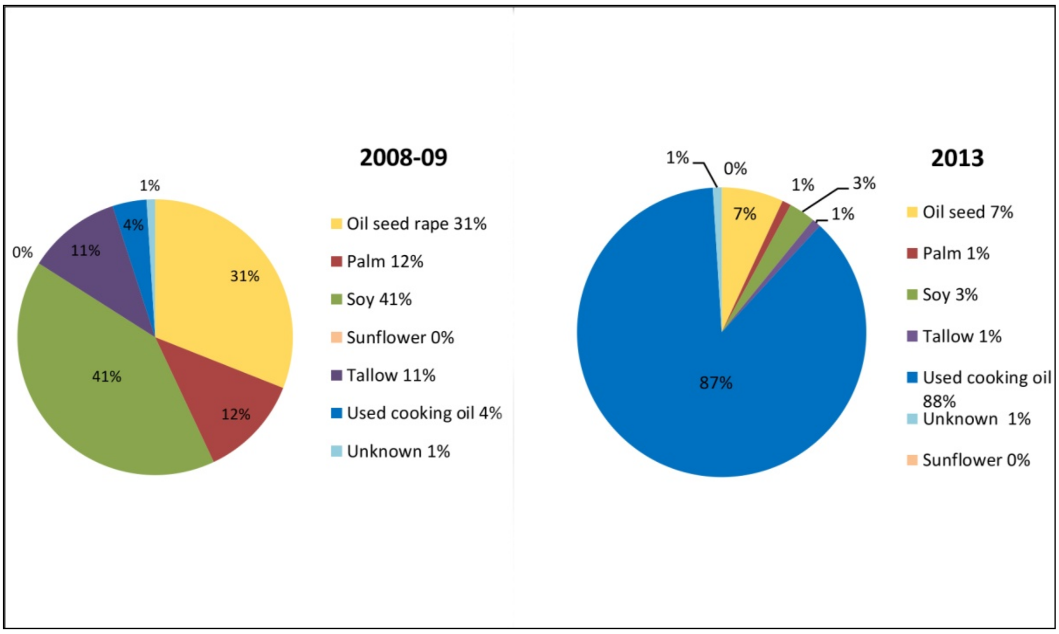


Fig. 4.5: Comparison between feedstocks of biodiesel supplied in the UK in 2008/09 (AQEG, 2011) and in 2013 (IISD, 2013).

The same trend is also reported for bioethanol as the most widely reported source (by feedstock and country of origin) for bioethanol is currently corn from the USA (providing 517 million litres out of a total 674 million litres consumed in 2011/2012 (IISD, 2013). There are hundreds of varieties of corn across the world, but they are not commercially grown on a large scale in the UK due to weather condition (Thornley et al., 2009). Recently, a significant reduction of sugarcane feedstocks sourced from Brazil has been reported compared to previous years which was 80% (AQEG, 2011). The share of bioethanol feedstock sources is displayed in Fig 4.6.

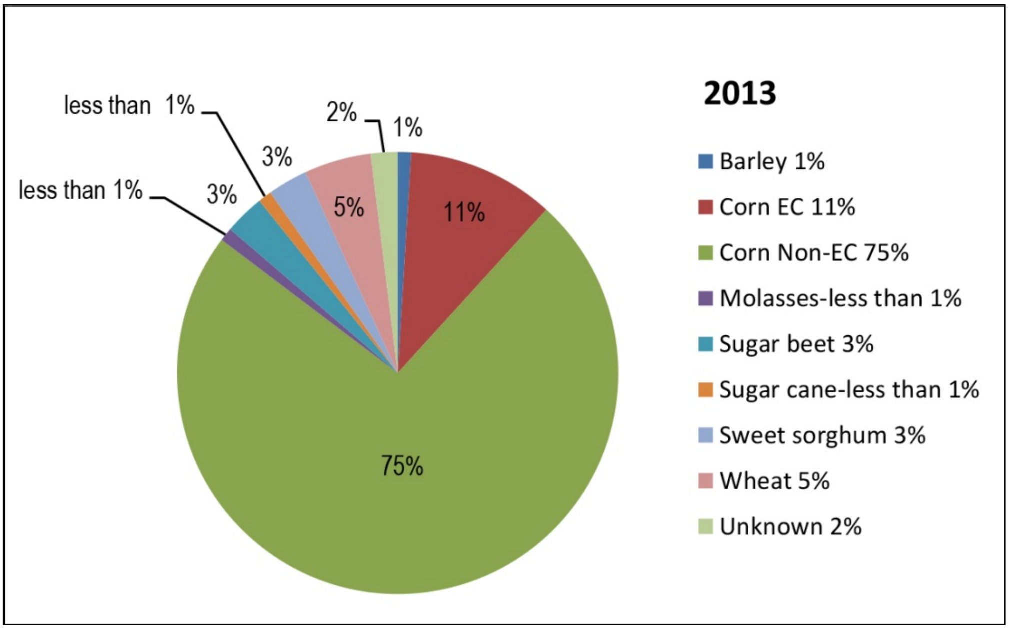


Fig. 4.6: Bioethanol feedstock sources consumed in the UK in 2011/2012 (total percentage is not equal to 100 due to rounding), adapted from (IISD, 2013)

4.5 Institutions, Regulations and Mandates

The main regulatory frameworks in the UK related to biofuels are the transport biofuels strategy and excise duty reduction. The National Government places biofuels in the context of creating a low carbon economy (Bomb et al., 2007).

The Renewable Transport Fuel Obligation (RTFO) is one of the UK Government's main policies for reducing greenhouse gas (GHG) emissions from road transport in the UK (RTFO, 2013b). Department of Transport (DfT) has been responsible for monitoring the implementation of the RTFO since 2011 (prior to 2011, the Renewable Fuels Agency-RFA-was in charge). Obligated companies are required to submit monthly reports of the volumes of fuels sold and the biofuel content (Florio and Vandervell, 2013). The RTFO was introduced in April 2008, with an original target of 5% biofuel content (by volume) in road fuels by 2010/11 (UKPIA, 2013). However, this was revised in 2009, due to sustainability concerns and the new targets were 2.5% by volume of biofuels in 2008/9, 3.25% in 2009/10, 3.5% in 2010/11, 4% in 2011/12, 4.5% in 2012/13 and 4.75% in 2013/14 (Florio and Vandervell, 2013) (Fig. 4.7);

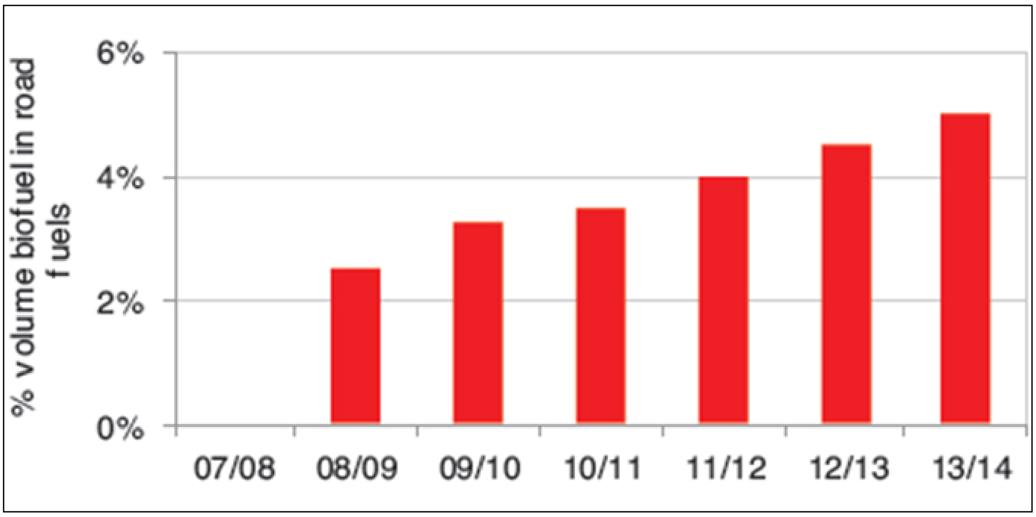


Fig. 4.7: UK RFTO targets: % volume biofuel in road fuels (UKPIA, 2013)

The UK government is currently considering what policies will ensure that it meets the EU's RED commitment of using 10% renewable sources in transport fuels by 2020 (IISD, 2013).

4.6 Barriers and Incentives

Sustainability uncertainty, lack of long term policy and government directions (TTR, 2009), limit investments in research and development fields, also mistrust between local communities, developers and governmental agencies (Adams et al., 2011) are among the main obstacles to the biofuel industry in the UK.

Furthermore, the domestic industry for biofuels is undeveloped and inexperienced (Bomb et al., 2007) but the main barrier to the increased use of biofuels is the relatively low cost of conventional petrol and diesel in comparison. This is a fact that biofuels cost more without subsidy or support (TTR, 2009). In the UK, there are no direct subsidies for cultivating biofuel crops but the government-set regulations put in place in recent years have created an interest in producing energy from biomass (DECC, 2009). A number of general subsidies are available within the UK to help grow feedstocks for bioenergy processes, including the "Single Payment Scheme" (SPS) (started in 2005, farmers are paid annually for the land that they manage or own), and the "Entry Level Environmental Stewardship Scheme" (started in 2005, farmers are paid a flat rate of £30 per hectare per year based on this scheme) (Adams et al., 2011). Apart from these subsidies, other potential supports are provided to the UK biofuels sector through excise tax exemptions and blending mandates. Excise tax exemptions have been a main support tool for the promotion of biofuel in the UK since 2002 (Bomb et al., 2007). Until very recently (March 31, 2012), biodiesel produced from used cooking oil was benefiting from an exemption of 20 pence per litre tax exemption. The mandatory blending rates are one of the most important incentives for biofuel promotion in the UK. Fossil-fuel suppliers are obliged to blend a percentage of fuels for road transport supplied in the UK from renewable sources. If oil companies do not meet their obligations, they need to pay a so-called buyout price currently set at 30 pence per litre (ppl). But the problem is the buyout money usually act as a safety valve for suppliers unable to redeem enough Renewable Transport Fuel Certificates (RTFC) to meet the target (IISD, 2013). But none of these supportive mechanism favours domestic over imported biofuels, and they do not reduce market opportunities for non UK/or non-EU suppliers (Swinbank, 2009). The results of a study suggest that in the UK, the financial reward/support is the main driver for bioenergy sector, including biofuel producers, followed by "reduce dependency on fossil fuels" (Adams et al., 2011).

4.7 The future of biofuels in the UK

It is difficult to predict what the long term biofuel policy would be. The "UK Bioenergy Strategy" has set a framework of principles to guide bioenergy policy in the UK in 2020 and up to 2050. According to the strategy; "policies should aim to deliver genuine carbon reduction in the most cost-effective way, while avoiding adverse effects on the wider economy" (DfT, DECC & DEFRA, 2012). Therefore, there is a task for the government to push sustainable development of bioenergy in the UK, in a way that secures its benefits, while managing the risks. Based on this strategy, renewable energy technologies will be supported in the UK beyond 2020 and the UK government will continue to push biofuel production. The intention is also to support shale gas (Chapter 7) and other alternative energies (such as wind and nuclear) also as a valid low carbon options. In other words, there will be diverging strategies for the future (Meeus et al., 2012). Setting no targets beyond 2020 will help the system to be flexible enough to remain valid in the face of evolving evidence and technological innovation (DfT, DECC & DEFRA, 2012). The results of a separate study also projected that UK fulfils the amended RTFO biofuel target by 2014, but does not exceed this target by a significant margin during the rest of the projection period (Kim et al., 2013b). The supply of bioethanol has exceeded that of biodiesel, but both are expected to grow in the future to meet the EU and domestic renewable fuel targets. For the foreseeable future, it is projected that the biodiesel capacity will increase to 1.17 million tonnes in 2018, and for bioethanol, it is projected that UK production capacity will increase to 1.56 million tonnes in 2018 (Kim et al., 2013b). Therefore, the preference for bioethanol production seems to continue in the UK. The reason is that bioethanol production is cheaper compared to biodiesel on a per litre basis, making it a favourite for suppliers to meet their volumetric obligations under the RTFO. Although, the cap for bioethanol blending (currently E5) will limit the volume of ethanol that can be blended in the near future; the government has requested suppliers to hold the introduction of E10, due to the concerns that a major proportion of the existing UK vehicle fleet may be incompatible with the higher bioethanol blend (Bailey, 2013). Regarding feedstock, a large expansion in rape oil and rapeseed production is expected, while wheat production remains unchanged (AQEG, 2011). Although , the UCO and tallow are possibly to remain the favourite biodiesel feedstocks in the short term, rapeseed will be the source for about half of biodiesel production by 2018 and almost all (about 97%) of domestic bioethanol production in the UK is projected to come from wheat in 2018 (Kim et al., 2013b). Also other types of oxygenated fuels such as biobutanol and various types of ethers may be preferable if these can be produced economically and sustainably (AQEG, 2011). The second generation lignocellulosic biomass feedstocks such as wood and straw could become much more significant players in the UK market and may emerge as sources of biodiesel beyond 2020 (Sims et al., 2010). Also algal fuels are still at the development stage, and at present neither microalgae nor macroalgae are being commercially cultivated in the UK (Roberts and Upham, 2012). However, it remains a very promising source of renewable energy for the future if the existing cost estimates could be improved. As experience with algal cultivation increases it may also be found that third generation biofuels have a big role to play in the future (Slade and Bauen, 2013), but to reach that point more algal research projects are needed and the third generation biofuels are not expected to make a significant contribution to the UK biofuel supply in the near future (Bailey, 2013).

Chapter Five

Technical Perspective,

Types and Generations of Biofuels

Chapter Five: Technical Perspective, Types and Generations of Biofuels

In this chapter, the technical perspective of the biofuel industry is discussed. Firstly, it examines the biomass to biofuel conversion routes. Next, it focuses on the biofuels' various generations and their advantages and limitations. Finally, the new technologies are discussed and how these technologies affect the biofuel production in the future.

5.1 Biofuels definition

The first step of any biofuel production is conversion of biomass. Various technologies are needed to make use of this diverse energy source. Some technologies are already developed over the years, while others are in the process of being developed. Currently biofuels are categorised into four generations, according to the type of technology they rely on and the biomass feedstocks they convert to fuel;

First generation biofuels are produced from traditional food and oil crops such as corn, rapeseed, palm, sugarcane, sugar beet and wheat, as well as animal fats using conventional technology (Singh et al., 2011b).

Second generation biofuels are produced from non-food feedstocks (e.g. wastes, agricultural and forestry residues, energy crops) (DEFRA, 2008), using advanced technology. The cell walls of the carbohydrate-rich lignocellulosic biomass are broken by hydrolysis to allow access to sugars for fermentation (Sivakumar et al., 2010). The remaining production routes may include bio-chemical, thermo-chemical (will be discussed later in this chapter), or anaerobic digestion (bacterial breakdown of biodegradable organic material in the absence of oxygen). The primary end-product of the biochemical processes (specifically anaerobic digestion method) is biogas which can be upgraded to 97% methane content and used as a substitute for natural gas (Cherubini, 2010).

Third generation biofuels are produced from algae and rely on the lipid content of them. Generally, species like *Chlorella* are targeted because of their high lipid content (around 60% to 70%) (Liang et al., 2009).

Fourth generation biofuels are produced from genetically modified crops (Biopact, 2008) and modified microorganisms (Daroch et al., 2013), and they are aimed at, not only producing sustainable energy, but also a way of capturing and storing carbon dioxide. The term "advanced biofuels" is also applied to the second, third and fourth generations due to the advance technology involved.

5.2 Biomass to biofuels conversion routes

There are four main routes available to convert biomass to biofuels; Direct Combustion, Chemical, Thermochemical and Biochemical;

5.2.1 Direct Combustion route

Combustion or burning is a traditional and the most common way of converting solid biomass into energy. Traditional use of wood generally has a low efficiency (average 35% but sometimes as low as 10%) and generally goes with considerable emissions (e.g. dust and soot). Yet in recent years, the technology development has led to the application of more efficient systems (up to 70%) which is now widespread in Scandinavian countries, Austria and Germany. In Sweden in particular, a significant market is developed for biomass pellets, which are fired in automated firing systems (Faaij, 2006). Wood and charcoal are by far the most commonly used biomass based "bio-energy" carriers. The FAO estimated that in 2010, about 60% of the world's total wood removals from forests and trees outside forests were used for energy purposes (Vandamme et al., 2011).

5.2.2. Chemical route

Chemical route is a relatively simple method to produce biofuels. Some of the most important added value chemicals (such as reduced sugars or ethanol) are produced from biomass through chemical route using catalysed (such as acid and enzyme) hydrolysis. The conversion of lignocellulosic materials is difficult because first, sugars need to be produced via hydrolysis. Hydrolysis is an important pre-treatment step to destroy the cellular structure of biomass, to make it more accessible to further chemical or biological treatment (Faaij, 2006). Acid-catalysed hydrolysis of biomass is a much faster reaction than enzyme-catalysed hydrolysis (Küçük and Demirbaş, 1997). Therefore, the chemical route refers mainly to acid degradation by using inorganic acid catalysts. One of the primary examples of chemical process is "Transesterification" which is the most commonly used method for the production of fatty acid esters, such as Fatty Acid Methyl Esters (FAME), the most produced biodiesel from plant/animal oils. Transesterification is the process of reacting a triglyceride with an alcohol in the presence of a catalyst, and as a consequence, a mixture of fatty acids alkyl esters and glycerol will be produced (Vandamme et al., 2011) (Fig 5.1). The catalyst used in transesterification could be a strong acid, base or an enzyme.

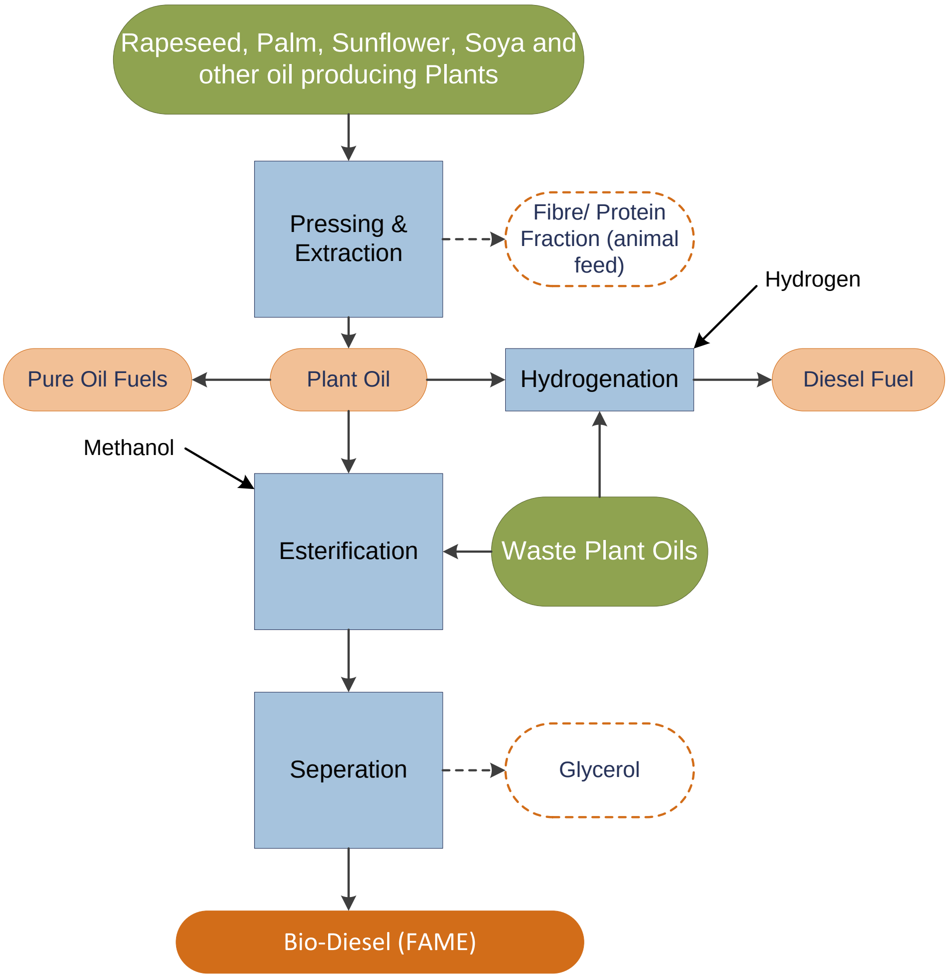


Fig 5.1: Transesterification, the production of biofuels from vegetable oils, adapted from (EBTP, 2012a) and (Faaij, 2006)

The important parameters for chemical processes are acid concentration, pre-hydrolysis, temperature, time at reaction conditions and kind and moisture of used materials (Küçük and Demirbaş, 1997).

5.2.3 Thermo-chemical route

In this pathway, heat and chemical treatments are used in order to convert biomass to liquid or gaseous intermediates (e.g. syngas ($CO + H_2$) and (bio-oil) which ultimately produces biofuels (Cherubini, 2010). Common thermochemical processes are pyrolysis and gasification of biomass (Damartzis and Zabaniotou, 2011). Pyrolysis is a process which decomposes biomass by heating it under anaerobic condition, which results in the production of charcoal (solid), bio-oil (liquid), and fuel gaseous products (Fig. 5.2); (Naik et al., 2010)

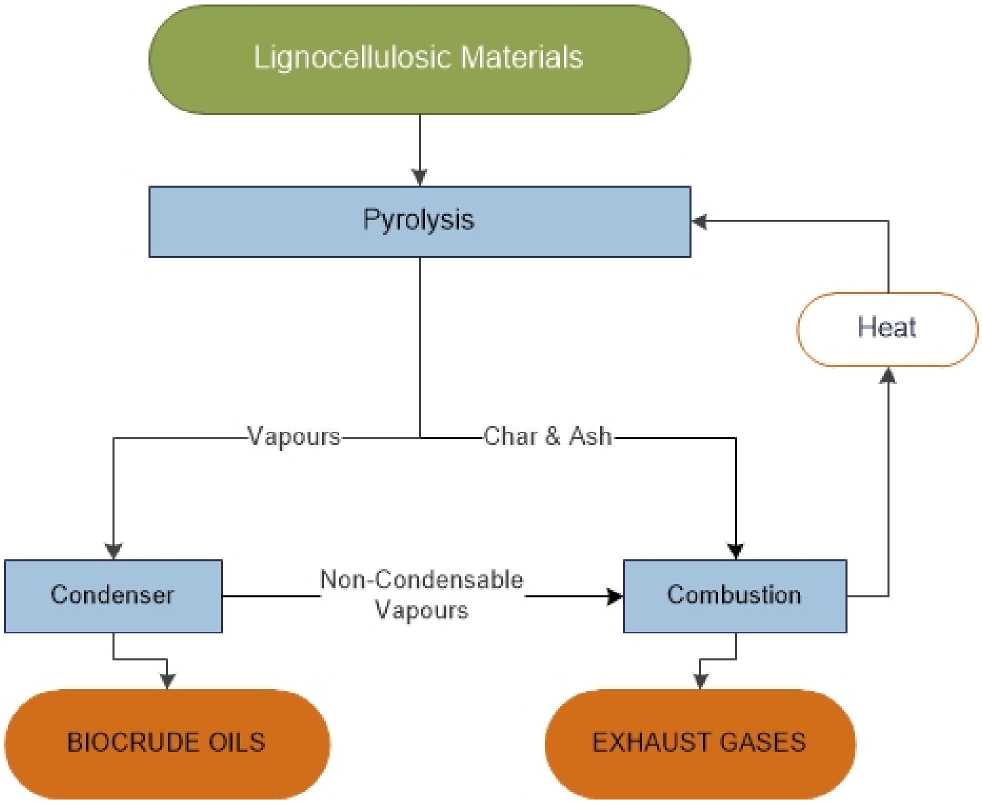


Fig. 5.2: Biomass pyrolysis process, adapted from (Naik et al., 2010)

Gasification is a process by which heat and limited amount of oxygen are used to convert biomass into a hot synthetic gas called "syngas". This reaction takes place in either updraft or downdraft gasifiers. In an updraft gasifier, biomass enters from the top, and air is blown-in from the bottom. In this type of gasifier, the produced syngas is contaminated by tar and is therefore dirty, while in a downdraft gasifier, the main reactions take place in a 'throat', where the tars break down into CO and H_2 at a higher temperature than in an updraft gasifier. So downdraft gasifiers produce cleaner syngas, Fig. 5.3;

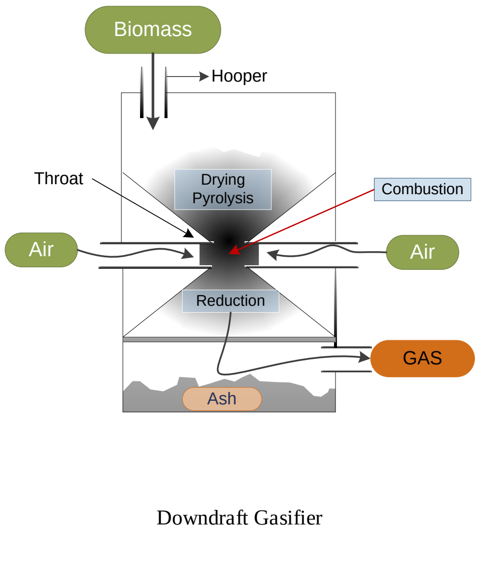


Fig. 5.3: Biomass gasification process

This syngas can be burnt and used to produce electricity in a gas turbine or converted to alcohols, ethers, hydrocarbons and other chemical products (Damartzis and Zabaniotou, 2011). Both syngas and bio-oil can be used directly or can be converted to clean fuels and other valuable chemicals. Catalysis is vital to achieving this aim (Skoulou and Zabaniotou, 2012) (Fig 5.4). Thermochemical routes of biomass conversion are more attractive compared to other routes due to certain advantages such as higher productivity, complete utilization of feedstocks leading to multiple products, applicability to a wide range of feedstocks, independence of climatic conditions and better control over the process relative to biological processes (Bolan et al., 2013).

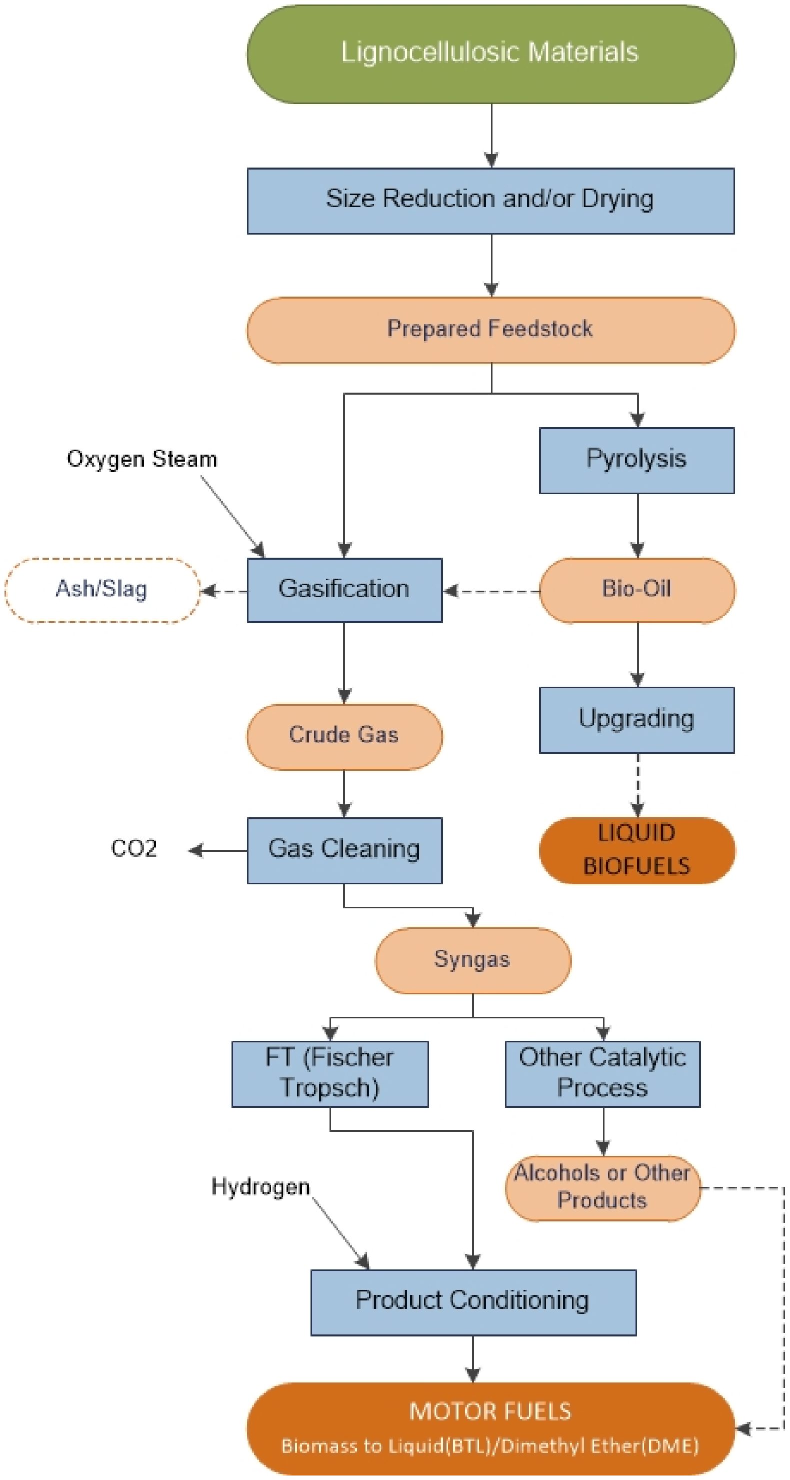


Fig. 5.4: Thermochemical routes to liquid biofuels, adapted from (EBTP, 2012a) and (Cherubini, 2010)

5.2.4 Biochemical route

Biochemical route is the process by which biomass is converted to gas (CO_2 and CH_4), waste (compost or fertilizer) and ethanol, by using microorganisms and/or enzymes (Küçük and Demirbaş, 1997). The biochemical conversion route consists of three major conversion process steps: pre-treatment (grinding, milling,...), enzymatic hydrolysis and fermentation (Sohel and Jack, 2011). Enzymes and/or microorganisms (bacteria, yeast, fungi, ...) are used to convert cellulose and hemicellulose components of the feedstocks to sugars before their fermentation to produce bioethanol (Sims et al., 2010) (Fig 5.5).

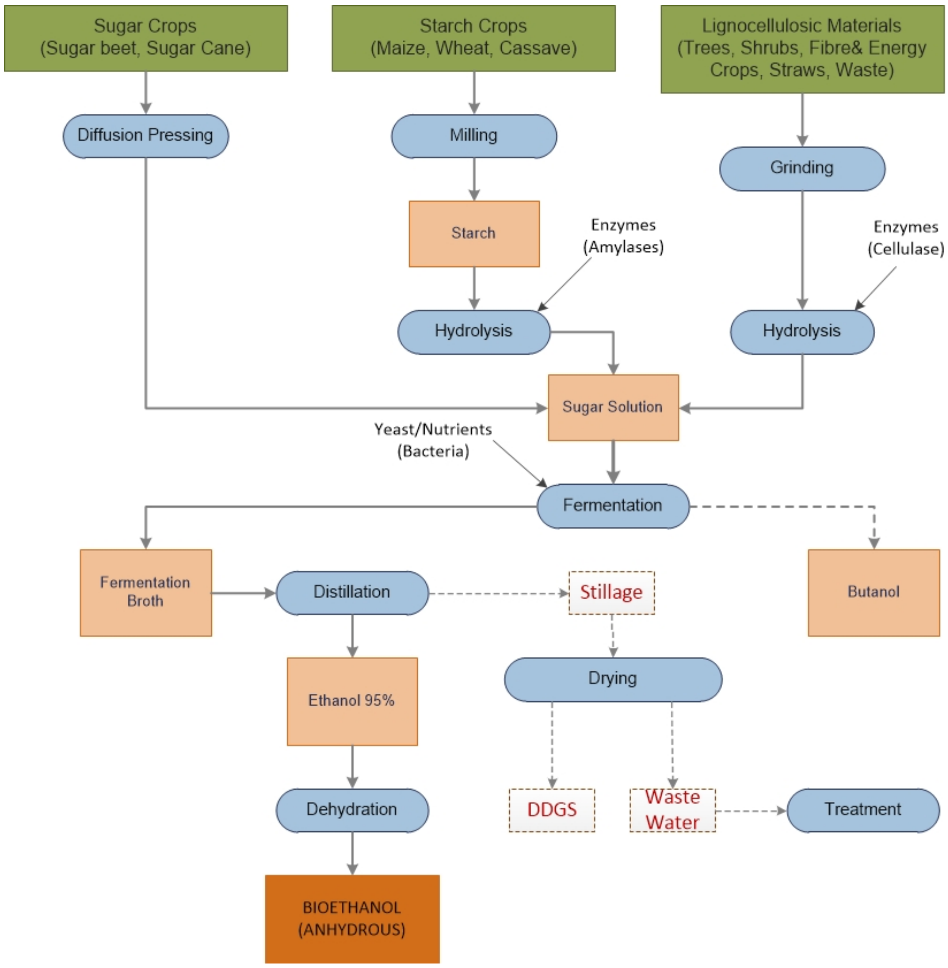


Fig. 5.5: Biochemical routes to liquid biofuels, adapted from (EBTP, 2012a), (Küçük and Demirbaş, 1997) and (Sims et al., 2010)

This method is currently expensive and researchers are exploring new technologies for more efficient and cost effective ways to gain access to these useful sugars. The important parameters for biochemical processes are reaction temperature, pH, moisture and time under reaction conditions (Küçük and Demirbaş, 1997). In a recent research (Sohel and Jack, 2011), the efficiencies of the thermochemical and biochemical processes were compared and as a result, the thermochemical route is considered to be approximately 2% more efficient. In both thermochemical and biochemical processes heat and power production was the biggest contributor to losses: 36.2% and 67.3%, respectively, and the biochemical route's share is significantly larger. In Fig. 5.6, the summary of main available routes for converting biomass to biofuels is illustrated;

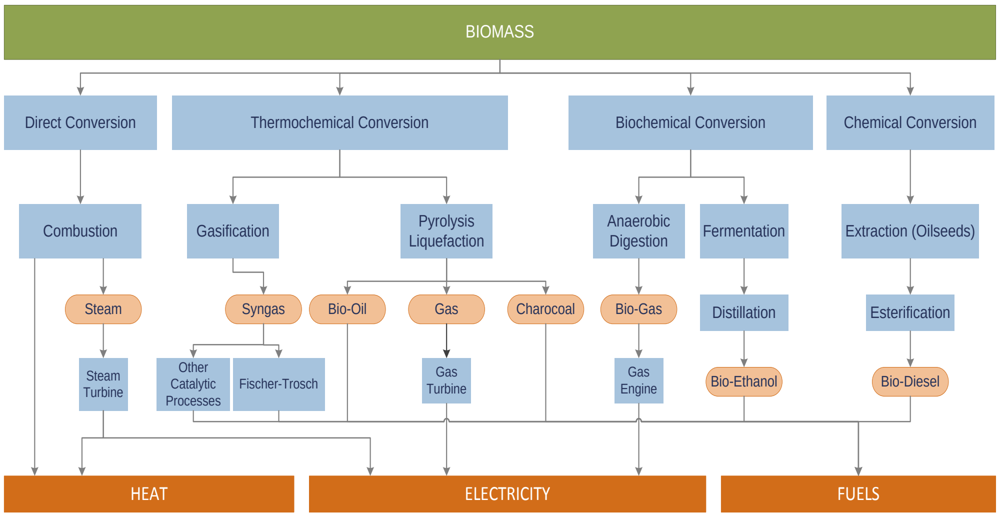


Fig. 5.6: Main conversion options for biomass, adapted from (Faaij, 2006), (Damartzis and Zabaniotou, 2011) and (Bolan et al., 2013)

5.3 Biofuels categorization

There are currently four generations of biofuels: first, second, third and fourth.

5.3.1 First-generation biofuels

First generation biofuels are produced from sugar crops (e.g. sugar beet, sugar cane), cereal crops (e.g. wheat, maize) and oil crops (e.g. rapeseed, palm oil). The first generation biofuels have been the subject of huge media attention and extensive public and political debate, because of the potential impacts on the environment and food prices. The most common first generation biofuels are bioethanol, biodiesel, biogas (DEFRA, 2008), but straight vegetable oils (SVO), and bioethers may be included in this category as well (Cherubini, 2010).

5.3.1.1 Bioethanol

Bioethanol is usually attained from sugar cane, sugar beet and starch crops through fermentation. In general, all fermentable sugars may be converted to bioethanol by fermentation. Such sugars are present in a more or less polymerized state in many crops. Initially the raw materials are submitted to a process where the sugars are extracted. During the subsequent fermentation process for converting glucose into ethanol, yeast is used. The distillation and the dehydration are used as the last steps for achieving the desired concentration of ethanol in hydrated or anhydrous state, which can be blended with petrol or directly used as fuel in dual-fuel vehicles (Escobar et al., 2009) (Fig. 5.7).

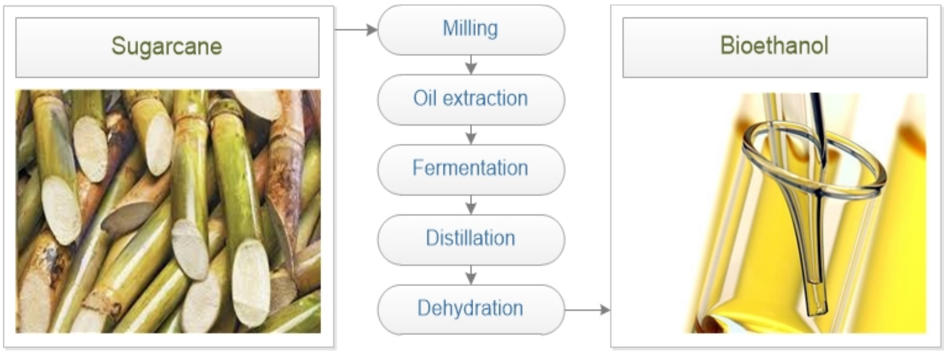


Fig. 5.7: Production of first generation bioethanol from sugarcane

Different blends of bioethanol have shown different impacts on air pollution. While using low strength blends of bioethanol reduce or have little effect on air quality, high strength blends of bioethanol (E85) are proved to be effective in the overall reduction of CO emissions (AQEG, 2011). It is reported that bioethanol produced from sugarcane appears to meet many of the acceptable sustainability criteria (see section 6.1.5.1) (Sims et al., 2010), therefore these fuels will play a continuing role in future transport fuel demand.

5.3.1.2 Biodiesel

Biodiesel typically produced from oil-based crops such as rapeseed, sunflower, palm, soybean (EBTP, 2012a) uses transesterification process or cracking to convert the vegetable oils into a fuel which is suitable for vehicles without any engine modification. It is thus distinguished from the straight vegetable oils (SVO) or waste vegetable oils (WVO) used as fuels in some modified diesel vehicles (Porteous, 2000). Transesterification can use alkaline, acid or enzymatic catalyzers (usually potassium hydroxide or sodium hydroxide) and an alcohol (usually methanol), and produces fatty acid and glycerine as residues (Escobar et al., 2009) (Fig. 5.8). The transesterification process is carried out at moderate temperature (20-80 °C) and atmospheric pressure.

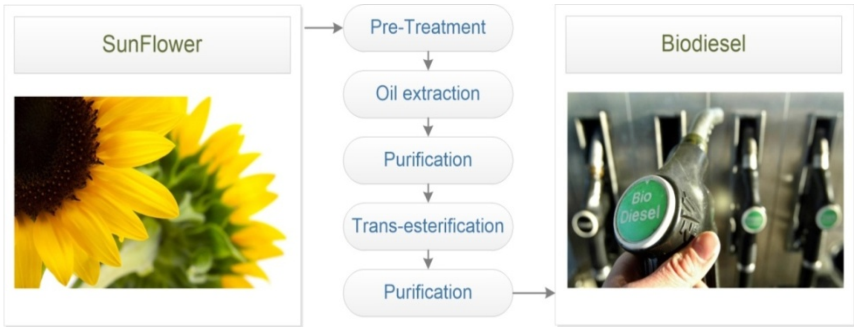


Fig. 5.8: Production of first generation biodiesel from sunflowers

5.3.1.3 Biogas

Biogas or biomethane, is produced during anaerobic digestion (also referred to as "methanisation") of biomass and consists mostly of methane and carbon (DEFRA, 2008), methane (60-70%), carbon dioxide (30-40%) and small amounts of other gases (Porteous, 2000). Sometimes organic wastes such as sewage, manure and dung are used to produce biogas (Naik et al., 2010). After removal of contaminants, biogas is ready to be used (Fig. 5.9) as a transport fuel in the form of Liquid Natural Gas (LNG) or Compressed Natural Gas (CNG). These are different from Bio-SNG (Bio Synthetic Natural Gas) which is produced by gasification of lignocellulosics and has been categorised as second generation biofuels (EBTP, 2012a).

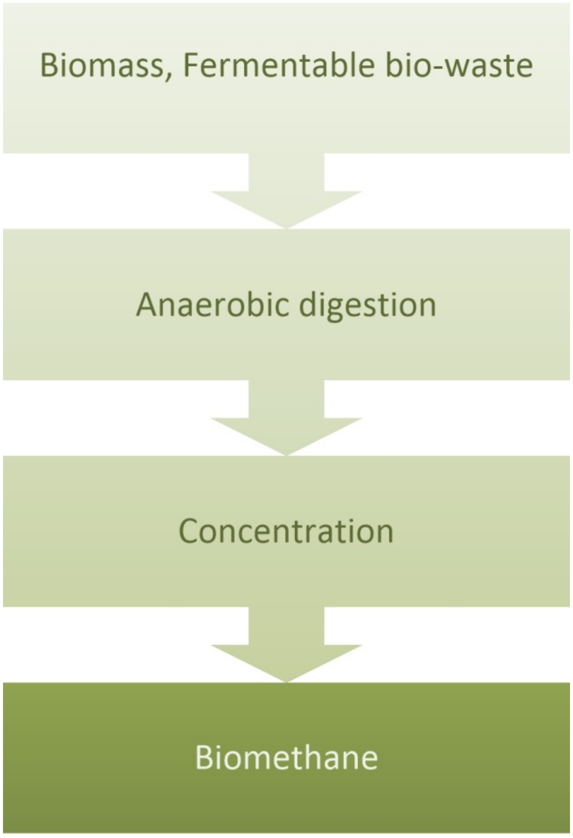


Fig. 5.9: Production of first generation biogas from biomass

When biogas is mainly derived from waste and residues, it can be categorized as second generation biofuel and there is no competition with food production (Cherubini, 2010). This was first reported in 2009 by the researchers at the Fraunhofer Institute in Germany who developed the first-ever biogas plant to run purely on agricultural wastes (Stelter, 2009) such as corn stalks. Unlike the conventional method where biomass is normally kept in the fermenter for 80 days to build up biogas, this method takes about 30 days. Corn stalks contain cellulose which cannot be directly fermented but in this method, cellulose is broken down by some enzymes (not revealed, under patent) before the silage ferments (Stelter, 2009). This demonstrates that pre-treatment with enzymes can increase biogas yields from cellulosic residues such as cornstalks.

5.3.1.4 Straight vegetable oils (SVO)

SVO, also referred to as "pure vegetable oil" (PVO) or "pure plant oil" (PPO), is the use of plant and vegetable oils without any modification to their chemical structure as a fuel to be combusted inside a diesel engine (Russo et al., 2012). They are an excellent solution in feeding agricultural machinery, since they can be directly produced locally. This is mostly important for rural areas and it helps developing countries to reduce the fossil fuel imports (Russo et al., 2012). This method should not be confused with biodiesel, and unlike biodiesel, the use of SVO requires modifying the engine.

5.3.1.5 Bioethers

Bioethers such as "ethyl tertiary butyl ether" (ETBE), are produced from ethanol and isobutylene in a catalytic reaction. Bioethers may also be produced from methanol, such as tert-amyl methyl ether (TAME), and methyl tert butyl ether (MTBE) (EBTP, 2012a). They are widely used as gasoline/petrol additives in order to reduce emissions of carbon monoxide, ozone, and unburned hydrocarbons (Bartling et al., 2011).

5.3.2 Second generation biofuels

Second generation biofuels are produced from a variety of non-food crops. These include the utilization of lignocellulosic materials, such as residues from agriculture, forestry and industry and dedicated lignocellulosic crops. Where these biomass materials are available, it should be possible to produce biofuels from them with no additional land requirements or impacts on food (Sims et al., 2010). The total biomass production on earth is estimated around 100 billion tonnes of land biomass per annum and 50 billion tonnes of aquatic biomass. Only 1.25% of the entire land biomass is used as food and the remainder can be used as raw materials for biofuel production (Naik et al., 2010) . The use of plant crops or plant wastes as raw material determines a frontier between the first and the second generation biofuels (Fig. 5.10)

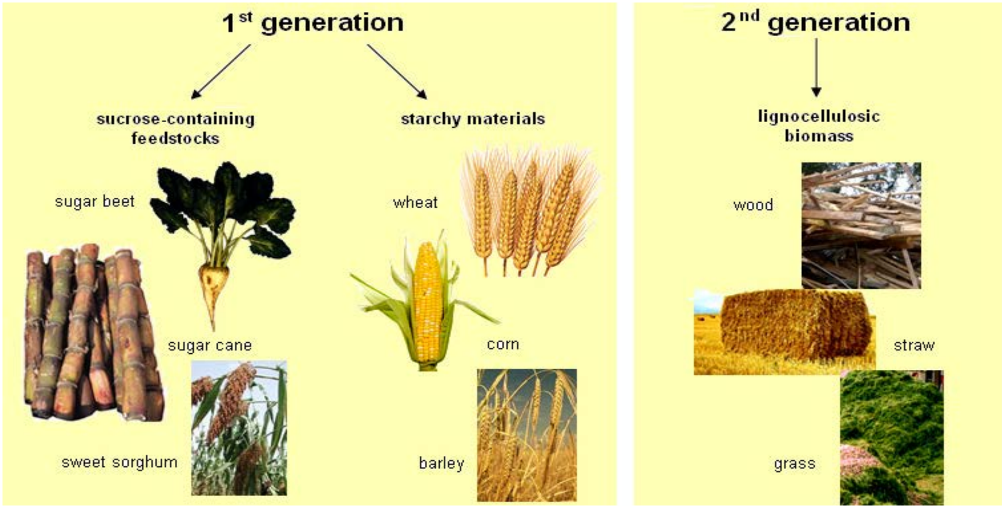


Fig. 5.10: A simple schematic comparison between the first and the second generation biofuels, based on the use of plant components as raw material, adapted from (Rebel, 2009)

Second generation biofuels are becoming widely accepted as superior to the first generation. It has been estimated that by 2050, half of biofuel consumption is achieved from the second generation conversion pathways (ELOBIO, 2010).

The main advantage is that they permit the utilization of inedible raw materials which are widespread, relatively cheap and easily available (Singh et al., 2011b). However, significant progress needs to be made to overcome the technical and economic challenges, as the second generation biofuels are relatively costly based on current technologies. In Fig. 5.11, the conversion processes for lignocellulosic biomass and utilization of a combination of technologies for production of other value-added chemicals are illustrated;

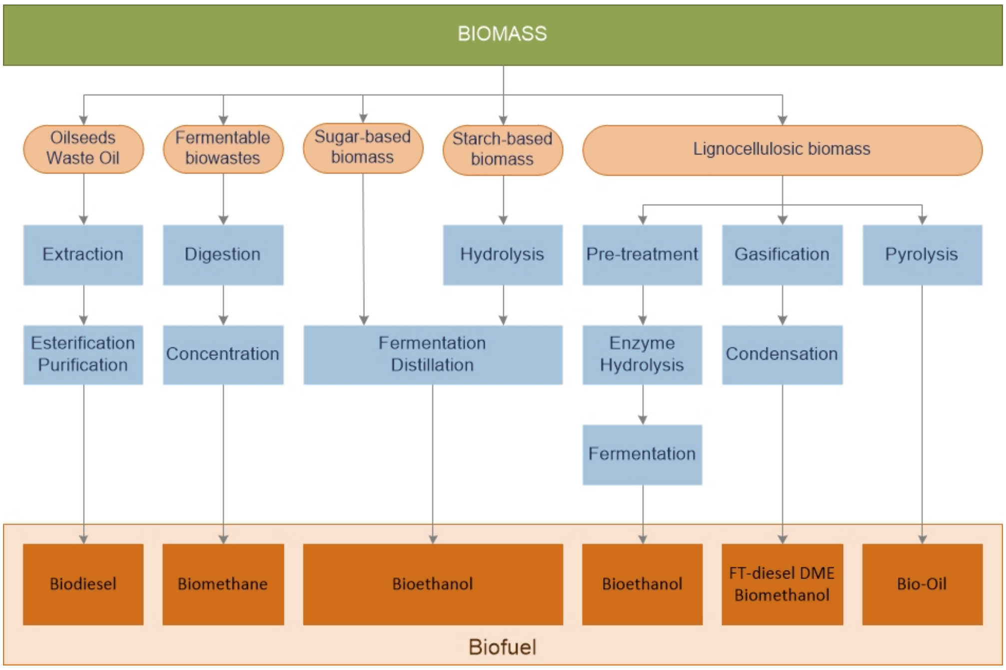


Fig. 5.11: Second generation biofuel production from biomass, adapted from (Naik et al., 2010)

Lignocellulosic materials are a group of feedstocks, which can be processed either through hydrolysis and fermentation (i.e. bioethanol) or through gasification (i.e. Fischer–Tropsch bio-diesel, bio-DME and bio-SNG). The complete list of the second generation biofuels includes:

5.3.2.1 Biomass to Liquid (BtL) fuels

The biomass to Liquid (BtL) refers to synthetic fuels which are made from biomass using a thermochemical route. They are also known as Synfuels (Swain et al., 2011). BtL fuels may be produced from any type of low moisture biomass, residues or organic wastes. BtL process includes grinding and drying of biomass and converting it into pellets. Then in a low temperature gasification process, these pellets are diverted into a gas and solid fraction (charcoal) and transformed into a synthetic gas. The gas is then liquefied in a so called "Fischer–Tropsch" reaction, in which carbon monoxide and hydrogen react and form carbon-hydrogen chains (Kim et al., 2013b). The resulting liquid is then distilled or "hydro-treated". In this step, the specifications of the fuel can be fine-tuned to fit the requirements of the engines. This fine-tuning is not possible given current standards in refining diesel or petrol, for this reason BtL is also nicknamed "designer fuel". Most of the distillate (almost 60%) is used directly as a diesel fuel, while the other fractions are used in the chemical industry or can be further processed into gasoline or kerosene (Swain et al., 2011). The advantage of the BtL method to liquid transport fuels lies in the little pre-treatment and the ability to use almost any type of biomass.

5.3.2.2 Cellulosic ethanol

Second generation cellulosic ethanol is chemically identical to first generation bioethanol (i.e. CH_3CH_2OH). However, it is produced from different raw materials via cellulose hydrolysis, which is a more complex process. The raw materials for second generation ethanol may be agricultural residues (e.g. straw, corn stover), other lignocellulosic raw materials (e.g. wood chips) or energy crops (miscanthus, switchgrass, etc.) (EBTP, 2012a). The cellulosic ethanol is considered environmentally superior to first generation ethanol (Stephen et al., 2013). Whereas conventional corn ethanol is estimated to have a net greenhouse gas reduction of approximately 12–13% relative to baseline gasoline, dependent upon feedstock and processing conditions, lignocellulosic ethanol is expected to have greenhouse gas reductions exceeding 80%. This is in the same range as commercial sugarcane ethanol, which has estimated reductions of 75–85%. It is also anticipated that lignocellulosic ethanol will require reduced water withdrawals and consumption compared to corn ethanol, especially relative to fuel produced from irrigated crops. However it has been shown that it will be difficult for woody feedstock lignocellulosic ethanol to compete economically with conventional ethanol produced from corn and sugarcane in the short term without substantial governmental subsidies (Stephen et al., 2013).

5.3.2.3 Cellulosic methanol

Methanol can be produced from various biomass feedstocks through a thermochemical route. It can be blended with petrol at 10%-20%. Methanol can be converted to dimethyl ether (DME) by catalytic dehydration. DME can also be produced directly from syngas (EBTP, 2012a). The EU is world leading in BioDME industry. The world's first biofuel plant to convert biomass into DME was built in northern Sweden using waste material from pulp and paper mills, based on gasification technology. The gasification process allows almost 100% carbon conversion and sulphate reduction, with low syngas tar and methane content (Focus, 2010). Second generation ethanol and methanol are both considered as promising fuels for the future. In a comparison study between these two (Hasegawa et al., 2010), fuel yield, energy conversion efficiency, carbon conversion and environmental burden were evaluated. The outcome of the study shows biomethanol production process is better compared to the bioethanol process in terms of energy output, carbon conversion and environmental burden except for electrical energy consumption. Moreover, when biofuels used in internal combustion engines, biomethanol has greater potential and in the long-term has greater potential, for CO_2 mitigation (Hasegawa et al., 2010).

5.3.2.4. Biosynthetic natural gas (Bio-SNG)

Bio-SNG is produced by gasification of cellulosic materials while "biogas" is produced by anaerobic digestion of organic materials (e.g. manure, organic waste). Bio-SNG is normally produced via a gasification step followed by gas conditioning, SNG synthesis and gas upgrading (EBTP, 2012a). The largest commercial BioSNG project is the Göteburg Biomass Gasification Project, GoBiGas, launched in 2012 in Göteborg, Sweden (Carbo et al., 2011). The capacity of the first phase of this project is 20 MW. The second phase is scheduled to be operational by 2016, which involves a SNG plant with a capacity of 80 MW (CCS, 2014).

5.3.2.5. Bio-oil/Bio-crude

A number of researchers are developing innovative processes (pyrolysis and thermochemical conversion) to turn a wide range of biomass (forestry residues, crop residues, waste paper and organic waste) into stable, concentrated bio-oil (biocrude) that can be converted into second generation biofuels (EBTP, 2012a). Particularly in Europe, the interest in bio-oil is growing due to its logistic advantages. In 2012, the building of the first industrial scale bio-oil plant in Joensuu, Finland was announced, with a capacity of 50,000 tonnes of bio-oil. The feedstock is planned to come from forest chips together with other woody biomass (Sorsa and Soimakallio, 2013).

5.3.2.6 Biohydrogen

Hydrogen is an alternative fuel but a major doubt for hydrogen as a clean energy alternative is that most of the hydrogen gas at present is produced from fossil fuels by thermochemical processes, such as hydrocarbon reforming, coal gasification and partial oxidation of heavier hydrocarbons (Lee et al., 2011a). However, biohydrogen produced from cellulosic feedstock, such as second generation feedstock (lignocellulosic biomass) and third generation feedstock (carbohydrate-rich microalgae) (see section 5.3.3) could be a promising candidate as a clean, CO_2 neutral, non polluting and high efficiency energy carrier to meet the future needs (Cheng et al., 2011). Biohydrogen maybe produced by steam reforming of methane produced by anaerobic digestion of organic waste. It may also be produced by fermentation of renewable materials by bacteria. This process may take place in light (photo fermentation) or in the absence of light (dark fermentation) (EBTP, 2012a). The first step of the overall cellulosic biohydrogen production process is the pre-treatment and saccharification of lignocellulosic feedstock, turning it into reducing sugars (hexose and pentose) that are used as the substrate for the fermentative hydrogen production by a selected group of anaerobic bacteria. Therefore, the key to the success of cellulosic biohydrogen relies on the development of breakthrough technology allowing effective and low-cost saccharification of lignocellulosic feedstock (Cheng et al., 2011). Among these biological processes, currently, anaerobic hydrogen fermentation seems to be more favourable, since hydrogen is yielded at a high rate and various organic waste and wastewater enriched with carbohydrates as the substrate results in low cost for producing hydrogen (Lee et al., 2011a).

5.3.2.7 Bioelectricity/CHP

A broad variety of biomass resources, including wastes, can be used as a fuel in Combined Heat and Power (CHP) plants, also called cogeneration plants, for the generation of bioelectricity (EBTP, 2012a). On average, conventional power generation plants are only 35%, since up to 65% of the energy potential is released as waste heat. But with new CHP plants, the efficiency of cogeneration plants can improve to 90% or more (Vandamme et al., 2011). Therefore, the advantages of this method are apparent: higher energy efficiencies and lower costs. Furthermore, the involvement of local communities has proven important, and in Europe, municipalities and forest owners are often the owners of the CHP-plants (Faaij, 2006).

5.3.2.8 Biobutanol

Biobutanol can be produced from cereal crops, sugar cane and sugar beet, but can also be made from cellulosic raw materials. Butanol can be produced by traditional "acetone–butanol–ethanol" (ABE) fermentation - the anaerobic conversion of carbohydrates by strains of *Clostridium acetobutylicum* into acetone, butanol and ethanol. However, this method is costly, relatively low-yield and the process pace is slow. For these reasons ABE fermentation could not compete on a commercial scale with butanol produced synthetically (EBTP, 2012a). However, using butanol instead of ethanol as a biofuel provides a number of significant advantages. First, while ethanol can be blended only up to 85%, biobutanol can be utilized in pure form or blended in any concentration with petrol. Second, using bio butanol as a sole fuel or as a fuel extender will not require modification of car engines. Third, it has a lower vapour pressure and is thus safer to handle. Fourth, while blending with ethanol must take place shortly before use, blending with biobutanol can be well in advance of storage and distribution. Fifth, it is less corrosive. This means less infrastructure maintenance cost (tanks, pipelines, pumps, filling stations, etc.) and less environmental concerns (Dürre, 2007). Still, challenges remain. Problems associated with feedstock availability and economic feasibility of fermentation are the main challenges in the current age. The possibility of using waste cellulosic materials as feedstocks marks a new way in the industrial production of biobutanol. Researchers are also working on aerobic production of biobutanol using genetically engineered organisms like *Escherichia coli*, and *Saccharomyces cerevisiae* (Kumar and Gayen, 2011). Therefore, there is potential for future development of biobutanol but needs the support of governments, commercial and research institutions.

5.3.3 Third generation biofuels

The third generation of biofuels has emerged from algal cells with the aim to overcome the technical and cost problems of the second generation. The algae have high lipid content and rapid growth, which result in a productivity significantly higher than oilseed crops. Some algal strains are capable of doubling their mass several times per day (Singh et al., 2011b) and because algae are grown in water rather than soil, algal production can be executed on non-arable lands (Weyer et al., 2010).

Algae range from single celled organisms to multi cellular organisms and include seaweeds (macroalgae) and phytoplanktons (microalgae). Microalgae are being researched as a fuel, because of their ability to produce lipids, and due to the sugar contents of macroalgae, they can be used to produce either ethanol or biogas through fermentation (Singh et al., 2011a).

Algae require sunlight, CO_2 and water to produce biomass and they are categorized into four main classes: diatoms, green algae, blue–green algae and golden algae. Diatoms as a group include approximately 100,000 organisms, mainly marine phytoplankton (Singh et al., 2011a). They have silicate cell walls and can accumulate high levels of lipid. Diatoms use the triacylglycerol lipid molecules (TAGs) as energy packages which can be transesterified to biodiesel, however, a large portion of the lipids contained in diatoms is phospholipids which are not convertible to biodiesel using traditional transesterification procedures (Singh et al., 2011a). As Fig 5.12 shows, oil content in microalgae can be up to 80% of dry biomass (Singh et al., 2011b) (Appendix H):

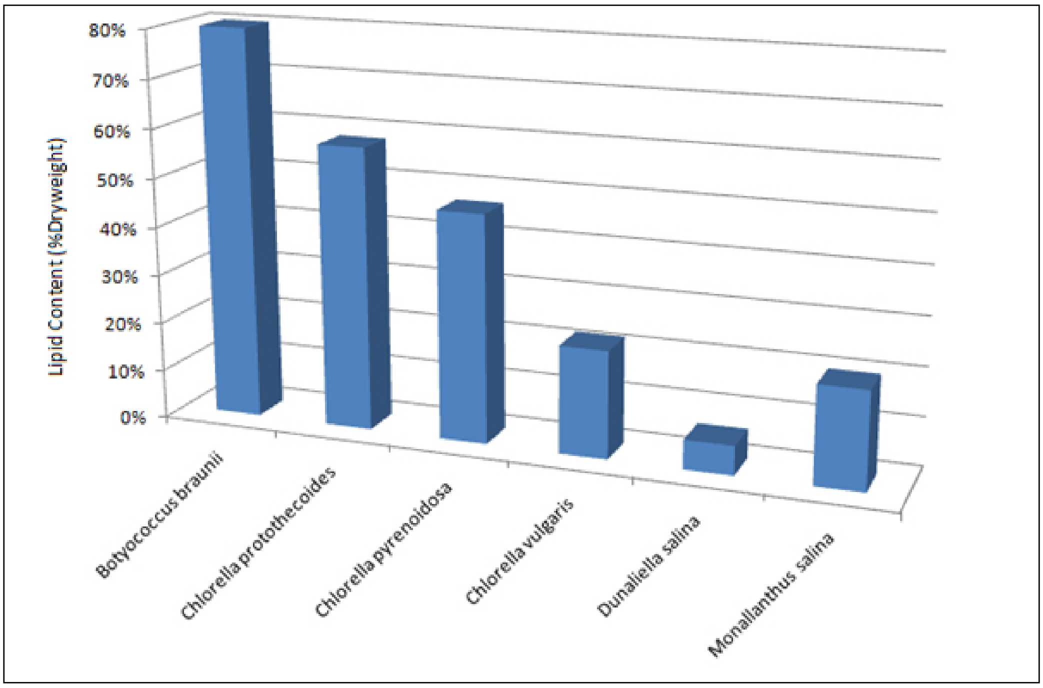


Fig. 5.22: Lipid content in the dry biomass of various species of microalgae, adapted from (Singh et al., 2011b)

5.3.3.1 Cultivation of algae

Algae can grow in salt water, freshwater, at sea or in ponds, and on marginal unsuitable land for food production (Demirbas, 2010). Algae can be cultivated photosynthetically using sunlight for energy and

CO_2 as a carbon source. They may be grown in salt and fresh water, in shallow lagoons or raceway ponds on marginal or closed ponds. Productivity is higher in the controlled, contained environment of a photo-bioreactor, but the operational cost is also substantially higher than open systems (EBTP, 2012a). For the cultivation of algae biomass: Two main systems are used; open pond and closed photo-bioreactors (PBR).

5.3.3.1.1 Open Pond

Open pond is the oldest and simplest system for mass cultivation of microalgae. It has been used since the 1950s (Demirbas, 2010). For open pond systems, both natural waters (lakes, lagoons, ponds) and artificial ponds or containers (Ugwu et al., 2008) are used. Algae are grown in suspension, utilizing solar light, fertilizers and gas exchange with the surrounding atmosphere. The best efficiency in open pond systems is achieved in raceway systems: a shallow pond, in which the algae, water and nutrients circulate around a racetrack (Singh et al., 2011a). The raceways are typically made from concrete, or they are simply dug and covered with plastic liners to prevent water soaking (Fig. 5.13) (Wen and Johnson, 2009b).

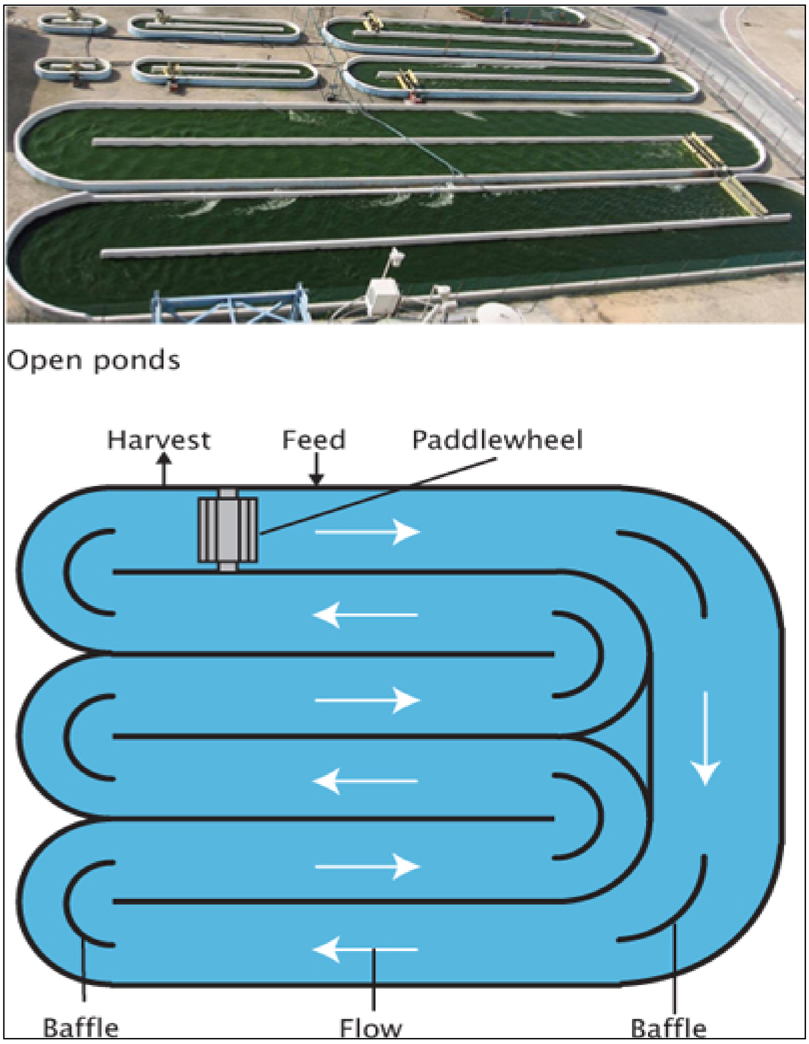


Fig. 5.13: Open pond system (Wen and Johnson, 2009b)

Algae are circulated back up to the surface on a regular frequency. The ponds are kept shallow, about 15–35 cm deep to ensure adequate exposure to sunlight and are between 0.2 and 0.5 hectares in size. The ponds are operated continuously; that is, water and nutrients are constantly fed into the pond, while algae-containing water is removed at the other end. The size of these ponds is measured in terms of surface area, which is so vital to get sunlight. Careful control of pH and other physical conditions for introducing CO_2 into the ponds are also important (Demirbas, 2010).

Although open ponds cost less than enclosed photobioreactors, they have their own disadvantages. Major limitations include the poor light use by the cells, evaporative losses and need of large areas of land (Ugwu et al., 2008). Biomass yield is also limited by contamination with unwanted organisms (including other algal species) that could feed on algae. In open ponds, maintaining the optimal culture conditions is difficult and extracting lipid/oil content from the dilute culture is costly (Wen and Johnson, 2009b).

5.3.3.1.2 Photo-bioreactor (PBR)

The photo-bioreactor (PBR) system is closed; water is circulated by pumps and nutrient and gas levels are monitored continuously. Some photo-bioreactors consist of an array of straight transparent tubes- called tubular array or solar collector- where the sunlight is captured as seen in Fig. 5.14 (Wen and Johnson, 2009b). The solar collector tubes have limited diameter- generally 0.1 m or less- because light does not penetrate too deep in the dense culture broth that is necessary for ensuring a high biomass productivity of the photobioreactor. The tubular photobioreactor is one of the most useful types of outdoor mass cultures. Most tubular photo-bioreactors are generally made from either glass or plastic tubes and their cultures are re-circulated with pumps (Ugwu et al., 2008).

Another example of photobioreactors is column photobioreactor, which uses helical coils placed across a column-like structure. Each helical coil runs independently with its own gas injector, pump, and gas removal system. The helical coils operate both indoor (fluorescent light) and outdoor (sunlight) (Demirbas, 2010).

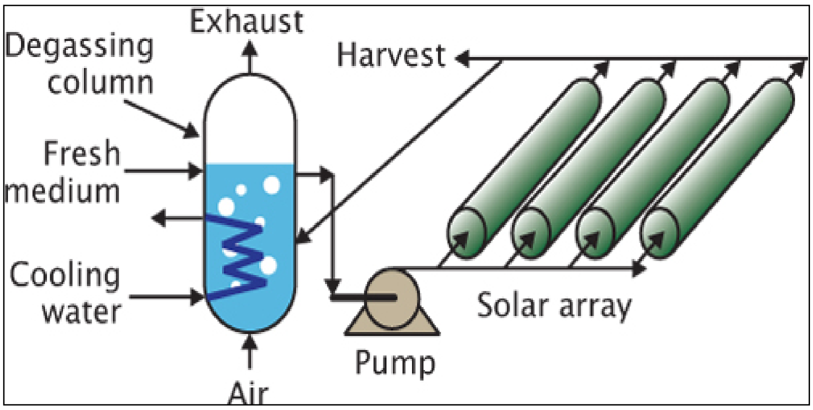


Fig. 5.14: A tubular photobioreactor, adapted from (Wen and Johnson, 2009b)

Each of these two cultivation methods has their own advantages and limitations which are summarized in table 5.1 (Ugwu et al., 2008). A combination of both systems is probably the most logical choice for cost-effective cultivation of high yielding strains for biofuels.

Production system	Advantages	Limitations
Raceway pond	Relatively cheap Easy to clean Utilises non-agricultural land Low energy inputs Easy maintenance Good for mass cultivation	Poor biomass productivity Large areas of land required Limited to a few strains of algae Poor mixing, light and CO_2 utilisation Cultures are easily contaminated Difficulty in growing algal cultures for long periods
Tubular photobioreactor	Large illumination surface area Suitable for outdoor cultures Relatively cheap Good biomass productivities	Some degree of wall growth fouling Requires large land space Gradients of pH, dissolved oxygen and CO_2 along the tubes
Column photobioreactor	Compact High mass transfer Low energy consumption Good mixing with low shear stress Easy to sterilize High potentials for scalability Readily tempered Good for immobilization of algae Reduced photoinhibition and photo oxidation	Small illumination area Expensive compared to open ponds Shear stress Sophisticated construction Decrease of the illumination surface area upon scale-up

Table 5.1: Comparison of the algal cultivation methods, adapted from (Leite et al., 2013)

Algae can produce 30–100 times more energy per hectare compared to terrestrial crops (Demirbas, 2010) and this process could be improved through the improvement of algal strains. In Fig. 5.15, four main commercially cultivated algal species are shown. Among them Spirulina is a cyanobacterium, the other three are green algae (chlorophyceae) (Benemann, 2009).

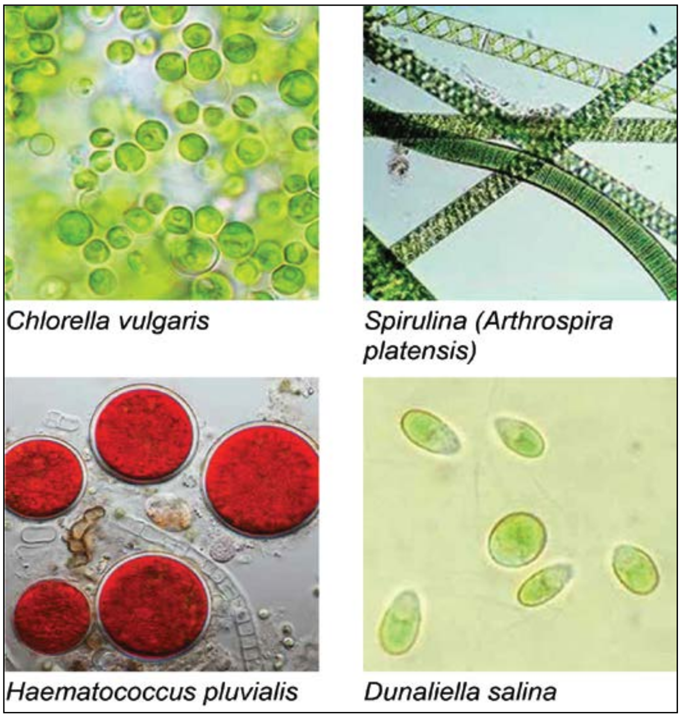


Fig. 5.15: Micrographs of commercially cultivated algal species, adapted from (Benemann, 2009).

5.3.3.1.3 Heterotrophic growth

Both open pond and PBR are phototrophic cultures. In these methods, the photosynthetic ability of algae is used to convert solar energy. However, there is a feasible alternative for phototrophic cultures which use heterotrophic growth capacity of a few microalgal species to convert energy, in the absence of light (Perez-Garcia et al., 2011). Heterotrophic growth uses available and cheap carbon sources (glucose, acetate and glycerol) as the source of energy.

Although this method is restricted to a few microalgal species, the most common and best-studied microalgae, such as *Chlorella*, are heterotrophs. Heterotrophic conditions can considerably increase growth rates and cell mass in microalgae cultures, compared to phototrophic growth (Morales-Sánchez et al., 2013). However, using heterotrophy growth for large-scale biofuel production is rather more problematic, because microalgae cultivation alone cannot maintain biofuel production with the current technologies (Perez-Garcia et al., 2011). More research needs to be done in this promising field in the future.

5.3.3.2 Third generation biohydrogen

Biohydrogen produced from third generation feedstock (carbohydrate-rich microalgae) could be a promising candidate as a clean, CO_2-neutral, non-polluting and high efficiency energy carrier to meet the future energy needs (Cheng et al., 2011). Several species of algae (e.g. *Chlamydomonas reinhardtii*) produce hydrogen under anaerobic conditions, and new methods are being used to boost yields (EBTP, 2012a). Combining microalgae culture and cellulosic hydrogen fermentation process is an innovative and technically feasible concept, as autotrophic growth of microalgae could uptake all the CO_2 produced from dark and photo fermentation to achieve mitigation of CO_2 emissions, and allow re-utilization of CO_2 via the produced microalgal biomass, thereby generating additional benefits (Cheng et al., 2011). Biohydrogen is expensive and the relatively low hydrogen yield and output rate are two common challenges for the biohydrogen producing systems, preventing them from becoming a practical means of hydrogen production (Lee et al., 2011a).

5.3.4 Fourth generation biofuels

The concept called ‘‘fourth generation biofuels’’ or ‘‘photosynthetic biofuels’’ has been recently introduced. It is anticipated that the breakthrough in algal biofuels will come through metabolic engineering of photosynthetic microorganisms (Daroch et al., 2013). Therefore, it can be said that fourth generation biofuel is based on the crops that are genetically modified to consume more CO_2 from the atmosphere than they will produce later as a fuel. These biomass crops as efficient 'carbon capturing' machines take CO_2 from the atmosphere and lock it up in their organs. The carbon-rich biomass is then converted into fuel and gases. The resulting fuels and gases are not only renewable, but also effectively carbon-negative (Biopact, 2008) Fig. 5.16:

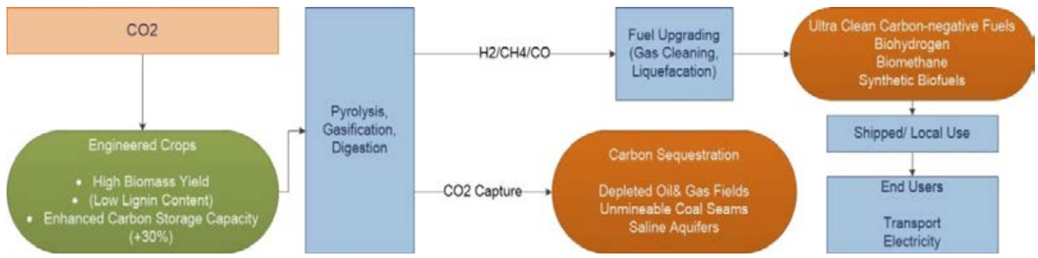


Fig. 5.16.: Fourth generation biofuels, adapted from (Biopact, 2008)

Taking CO_2 emissions from the atmosphere is a wining point because all other renewable energies such as wind and solar are all carbon-neutral at best, but carbon-positive in practice (Biopact, 2008). However, the achieved progress in the fourth generation technologies is still limited. There has been some progress in production of ethanol and butanol by metabolic engineering of cyanobacteria, the so called green-blue algae (Daroch et al., 2013). However, no other improvements have been reported to date in peer-review journals regarding molecular engineering of eukaryotic algae for production of the fourth generation biofuels. Some companies have issued several studies on their own progresses regarding fourth generation biofuel production which have not been necessarily based on photosynthetic process, such as GreenTech Media Research which reported the production of fourth-generation biofuels using petroleum-like hydroprocessing or advanced biochemistry (Kagan, 2010). Some studies (Gressel, 2008) suggested that fourth generation technologies would be based on producing biohydrogen using solar energy for photosynthetic mechanisms directly or by embedding parts of the photosynthetic apparatus in artificial membranes. One such technology is similar to what was developed by Joule Biotechnology (JOULE, 2011), in which sunlight, CO_2 and microorganisms combine in a "solar converter" to create fuel. There are some other definitions on fourth generation based on the conversion of veg-oil and biodiesel into bio-gasoline using most advanced technology (Fatih Demirbas, 2009). It is hard to find a solid explanation for the fourth generation biofuel with all these different definitions. Although the first steps have been taken, significant progress needs to be made in this regard. The problem with fourth generation biofuels is that they need more complicated molecular tool-kit and expensive equipment, so the fourth generation biofuels might be very off in the future, and will not be discussed in this study.

5.4 New Technologies

Advanced biofuels (second, third and fourth generations) can only be competitive when the production costs are competitive with crude oil, and therefore the viability of biofuels depends on cost reduction measures. In order to achieve this aim, some promising technologies that have been emerged in the past two decades may prove useful.

5.4.1 Metabolic Engineering

Metabolic engineering emerged 20 years ago and is about engineering cell factories for the biological manufacturing of chemical and pharmaceutical products (Stephanopoulos, 2012). In biofuel industry, metabolic engineering is used to shorten the production pathways in order to reduce the production cost. The conversion of biomass to biofuels involves the development of dedicated energy crops that converts solar energy to cellulose, and then through two main processes, the advanced biofuels are produced: (a) Hydrolysis of cellulose in the plant biomass to produce reducing sugars and (b) Fermentation of the simple sugars into alcohol (biofuels) (Lee et al., 2008). Based on current technologies, this process is expensive mainly because of the low efficiency of the hydrolysis process, high cost and low activity of currently employed enzymes (Sebastian et al., 2013). To overcome these limitations, one method is to perform cellulose hydrolysis and fermentation in one step, called consolidated bioprocessing (CBP); (Fig 5.17);

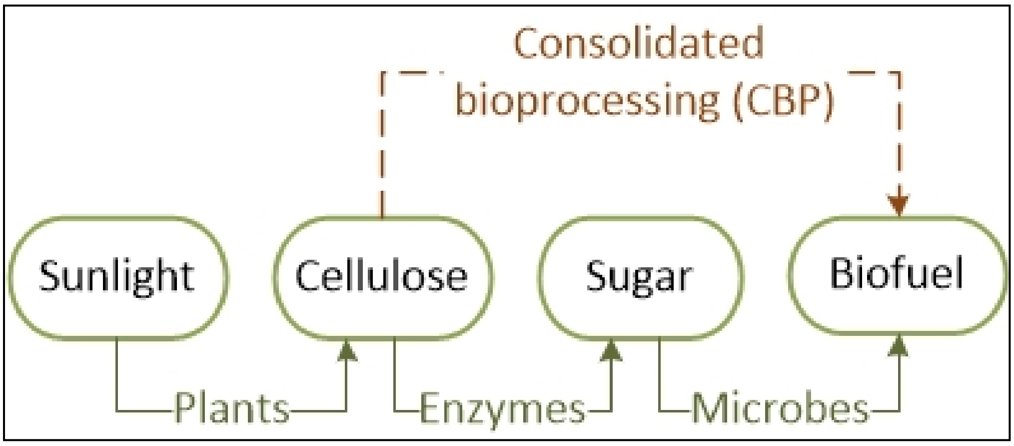


Fig. 5.17: Illustration of "consolidated bio-processing" (CBP) as a shortcut in biofuel production, adapted from (Lee et al., 2008).

CBP has the potential to significantly increase efficiency, decrease costs, and therefore allows a move to a sustainable energy economy that is largely independent of fossil fuels (Savage et al., 2008). It is in principle applicable to the production of a broad range of products from biomass, but so far has been used mainly with respect to bioethanol production (Olson et al., 2012). Since the CBP-enabled microbes have not been found in nature, genetic engineering and "synthetic biology" are required.

5.4.2 Synthetic Biology

The "synthetic biology" is biological research facilitated by the use of synthetic DNA/RNA and genetic engineering (Stephanopoulos, 2012). As the viability of any biofuel production is highly depend on production costs, synthetic biology can provide tools and design principles for developing of such processes (Connor and Atsumi, 2010). Synthetic biology has been utilized to metabolically engineer a range of microbial hosts including yeast and bacteria, in order to produce many types of biofuels. Advances in technology allowing for microbial genetic manipulation have increased exponentially over the past decade, along with understanding of enzymatic mechanisms and the energetic balance required for efficient growth and production. However, more details about the activity of key enzymes, and the full capacity for microbial biofuel production is yet to be realized (Rabinovitch-Deere et al., 2013). Production of advanced biofuels by microorganisms will require a significant retooling of their metabolism. The ability to manipulate microbial metabolism requires understanding of metabolism and the ability to monitor and manipulate many variables simultaneously. So a databank of sequenced genomes provides the metabolic toolkit needed to build large numbers of metabolic pathways (Mukhopadhyay et al., 2008). This limitation was in the late 1990s and led to the emergence of metagenomics; an advanced methodology for extracting all microbial genomic DNAs in a certain environment (Ferrer et al., 2005).

5.4.3 Metagenomics

Metagenomics was developed to discover new microbial enzymes for industrial biocatalysis. Microbial enzymes are used as catalysts in biorefineries, however, the inefficiency and poor performance of currently available enzymes for biofuel production has limited their use. The metagenomic data present an unexplored genomic pool by the discovery of new useful enzymes. Metagenomics is now one of the promising tools for discovering novel enzymes for biofuel production (Sebastian et al., 2013).

5.5 Summary of advantages and disadvantages of biofuel categories

Overall assessment of limitations and advantages of different generation of biofuels is shown in Table 5.2:

	1st generation	2nd generation	3rd generation
Feedstock	Cereal crops (e.g. Wheat, maize), oil crops (e.g. rape, palm oil) and sugar crops (e.g. Sugar beet, sugar cane)	Plants waste, non food biomass, lignocellulosic materials (residues from agriculture, forestry and industry)	Algae
Products	Bioethanol, biodiesel, biogas, Straight Vegetable Oils (SVO), and bioethers (such as Ethyl Tertiary Butyl Ether (ETBE)	BtL fuels, FT oil, Cellulosic ethanol, Cellulosic methanol/ bio-DME, butanol, bio oil, bio SNG	Bioethanol, biodiesel, Biomethane, biobutanol
Advantages	Economical, high sugar/oil content, some are environmentally friendly	Environmentally friendly, No competition with food	Fast growing, absorbs CO_2, can use wastewater and non-arable land, no competition with food, Can produce 30–100 times more energy per hectare compared to terrestrial crops
Disadvantages	Limited feedstock, competition with food , blended partly with conventional fuel, high water and fertilizer requirements	Currently not economical, Costly, advanced technology needed	Expensive to grow and harvest, easily contaminated, Difficulty in growing algal cultures for long, expensive, needs constant maintenance

Table 5.2: Comparison of different generations of biofuels

The first-generation biofuels are well implemented globally, the main advantages of them are due to the high sugar or oil content of the raw materials and their easy conversion into biofuel (Singh et al., 2011b). Although some researchers argue that there are no reliable data that advance biofuels are more productive than first generation crops (Walker, 2010), the limited potential of the first generation biofuels in reducing greenhouse gas (GHG) emissions, high water and fertiliser requirements, lack of well managed agricultural practices in emerging economies, biodiversity conservation and regionally constrained market structures unleashed a sense of urgency for the transition towards second generation biofuels (Carriquiry et al., 2011). Moreover, the first generation biofuels competition with food for the use of arable land, give rise to some ethical, political and environmental concerns. In order to overcome these issues, the second generation of biofuels has been developed (Cherubini, 2010), which offer the prospect of higher yield per hectare and significantly improved emissions benefits compared to most first generation biofuels. The main limitation for the development of second generation biofuels is currently the high production costs and remaining technical uncertainties regarding these advanced technologies. Unless there is a technical breakthrough in lowering the production costs, it is expected that the successful commercialisation of the second generation biofuels will take several years (Escobar et al., 2009). However, based on the current support for research and investment, some researchers believe that after 2020, the second generation biofuels could become a much more significant player in a global biofuels market characterised by a balance between the first and the second generation technologies (Sims et al., 2010).

And finally, the third generation biofuels are attracting a great deal of interest, as they do not compete with food crop plants and take advantage of the production of biomass in highly productive organisms such as algae. Using algae for biofuel production can be more environmentally sustainable, cost-effective and profitable, if combined with procedures such as wastewater and flue gas treatments (Mata et al., 2010). But currently, algal-biofuel production is too expensive to be commercialised. The future cost-saving efforts for the third generation biofuel production could be approached through enhancing algal biology (in terms of biomass yield and oil content) and culture-system engineering (Wen and Johnson, 2009b).

Chapter Six

Biofuel Impacts

Chapter Six: Biofuel Impacts

Biofuels have some techno-economic advantages and disadvantages and also positive and negative impacts on human life and ecosystems. Most researches to date have focused on the impacts of the first and the second generation biofuels on GHG emissions and direct and indirect land use change. However, far less attention has been paid to the other potential impacts of biofuels. Therefore, in this chapter, the main impacts of biofuels are discussed, including environmental and economic impacts.

6.1 Impacts on Environment

Typical of the concerns about biofuel impacts on the environment are the implications for climate change, land use change, biodiversity and agriculture. Environmental impacts vary broadly across feedstocks, production methods and locations (ELOBIO, 2010). When energy is produced from residues or wastes (agriculture for food and feed, paper and pulp production, forest management, households, etc.), the environmental impact is in general very low and even in some cases is positive (see section 6.1.1.), depending on the type of feedstock and on what would otherwise be done with the feedstock (Cherubini, 2010). However when biomass is cultivated as a dedicated crop, the situation becomes more complex and it will have some form of environmental impact (Kampman et al., 2010).

6.1.1 Climate change and reduction of greenhouse gas (GHG) emissions

In the last 20 years, climate change and global warming concerns have moved to the top of the environmental policy discussions. Evidence shows that since the 1950s, there has been an increase in the temperature of the atmosphere and the oceans. The amounts of snow and ice have reduced and sea level has risen. Human influence on the climate system is now clear. This is evident from the increasing greenhouse gas (GHG) concentrations in the atmosphere, mainly carbon dioxide (CO_2) produced during the burning of fossil fuels, positive "radiative forcing" (difference of radiant energy received by the Earth and energy flowing back to space) and understanding of the climate system (IPCC, 2013). Climatic change has been causing significant changes in ecosystems, leading to the growing risk of hunger, floods, water shortage and diseases (Escobar et al., 2009). Continued emissions of GHGs would cause further warming and changes in all mechanism of the climate system. Therefore, limiting climate change requires sustained reductions of greenhouse gas emissions. In order to unify the efforts to battle the climate change and global warming, the Kyoto Protocol was discussed in Kyoto, Japan, on 11 December 1997. It took more than seven years to enter into force on 16 February 2005 (UNFCCC, 2008). The Kyoto Protocol set a target for 37 industrialised countries and the European community for reducing greenhouse gas (GHG) emissions during the first commitment period which was 2008-2012 (UNFCCC, 2008). In this 5 year plan, industrialised countries were committed to have an average reduction in GHG emissions of 5% against 1990 levels (Capros et al., 2011). There is also a second commitment period, which countries are committed to reduce GHG emissions in the eight-year period from 2013 to 2020 (by at least 18% below 1990 levels). However, the countries in the second commitment period are different from the first (for example Canada withdrew from the Kyoto Protocol on 15 December 2012) (UNFCCC, 2011). In this context, biofuels seemed to be a good option to reduce GHGs (for example the second generation biofuels shows a reduction of GHG emissions by 27% lower compared to the ‘‘No biofuel’’ scenario and were considered a robust option for reducing CO_2 emissions (Havlík et al., 2011). The reason for this line of argument was that although biofuels have roughly the same carbon emissions as fossil fuels, this carbon was previously absorbed from the atmosphere when the biofuel feedstock was grown. Therefore, the overall understanding was that biofuels would by and large reduce emissions compared with fossil fuels. However, over the past few years much evidence has emerged that this thinking is only part of the story and that it does not capture the full climate impact of biofuels (Croezen et al., 2010). Biofuel crops, as they grow, can reduce GHG emissions by removing CO_2 from the atmosphere and storing it in crop biomass and soil. But researches have shown different biofuels vary widely in their GHG balances when compared with petrol. Depending on the methods used to produce the feedstock and process the fuel, some crops can even generate more GHGs than do fossil fuels. One example is nitrous oxide (NO), which is released from nitrogen fertilizers and it is a greenhouse gas with a global warming potential around 300 times greater than that of CO_2 (ELOBIO, 2010). These results have wider implication for the sustainability of biofuels and should be taken into account in targets for biofuels (DEFRA, 2008). One way to do this is Life Cycle Assessment (LCA). LCA has been the standard framework for assessing sustainability of biofuels (Sheehan, 2009) by calculating GHG balances. The GHG balance is the result of a comparison between all emissions of GHG throughout the biofuel production phases and all the GHG emitted in producing and using the same energy amount of the respective fossil fuel (ELOBIO, 2010) .

LCA analyses typically estimated emissions of CO_2, methane and NO emitted from the cultivation of biofuel feedstocks (e.g., growing corn), the production process of the biofuel (e.g., producing ethanol from corn), and the final distribution of the biofuels (e.g., the use of ethanol in vehicles).

In most biofuel LCAs, the estimated climate impact is a function of four factors; (Delucchi, 2010)

1- The amount and kind of fossil fuel used in cultivation of biomass feedstocks and in the production process of the biofuel
2- The amount of nitrogen NO emissions from nitrogen fertilizers
3- The benefits of any co-products of the biofuel production process (e.g., animal feed is produced along with ethanol in biorefineries)
4- The amount of indirect carbon emissions from land use change (LUC)- (see Section 6.1.2)

Some LCA studies have evaluated the impact of other environmental factors, including local air pollution, acidification, ozone depletion, etc. on biofuel climate impacts. These issues are much more affected by location-specific assumptions than GHG and energy balances, showing that straightforward conclusions may not be helpful. However based on these methods, it is possible to make some useful qualitative statements on the climate change impacts of biofuels. Some studies suggest that first generation biofuels show at least some net benefits in terms of GHG emissions reduction and energy balances (Sims et al., 2010 and Al-Riffai et al., 2010). However, it is also reported that first generation biofuels will not offer meaningful reductions in CO_2 emissions, and might have a negative impact on climate change (Delucchi, 2010). The same results have emerged from a comprehensive research on the Indirect Land Use Change (ILUC) effect by 2030 (Havlík et al., 2011). This study suggests that using first generation biofuels by

2030 might lead to a significant increase in net carbon emissions from Land Use Change (LUC). But for the second generation biofuels, there are more positive projections. The same study suggests that second generation biofuel production (using wood residues) would lead to a negative ILUC factor and therefore the overall GHG emissions are up to 27% lower compared to the ‘‘no biofuel’’ scenario by 2030 (Havlík et al., 2011). A separate study has also shown the same result; biofuels produced from waste material do not affect agricultural practices or land uses, and therefore will not intensify climate change significantly, and similarly biofuels produced from cellulosic materials have less climate change damage than do fossil fuels (Delucchi, 2010). It is also important to note that GHG savings resulting from the replacement of fossil fuels with biofuels accumulate only gradually over time (ELOBIO, 2010). With our current knowledge, it is difficult to mathematically assess the future impact of different generation of biofuels on GHGs as it creates a mixture of positive and negative effects.

6.1.2 Direct and Indirect land-use change

One of the key factors in biofuel research is the indirect land use change (ILUC) which has become an important issue in the “Food vs. Energy” debates. The basic concept of ILUC is that natural ecosystems might be converted to agricultural lands to replace crops that are lost due to biofuel production (Kim and Dale, 2011). As a result of conversion of forests or pastures to croplands, very significant releases of carbon to the atmosphere occurs (Croezen et al., 2010) which is a potential negative impact of biofuel.

To understand the concept of the ILUC, it is vital to estimate the total amount of land available on the planet. Only 25% of the earth’s land is devoid of human use, and as little as 11% of current aboveground net primary production (NPP) of biomass (mainly through photosynthesis) takes place there (Haberl et al., 2010). In general, biofuels require 10 to 20 times (McDonald et al., 2009) more land than do fossil fuels (Table 6.1) (Delucchi, 2010). The land requirement per unit of biofuel can be calculated as crop output per unit area, energy per unit crop and a factor that accounts for the land-use impacts of any co-products of the production process. According to the results of a research project (McDonald et al., 2009) which used this method to estimate the land-use intensity of different energy production techniques, biofuels will require more land than do fossil fuels by the year 2030.

Fuel	Land-use intensity (km^2/TWh*/yr)
Petroleum	45
Ethanol from corn	350
Ethanol from cellulose	460
Biodiesel from soy	890

Table 6.1: Land-use intensity of petroleum fuels and biofuels

*TWh: Terawatt hour, 1 TWh/year = 114 MW, Source: (Delucchi, 2010)

The above mentioned numbers are based on the estimation that biofuel crop production will occur mainly in temperate deciduous forests (55%), temperate grasslands (34%), and temperate conifer forests (9%) (McDonald et al., 2009). In another study, it has been estimated that in 2050, the amount of lands required by second generation cellulosic biofuel crops would be 6% of current global permanent pasture land and 16% of current global arable land (Delucchi, 2010). In this study, in order to put the discussion of land impacts in a realistic context, Delucchi used a comprehensive set of global energy projections by the International Energy Agency (IEA) called “BLUE Map 2050” scenario. Although the land requirements of biofuels are very large compared to fossil fuels, Delucchi argued that at the global level there will be no obvious land resource limitation on the development of bioenergy for the foreseeable future, so there will be no immediate action required. However, it is likely that first generation biofuels using usual agricultural practices, will not lessen the impacts of climate change, and will intensify stress on water quality, water supplies and land use, compared to fossil fuels. Therefore to avoid these problems, biofuel feed stocks will have to be cultivated on land that has no other commercial use, in areas with abundant rainfall or groundwater, and with little (or preferably no) inputs of the use of fertilizers, chemicals and fossil fuels (Delucchi, 2010).

The impact of biofuel expansion on the indirect land use change has been analysed in a recent study by (Havlík et al., 2011). The results of the study show that if some marginal non-agricultural land could be used for biofuel production, the overall pressure on deforestation would be lower and second generation biofuels are performing much better with respect to deforestation than first generation biofuels (Havlík et al., 2011). This study also confirms that first generation biofuels have negative effects on the global carbon balance through ILUC emissions. It suggests that by 2030, the increasing net carbon emissions from land use change would be ~70–80% higher in ‘‘First generation’’ scenario than in ‘‘No biofuels’’ scenario (Havlík et al., 2011). It also suggests that in general, the second generation biofuels improve the global carbon balance. The net emissions in the ‘‘Second generation’’ scenario are lower than in the ‘‘No biofuels’’ scenario, by 7% and 27%, respectively (Havlík et al., 2011).

At present there are lots of uncertainties in indirect land use change and reducing these uncertainties will help to set biofuel policies. As yet, the most recent studies have not been compared and summarized systematically.

6.1.3 Impacts on Water and Soil

Cultivation of biofuel crops may affect water resources and soil erosion across the world. This could cause a range of social and environmental issues. In dry areas, the increasing demand for irrigation puts more pressure on limited water resources and during the process of removing residues from the field, soil erosion occurs and fewer nutrients and less organic matter is returned to the soil. Additional fertilizer may be required to balance any loss, and using them will result in extra environmental impacts (Delucchi, 2010). The results of a research suggest that although the soil erosion resulting from the production of the first generation of biofuels is serious, it can be avoided by switching to second generation biofuels based on perennial crops and their residues grown on native and marginal lands if regular monitoring and maintenance are provided (Solomon, 2010).

The water requirements in biofuel production depend on the type of feedstock as well as geographic and climatic conditions. Feedstock cultivation, usually raw-crop agriculture, is the most water-intensive of biofuel production stages. For example, consumptive water requirements to grow enough feedstock to produce 1 litre of ethanol (Le) is about 500−4000 litre of water (Lw). However the processing water requirements for a typical sugar cane or corn ethanol refinery are only 2−10 Lw/Le (Fig 6.1) (Dominguez-Faus et al., 2009). Nevertheless, the water used in biofuel production is often withdrawn from local sources; therefore, local impact on water shortages is expected.

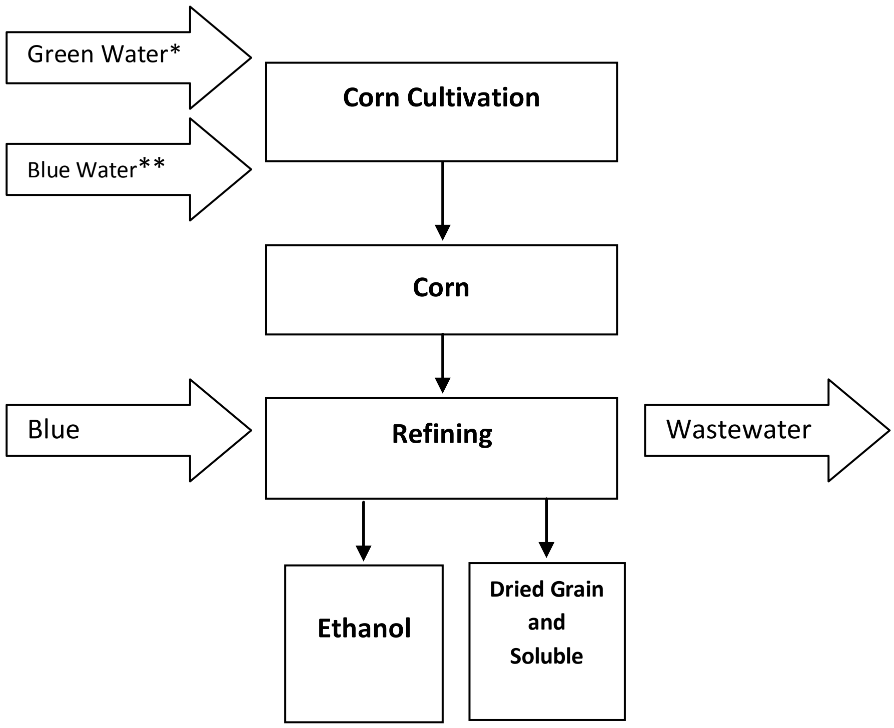


Fig. 6.1: Ethanol production from corn, adapted from (Jeswani and Azapagic, 2011)

*Green water: Rainwater (stored in the soil as soil moisture) used by plants and vegetation.

**Blue water: Freshwater available in surface water bodies (rivers, lakes).

To minimize the water impacts of biofuels, it is important to distinguish that some crops produce more biofuel energy with lower needs for land, fertilizer and water. Results of a study show how the highest water and land footprints are due to soybean feedstock, followed by rapeseed (Russo et al., 2012) while other kinds of crops use significantly less water. However, in general, the water requirement to produce energy from biofuel crops (e.g., ethanol from corn) is significantly higher, compared to the fossil fuels (Delucchi, 2010) (Table 6.2).

Process	L/MWh*
Petroleum extraction	10–40
Oil refining	80–150
Oil shale surface retort	170–681
Natural gas combined cycle power plant	230–30,300
Coal, integrated gasification combined-cycle	~900
Nuclear power plant, closed loop cooling	~950
Geothermal power plant, closed loop tower	1900–4200
Nuclear power plant, open loop cooling	94,600–227,100
Corn ethanol irrigation	2,270,000–8,670,000
Soybean biodiesel irrigation	13,900,000–27,900,000

Table 6.2: Water Requirements for Energy Production by Different Processes , adapted from (Dominguez-Faus et al., 2009)

*MWh: Megawatt hour (10^6 wh)

Table 6.2 highlights the major need of biofuel processing for water resources compared to the fossil fuels, however it is also important to take into consideration that while fertilisers can pollute water bodies, which is an additional issue, fossil fuels also have a substantial impact on water quality, which may have significant impacts on available usable water (Russo et al., 2012).

The results of a study (Havlík et al., 2011) show that the overall irrigation water use due to first generation biofuels cultivation would at maximum lead to some 3% increase compare to “No-biofuels” scenario. But the same study suggests that second generation biofuels is the most water demanding scenario and increasing in water consumption by some 4% compared to the ‘‘No-biofuels’’ scenario is expected. This is mainly due to the fact that lower yields from growing trees require more land, which needs to be compensated by higher agricultural yields through increased irrigation (Havlík et al., 2011). So with these rates, it can be concluded that should biofuel feedstocks be grown in areas with ample rainfall or groundwater, there will be no obvious water resource limitation on the development of bioenergy in the short term (Delucchi, 2010). However, in the long run, the situation will be different. Two recent studies suggest that by 2030 and 2050 the water demand for biofuels production will increase significantly. It was estimated that by 2030, the global annual biofuel water footprint will increase significantly from about 90 km^3/year in 2005 to 970 km^3/year in 2030 (Gerbens-Leenes et al., 2012). This study also suggests that the USA, China and Brazil contribute the most, half of the global biofuel water footprint in 2030. According to another study the water requirements (including water needed to dilute pollution) of the biofuel consumption levels in 2050 would be up to 117% of current global water use by agriculture and 82% of the current total global water use (Delucchi, 2010).

6.1.4 Impacts on Biodiversity

Another aspect of biofuels that remains mainly unstudied is the impact on biodiversity. Biodiversity is the variety of plant and animal life in a particular habitat. It is obvious that biofuels will only be valuable if they are cultivated under sustainable, biodiversity-friendly practices. But there is no simple answer to the question as biofuel policies may have negative impacts on biodiversity. Air and water pollution, soil degradation, and climate impacts are just some examples of these negative impacts through their cultivation, transportation, refining, and burning. Heavy water use in cultivation and refining may also have a negative impact on biodiversity. Most significantly, expansion of agricultural lands for biofuels into sensitive and less-developed areas would decrease the availability of habitats suitable for many species and reduce the ecosystem services offered by more complex ecological systems (Groom et al., 2008). Dramatic loss of biodiversity is directly associated with habitat change, climate change, invasive alien species, overexploitation and pollution. However, biofuel production can affect biodiversity in some positive ways as well, such as restoration of degraded lands (ELOBIO, 2010). It is important to note that most of the evidence of the potential impact of biofuel crops on biodiversity is about what might happen in future rather than what is currently happening. This is because, except in Brazil and the USA, the large-scale production of biofuels is fairly new and little work has been done (DEFRA, 2008).

6.1.5 Impacts on Sustainability

The term "Sustainability" is interpreted differently by different interest groups and there is no single "best" methodology for conducting a sustainability assessment. However since 1987 when the "World Commission report on Environment and Development" (WCED) was published (Brundtland, 1987), the definition of sustainable development has been widely accepted, although the concept has undergone changes through years. According to Brundtland, "sustainability" means the "Development that meets the needs of the present, without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). The original idea was to reconcile environmental protection and economic development, but differences in meaning and views still exist (Diaz-Chavez, 2011). Nowadays, there are many ways to examine the sustainability of biofuel crops and production procedures. Since the early years of the 21st century, there has been a growing demand to create sustainability criteria for biofuels production and trade, which ultimately started to come to fruition in 2008 (Solomon, 2010), and has been developed ever since.

Today, sustainability criteria usually comprise a set of environmental/social factors that are directed by principles of sustainability as globally agreed. The main axis of the sustainability principles are maintaining ecosystem and natural resources as well as preserving the ability of future generations to meet their own needs. Such principles include adherence to national legislation and regulations, good agricultural methods, environmental protection and commitment towards the continuous improvement of management practices in environmental projects. And also in the social part of the sustainable development, responsibility for employees and local communities are among the main principles (Lee et al., 2011b).

6.1.5.1 Sustainability standards

Traditionally, the concept of sustainability of biofuels has focused on three subjects (social, environmental and economic) but in recent years, it has developed to include other factors, such as policy and institutions (Diaz-Chavez, 2011). The first certification system for verifying sustainable ethanol was created by the Swedish ethanol company SEKAB, and international principles and criteria have been proposed by the "Roundtable on Sustainable Biofuels" (based in Lausanne, Switzerland). In addition, the International Organization for Standardization is in the process of developing an international standard for solid biofuels (ISO/TC 238). The Roundtable on Sustainable Biofuels released "Version Zero" in 2008 and a revised version (Version 0.5) in August 2009 (Table 6.3) (Solomon, 2010).

Principle	Explanation
Legality	Biofuel production shall follow all applicable international laws and regulations.
Planning, monitoring, and continuous improvement	Sustainable biofuel operations shall be planned, implemented, and continuously monitored and improved through an open and transparent Environmental and Social Impact Assessment (ESIA)
Greenhouse gas emissions	Biofuels shall contribute to climate change mitigation by reducing life-cycle GHG emissions as compared to fossil fuels.
Human and labour rights	Biofuel production shall not breach labour rights/human rights and shall encourage decent work and the well-being of workers.
Rural and social development	Biofuel production shall contribute to the social and economic development of local/ rural comunities.
Local food security	Biofuel production shall ensure the right to sufficient food and improve food security in food insecure regions/countries.
Conservation	Biofuel production shall avoid negative impacts on biodiversity and ecosystems.
Soil	Biofuel production shall apply practices to maintain soil health and reverse degradation.
Water	Biofuel production shall maintain the quality and quantity of surface and ground water resources, and respect prior formal or customary water rights.
Air	Air pollution from biofuel production shall be minimized.
Use of technology, inputs, and management of waste	The use of technologies in biofuel production shall seek to maximize production efficiency and minimize the risk of damages to the environment and people.
Land rights	Biofuel production shall respect land rights and land use rights.

Table 6.3: Principles for sustainable biofuels, version 0.5 (Solomon, 2010)

The Roundtable developed its draft in part based on the work and experience of numerous sustainable agriculture and forestry initiatives (Solomon, 2010). Additional guidance and criteria have also been provided in different references, which are similar to table 6.3. Based on these standards, 12 general principles have been recommended to policy makers to promote sustainably grown, biodiversity-friendly biofuels (Groom et al., 2008).

1. Evaluate the entire life cycle of biofuel production, use, and waste disposal to calculate the ecological footprint of any biofuel.
2. Require that the sustainability of biofuel feedstock production be assessed, and promote only biofuels that can be produced sustainably.
3. Select species with high conversion efficiencies to minimize land area needed to produce biofuels. This will generally include lignocellulosic feedstocks for next-generation biofuel production and, most promisingly, microalgae.
4. Encourage restoration or reclamation of degraded areas for biofuel cultivation, wherever appropriate.
5. Prohibit clearing of natural areas to increase the area under cultivation.
6. Ensure that feedstock production does not adversely affect ecosystem processes and sensitive habitats and investigate production methods that may enhance ecosystem processes over time.
7. Promote use of energy crops that can be grown with low fertilizer, pesticide, and energy inputs in most settings.
8. Promote the use of native and perennial species.
9. Prohibit use of species that can become invasive.
10. Promote polyculture (the simultaneous cultivation of several crops) to reduce soil depletion and create biofuel cropping systems that can be used by a greater diversity of wild species.

11. Employ conservation tillage or other appropriate techniques to conserve soils.

12. Measure the greenhouse gas emissions over the biofuel production and use life cycle assessment, and promote only those biofuels that are based on feedstocks and refining methods that are net carbon neutral or that sequester carbon (the carbon removed from the atmosphere and deposited in a reservoir) (Groom et al., 2008).

It can be concluded that the development of sustainable biofuels depends both on technological progress in growing crops and incentive policies and regulations to benefit the societies (Delucchi, 2010). Considering all factors, it is suggested that, among the currently commercial biofuels, only cellulosic ethanol has the potential to be produced and consumed on a sustainable basis. This is based on all possible socio-economic and environmental criteria, including the meeting of soil residue maintenance requirements. The reasons for this conclusion include: a larger resource and land base for the feedstocks; higher energy return on investment, potentially greater economical efficiency; equitable resource distribution, little or no conflict with food resources; and much lower greenhouse gas emissions, and other environmental effects (Solomon, 2010).

6.2 Impacts on economy

Although the trade of biofuels has been growing rapidly since the beginning of this century, the international biofuel market is still at early stages (Heinimö and Junginger, 2009), and the statistical data on trade in biofuels is very scarce. Tracing biofuel in the global markets is not straightforward because there are no specific codes identifying biofuels in international trade catalogues. Both bioethanol and biodiesel are classified under the codes referring to the product regardless of the final use and, therefore, it is not possible to get a close picture of biofuel trade volumes.

Ethanol is classified as an agricultural product while biodiesel is an industrial product (EUFCC, 2013). Direct investment into biofuels production capacity has been growing rapidly since 2000. In some developed countries (e.g. USA) and developing countries (e.g. Brazil) the industry with government support invests heavily in biofuel production (Bringezu et al., 2009). However, meeting the high energy demands, particularly for transportation, calls for large areas of available and cheap cultivable land (Kuchler, 2010) which can usually be found in developing countries. On the other hand, the production of biofuel crops may offer opportunities for farmers in developing countries. In the long term, growing demand for biofuels and the resulting rise in agricultural commodity prices can promote agricultural growth and rural development. Therefore biofuel production may be used as an engine of growth for poverty lessening (FAO, 2008), but the economic viability of biofuel in the long term is dependent on careful control of the input prices. To estimate the exact economical impact of biofuels, the cost-benefit analysis of the biofuel industry is needed. This analysis varies from country to country and factors such as production costs, environmental impacts, conflicts with food production and social benefits should be considered (Fig. 6.2) (Bell et al., 2011).

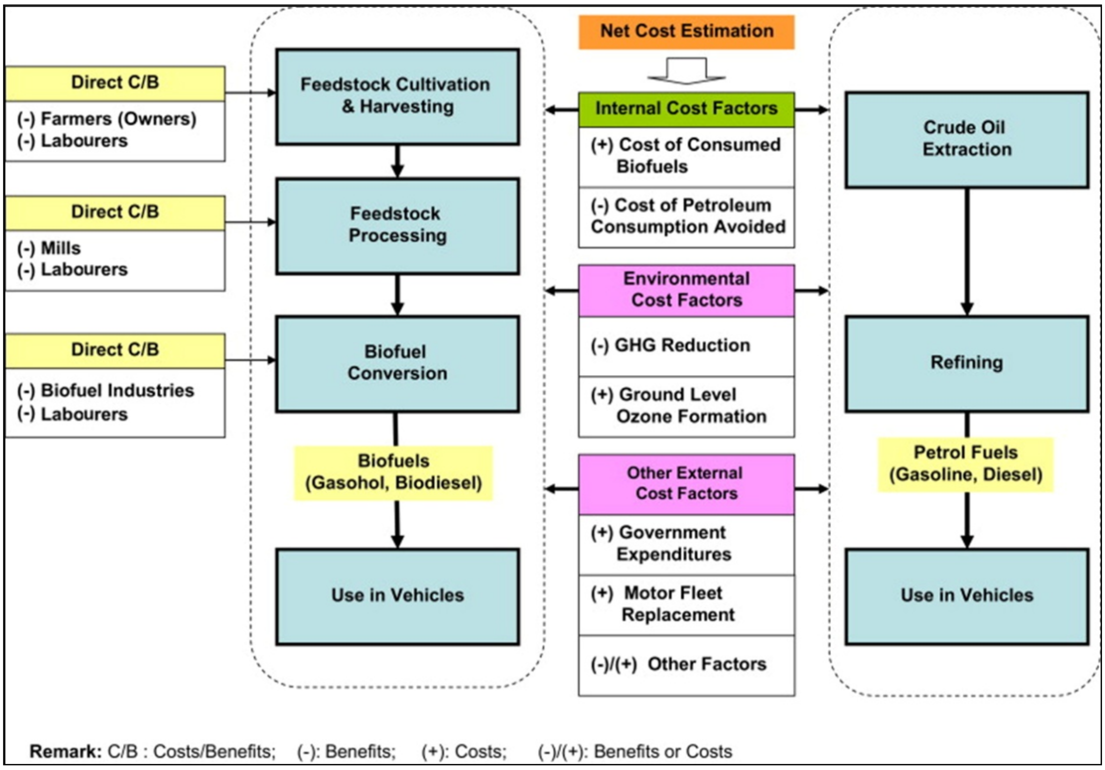


Fig. 6.2: Net cost estimation of biofuels (Bell et al., 2011)

Fig 6.2 shows that the economic assessment is described in two parts: (1) the direct economic impacts on the parties involved in the biofuel production processes, e.g. farmers, mills/refineries and biofuel industries, and (2) the assessment of the benefits and costs of the impacts of achieving the biofuels program targets (Bell et al., 2011). Biofuel production requires strong government support and the essential areas are investment in infrastructure, rural finance, market information, market institutions and legal systems (FAO, 2008).

6.2.1 Impacts on agriculture

Considering the expected population growth, which by the year 2050 may reach about 8.92 to 9.2 billion people, according to the UN (UNDESA, 2004) (Escobar et al., 2009), world food and agriculture are facing significant challenges year on year. Currently, around 1.6 billion hectares (ha) of land are under cultivation globally- nearly 1 billion ha in the developing countries. The world's crop area is expanding by some 5 million ha annually; Latin America alone accounts for 35 % of this increase (ELOBIO, 2010). Sufficient feeding of the world in 2050 will require considerable yield increases and larger agricultural lands. According to FAO projections, cropland areas are expected to grow until 2050 by 9% and average yields on cropland by 54% compared to the year 2000, thus indicating that most of the expected increase in food production can be met through yield increases (Haberl et al., 2010). However some researchers (Pimentel et al., 2009) believe that there will be insufficient land and water to produce biofuel crops and as a result of this process, soil erosion and water pollution will intensify. However, the expansion of arable lands might be one solution. This potential exists mainly in Africa and South America while there is little scope for expansion in Asia, which is home to some 60% of the world's population. One study shows (ELOBIO, 2010) that in order to keep the 2008 first generation biofuel production constant for 2030 and 2050, the arable land expansion needs to be around 120 million ha by 2030 and 170 million ha by 2050 to meet growing future food demand.

6.2.2 Biofuels vs. food, the impact on commodity prices

In recent years, a range of studies has been published analyzing the impact of biofuel production on global food prices and agriculture commodity markets. However, measuring the net impact of biofuels is not easy, because all the socio-economic aspects have not been observed yet and the available data brings conflicting conclusions. Some analysts are concerned that biofuels will displace food production and result in shortages; whilst others are convinced that if best crops and methods are used, sufficient land will be available for both biofuels and food production (DEFRA, 2008). Hence a careful evaluation of costs and benefits is needed to shape more informed policy in the future (Koh and Ghazoul, 2008).

In the past 5 years, higher food prices sparked riots in several countries and some governments have been forced to impose emergency measures. Based on FAO's analysis (Fig.6.3), global expenditures on imported food in 2007 rose by about 29 percent compared to the previous year (FAO, 2008). The rise in food and commodity prices is expected to continue and it is estimated that by 2020, cereal and other agricultural crops experience price increases of at least 10% to 19% (ELOBIO, 2010).

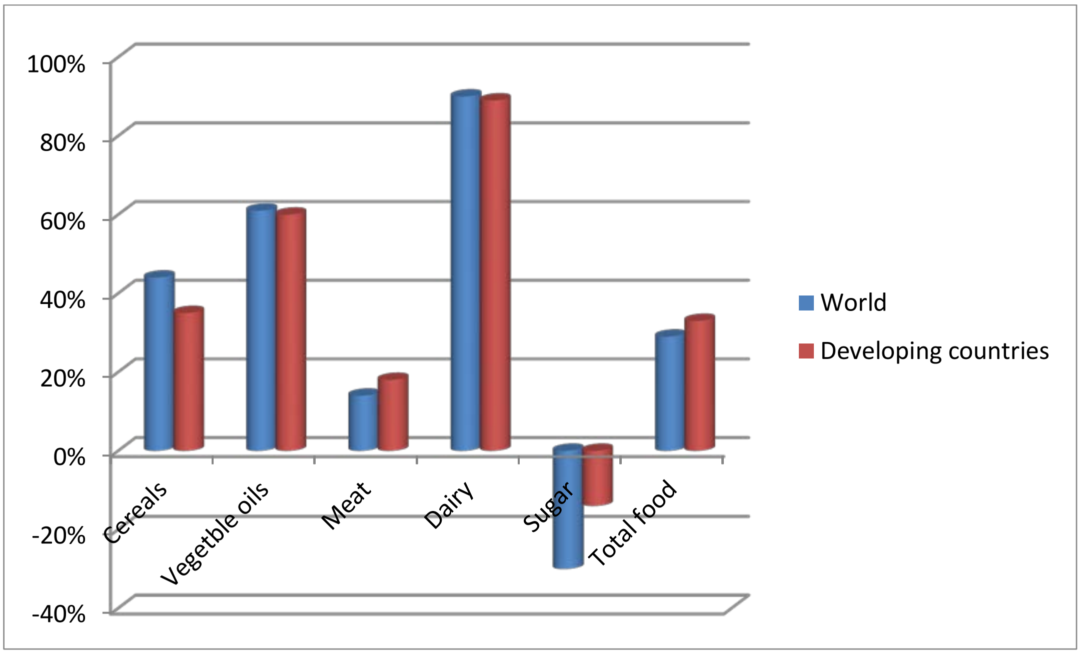


Fig. 6.3: The percentage increase in global expenditure of major food commodities in 2007, compared to 2006, (adapted from (FAO, 2008).

For food importing countries, higher commodity prices will have negative consequences (FAO, 2008) and will put higher pressure on the poor. Some studies show (ELOBIO, 2010) that the additional production of first generation biofuels causes higher food prices and results in additional number of people at risk of hunger. At the moment it is estimated that two thirds of the Africa and South Asia population are at risk of hunger in 2020 and 2030 (ELOBIO, 2010). Many factors are to blame for the recent sharp increases in agricultural commodity prices, and the demand for biofuels is one of them (Singh et al., 2011b). Other reasons are:

changes in climate conditions in some areas, reduction of the reserves of some grains such as wheat, shortage of arable land and finally the rise in the oil prices (Escobar et al., 2009). The last one is unexpectedly significant. There is a correlation between oil prices and the prices of commodities. However, there is some uncertainty on how big this effect is, but studies show that the price of a commodity will increase when the oil price increases. For example, an Oil Cost Factor (OCF) of 0.5 would result in a 50% increase of a given commodity price (Duer and Christensen, 2010) as a result of higher cost of production and/or shortage of supply. The results of a study show that a 25% increase in oil price would reduce global food supply by 0.7% (Sims et al., 2010).

6.2.3 Socio-economic impacts

Promoting the biofuel production and consumption can contribute to some socio-economic policy goals such as energy security and rural development.

6.2.3.1 Energy security

The increasing costs of fossil fuels and insecurity regarding future energy supplies will affect especially oil importing countries. Therefore, it is obvious that biofuel production will help these countries in the long term. At least two thirds of the commodity dependent developing countries are net oil importers (Kampman et al., 2010). It is also important to note that energy supply in many developing countries depends on oil and gas imports. Increased oil and gas prices put great pressure on national budgets in these countries. The 2005 oil price rise reduced GDP growth of net oil importing countries by almost 50%, and, as a result, the number of people in poverty rose by up to 6%. The domestic biofuel production offers oil importing countries an opportunity to replace oil imports and improve their trade balance. The experience in Brazil, for instance, shows that replacing imported petrol by bioethanol saved the country some US$ 43.5 billion between 1976 and 2000 (US$ 1.8 billion/year) (Kampman et al., 2010). Although the higher crude oil prices will significantly improve the benefits of biofuels production, the specific socio-economic effect of rising oil prices on biofuels depends on the pass through rate of oil prices to biofuels costs. The market has a tendency to allow amplified feedstock prices if oil prices are high, and the higher the pass through, the lower the effect of oil price on the costs of biofuels (Duer and Christensen, 2010)

6.2.3.2 Rural development

Rural development is considered as one of the major benefits of biofuel production (ELOBIO, 2010). However, these benefits differ for developing and developed countries. While in developed countries, rural development is a way of supporting the agriculture industry, in developing countries rural development should be seen in a broader context. In these agricultural-based countries, rural development is an important way to create employment, income and a stimulus to develop the agricultural sector. This highlights the potential benefits of biofuel production for these countries. It is estimated that biofuel industries may require about 100 times more workers per unit of energy than the fossil fuel industry (Kampman et al., 2010). But in terms of socio-economic impacts, all effects are not positive and biofuel production also has several negative socio-economic issues such as land use conflicts, water use conflicts, labour issues and increased inequality in terms of income, access to land and gender (Kampman et al., 2010).

6.3 Discussion: biofuels' positive and negative impacts

Policy makers' interest in biofuels emerges from the need for reducing dependence on imported fuels, lowering emissions of GHGs and meeting sustainability goals and rural development plans. However, there is a high degree of uncertainty surrounding the potential biofuel impacts on the environment, the global energy supplies and GHGs emission reduction. There are some negative impacts associated with the production of first generation biofuels on food production, water pollution and biodiversity, but this should not lead us to label all biofuels risky; this is a developing area and extensive research is needed. Besides, the development of second and third generation biofuels offers significant potential for emissions reduction. As new fuel technologies emerge, the situation may change and we may be able to minimise the environmental impact down to a fraction of current biofuel production. In terms of food security, despite the media pressure during the food price crisis a few years ago, the reality is that the contribution of biofuels towards that spike was quite small. It is likely that food prices can be affected in the short term, but in the longer view lower and arguably more stable food prices by improving technical efficiency in developing countries can be predicted. Analyzing the potential impact of GHG emission reduction from biofuels development is not possible without assessing LUC and ILUC. Current studies show that in general, there is enough land for biofuel production across the world, and investment in the production of second (non-food crops) and third generation (algae) biofuel could also lessen direct and indirect land use change. However, it is over-simplistic to assume that the first generation (food crops) biofuels always compete with food leading to ILUC, while second generation (non-food crops) never does it. The risk will be decreased or eliminated only if certain limitations will be set on land use for biofuels production. Regarding the third generation biofuels, there are still many uncertainties. Algal LCA suggests that currently the process is marginal in terms of positive energy balance and global warming potential (Scott et al., 2010). However, the lack of data from industrial scale means that economic assessments are basically theoretical. There is a serious need to conduct pilot studies to assess achievable productivities. This is an essential step to lead to the development of infrastructure and policies for the third generation biofuels. The rising demand for biofuels could be a chance for poor countries to establish a new export product. The higher biofuels demand from industrialized countries should be combined with further value-adding production processes and industries in the poorer countries. Otherwise, there will be a risk of degrading the poorer countries to the level of mere raw-materials suppliers.

Chapter Seven

Forecasting Scenarios: Biofuel vs. fossil fuels

Chapter Seven: Forecasting Scenarios: biofuel vs. fossil fuels

This chapter aims to explore the uncertainty around the future of biofuel versus the global potential of fossil oil and natural gas developments. Firstly, it estimates the future need for energy across the world and its links with potential biofuel production. Next, it closely examines the current and future discoveries of fossil fuels reserves and in particular crude oil and natural gas, in relation to exploring the uncertainty about the existence of crude oil resources in the future. Finally, it focuses on the future price and production cost of crude oil and how this affects the biofuel production in the future.

7.1 Wider prospects of future energy supplies

Estimates of global energy demand vary extensively depending on the modelling approaches, however, some researchers suggest 1000 Exajoule per year (EJ/year) as the total energy demand for 2050 (Kampman et al., 2010) (Fritsche et al., 2010). This figure is twice the total energy demand in 2008 (Kampman et al., 2010) of which 10% -around 50 EJ (1.2 GtOE gigatonne of oil equivalent)-

estimated to be provided by biomass in the form of combustible biomass and wastes, liquid biofuels, municipal solid waste, solid biomass/charcoal, and gaseous fuels. Technical potential for biomass production in 2050 will be 1500 EJ/year (Kampman et al., 2010) , but only a small share of it is achievable. According to a recent study (OEKO and IFEU, 2010), in 2050, sustainable bioenergy may contribute up to 25% of the global energy demand (250 EJ/YEAR) (Fig 7.1). However, the sustainable biomass potential is much bigger and could contribute up to 50% the global energy demand (500 EJ/YEAR or 11.9 GtOE) (Fritsche et al., 2010), if agricultural productivity improves and extra forest production and residues are collectable (Fig. 7.1);

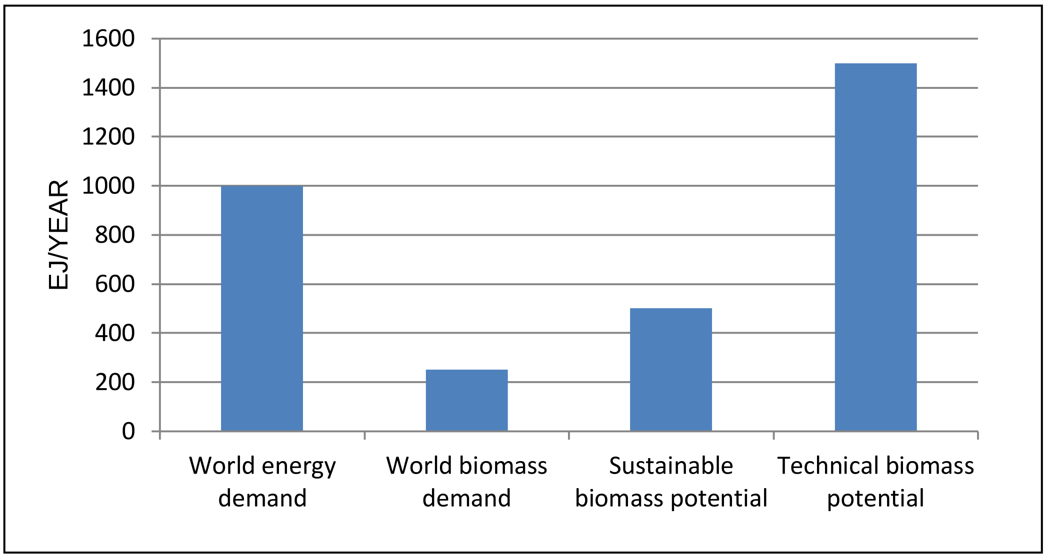


Fig. 7.1: Global Energy potentials from biomass in 2050, adapted from (Fritsche et al., 2010).

In the past, biomass was primarily limited to woody feedstocks, but today bioenergy resources include residues from the food industry to the dedicated energy crops and in the future may possibly extend to aquatic biomass, too. There is an intense debate about future potential biomass, especially in the light of sustainability requirements. Table (7.1) shows the potential of land-based bioenergy supply in 2050 across the world. Bioenergy from macro- and micro-algae is not included here, due to its early stage of development.

Biomass category	Technical potential in 2050 (EJ/yr)
Energy crop production on surplus agricultural land	0 – 700
Energy crop production on marginal land	<60 – 110
Agricultural residues	15 – 70
Forest residues	30 – 150
Dung	5 – 55
Organic wastes	5 – 50+
Total	<50 - >1,100

Table 7.1.: Overview of the global potential of bioenergy supply in 2050 (Kampman et al., 2010)

7.2 The future of Biofuels

Currently the contribution of renewable energy sources (solar, wind, geothermal, biofuels) to world energy production is around 17% where biofuel production itself does not play a major role. As it is seen in Fig 7.2, in 2007, fossil fuels with 78% share were the biggest source of energy and biofuels production had less than 1% the energy share.

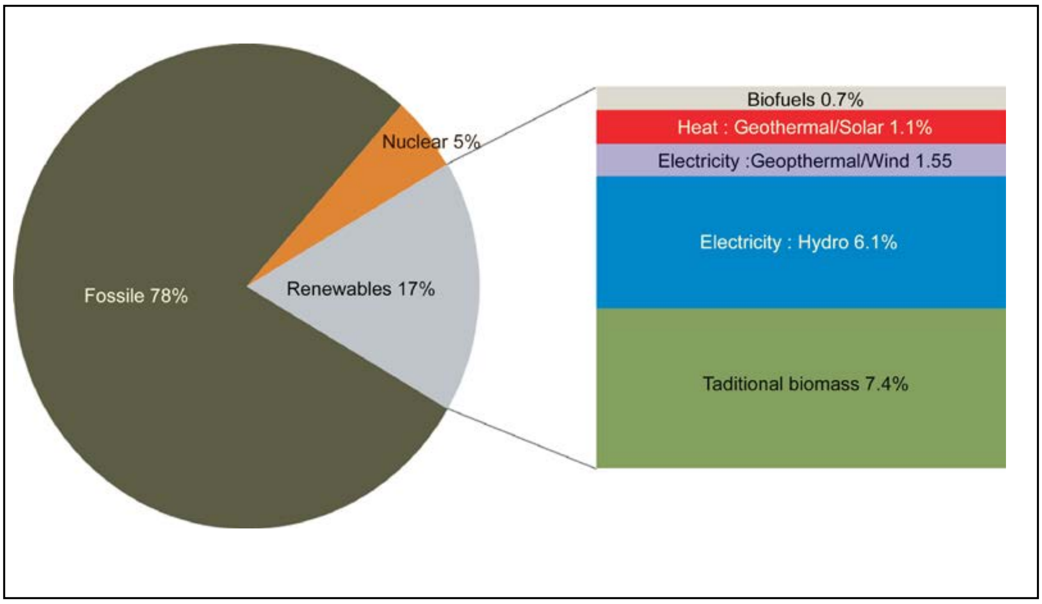


Fig. 7.2: Biofuel share of total energy use in 2007, adapted from (GEA, 2012)

However, it is projected that by 2100, these figures change dramatically. The share of renewable fuel is expected to increase up to 80% in 2100 while solar and biomass together are expected to contribute up to 70% in total energy production (GEA, 2012).

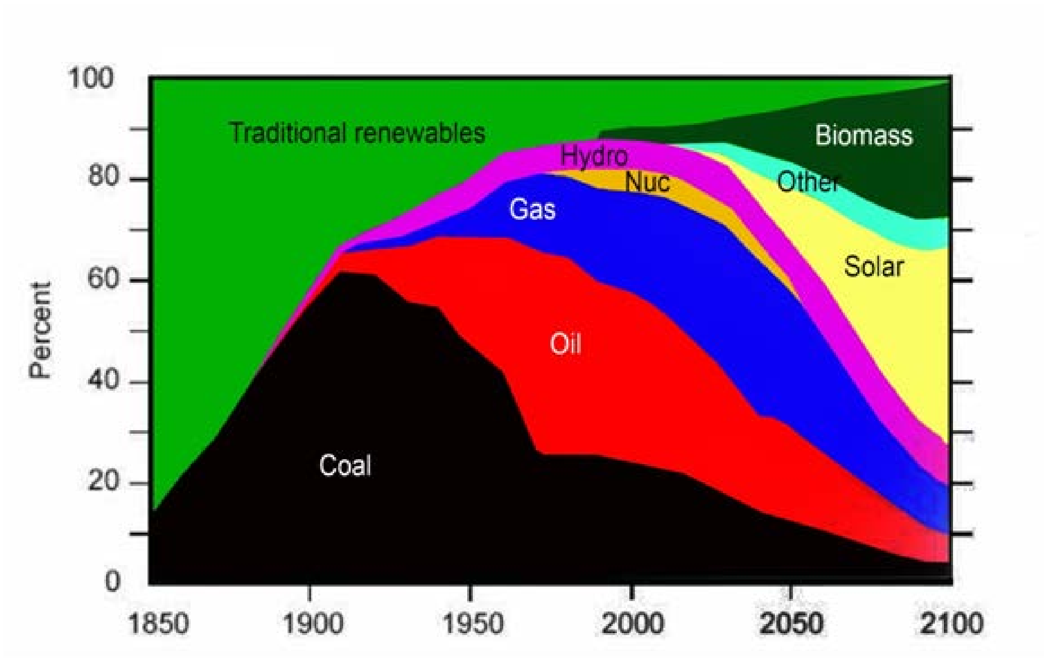


Fig. 7.3: World energy use projection in 2100 (GEA, 2012)

In a shorter period projection, biofuel production itself is likely to rise 370% from its current level by 2030 (from 1.8 to 6.7 million barrels a day) (Lee et al., 2011b) with first generation biofuels, such as sugarcane, soy and palm oil, accounting for much of this boost. Also by 2030, it is estimated that biofuels contribution to fuel requirements reach 7%, which is a 700% rise compared to 2011 level (Cha and Bae, 2011). The new European Union Directive goal is to achieve by 2020 a biofuels usage target of 10% in transport. To meet this target some 22–46 million hectares of cultivated land must used for bioenergy feedstock production and it means between 18.5 and 21.1 millions of the dedicated hectares are needed (Russo et al., 2012). It is also expected that international trade in bioethanol grows rapidly over the next decade, compared to other biofuel products (EBTP, 2012b). Both “Organisation for Economic Co-operation and Development” OCED and “UN Food Agency” (FAO), projected that global ethanol production will double between 2007-2017 reaching 125 billion litres. And for the third generation of biofuels, commercialisation is still a long way to go as dramatic reductions in the capital cost would be needed to approach the level required to service the biofuels market (Slade and Bauen, 2013). Some researchers believe that due to the relatively static cost associated with oil extraction from algae, the future cost saving efforts for third generation biofuels should focus on the production methods (Wen and Johnson, 2009a). Therefore, more research needs to be done in order to make them competitive, as there are big differences in the cost of various algal biomass production methods. For example the production cost of algal biomass in an idealised tubular photo-bioreactor system is up to 5 times bigger than an idealised raceway pond system (Slade and Bauen, 2013).

7.3 The future of crude oil and natural gas

For a comprehensive understanding of the future of biofuels, the study of the future of oil is crucial. Robust global economic growth and increases in industrial production led to a very rapid rise in demand for fossil energy in the early 2000s (Appendix I). The oil industry claims that there are sufficient oil resources to meet global demand for many years to come and adequate financial resources will be put in place to explore, develop and produce oil and gas. However, some are concerned that the global oil production is close to peak, and that peak will be followed by a quick decline in production (Kjärstad and Johnsson, 2009). In the past, various studies (Duncan and Youngquist, 1999) put the date of the global peak in oil production between 1996 and 2035. However, based on current projections, with the actual rate of consumption, global oil reserves are expected to last at least until 2050s, without considering possible undiscovered mineral reserves that might extend fossil fuels supply for another 20 to 40 years (Russo et al., 2012), depending on how quickly it is used. Based on “Proved Reserves” and production of crude oil in 2012, Chojna and colleagues estimated that crude oil, natural gas and coal production are secured for 53, 56 and 109 years, respectively (Chojna et al., 2013). Fig 7.4 illustrates a simplified presentation of total fossil oil reserves on earth. "Proved Reserves" are those quantities of petroleum, which can be estimated with reasonable certainty to be commercially recoverable, from a given date forward, from known reservoirs and under defined economic conditions, operating methods, and government regulations. However, higher oil prices and better technological advances (such as data utilization, intelligent 3D modelling, precise computation and advanced deepwater drilling) that improve efficiency of production (i.e. decreasing production cost) will lead to use more "economically recoverable resource", but it is limited to profitability. Beyond these zones, there is a "Technically recoverable resource" zone, which has lots of uncertainty, but depends on the advance technology available in the future. There is also another zone called "Resource in Place", which is the total resource endowment on earth, no one knows how much but there is a number for this and it is impossible to get beyond this ultimate number (Chojna et al., 2013).

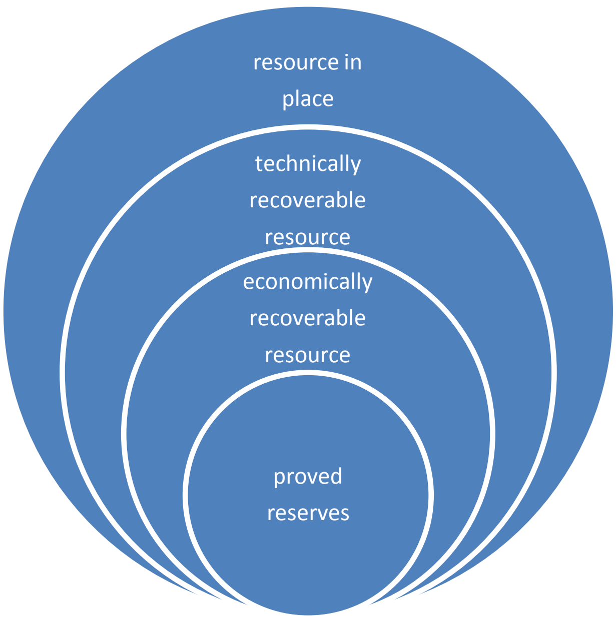


Fig. 7.4: A simplified presentation of total fossil oil reserves, adapted from (Chojna et al., 2013)

In 2007, the International Energy Agency (IEA) calculated the global cumulative production of conventional oil at around 1128 billion barrels (gigabarrels, Gb) and estimated that this was just one third of the total global fossil oil reserves (Fig 7.5);

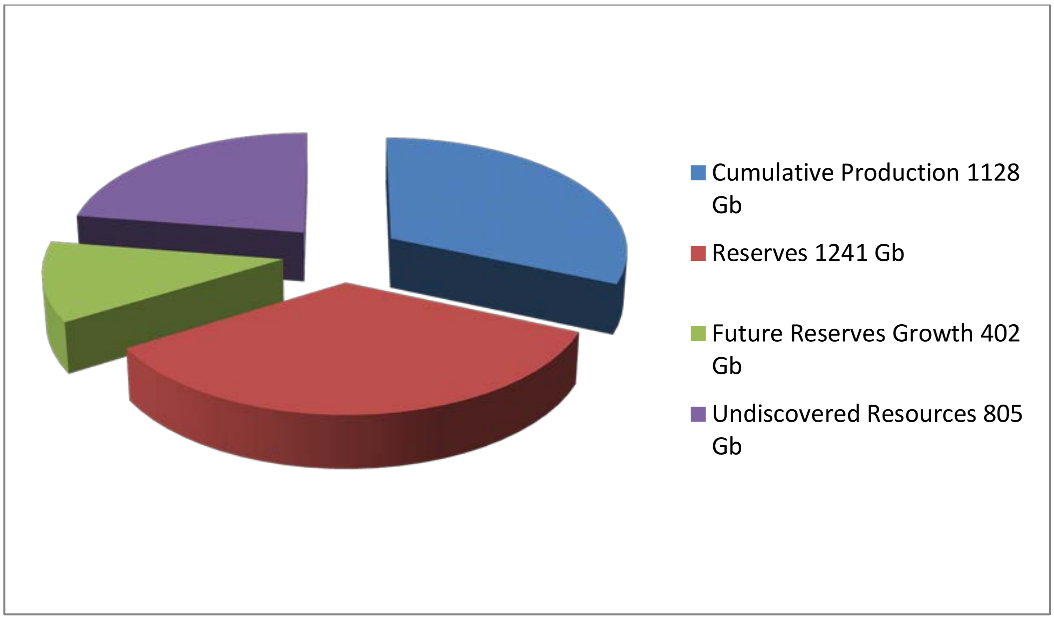


Fig. 7.5: The estimation of total global fossil oil reserves, adapted from (Sorrell et al., 2010)

In 2008, World Energy Outlook (WEO 2008) was published. This was the first in this series of annual reports to quantify the worldwide energy. Based on WEO 2008, the global crude oil production is declining (Fig.7.6) (Miller, 2011). In this figure, the dark blue sector representing current oil producing fields is in decline from 2007 onwards. The pale blue sector represents fields already discovered but not yet in production, and so it includes both current development projects and the so- called ‘‘fallow fields’’, which are not yet scheduled for development. Some of these fields may never be developed, depending upon their size, complexity, future economics, local infrastructure, technological developments or political considerations. Even with adding estimates for non-conventional oils such as Synfuels and for oil which Enhanced Oil Recovery (EOR) (e.g. in-fill drilling or gas injection) produces from old fields, the IEA would face a large proportion of demand in 2030. This demand would have to be met from fields not yet discovered, the pink sector in Fig. 7.6 (Miller, 2011). Synfuels are synthetic fuels made from natural gas (gas-to-liquids, GTL) and coal (coal-to-liquids, CTL).

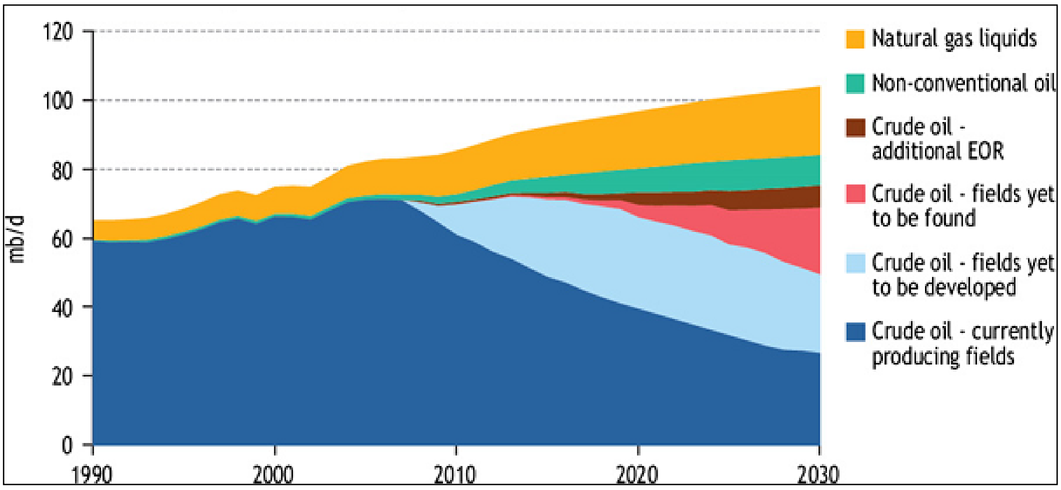


Fig 7.6: World Oil production by source (Miller, 2011)

7.3.1 Recent oil discoveries

Most of the world's conventional oil was discovered between 1946 and 1980 and since that time, annual oil production has exceeded annual discoveries (Stark and Chew, 2005). Around 11% of the estimated undiscovered oil had been discovered in the 8 year period between 1996 and 2003 (Kjärstad and Johnsson, 2009). It is also estimated that between 2000 and 2007 an average of 48 billion barrels (Gb) was added to global reserves each year, split between 15 Gb per year of new discoveries and 33 Gb per year of reserve growth. However, these figures are uncertain and contested and many analysts expect the rate of reserve additions to decline (Sorrell et al., 2010) due to revisions to reserve estimates for the known fields. It is obvious that resource growth has played an important role in replacing reserves in the past, but continued growth will depend on costs, oil price, technology development and access to reserves. Reserves in Kuwait and UAE are believed to be noticeably below official estimates, while there are signs that Iran in particular is struggling to maintain its production levels, due to recent sanctions. On the other hand, there are clear signs that Russian resources are underestimated and that Saudi Arabia is increasing its oil production capacity significantly. In addition to the remaining conventional resources, it is commonly accepted that there are very large unconventional resources, defined as oil shale and synthetic fuels, mainly in Canada, US and Venezuela. The potential for remaining undiscovered oil is of course uncertain, but it is nevertheless concluded here that a number of potential regions remain to be thoroughly explored. Moreover, the potential in deeper parts of lands and seas remains to be examined in the future (Kjärstad and Johnsson, 2009).

7.3.2 Future discoveries

When it comes to future discoveries, any estimation is obviously bound to be uncertain but it can safely be said that there are still some large regions, which are poorly explored for a range of reasons. The most cited study on undiscovered oil and gas resources is the World Petroleum Assessment (WPA) published in year 2000 by the United States Geological Survey (USGS). The 2000 WPA estimated worldwide undiscovered conventional liquid resources as of the end of 1995 to be between 0.5 and 1.6 trillion barrels (Tbls) with an average of 0.9 Tbls (USGS, 2000). Fig. 7.7 shows the regional breakdown of the average estimate for crude oil and natural gas liquid (NGL). As can be seen from Fig. 7.7, most undiscovered oil is expected to be found in the Middle East and North Africa, on the American continent and in former Soviet Union countries, which together are believed to contain some 770 billion barrels (Gb) of undiscovered liquids or 82% of the total global estimate (Kjärstad and Johnsson, 2009).

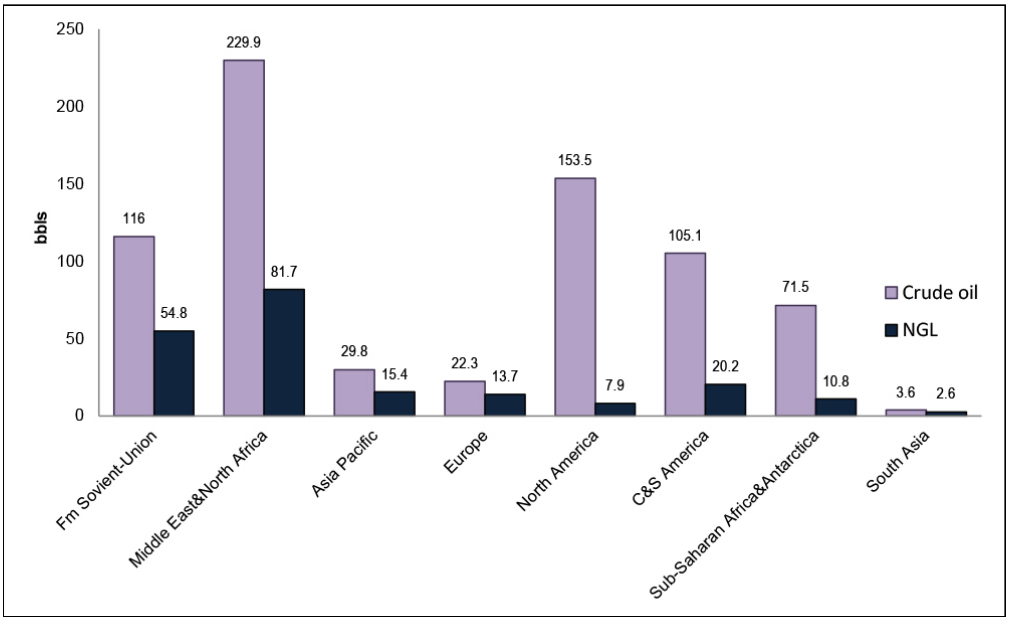


Fig. 7.7: Estimate of worldwide undiscovered crude oil and NGL by region and as of January 1st 1996, based on USGS report in 2000 (Kjärstad and Johnsson, 2009)

Although the USGS study is the most comprehensive evaluation of the remaining global resources to date, there are further recent studies providing better estimates on regional levels including the Arctic. The evaluation of the Arctic resources is highly uncertain, as most of the assessment technologies could not be applied due to lack of data availability. Furthermore, there are significant geological, engineering, economic and environmental uncertainties with regard to the Arctic resources (Kjärstad and Johnsson, 2009).

7.3.3 Arctic oil and gas resources

In the past decade, due to climate change, Arctic sea ice started melting, making the Arctic waters and petroleum resources far more accessible for extraction and transportation. With almost a quarter of the global undiscovered petroleum resources, the Arctic has attracted attention as the last large frontier of conventional petroleum outside the OPEC (Organization of the Petroleum Exporting Countries) cartel. The area came under the spotlight as the EU and USA looked to the Arctic to ease their dependence on the limited number of large oil producing countries. In November 2006, Wood Mackenzie and Fugro Robertson released an extensive study on the Arctic region indicating much less potential crude oil resources than previously estimated and that gas probably would be the dominating hydrocarbon in the region (Kjärstad and Johnsson, 2009). The entire Arctic region was assessed applying detailed geo-scientific analysis of individual basins and their various petroleum reservoirs were calibrated against industry data on exploration wells and existing discoveries. According to Wood Mackenzie's press release, the study shows only about a quarter of the oil volume previously assessed in key North American and Greenland basins. There are also other indications that the Arctic may contain less oil than previously anticipated. Also, in August 2007, USGS released a new study of prospective oil and gas resources of northeast Greenland, which indicated significantly less hydrocarbon resources than in the 2000WPA. The assessment also confirmed the results from the Wood Mac study that the region is believed to hold mainly gas resources. The results from the two studies are shown in Table 7.2.

	Oil (bbls)*	**Gas (tcf)****	**NGL*** (bblsoe)******
2000 WPA	47.1	80.7	4.2
2007 assessment	8.9	86.2	8.1

Table 7.2: East Greenland rift basins assessment results, 2000 and 2007 WPA study (Kjärstad and Johnsson, 2009)
*bbls: billion barrels
**tcf: trillion cubic feet
***NGL: Natural Gas liquids: Natural gas liquids are the heavier hydrocarbons in natural gas, ethane, propane, butane, and so on that can be extracted during natural gas processing.
****bblsoe: billion barrel of oil equivalent

However, with all these amendments, the Arctic is still considered as a huge reserve of fossil fuels. A recent assessment by the USGS estimated the total amount of undiscovered fossil fuel resources in the Arctic to be 413 Billion

Barrel of Oil Equivalent (bboe), about 22% of the global undiscovered conventional oil and gas resources. Further, it was found that about 279 bboe or close to 70% of the Arctic resources is gas (Lindholt and Glomsrød, 2012). However, even if almost a quarter of the world's undiscovered petroleum resources were situated in the Arctic basins, it is essential to look at the profitability outlook of Arctic oil extraction to understand the scale of future Arctic production levels.

7.3.4 Developing shale gas and oil

New estimates suggest the world could have vast unconventional oil and gas resources called "Shale". The existence of large amounts of hydrocarbons entrapped in layers of sedimentary rocks has been known for many years. Shale resources are formations of organic-rich shale, a sedimentary rock formed from deposits of mud, silt, clay, and organic matter. In the past these were not seen as exploitable resources, however, over the past decade energy companies have been able to economically extract natural gas from shale resources by using two technologies: hydraulic fracturing (also known as fracking) and horizontal drilling (Chevron, 2013). Once drilling is done, a fluid and a propping agent ('proppant') such as sand are then pumped down under high pressure to create fractures in rocks (this process is known as hydraulic fracturing). These fractures start at the injection well and extend as far as a few hundred metres into the reservoir rock. The gas is then able to flow onto the surface (Tyndall, 2011) and is referred to as "unconventional gas" (Fig 7.8).

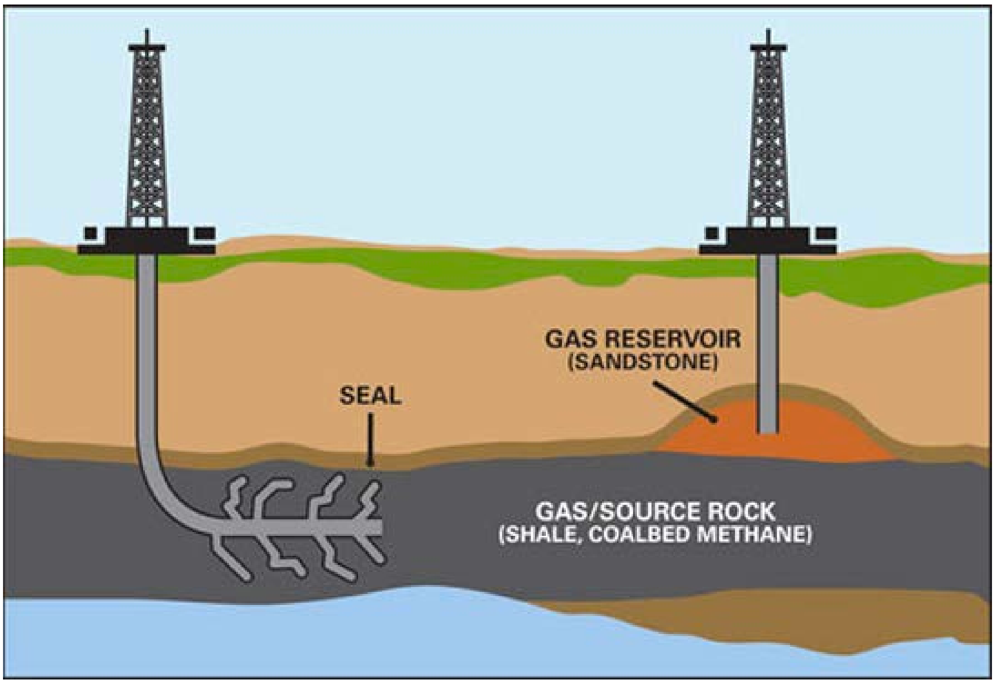


Fig 7.8: A simple illustration of shale gas compared to conventional gas deposits (Scitechdaily, 2012)

According to the International Energy Agency (IEA), the total global amount of shale gas reserves stands at 7,345 trillion cubic feet (Chevron, 2013). Among the small number of countries with unconventional natural gas reserves, it is the US that has been most successful in exploiting shale gas and oil reserves. According to the EIA, almost 25% of the 2,300 trillion cubic feet of technically recoverable natural gas resources estimated to be in the US, is held in shale rock formations (Chevron, 2013). The US production success can be attributed to a combination of the following factors: a large domestic gas market, an extensive land-based oil and gas exploration and production industry, developed pipeline infrastructure, high-level technical know-how and accommodative legal regulations (Chojna et al., 2013). According to the EIA, this resource could account for nearly 50% of US production by 2035 (Chevron, 2013). As a result of the strong increase in the production of shale oil, US crude oil imports dropped from more than 10 million barrels per day in mid 2007 to less than 8 million barrels per day at the beginning of 2013

(Chojna et al., 2013). For the first time in 60 years, the US has become a net exporter of refined oil products. Due to the shale boom, the US is expected to be the world's largest crude oil producer in a few years, providing the oil price stays above US$ 75 per barrel. US shale oil production could grow from about 1.5 million barrels per day at the end of 2012 to 5 million barrels per day in 2017. As a consequence of this, total US crude oil production may increase from just over 9 million barrels per day to close to 12 million barrels per day in 2017. This compares to the previous peak in US oil production of 10.9 million barrels per day in 1970. As a result, US crude oil imports should fall by at least 1 million barrels per day by 2020 from about 9 million barrels per day in spring 2013 (Chojna et al., 2013). The shale gas production growth has already had an impact on global gas markets, in particular Europe. Its period of rapid growth has coincided with a temporary recession-driven fall in natural gas demand in Asia, Europe, and, to a limited extent, in North America itself. In addition, this has coincided with a sudden and significant increase in global LNG supply. Of the new LNG supply projects in Qatar, Iran, Russia, Yemen, and elsewhere, some volumes were originally 'tagged' for the North American market. These volumes have been re-directed to Europe (most notably the UK) and to Asian markets. As a consequence of this redirection of LNG, Europe in 2009 and 2010 has imported less Russian pipeline gas than would otherwise have been the case, and its traded gas prices have been lower than oil-indexed Russian contract prices (Rogers, 2011). This drop in gas prices can be attributed in part to an increase in unconventional supplies, including shale gas. Accounting for only one percent of US gas output in 2000, the shale gas represented 20% in 2012 and a potential of 50% by 2035 is forecast (Asche et al., 2012).

7.3.4.1 Global Shale gas

The volume of gas bound within a specific shale (gas-in-place) is known as the gas resource. The reserves are the volume of gas that can be technically and economically extracted. Reserves are therefore much smaller than the resource. The US Energy Information Administration (EIA) estimates that 22% of shale resources are technically recoverable however the economically recoverable fraction may be much smaller as it depends on gas prices and production costs (MacKay and Stone, 2013). Based on these facts, EIA assessed 48 shale gas basins in 32 countries, containing almost 70 shale gas formations (Asche et al., 2012). The distribution of potential global shale gas resources in some of these countries is shown in Fig 7.9, but to date, the commercial extraction has been achieved only in North America (BGS, 2013).

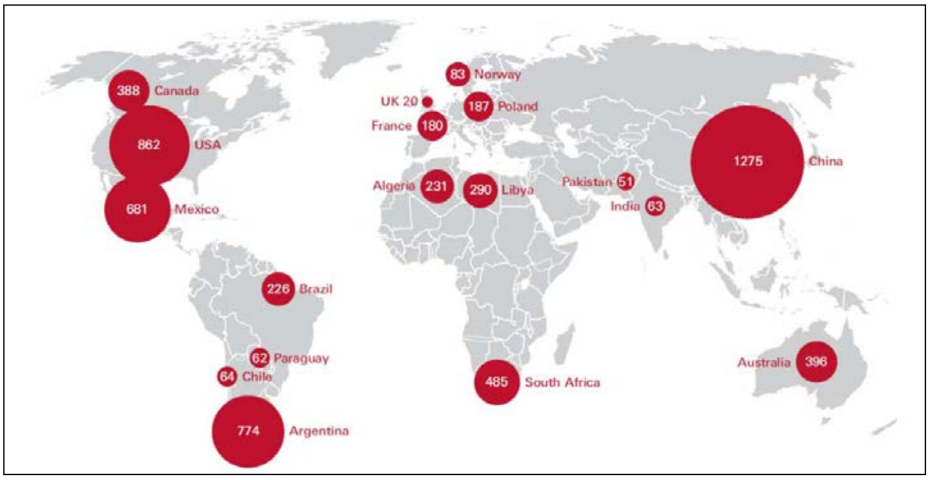


Fig 7.9: Technically recoverable shale gas reserves in trillion cubic feet (tcf) (BGS, 2013)
Note 1: No data available for Russia, Central Africa, Middle East, Southeast & central Asia
Note 2: tcf: trillion (10^{12}) cubic feet

As shown in Fig 7.9, the international shale gas resource base is vast, with proven reserves being at the same level as conventional natural gas. The resource potential for shale gas in Europe has not been properly investigated so far but France and Poland, with vast shale gas reserves, may be motivated for development. Both countries are currently natural gas importers and having estimated shale gas resources might help to reduce their dependence on import (Asche et al., 2012). It is also reported that South Africa, China and Argentina will soon adopt the US technology of extraction in the next 5–10 years, to make their shale resources accessible (Chojna et al., 2013).

7.3.4.2 Shale gas in the UK

The assessment of shale resources in the UK is in its early stages. Although The UK's first well to encounter shale gas was drilled in 1875, but its significance was not realised at the time. In 1980s, researchers at Imperial College in London tried to apply the US shale gas concept to evaluate the shale gas potentials in the UK (Selley, 2012) and it was only in 2008 that the British Geological Survey (BGS) started reviewing the UK shale gas resources. Only one shale gas well has been hydraulically fractured, Cuadrilla's Preese Hall 1 well during 2011, but that test was suspended before completion of the fracturing programme after two small earthquakes were induced (BGS, 2013). The UK government's current policy is to actively encourage shale gas exploration (Selley, 2012). The 2013, UK Institute of Directors' report claimed that developing shale gas resources could create 74000 jobs (IOD, 2013). The British Geological Survey (BGS) estimates the total shale gas resource (gas-in-place) in part of the central Britain (Selley, 2012) (Fig 7.10).

Fig. 7.10: Location of the shale gas study area, central Britain (BGS, 2013). Contains Ordnance Survey data © Crown copyright and database right 2013

To reflect the geological uncertainty, the provided estimation has a range. The lower limit is 822 tcf and the upper one is 2281 tcf, but the central estimate for the resource is 1329 tcf (BGS, 2013). This is the resource figure (gas in place) and therefore shows the total amount of gas, but not all of it, is extractable. The proportion of extractable gas depends on many factors such as; the economic, geological and social factors. However it is estimated that at least 20 tcf of the UK shale gas are extractable (BGS, 2013). Shale gas clearly has potential in the UK but it needs expertise and investment. The environmental concerns also need to be noted.

7.3.4.3 Environmental impacts of shale gas production

The extensive and unexpected development of shale gas in the United States and the rush to explore the shale gas potential by other countries, has created a broader anticipation that this new technology would change the world, however, environmental concerns against hydraulic fracturing are significant. In summary, the environmental concerns of shale gas production are: GHG emissions, water consumption and pollution with toxic material, competing land-use requirements in densely populated areas and increasing seismic activities and possible earthquakes (BGS, 2013).

7.3.4.3.1 GHG emissions

The GHG emissions resulting directly from shale gas operations are vented release of methane and CO_2, emissions from combustion of fossil fuels on site (as diesel engines used for drilling, hydraulic fracturing and natural gas) which would be mainly CO_2 and fugitive emissions which are unintentional gas leaks and are difficult to quantify and control (MacKay and Stone, 2013). It is estimated that combustion of shale gas generates less CO_2 than combustion of coal, and the use of shale gas in place of coal, which generates over 80% of CO_2 emissions from the US electric power sector, is hoped to reduce greenhouse gas (GHG) emissions (Wang et al., 2011). The carbon footprint of shale gas is reported to be in the range 200 – 253 g CO_2e (equivalent) per kWh of chemical energy, which makes its overall carbon footprint comparable to conventional sources (199 – 207 g CO_2e/kWh), and even lower than the carbon footprint of Liquid Natural Gas (LNG) which is (233 - 270g CO_2e/kWh. When shale gas is used for electricity generation, its carbon footprint is between 423– 535 g CO_2e/kWh, which is much lower than the carbon footprint of coal, 837 – 1130g CO_2e/kWh (MacKay and Stone, 2013). However, there are growing objections to this expectation given that methane, the principal component of shale gas, is a more powerful GHG than CO_2. Shale gas production emits more methane than conventional gas production does, and the overall equivalent CO_2 emission could therefore be more than that of coal (Wang et al., 2011). Therefore, developing technologies to keep methane emission low is significant.

7.3.4.3.2 Water consumption and pollution

Hydraulic fracturing requires large volume of water. It is suggested that between 15000 -29000 m^3 of water are required per well (MacKay and Stone, 2013), but the bigger risk is the potential for contaminating of groundwater. Although there is limited evidence that the fluid used in hydraulic fracturing contains numerous chemical additives, groundwater pollution could happen in case of a big failure in the system or loss of integrity of the wellbore (Tyndall, 2011). There are a number of other potential sources of pollution such as well cuttings and drilling mud and flowback fluid. Unanswered questions also exist over whether the water and chemicals used in the production can migrate into drinking water, and whether the wastewater can be handled acceptably to avoid pollution. Whether adequate geological separation exists between sub-surface fracture zones and adjacent drinking water reservoirs is another question (Asche et al., 2012)

7.3.4.3.3 Landscape impacts

The construction of wells requires access roads, storage buildings, fuel tanks, heavy equipment, lorries and other vehicles. Well pads take up around 1.5-2 ha and the well pads will be spaced between 1.25 to 3km^2. This level of activity is likely to face considerable opposition at the local level and may well be seen as unacceptable more widely (Tyndall, 2011)

7.3.4.3.4 Earthquakes

The UK Department of Energy and Climate Change (DECC) announced that the earthquakes near Blackpool in April and May 2011 were induced by fracking treatments at the Preese Hall well (DECC, 2013b). This report also warns that further small earthquakes may occur, however, based on this report, the risk is low, and structural damage is extremely unlikely. To minimise the risk of earthquakes associated with hydraulic fracturing, the British Geological Survey has made some recommendations for a number of measures which include constant monitoring and injecting less fluid during future hydraulic fracture treatments (BGS, 2013). Injecting less fluid should reduce the chance of larger earthquakes, as the number of earthquakes should increase proportionally to the injected volume. Also, to minimise the chance of fluids percolating, the fluid should be allowed to 'flow back' out of the formation after the fracking forms (BGS, 2013).

Therefore, because of these environmental concerns, political opposition is likely to gain strength against the exploitation of shale hydrocarbon reserves (Chojna et al., 2013). In the US, in a 2010 letter to the US President Obama, the Council of Scientific Society Presidents, who represents 1.4 million US scientists and science educators, urged great caution in the shale gas development, noting that shale gas may actually worsen global warming, rather than help mitigate it (Wang et al., 2011). In Europe, the challenges facing shale gas in relation to public opinion seem to be even greater. Higher population density could be an explanatory factor. In France oil companies agreed to postpone further activity until the government has conducted studies of the economic, social and environmental impact of drilling and hydraulic fracturing. Germany's Der Spiegel used the formulation ''massive doubts'' and pointed to the risk of pollution and explosions (Asche et al., 2012) and in the UK, there have been some demonstrations near potential fracking sites in December 2013 and January 2014 (BBC, 2014) . However, the UK government tries to win support for the controversial expansion of fracking and David Cameron, the prime minister, on 13 January 2014, publicly supports shale gas exploration (Channel4, 2014). The UK government claims that the UK shale gas can be developed sensibly and safely, protecting the local environment, with the right regulation (Channel4, 2014). Also the results of a study commissioned by the Secretary of State for the DECC suggested that the net effect on UK GHG emissions from shale gas production will be relatively small, if the right safeguards are considered (MacKay and Stone, 2013). In the UK, and in the broader picture in the EU, there have been few attempts to quantitatively explore the uncertainty around the global potential of shale gas development, and most studies rest on qualitative analysis of the potential for shale gas (Gracceva and Zeniewski, 2013).

7.3.5 Analysis of future production for crude oil

The lack of transparency within the oil industry clearly prevents any specific analysis of future production and supply capacity. Although no decisive conclusions or quantitative assessment can be made with respect to the oil resource base, resources appear to be sufficient to meet demand for decades ahead (Kjärstad and Johnsson, 2009). This is due to several facts;

- There is still a large potential for the resource growth in the fields already discovered
- Most oil companies and countries have already discovered resources that are substantially larger than proven reserves
- The prospects to find more oil appear promising
- There are very large deposits of unconventional oil

However, although the source base appears large, the oil will have to be produced and transported to the market in a timely manner to meet increasing demand which is a completely different subject. The global supply of oil most likely will continue to be tight, not only in the medium term but also in the long term. The main reasons behind this are assumed to be the rapid decline in oil production in Mexico and the North Sea, slow progress of the announced oil and gas projects in some countries and limited access to large resources in the Middle East, Russia and Venezuela. In addition, it is a fact that new oil will have to be found and produced under more difficult environment. Furthermore, the current condition of the world's 20 ageing supergiant fields- which together account for almost a quarter of global production- is unknown. For instance, Iraq and Iran's supergiants may have been mismanaged in the past leading to considerable problems in maintaining field production. Production of unconventional gas and oil is believed to rise rapidly in the future, while the prospects for growth in conventional oil and gas are more uncertain and the share of unconventional oil in global oil production is unlikely to exceed the projections, i.e. less than 5% in 2015 and 8% in 2030 (Kjärstad and Johnsson, 2009).

Given the above analysis, it is difficult to project anything but continued tight oil supply, in the long term. It is also concluded that it is very unlikely that the global oil production would peak or plateau in a relatively near future.

However, it is important to emphasize that this hypothesis is under current market conditions and policies, which may very well be subject to change over time. For instance, the global effort to ease climate change may, alone or together with concerns for energy security, reduce the long- term demand for oil. But if the world seriously wants to reduce CO_2 emissions in order to meet global emission reduction targets, drastic measures will have to be taken to reduce consumption of fossil fuels, including oil and this could be interpreted as raising demand for biofuels in the future.

7.4 Biofuel vs. Crude Oil: Forecasting scenarios

Currently biofuel is not competitive with petroleum, and does not appear to be for decades, and high production cost remains the main challenge. However, high crude oil prices improve the economic benefit of biofuels. The key question is when biofuels are going to be economically comparable with crude oil? A quick look at the history of crude oil shows the global crude oil prices skyrocketed to approximately US$137 per barrel in the first week of July 2008 (Appendix F), and a few months later, the effect on biofuel market was evident. In the third quarter of 2008, the US ethanol production volume exceeded 14 times higher than the production level in the same quarter of 1986 (Lindholt and Glomsrød, 2012). Therefore, it is obvious that the biofuel production is very much affected by changes in oil price. A team of researchers (Timilsina et al., 2011) have estimated the extent of the increase in the biofuels production level in response to the increase in oil prices. Three simulations for this analysis were considered; increase in oil prices by 25%, 50% and 100% from their corresponding baseline values starting from 2012. According to this study, increasing oil prices to $186/barrel will result in a 77% increase in biofuel production in 2020 from the 2009 level (See table 7.3) (Timilsina et al., 2011).

Oil prices forecast (US$/barrel)	**Biofuel production (%)**		
	High income countries	Middle and low income countries	World total
116	20.6	20.2	20.4
140	40.5	39.7	40.0
186	78.1	76.6	77.3

Table 7.3: Oil prices and the percentage of Biofuel production changes in 2020, adapted from (Timilsina et al., 2011)

However, this does not mean that a rapid increase in oil price today would result in a massive boost in biofuel production overnight because the necessary infrastructures for biofuel production do not exist. The crude oil industry has already benefited from many years of investment on the infrastructure and technology but biofuels have not had that advantage. It is highly expected that eventually, the benefits of reducing of GHG emissions will reduce the cost gap. Socio-economic costs for biofuels production require a market with a clear pricing of GHG emissions to ensure that this factor is included in the decision-making of actors in all links of the fuel chain (Duer and Christensen, 2010). The results of a survey conducted by Bloomberg New Energy Finance (Isola, 2013) show the second generation ethanol is on course to be cost competitive with first generation ethanol by 2016. In 2011, the production costs of second generation ethanol were estimated in the range of US$0.60–US$1.30 per litre (Carriquiry et al., 2011) while in 2012, the Bloomberg's survey showed that the average cost of cellulosic ethanol production was US$0.94 per litre. This was almost 40% higher than the cost of producing ethanol from corn (US$0.67 per litre), which was almost competitive with petroleum (Isola, 2013). Based on the results of this survey, by 2016, the price of cellulosic ethanol would match that of corn ethanol (Isola, 2013). The technological advances are expected to drive production costs of second generation ethanol down to as low as US$0.30–US$0.40 per litre by 2020 (Carriquiry et al., 2011). However, the third generation of biofuels is still far more expensive than first and second generations of biofuels and estimating the production cost is complicated as it depends on many factors, such as oil content, yield of biomass from the culture system, scale of production systems and the cost of extracting oil from algal biomass. However Chisti (Chisti, 2007) estimated a competitive production cost of US$2.80 per litre (US$10.50 per gallon) for third generation biofuels, assuming the oil content of the algae to be around 30%. The equation below was used by Chisti to estimate the competitive cost of algal oil:

$C_{algal\ oil*} = 25.9 \times 10^{-3}\ C_{petroleum**}$ (Chisti, 2007)

*Calgal oil is the price of microalgal oil in dollars per gallon and

**Cpetroleum is the price of crude oil in dollars per barrel

This estimation does not include costs of converting algal oil to biodiesel, distribution, marketing and taxes. This equation assumes that algal oil has roughly 80% of the caloric energy value of crude petroleum. For example, assuming the price of crude oil is $100 per barrel, algal oil should cost less than $2.59 per gallon (US$0.68 per litre) in order to be competitive with petroleum diesel fuel (Wen and Johnson, 2009a). Therefore, the increase in oil prices would raise demand for biofuels and make them more competitive. In 2011, a detailed analysis study showed how biofuel production was very much affected by changes in oil price (Timilsina et al., 2011). Based on this study, a 65% increase in oil price in 2020 compared to the 2009 level would increase the global biofuel penetration to 5.4% in 2020 from 2.4% in 2009. “Biofuel penetration” refers to the share of biofuels (i.e., bioethanol and biodiesel) in total liquid fuel consumption for road transportation. Table 7.4 presents biofuel penetration for the year 2020 as biofuel targets are supposed to be met by 2020 in several countries.

Region/country	Biofuel penetration in 2020	% increase in oil prices compared to the 2009 level ($56)	Predicted oil price (USD/Barrel)
Australia and New Zealand	1.2	86.9	104.6
Japan	0.6	22.2	68.4
Canada	4.1	138.0	133.2
United States	4.1	48.5	83.1
France	10.0	184.0	159.0
Germany	10.0	143.5	136.3
Italy	10.0	344.0	248.6
Spain	10.0	377.1	267.1
UK	10.0	932.5	578.2
Rest of EU	10.0	652.1	421.1
China	3.7	111.5	118.4
Indonesia	5.0	101.9	113.0
Malaysia	1.8	0.6	56.3
Thailand	5.2	143.4	136.3
Rest of East Asia and Pacific	1.5	113.4	119.5
India	16.7	244.7	193.0
Argentina	5.0	114.9	120.3
Brazil	9.5	11.3	62.3
Rest of Latin America and Caribbean	1.5	49.6	77.3
South Africa	2.0	21.3	67.92

Table 7.4: Biofuel penetration in 2020 corresponding to announced targets and oil price increase required to meet those targets, adapted from (Timilsina et al., 2011)

The estimated oil prices in 2020 have been compared to the average oil price in 2009, which was US$56 per barrel. The table 7.4 offers some interesting observations. In the United States, for example, biofuel penetration in the year 2020 corresponding to its announced target is 4.1%. An oil price of US$83.1 per barrel would be sufficient to increase biofuel penetration in the United States to its target level (Timilsina et al., 2011). As this oil price prediction is reasonable by 2020, it means that the announced target in the USA is reachable. On the other hand, The UK will meet the announced target, only if the price of oil in

2020 will reach $578.2 per barrel, which looks unrealistic. Some countries/regions like Japan and Latin America and the Caribbean (excluding Brazil and Argentina) have such low targets that they could meet them much earlier than 2020 under the baseline (Timilsina et al., 2011).

Chapter Eight

Interviews

Chapter Eight: Interviews

This chapter aims to elicit the views of the stakeholders and experts in relation to what they perceive to be the most achievable and effective regulations and actions for the biofuels industry over the next few decades. As discussed in detail in chapter 2, the participants were experts from government, private industries and universities from 11 countries. In this chapter, first, a summary of the participants' views on various biofuel issues are provided, then the different sectors' views on biofuels are discussed. The interview data and the detailed literature review information are brought together, analysed and discussed in the next chapter (Chapter 9).

8.1 The summary of views

The participants had very different outlooks towards the biofuel's future, impact and regulations. These are discussed in sections 8.1.1 to 8.1.5. To obtain a better picture of the variety of the views, a customary pictorial representation of the most frequent key words, mentioned by each sector's representatives is illustrated by using the online resource www.wordle.net (Figs 8.1) to (8.12); the size of the illustrated words is related to the frequency with which they were mentioned; choice of colours is random.

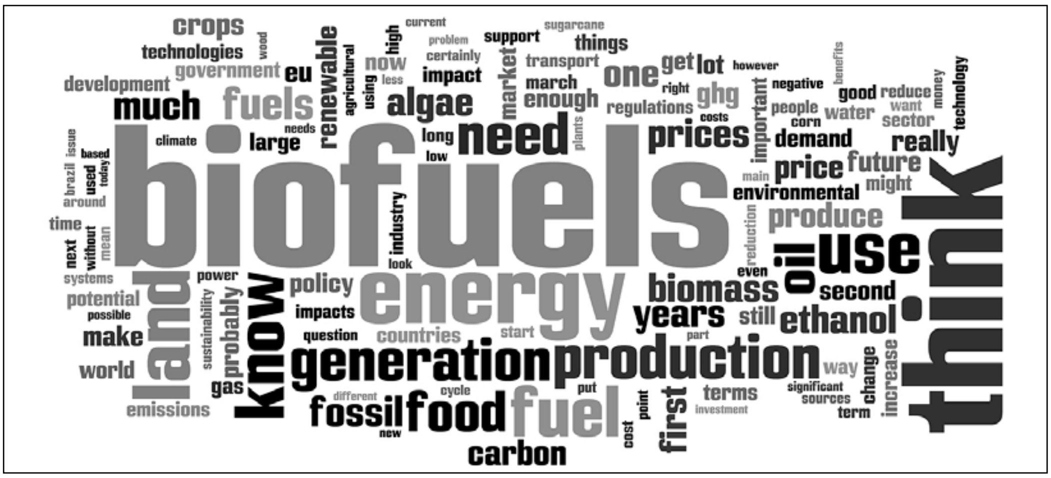


Fig. 8.1: Wordle illustration of frequent words given by participants in all interviews

Based on figure 8.1, the participants used words such as “fossil fuel”, “land”, “food”, “GHG” and “algae” more frequently and this suggests that for them, the environmental and cost concerns as considered as major issues in developing biofuels.

8.1.1 The future of biofuels

8.1.1.1 Long-term projection

When asked in the interviews whether they saw a future for biofuels by 2050, the participants provided various replies, from extremely positive to extremely negative. An overall picture of the frequent words used by the participants shows that “energy” “ethanol”, “price”, "fossil fuel", "impact" and "first and second generations" are among the most frequent words addressed by participants with regards to the future of biofuels (Fig 8.2);

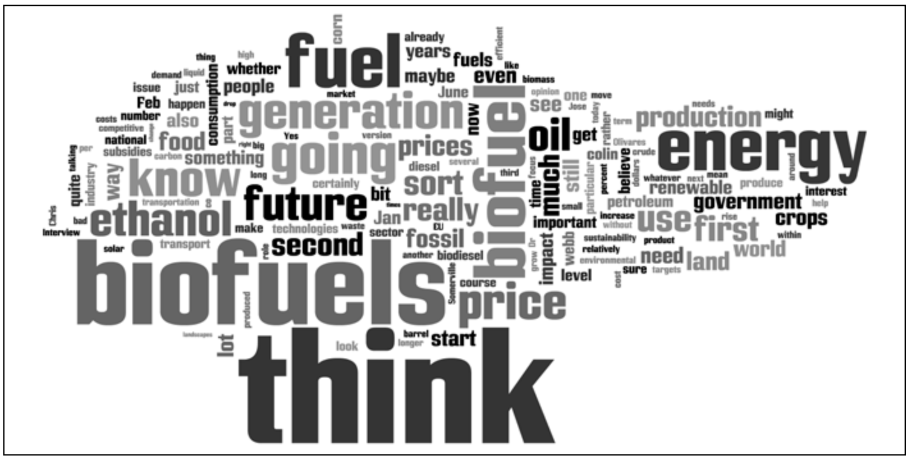


Fig. 8.2: Wordle illustration of views on the future of biofuels given by participants

Seventeen participants argued that there would be a future for biofuels and biofuels could play an important role at least for decades ahead, although there was no consensus about the scale of the role. Among this group, five participants strongly believed that biofuel should be considered as the main future fuel, but twelve participants believed that although biofuel has a strong projection in the decades ahead, it is just one of the options to fulfil the global energy requirements. Two participants from both academic and private sectors even mentioned that other possible renewable options for future energy supply (water, wind, solar, hydro and geothermal) must be considered as well.

Those participants who had negative views about the future of biofuels put a number of reasons forward:

- Negative environmental and economic impact: *"People (have) lot of difficulty to argue that we need biofuel now, because the* *environmental impact is not clear, the economic impact is bad and it has a lot of side effects"* (Academic sector participant).

- Not energy efficient: *"(The biofuels') efficiency is relatively low. For most crops it is maybe, 2- 3%,... with microalgae in the lab you can go to maybe 8% but is very unlikely you will ever achieve that in large scale, so it's not the most efficient way.... solar panels are more efficient, have efficiencies for 15% or higher so that is why I am a bit sceptic about biofuels, sceptical. So I don't really believe that they will make a very big contribution to our energy"* (Business/private sector participant)
- Expensive and not able to compete with fossil fuel: *"If ethanol is cheaper than petrol then people will use ethanol. But that's a long way off I think. I think the finding of shale gas is going to slow things down. And there's going to be a major lever on the interest in biofuels. So I think for now... the European parliament is losing its focus on what we want to do with biofuels"* (Government sector participant)

Most participants were aware of the impact of fossil fuel price on the future of biofuels. For example, one participant said: *"The prospects are highly contingent upon the trajectory for fossil fuel prices and that of course is driven by considerable uncertainty in sources for fossil fuels as we are seeing unrest in the Middle East. So I say it's highly contingent on fossil fuel prices"* (Government sector participant). Only two participants believed that biofuel will be competitive with crude oil in less than 10 years and the reasons provided were: first, the crude oil price will continue to rise and second, huge investment on biofuel infrastructure and production and the market traction.

8.1.1.2 Main targets

Participants also identified the transport system- and in particular aviation industry- as the main target area for biofuels in the future. When asked about the current transport biofuel targets, the participants were optimistic and some showed a desire for increasing the current targets beyond 2020: "*biofuels can provide between 5-20% of transport fuel needs without affecting food production*" (Academic sector participant) or "*A reasonable goal is to get about 30% of our transportation fuel use by about 2030. I hope that we will also get a 50% improvement in fuel efficiency so the actual contribution of biofuels could be up to 50% of transportation fuels*" (Academic sector participant).

8.1.2 Biofuel generations and their limitations and advantages

It is argued by participants that although biofuels offer many advantages, it is wrong to think that biofuels are the panacea to solve our energy problem (Academic sector participant) and it is still too early to be sure of which generation of biofuels will be the "*winner*" (Business/private sector participant). One participant from academic sector suggested that the term "generations" is no longer valid: "*We will stop talking about different generations of biofuels soon. I think all biofuels are biofuels, they are all derived ultimate from photosynthetic origins and whether you use sugars directly or whether you use others, in the end the balance is still the same. It's still part of the same carbon balance so I think we will stop talking about generations in the future*" (Academic sector participant). Some participants from all three sectors (Leal, 2011)(Leal, 2011)(Leal, 2011)(Leal, 2011)(Leal, 2011)believed that first generation biofuel will survive in the long term, although the second generation biofuels offer significantly improved emissions and land use benefits compared to most first generation biofuels. It was also argued by participants that it might be too early to assess if algae can replace the first and the second generation of biofuels. One academic participant believed that the third generation biofuels would never be a commercial alternative due to the high cost of production, while some others believed they have such important benefits, which are worth pursuing. One participant even labelled algae as "*The best option we can see for a scale of production that meets our needs*" (Business/private sector participant).

8.1.2.1 First generation of biofuels

Fig. 8.3: Wordle illustration of views on the first generation biofuels given by participants

The participants had varying perspectives on the first generation of biofuels which are illustrated in Fig. 8.3; using words such as "food", "raw crops", "bioethanol", "sugar", "wheat", "cereal" "priceless" "expensive", "land" and "water" shows that the participants argued different aspects of the first generation biofuels.

Some of the participants from business/private sector believed that the first generation is dead and now focus should be on second and third generations. For example: "*First generation biofuels are food, these need to (be) phased out quickly, food is expensive and getting more* *expensive, we cannot exchange food for fuel"* (Business/private sector participant) or *"First generation biofuels are a dying species, especially the bioethanol from cereal crops (e.g. wheat, maize, etc.). A lot of large wheat bioethanol plants are on the verge of closure or have already closed down due to high prices of cereal crops. The only first generation bioethanol process that might survive for a longer period is bioethanol from sugar beet and sugar cane"* (Business/private sector participant). However some participants from the academic sector believed that the first generation will continue to grow for the foreseeable future: *"The first generation are here, they are invested, the plants can be here for 30 years and they are not going to disappear just because some environmentalist group wants them to disappear and they know that one of the threats for them can come also from the second generation forests which is why we are going to see something of I think political games, kinds of complex things"* (Academic sector participant) or *"Corn ethanol has a relatively minor improvement in GHG emission per unit of energy produced (20%). However, if there was a carbon tax or related incentive, the GHG benefit could easily be improved by using corn stover for generation of process heat (instead of coal or natural gas). Sugarcane ethanol has a very significant reduction in GHG (about 65% according to EPA as I understand it)"* (Academic sector participant). Some of the participants pointed out the uncertainty around the first generation biofuels in terms of environmental impacts, net energy gain and land use change. These will be discussed in section 8.1.3. However, it was suggested by participants from all three sectors that the impacts/benefits of the first generation biofuels might be different according to regions and crops and a proper monitoring is needed. One of the participants said: *"Biofuels, either first or second generation, will have to be evaluated in terms of GHG emissions reduction potential, land/water demand, production costs as a* *minimum. There should be no prejudice with respect to first and second generations if they pass this screening. I think the second generation is a decade ahead at least and we cannot wait; in my opinion, sugarcane ethanol will survive in the long term"* (Academic sector participant).

8.1.2.2 Second generation of biofuels

Fig. 8.4: Wordle illustration of views on the second generation biofuels given by participants

Generally, the participants supported the second generation biofuels compared to the first generation, however, as it can be seen in Fig.8.4, words such as "technologies", "price", "facility" and "cost" were the most discussed issues in the interviews. Most participants underlined the production cost of the second generation biofuels as a major issue as to why the second generation is not commercialised yet. The participants had various estimations for "commercialisation of the second generation"; *"not sooner than 10 years*" (Government sector participant) or *"20 years"* (Business/private sector participant), however, some of them were more optimistic, for example: *"With the right investments in these technologies, they (the second generation) will enter the market within the next 5-10 years...The second generation biofuels could compete with crude oil and other fossil fuels in the long term"* (Business/private sector participant). The views about the second generation biofuels were also linked to the limitations of the first generation biofuels. Most participants argued that the second generation biofuel could overcome the limitations of the first generation: *"it (the second generation biofuel) is much safer than when you use crops to produce energy"* (Academic sector participant), or *"The second generation biofuels offer the prospect of higher yield per hectare and significantly improve emissions benefits compared to most first generation biofuels"* (Government sector participant).

8.1.2.3 Third generation of biofuels

By and large, the participants appreciated the environmental benefits of algal fuels, the potential of being grown on non-arable land and also the potential of being grown in oceans.

Fig. 8.5: Wordle illustration of views on the third generation biofuels given by participants

However, participants expressed some concerns and a quick look at figure 8.5 gives a brief idea of what they said; words such "price", "cheap", "pay", "cheaper" and "expensive" suggest that the participants addressed funding and production cost as major issues in developing algal fuels: *"Needs other 20 years of research"* (Business/private sector participant), *"It may be too early to assess"* (Business/private sector participant), *"Still under development"* (Academic sector participant), *"The potential is high but the future very uncertain due to the production costs"* (Academic sector participant) and *"I am very optimistic about algae but...that's a bit harder technology and not as economically feasible with the current technology systems for cultivation and harvesting and it will take a little bit longer to make that economically feasible technology"* (Academic sector participant). However, two participants from business/private and academic sectors believed that there are some ways for the commercialising algae even sooner, if it is well established. One participant even went further and believed that algae has shown economic benefits which make it attractive for private sector investors: *"Fuel from algae today is too expensive to compete with fossil fuel, but the energy return on investment (EROI) from algae is now projected to be 2.5 to 1, and a positive energy return like that means that it can compete with fossil fuel, we simply need to reduce the cost of the production systems with better engineering and better recycling of the non- hydrocarbon inputs, like water, nutrients and energy"* (Business/private sector participant). Although this claim is backed by the published literature review, it is worth noting that while the EROI of some first generation biofuels is less than 1, the EROI of sugarcane bioethanol from Brazil is almost 10. The EROI of cellulosic ethanol is also reported between 4.4 to 6.6 from different research results (Basset et al., 2010). The highest EROI belongs to coal (80) and then crude oil (20).

The feasibility of algal biofuel, however, was not supported by all participants. Some pointed out the 18-year programme research done by the US department of Environment in 1978-1996 (as described in section 1.1) as an example of how algae failed to be a commercial alternative. Some participants believed that algae was useful , but not for producing biofuels: *“5 years ago there was a boom in algae biofuels, it started when the oil prices started increasing up to 150 dollars a barrel and ...everybody started looking in the direction of microalgae, but 5 years later there's not really, not an enormous progress in that field. So, production is still very low, there is nothing on the market available, algae are now, are already being produced but for really high value applications...so I think algae have a future and have useful applications but I don't think (as) biofuels”* (Business/private sector participant).

8.1.3 Biofuel impacts

8.1.3.1 Environmental impact

The environmental impacts of biofuels were the most controversial part of the interviews. As perfectly illustrated in figure 8.6, “land”, “greenhouse gases”, “emissions”, “ life cycle”, “water”, “impact”, “fertilizers” and “biodiversity” were among the main frequent words that the participants mentioned in their interviews.

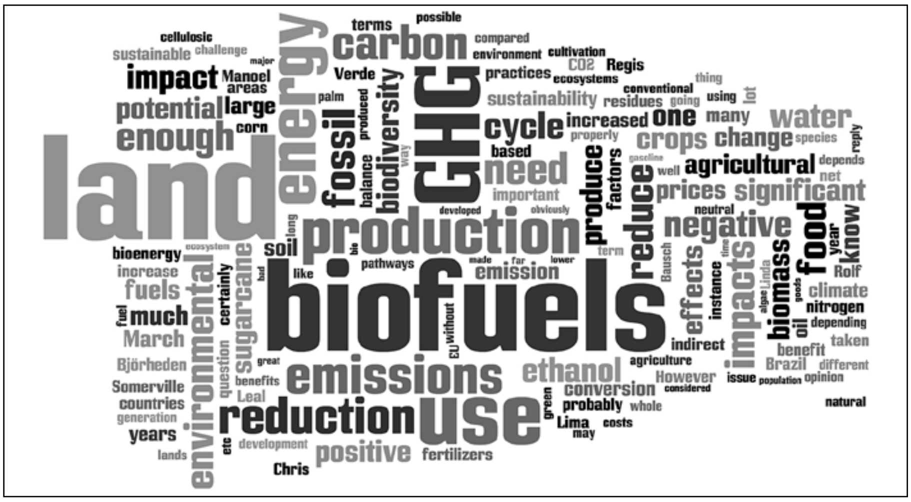


Fig. 8.6: Wordle illustration of views on the environmental impacts given by participants

One participant from the academic sector believed that this was a complex issue, which has been overblown by the media, while another participant from the business sector emphasized that the concern was genuine.

Participants addressed the environmental concerns such as: *"Biofuels have worse impacts on land and water use, habitat and the nitrogen cycle"* (Academic sector participant), or *"Food competition, higher production cost and biodiversity risks"* (Academic sector participant). Some also believed that while crude oil is relatively easy to handle, the biofuels chain is far more complex (e.g. land use, productivity, social and economic implications and potential climate impacts). Also the employment of poor operations and systems that are not sustainable, but instead detrimental to environment biodiversity and long term yield were seen as major risk by one participant from the academic sector. However, the participants also marked a list of environmental benefits of biofuels, such as: *"They are renewable and some biofuels might reduce GHG emissions compared with traditional fuels"* (Government sector participant), *"Biofuels give a better* *security of energy supply*" (Academic sector participant), and "*greater energy autonomy*" (Academic sector participant). There are also "*sustainability benefits in terms of socio-economy*" (Government sector participant), because they provide employment and income in rural areas due to the dispersed nature of production.

It was argued by the participants that the environmental impacts could be many and varied and much will depend on the specific crop, geographical circumstances and agricultural practices. Some themes which emerged from analysing the interviews are listed below:

8.1.3.1.1 GHG emissions

The biofuels' potential ability to reduce GHG emissions was an important part of the environmental benefits/impacts of biofuels discussed by the participants. It was argued that depending on the crop, production method and area, biofuels are able to contribute to a reduction of greenhouse gas emissions compared to fossil fuels. The general idea was that while many first generation biofuels have limited capacity to reduce GHG emissions, the development of second and third generation biofuels offers significant potential for emissions reduction.

Two participants from business/private sector, though, questioned the biofuels' ability to reduce GHG emissions: *"The net emissions might not decrease at all, or the decrease is minimal compared with other damages and costs"* (Business/private sector participant), *or "The gains are not so big,....because you need fossil energy to produce biofuels, you need it to produce fertilizers to produce pesticides which is* *almost consuming as much energy as production of fertilizers"* (Business/private sector participant).

Unsurprisingly, the number of the participants who argued in favour of biofuels with regards to GHG emission reduction was bigger. They provided various estimations of GHG between 20 to 71%, depending on the crops and management practices: *"Corn ethanol has a relatively minor improvement in GHG emission per unit of energy produced (i.e. 20%). Sugarcane ethanol has a very significant reduction in GHG (about 65% according to EPA) and we expect cellulosic fuels to have GHG footprints that can meet the EPA rules (65% reduction in GHG emission relative to gasoline)"* (Academic sector participant), or *"Sugarcane ethanol has reduction potential of 71% compared with gasoline according to the Directive 2009/28/EC default values. For wheat ethanol this value is in the range of 32 to 69% depending on the production path"* (Academic sector participant).

8.1.3.1.2 Land

When asked in the interviews if there was enough land for biofuels production, the majority of participants from all three sectors said that there would be enough land to produce biofuels: *"There is land available that can support more than 100% of future energy need based on biomass"* (Business/private sector participant), or *"We do have enough land if the adequate alternatives of biofuels are selected"* (Academic sector participant) or *"For current targets there is enough land, provided that it is properly exploited and that effort is maximised to use land that is out of use/underutilised"*

(Government sector participant). Some participants, however, underlined the distribution of land from country to country: *"Densely populated countries like the UK or Japan do not have enough suitable land to produce significant proportions of their energy needs from biomass. However, other countries such as Brazil have enormous amounts of land available for biofuel production"* (Academic sector participant). Some other participants placed the emphasis on the importance of the best use of land and argued that biofuel production will eventually lead to a shortage of water and water pollution.

8.1.3.1.3 Sustainability

Participants were also asked about their views on sustainability. Most participants emphasized on far stricter sustainability criteria in order to reduce the negative impacts of biofuels: *"If sustainable systems are developed, it has the potential to deliver large volumes of fuel with very limited negative effects. If carried out improperly, the biodiversity can suffer, soil productivity decrease, water quality deteriorates and the local population can be empowerished... So it can be "good" or "bad" depending on HOW it is carried out"* (Academic sector participant). Participants also underlined the importance of research on sustainable crops with respect to the future needs. For example: *"There is no point making a massive changeover from fossil to biofuel if it is not sustainable. In my institute, we are making a huge investment in understanding the sustainability of potential energy crops. Our current opinion is that it is possible to produce dedicated energy crops in ways that ensure long term sustainability. We are focused on perennial species that sequester mineral nutrient in rhizomes* *at the end of the season so that they do not require fertilizers. The key thing about dedicated energy crops is that they do not have many of the constraints of food crops so we can reinvent the management practices to be more compatible with natural ecosystems"* (Academic sector participant).

In general, the participants believed that the potential environmental benefits of biofuels, if properly managed, outweigh the potential negative environmental impacts, so what is important is to understand the best way for the future: *"Biofuels can of course be "done wrong" and cause environmental problems, but with a little bit of thinking we can design biofuel systems to provide very large environmental benefits"* (Academic sector participant).

8.1.3.2 Food vs. Fuel

Fig. 8.7: Wordle illustration of views on "food vs. fuel" given by participants

As illustrated in Fig. 8.7, the participants' opinion on the potential impact of biofuels on food prices and commodities were wide ranging. Using words such as "food", "prices", "crops", "increase", "crisis", "corn" and "wheat" shows how the biofuel impact on food was discussed by the participants. While some participants from all three sectors strongly believed that there was a minimum connection between "biofuel production" and "high food prices": *"There is no impact on food"* (Business/private sector participant), *"The biofuels contribution to that spike was quite small"* (Government sector participant) and *"Biofuels have had a minor effect on food prices"* (Academic sector participant), some others underlined a strong link between these two.

The majority of participants believed that biofuel was just "one" of the factors involved in increasing food prices: *"Biofuels have been blamed for most of the food prices increases but this is far from the truth- the impacts of biofuels were overstated"* (Academic sector participant), *"There are other factors such as demographic change, speculation on agricultural goods, climate change, droughts, volatile fossil fuel prices which have a large impact on prices for agricultural goods"* (Academic sector participant), and *"It (biofuel) is probably part of the story I think the increase in food prices is also due to the fact that fossil fuels got more expensive"* (Business/private sector participant). Surprisingly, some participants argued that biofuel might contribute to reducing food prices: *"In contrast to the speculation in the popular press, biofuels have had a minor effect on food prices. In fact, some economists think that biofuels could reduce wide price swings in food prices by providing a buffer against poor harvests"* (Academic sector participant). One participant even argued that "*farmers should be free in whatever they want to cultivate, so the whole discussion is irrelevant*" (Business/private sector participant).

8.1.4 Regulations and governments' supports

Whether the current regulations support the future biofuel production across the world or not, was another issue discussed by the participants and their points of views again varied (Fig. 8.8):

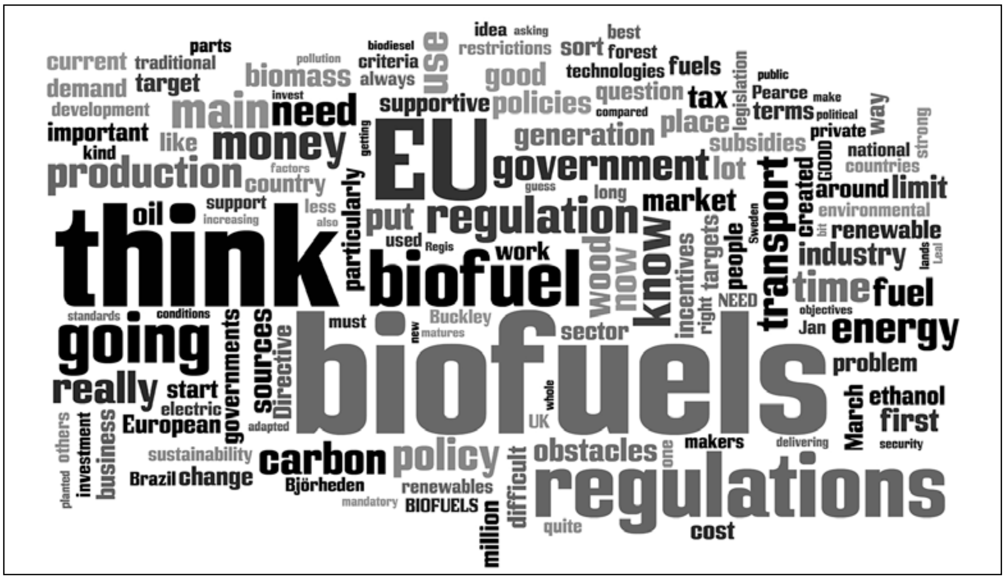


Fig. 8.8: Wordle illustration of views on "regulations" given by participants

One participant said *"the current regulations around the world are supporting biofuel production in the coming years"* (Academic sector participant), while others said: *"In general they are not (supportive). They need to become much more tuned to the actual differences between biofuels and petroleum fuels"* (Academic sector participant), and some argued that the regulations are *"patchy and often reflect business branch perspectives"* (Academic sector participant), and *"Most regulations are the result of a single industry asking for some special treatment, this is NOT a very good way to regulate anything"* (Business/private sector participant). The participants also argued that *"Biofuels are driven mostly by policy rather than market forces and this is necessary in the short and perhaps to medium terms...in the longer term, biofuels need to compete with other sources"* (Academic sector participant). One participant from the government sector emphasised that until biofuels become competitive with fossil fuels, government support is needed, while a participant from business/private sector believed that these supports should be directed to improve the sustainability framework, not the biofuel production or use. One other participant from academic sector also believed that the subsidies must have a reasonable period of existence to minimize the risk of supporting the wrong alternative.

8.1.4.1 Regulations and mandates

Unsurprisingly, the global biofuel regulations were among the most controversial subjects from the participants' perspective. While none of the participants marked the regulations as "perfect", some of them had extremist views and described them as "destructive", for example: *"This market has been created by policy makers to address some of the goals they think that were relevant for their agenda, and if today you eliminate these policies, particularly in most of the market, the biofuel production will collapse"* (Academic sector participant), or *"I think without these EU regulations there wouldn't be any biofuels on the market, it's been subsidized so much that biofuels are so expensive compared to fossil fuels that without subsidies nobody would use it"* (Business/private sector participant). Some other participants from all three sectors believed that the regulations work, but need to be adjusted based on the facts, not dreams. Three examples of these views are: *"I think is essentially a good one, even though none of these things is perfect. And doing things because of legislation rather* *than the underlying causes is probably not the best, politically it's probably we can hope for really, but the approaches are reasonable"* (Academic sector participant), *"As the legislation currently stands, it's fair to say that it works...Current policy is working for volume but I'm not convinced its working in terms of the actual climate objectives"* (Business/private sector participant) and *"The targets are definitely challenging. It will be very difficult to attain the 10% from renewable (by 2020) and will require significant biofuels development. It is likely that large quantities of biofuels will need to come from other parts of the world, driving production in other countries, particularly developing countries"* (Government sector participant).

There was also a third group of participants who believed in reform in regulations. This group said the current regulations do not support the future needs and the most urgent amendment to the regulation should be the introduction of the carbon tax, for example: *"We need a more reasoned long term approach to our biofuels regulation, and we need a carbon tax. If we actually taxed people for the pollution from their carbon output proportional to the cost that pollution has on society, we would reduce* CO_2 *output, and have the money to fund reduced carbon fuels ... but we don't do that right now"* (Business/private sector participant) and *"We (should) start charging the existing industries for the true cost of the environmental damage caused by carbon emissions"* (Academic sector participant).

8.1.4.2 Governments supports and subsidies

When asked whether they saw any benefits in regard to governments' support and subsidies, the participants from different sectors provided three different replies:

- The subsidies are a "waste of money": *"As long as we have money to waste on this we can, we will do it, but we will see with this crisis how it resolves and you'll have less and less money to spend on these kind of things"* (Business/private sector participant).

- The government support is "*weak*" and for a real impact, it needs to be realistic: *"It's very weak clearly because nothing is happening....It's belated realised that the European parliament going to put a cap on first generation biofuels so do it now needs to invest time and effort into some sort of second generation demonstration plants in the UK and has announced a project to invest £25 million. Unfortunately 25 million is not a lot of money... 25 million doesn't go a long way to build the pilot plant"* (Government sector participant).

- The government support is fine, but it needs to be gradually reduced and ultimately stopped: *"I think ultimately these things have to be self sustaining so the government approach of legislating without really giving huge incentives" (Webb, 2014).* And *"The subsidies for corn ethanol are being removed...and the industry is still moving forward. So I think direct subsidies can be removed. even the petroleum industry gets benefits significantly from a number of government subsidies. So I am not really sure that that's and an issue just for biofuels"* (Academic sector participant).

8.1.5 Other energy resources

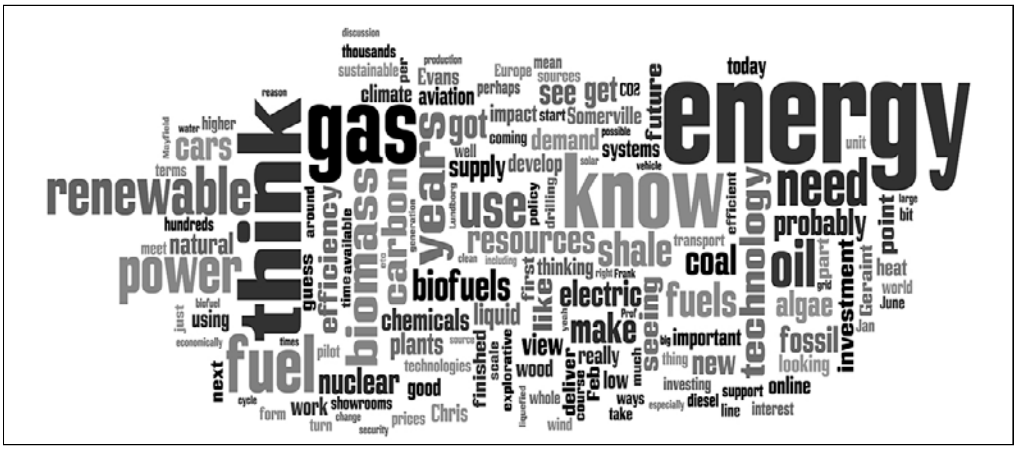


Fig. 8.9: Wordle illustration of views on “other energy resources” given by participants

The participants were asked what they thought about “the future of other energy resources” and whether this has any impact on the future of biofuels. As illustrated in figure 8.9, they provided various replies. Words such as “oil”, “nuclear”, “gas”, “coal”, “cars”, “water”, “wind”, “solar”, “fossil fuel” and “shale” are among the main frequent words that the participants mentioned in their interviews.

Some of the participants emphasized the benefits of other renewable resources. For example: *“Other renewables and increased energy efficiency is needed”* (Government sector participant), *“Wind power has taken a good proportion of investment in recent years”* (Academic sector participant), and *“All possible options should be considered especially other renewable energies like water, wind and solar power”* (Academic sector participant). Some other pointed out the importance of investment in nuclear energy, but the majority of participants believed that fossil fuels continue to dominate the world in the foreseeable future. Two participants pointed out that car technology is an indicator of this dominance: *“For at least the next 30 years, we simply do not have a replacement. A new truck, train or plane purchased* *today will need fuel from oil in 20, 30 or 40 years, there is no way around that"* (Business/private sector participant) and *"Cars last 12 to15 years, before they are thrashed. So the cars in the showrooms today are going to be on the road in 2030. If you go around all of the car showrooms you can see that, there's a few electric cars, but most cars that's going to be around in 2020 are going to petrol and diesel fuels. They are not designed to be electric powered, or very few of them are"* (Government sector participant).

It was argued by some participants that "shale gas" and "fracking technology" were real game changers and the world has now found a vast resource of "clean" and "cheap" energy: *"As far as I can see is that shale gas is going to be a game changer. If you have large volumes of a low cost fuel available which is gas, which can either be used directly in transport or converted into a liquid form. You've got a higher supply, demand can't keep up"* (Government sector participant), and *"We are seeing a cheap supply of natural gas (shale gas) which is cleaner than coal, cleaner than oil, it doesn't emit as many pollutants and it emits less CO_2 per unit energy, about two times less CO_2 per unit energy so, I think, up to 2050, we will see a shift from oil and coal towards natural gas"* (Business/private sector participant). On the other hand, the fossil fuel critics focused on environmental impacts rather than price and availability, for example: *"Bringing any fossil fuel to the surface of the earth and burning it creates a net production of CO_2 which is adding to the atmospheric levels which we know are increasing at a rate which isn't sustainable. So shale gas in a sense on the one hand it's a saviour from the point of view of energy and fuel, on the other hand it's a disaster from the point of view of yet more stuff that we are going to dig out of the earth and put into the atmosphere"* (Academic sector participant), or *"From the climate change point of view, shale gas isn't going to deliver any benefit at all. I don't think there's going to be an appetite to move the whole vehicle to compressed natural gas or liquefied natural gas which would offer some moderate carbon improvement"* (Business/private sector participant). Some other fossil fuel critics also argued that in spite of its huge resources, shale gas contribution would be limited: *"It appears it will add about 9% to our total world reserves, meaning that we will be hard pressed to produce enough by 2030 to meet world demand. By 2050 the prospects are not good that we be able to meet anything close to demand"* (Business/private sector participant). But on the other hand, some other participants strongly believed that in the future, new oil and gas resources would be found: *"They will always find new oil and cheaper ways to exploit it. In the 1960s they had oil for about, up to about 10 years ago, and then it would be finished but of course we keep finding new oil and, and it's not finished yet"* (Business/private sector participant).

8.2 Sectors' analysis

In general, there was an overall agreement among the three sectors (government, private industries and academics), on the importance of biofuel as one of the sources to meet the global energy demands. All of the participants argued that one of the main factors in shaping the future of biofuels is the price of crude oil.

8.2.1 Comparison between sectors

As discussed in Chapter 2, the three sectors were considered to provide a broad sample of experts 'opinions in different fields. The sectors were compared based on their opinion about the future of biofuels, regulations and policies and the biofuel impacts. As illustrated in Fig (8.10), Fig (8.11) and Fig (8.12), words such as "energy", "regulations", "fossil fuel", "land", "food" and "cost" were frequently repeated in all interviews, regardless of sectors. However, from their different fields, it was expected that the participants' opinions would be different. The degree to which their views differed, could indicate the variety of agreements or disagreements between the sectors.

Table 8.1 summarised the different biofuel topics, discussed by participants from different sectors, based on the frequency of the words;

Topics	Industrial/Private	Academic	Governmental
Environmental impact	Low	High	Middle
Economic impact	Middle	Middle	Middle
Social impact	Low	High	Middle
Regulations	High	Middle	Middle
Technologies	High	Middle	Middle
Future of biofuels	Middle	High	Middle
Subsidies	Middle	Low	Middle
Other resources	High	Middle	High

Table 8.1: Frequency table for the main biofuels topics, discussed by participants from different sectors

8.2.1.1 Academic sector

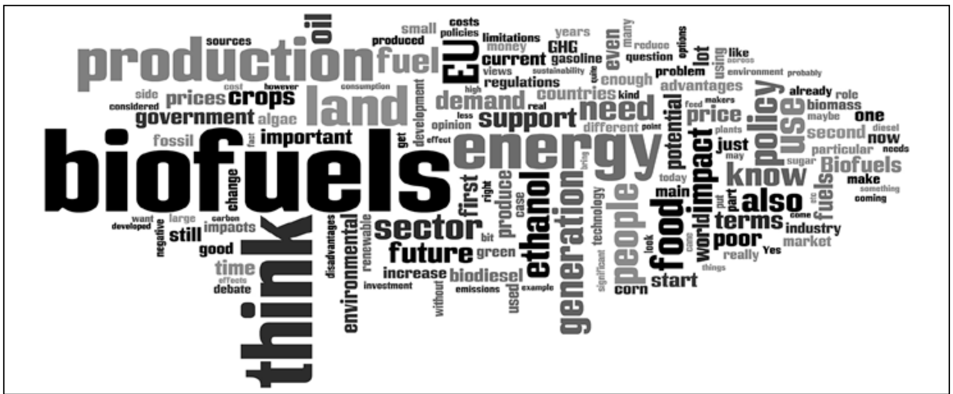


Fig. 8.10: Wordle illustration of the views of academic sector

Academics were very much engaged with the “environmental impacts” of biofuel. Fig. 8.10 clearly shows that academic participants used words such as “land”, “energy”, “GHG”, “impact”, “change”, “crops”, “environment” and “people” more often. For example: “*The positive components of biofuels are the renewable component, utilization of* *land plants and aquatic species that utilize carbon dioxide is a positive effect on the environment. There are, obviously the negative impacts that need to be considered in bringing a large biofuels industry on board."* (Academic sector participant*)*. Apart from the environmental impact, "social impact" and "the future of biofuels" were mostly discussed by academics. However, "subsidies" and "governmental support" were least discussed by academics while they were frequently discussed by the other two sectors.

8.2.1.2 Government sector

The government sector participants used words such as "renewable", "electric", "power", "government", "support", "subsidies" and "future needs" more frequently (Fig. 8.11);

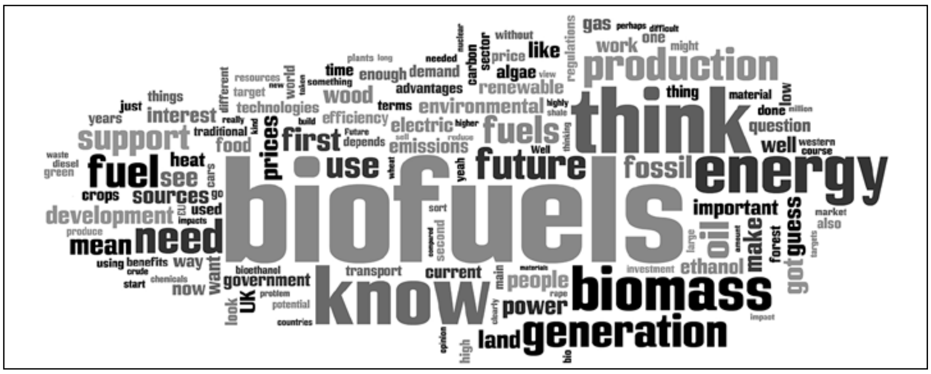


Fig. 8.11: Wordle illustration of the views of governmental sector

The government sector participants' views were more broadly towards the future alternatives for biofuels in terms of meeting the energy targets, for example one participant said: *"It's good to use biomass for fuels today because you can think about using them for chemicals and aviation fuels in the future for which you have no other option, so* *you've got to think...you need to develop the low carbon infrastructure... you've got to think about wind, wave, nuclear,...and nuclear in a big way, probably..."* (Government sector participant). As Table 8.1 suggested, the participants from the government sector seemed to be more conservative in their conclusions than the other two sectors.

8.2.1.3 Business/private sector

Fig. 8.12: Wordle illustration of the views of industrial/private sector

As illustrated in Fig. 8.12, the participants from business/private sector used words like "subsidies", "algae", "carbon tax", "future vehicles", "cost" and "cheap" more often in the interviews. They emphasized on clear, simple and stable regulations, freedom of trade and the necessity for governments not to control the biofuel markets. For example: *"The development of the biofuels business is not a governmental issue but a company- supply chain issue. Policies could be needed in for of sustainability rules, protection of investments, etc."*

(Business/private sector participant) and *"The support should be directed to improve the sustainability framework, not the biofuel production or use"* (Business/private sector participant).

Apart from the "regulations", "the technologies" and "the future of biofuels" were among the most discussed topics by this group, while the "environmental impact" and the "social impact" were among the least discussed topics. The participants from the business/private sector showed a desire for new biofuel technologies and they had faith in the future of the third generation biofuels more than the other two sectors.

Chapter Nine:
Discussion

Chapter Nine: Discussion

This chapter is dedicated to the final discussion. Firstly, the general complexities around biofuel are discussed. Next, the data collected through both literature review and the interviews, is discussed and compared thematically. Finally, the complexities around the future of biofuels in the EU/UK are discussed.

9.1 Biofuels complexities

Biofuel production and consumption are growing rapidly and in the coming years, are set to rise in order to meet the mandatory targets (Chapter 3). In the first decade of this century, the unrests in some oil producing regions, high energy prices, the uncertainties surrounding the future availability of energy resources paired with environmental concerns made biofuel issue rise to the top of most governments' policy agenda (Heinimö and Junginger, 2009). However, the complexities surrounding biofuels to date have led to controversial debates on feasibility of biofuels' production and consumption. Based on the literature reviews (chapters 3-7) and the interviews (chapter 8), the themes, which contribute to the complexities were identified as the combination of the following (in no specific order):

- Economic impacts
- Fuel vs. Food
- Environmental impacts
- Biofuel generations, current technologies
- Future advances (discoveries, technologies)
- Competition with fossil fuels
- Other Energy alternatives (solar, wind, geothermal, hydro)
- Policies, targets, trends and drivers
- The future of biofuels in the EU
- The future of biofuels in the UK

9.1.1. Economic Impacts

One of the crucial discussions in this study was the economic impact of biofuel production. The assumption within the discourse was that the impacts on economy (both positive and negative impacts) are huge, but the scale is varied from country to country. As such, this is strongly associated with the economic situations, trade regulations and development potentials. The following discussion analyses some of the factors within this assumption;

Rural development is considered as one of the major processes to benefit biofuel production (ELOBIO, 2010). However, these benefits differ for both developing and developed countries. While in the developed countries, the rural development is mainly considered a way for supporting the agriculture industry, in the developing countries rural development is seen as an important way to create employment, income and a stimulus to develop the agricultural sector. This highlights the potential benefits of biofuel production in developing countries. However, some themes emerged from the analysing of interviews, which show the risks of the economic impact of biofuels as below;

- Risk of redundancies due to use of modern technologies instead of using traditional work force

- Risk of degrading the poorer countries to the level of mere raw-materials suppliers, damaging the economy in the long term

A third, although less common, risk was also mentioned; risk of lacking or having insufficient local policies to ensure that biofuel production was sustainable and brought welfare to rural areas (Academic and government sectors' participants). These concerns are backed by the results of the literature review (Ewing and Msangi, 2009). In addition, several other negative socio-economic issues such as land use conflicts, water use conflicts, labour issues and increased income inequality (Kampman et al., 2010) can be added to this list.

In summary, the economic viability of biofuel industry in the long term depends on scientific/technical advances, and careful control of cost/benefit balance, strong government support, investment in infrastructure, legal system, rural finance and market institutions (Table 9.1);

Positive Impacts	Negative Impacts
Secure income for farmers through subsidies	Land use conflicts
Rural developments	Water use conflicts
Infrastructure/Construction; mills/biorefineries, roads etc.	Labour issue
Employment opportunities	Income inequality
Modernisation: Technology/Machinery	Vanishing of small farms
No monopolisation risk	
Enhancing trade opportunities	

Table 9.1: Economic impact assessments of biofuels

Risk management is central to biofuel production. Therefore adopting a proper assessment process prior to any large-scale biofuel production programme is recommended. In addition, although the rising demand for biofuels could be seen as a chance for poor countries to establish a new export product, it is recommended that higher demand for biofuels by the industrialized countries be combined with further value-added-production processes/industries in the developing countries, in order to keep financial benefits and technical knowledge inside the countries. It is also important for farmers in developing countries to avoid monoculture farming to minimise the risk of dependency.

Also, due to the continuous expansion of international trade in this sector, the international trade regulations will need to be re-considered to meet the new requirements. The participants from the business and academic sectors highlighted this point. Any large-scale production of biofuels would require the removal of current trade and technical barriers.

9.1.2. Fuel vs. Food

The impact of the food price shock of 2006–2008 on a number of countries across the world was huge and most of these countries were in Africa (FAO, 2011). Between 2007 and 2008, the number of the undernourished was essentially constant in Asia (an increase of 0.1%), while it increased by 8% in Africa (FAO, 2011). However, in spite of the media pressure during the food price crisis, the contribution of biofuels towards that spike was quite small. This is indeed supported by twenty participants from all three sectors, while just two participants (one from the academic and one from the business/private sector) believed that the biofuels contribution to the rising food prices was significant. Based on both literature review and interviews, it is clear that biofuels are just “one” of the factors involved in the increasing food prices. One of the most important factors, which was discussed in both interviews and published literature, is the role of crude oil price, known as Oil Cost Factor (OCF). One participant from the academic sector discussed the role of OCF in rising food prices while Sims et al. calculated that a 25% increase in crude oil price would reduce global food supply by 0.7% (Sims et al., 2010). The factors participating in food price crisis are summarised in Figure 9.1;

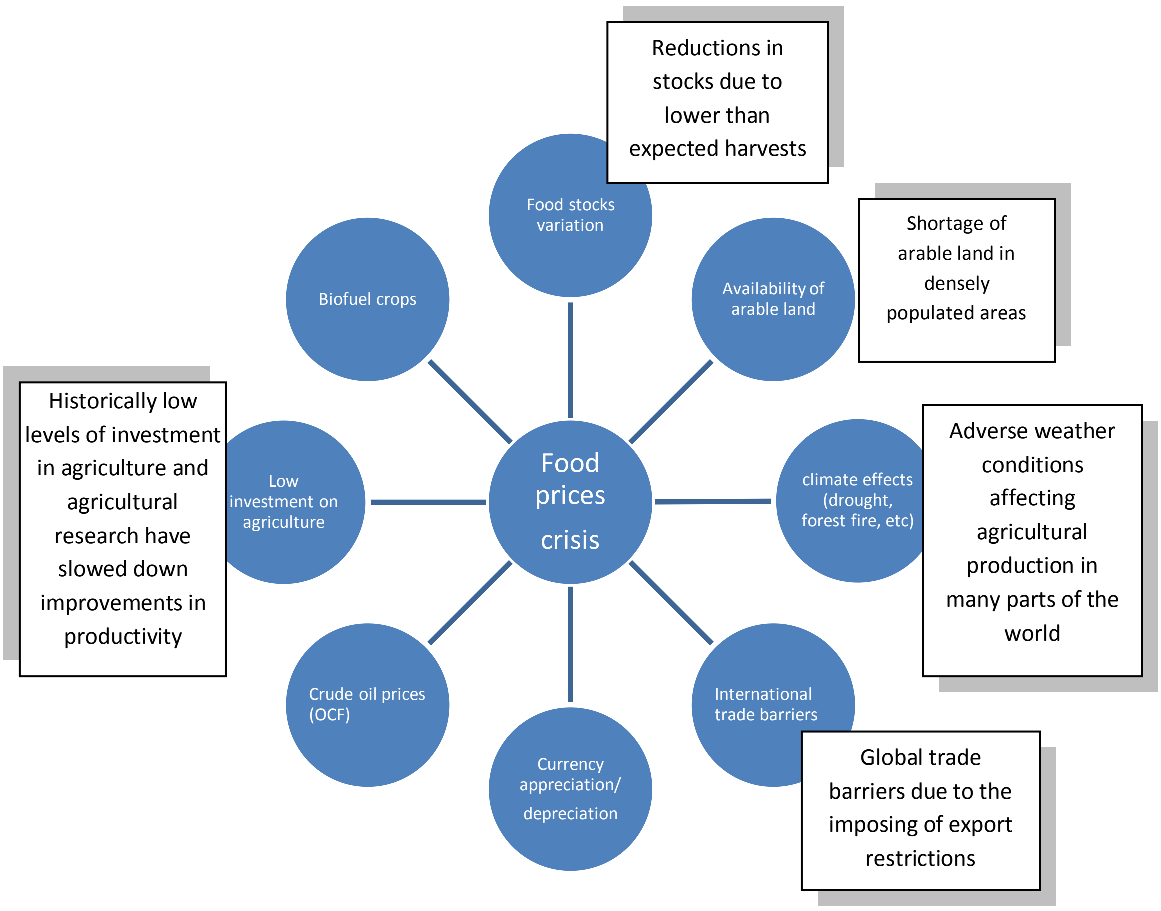


Fig. 9.1: The possible factors in rising food prices, indentified from interviews and literature review

Having an "Intensity Factor" for each of the elements in Fig. 9.1 will be useful but it is not feasible for this study due to lack of a comprehensive experimental validation for each item, and the necessity to have further studies beyond the aims of this dissertation. However, based on findings of this study, it is clear that the role of biofuel crops falls into the "low intensity factor" category. Being a low intensity factor means that the impact is minor but it must not be ignored; however, no shift in the current biofuel policy is recommended. Furthermore, the impact can be controlled easily by producing a substantial portion of biofuel crops on abandoned land (see section 9.1.3.2) that is not used directly for food production (Campbell et al., 2008).

There are several reasons to believe that food prices will go higher in the near future. As global warming increases the frequency of extreme weather events, food stock shocks will become more frequent. Food prices are also likely be driven up by population growth, natural disasters and natural resource constraints (FAO, 2011). According to the FAO, high food prices could even be a chance to catalyse long-term investment in agriculture in developing countries (FAO, 2011). Therefore, it may be argued that although in the short term, with the current/expected rate of biofuel production, it is likely that food prices are affected, as a longer perspective, lower and arguably more stable food prices are expected because of improving technical efficiency of food production in developing countries. However, it requires a systematic approach by governments in the developing countries to invest in the profits from price rises in infrastructure, which could lead to the enhanced food production.

9.1.3. Environmental impacts

Biofuel production creates a case for some environmental concerns, which were discussed thoroughly in the interviews. Typical of the participants' concerns about biofuel impacts on environment were GHG emissions, land and water requirements, sustainability and biodiversity. Table 9.2 shows a summary of the themes that emerged from analysis of interviews;

Biofuels	Environmental benefits	Environmental concerns
1st G	+Some are environment-friendly (depending on crop, technology and location) +70% GHG emission reduction by sugarcane ethanol	-Some have negative impact on GHG -High water and fertilizer requirements -biodiversity risk -Most crops not sustainable -Use arable land -Direct and indirect land use change
2nd G	+Environmental-friendly +No use of arable land +Good GHG emission reduction +Mostly sustainable +No risk to biodiversity	-High water requirement
3rd G	+Absorbs CO_2 +Can use wastewater +No use of arable land	-There is no evidence in industrial scale - GHG reduction is marginal in pilot scale

Table 9.2: Environmental impacts of biofuels generations as discussed by participants

As it can be seen in Table 9.2, the majority of participants from all sectors showed interest in the commercialisation of the second generation biofuels, as almost there is no environmental concerns attached to it. In just the same way as the second generation, the potential benefits of the third generation biofuels were discussed in the interviews, but due to the lack of evidence at the industrial scale, it is still too early to make conclusions. Whilst the participants argued differently on the scale of the environmental impacts, all agreed that the impacts were generation-specific and associated with the type of biofuels.

9.1.3.1. Greenhouse gas emissions

It has been argued by participants that one of the main purposes of moving toward biofuel is based on trying to reduce GHG emission. In this context, the first generation biofuel has demonstrated a mixed impact;

- It is reported by Havlic et al. and many others that using first generation biofuels led to a significant increase in net carbon emissions (Havlík et al., 2011)
- Delucchi (2010) stated that the first generation biofuels will not offer meaningful reductions in CO_2 emissions
- Ten participants from all three sectors stated that the first generation biofuels show some benefits in terms of GHG emissions reduction and energy balances and this claim is backed by literature reviews (Al-Riffai et al., 2010).

From both literature review and the interviews, it may be concluded that first generation biofuels may help reduce greenhouse gas emissions but it depends crucially on the type of feedstock and the location. While corn ethanol from the US has a relatively minor improvement of less than 20% in GHG emission per unit of energy produced (Bausch, 2011), sugarcane ethanol from Brazil has a very significant reduction in GHG-from 65% (Somerville, 2011) to 71% (Leal, 2011) compared to petrol. For the wheat ethanol this value is reported in the range of 32% to 69% depending on the production path (Leal, 2011). This also depends on possible GHG emissions that occur due to land use conversion or indirect land use change, which will be improved by good agricultural practice, technological developments and investments in infrastructure. Many participants argued in favour of a desire for developing second generation biofuels to reduce greenhouse gas emissions. There is clear evidence that second generation technologies improve the greenhouse gas balance of biofuel production significantly (FAO, 2011). A range from 27% (Havlík et al., 2011) to 65% (Somerville, 2011) reduction in GHG emission are reported based on the production path. However, currently, these technologies are not the most cost effective ways of achieving this aim (FAO, 2011). Regarding the third generation biofuels, two participants said they expect a drastic reduction in GHG emissions by using algae, but this expectation has not been supported by any evidence to date. There are currently big challenges associated with the development of infrastructure and policies for the third generation biofuels and with our current knowledge, it is difficult to mathematically assess, reliably, the future impact of algal biofuels on GHGs as it creates a mixture of positive and negative effects. Figure 9.2 demonstrates a summary of biofuel generations' impacts on GHG emissions:

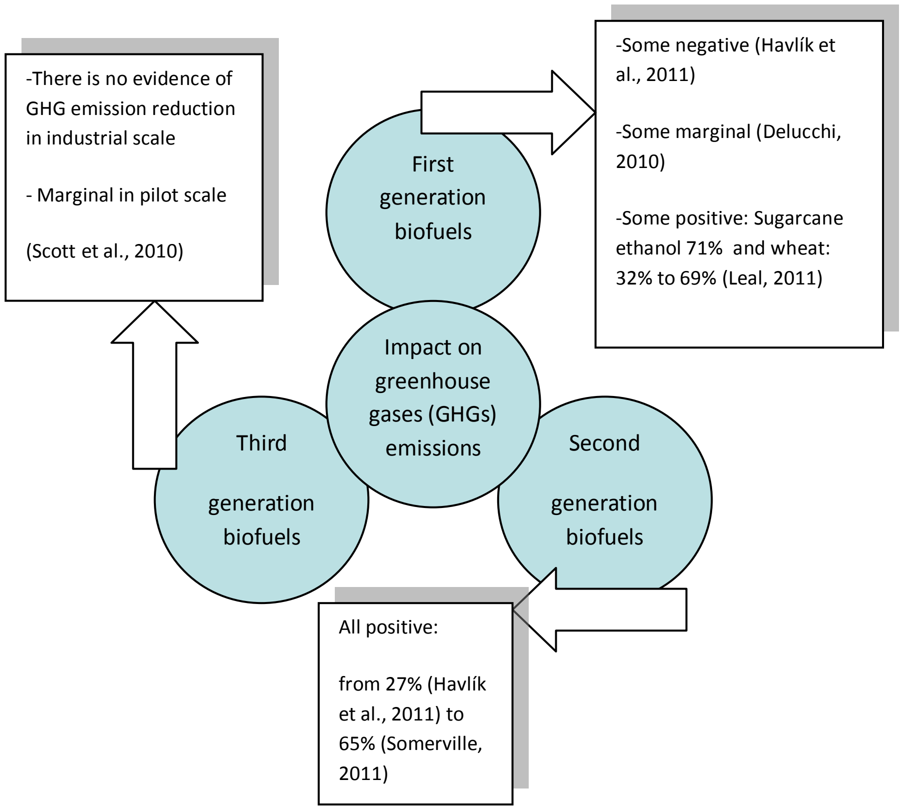


Fig 9.2: Summary of biofuel generations' impacts on GHG emissions, determined by data from analysis of the interviews

As it can be seen in Table 9.2 and Fig 9.2, both literature review and interviews support the development of second generation biofuels as the best option to tackle the GHG emissions concerns.

9.1.3.2 Direct and indirect land-use change

As chapter 6 argues, analysing the potential impact of GHG emission reduction via biofuels development is impossible without assessing LUC and ILUC. Also, the role of "the amount of arable land" in this broad imperative subject was argued by all participants. One of the biggest challenges for biofuel production is finding suitable land to grow the crops. When querying whether there is enough land for biofuel production, most participants argued that in principle there is enough land for biofuel production across the world and production of second and third generation biofuels in the future could also lessen the arable land requirements. This has been backed by literature review. Researchers at Stanford University and the Carnegie Institution for Science identified between 1 and 1.2 billion acres of land worldwide that has been farmed in the past and then abandoned for various reasons ranging from economic factors (e.g. overproduction of food) to destructive farming practices that destroyed soil fertility (Campbell et al., 2008). This is about 25% of the total amount of the currently usable cropland across the world. If this land is used to grow first generation biofuel crops, it will help ease the energy crunch without major negative impact on GHG emissions or food prices. Therefore, the land appears to be available but "the global distribution" is an important factor. Densely populated countries like the UK or Japan do not have enough suitable land to produce significant proportions of their energy needs from biomass. Figure 9.3 summarises the themes related to land across the world that emerged from both literature review and the interviews;

Figure 9.3: The themes related to land across the world, emerged from both literature review and the interviews

Developing second and third generation technologies in the future will theoretically lessen the pressure on arable land. However, participant from all three sectors argued that still for the foreseeable future, first generation biofuels will continue to dominate the biofuel market. Also academic participants argued that a global agricultural governance is essential to coordinate the policies in terms of easing the pressure on deforestation. The expansion of arable land, by using the previously farmed areas is one solution. This potential exists mainly in Brazil, China, India, the southern republics of the former Soviet Union, Australia and the United States (Campbell et al., 2008). To reach this point, an enforcement of land use restrictions, especially in the developing world, would provide major environmental benefits.

9.1.3.3 Other environmental impacts

The environmental impact of biofuel production was discussed earlier in this thesis, considering four fields: water resources, soil erosion, biodiversity and sustainability. There is clear evidence that first generation biofuel production puts significant pressure on water resources, particularly in the dry areas. The data from the interviews showed an awareness of the variability of water requirement in biofuel production, depending on the type of feedstock and geographic/climatic conditions. There was, however, no discussion beyond this, in the interviews, about the amount of water footprint (the amount of water utilized in the production procedure) of first generation biofuels or the water requirement of the second and the third generations. Most participants focussed on the pollution caused by increasing use of nitrogen fertilizers and direct irrigation of biofuel crops, which depends on the type of feedstock as well as geographic and climatic conditions. Based on literature reviews, raw crop cultivation is the most water-intensive of biofuel production procedures and the water requirements at the refinery stages are much less (Fig 9.4) (Dominguez-Faus et al., 2009);

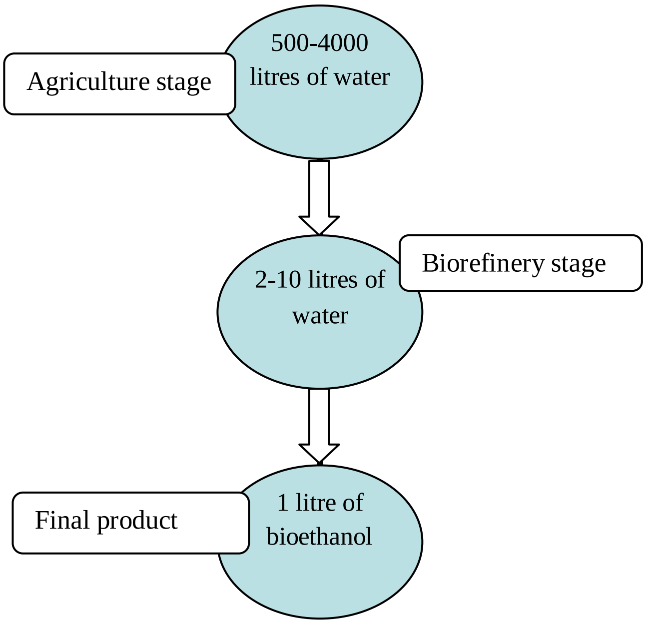


Fig. 9.4: The average water requirement for producing one litre of bioethanol from corn

Also the water requirements of biofuel production procedure are more consumptive compared to the fossil fuels (Delucchi, 2010). For example, while for producing one Megawatt hour (10^6 wh) energy from conventional crude oil refineries, maximum 150 litres of water (lw) are required, 681 lw are needed for producing the same amount of energy from unconventional oil (Oil shale surface retort) and up to 27.9 million lw for sugarcane ethanol (Dominguez-Faus et al., 2009). This means that for producing the same amount of energy, sugarcane ethanol requires more than 186,000 times water compared to the crude oil. Russo and colleagues (2012) argued that soybean feedstock has the highest water footprints (Russo et al., 2012), while based on the results of a recent study in Thailand, although soybean feedstock requires sizable irrigation water (blue water) (1648 m^3/ton), the total water footprint (WF) of soybean is much less than other crops such as sugarcane and Cassava (Table 9.3) (Kaenchan and Gheewala, 2013);

Crops	Yield ton/ha	Blue WF* M^3/ton	Green WF M^3/ton	Blue+Green WF/ha (M^3/ha)
Soybean	1.6	1648	227	3000
Maize	4.2	778	86	3670
Cassava	15.9-23.6	42-232	192-413	7235-9652
Sugarcane	59.1-72.8	81-128	67-148	11630-16312
Oil Palm	5.5-16	421-1829	474-1071	12942-17484

Table 9.3: Water footprint of some biofuel crops, adapted from (Kaenchan and Gheewala, 2013)
*WF=Water footprint: The amount of water utilized in the production procedure

Another crucial conclusion from Table 9.3 is that even if all considered crops need irrigation water, for most crops, the most water used is from rainwater. Therefore, this thesis recommends two simple solutions to minimize the water impacts of biofuels:

- To specify the crops which produce higher biofuel energy with lower needs for water in different regions and encourage farmers to cultivate these crops
- The biofuel feedstocks need to be grown in areas with ample rainfall or groundwater. Suggested areas are the USA, China and Brazil which will contribute the most (more than half) of the global biofuel water footprint in 2030.

It is worth noting that by 2030, the global annual biofuel water footprint will increase more than ten times compared to the 2005 level (Gerbens-Leenes et al., 2012). Therefore, a rapid decision is needed in terms of supervising global biofuel production and its water requirements. This could be part of the tasks of a new international biofuel governing body (recommended in Chapter 10).

The first generation biofuels are not the only water-intensive biofuels. The results of a study show that second generation biofuels increase water consumption by some 4% compared to the ‘‘No-biofuels’’ scenario. This is mainly due to the fact that lower yields from growing trees require more land, which needs to be compensated by higher agricultural yields through increased irrigation (Havlík et al., 2011). Also large-scale terrestrial algae cultivation for biofuel production requires more water-compared to the first and the second generation biofuels- to make up for evaporative losses (especially in open ponds). Again, there is no suggestion made by participants in this regard, but one recommendation based on literature review is to integrate algal cultivation and wastewater treatment facilities (Cho et al., 2013; Letite et al., 2013). This will result in considerable water savings. However, it should be noted that different wastewater streams vary in their composition, which should be considered to minimise pollution. In terms of marine algae cultivation, one participant from the academic sector argued that based on the current knowledge, no major impact on water resources is expected.

Cultivation of biofuel crops also exacerbates soil erosion across the world. In just the same way that biofuel impact on water was discussed, the participants argued that soil erosion could lessen the nutrients and the organic matter of the soil. Additional fertilisers may be required to balance any loss, and using them will result in extra environmental impacts (Delucchi, 2010). However, three academic sector participants argued that soil erosion is mainly related to the production of the first generation of biofuels, and it can be avoided by switching to the second and definitely the third generation biofuels. The results from published data recommended the use of perennial crops and their residues grown on native and marginal lands (Solomon, 2010).

With respect to impact on biodiversity, the participants argued that appropriate policy measures are required to minimise possible negative effects on biodiversity, as biofuels will only be valuable if they are cultivated under biodiversity-friendly practices. The literature review results reveal that the dramatic loss of biodiversity is associated with habitat change, invasive alien species, overexploitation and pollution (ELOBIO, 2010). However, these impacts vary across feedstocks and locations and directly depend on cultivation (FAO, 2011) which could be avoided if properly monitored and managed.

In terms of biofuel impacts on sustainability, there is a clear uncertainty in both published literature and the interviews. While all participants agreed that sustainability is obviously a crucial concern, there is no unanimous definition for sustainability. The same applies to the results of published literatures to date. Historically, the concept of sustainability of biofuels has been focused on three subjects (social, environmental and economic) and a balance of the three is recommended by some participants. In recent years, sustainability is developed to include other factors, such as policy and institutions (Diaz-Chavez, 2011). Based on this interpretation, schematic criteria for sustainable biofuels are shown in Fig. 9.5:

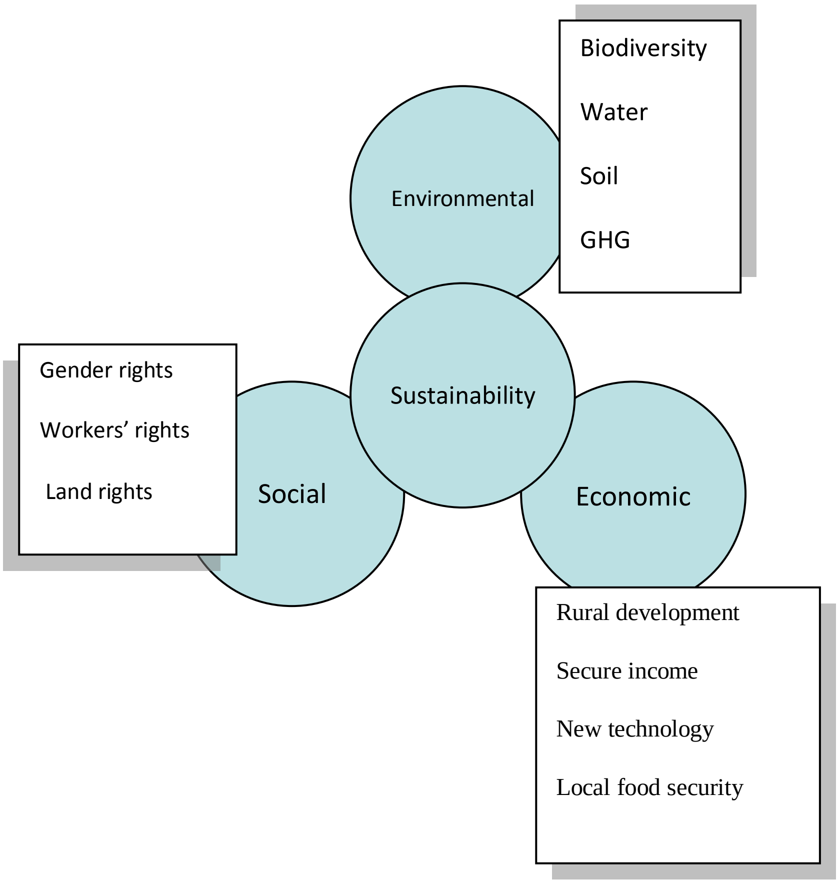


Fig. 9.5: Schematic criteria for sustainable biofuels

Based on all aspects of Fig. 9.5, it was argued by the participants that first generation biofuels are unsustainable and among the current biofuels, only the cellulosic bioethanol has the potential to be produced and consumed on a sustainable basis. This outcome is supported by the literature review results (Solomon, 2010). Therefore, the investment on cellulosic ethanol was recommended by the participants in order to answer sustainability concerns.

However, the data emerged from both the interviews and published data showed that there have been some doubts regarding the sustainability criteria. One academic sector participant argued that it is not clear how viable these certification criteria are and Pacini et el. (2013) underlined that introducing these regulations has brought new costs to the biofuels industry and it can be problematic for small producers in some regions. Therefore, this thesis recommends an aid scheme for small producers in developing countries, to provide ample technical support and efficient private investment in order to meet sustainability requirements.

9.1.4. Biofuel generations and available technologies

One of the most important complexities surrounding biofuels to date is investing on the right type of biofuel technology. This is strongly associated with assessment of different biofuel generations considering environmental, economical and energy security concerns. The following analyses some of the common concerns within these complexities;

The participants discussed the advantages and disadvantages of various biofuel generations and mainly focussed on three perspectives:

- Cost: The production cost (cultivation, harvesting, transport, refinery and marketing) compared to fossil fuel cost
- Technology: Availability of relevant technologies for a large scale production in different regions/areas and practicality of production methods
- Impacts: Including impact on the environment (air, water, soil, GHG emissions, biodiversity and sustainability), impact on the economy and food production

Based on both literature review and interview results, the overall assessment of limitations and advantages of different generations of biofuels is summarised in Fig. 9.6:

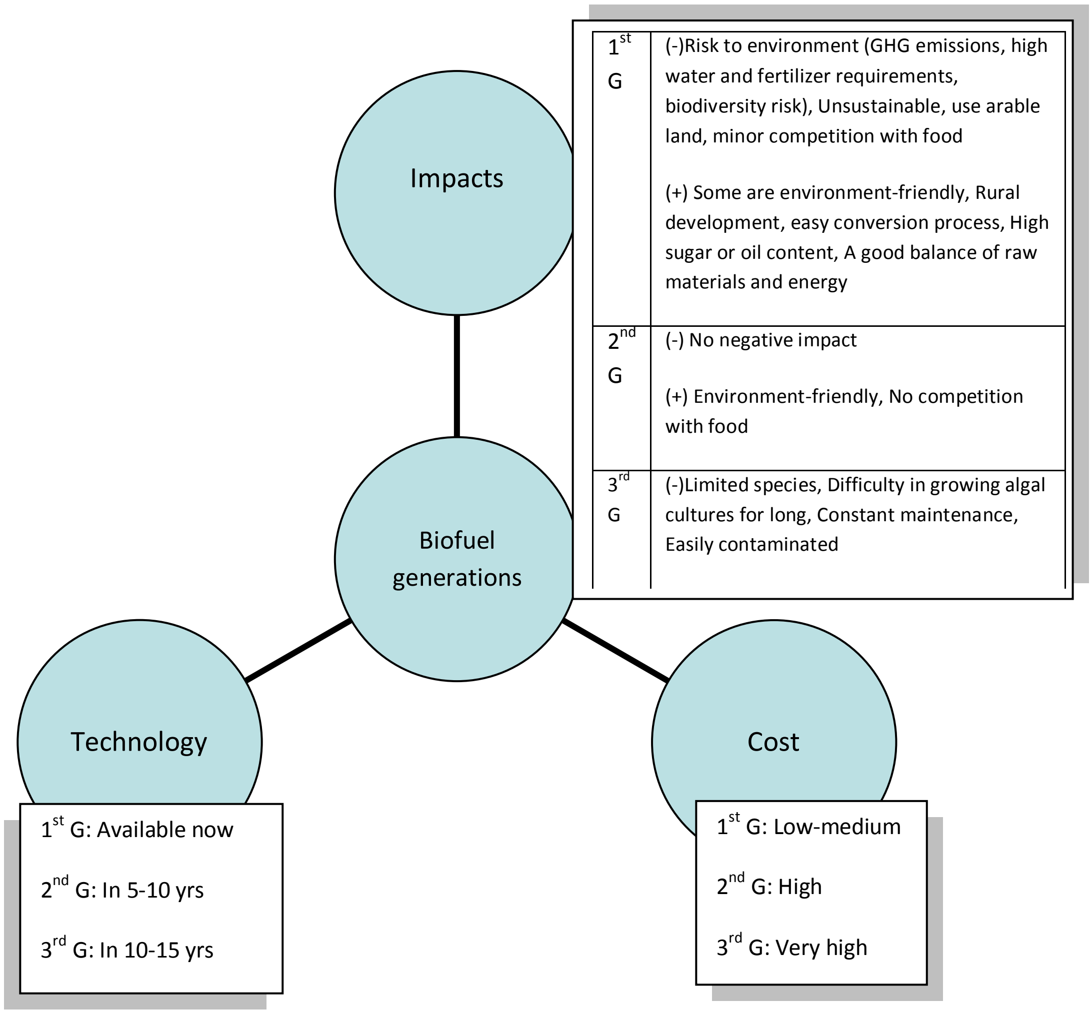


Fig. 9.6: Comparison of different generations of biofuels, based on the data emerged from both the interviews and literature review

Fig. 9.6 shows clearly that while first generation biofuels have some negative impacts, second generation biofuels have no major impacts on the environment, economy or food. However, the cost and technology barriers are the biggest concerns about the second generation biofuels.

It was argued by the participants that the first generation biofuels are:

- Well implemented around the world
- Already proved to be effective
- Heavily invested
- Needed to be available for years to come to fulfil the requirements

This means that, in spite of their negative impacts, the first generation biofuels will be a major part of the total biofuel production until advanced generations become totally commercial and viable. However, this thesis recommends:

- A "phase out" plan to reduce the share of first generation biofuels in the total biofuel market by 2030, and
- A targeted research activity to reduce the negative impacts of first generation biofuels

The results of both the literature review and the interviews suggest that in the period between 2016 to 2022, the cost and technology barriers of the second generation biofuels will be overcome and it could become a much more significant player in a global biofuels market characterised by a balance between the first and the second generation technologies (Sims et al., 2010). It is now estimated that by 2022, in the USA, the second generation biofuel's share in the market will be the same as the first generation's (Klein, 2012). This thesis recommends more research on both improving and diversifying the second generation technologies, in order to reduce cost and also produce by-products to turn the biofuel industry into an even more attractive one for private investors.

Whilst all participants argued the importance of both first and second generation biofuels for the decade ahead, none believed that third generation biofuels could play a major role in less than 10 years. Third generation biofuels are attracting notable interest, as they do not compete with the food crop plants and can be more environmentally sustainable. Many participants argued a desire for the third generation biofuels, but specifically noted that more research is needed due to uncertainties as to cultivation strategies, the lack of effective harvesting methodologies, and the need for a low cost oil extraction technology adapted to algal biomass. Table 9.4 summarises the participants' arguments regarding the future prospect of biofuel generations;

Biofuels	Future prospect	Benefits	Problems
1st G	-Currently available, -Will be used for at least another 15-20 years -Mainly replaced by the second generation by 2030s	+Some are environment-friendly +Economical, low cost +High sugar/oil content +Rural development +Accessible technology +Net Energy balance + No monopoly +Easy conversion process	-Many negative environmental impacts -Limited feedstock -Competition with food -Blended partly with conventional fuel
2nd G	-Currently not available on a commercial scale -Will be commercialised in 5-10 years -Main biofuel by 2030s	+Environmental-friendly +No competition with food	-Currently expensive -Advance technology needed - Complicated conversion process
3rd G	Currently not available on a commercial scale -Will be commercialised in 10-20 years	+Fast growing +No competition with food +Can produce 30–100 times more energy per hectare compared to terrestrial crops	- Very expensive -Difficult to harvest -Easily contaminated -Difficulty in growing algal cultures for long -Need constant maintenance -Advance technology needed -Limited species

Table 9.4: Future prospects of biofuels generations as discussed by the participants

In general, it is projected that biofuel production will continue to rise for the foreseeable future while first generation biofuels accounting for much of this increase by the 2020s. It is forecasted that the global ethanol production will double between 2007-2017 reaching 125 billion litres (Slade and Bauen, 2013). It is also projected that second generation biofuels will be commercialised between 2016-2018 and by 2022, they will contribute to more than half of the US biofuel production (Klein, 2012). And for the third generation biofuels, commercialisation needs another 10-15 years as dramatic reductions in the capital cost would be needed to approach the level required to service the biofuels market (Slade and Bauen, 2013).

9.1.5 Future advances (discoveries and technologies)

As seen in Sections 5.3.4 and 5.4, there are emerging technologies which, should they be successful, would lead to alternative ways of biofuel production. These novel technologies including system biology and synthetic biology promise future applications that could be utilised for biofuel production and be categorised under "Fourth Generation Biofuels". These technologies could help in overcoming limitations of current biofuel technologies. The results of the literature review show that although many studies have been carried out since 20 years ago, there is still much uncertainty surrounding these novel approaches. In the interviews also, only one participant argued that the synthetic biology could lead to a new era in biofuel production. Although the first steps have been taken, significant progress needs to be made in this regard. Currently the technology is complicated, costly and not tested at the commercial level. However, these challenges may be overcome in some near future by a scientific breakthrough. This thesis recommends further studies in this promising field, both in developing the technology and solving the ethical and safety complexities, which may be an issue in the future in regards to the engineering/redesign of microorganisms. Clear regulations need to be established and globally agreed regulations need to be prepared and put forward in order to unify the rules.

9.1.6 Competition with fossil fuels

Fossil fuel price is a very important factor contributing to the future viability of biofuels. As long as oil prices are relatively low, biofuel sector needs a strong government support to compete with fossil fuels. From the review of published literatures and assessment of the interviews, this thesis has tried to find out how strong this link is, what the actual production costs for fossil fuel/biofuels are and what the competitive price for biofuel should be. Unsurprisingly, all the participants agreed that currently used biofuels are not competitive with petroleum, and that the production cost remains the main challenge for, particularly, second and third generation biofuels. Almost all participants underlined fossil fuel as the dominant fuel for decades ahead due to the price advantage and huge available resources. Fig. 9.7 shows the comparison of the average price of different fuels, based on the crude oil price of US$100 per barrel:

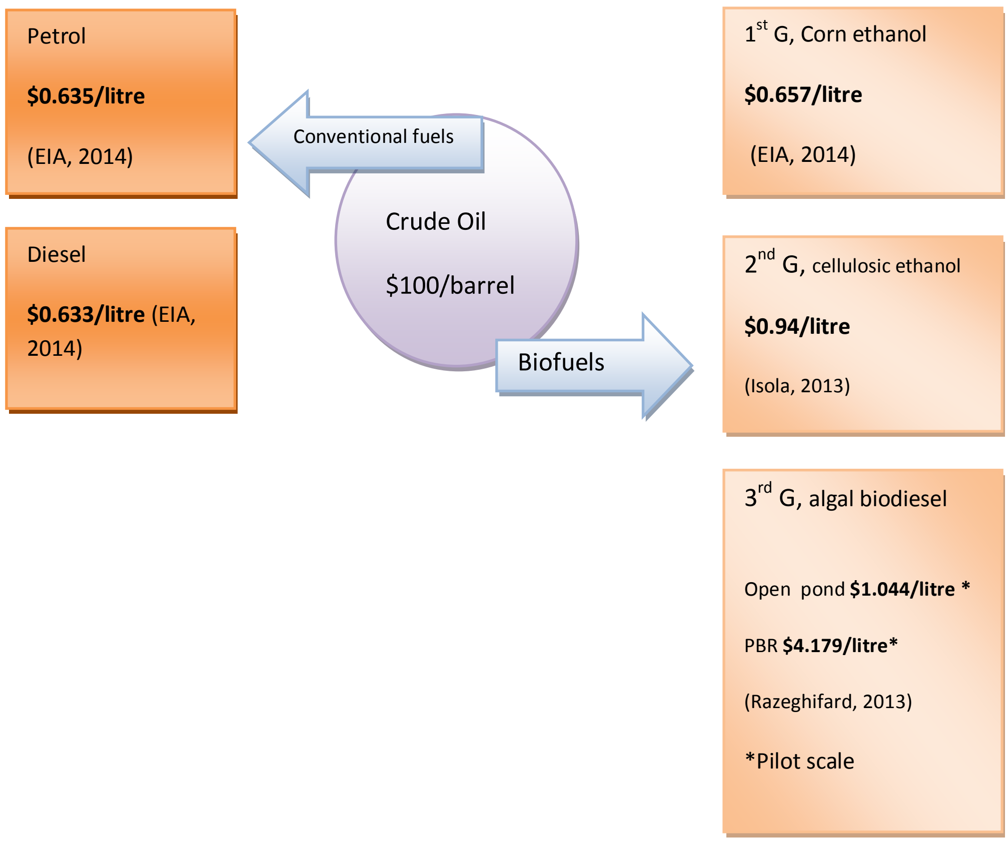


Fig. 9.7: The average price of different fuels, based on the crude oil price of US$100 per barrel (*Pilot scale production cost of about 0.6 tons of microalgae biodiesel (harvested every 12 days) for the first year of operation)

Fig 9.7 shows clearly that while the first generation biofuels are now almost comparable with crude oil, the second generation biofuels are relatively close and the third generation biofuels are very far in terms of commercialisation. However, the next decade will probably see the successful demonstration of algal biofuel production on the pilot scale and then it will be possible to answer many questions with regard to actual large-scale production costs, contamination, maintenance and water requirements. This assumption is based on the crude oil price of US$ 100 per barrel and any drastic change in the price of crude oil in the future will change this equation. So estimating the future crude oil price would be an important factor to forecast the future of biofuels. In January 2014, the World Bank released its Commodity Forecast, which predicts that world crude oil price will decrease to US$ 97/barrel by 2023 (compared to US$ 104.1/barrel in 2013). Also the same decrease is predicted for the price of European natural gas; US$9.4/mmbtu compared to US$11.8/mmbtu in 2013 (WorldBank, 2014), Table 9.5:

Commodity	Unit	2013	2015	2017	2019	2021	2023
Crude oil (average)	$/bbl*	104.1	99.8	98.2	97.6	97.3	97.0
Natural gas, Europe (average)	$/mmbtu**	11.8	11.0	10.6	10.2	9.8	9.4

Table 9.5: World Bank commodities price forecast in nominal U.S. dollar, adapted from (WorldBank, 2014)
*bbl: oil barrel (159 liters)

** mmbtu: million British Thermal Unit (1million BTU = 1.054615 GJ (gigajoule)

So based on the World Bank forecast, in the next decade, the price of both crude oil and natural gas will decrease and this will not be helpful for the development of the biofuel industry. But the biofuel industry will continue to develop by 2022 in order to meet the already set targets. A useful way to consider biofuel future policy is to organise them around three possible scenarios based on the crude oil price:

- Scenario I: If the contribution of relatively cheap shale gas (Chapter 7) continues, in the future, the price of crude oil will continue to decrease/stay under US$ 100 per barrel and as a result, the world would be unsuccessful in commercialising new biofuel technologies at least in the near future. In this case, it would be a legitimate reason for completely backing away from investing in biofuels. This scenario was discussed by two participants, and as a result, a re-focusing on other climate mitigation methods is forecasted beyond 2030.
- Scenario II: Although in the next decade, the price of fossil fuels is forecasted to be less than US$ 100 per barrel, the global supply of fossil fuels will continue to be tight and beyond 2030, the price of crude oil will go drastically above US$100 per barrel. The difficulty of extracting oil from the new fields, ageing of current supergiant fields, political instability in some crude oil exporting countries and increasing market requirements are some facts that support this assumption. According to a study, increasing oil prices to US$186/barrel will result in a 77% increase in the biofuel production compared to the 2009 level (Timilsina et al., 2011). In this scenario, increasing crude oil price is interpreted as increasing demand for biofuels in the future and a robust biofuel development and tighter mandatory policies for biofuel blending is forecasted.
- Scenario III: In this scenario, in spite of huge demand, the price of crude oil will not go too high and will stay almost the same as the current price (around US$100 per barrel). This is due to exploitation of very large unconventional oil and gas (shale) resources, and access to new conventional oil fields (Arctic and offshore fields). In this scenario, the current level of investment on biofuels technology will continue and biofuels will be seen as one of the alternatives to replace fossil fuel in the long term and at the same time, the investment on other renewable energy resources such as wind, solar and geothermal will continue. The majority of participants supported this scenario.

This thesis suggests that the first scenario is unlikely, but either the second or the third scenario could happen, depending on the overall circumstances in the next decade. The reason for ruling out the first scenario is, there have been already heavy investments on biofuels production across the world, biofuel trades are profitable for big companies and many targets are set at the national and international levels. It is not feasible for governments around the world to stay back from the already established regulations, policies and targets in the short term (by 2030).

Both scenarios 2 and 3 will result in developing biofuel technologies, although at the different scales. However, there are two more factors, which need to be addressed. One is the biofuel mandatory targets that directly affect the capability of biofuel industry in competing with fossil fuels (this will be discussed in section 9.1.8) and the other is the hidden costs of fossil fuels, which has been discussed in the interviews and backed by literature review. The hidden cost of fossil fuels refers to the additional costs in producing fossil fuels, which are not directly calculated and therefore the “actual” cost of petrol or diesel is much higher than the price at the pump stations. For example, in 2005, for the US alone, the extra cost of fossil fuels from external effects such as impacts on the respiratory system were estimated at US$ 120 billion (Leite et al., 2013). The main part of this is increased human mortality because of air pollution caused by burning fossil fuels. To this, the costs of climate change damages, due to fossil fuel use, must be added which is estimated to be between US$49 to 171 billion per annum (UNFCCC, 2007). These figures would drastically increase the real production cost of crude oil and as a result, the biofuel industry has a better chance to compete with fossil fuels.

9.1.7 Other energy alternatives

The development of other energy sources was underlined by the participants as one of the most important tasks that governments should follow globally. In the EU, it is estimated that more than a third of the transport energy demand by 2020 will be supplied by other alternatives to biofuels (Leal, 2011). But the risk is that with the predicted biofuel expansion, some competition would appear between different bioenergy sectors for biomass resources (Schippers et al., 2011). Certainly, investing in other renewable energy resources, such as wind, solar, geothermal and hydro energy, would affect the development of biofuels technologies. Therefore, this thesis suggests avoiding picking a single “winner” technology and investing in all clean and renewable technologies.

The future prospect for other energy sources is strong as literature review suggests. In 2011, the contribution of renewable energy sources (solar, wind, geothermal, biofuels) to the world energy production was estimated to be less than 20%, where biofuel production itself had less than 1% of the energy share (GEA, 2012). However, in the future, these figures are likely to be changed dramatically and by 2100, the share of renewable energy is expected to increase by up to 80% (with solar and biomass as the main factors).

9.1.8 Policies, targets, trends and drivers

Another crucial discussion in the interviews was the global policies, regulations and targets and the drivers behind the biofuel production across the world. Mandatory blending targets, tax exemptions and subsidies are the main elements globally adopted by governments to boost production and consumption of biofuels. Although none of the participants fully supported the global regulations, most agreed in principle that regulations work.

The key drivers for governmental involvement in the biofuel industry vary from country to country. While energy security, rural/technological developments and economic reasons are among the main drivers for investing in biofuel industry globally, environmental concerns are seen as main drivers for EU countries only. This is reflected in the EU legislation, which is being implemented to require significant reductions in GHG emissions. Table 9.6 compares the biofuel penetration targets (the share of biofuels in total liquid fuel consumption) in three EU countries: Germany, France and the UK, to three non-EU leading biofuel producer countries in the world:

Country	Biofuel penetration target in 2020 (%)
United States	4.1
France	10.0
Germany	10.0
UK	10.0
China	3.7
Brazil	9.5

Table 9.6: Comparison of biofuel penetration targets by 2020, in EU and non EU countries, adapted from (Timilsina et al., 2011)

It was argued by many participants that the EU targets are ambitious and unrealistic. This is based on the fact that biofuel penetration is so limited in the UK. The biofuel penetration depends on the renewal of car fleet, available infrastructure and country's potential for adapting transport industry. The biofuel penetration is also very much related to the crude oil price. The result of a published study by Timilsina and colleagues (2011) offered some interesting observations; in the United States, for example, biofuel penetration target for 2020, is set to be 4.1%. A crude oil price of US$83.1/barrel would be sufficient to meet this target. As this oil price prediction is reasonable by 2020, it means that the announced target in the

USA is realistic. Some other countries such as Brazil, Malaysia and India would experience a significant increase in the penetration of biofuels if oil price increase. But the UK's potential for increasing biofuel penetration is limited. Timilsina and colleagues reported that in the UK, biofuel penetration target for 2020, is set to be 10%. A crude oil price of US$578.2/barrel would be needed to meet 10% biofuel penetration target by 2020 (Timilsina et al., 2011) (Fig. 9.8):

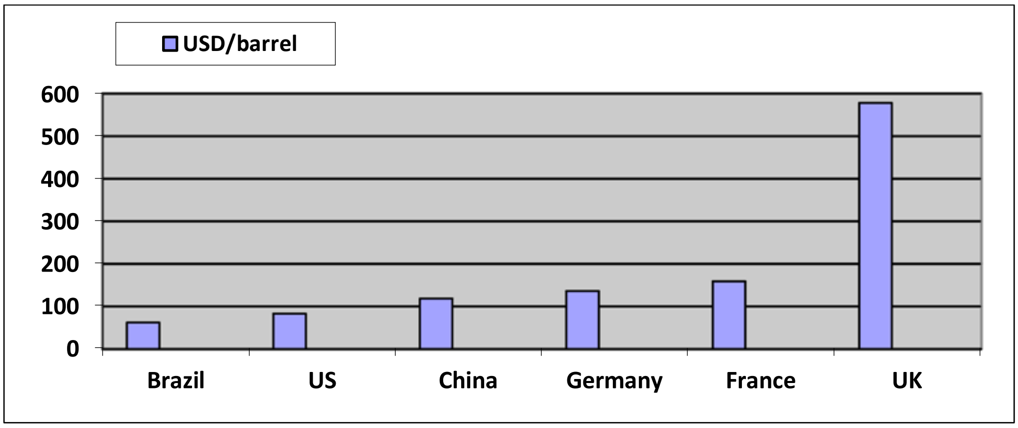


Fig. 9.8: The amount of oil price increase required to meet the biofuel penetration targets by 2020, based on the data from (Timilsina et al., 2011)

This thesis suggests developing a roadmap in the UK, for increasing biofuel penetration in an effective way. This roadmap needs to be realistic, based on national (not EU) characteristic and agreed by a wide range of UK stakeholders.

In spite of the clarity of the drivers, due to the high production cost, the biofuels industry is not quite conducive to attract investments yet. To overcome this obstacle, subsidies and tax exemptions have proven to be the most effective tools used by governments to boost biofuel production. However, "how long this support should last" was the subject of a crucial discussion in the interviews.

It is argued by the participants that at present, Brazil is the only country with a credible and profitable biofuels production programme, in which ethanol is able to compete with fossil fuels in a free market. But Brazil's success does not mean that the biofuel industry is currently profitable elsewhere. Brazil's success is the result of several elements such as availability of low cost sugarcane and several years of governmental support in the past (Sorda et al., 2010). It has favourable climate conditions and exceptional availability of land and water for the production of biofuels (Escobar et al., 2009). Considering these points, the participants argued that without governments' support, biofuel production would never survive in other parts of the world. It is concluded that until biofuels become competitive with fossil fuels, various types of government support is needed. Fig 9.9 shows the variety of government supports for the biofuel industry:

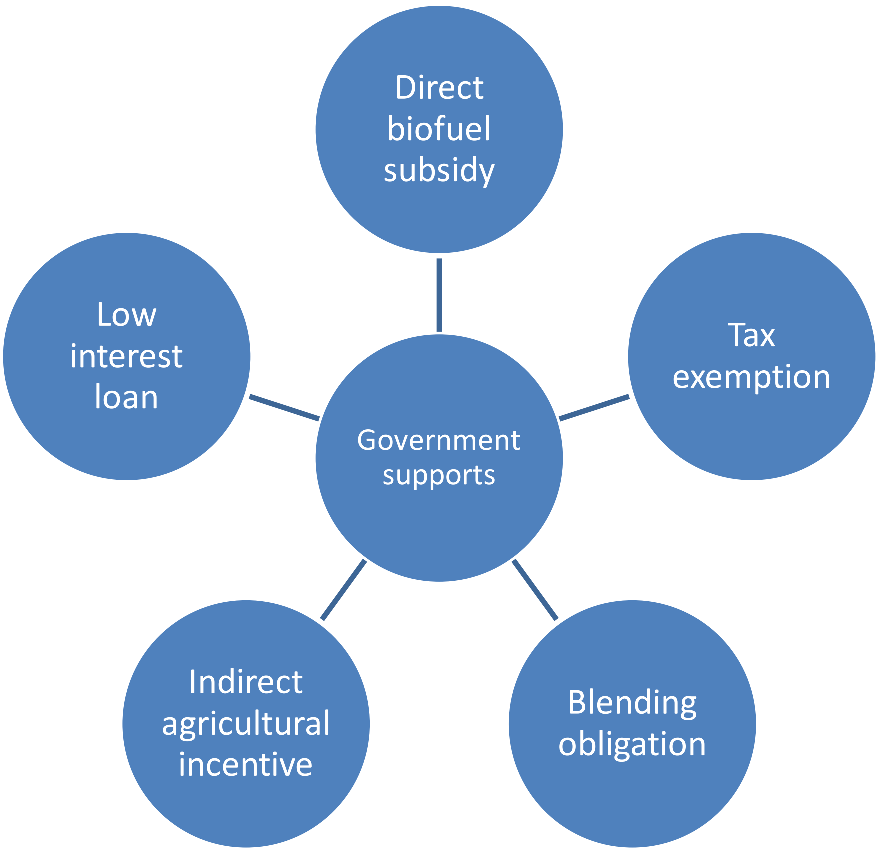


Fig 9.9: Government supports for biofuel industry across the world

However, the majority of the participants argued that these supports should be clearly related to the overall aims and targets and need to be gradually reduced to create a “fair playing field" for all energy sources. Among these support methods, the direct subsidies are gradually being abolished, as it happened in Brazil and the US, and the indirect agricultural incentives and tax exemptions have been notably reduced over the past decade. Therefore, the government support literally translates into a biofuel-blending obligation for fuel suppliers, which is currently on many countries’ top priority agenda. However, in the longer term, this needs to be abolished, as the biofuel industry needs to create self-credibility and compete with other sources in a free market.

9.1.9 Complexities around the future of biofuels in the EU

To meet the targets set by the EU legislation, several complexities have to be dealt with by the biofuel industry in the EU:

- Availability of biofuels: The EU countries are unable to produce the valume of biofuels needed. So in order to achieve the biofuel 2020 targets, the EU needs to import biofuels from abroad. This needs to be addressed by improving trade regulations and creating a better distribution system across the EU.
- Market segmentation: All member states have different regulations, targets and compliance systems, which create spaces for significant market distortions and trade barriers inside the EU.
- The improvement of the right technology: The dominant biofuel in the EU market is now first generation biofuels, but the EU is focussing on the development of second and third generation technologies. Uncertainty with regard to the future of advanced biofuels together with

sustainability concerns are creating questions in the industry regarding the type of biofuel generation that needs to be invested in.

- Consumer acceptance: The studies in Germany show that consumers are choosing lower biofuel blends even at a higher cost. This is due to the media reports about the negative impacts of biofuels on deforestation or food crises. This clearly shows that the right information has not been transmitted, and that even if targets are set, final users are not on board (Linares and Pérez-Arriaga, 2013).

In order to meet the 2020 target, the EU needs to address these complexities. It was argued by the participants that these challenges are enough reason to amend the EU targets for 2020, or at least to increase the flexibility for member states to achieve them.

9.1.10 Complexities around the future of biofuels in the UK

The achievements and limitations of the biofuel industry in the UK and its future prospects were specifically discussed in the interviews. The UK government may want to continue to push biofuel production beyond 2020, therefore renewable energy technologies will be supported in the UK. However, the results of the literature review and interviews show that the UK government may not introduce new targets for biofuel beyond 2020, because the intention is to support other alternative energies (such as wind and nuclear) as other valid low carbon options (Meeus et al., 2012). It has been argued by two participants that the future of biofuels in the UK was deemed to be uncertain, as the UK government had lost its faith in biofuel. Therefore, other energy resources, particularly shale gas and nuclear energy, might be in the pipeline for the future of the country. However, another participant stated that in the future, the UK would continue investing in biofuel due to its EU commitments. In order to meet the EU commitments, it is projected that the

UK biodiesel capacity will increase to 1.17 million tonnes in 2018, and for bioethanol, it is projected that UK production capacity will increase to 1.56 million tonnes in 2018 (Kim et al., 2013b), so bioethanol would be the main biofuel source in the UK. The reason is that bioethanol production is cheaper compared to biodiesel, making it a favourite for suppliers. However, the cap for bioethanol blending (currently E5) will limit the volume of ethanol that can be blended in the near future. A major proportion of the existing UK vehicle fleet may be incompatible with the higher bioethanol blend. Therefore, improvement of the fuel efficiency system in cars is recommended (Chapter 10, recommendation No. 16).

Regarding feedstocks, the main biofuel feedstocks in the UK, will be soy, sugarcane, rapeseed and palm oil while higher demand for used cooking oil (UCO) biodiesel could see UCO prices exceed those for refined palm oil in near future.

The second generation lignocellulosic biomass feedstocks could become much more significant players in the UK market and may emerge as sources of biodiesel beyond 2020 (Sims et al., 2010).

The third generation biofuels are not expected to make a significant contribution to the UK biofuel supply in the near future, due to the existing cost; however, it remains a very promising source of renewable energy in the UK.

The results of both the literature review and the interviews also show that sustainability uncertainty, lack of long term policy and government direction, alongside the limited investments in research and development fields seem to be the main complexities of the biofuel industry in the UK, in the near future and need to be dealt with.

Chapter Ten: Conclusions and Recommendations

Chapter Ten: Conclusions and recommendations

This study has established a biofuel framework through which the published literature, reports and views of experts in three different sectors (academic, government and industrial/private) are considered, scrutinized and analysed. To date, although a large number of articles are published in the field of biofuels, the information is scattered, often with mixed messages. Therefore, there has been a need for a coherent integration of scientific facts, economic drivers and environmental concerns to provide informed recommendations for policy makers. In order to go beyond the published material, the experts were interviewed and their views were analysed in relation to the published literature in order to drive an insight and arrive at recommendations for the future policies within the EU/UK. The conclusions are authoritative, they are endorsed by both the interviews and the results of the comprehensive literature review. On this basis, this study has developed novel recommendations for biofuels agenda and has extended the knowledge in this platform. The recommendations are presented after the concluding remarks.

10.1 Conclusions

In response to the literature review and the results of the interviews (Chapter 8), this thesis provides the following findings and conclusions:

- The problems associated with the biofuel production cannot be dealt with in an isolated manner. However, there is no unique organization to oversee biofuel production and consumption globally.

- The first generation biofuel is problematic because of its limitations in reducing greenhouse gas (GHG) emissions, land-use, biodiversity loss, demand for fertilisers and huge volumes of water, food versus fuel issue and rising grain prices. However, first generation biofuel will remain as the dominant method of production until 2022, mainly due to the relatively low production cost.

- The second generation biofuel is costly and is not commercially viable yet. Beyond 2022, it is very likely that the second generation biofuel will become the dominant method of production. Second generation biofuels would be less intensive harmful to the arable land, would show a better energy balance, and would improve GHG emission reductions, when compared with the first generation.

- The potential of the use of algae as the “third generation” biofuels has become increasingly attractive as it does not compete with food crop plants and can be more environmentally sustainable. However, further research needs to be done to lower the high cost of production. To date, it is difficult to predict any time period for this method to become a commercial reality. Currently the cost of biofuel production from algae is up to 6 and 4.5 times higher than the price of the first and the second generation biofuels respectively.

- Although advanced biofuel technology (the second and the third generations) looks promising in mitigating the concerns associated with the first generation biofuels, the achievement of these technologies will not guarantee success in the global energy market, but is a precondition for any major role in the world's energy future.

- Biofuel technology is moving into the fourth generation and advanced technologies where the systems biology and the synthetic biology have opened up a new field for the future. However, significant progress needs to be made in this regard. Currently the technology is complicated, costly and is not tested at the industrial level. The commercial exploitation of this technology is very likely to be way off in the future.

- There is a consensus that biofuels have a role to play in supplying the world energy, and this role would be bigger in a decade, with developing second and third generation biofuels. However, it is very unlikely that biofuel will be the dominant fuel or "the" future fuel in the decades ahead.

- Currently biofuel is not competitive against petroleum, and does not appear to become competitive for decades. Notable volumes of crude oil reserves exist (although ultimately limited), and as science and technology develop, more of these reserves can be recovered. It is now predicted that the price of crude oil will be unchanged (around US$100 per barrel) by 2030. This is not encouraging for the biofuel industry.

- Fracking and shale gas offer cheap, viable and huge sources of energy. This adds further complication to an already complicated case.

- The market for biofuel is predicted to be demanding in the near future. Global bioethanol and biodiesel productions are expected to expand by 2022. Corn, sugarcane and vegetable oil are expected to be the main raw materials. Ethanol market is predicted to being dominated by the US, Brazil and the EU, while the main biodiesel producers will be the EU and to some extent the US, Argentina and Brazil.

- So far, the biofuels' contribution to the greenhouse gas reductions and greater energy security balance has been minor. There seems to be little prospect for a significant biofuels contribution by 2022, but developing second generation biofuel technologies promise a major contribution in reducing GHG emissions beyond 2022.

- Based on the findings of this study, sustainability will remain a main concern (in particular, the issue of indirect land use change), but this is not enough to stop biofuels as an emerging industry. Developing the advanced biofuel technologies will lessen the sustainability concerns, but until such development becomes a reality at the industrial scale, the use of abandoned land, new biofuel crops and new combinations for existing crops will help minimise the current concerns.

- The EU biofuel supportive regulations will continue for the foreseeable future. The biofuels supply and demand are expected to grow, driven by the EU's need to reduce carbon emission and diversify energy sources.

- In spite of the relatively low production cost (still higher than mineral-based fuels), first generation biofuels provide a costly way for reducing emissions. Therefore, in order to meet the EU 2020 target, in the UK alone, motorists' cost (the difference between the price of petrol/diesel and biofuel) is likely to be in the region of US$2 billion per year.

- The UK government seems to push biofuel production beyond 2020, but without targets because the intention is to support other alternative energies (such as shale gas, nuclear and solar) and focus on a strategy for the use of parallel technologies in the future.

- In the UK, both bioethanol and biodiesel production will continue to grow in the near future, but the priority seems to be for bioethanol production, as it is cheaper compared to biodiesel based on unit volume.

- Meeting the EU 2020 target will require increasing biofuel consumption several times over compared to the current usage. However, the improvements in fuel consumption by the car industry continue to reduce fuel demand.

- The planned increases in biofuel blends will require the introduction of advanced biofuels. In the absence of the second and third generation technologies, meeting the EU targets is likely to result in negative consequences for land-use change and food security, unless a breakthrough in technologies happens.

10.2 Recommendations

One of the important findings of this study is that there is no single, simple and generic solution for the biofuels issue. The picture is mixed and there is a range of uncertainties and scenarios. Considering this and the concluding points of section 10.1, this thesis provides the following novel recommendations:

1. This thesis recommends establishing an international biofuel governing body, which oversees sustained global biofuel production and consumption. This governing body could be an independent international organization, managed by the United Nations, reporting annually to its members, and acting as a guiding watchdog to ensure compliance of the Member States with the environmental, trade and socio-economic regulations. This organization should work with its Member States and multiple stakeholders worldwide to secure the

interests and the needs of the Member States, and to set standards and the strategic visions for changes in the future of biofuel technology, production and market. Currently, there is no definitive governing body overseeing biofuels agenda. The International Biofuels Forum (IBF), the International Renewable energy Agency (IRENA), the International Energy Agency (IEA), the Global BioEnergy Partnership (GBEP), and at some extent, the Intergovernmental Panel on Climate Change (IPCC) are the most widely recognized international organizations sharing this responsibility. However, they are not representing all stakeholders and have limited supervisions. For example, IBF, which is the main guiding body, was formed in 2007 and only oversee the governmental initiative among Brazil, China, the European commission, India, South Africa and the US. IRENA, formed in 2009, is an intergovernmental organisation that supports countries in their transition to a sustainable energy future with technical advice and GBEP, formed in 2007, provides a platform to suggest rules and tools to promote sustainable biomass and bioenergy development. These organizations are mostly a platform where voluntary cooperation works towards consensus among governments and international organizations, while the recommended international biofuel governing body should have the authority to set the agenda and punish the member states over failure to comply with regulations. Reporting annually to member states with the environmental, trade and socio-economic regulations, facilitating research on advance biofuel technologies, easing the trade and technology flow between the member states and sharing information and examples of good practice would be part of the tasks of the new biofuel governing body.

2. This thesis suggests a "global village" approach to the biofuel issue. Biofuels agenda could be successful if it is treated as a "local-community-driven" enterprise based on local needs and social,

economic and geographic conditions. However, the international biofuel governing body or the governments need to ease the trade relations and technology-flow among these local communities.

3. This thesis recommends that there is a need for a systemic redesign, and radical changes in the philosophy of global energy production and use. This philosophy needs to go beyond the national boundaries, welcome the positive changes and be ready for paying a higher price to tackle the environmental concerns. Globally, governments need to engage in policy dialogue, research, analysis and problem-solving activities in order to meet the real global needs and requirements. The world must be seen as one society and policies need to be set based on what this society needs, whatever the price is.

4. The findings of this thesis show that there is a strong link between crude oil price and biofuel investment globally. In a world of volatile crude oil prices, this linkage causes huge damages. Even pioneering companies stopped their research and production plans, due to the market uncertainties - a recent example was the British biofuel giant, Ensus. Therefore, this thesis recommends a crude-oil-price-independent-investment-policy to drive biofuel industry; otherwise, a competitive advanced biofuels technology would never emerge.

5. A secure climate for investment in biofuel industry is a precondition for future development. This needs explicit targets for the transport sector in the long term. If no specified requirement existed, other cheaper forms of energy may be used which are not necessarily the best options in terms of carbon mitigation and energy security.

6. An efficient biofuel industry needs a dynamic agricultural sector with sufficient investment in new technologies. Therefore, the establishment of relevant institutions, organisations and long term planning is recommended.

7. In the short term, increasing the production of sustainable first generation biofuel should be the goal while developing second and third generation biofuels need to be the long term aims. This thesis recommends a “phase out” plan to reduce the share of the first generation biofuels in the total biofuel market by 2030, alongside a targeted research activity to reduce the negative impacts of first generation biofuels.

8. This thesis suggests further studies in the system biology and the synthetic biology as the potential future applications in the biofuels industry. The technical barriers, the ethical issues and the safety complexities should be overcome in order to establish globally agreed regulations in these promising fields.

9. With the predicted biofuel expansion, some competition would appear between different bioenergy sectors. Investing in other renewable energy resources, such as wind, solar, geothermal and hydro energy, would affect the development of biofuels technologies and vice versa. Therefore, this thesis suggests avoiding picking a single “winner” technology and investing in all clean and renewable technologies.

10. For a sustainable biofuel industry, in addition to the advanced technologies, pragmatic policies, regulations, and incentives are needed to drive commercial biofuel development. These policies vary from country to country but there is a need for a clear coordinated strategy for the long term.

11. Biofuels development needs to take place in a sustainable framework, with the aim of lowering and cutting subsidies. This can be achieved through a global comprehensive policy, although it is almost impossible to formulate detailed global sustainability rules. They must be specific to each country based on the local social and ecological conditions.

12. Developing countries need to consider carefully the benefits and limitations of biofuels. Strengthening local production to satisfy national needs is vital. Biofuel development could act as driver for income generation in poor countries. Alternatively, it could lead to greater exploitation with little local benefit. It is also important for farmers in developing countries to avoid monoculture farming to minimise the risk of dependency. Strong certification schemes with emphasis on socio-economic impacts for the producers are crucial.

13. Many countries are now fostering sustainability certification schemes in order to avoid negative ecological and social effects on the producer countries. This thesis suggests a systematic constant monitoring of production sites to prevent serious damage to the environment, although such a system would be expensive and currently impractical in most parts of the world.

14. It is difficult to assess the real benefits of biofuel production compared to fossil fuels. There are "hidden costs" for both fossil fuels (e.g., pollution, impacts on the health system and increasing mortality) and biofuels (e.g., huge water demand, soil erosion and use of fertilisers). If "hidden costs" of production of either fossil fuels or biofuels were considered, the cost differential would change from what it is currently a common understanding. Furthermore, the positive impacts of each on economic welfare (e.g., through rural development, vacancies and energy security) should also be taken into account, and this will affect the social cost differential. This thesis suggests more research to clearly quantify the biofuels and mineral fuels benefits/costs and this needs to be reflected in the market price.

15. The EU's 2020 biofuels target is only achievable if biofuels from other regions of the world are imported into the EU. As a result, the international trade will rise in this sector. This thesis recommends that

the international biofuel trade regulations need to be re-considered, in order to meet the emergence of new requirements. Any large-scale production of biofuels would require the removal of current trade and technical barriers to facilitate this trade.

16. Improving the fuel efficiency of transport fleet across the EU will help biofuel penetration. Therefore, the use of technological achievements and improvements in vehicles should be mandatory in all EU energy policies.

17. In some EU countries, there is no balance between diesel and petrol consumption as the mandatory blending target for ethanol is higher than diesel. Advanced diesel blends are needed in those countries where diesel has a significant share.

18. This thesis recommends an informative and comprehensive multimedia project across the EU, to clarify biofuel prospect for all people. In future, increasing mandatory biofuel blending may cause higher fuel prices and in order to manage the expectations, governments need to win consumers' acceptance. The project needs to provide true and honest information about biofuels for ordinary people.

19. This thesis suggests a shorter periodic monitoring-compared to the current one- and reviewing of biofuel policies, across the EU, to ensure that biofuels regulation and market needs are in alignment.

20. This thesis recommends developing a roadmap in the UK, for increasing biofuel penetration in an effective way. This roadmap needs to be realistic, based on the national (not EU) characteristic and agreed by a wide range of UK stakeholders.

Chapter Eleven
References

Chapter Eleven: References

1. ADAMS, P. W., HAMMOND, G. P., MCMANUS, M. C. & MEZZULLO, W. G. 2011. Barriers to and drivers for UK bioenergy development. *Renewable and Sustainable Energy Reviews,* 15, 1217-1227.

2. AL-RIFFAI, P., DIMARANAN, B. & LABORDE, D. 2010. Global Trade and Environmental Impact study of the EU Biofuels Mandate. *International Food Policy Research Institute*.

3. AMEZAGA, J. M., BOYES, S. L. & HARRISON, J. A. 2010. Biofuels Policy in the European Union. *7th International Biofuels Conference.* New Delhi

4. AMIGUN, B., MUSANGO, J. K. & STAFFORD, W. 2011. Biofuels and sustainability in Africa. *Renewable and Sustainable Energy Reviews,* 15, 1360-1372.

5. AQEG 2011. Road Transport Biofuels: Impact On UK Air Quality. The Air Quality Expert Group (AQEG).

6. ASCHE, F., OGLEND, A. & OSMUNDSEN, P. 2012. Gas versus oil prices the impact of shale gas. *Energy Policy,* 47, 117-124.

7. AVAMI, A. 2012. A model for biodiesel supply chain: A case study in Iran. *Renewable and Sustainable Energy Reviews,* 16, 4196-4203.

8. BAGHAEI-YAZDI, N. 2013. *RE: Personal Communication.*

9. BAILEY, R. 2013. The Trouble with Biofuels: Costs and Consequences of Expanding Biofuel Use in the United Kingdom. London: Chatham House.

10. BARTLING, J., ESPERSCHÜTZ, J., WILKE, B.-M. & SCHLOTER, M. 2011. ETBE (ethyl tert butyl ether) and TAME (tert amyl methyl ether) affect microbial community structure and function in soils. *Journal of Hazardous Materials,* 187, 488-494.

11. BASSET, N., KERMAH, M., RINALDI, D. & SCUDELLARO, F. 2010. THE NET ENERGY OF BIOFUELS. *EPROBIO*.

12. BAUSCH, L. 14 March 2011. *RE: Personal Communication.*

13. BBC. 2014. *Anti-fracking protest march staged at Barton Moss* [Online]. Available: http://www.bbc.co.uk/news/uk-england-manchester-25704852 [Accessed 12 January 2014].

14. BD. 2012. *Brazil sets up $38 billion ethanol subsidy program to stimulate expansion* [Online]. Biofuel Digest. Available: http://www.biofuelsdigest.com/bdigest/2012/02/27/brazil-sets-up-38-billion-ethanol-subsidy-program-to-stimulate-expansion/ [Accessed 16 February 2014 2014].

15. BELL, D. R., SILALERTRUKSA, T., GHEEWALA, S. H. & KAMENS, R. 2011. The net cost of biofuels in Thailand--An economic analysis. *Energy Policy,* 39, 834-843.

16. BENEMANN, J. R. 2009. Microalgal Biofuels: A Brief Introduction. Benemann Associates and MicroBio Engineering, Inc.

17. BERTI, A. 21 February 2011. *RE: Personal Communication.*

18. BGS 2013. The Carboniferous Bowland Shale gas study: geology and resource estimation. DECC ed. London: British Geological Survey.

19. BIOFRAC 2006. Biofuels in the European Union – A vision for 2030 and beyond. Luxembourg: European Commission Biofuels Research Advisory Council.

20. BIOPACT. 2008. *A quick look at 'fourth generation' biofuels* [Online]. Biopact. Available: http://news.mongabay.com/bioenergy/2007/10/quick-look-at-fourth-generation.html [Accessed 11th February 2011].

21. BJÖRHEDEN, R. 23 February 2011. *RE: Personal Communication.*

22. BLANCO, S. 2006. *Appalachian Ethanol. Another primer on the history of biofuels* [Online]. Autobloggreen. Available: http://green.autoblog.com/2006/04/27/appalachian-ethanol-another-primer-on-the-history-of-biofuels/ [Accessed].

23. BLOOMBERG. 2013. *Brazil Sugar-Mill Shutdowns Seen Enduring After Fuel Subsidy Cut* [Online]. Available: http://www.bloomberg.com/news/2013-12-02/brazil-sugar-mill-shutdowns-seen-enduring-after-fuel-subsidy-cut.html [Accessed 16 February 2014 2014].

24. BOLAN, N. S., THANGARAJAN, R., SESHADRI, B., JENA, U., DAS, K. C., WANG, H. & NAIDU, R. 2013. Landfills as a biorefinery to produce biomass and capture biogas. *Bioresource Technology,* 135, 578-587.

25. BOMB, C., MCCORMICK, K., DEURWAARDER, E. & KÅBERGER, T. 2007. Biofuels for transport in Europe: Lessons from Germany and the UK. *Energy Policy,* 35, 2256-2267.

26. BP 2013. Statistical Review of World Energy. Beyond Petroleum.

27. BRENHOUSE, H. 2010. Canada Produces Strain of Algae for Fuel. *The New York Times*.

28. BRINGEZU, S., SCHÜTZ, H., O´BRIEN, M., KAUPPI, L., HOWARTH, R. W. & MCNEELY, J. 2009. Assessing biofuels, towards sustainable production and use of resources. *United Nation Environmental Programme.* Paris: UNEP.

29. BRUNDTLAND, G. H. 1987. Our Common Future—Call for Action. *Environmental Conservation,* 14, 291-294.

30. BUCKLEY, P. 7 March 2011. *RE: Personal Communication.*

31. CAMPBELL, J. E., LOBELL, D. B., GENOVA, R. C. & FIELD, C. B. 2008. The Global Potential of Bioenergy on Abandoned Agriculture Lands. *Environmental Science & Technology,* 42, 5791-5794.

32. CAPROS, P., MANTZOS, L., PAROUSOS, L., TASIOS, N., KLAASSEN, G. & VAN IERLAND, T. 2011. Analysis of the EU policy package on climate change and renewables. *Energy Policy,* 39, 1476-1485.

33. CARBO, M. C., SMIT, R., VAN DER DRIFT, B. & JANSEN, D. 2011. Bio energy with CCS (BECCS): Large potential for BioSNG at low CO2 avoidance cost. *Energy Procedia,* 4, 2950-2954.

34. CARRIQUIRY, M. A., DU, X. & TIMILSINA, G. R. 2011. Second generation biofuels: Economics and policies. *Energy Policy,* 39, 4222-4234.

35. CCS 2014. Substitute Natural Gas (BioSNG). *Global CCS Institute.*

36. CHA, K. S. & BAE, J. H. 2011. Dynamic impacts of high oil prices on the bioethanol and feedstock markets. *Energy Policy,* 39, 753-760.

37. CHALMERS, J. & ARCHER, G. 2011. Development of a sustainability reporting scheme for biofuels: A UK case study. *Energy Policy,* 39, 5682-5689.

38. CHANNEL4 2014. Fracking: truths and myths about shale gas. *In:* 4, C. (ed.).

39. CHENG, C.-L., LO, Y.-C., LEE, K.-S., LEE, D.-J., LIN, C.-Y. & CHANG, J.-S. 2011. Biohydrogen production from lignocellulosic feedstock. *Bioresource Technology,* 102, 8514-8523.

40. CHERUBINI, F. 2010. The biorefinery concept: Using biomass instead of oil for producing energy and chemicals. *Energy Conversion and Management,* 51, 1412-1421.

41. CHEVRON. 2013. Unlocking Energy From Shale Rock Formations. *Natural gas from shale* [Online]. Available from: http://www.chevron.com/deliveringenergy/naturalgas/shalegas/?utm_campaign=Energy_Sources_-

_Shale_Gas_English&utm_medium=cpc&utm_source=google&utm_term=Shale_Gas&utm_content=sfdgnQ8Jf_dc|pcrid|19965553009|pkw|shale%20gas|pmt|p [Accessed June 2013].

42. CHISTI, Y. 2007. Biodiesel from microalgae. *Biotechnology Advances,* 25, 294-306.

43. CHOJNA, J., LOSONCZ, M. & SUNI, P. 2013. Shale Energy Shapes Global Energy Markets. *National Institute Economic Review,* 226, F40-F45.

44. COLARES, J. F. 2008. A BRIEF HISTORY OF BRAZILIAN BIOFUELS LEGISLATION. *Syracuse Journal of International Law & Commerce,* 35, 293-308.

45. CONNOR, M. & ATSUMI, S. 2010. Synthetic Biology Guides Biofuel Production. *Journal of Biomedicine and Biotechnology,* 2010, 9 pages.

46. CROEZEN, H. J., BERGSMA, G. C., OTTEN, M. B. J. & VALKENGOED, M. P. J. V. 2010. Biofuels: indirect land use change and climate impact. The Neatherlands: Delft, CE Delft.

47. CUEVAS-CUBRIA, C. 2009. Assessing the environmental externalities from biofuels in Australia. *Australian Commodities,* 16, 1-13.

48. DALE, B. E. 2011. *RE: Personal communication.*

49. DAMARTZIS, T. & ZABANIOTOU, A. 2011. Thermochemical conversion of biomass to second generation biofuels through integrated process design—A review. *Renewable and Sustainable Energy Reviews,* 15, 366-378.

50. DAROCH, M., GENG, S. & WANG, G. 2013. Recent advances in liquid biofuel production from algal feedstocks. *Applied Energy,* 102, 1371-1381.

51. DECC 2009. The UK Renewable Energy Strategy. *In:* CHANGE, U. D. O. E. A. C. (ed.). London: TSO.

52. DECC 2013a. Digest of United Kingdom energy statistics (DUKES). 25 July 2013 ed.: Department of Energy & Climate Change (DECC).

53. DECC 2013b. Oil and gas: onshore exploration and production. Department of Energy and Climate Change

54. DEFRA 2008. Review of work on the environmental sustainability of international biofuels production and use. *In:* PLC, A. T. (ed.). London: Department for Environment, Food and Rural Affairs (DEFRA).

55. DEFRA April 2008. The Impact of Biofuels on Commodity Prices. *Report by Department for Environment, Food and Rural Affairs*.

56. DELUCCHI, M. A. 2010. Impacts of biofuels on climate change, water use, and land use. *Annals of the New York Academy of Sciences,* 1195, 28-45.

57. DELUCCHI, M. A. 17 February 2011. *RE: Personal communication.*

58. DEMIRBAS, A. 2010. Use of algae as biofuel sources. *Energy Conversion and Management,* 51, 2738-2749.

59. DfT, DECC & DEFRA 2012. UK Bioenergy Strategy, https://www.gov.uk/government/publications/uk-bioenergy-strategy, accessed 06/08/2014.

60. DIAZ-CHAVEZ, R. A. 2011. Assessing biofuels: Aiming for sustainable development or complying with the market? *Energy Policy,* 39, 5763-5769.

61. DOE 2010 Obama announces steps to boost biofuels, clean coal. *FDCH Regulatory Intelligence Database,* (202) 586-4940

62. DOKU, A. & DI FALCO, S. 2012. Biofuels in developing countries: Are comparative advantages enough? *Energy Policy,* 44, 101-117.

63. DOMINGUEZ-FAUS, R., POWERS, S. E., BURKEN, J. G. & ALVAREZ, P. J. 2009. The Water Footprint of Biofuels: A Drink or Drive Issue? *Environ. Sci. Technol.,* 43, 3005–3010.

64. DUER, H. & CHRISTENSEN, P. O. 2010. Socio-economic aspects of different biofuel development pathways. *Biomass and Bioenergy,* 34, 237-243.

65. DUNCAN, R. & YOUNGQUIST, W. 1999. Encircling the Peak of World Oil Production. *Natural Resources Research,* 8, 219-232.

66. DÜRRE, P. 2007. Biobutanol: An attractive biofuel. *Biotechnology Journal,* 2, 1525-1534.

67. DUVENAGE, I., LANGSTON, C., STRINGER, L. C. & DUNSTAN, K. 2013. Grappling with biofuels in Zimbabwe: depriving or sustaining societal and environmental integrity? *Journal of Cleaner Production,* 42, 132-140.

68. EBTP. 2012a. *Biofuel Production* [Online]. Available: http://www.biofuelstp.eu/fuelproduction.html [Accessed 14/10/2012].

69. EBTP. 2012b. *Global biofuel, an overview* [Online]. European Biofuels Technology Platform. Available: www.biofuelstp.eu [Accessed 13/10/2012].

70. EIA 2013. International Energy Statistics. US Energy information adminstration.

71. EIA 2014. Short term energy outlook. *daily.* US Energy information adminstration.

72. ELOBIO 2010. Reconciling biofuels, sustainability and commodities demand. Energy research Centre of the Netherlands (ECN).

73. EPURE. 2011. *EU biofuels policy* [Online]. Brussels: European Renewable Ethanol. Available: http://www.epure.org/eubiofuels.php [Accessed 15/01/2011].

74. ESCOBAR, J. C., LORA, E. S., VENTURINI, O. J., YÁÑEZ, E. E., CASTILLO, E. F. & ALMAZAN, O. 2009. Biofuels: Environment, technology and food security. *Renewable and Sustainable Energy Reviews,* 13, 1275-1287.

75. EUFCC 2013. Assessing the impact of biofuels production on developing countries from the point of view of Policy Coherence for Development. European Union's Framework Contracts Commission.

76. EUROPARL. 2013. *Fuel quality directive and renewable energy* [Online]. European Parliament. Available: http://www.europarl.europa.eu/sides/getDoc.do?type=TA&language=EN&reference=P7-TA-2013-357 [Accessed 27 March 2014 2014].

77. EUROSTAT. 2011. *Share of renewable energy in fuel consumption of transport* [Online]. European Commission. Available: http://epp.eurostat.ec.europa.eu [Accessed 15/01/2011].

78. EVANS, G. 2013. *RE: Personal Commnication.*

79. EWING, M. & MSANGI, S. 2009. Biofuels production in developing countries: assessing tradeoffs in welfare and food security. *Environmental Science & Policy,* 12, 520-528.

80. FAAIJ, A. 2006. Modern Biomass Conversion Technologies. *Mitigation and Adaptation Strategies for Global Change,* 11, 335-367.

81. FAO 2008. The state of food and agriculture. Rome: Food and Agriculture Organization of the United Nations (FAO).

82. FAO 2011. The State of Food Insecurity in the World. Rome: Food and Agriculture Organisation.

83. FATIH DEMIRBAS, M. 2009. Biorefineries for biofuel upgrading: A critical review. *Applied Energy,* 86, S151-S161.

84. FERRER, M., GOLYSHINA, O. V., CHERNIKOVA, T. N., KHACHANE, A. N., REYES-DUARTE, D., SANTOS, V. A. P. M. D., STROMPL, C., ELBOROUGH, K., JARVIS, G., NEEF, A., YAKIMOV, M. M., TIMMIS, K. N. & GOLYSHIN, P. N. 2005. Novel hydrolase diversity retrieved from a metagenome library of bovine rumen microflora. *Environmental Microbiology,* 7, 1996-2010.

85. FLORIO, N. & VANDERVELL, N. 2013. Renewable Transport Fuel Obligation. UKPIA.

86. FOCUS 2010. Work begins on new bio-methanol and DME project. *Focus on Catalysts,* 2010, 4.

87. FRITSCHE, U. R., KAMPMAN, B. & BERGSMA, G. 2010. BUBE: Better Use of Biomass for Energy; Position Paper of IEA RETD and IEA Bioenergy. CE (CE Delft)/OEKO (Oeko-Institut - Institute for applied ecology) in collaboration with Clingendael International Energy Programme (CIEP) and Aidenvironment; commissioned by IEA RETD and IEA Bioenergy; .

88. FULLWIKI. 2010. *Timeline of alcohol fuel: Reference* [Online]. The Full Wiki Encyclopedia. Available: http://www.thefullwiki.org/Timeline_of_alcohol_fuel [Accessed].

89. GEA 2012. Global Energy Assessment - Toward a Sustainable Future. Vienna, Austria: International Institute for Applied Systems Analysis.

90. GERBENS-LEENES, P. W., LIENDEN, A. R. V., HOEKSTRA, A. Y. & VAN DER MEER, T. H. 2012. Biofuel scenarios in a water perspective: The global blue and green water footprint of road transport in 2030. *Global Environmental Change,* 22, 764-775.

91. GHELFI, C. 2008. *New algae trade group formed* [Online]. Cleantech Group Available: http://cleantech.com/news/2909/algal-biomass-organization-forms [Accessed May 29, 2008].

92. GHOBADIAN, B. 2012. Liquid biofuels potential and outlook in Iran. *Renewable and Sustainable Energy Reviews,* 16, 4379-4384.

93. GRACCEVA, F. & ZENIEWSKI, P. 2013. Exploring the uncertainty around potential shale gas development – A global energy system analysis based on TIAM (TIMES Integrated Assessment Model). *Energy,* 57, 443-457.

94. GRESSEL, J. 2008. Transgenics are imperative for biofuel crops. *Plant Science,* 174, 246-263.

95. GRFA 2014. Global Ethanol Production Will Rise to Over 90 Billion Litres in 2014. 27 March 2014 ed.: Golabl Renewable Fuels Alliance.

96. GRONOWSKA, M., JOSHI, S. & LEAN, H. M. 2009. A Review of US and Canadian biomass supply studies *BIORESOURCES,* 4, 341-369.

97. GROOM, M. J., GRAY, E. M. & TOWNSEND, P. A. 2008. Biofuels and Biodiversity: Principles for Creating Better Policies for Biofuel Production. *Conservation Biology,* 22, 602-609.

98. H.RES 2010. H.R. 4168: Algae-based Renewable Fuel Promotion Act of 2010. *In:* REPRESENTATIVES, U. H. O. (ed.). govtrack.us website.

99. HABERL, H., BERINGER, T., BHATTACHARYA, S. C., ERB, K.-H. & HOOGWIJK, M. 2010. The global technical potential of bio-energy in 2050 considering sustainability constraints. *Current Opinion in Environmental Sustainability,* 2, 394-403.

100. HASEGAWA, F., YOKOYAMA, S. & IMOU, K. 2010. Methanol or ethanol produced from woody biomass: Which is more advantageous? *Bioresource Technology,* 101, S109-S111.

101. HAVLÍK, P., SCHNEIDER, U. A., SCHMID, E., BÖTTCHER, H., FRITZ, S., SKALSKÝ, R., AOKI, K., CARA, S. D., KINDERMANN, G., KRAXNER, F., LEDUC, S., MCCALLUM, I., MOSNIER, A., SAUER, T. & OBERSTEINER, M. 2011. Global land-use implications of first and second generation biofuel targets. *Energy Policy,* 39, 5690-5702.

102. HEINIMÖ, J. & JUNGINGER, M. 2009. Production and trading of biomass for energy - An overview of the global status. *Biomass and Bioenergy,* 33, 1310-1320.

103. HEKTOR, B. 21 February 2011. *RE: Personal Communication.*

104. HITCHINGS, M. 2010. Report: Brazilian Ethanol Outreach. *Global Refining & Fuels Report,* 14, 19-19.

105. HMRC 2013. VAT, excise duties and other minor industry specific duties and levies. *Hydrocarbon Oils Bulletin.* HM Revenue & Customs.

106. HU, M.-C. & PHILLIPS, F. 2011. Technological evolution and interdependence in China's emerging biofuel industry. *Technological Forecasting and Social Change,* 78, 1130-1146.

107. IISD 2013. Biofuels—At What Cost? A review of costs and benefits of UK biofuel policies. Winnipeg, Manitoba, Canada: The International Institute for Sustainable Development.

108. IOD 2013. Why shale gas could be good for the economy. London: The UK Institute of Directors.

109. IPCC 2013. Climate Change 2013, The Physical Science Basis. Intergovermental panel for climate change.

110. ISOLA, J. 2013. CELLULOSIC ETHANOL HEADS FOR COST COMPETITIVENESS BY 2016 *BLOOMBERG NEW ENERGY FINANCE*.

111. IWG 2009. Growing America's Fuel, An Innovation Approach to Achieving the President's Biofuels Target. Interagency Working Group

112. JESWANI, H. K. & AZAPAGIC, A. 2011. Water footprint: methodologies and a case study for assessing the impacts of water use. *Journal of Cleaner Production,* 19, 1288-1299.

113. JOULE. 2011. *Liquid Fuel from the Sun™* [Online]. Cambridge, MA: Joule Unlimited, Inc. Available: http://www.jouleunlimited.com/why-solar-fuel/overview [Accessed 11th February 2011].

114. JUMBE, C. B. L., MSISKA, F. B. M. & MADJERA, M. 2009. Biofuels development in Sub-Saharan Africa: Are the policies conducive? *Energy Policy,* 37, 4980-4986.

115. KAENCHAN, P. & GHEEWALA, S. H. 2013. A Review of the Water Footprint of Biofuel Crop Production in Thailand. *Journal of Sustainable Energy & Environment,* 4, 45-52.

116. KAGAN, J. 2010. Third and Fourth Generation Biofuels: Technologies, Markets and Economics Through 2015. GreenTech Media Research.

117. KAMPMAN, B., BERGSMA, G., SCHEPERS, B., CROEZEN, H., FRITSCHE, U. R., HENNEBERG, K., HUENECKE, K., MOLENAAR, J. W., KESSLER, J. J., SLINGERLAND, S. & LINDE, C. V. D. 2010. BUBE: Better Use of Biomass for Energy; Background Report to the Position Paper of IEA RETD and IEA Bioenergy. IEA RETD and IEA Bioenergy.

118. KIM, I. S., BINFIELD, J., PATTON, M., ZHANG, L. & MOSS, J. 2013a. Impact of increasing liquid biofuel usage on EU and UK agriculture. *Food Policy,* 38, 59-69.

119. KIM, K., KIM, Y., YANG, C., MOON, J., KIM, B., LEE, J., LEE, U., LEE, S., KIM, J., EOM, W., LEE, S., KANG, M. & LEE, Y. 2013b. Long-term operation of biomass-to-liquid systems coupled to gasification and Fischer–Tropsch processes for biofuel production. *Bioresource Technology,* 127, 391-399.

120. KIM, S. & DALE, B. E. 2011. Indirect land use change for biofuels: Testing predictions and improving analytical methodologies. *Biomass and Bioenergy,* 35, 3235-3240.

121. KJÄRSTAD, J. & JOHNSSON, F. 2009. Resources and future supply of oil. *Energy Policy,* 37, 441-464.

122. KLEIN, T. 2012. Biofuel Outlook: Policy, Market and Technology Trends. *In:* ENERGY, H. (ed.). HartEnergy.

123. KOH, L. P. & GHAZOUL, J. 2008. Biofuels, biodiversity, and people: Understanding the conflicts and finding opportunities. *Biological conservation,* 141(10), 2450-2460.

124. KOIZUMI, T. 2013. The Japanese biofuel program – developments and perspectives. *Journal of Cleaner Production,* 40, 57-61.

125. KOVALYOVA, S. 2009. European body sees algae fuel industry in 10-15 years. Available: http://www.reuters.com/article/idUSTRE5526HY20090603 [Accessed Jun 3, 2009].

126. KUCHLER, M. 2010. Unravelling the argument for bioenergy production in developing countries: A world-economy perspective. *Ecological Economics,* 69, 1336-1343.

127. KÜÇÜK, M. M. & DEMIRBAŞ, A. 1997. Biomass conversion processes. *Energy Conversion and Management,* 38, 151-165.

128. KUMAR, M. & GAYEN, K. 2011. Developments in biobutanol production: New insights. *Applied Energy,* 88, 1999-2012.

129. LA ROVERE, E. L., PEREIRA, A. S. & SIMÕES, A. F. 2011. Biofuels and Sustainable Energy Development in Brazil. *World Development,* 39, 1026-1036.

130. LABORDE, D. 15 September 2010 2010. *RE: Personal communication.*

131. LE ROY, D. G. & KLEIN, K. K. 2012. The Policy Objectives of a Biofuel Industry in Canada:An Assessment. *Agriculture*, 436-451.

132. LEAL, M. R. L. V. 23 February 2011. *RE: Personal communication.*

133. LEE, D.-J., SHOW, K.-Y. & SU, A. 2011a. Dark fermentation on biohydrogen production: Pure culture. *Bioresource Technology,* 102, 8393-8402.

134. LEE, J. S. H., RIST, L., OBIDZINSKI, K., GHAZOUL, J. & KOH, L. P. 2011b. No farmer left behind in sustainable biofuel production. *Biological conservation,* 144, 2512-2516.

135. LEE, S. K., CHOU, H., HAM, T. S., LEE, T. S. & KEASLING, J. D. 2008. Metabolic engineering of microorganisms for biofuels production: from bugs to synthetic biology to fuels. *Current opinion in biotechnology,* 19, 556-563.

136. LEITE, G. B., ABDELAZIZ, A. E. M. & HALLENBECK, P. C. 2013. Algal biofuels: Challenges and opportunities. *Bioresource Technology,* 145, 134-141.

137. LIANG, Y., SARKANY, N. & CUI, Y. 2009. Biomass and lipid productivities of Chlorella vulgaris under autotrophic, heterotrophic and mixotrophic growth conditions. *Biotechnology Letters,* 31, 1043-1049.

138. LINARES, P. & PÉREZ-ARRIAGA, I. J. 2013. A sustainable framework for biofuels in Europe. *Energy Policy,* 52, 166-169.

139. LINDHOLT, L. & GLOMSRØD, S. 2012. The Arctic: No big bonanza for the global petroleum industry. *Energy Economics,* 34, 1465-1474.

140. LUNDBORG, A. 18 February 2011. *RE: Personal Communication.*

141. MA, H., OXLEY, L., GIBSON, J. & LI, W. 2010. A survey of China's renewable energy economy. *Renewable and Sustainable Energy Reviews,* 14, 438-445.

142. MABEE, W. E. & SADDLER, J. N. 2010. Bioethanol from lignocellulosics: Status and perspectives in Canada. *Bioresource Technology,* 101, 4806-4813.

143. MACKAY, D. & STONE, T. 2013. Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use. London: Department of Energy and Climate Change.

144. MALINS, C. September 2013 2013. *RE: Personal communication.*

145. MATA, T. M., MARTINS, A. A. & CAETANO, N. S. 2010. Microalgae for biodiesel production and other applications: A review. *Renewable and Sustainable Energy Reviews,* 14, 217-232.

146. MAYFIELD, S. 2013. *RE: Personal Commnunication.*

147. MAZAHERI, M. 2014. *RE: Personal communication.*

148. MCDONALD, R., FARGIONE, J., KIESECKER, J., MILLER, W. & POWELL, J. 2009. Energy Sprawl or Energy Efficiency: Climate Policy Impacts on Natural Habitat for the United States of America. *PLoS ONE,* 4.

149. MEEUS, L., AZEVEDO, I., MARCANTONINI, C., GLACHANT, J.-M. & HAFNER, M. 2012. EU 2050 Low-Carbon Energy Future: Visions and Strategies. *The Electricity Journal,* 25, 57-63.

150. MEYER, S., BINFIELD, J. & WESTHOFF, P. 2012. Technology adoption under US biofuel policies: do producers, consumers or taxpayers benefit? *European Review of Agricultural Economics,* 39, 115-136.

151. MILLER, R. G. 2011. Future oil supply: The changing stance of the International Energy Agency. *Energy Policy,* 39, 1569-1574.

152. MILLIKIN, M. 2008. *First Airlines and UOP Join Algal Biomass Organization* [Online]. Green Gar Congress Website. Available: http://www.greencarcongress.com/2008/06/first-airlines.html [Accessed 19 June 2008].

153. MITCHELL, C. & CONNOR, P. 2004. Renewable energy policy in the UK 1990–2003. *Energy Policy,* 32, 1935-1947.

154. MOAZAMI, N. 2013. What can we do with 10 hectares of microalgae? *In:* TEDX (ed.) *TEDx Talks.* Tehran.

155. MORALES-SÁNCHEZ, D., TINOCO-VALENCIA, R., KYNDT, J. & MARTINEZ, A. 2013. Heterotrophic growth of Neochloris oleoabundans using glucose as a carbon source. *Biotechnology for Biofuels,* 6.

156. MUKHOPADHYAY, A., REDDING, A. M., RUTHERFORD, B. J. & KEASLING, J. D. 2008. Importance of systems biology in engineering microbes for biofuel production. *Current opinion in biotechnology,* 19, 228-234.

157. MUYLAERT, K. 2012. *RE: Personal Communication.*

158. NAIK, S. N., GOUD, V. V., ROUT, P. K. & DALAI, A. K. 2010. Production of first and second generation biofuels: A comprehensive review. *Renewable and Sustainable Energy Reviews,* 14, 578-597.

159. NAJAFI, G., GHOBADIAN, B., TAVAKOLI, T. & YUSAF, T. 2009. Potential of bioethanol production from agricultural wastes in Iran. *Renewable and Sustainable Energy Reviews,* 13, 1418-1427.

160. NERSESIAN, R. L. 2008. Biofuels, fuels of the future? *Energy intelligence publications*.

161. Author. 1906. Auto Club Aroused Over Alchohol Bill. *The New York Times*, April 26, p.12.

162. Author. 1907. Successful Fuel Test Run. *The New York Times*, 31 January 1907, p.10.

163. OEKO & IFEU 2010. Development of strategies and sustainability standards for the certification of biomass for international trade. Darmstadt/Heidelberg OEKO (Oeko-Institut - Institute for applied ecology)/IFEU (Institute for Energy and Environmental Research).

164. OJ 2009. DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT on the promotion of the use of energy from renewable sources. *Official Journal of the European Union (OJ).* EU.

165. OLIVARES, J. 29 June 2012. *RE: Personal comunication.*

166. OLSON, D. G., MCBRIDE, J. E., JOE SHAW, A. & LYND, L. R. 2012. Recent progress in consolidated bioprocessing. *Current opinion in biotechnology,* 23, 396-405.

167. ONG, H. C., MAHLIA, T. M. I. & MASJUKI, H. H. 2011. A review on energy scenario and sustainable energy in Malaysia. *Renewable and Sustainable Energy Reviews,* 15, 639-647.

168. PEREZ-GARCIA, O., ESCALANTE, F. M. E., DE-BASHAN, L. E. & BASHAN, Y. 2011. Heterotrophic cultures of microalgae: Metabolism and potential products. *Water Research,* 45, 11-36.

169. PIMENTEL, D., MARKLEIN, A., TOTH, M., KARPOFF, M., PAUL, G., MCCORMACK, R., KYRIAZIS, J. & KRUEGER, T. 2009. Food Versus Biofuels: Environmental and Economic Costs. *Human Ecology,* 37, 1-12.

170. PINTO, M. S. 2011. GLOBAL BIOFUELS OUTLOOK 2010-2020. *WORLD BIOFUELS MARKETS.* ROTTERDAM, THE NETHERLAND: HART ENERGY.

171. PONTI, L. & GUTIERREZ, A. P. 2009. Overview on Biofuels From a European Perspective. *Bulletin of Science Technology Society,* 29, 493-504.

172. PORTEOUS, A. 2000. *Dictionary of Environmental Science and Technology*, Wiley.

173. POUDEL, B. N., PAUDEL, K. P., TIMILSINA, G. & ZILBERMAN, D. 2012. Providing Numbers for a Food versus Fuel Debate: An Analysis of a Future Biofuel Production Scenario. *Applied Economic Perspectives and Policy,* 34, 637-668.

174. POUSA, G. P. A. G., SANTOS, A. L. F. & SUAREZ, P. A. Z. 2007. History and policy of biodiesel in Brazil. *Energy Policy,* 35, 5393-5398.

175. PRESSTV 2013. Biodiesel production plant opens in central Iran. *Press TV.*

176. PURI, M., ABRAHAM, R. E. & BARROW, C. J. 2012. Biofuel production: Prospects, challenges and feedstock in Australia. *Renewable and Sustainable Energy Reviews,* 16, 6022-6031.

177. R&M 2013. Biofuels Market in China 2012-2016. Research and Markets.

178. RABINOVITCH-DEERE, C. A., OLIVER, J. W. K., RODRIGUEZ, G. M. & ATSUMI, S. 2013. Synthetic Biology and Metabolic Engineering Approaches To Produce Biofuels. *Chemical Reviews,* 113, 4611-4632.

179. RAJCANIOVA, M., DRABIK, D. & CIAIAN, P. 2013. How policies affect international biofuel price linkages. *Energy Policy,* 59, 857-865.

180. **RANTA, T. 23 February 2011. *RE: Personal Communication.***

181. RAZEGHIFARD, R. 2013. Algal biofuels. *Photosynthesis Research,* 117, 207-219.

182. REBEL 2009. classification of used/converted feedstocks for bioethanol production Rebel.

183. REN21 2010. Renewables 2010: Global Status Report. Revised edition as of September 2010 ed.: Renewable Energy Policy Network for the 21st Century.

184. RFA 2008. The Gallagher Review of the indirect effects of biofuels production. London: Renewable Fuel Association.

185. RFA 2014. World Biofuel Production statistics. Renewable Fuel Association.

186. RICHARDSON, J. 2009. Boom and bust. *ICIS Chemical Business,* 275, 22-23.

187. RICKMAN, J. 2009. Algae To Be Top Biofuel By 2022--Report. *Energy Daily*, 2-2.

188. ROBERTS, T. & UPHAM, P. 2012. Prospects for the use of macro-algae for fuel in Ireland and the UK: An overview of marine management issues. *Marine Policy,* 36, 1047-1053.

189. ROGERS, H. 2011. Shale gas—the unfolding story. *Oxford Review of Economic Policy,* 27, 117-143.

190. **ROSILLO-CALLE, F. 24 February 2011. *RE: Personal Communication.***

191. RTFO 2013a. Biofuel statistics: Year 5 (2012 to 2013). *Biofuels statistics* Department for Transport.

192. RTFO 2013b. Renewable Transport Fuel Obligation statistics: obligation period 4, 2011/12, report 6 *Biofuels statistics.* London: Department of Transport.

193. RUSSO, D., DASSISTI, M., LAWLOR, V. & OLABI, A. G. 2012. State of the art of biofuels from pure plant oil. *Renewable and Sustainable Energy Reviews,* 16, 4056-4070.

194. SAT. 2012. *SEE ALGAE Technology GmbH Announces Sale of Algae Farm to Brazils Grupo JB* [Online]. Available: http://www.seealgae.com/article32.htm [Accessed 16 February 2014 2014].

195. SAVAGE, D. F., WAY, J. & SILVER, P. A. 2008. Defossiling Fuel: How Synthetic Biology Can Transform Biofuel Production. *ACS Chemical Biology,* 3, 13-16.

196. SAVOLAINEN, I. 24 February 2011. *RE: Personal Communication.*

197. SCHIPPERS, M., JOSSART, J. M. & MERTENS, L. 18 February 2011. *RE: Personal Communication.*

198. SCHLARB-RIDLEY, B. 2011. Algal Research in the UK. BBSRC.

199. SCITECHDAILY. 2012. Natural Gas Mining Could Leak Enough Methane, No Longer Considered as Clean. *Sci Tech Daily* [Online]. Available from: http://scitechdaily.com/natural-gas-mining-could-leak-enough-methane-no-longer-considered-as-clean/ [Accessed 15 January 2014].

200. SCOTT, S. A., DAVEY, M. P., DENNIS, J. S., HORST, I., HOWE, C. J., LEA-SMITH, D. J. & SMITH, A. G. 2010. Biodiesel from algae: challenges and prospects. *Current opinion in biotechnology,* 21, 277-286.

201. SDTC. 2013. *SDTC to Support Commercial-scale Biofuels Facility* [Online]. Ottawa: Sustainable Development Technology Canada. Available: http://www.sdtc.ca/index.php?mact=News,cntnt01,detail,0&cntnt01articleid=337&cntnt01origid=132&cntnt01detailtemplate=news-details&cntnt01returnid=143&hl=en_CA [Accessed 16/02/2014].

202. SEBASTIAN, R., KIM, J.-Y., KIM, T.-H. & LEE, K.-T. 2013. Metagenomics: A Promising Approach to Assess Enzymes Biocatalyst for Biofuel Production. *Asian Journal of Biotechnology,* 5(2), 33-50.

203. SELLEY, R. C. 2012. UK shale gas: The story so far. *Marine and Petroleum Geology,* 31, 100-109.

204. SHAY, E. G. 1993. Diesel fuel from vegetable oils: Status and opportunities. *Biomass and Bioenergy,* 4, 227-242.

205. SHEEHAN, J., DUNAHAY, T., BENEMANN, J. & ROESSLER, P. 1998. A Look Back at the U.S. Department of Energy's Aquatic Species

206. Program—Biodiesel from Algae. *In:* LABORATORY, T. N. R. E. (ed.). NREL.

207. SHEEHAN, J. J. 2009. Biofuels and the conundrum of sustainability. *Current opinion in biotechnology,* 20, 318-324.

208. SIMS, R. E. H., MABEE, W., SADDLER, J. N. & TAYLOR, M. 2010. An overview of second generation biofuel technologies. *Bioresource Technology,* 101, 1570-1580.

209. SINGH, A., NIGAM, P. S. & MURPHY, J. D. 2011a. Mechanism and challenges in commercialisation of algal biofuels. *Bioresource Technology,* 102, 26-34.

210. SINGH, A., NIGAM, P. S. & MURPHY, J. D. 2011b. Renewable fuels from algae: An answer to debatable land based fuels. *Bioresource Technology,* 102, 10-16.

211. SIVAKUMAR, G., VAIL, D. R., XU, J., BURNER, D. M., LAY, J. O., GE, X. & WEATHERS, P. J. 2010. Bioethanol and biodiesel: Alternative liquid fuels for future generations. *Engineering in Life Sciences,* 10, 8-18.

212. SKOG, K. 2011. *RE: Personal Communication.*

213. SKOULOU, V. & ZABANIOTOU, A. 2012. Fe catalysis for lignocellulosic biomass conversion to fuels and materials via thermochemical processes. *Catalysis Today,* 196, 56-66.

214. SLADE, R. & BAUEN, A. 2013. Micro-algae cultivation for biofuels: Cost, energy balance, environmental impacts and future prospects. *Biomass and Bioenergy,* 53, 29-38.

215. SLADE, R., PANOUTSOU, C. & BAUEN, A. 2009. Reconciling bio-energy policy and delivery in the UK: Will UK policy initiatives lead to increased deployment? *Biomass and Bioenergy,* 33, 679-688.

216. SOCCOL, C. R., VANDENBERGHE, L. P. D. S., MEDEIROS, A. B. P., KARP, S. G., BUCKERIDGE, M., RAMOS, L. P., PITARELO, A. P., FERREIRA-LEITÃO, V., GOTTSCHALK, L. M. F., FERRARA, M. A., SILVA BON, E. P. D., MORAES, L. M. P. D., ARAÚJO, J. D. A. & TORRES, F. A. G. 2010. Bioethanol from lignocelluloses: Status and perspectives in Brazil. *Bioresource Technology,* 101, 4820-4825.

217. SOHEL, M. I. & JACK, M. W. 2011. Thermodynamic analysis of lignocellulosic biofuel production via a biochemical process: Guiding technology selection and research focus. *Bioresource Technology,* 102, 2617-2622.

218. SOLOMON, B. D. 2010. Biofuels and sustainability. *Annals of the New York Academy of Sciences,* 1185, 119-134.

219. SOMERVILLE, C. R. 2011. *RE: Personal communication.*

220. SONGSTAD, D. D., LAKSHMANAN, P., CHEN, J., GIBBONS, W., HUGHES, S. & NELSON, R. 2009. Historical perspective of biofuels: learning from the past to rediscover the future. *In Vitro Cellular & Developmental Biology-Plant,* 45, 189-192.

221. SORDA, G., BANSE, M. & KEMFERT, C. 2010. An overview of biofuel policies across the world. *Energy Policy,* In Press, Corrected Proof.

222. SORRELL, S., MILLER, R., BENTLEY, R. & SPEIRS, J. 2010. Oil futures: A comparison of global supply forecasts. *Energy Policy,* 38, 4990-5003.

223. SORSA, R. & SOIMAKALLIO, S. 2013. Does bio-oil derived from logging residues in Finland meet the European Union greenhouse gas performance criteria? *Energy Policy,* 53, 257-266.

224. SPARKS, G. D. & ORTMANN, G. F. 2011. Global biofuel policies: A review. *Agrekon,* 50, 59-82.

225. STELTER, M. 2009. *Electricity from straw* [Online]. Fraunhofer-Institut für Keramische Technologien und Systeme IKT. Available: http://www.fraunhofer.de/en/press/research-news/2009/02/ResearchNews022009Topic1.html [Accessed 04/11/2012].

226. STEPHANOPOULOS, G. 2012. Synthetic Biology and Metabolic Engineering. *ACS Synthetic Biology,* 1, 514-525.

227. STEPHEN, J. D., MABEE, W. E. & SADDLER, J. N. 2013. Lignocellulosic ethanol production from woody biomass: The impact of facility siting on competitiveness. *Energy Policy,* 59, 329-340.

228. STERN, N & TREASURY G. B. 2007. The economics of Climate Change: The Stern Review*, Cambridge University Press*.

229. SWAIN, P. K., DAS, L. M. & NAIK, S. N. 2011. Biomass to liquid: A prospective challenge to research and development in 21st century. *Renewable and Sustainable Energy Reviews,* 15, 4917-4933.

230. SWINBANK, A. 2009. EU Policies on Bioenergy and their Potential Clash with the WTO. *Journal of Agricultural Economics,* 60, 485-503.

231. SWINBANK, A., TRANTER, R. & JONES, P. 2011. Mandates, buyouts and fuel-tax rebates: Some economic aspects of biofuel policies using the UK as an example. *Energy Policy,* 39, 1249-1253.

232. THORNLEY, P., UPHAM, P. & TOMEI, J. 2009. Sustainability constraints on UK bioenergy development. *Energy Policy,* 37, 5623-5635.

233. TIMILSINA, G. R., MEVEL, S. & SHRESTHA, A. 2011. Oil price, biofuels and food supply. *Energy Policy,* 39, 8098-8105.

234. TOMEI, J. & UPHAM, P. 2009. Argentinean soy-based biodiesel: An introduction to production and impacts. *Energy Policy,* 37, 3890-3898.

235. TTR 2009. Evaluating the opportunities for high blend liquid and gaseous biofuel penetration in the UK. London: Transport and Travel Research.

236. TYNDALL 2011. Shale gas: a provisional assessment of climate change and environmental impacts Manchester: Tyndall Centre of University of Manchester

237. TYSON, K. S. 2005. DOE analysis of fuels and coproducts from lipids. *Fuel Processing Technology,* 86, 1127-1136.

238. UGWU, C. U., AOYAGI, H. & UCHIYAMA, H. 2008. Photobioreactors for mass cultivation of algae. *Bioresource Technology,* 99, 4021-4028.

239. UKPIA 2013. *Statistical Review,* London, UKPIA.

240. UNDESA 2004. World population to 2300 New York: UN Department of Economic and Social Affairs.

241. UNFCCC 2007. Investment and Financial Flows to Address Climate Change. United Nations Framework Convention on Climate Change.

242. UNFCCC 2008. Kyoto Protocol, Reference Manual. United Nations.

243. UNFCCC 2011. Doha amendment to the Kyoto Protocol. United Nations.

244. UPHAM, P., TOMEI, J. & DENDLER, L. 2011. Governance and legitimacy aspects of the UK biofuel carbon and sustainability reporting system. *Energy Policy,* 39, 2669-2678.

245. USGS 2000. U.S. Geological Survey World Petroleum Assessment 2000: Description and Results. *In:* TEAM, U. W. E. A. (ed.) *Data Series.* United States Geological Survey

246. VANDAMME, E., ANTHONIS, T., DOBBELAERE, S., BOURDEAU, P., CARREZ, D., GOSSELING, D. & VERSTRAETE, W. 2011. Industrial biomass: source of chemicals, materials, and energy!: implications and limitations of the use of biomass as a source for food, chemicals, materials and energy. Brussels, Belgium: Royal Belgian Academy Council of Applied Science (BACAS).

247. WALKER, D. A. 2010. Biofuels – for better or worse? *Annals of Applied Biology,* 156, 319-327.

248. WANG, J., RYAN, D. & ANTHONY, E. J. 2011. Reducing the greenhouse gas footprint of shale gas. *Energy Policy,* 39, 8196-8199.

249. WEBB, C. 22 January 2014. *RE: Personal communication.*

250. WEN, Z. & JOHNSON, M. B. 2009a. Microalgae as a Feedstock for Biofuel Production. *Virginia Polytechnic Institute and State University,* 442-886.

251. WEN, Z. & JOHNSON, M. B. 2009b. Microalgae as a Feedstock for Biofuel Production. *Virginia Polytechnic Institute and State University,* PUBLICATION 442-886.

252. WEYER, K., BUSH, D., DARZINS, A. & WILLSON, B. 2010. Theoretical Maximum Algal Oil Production. *BioEnergy Research,* 3, 204-213.

253. WICKE, B., SIKKEMA, R., DORNBURG, V. & FAAIJ, A. 2011. Exploring land use changes and the role of palm oil production in Indonesia and Malaysia. *Land Use Policy,* 28, 193-206.

254. WIESENTHAL, T., LEDUC, G., CHRISTIDIS, P., SCHADE, B., PELKMANS, L., GOVAERTS, L. & GEORGOPOULOS, P. 2009. Biofuel support policies in Europe: Lessons learnt for the long way ahead. *Renewable and Sustainable Energy Reviews,* 13, 789-800.

255. WORLDBANK 2014. Commodity markets outlook The World Bank.

256. WRIGHT, L. 2006. Worldwide commercial development of bioenergy with a focus on energy crop-based projects. *Biomass and Bioenergy,* 30, 706-714.

257. XYNTEO 2011. UK Biofuels-industry overview.

258. YAHYAEE, R., GHOBADIAN, B. & NAJAFI, G. 2013. Waste fish oil biodiesel as a source of renewable fuel in Iran. *Renewable and Sustainable Energy Reviews,* 17, 312-319.

259. YUSAF, T., GOH, S. & BORSERIO, J. A. 2011. Potential of renewable energy alternatives in Australia. *Renewable and Sustainable Energy Reviews,* 15, 2214-2221.

260. YUSOFF, M. H. M., ABDULLAH, A. Z., SULTANA, S. & AHMAD, M. 2013. Prospects and current status of B5 biodiesel implementation in Malaysia. *Energy Policy,* 62, 456-462.

261. ZHENG, B. 2013. Overview of Biofuel Technologies in China. *BERC,* China Focus.

262. ZHOU, A. & THOMSON, E. 2009. The development of biofuels in Asia. *Applied Energy,* 86, S11-S20.

Chapter Twelve

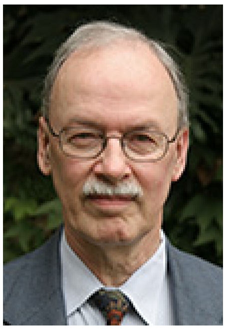
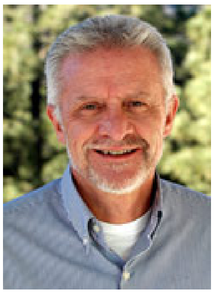
Appendices

Chapter Twelve: Appendices

Appendix A: Hi Ball, one of the trade names for alcohol/gasoline blends in 1930s (Blanco, 2006)

Appendix B: Promoting 10% ethanol in a gasoline filling station in Nebraska, 1933 (Credit—Nebraska History Museum) (Songstad et al., 2009) (Section 1.6)

Appendix C: List of participants

	Name	Position	Institute/company	Country	Sector
1	Bruce Dale 	Professor	Editor-in-chief of Biofpr/ Professor of Michigan State University	USA	Academic/Research Centre
2	David Laborde 	Senior Researcher	IFPRI International Food Policy Research Institute	USA	Research Centre/Academic
3	Chris R Sumerville 	Professor of Alternative Energy and EBI Director	Melvin Calvin Laboratory Berkeley, California 94720	USA	Academic/Research Centre
4	Jose Olivares 	PhD, Director Also Co-Editor-in-Chief of the scientific journal Algal Research	National Alliance For Advanced Biofuels and Bio-Products	USA	Academic, Research Centre

	Name	Position	Institute/company	Country	Sector
5	Jean-Marc Jossart 	Liquid biofuels, VALBIOM association, AEBIOM association	Catholic University Louvain - UCL	Belgium	Academic
6	Chris Malins 	PhD, Head of Fuels	ICCT (The international council on clean transportation)	UK	Business Sector/ Research Centre
7	Marie Schippers	Walloon government representative, in charge of renewable energy	Patrimoine et de l'Energie	Belgium	Research centre/ Governmental
8	Lara Mertens	Project Manager ValBiom ASBL	Catholic University Louvain - UCL	Belgium	Academic
9	Manoel Regis Lima Verde Leal 	PhD	Bioethanol Science and Technology Center	Brazil	Research centre/ Academic
10	Ilkka Savolainen 	Energy Systems	VTT (Technical research center of Finland)	Finland	Research centre/Business sector

	Name	Position	Institute/company	Country	Sector
11	Anna Lundborg	Climate Change Division	Swedish Energy Agency	Sweden	Governmental
12	Mark A. Delucchi 	alternative fuels, greenhouse-gas emissions, biomass, bioenergy,	University of California, Davis	United States	Academic
13	Kenneth Skog 	carbon sequestration in wood products, forest sector modeling, wood decay in landfills	US Department of Agriculture	United States	Governmental
14	Pearse Buckley 	PhD, Programme Manager	Sustainable Energy Ireland	Ireland	Governmental
15	Tapio Ranta 	Professor	Lappeenranta University of Technology	Finland	Academic
16	Alessandro Berti 	Project Manager	Api Nòva Energia	Italy	Business sector

	Name	Position	Institute/company	Country	Sector
17	Bo Hektor 	Senior Advisor	First Bioenergy AB	Sweden	Business sector
18	Frank Rosillo-Calle 	Professor	Imperial College London, CEP	UK	Academic
19	Rolf Björheden 	Professor	Uppsala Science Park	Sweden	Academic
20	Linda Bausch 	PhD	German Biomass Research Centre – DBFZ	Germany	Academic/Research centre
21	Koenraad Muylaert 	Professor	Algae Pro Tech Consortium	Belgium	Private industry, Research Centre
22	Geraint Evans 	PhD, Head of Biofuels and Bioenergy	NNFCC	UK	Private sector, Consultancy to government

	Name	Position	Institute/company	Country	Sector
23	Namdar Baghaei Yazdi 	PhD, Technical Director	E3 Biotechnology Ltd.	UK	Private sector/Academic
24	Stephen Mayfield 	Professor, Director	San Diego Center for Algae Biotechnology and John Dove Isaacs Chair of Natural Philosophy	USA	Business sector, Academic
25	Colin Webb 	Professor	The University of Manchester	UK	Academic
26	Annonymous 1	PhD		Austria	Governmental
27	Annonymous 2	PhD		Iran	Research Centre/Academic
28	Mahnaz Mazahri-Assadi 	Professor	Iranian Research Organizationf for biotechnology and science (IROST)	Iran	Research Centre/Academic

Appendix D: Interviews' questions

Interview questions (first series)

Future:

1- Is there any prospect for biofuels?

2-What are your views on the advantages and disadvantages of Biofuels compare to traditional fuels?

3-What do you think about advantages and limitations of different generations of biofuels?

4- Can algae overcome the limitations? Is Algae the future's fuel?

5- Is the current projection achievable or not?

6- Should other options than biofuels be considered for future?

Regulations and directives:

7- Do the current regulations support the biofuel production across the world in future?

8- What are the main factors favouring the development of biofuel use in the EU? What are the main obstacles?

9- How much government support does the biofuels sector need?

10- How developed world demand affects poor countries policy?

Environment:

11- What are the environmental Impacts?

12- What are the potential impacts on food prices and lands? Do we have enough land?

13- What are the real advantages or disadvantages of biofuels in terms of reducing Green House Gases?

14- Interaction of green energy sources with biofuels? Have other green energy sources affected the biofuels expanding?

15- As a result of biofuel production, will habitat fragmentation occur and will the ecosystem change?

Interview questions (second series)

Future:

1- Would you please tell me about the long term prospect for liquid biofuels-up to 2050's?

Forecasting Scenarios for First Generation Biofuels?

Forecasting Scenarios for Second Generation Biofuels?

Forecasting Scenarios for Third Generation Biofuels?

2- What will be the future's fuel? Can they overcome the limitations?

3- What other options than biofuels be considered for future?

4- Although fossil fuels will never finish but when the remaining crude oil decreases, the price will increase and makes biofuel industry profitable. What is this turning point price for petroleum and when it is going to happen?

Regulations and directives:

5- What is your view on EU regulations? Do the current regulations support the biofuel production across the EU in future?

6- What are the main factors favouring the development of biofuel use in the UK/EU? What are the main obstacles?

7- How much government support does the biofuels sector in the UK/EU need?

8- Forecasting Scenarios for future regulations and directives in the EU?

Environment:

9- What are the environmental Impacts? On agriculture, biodiversity, Climate Change, water and Soil?

10- What are the potential impacts on food and commodity prices?

11- Direct and indirect land-use change?

12- What are the real advantages or disadvantages of biofuels in terms of reducing Green House Gases?

Interview questions (third series)

Future:

1- What will be the future's fuel?

2-Your views on long term prospect for liquid biofuels-up to 2050?

2-a: Forecasting Scenarios for First Generation Biofuels?

2-b: Forecasting Scenarios for Second Generation Biofuels?

2-c: Forecasting Scenarios for Third Generation Biofuels (algae)?

3- What other options than biofuels be considered for future?

Regulations and directives:

4- What is your view on EU/UK regulations? Do the current regulations support the biofuel production in the UK in future?

5- What are the main factors favouring the development of biofuel use in the UK? What are the main obstacles?

6- How much government support does the biofuels sector in the UK need? What kind of support needed?

7- Forecasting Scenarios for future regulations and directives in the UK/EU?

Environment:

8- What are the environmental Impacts (agriculture, biodiversity, Climate Change, water and Soil)? Positive or negative?

9- What are the potential impacts on food and commodity prices?

10- Direct and indirect land-use change?

11- What are the real advantages/disadvantages of biofuels in terms of reducing Green House Gases?

Oil industry:

12- Looking into the short/medium term future, what will be the availability of oil in medium (up to 2030) and long term (up to 2050)?

13- Will oil demand continue to grow? Will it remain the world's single most important source of energy for the foreseeable future?

14- Any alternative to crude oil? Biofuel maybe?

15- Will biofuels be able to compete with crude oil? When it is going to happen?

Appendix E: Interviews' transcripts

Participants	Interview transcription
Participant A	I.What you think about Biofuel as a potential source of Energy for future? What are your views on the advantages and disadvantages of > Biofuels? P. ***I am not in favour of using food crops for fuel with the exception of sugarcane (I consider refined sugar a dispensible "food") because such crops were not designed for fuel production and have relatively low net energy returns. I am also concerned that using food crops is unsustainable because of expanding food demand due to population growth and increased living standards (i.e., demand for animal potein) in asia and elsewhere. However, I believe that it is possible to produce a substantial portion of our transportation fuel from biomass species that are grown specifically for fuel production on land that is not used directly for food production. I think that a reasonable goal is to get about 30% of our transportation fuel use by about 2030. I hope that we will also get a 50% improvement in fuel efficiency so the actual contributin of biofuels could be up to 50% of transportation fuels. Since transportaion uses about 20% of energy consumption worldwide, the implication is that we might get to about 10% of total energy demand sometime after about 2030. 2- Can next-generation biofuels overcome the limitations of the current generation? ***yes. I am confident that we can develop energy crops that grow on land that is not needed for food crops and that yield much higher amounts of fuel per unit of land than the current biofuels - biodiesel in particular is very inefficient use of land 3- Can biofuels play a more significant role in the world's portfolio of energy resources? Have other green energy sources affected the biofuels expanding? ***As noted above,biofuels will continue to expand very strongly for the next several decades. Other source sof renewable energy are not in competition with biofuels and generally address other needs in the energy markets. As I recall, biofuels already account for about 100 times as much energy as all photovoltaics worldwide (but you should check that number - I recall hearing thatstatement but I have not done the calculation myself). 4- Should the EU continue acting in favour of biofuels after 2010? If yes, what are the main factors favouring the development of biofuel use in the EU? What are the main obstacles? ***I dont have an informed opinion about what the EU should do except to sy that I think that support for development of advanced biofuels is an important component of an overall strategy for moving away from fossil fuels. I am very concerned about the negative consequences of continuing reliance on fossil fuels and I am convinced that we need to take drastic action to reduce our reliance on such fuels. Biofuels can be an mportant part of an overall portfolio of renewable low carbon energy but they are just a part, as noted above. I think the need for change is so urgent that we should not try to pick a single "winner" technology but should support all renewable technologies (including energy efficiency in particular) and should push these technologies to develop in ways that meet our long-term societal goals. In the case of biofuels that means developing systems that support ecosystem services and do not compete with ensuring adequate food

Participants	Interview transcription
	production. 6- What are the potential impacts on food prices and lands? Do we have enough land? ***Densely populated countries like the UK or Japan do not have enough suitable land to produce significant proportions of their energy needs from biomass. However, other countries such as Brazil have enormous amounts of land available for biofuel production. For instance, the brazilians currently get 40% of their transportation fuels from 4M ha of sugarcane. The government passed a law that will allow the sugarcane area to expand to 64 M ha by intensifying the production of cattle (cattle are currently produced at very low density on about 234 M ha). Studies during the past several years have indicated that, in contrast to the speculation in the popular press, biofuels have had a minor effect on food prices. In fact, some economists think that biofuels could reduce wide price swings in food prices by providing a buffer against poor harvests (ie., in years of poor harvests grains that were grown for biofuel would be redirected toward "food" production through a predefined contractual system that benifts everyone in the system. I say "food" because the crop most intensively used for biofuel production (ie., corn) are not used directly for human food but are actually used to feed animals - usually at very low efficiency). 7- What do you think about the sustainability of crops used for the > production of biofuels, particularly land use, degree of intensity of cultivation, crop rotation and use of pesticides? ***Sustainability is obviously a crucial concern. There is no point making a massive changeover from fossil to biofuel if it is not sustainable. In my institute we are making a huge investment in understanding the sustinability of potential energy crops. Our current opinion is that it is possible to produce dedicated energy crops in ways that enure longterm sustainability. We are focused on perennial species that sequester mineral nutrient in rhizomes at the end of the season so that they do not require fertilizers (or ploughing etc). There was a nice study pulished at Rothamstead recently where a group there showed that plots of miscanthus that were hrvested for 14 years did not require any nitrogen inputs (i.e., there wa sno difference in production with or without fertilizer for the 14 years of the study). We also envision that decicate dbiomass crops will be genetically diverse and possibly mixed species so that it is not necesaary to use pesticides. There is lots of genetic resistane to pests in natural populations and we hope to use that resistance. The key thing about dedicated energy crops is that they do not have many of the constrainst of food crops so we can reinvent the managment practices to be more compatible with natural ecosystems. 8- What are the limitations to bio fuel feedstock availability? ***The limitations vary from one region to another. In some regions there is not enough suitable land available or there are competing uses for the biomass. However, for lignocellulosic biofuels the main limitation seems to be organizational. That is, farmers will not grow the biomass until there is a processing facility nearby and a committment from the facility to purchase biomass at an attractive price. On the other hand, the potential owners of processing facilities will not make the capital committment until they are assured that growers will make long term committments to provide biomass at attractive prices. This standoff will be resolved on a case-by-case basis but probably not until most of the technical

Participants	Interview transcription
	risk has been removed from the proceses for making lignocellulosic fuels. 9- Do the current regulations support the biofuel production across the world in future? ***I dont know enough about the regulations to comment. The regulations in the US and Brazil appear to be adequately supportive. 10- How much government support does the biofuels sector need? ***How much in what terms? My opinion is that government support or madndates are necessary for some period of time because it is probably impossible for any new energy technology to displace the existing mature technologies on a price basis until we start charging the existing industries for the true cost of the environmental damage caused by carbon emissions. 12- What are the real advantages or disadvantages of biofuels in terms of reducing Green House Gases? ***Studies at Berkeley have indicated that corn ethanol has a relatively minor improvement in GHG emission per unit of energy produced (i.e.,20%). However, if there was a carbon tax or related incentive, the GHG benefit could easily be improved by using corn stover for generation of process heat (instead of coal or natural gas). Sugarcane ethanol has a very significant reduction in GHG (about 65% according to EPA as I understand it). We expect cellulosic fuels to have GHG footprints that can meet the EPA rules (65% reduction in GHG emission relative to gasoline). 13- As a result of biofuel production, will habitat fragmentation occur and will the ecosystem change? **the relevant question is whether there will be any intact ecosystems if we dont stop fossil-fuel induced climate change. The whole purpose of moving toward biofuel is base don trying to reduce GHG so you have to estimate the net benefit from that as a baseline. More generally, I think the effects of biofuel production on ecosystems will be a matter of degree. there is a lot of land worldwide where production of biofuels will not cause GHG emission from land conversion or ecosystem effects. An ecology group at Stanford identified more than a billion acres of land wrldwide that has been farmed in the past and then abandoned to agriculture for various reasons ranging from economic factors (eg overproduction of food) to destructive farming practices that destroyed soil fertility. certainly that land appears to be available without negative consequences. 15- Should other options than biofuels be considered? ***all other options should be vigorously pursued as noted above. Biofuels could only be part of a solution to the GHG problem at best.
Participant B	Interviewer (I): Do you really consider biofuel as future fuel? Participant (P): As a future fuel, yes. As the future fuel, I'm not sure, but as a future fuel certainly. I: And how much percentage should this be in your view? P: Well, yes that's a difficult question because I think we have to reach as high a percentage as we possibly can. I mean, ultimately we have to reach a steady state where biofuels provide almost all our fuel needs. So I would say just arbitrarily I would say 50% has to be a minimum target.

Participants	Interview transcription
	I: And among the different generations of biofuels, which one is your favourite? P: Haha, that's also a difficult question, I think the, I think we will stop talking about different generations of biofuels soon. I think all biofuels are biofuels, they are all derived ultimate from photosynthetic origins and whether you use sugars directly which is easy, but competes with food, or whether you use other less easy to access materials, in the end the balance is still the same. It's still part of the same carbon balance so I think we will stop talking about generations in the future. I: But for example, if you talk about algal fuel, do you think there is any future for algal fuel? P: Yes I think there is because ultimately we have to make use of the oceans, we have to capture as much sunlight as we can to produce biofuels and the oceans are you know, more than half of the surface. And algae are good converters of solar energy so yes we must make better use of algae fuels in the future. I: But is there any possibility for algal fuel to be competitive with for example fossil fuels in future? P: Only when the fuels become sufficiently scarce that they become very, very expensive. I mean the, these things, there are economic trajectories and fossil fuels become ever more expensive as they become rarer or scarcer of more difficult to process. And also of course as we learn more about the environmental issues, that puts a negative value on them so ultimately they will become competitive. But not for a while yet. I: And how can we reduce the production cost of algal fuel? Is it somehow possible? P: Well I think, the, I guess the first thing is that fossil fuels are essentially free, we only have to dig them out of the earth and they are there readymade, so you can't really compete with those sort of prices, those sort of costs, but at the same time, what ever we produce biologically, history tells us that we make it cheaper and cheaper very quickly. So algal biofuels are expensive at the moment because processing is not well established. As it becomes better established the price, the cost will come down I think quite dramatically. I: And you mentioned when we talk about algal fuels, you mentioned about oceans. So you believe that marine algae has the edge? P: Well I think so ultimately I think in a sense there's not a great deal of point in land based algal systems which simply take up the same are which you might occupy with crops for example. So I think, yeah I think marine algae are the future in that sense. Algal stations in the oceans capturing sin, converting it to biofuels and harnessing those fuels. A little bit like offshore oil rigs. I: And some researchers now say that with the developing of shale gas, there would be no future for biofuels, what do you think about that? P: Well that depends on your perspective both in terms of time and in terms of environment. We all I think realise that in terms of environmental impact,

Participants	Interview transcription
	bringing any fossil fuel to the surface of the earth and burning it produces, creates a net production of CO2 which is adding to the atmospheric levels which we know are increasing at a rate which isn't sustainable so. So shale gas in a sense on the one hand it's a saviour from the point of view of energy and fuel, on the other hand it's a disaster from the point of view of yet more stuff that we are going to dig out of the earth and put into the atmosphere. We have to head towards a sustainable situation where we use the carbon cycle sensibly and that means, you know, a live carbon cycle with biomass. So I think… I: But to be advocates, there will, I mean we should say that biofuel has it's own negative environmental impact. Do you agree with this? P: No I don't, because you only have to look at the balance… Ok there are situations in which it does, if you start chopping down forests in order to produce biofuels then you have effectively sequestered carbon and put that into the atmosphere. If on the other hand you use the existing carbon cycle, it's a two year cycle. Or, or even less one or two year cycle, and as long as you maintain that cycle you are not disturbing that steady state. So whatever… I: What about water pollution or land use change? P: Yeah ok, well land use change I've just said, if you start doing things that change the land use then you are disturbing the reservoir rather than the cycle and that's something that we have to do carefully. As far as the water balance is concerned, that's another balance that we have to respect and maintain and sustain but the carbon balance fit quite comfortably with the water balance so if you started growing algae in the oceans to produce biofuels, it doesn't really impact greatly on the, as far as we know, it doesn't impact greatly on the water cycle. But all of these things, any dynamic interference with what should be a relatively steady cycle will have it's repercussions. But ultimately, if you are thinking of a 10, 50, 100 year lifecycle then it's completely different issue. And that's the one that the energy companies thing on, then that's completely different issue if you are thinking about sustainability in terms of thousands of years. I: Yeah, yeah. And what do you think about the EU or UK regulations. Do the current regulation support biofuel production? P: I think they do, I think we've, it's a learning curve and I think the governments are trying their best to, to embrace the concepts, if not necessarily understand the full implications. So the idea of increasing the requirements for biofuels in fuel blends I think is essentially a good one, even though none of these things is perfect. And doing things because of legislation rather than the underlying causes is probably not the best, politically it's probably we can hope for really, but the approaches are reasonable. The problem of course is that our government for example will say, ok now we have shale gas we don't have to worry about all of these things. Lets breath a sigh of relief and rake in the cash. So it's a difficult one. It's a difficult, it a dilemma for governments how to best behave but I think European governments are doing a reasonable job. I: In the UK how much government support does the biofuel need? P: Well I think I mean, that's a difficult one because I think ultimately these things have to be self sustaining so the government approach of legislating

Participants	Interview transcription
	without really giving huge incentives. I think what you really don't want to do is to create a situation where you are throwing money at a problem, everyone says the right things in order to access the funding and then doesn't really do anything with it. I think there is always a struggle between getting things of the ground and making them work. And throwing money away for no good So if you look at the Brazilian situation where they have been subsidizing ethanol production for 40 years now, it got it off the ground and they have a sort of steady, stable economy based on it, but it still doesn't manage without government subsidies so it's a difficult one I think. I: And I was interviewing an energy expert the other day, and he claimed that for the UK government biofuel is dead. He said that because the government now focuses more on nuclear and shale gas. Is it true in your view? P: I think it's certainly the way it's going yes, I think yeah, I think there isn't the thrust that there might have been a few years ago and I think that the UK government have sort of made the decision that nuclear is the future and of course nuclear will be part of the future but I'm not sure it will, within the European context be able to drop the biofuels completely. I: So is there any chance to change this mentality within the government in your view? P: Well I think the key thing is the environmental issue rather than the energy resource issue. I think if it's simply seen as a 'we are running out of energy we need an alternative' then I don't think biofuels will ever get a proper sensible audience in the government, particularly with issues around whatever you use for biofuels, ultimately you are competing with food, even if it's lignocellulosic stuff it's still competing one way or another with fuel. The real issue is the one of environment and I think if you can, if governments can learn that we are unbalancing the atmospheric environment of the planet, and of course that has to be recognised at a planetary level rather than a local level, but that would be the driver that I think would be the key one. I: And my last question. If you are going to recommend the policy to the government to promoting biofuel, what do you think this policy should be? P: Well I think again just stressing the environmental benefits of not, I mean the way that they should, the life cycle assessment should be on the basis of not so much the carbon associated with the biomass itself but the net reduction in additional carbon taken out of the earth so the policy should be based around reducing the green house gasses.
Participant C	I: Ok biofuels, lets talk about it first in a broad sense, what are your views on the advantages and disadvantages of biofuels? P: OK, let me start by saying the biofuel debate takes place in the world about how we can use biomass to produce energy. And I think that we have to keep in mind that we speak a lot about biofuels when... maybe a small window in the world debate and maybe we are focusing too much energy and attention on biofuels and not on other things. So for biofuels the question we have today is to replace first of all the fuel we put in cars and trucks by biofuel and as you know it was an idea that is very old because the first engine has been developed using ethanol with the oil. Now it takes place in a debate that is a little strange

Participants	Interview transcription
	because people have bring arguments about environment, at least in the EU it has been promoted as kind of green policy, when, when you start to look ...you start to understand that there is much more than environment at stake and maybe the main motivation of policy makers, environment was not clear at the beginning. In the US we see clearly that the question of… but more independent toward foreign source of energy is important in the pentagon and play a role in this, so very easy energy policy dimension, that is going to have an impact later when we are going to discuss biofuel and for example what kind of tread policy for biofuel. Because if from the beginning you know that what you want is to not rely on foreign source of energy it can be oil from the middle east, it can be ethanol from brazil, so you see it's understanding really what were the reasons to have a biofuel policy is something quite important and maybe in the debate, think that is not always clear, and after of course you have all the farm lobbies directly and indirectly that in a global context of increased discipline coming from the WTO to limit direct farm subsidies in the European (?? 2:35) policy reform and so on, they have seen here a new space to get subsides grants or just to have support for the demand of their product. And then it, I would say it's still environmental argument has been bring in the front line of the discussion, when we have start to look at it more seriously because once again I think what is very interesting in biofuel, that policy maker second decision and very ambitious decision and have make important statement and position before any kind of scientific evidence both from the... point of view, like economy or even from the outside ..., while we hear to say if it's a good or not a good decision. So policy maker have taken decision on there, with their own motive and incentives and then science starts to step in so in that no biofuel may not be so good in terms of energy efficiency in terms of environmental and so all the debates and even in terms of economy decision what is the cost for the tax payer, what is the cost for the consumer, and who is going to gain from this policy in the end. And nowhere in this situation. And the last point on this overall debate is, we speak a lot about ethanol and biodiesel… third generation biofuel, and the problem that if you look 5 years ago people were announcing that the 2nd generation would come very quickly and we solve all the problems of the 1st generation. And if you look today you see that even in the US the target of 2nd generation has been reduced and people doesn't see when the second generation are going to come on a commercial basis to… And once again policy makers have from the beginning sold some ideas that were not sustainable in terms of real implementation. I: So in this case what do you think about the future of biofuels in general? P: So the future of biofuel, I will say that we say first… right now we are very strong lobbies that are defending the biofuel both in the EU and in the US for industrial interest and even among policy makers you will see by the commission or in the US it will say there is so much money at stake here but we shall not focus too much about this impact assessment or this kind of thing. So there is a kind of lock in movement. Some policy maker we never say that they have make ten years of mistake or that they have spent billions in wrong incentives, now at the same time I think at least in the EU people are more and more careful and they can start to reduce their ambition. Particularly because we see the cost of producing biofuel is still high, right now we don't have so much incentive coming from the oil prices so… this is I think a very important idea that the future of biofuel is still going to be related to what is going to happen on the oil market. Because with the current level of oil prices, biofuel is not economically efficient and people are very, lot of difficulty to argue that we

Participants	Interview transcription
	need to biofuel now, because the environmental impact is not clear, the economic impact is bad and it has a lot of side effects. If the price of oil was lets say at 120 dollars a barrel, something like this or even more, you would start to see very different ... so the future of biofuel depends first on the lobbies we have in each region and country but also on the price of fossil fuel that can help the pro biofuel people to push for it. Now within biofuel we have the important thing between the first generation and the second generation, maybe also the third generation, that is discussed later. And here within this biofuel sector we are going to huge conflicts of interest, today in the US the corn ethanol is so large that there is basically no more room for the second generation ethanol and in order to bring second generation ethanol on the market we need even more market even more policies to support the second generation due to the competition of the first generation. At the same time the first generation ethanol and biofuel based on crops have been in this debate about fuel versus food verses feed, then they try to defend themselves saying that the first generation ethanol and biodiesel produced significant amount of co product, then they tried to increase quality of co–product, so that they are not so bad and what they say today that look the second generation will not produce co product so at the end the land use can be even worse if you start to put sweetgrass instead of corn you will start. To conclude on this I really think also that the future of biofuel will not be about crops maybe but we are going to for the cellulosic ethanol in particular we are going to see the forestry sector playing, I believe, a more important role. I: So that next generation of bio fuels can over come the limitations of the current generation. P: Yeah, I think that in particular if we start to produce the second generation based on wood and using the forestry sector we can see much better economy can environmental outcome, because to some extent managing forests produced energy is something that mankind is doing for several hundred years. So it's a different solid, it's a different matter of land use, it's also in terms of you know, carbon, when the forest regrowing you still capture carbon. So it's much softer than when you use this annual crops to produce energy, but right now the situation is clear that we are going to see a debate about what is the future of biofuels in general and we are going to see in the EU I think more than in the US, people that want to limit biofuel in particular third generation biofuel due to their, their environmental impact and you see all the debate about palm oil coming from south east asia and so on. But at the same time the first generation are here, they are invested, the plants can be here for 30 years and they are not going to disappear just because some environmentalist group wants them to disappear and they know that one of the threats for them can come also from the second generation forests which is why we are going to see something of I think political games, kinds of complex things. Last if we think about the EU in particular we still have very conflictual interests among different member of states that can bring less visibility about where we are going. I: And is there any link in your opinion between rising food costs throughout the world and this push towards biofuel? P: So, there is a link but it is very small ok, because if you just look at a global level what is the share of crops going to bio energy production it's not more than 2 percent, it's even less depending what you put in the food basket, the only crops that have been directly hurt at this stage was the corn and it's true

Participants	Interview transcription
	that for the US one third of their corn production... moved from the… food and seed basket to the, to the production of ethanol. But it's not what has lead to rising hunger in Africa or even the 2008 prices increased, even today if you look for example what has happened with the wheat market, climatic evens and policy ...coming from Russia gets a much wider impact on wheat price and so on, and price for flour and bread all over the world than any bio fuel policy so, people have blamed a lot biofuel for something they are not so much responsible. And if you still go back to the corn story in the US you will see that the main victim of this increase of price of corn is the meat producer, in the livestock sector, so really when we speak about the debate it's bio… crops for producing bio fuel but we are to think that they can go to seed and they can go to food for the consumers but most of the cereals that are ethanol go in general to feed livestock and in the end what is going to play a critical role is all how this livestock sector is going to mitigate the effect by using co products and by using products on one had, but also one a more land use perspective, if you think about Brazil, hold a huge amount of land that is used as pasture for brazil can now be used to produce some crops and to have more intensification of the live stock sector in brazil, more rationalization of this land use. I: So what are the in your opinion, what are the potential impacts on lands, on the other hand, do we have enough land in the world? P: I think we enough land to deal with biofuel, but the real challenge is, and I think once again I think it is a matter of scale, the challenge is that the planet has to deal with the increase in population, an income per capita from now until 2030, 2050 is a totally different scale from the relatively small problem of biofuel. Even 15 years of economy graph of China is going to build more pressure on land at the one level than the biofuel mandate of the US and the EU so the problem is that biofuel is going to marginally make things a little worse but in terms of priorities, you know the biofuel is not responsible for this so, yes we have enough land to produce biofuel, we may have also enough land to produce food for every one but it means that at the same time we need to make effort in terms of irrigation because land pollen is not enough and the water management will be a very important challenge that we have to face nearly everywhere, but also the use of fertilizers because we need to increase yield and we know that fertilizers have good aspects on yields but also bad effects on environmental. But also the technology, the GMO and more generally any increase in yield coming from better technology in seeds. I: And what do you think about the regulations, do the current regulations support the biofuel production across the world, in the US or in the EU, it doesn't matter? P: So all the different policies that have been implemented have radically created this sector ok, it not, I think, thats the important thing, (?? 16:12) debate, not the private sector or the private demand that have created the market for biofuel, it has been an artificial market that has been developed and even today survive only because we have regulation. So some regulation are going to just force people to use biofuel and lead to an increase of cost for consumers and other policies are going to give subsidies or tax credit like in the US to use biofuel and in this case it's, the tax payer pays the bill and in the US we can have some policies nowadays. So this market has been created by policy makers to address some of the goals they think that were relevant for their agenda, and if today you eliminate this policies, particularly in most of the

Participants	Interview transcription
	market, the biofuel production with collapse. At the same time we have this policy that has supported the production of biofuels we have seen both in the US and in the EU increasing pressure from environmentalists and green lobbies to try to limit the negative effects of biofuel and they are asking for more and more sustainability criteria, turned out and the problem in that in some case they also used, or maybe used as a protectionist tool because in the US and in the EU strong support for using biofuel if you are using domestic feedstock many of your producer are going and your farmers are going to get money for this, as soon as you say that the EU biofuel policies can be fulfilled by importing ethanol from Brazil and 18:22 oil from south east asia, you start to see more people that, in the private sector that are excited by the idea of having this kind of policy. So this is all the problem, we are reading with products and the sector that has been created policy makers that survive thanks to policy makers and so to directly or indirectly through, public money that may not be so good for the environment and CO2 emmissions, but was officially the goal, in particular in the EU. And so people try to now add new layer of regulation to limit potential negative facts and we don't really know in which direction things are going to be because if you look at some, systemic criteria that are added, they start to be a little like we have seen you know when, at world trade organization, ...start to put things on labour rights and this kind of things. You don't know where you have to put the limit between what the country can apply in this regulation without provoking trade disputes. I: Yeah, and how much you think that government support does the biofuel sector in the EU especially? P: So in the EU, first the ethanol sector in the EU, is far from being competitive so it needs border protection, so tread policy measures and at the same time it needs a domestic demand that has to be created by policy makers, in particular because, contrary to the US we are nearly all cars are going to work on gasoline, in the EU, and so gasoline can be replaced by ethanol. In the EU you have this issue about the fact that we are using a lot of cars based on diesel and for the oil industry and the refinery, right now they already, because you have some, you know technical coefficient when they are refining good oil they produce a given amount of gasoline and a given amount of diesel and in the EU right now, most of the oil producers and so the refinery have already a... of gasoline, compared to the demand of diesel. So they have too much gasoline and so they are not happy to see in addition the fact that you bring ethanol that costs much more than the gasoline, so for the ethanol sector you need to protect some, the ethanol that can be produced some where else, but you also need to force people to use this share of ethanol in the gasoline when the EU is already producing too much gasoline. So without strong public intervention you don't give room for the ethanol sector in the EU. For the biodiesel and particularly nowadays more than 85 percent of the production of biofuel in Europe is biodiesel, for biodiesel the EU is more competitive because they have a larger set of feedstock in the oil seeds, so rape seed, but first of all rapeseed can be used for other things. That is produced in Europe at a really competitive price, this rape seed also produce ...so the coproduct that can be used by the livestock sector in Europe so there is already, I would say, a commercial and industrial pattern that can absorb this sector and the fact that the EU has a strong consumption of diesel for it's cars and I have told you on the diesel side we are a little short in terms of diesel production from fossil fuel, so the biodiesel here is more, can place as a role of the compliment, but for the problem we have with the biodiesel production, is that the biodiesel production in terms of land

Participants	Interview transcription
	use effect and potential, even the processing of the ...oils to make it the biodiesel is much more intensive in energy and the emission balances out, the biodiesel is less good. So from an economic point of view, the biodiesel sector has more probability to survive without policies but at the same time it is less good in terms of environmental impact. I: Yeah, and another question is, have, I mean, other green energy sources affected the biofuel expanding, or not? P: So I think that one of the problems between biofuel and other green energy based not on biomass is the fact that we have focused a lot of energy and money on biofuel when they should have been used, I think much more efficiently in other domains relative to green energy. At the same time, for the, atleast for the EU market, one of the real challenges is do we need, do we want to have cars running on biofuel or do we want to have electric car. And so what is in terms of infrastructure, but also research and development, or even tax incentives for the consumers, what is done in terms of electric cars, because if you think that electric car is going to represent 20 percent of the EU car fleet, all biofuel story with the 5 or 6 or 7 percent mandate, or even 10 percent target, will be achieved without biofuel so you don’t really care, and it's producing energy… producing electricity, we have a lot of technical solutions that can be achieved using green technology, the solar, wind or even biomass, but we have the widest, the wider sector of options and maybe focusing too much on these biofuel story, both in terms of political capital, political investment but also in terms of money and economic investment, was not so well thought at the beginning. I: Yeah. And my last question. Some experts say that anyway the pressure would be on poor people in developing countries do you agree with them or not? P: So we are going to, if we look at the poverty side of the biofuel. A lot of people get excited at the beginning on what I call the demand and on the food price history, and after ... we cannot say that there is no impact, that this impact has been relatively low, and particularly there, a lot of other policies that are implemented today that have a much different impact on poor people in developing countries than the biofuel and already there too much excited to talk about it. But lets say that on some assessment I have done, yes because it has impact on food prices, it will have an impact on poor people because spend a lot of money on poor people and this impact can be about maybe one, up to two dollar a year per capita, if you try to assess the cost of theses EU policies for African people, you say in the worst case it is between 1 and 2 dollar a year by African. So you see it's less than 1 percent, so it's not so large, it still exists, we cannot negate it but it's not going to lead to a shift in poverty, this is impact on food but on the demand side you have also to think about what's happened on energy. And what is the cost on, what is the effect on oil prices and the side effects of the change in oil prices because if EU and US and more and more countries use biofuel it means that the demand for fossil fuel decline and that the price of fossil fuel will decline, so for other consumers of fossil fuel it's going to be good news. And you have a lot of poor people in the developing world that are still using for example, diesel, for producing electricity in (??), for generator because we don’t have another source of access to electricity so, and for them it's still an important source of expenses so the fact that you reduce the price of oil will also allow them to save money. So you have this

Participants	Interview transcription
	channel and depending on which country and which poor people you are dealing with, the channel can be more or less important. At the same time you have poor countries, lets say Angola, for which most of the income depend on the price of oil, so the fact that you depress the price of oil on oil markets from biofuel is going to cost this country money and if you were, so the problem is in many case what people are doing with the money ok, so in some country you have good governments, it's going to be invested in education, health and so clearly if you start to limit the money coming from oil to these government, it can have an indirect effect on public services, on poor people, at the same time, if you are in the country with bad governments who have this money could go to corruption and to wealthy people, is not a problem if you bring back, if you bring down oil prices. But this is what I call the demand side and we may see much more strong effects on the supply side and particularly how poor people are going to be impacted as producers by this biofuel. So for example you have for the production of palm fruit you use a lot of labour force and if the European union uses more biodiesel and more palm oil, at the end, producers and also workers in this sector in Indonesia are going to gain from this policy because they are going to be part of a sector that is expanding, you will see competition on wages in the region where you produce this so, and they are going to gain much more from this than any impact on their food price. At the same time, in the case of Brazil what we have seen is that traditionally for the sugar cane sector it was labour intensive and you have people going in the sugar cane field and cutting the sugar cane manually but now with the increased demand and the mutation of the sector you see more ... with the previous technology of production it will have been good for poor people in Brazil in particular because when you know the region where sugar cane is produced, the people that work in the sugar cane field are very poor ok, so more demand for their work would have been good news for them. But now we saw that the sector is changing and people are going for more capital intensive procedure mechanization. And in this case they are not going to gain, so the poor people are not going to gain anything from this mechanization and in this case if you think that the increase demand on the ethanol sectors have put more pressure on producer to become more efficient and more rational and go more quicker to mechanization you can think that it had a negative effect on these poor people. Last channel still on the supply side is as we have discussed before, you need more land to produce biofuel like any crops, the question is where this land is going to be taken and what is the kind of property right that is going to be implemented with small holders, in some news you have seen that people are complaining about the land grabbing that can take place in Africa, when you see some investor buying land with the government in order to produce biofuel or other crops, but biofuel is a part of the story, for the EU market and 6 months later you discover that you have small holders on this piece of land that have initially no real property rights because it was the government that was owning this land and these people are just kick out of their land without any kind of payment and so for them the situation is worse and the real issue is if you think that small holders can participate to the production they are going to gain, but if you think that, due to the demand, due to the need of increasing yields if you don’t want to use too much land we need to increase yields and if you think that this technical evolution is not compatible with small holders as it has been the case in many countries, you know, when you have change you are ... when you want more yield, more mechanization it means in general the disappearance of the small farms and the expansion of larger farms managed more like a ...not like a house hold. So if you think that to achieve this increase in yield, this

Participants	Interview transcription
	increase in production for biofuel, we need to push away the small holders from the production cycle, it will be bad for them. So what I just want to say that I really think that for poverty impact, what is going to happen on the supply side of biofuel, in some case can be much more important than what is the demand side, but we have discussed a lot until now. I: Thanks so much, thanks so much for your time. P: Good luck for your dissertation.
Participant D	Interviewer: So let's talk with you about your views about the future of fuels in common, and biofuels share in the next, lets say 3 decades, and is biofuel going to have a larger share in fuel markets in the future? Participant: Ok. Well first thing I will say for context, I tend to think, or we tend to look at things at the European level more than sort of member state by member state so while I did used to work at the UK biofuel regulators, so I certainly know the UK market better than the others I dont think too much specifically about the UK side of things so I will sort of try to speak to Britain but to some extent... I: In Europe, yeah. P: But to some extent talking about Europe. I: That's perfect. P: So it's a sort of a difficult question to answer with any clarity at the moment because the policy situation is quite fluid. If you'll excuse the pun. It's not really clear whether we are going to see an aggressive push to increase volumes of biofuel which has been the trajectory for the last 10 years of 5 years certainly. But given concerns about food versus fuel and indirect land use change and, you know it's (10%?) slower than anticipated commercialisation (1.49) of some of the, some of the next generation technologies. It's certainly plausible that we might… I mean one scenario would be that policy sort of pushes through until 2020 based primarily on first generation biofuels and that then that gets extended beyond 2020. And you had a sort of a fairly robust market penetration. All be it that you know, you've done food impacts and some indirect land use change and it might not be that clear how beneficial the whole thing was from a carbon point of view but in that case you know we might head towards, well we will probably head more or less to the ... by 2020 in that case so you'd be sort of looking going to E10 and B7 and then the sort of distribution maybe becomes the most important. How do you actually get fuel into the market and that might be a serious issue or you might be able to work around it and it sort of you know depends on some extent to political will and whether anyone, what I suppose the cost is of the drop in fuel technologies. So I mean that's not very categorical. I mean that's sort of one trajectory. Then alternatively we might get a relatively sort of… I suppose conservative if you like policy change out of Europe because of this concern about indirect land use change you might downsize the amount of conventional biofuel used. In that case you are going to see for the next certainly in the next 15 years maybe a sort of a refocusing, or maybe not that much additional volume. More of a sort of a shift than an increase in terms of absolute volumes but sort of a phase out of the first generation biodiesel capacity in particular. And a move would

Participants	Interview transcription
	hopefully would be a more sustainable footing for the industry and you know, maybe not delivering that… I mean I think everything that's on the table policy wise at the moment would involve some degree of increase in volumes to 2020 and then beyond. I mean you might be looking at a relatively mild sort of, total increase to 2025, and then if the technology is working and its cost viable you can imagine quite an aggressive increase after that, or a somewhat aggressive increase after that. Then the third sort of trajectory is whether to have a renewable target at all after 2020 is up for discussion at the moment. It's not a given that there would be the type of policy for support in the next decade that there has been in this one. And I think it would, I mean I would see it as unlikely sort of depending on how the next 5 years go and how politics shapes up. It would seem sort of surprising if the rug was pulled completely away under the feet of the biofuels industry, especially if we do have some success in commercialising new technologies but one scenario is that people just back away from renewable in transport all together and there would be legitimate reasons for doing that, sort of refocusing on other climate mitigation methods and so you know I suppose the worst case from the volume point of view would be that you would actually have a sort of a drop off through 2030 and then beyond 2030 its always sort of anyone's guess quite where things go. So there's I don't know, there's three versions and it's mostly policy driven but somewhat technology driven. Sort of robust growth including the first generation and then more of a transition scenario, and then a sort of a give up and do something else. I: Yeah, you mentioned about some of the policy and regulations. What's your view on EU regulations on biofuels? Do the current regulations support the biofuel production in the future? P: Well as the legislation currently stands it certainly… I think it's fair to say that it works, in the sense of getting biofuels into the fuel mix. And you have a couple of question marks around sort of blend wall, but if they did… If you did not change legislation you would get to whatever it will be 8-9 percent biofuel by energy in the fuel supply by 2020 I think that's sort of reasonably clear. In the place where the whole policy falls down is around the carbon question and whether it's actually delivering the carbon saving that it's supposed to be and the ICCT along with others have done a lot of work on indirect land use change and I would say that there's fairly strong evidence that biodiesel, or the current generation of biodiesel is not delivering any carbon savings so current policy is working for volume but I'm not convinced its working in terms of the actual climate objectives. I: Yeah. And is chance for biofuels to complete with biofuel in the future? P: In the sense of getting biofuel production costs down to sort of price parity with crude more or less. I think that's very plausible, I think the… one would expect to see that second generation biofuel technologies will get sort of cheaper over the next couple of decades and I think there's every opportunity in principle to get the production costs down so that production cost matches or you know goes lower than the sort of retail price or wholesale price I guess of crude oil. I mean in terms of looking at the production cost of most crude oil, that's pretty low. If you see what I mean, the cost of the Saudis of getting the stuff out the ground is a fraction of what it retails for so, I mean I think what you'll see is that probably we will have some biofuel production pathway at genuinely cost competitive with the oil price. And whoever, you know whoever

Participants	Interview transcription
	gets working will get quite wealthy so that will be nice for them but it's not, I think, I mean some people expect to see biofuel pull the oil price down and I think that's quite optimistic. You'd need an awful lot of fuel and an awful lot of cost savings before biofuels are really going to start undercutting. In terms of what the consumer pays I think for the foreseeable future the price of biofuel will be the price of well… certainly a drop in biofuel would be the price of the equivalent of the fossil fuel plus a bit of a sustainability premium and that's what you'll pay to some extend regardless of how much it costs to produce. Although, I mean it all gets a little more complicated when you think about the actual deals and off take agreements. People might be signing with producers, but I mean I think that's the basic cost story in terms of the price to the consumer it's just going to be a little bit more expensive than crude oil regardless how much it actually costs to make the stuff. I: So you think that biofuels industry need government support for the foreseeable future? P: Yeah, there's no question at the moment that if you took away policy support most of the industry would disappear, I think fairly quickly. There's, players out there – beta renewables, guider reinheart… no I don't mean them… I'm getting my guiders mixed up. Anyway I cant quite remember the chaps name but there's a guy from beta renewable, an Italian guy who goes around reassuring everyone that he doesn't need or want policy support, maybe he doesn't but I think the model that we are going to be in is that people will have government support, they will need government support and as you move to sort of second generation biofuels, waste and residue feedstocks, the biofuel producers will actually compete their own costs up by competing with each other for feedstock and that will sort of so the cost of producing biofuel given government support will actually be higher than it would be without it because of the increased feedstock demand if that makes sense. I: And what kind of support is needed if you are going to recommend it to policy makers, what kind of support do you think is better? P: Well it depends which phase of industrialisation you are looking at. I am minded to think that for the commercialisation stage, sort of the first 10 plants say, or 20. Some of these technologies, or even advanced technology as a whole, I would be minded to say that mandates which is what we largely have in Europe at the moment aren't that well suited to technological commercialisation so I would be very sympathetic to fiscal measures, sort of simple tax breaks that sort of stuff, but it's not, you know, the pendulum has swung away from that sort of support to a great extent. I think what would be best is something that gives a really well defined financial value to the first few operators and then transitioning to sort of mandate support a little later or, I mean I think what we are looking at at the moment is a sort of a combination of potentially support through targets and various sort of infrastructure funds and apparently there's a 4 billion euro public private partnership fund which is going to be available so there's a combination of market guarantee and a bit of actual money to help get things moving. I: And back to the biofuel generations, which generation would you, do you think would be more promising in the future? P: Well I prefer not to get hung up in arguing about what's first and second and

Participants	Interview transcription
	third and fourth, I think you read a dozen articles you will get a dozen different definitions of what an advanced biofuel is. The basic combination of territoistics, I think that we should be looking for, ideally, is a technology that allows you to use cellusoic material, a technology that ideally produces a dropping fuel at the end and feedstock which is quite quite clearly sustainable. So waste and residues or sort of appropriate sort of waste and residues being ideal and a, having a range of feedstocks I think will give people extra robustness. So that's the combination you can have, in something like ... you can have a hydrogenation technology which is sort of an advanced technology in the sense of being quite new, it produces a dropping fuel but it has primarily been using palm oil as a feedstock and I don't think there's a future for that, I certainly don't think there should be but if, you know, if someone, you can get economically get Fischer tropsch fuel working in from agricultural residues, say that would be the sort of pathway that I think would have a lot of promise. I mean what seems, what's possible, or what some of the ethanol guys tell me is that its just gonna be cheaper to do ethanol and I think. So an advanced technology and a good feedstock but a fuel that isn't dropping, I think that's fine but I would be surprised if we could see a real roll out in Europe of high ethanol vehicles but its, its certainly a possibility. Especially countries like Sweden where there's a bit more policy appetite for it. I: And some people, some experts say that with the discovery of shale gas you virtually never need to use biofuels any more, what's your view on that? P: Well I think the need is the same as it ever was. I don't think shale gas really… I mean I suppose if you a energy security nut which some people seem to be then… and if you believe that the shale gas in Europe is going to scale up like it did in America which is a contentious conclusion then you might say ok, energy security wise we have all of this gas in Europe we can use that, it never comes to the… you know the technology exists, it'll be no more expensive to convert gas to liquid than to convert biomass to liquid so you could actually use some of the technology so from a pure energy security point of view then I guess maybe they are right. The climate change point of view, shale gas to liquid isn't going to deliver you any benefit at all I don't think there's going to be an appetite to move the whole vehicle to compressed natural gas or liquefied natural gas which would offer some moderate carbon improvement. But you know in terms of climate change and in terms of wanting to throw some money at farmers which has always been part of this then shale gas can really do it. I: And you mentioned the environment and climate change, what are real advantages of biofuels in terms of reducing greenhouse gasses and in climate change? P: Well as I say, we consider indirect land use to be a significant problem and we think especially for biodiesel from vegetable oil, the evidence suggests that there is no carbon benefit, certainly over a 20 year period or 30 year period. So there's not short term cut, climate mitigation advantage. And that is the way that agriculture is linked to deforestation and loss of carbon rich habitats of one sort or another. You know all that said then there's certainly some pathways like I say based on wasted and residues stuff like agricultural residues, all that sort of think which clearly offer some significant benefit. There's sort of pathways around municipal solid waste collection and use which can offer significant additional savings by preventing waste decomposition and methane emission. So there's pathways that will be very beneficial but I think the weight

Participants	Interview transcription
	of evidence as we read it suggests that for Europe and America, biofuel policy to date has not delivered… has not delivered any carbon reduction over all, certainly not a large one, I. And do you think that in Europe especially we have enough land for biofuel cultivation. P: I think it's the wrong question, and this is something the European environment agency looked at this a few years ago, how much land would be available to grow biofuels. And the answer is in principle there's enough land to grow a lot of biofuels. The reality is we live in a market economy, we live in a, you know, a globally connected world and it's actually illegal under trade treaties to say we are going to use biofuel from Europe. So really the question isn't whether we have enough land in Europe. The question is where the material is actually grown and in that case the question isn't enough land, the question is are you going to, is there going to be an intelligent selection of the right land of are you going to end up competing with food production and causing deforestation. And the answer is that at the moment there isn't enough… global agricultural governance as such that you will end up competing with food production and driving deforestation whether you want to or not, and so within that context it's not about enough, it's sort of you know, there's enough money in the world for me to be a millionaire but it doesn't mean I'm going to become one. That's what I'm saying. I: And one last question to wrap it up. Are you optimistic about the biofuel? P: I think optimistic might be the wrong word, I believe that there is a opportunity there but I also believe that there is a substantial risk and I think at the sort of the small level, the short term level there's a risk of increasing carbon emissions rather than reducing them and sort of wasting a lot of time and money doing it. I think in the longer term there is a question about sort of thinking more ecologically and sort of speaking personally rather than institutionally I think there is a question mark about how we think about the global land use and whether… You know there's a sort of a scenario the international energy agency sort of points in this direction with their 2050 road map and there's a scenario where you start to move toward choosing every bit of land that's available that isn't being used for food to grow bioenergy crops and sort of ecologically speaking that has an implication. And there's a good version of that where you sort of protect forests and high bioversity eco systems and there's a bad version where you don't really have any effective protection at all, but in either version it does imply a big shift in whatever sort of passes for natural, relatively unmanaged landscapes to having the entire world dominated by managed bioenergy landscapes and I think this should be a big decision for the world as a whole, this isn't something that people should walk in to without reflecting on whether that's sort of really appropriate.
Participant E	Participant: So what will be the future fuel…? Interviewer: Future fuel, yeah. P: Very difficult to answer because... so many things… erm I: What do you believe in, in future, I mean, maybe... P: I mean, I think, I think biofuels have their place but I think in Europe the

Participants	Interview transcription
	findings of the vote on Thursday are very very negative and will damage and emerging industry and biofuels with struggle to make money for anybody into the future in Europe. I think there will be much more interest in US and Brazil and it will remain that way for quite a long time until, as you say, the price of crude gets so high that biofuels become more interesting in Europe. You know, when there no need for a mandate. You know, if ethanol is cheaper than petrol then people will use ethanol. But that's a long way off I think. I think the finding of shale gas is going to slow things down. And there's going to be a major lever on the interest in biofuels. So I think for now... um... I think the European parliament is losing its focus on why we want to do biofuels. And why we want to save green house gas emissions. So for example I was just reading in the text that they are going to allow, um, fuels made from carbon dioxide as a biofuel, which clearly it's not because the origin of the carbon was fossil, if it came out of an oil refinery so it doesn't save any green house gasses. In effect it's just a higher efficiency of use of the... err, existing fossil reserves. So yeah. Very depressing I think. I: And if we focus on biofuels itself among different generations of bio fuel, first generation, to third generations, which one is more promising in the future in your view and why? P: Well I think they are all promising and they all have their place. If you were wanting to replace fossil fuels, I think, you know you have to take into account energy density and biomass, what type of type, first generation or second generation. And so therefore you need to think in terms of layers of, of alternatives. So I, in my opinion you should always have first generation biofuels to five, six, seven percent. On top of that you can layer on second generation biofuels. Another 10 percent or so. And so on and so forth yes. And so you come to the, the wedges... Not Harvard, it's another US university beginning with a P. Princeton Wedges, have you ever come across that theory? I: No, no. P: It's worth looking up, and thinking about. I can see we live in a fossil world; fossil fuels are very, very energy dense. Biomass is very different. It arises in, in dispersed sources, wide areas. And so it's very difficult to get the energy density benefits you get with fossil fuel. So that's that. Future fuel, you're looking in the next ten years. You've essentially got to look at what cars are in the showrooms because cars last twelve to fifteen years, before they are thrashed. So the cars in the showrooms today are going to be on the road in 2030. You know, if you go around all of the car showrooms you can see that, yeah there's a few electric cars, but most cars that's going to be around in 2020 are going to petrol and diesel fuels. They are not designed to burn, sorry, to be electric powered. Or very few of them are. Petrol cars I think are suitable for E20 nowadays, the new ones. So you could potentially have a higher ethanol blend, but the new tax from the European parliament will slow that down. So I think we are going to be seeing a... Future fuel is still going to be fossil fuel over the next 10 years. It going to be 5, perhaps 10 percent biofuel. That's going to be about it. The cost of second generation biofuels is going to be too high for the next ten years. I: And you said you think, even first generation biofuels are necessary at some stand in future. But many experts are against it because of food versus fuel

Participants	Interview transcription
	competition, what do you think about it? P: In terms of people being hungry, it's a means of argument about disorganization. There is enough land to make some biofuel, a small amount, 5 or 10 percent, something like that, and if I think about rape seed, we have to grow rape seed because otherwise the wheat yield would go down. It has to be grown for the sustainable rotation. And if you haven't got a market for that rape oil, use it in biofuel. So if you increase the amount of wheat land, or increase the efficiency or growing wheat you will make more rape oil and you will make more wheat for bio ethanol. Farmers need new markets. If you limit the markets they go into, then the existing people like Unilevel who buy, you know, a lot of vegetable oil, can keep their prices low. Their feedstock prices low. So there are a lot of experts who are paid by the likes of Unilever to say, no biofuels are wrong. You know if I said to you, should Europeans be allowed to wash their hair every day, because shampoo comes from palm oil. Yeah. It's a silly argument because... shampoo is just a little squirt, but it comes from palm oil and so that's an increasing demand which is not a food. Should we be allowed to grow tobacco, yeah you could, you could say that tobacco is a non food crop and you know it's an irrelevance. I: Yes. P; where as energy is really important, without energy I can't grow food. Without energy, I can't make things, I can't move about. You know it's... This thing where people say, oh well its rich people moving about, you know, you've got to move food in trucks. So I get really quite irritated by people putting energy at the bottom the tree when... you know, I am an energy engineer, without energy, you cannot do anything so... and without reducing our greenhouse gasses we are going to have a problem with global warming. So how do you address emissions from transport and all these hold ups, holding everything up. I firmly believe we should try a little bit of biofuels and see where it gets us. We can't model our way out of this, you should set a target, 5%. Do that for ten years and see what it does. I: And if we focus on the UK, the history of biofuels in the UK was not a real successful story. How do you see the future in the UK? P: Very weak. Let's take first generation biofuels. Food can always out compete fuel on price; you always pay more for food than you do for fuel, if you think about it. The price of rape oil is now more expensive than diesel, because the food market has taken off. So we will continue making biodiesel from waste oil, I can see definition of waste oil being a problem because as soon as 00:09:01] waste oil becomes in demand, people start wanting it, they start paying more for it. So people, instead of frying chips all week in one batch of oil, they will fry chips just for one night in oil. You know, so we will carry on I think using as much waste oil as we can to make biodiesel. Wheat, yes we have some bioethanol plants. Two major world scale bioethanol plants, they will operate and they will do their thing. There's a third one planned, I don't know if that will be built now, but I think it will be fairly stagnant. I think the companies involved will look to sell their bioethanol abroad perhaps. So I think there will be this thing where we are buying in worse bioethanol than we actually produce, because the bioethanol we produce has got, you know it's high value material because it's got high green house gas savings.

Participants	Interview transcription
	Second generation, unlikely to happen, or if it does happen it will be very small, and it might be this way of demonstration plants. Because the UK is badly served, by well it doesn't have much land. It's very population dense, we don't have much forestry, we are not encouraging the growth of energy crops and there's new rules, doesn't encourage use of energy crops for biofuel. SO you've got to bring all of the biomass into the UK and because biomass is not very energy dense you might as well make it abroad and then ship the final product, yeah. So I don't see that we will build many factories... And it's also very, very difficult to build factories in the UK nowadays, people don't like them. They like to have the jobs but they don't see that it... the don't see the link between you've got to have a factory to have the jobs, you can't, and people are very stupid. Erm. Third generation biofuels, algae is not going to happen in the UK because it's not, not enough light and heat, it might happen abroad and again we might bring material in. Again I worry about algae because you need large... If you are going to build large ponds you need to cover large areas with water, perhaps concrete or plastic and that to me is a worse situation than, erm, standard first generation biofuels. Growing algae in the see, you know we are going to grow... modify the sea, is that the right thing to do... That's a problem. So I see the UK doing the bare minimum. It'll say a lot of words but it will do the bare minimum. And I don't see any growth. I: And how much government support does the biofuel sector in the UK need? Is current support enough? P: It's very weak clearly because nothing is happening. They introduce the RTFO and messed that up so the value of the certificates is lower than the buyout fine. DFT, err, clearly were relying on first generation biofuels to meet the 10% target. We decided, we had done some sums to decide that it probably could be done, the 10% target first gen biofuels. It's belated realised that the European parliament going to put a cap on first generation biofuels so do it now needs to invest time and effort into some sort of second generation demonstration plants in the UK and has announced a project to invest 25 million. Unfortunately 25 million is not a lot of money, sounds a lot but if you think about a Fischer Tropsch plant, it's going to be about half a billion pounds, first generation wheat ethanol plants are about 300 million pounds. You know 25 million doesn't go a long way to build the pilot plant. So the first thing... unfortunately is that you always need an end in mind and you need a fixed target that's not going to change and history has shown that biofuels are too dangerous to get into from a business sense so... yeah. I: And if you want to recommend some policies to the government to support biofuel production, what would it be? P: Nothing now, they've decided... essentially they have decided they don't want to do biofuels, they want to backtrack, and they want to get out. It, it's not what should you do, you've got to decide, do you want to do biofuels, and I think they have gone beyond that and I think they have got to the point where they have said, we like biofuels but it's too hard and we can't get over this so we don't want to do it, we want to get out. If you want to do biofuels the RTFO is a good mechanism. You need a set target with something for industry to aim for. And to agree that that target is not going to move. And if that's not there then there's no confidence. You know an industry needs a market to sell to that's big enough so that they are not going to be stuck with bioethanol on their hands, or

Participants	Interview transcription
	biodiesel that they can't sell because nobody wants it. Because you've got to stand up in front of your directors when you are pitching to say I am going to build a biofuel plant, directors going to say how much can you sell the material for, can you sell it all. If you can't do that then you are stuck and it's a mandated market, it's not a market that people will buy biofuel just because it exists. They will buy biofuel because they are told to at the moment. I: And in your view, would biofuels be able to compete with crude oil at some point in the future at all? P: Yeah possibly, but it's a long way away. I: Any time... estimation for that you have. P: No because I can't predict the future of the price of crude oil price. I mean I've previously worked out, it might be sort of 120-130 pounds a barrel, where it starts to get... equate. And there are some deck future crude oil scenarios that you can look up and that gives you an idea, a low central and a high. But the problem, as far as I can see is that shale gas is going to be a game changer and, for the expense of shale gas you can turn, if you use GTL technologies to make diesel from gas. And that's going to be, that's going to depress crude oil prices and I don't know how long for. If you'd have asked me this before shale gas existed I'd have said perhaps 10-20 years. I: And would you please tell me a bit more about shale gas, how you think that will affect the future of energy in the UK? P: Well clearly if you have large volumes of a low cost fuel available that can be turned into, sorry, yeah which is gas, which can either be used directly in transport or converted into a liquid form. It's supply and demand so, you know, you've got a higher supply, demand can't keep up. I: And my last question, apart from gas, I mean traditional oil and gas, and biofuels. What other options can be considered in the future for the UK for energy? P: For energy as a whole I think we need to invest time and effort in, in nuclear power. I think we need to look at our resources that we have and place them in the most effective way possible. So I think, you know, you should be thinking of using biomass, not for fuels... It's good to use biomass for fuels today because you can think about using them for chemicals and aviation fuels in the future for which you have no other option, so you've got to think, you know, develop electric cars, that's fine but you need to develop the low carbon infrastructure to deliver it and you need to be able to deliver that from something... Unfortunately you know, again is the Princeton Wedges, you've got to think about wind, wave, nuclear, and nuclear in a big way, probably... You know High Speed 2 is 50 billion investment, well that's going to buy 20-25 nuclear power plants. Should we be investing in a new railway line where there already is a railway line between Birmingham and London or should we be investing in 20 nuclear power stations which can provide us with 50-60% of our power requirements, perhaps more if you start thinking about investing in large scale electric vehicle fleets because clearly you are going to need, you know, investment in grid... electricity grid infrastructure to take the extra juice. You are going to need investment in... Extra power stations. I mean you could

Participants	Interview transcription
	work it out, we use something like 37 million tones of diesel and petrol, you could turn that into KWH and then work it out into a kilowatt capacity of a PowerStation that you need. So biomass whatever form, first generation, second generation, is the only source of renewable carbon. And chemicals rely on carbon, if you want renewable chemicals you've got to use biomass. You can't... you know, it's very difficult to make renewable chemicals if you don't know how to make renewable biofuels. So for me it's about thinking about the resources we have and thinking about the applications we need to do and placing our resources where they are. Now biomass, is a restricted resource, and the first thing people ask is what's the best thing to do with the biomass and people often say well the most efficient thing is to burn it and make heat. For me that's a waste of the renewable carbon atom. Yeah. Yes you've got the most energy out, but its heat. It's a low grade form of energy. Surely you should turn it into aviation fuel if you can. Now that efficiency is half the efficiency of making heat, but I've made aviation fuel which I couldn't make any other way. So for me, you know, there needs to be an overarching energy policy that looks at everything that we do that has a need, manufacturing, chemicals, aviation, trains, shipping, etc, etc. And then work out how each can be delivered, before you start looking at how you use biomass to deliver that. And then finally you get to a whole pile of things where you've got to use biomass for that.
Participant F	I: Would you please tell me about the long term prospect for liquid biofuels up to 2050? Do you think, is there any future for liquid biofuels? P: Definitely. Liquid biofuels are part of our economy today. Here in the US we produce already 14 billion gallons per year of liquid biofuels, I think it will be part of our future, it's a necessity, there are transportation methods that… such as aviation that do not fund themselves through any other options. I: And what do you think about the future of first generation of biofuels, from corn or anything, do you think in 2050 they are going to be the… first one or the second or third generation going to be? P: Yes I do think that some are second generation biofuel plants, will start to then come online by 2050. And we will see some production, you know I am not a producer and my organization does not manage production or anything like that so I can't tell you how much but I am sure you can find that information . But I do believe several plants are currently in the process of being developed that use other, other fuels other than second, other than first generation. Definitely here in the US we consider sugar cane as a second generation biofuel and as you know that is already a very established biofuel feed stock. I: And what other options other than biofuels would be considered for the future in your view? P: I think, as I said, we will see cellulosic feedstocks and… sugar cane feed stocks being a major part of our future in biofuels, but I think we will start seeing some of the oily plant and especially algae plants come online but I don't see that could be, the oil crop plants such as… algae coming on line until probably into 2020 right now.

Participants	Interview transcription
	I: And what's your reason, your not very optimistic about algae, what is your reason for that? P: I am very optimistic about algae, it's just a younger technology, it's just really getting off the ground. We are seeing the first few pilot plants being set up, we certainly have quite a bit of production, in the hundreds of thousands of gallons from heterotrophic algae by a company called Solosine that is already being done, but if we are looking at phototrophic algae, that's a bit harder technology and not as economically feasible with the current… current technology systems for cultivation and harvesting and it will take a little bit longer to make that economically feasible technology. So we are just seeing the first few hundreds of acre type test pilot plants being built here in the US And those will probably come online. Some of them are coming online this year but full fledged online probably not until 2015, 2014–2015 and that's our test pilot scale, hundreds of acres. To get to a level where you can say this a commercial, commercially viable plant you'd probably have to get into the thousands, and tens of thousands of acres size. That's, this is a significant step and I don't see that happening until the 2015–2020 time period. I: And what are your views on US or EU regulations on biofuels, do you think that the current regulations support the biofuel production across the US or EU in the future? P: Yeah I think the, you know certainly within the US, I'm not as familiar with regulations in the EU so I am not going to comment on those but within the US the atmosphere, the regulatory atmosphere is to... the regulations necessary to make this industry viable we see quite a bit of investment from the government where there's a number of incentives that the government has put in place, those incentives obviously are at a political whim depending on the administration and congress but you know I think that will be overcome as the industry matures. We see quite a bit of investment going into this area, it's not enough in my opinion but I think that it will continue. You know there are obvious permitting....issues and environmental issues that need to be overcome, that we need to work through but I think as the industry matures we should be able to put in place the right regulatory measures and environmental measures to make sure we protect the, the you know the interests of the nation and at the same time a lot of the industry to, to move forward. I: And if the prices of crude oil remains relatively low do you think that still, the biofuel grabs attention of governments? P: I certainly think that the price of oil has some, some impact, or quite a bit of impact as to the appetite from the government to, to move forward into these initiatives but I don't think it's the only reason for the government to move into these, into these areas, there are national security reasons for moving into these areas, there are environmental impact issues that need to be addressed both for the petroleum industry and other energy industries that need to be addressed and obviously climate and world change, which affects all of this picture. In my opinion it's a very complicated overall analysis and I think petroleum prices by themselves are no longer the only driver. I: And what is the turning point price for petroleum and what's going to happen if the governments can, want to focus on biofuel for future, not just US

Participants	Interview transcription
	government, across the world? P: I think we are seeing across the board in the world quite a bit of a change and biofuels being more a part of national initiatives. You know, there are a number of countries that have, that have energy security acts, or something similar that mandate or ask for a certain percentage of their petroleum fuel consumption to be replaced by renewable fuels. You know and they are still in the small, small levels in my opinion but that is changing so I don't think, again I don't really think it's driven by price any more. I: And what are the environmental impacts of biofuel in your views, positive or negative? P: Well you know I think the positive components of biofuels is there renewable component, utilization of land plants and aquatic species that utilize carbon dioxide is a positive effect on the environment. There is, obviously the negative impacts that need to be considered and they need to be appropriately addressed which are, that if one does not do this correctly the carbon dioxide, utilization is no longer neutral or near neutral and you know, it may not be feasible to cultivate starch based corn biofuels for very much longer for example, but there are other options such as cellulosic and algae and sugar cane that reduce CO2 admissions significantly. Other environment factors are water and land use, which are major resources that we need to contend with, there are nutrient utilization resources that are major impact on the environment, phosphorous and nitrogen and obviously other markets such as agriculture which need to be, need to be considered in bringing a large biofuels industry on board . I: Yes and my last question. How much government support does the biofuels sector need in the US do you think? P: Need or has? Need is a big question, you know, if you… I'm not sure I have a number in mind, that's a very tough question, you know obviously the more support you can put into it the quicker and faster you can move into it. I: Yeah lets ask in this way, do you think (?? 12:12) in the future the biofuel can survive without and subsidies and any governmental help? P: Yes. I: And when, timing in important I mean, when do you think its going to happen? P: You already see it, corn ethanol, the subsidies for corn ethanol are being removed, this past year or so and the industry is still moving forward. So I think that's, direct subsidies where you have the government essentially giving you a price per gallon produced or something like that, I think can be removed. Whether one can claim that's the only subsidy it's being given to a particular industry, that's another matter. You know even the petroleum industry get benefits significantly from a number of government subsidies. So I am not really sure that that's and issue just for biofuels.
Participant G	I: Thank you so much, Lets start with the future, in your opinion is there any prospect for biofuel at all?

Participants	Interview transcription
	P: Well, yes, it's highly contingent in my view on the competitiveness with fossil fuels. I gather when you are talking about biofuels you are talking about liquid biofuels…? I: Yes, mainly. P: As opposed to... for electric power production. So in the united states the prices for gasoline, for diesel fuel are going to be critical in determining whether or not particular technologies ...can be competitive with, with the fossil fuels. Right now the department of energy in their annual energy out look is some growth in fossil fuel prices and of course there are efforts to advance various technologies both biochemical technologies to convert biomass to primarily ethanol and then thermochemical technologies to convert wood material to… it could be ethanol, it could be diesel it could be a number of other Fischer–Tropsch sorts of liquid so I guess the prospects to me are very highly contingent upon the you know, the trajectory for fossil fuel prices and that of course is driven by considerable uncertainty in you know sources for fossil fuels as we are seeing you know, unrest in the middle east. So I say it's highly contingent on fossil fuel prices but if fossil fuel prices you know continue to rise, I've seen projections you know for world oil price going up to 120 dollars more and I've heard you know industrial producers in the united states saying if there is a sustained price in oil, you know 80 dollars or above they thought that they could be competitive, so, it's a matter of the confidence of investors that there will be this price differential… that will sustain a profit… to allow investment. I: And do you think that the current regulations supported biofuel production in future? P: Well the, my area of knowledge particularly is wood sources and the energy independence and security act of 2007 restricts wood biomass sources a fair amount too… particularly it excludes wood from most federal lands, most federal forest lands and it excludes wood biomass from forest areas that aren't planted which eliminates quite… a non trivial fraction of forest land. So there are those restrictions which will limit availability but in the projection work that I've done or estimates I've done with others we, there are wood biomass sources that could provide in the order of 4 billion gallons of ethanol equivalent, but that requires so expand… some loosening of the restrictions of what's… what are under the current energy independence and security act which does limit amounts of material from planted acres. So your question on the regulation, the regulations that restrict biomass sources, there are economic supports under the becap program biomass, what's the acronym for, it's not coming to me, but the becap program is meant to be a monetary incentive for a very short time period to get feed stocks in use from sources that aren't currently being used, like wood residue or... rotation woody crops which really haven't taken off very much. So those are, the restrictions are sourced of regulations. There are also a lot of supporting, I guess, regulations in terms of targets by individual states in the US, there are renewable portfolio standards which have targets for, now this is on the electric power side as opposed to biofuels I guess, the renewable portfolio standards aren't so much focused on the production of biofuels it's more electric power and heat. So state regulations to pertain so much to biofuels. Although course then there are tax incentives of various kinds, investment tax credits, those are supportive as well, there are a mix of supportive elements, there are then guarantees on the part of US department of

Participants	Interview transcription
	agriculture for biofuels investments but the require some pretty high hurdles in terms of demonstrating the technologies, performance of the technologies before (they were able to get a loan guarantee... so. I: correct me if I am wrong but you believe in expanding biofuel production in the western parts of the US, what are the main factors favouring the development of biofuels used in the western part? P: Well there are… there is interest, in doing treatments of forest land to reduce fire hazard, in other words taking out primarily small trees which increase fire hazard so there are activities in fact forest service has something, it's called a biomass grants program to help individual entities, they can be businesses or communities, development agencies, get more biomass out of federal forests in the west so it can help reduce fire hazard. So there is a push there is in an interest in using that biomass. But then there are also various things that slow it down. There's a lot of planning that I required on the national environmental planning act. There has to be a lot of collaboration with environmental groups because they can contest certain treatments, forest treatments in court if they, if they, you know claim they cause environmental damage so there has to be, there are a lot of kind of, procedural things to get material used, you know, the treatment sort of material used more, more widely, so there is that interest in doing it, there are a lot of efforts to, in individual locations to get materials, ply materials up to be used. There really aren't an facilities that you know, they really haven't commercialized any biofuels production, there are pilot facilities and there are certainly groups that are you know, have written kind of evaluations of prospects for placing biofuels in certain locations in the west. And kind of envisioned how they might work if there are certain amounts supplies, but those plans haven't come to the point where there are actually facilities being built. But there are a lot of planning, there is a lot of interest, there are a lot of reasons that there is this interest. I: If we think about the future about decades or hundred years from now on, do you think that we have enough land in, for example in the western part of the US, to plant biofuel crops, without pressing on food prices or anything? P: I'm not so familiar with agricultural production in the west, I know, I was part of a, a team that prepared a study for the western governors association that looked at all of the different sources of biomass that might be used for biofuels production, so you could look for that western governors association report on biofuels, it's on the western governors association website. And in that report as I recall one of the categories of biomass that they envisioned could expand the most is planting herbaceous crops. Now herbaceous can be things like switchgrass they can be slow rotation woody crops, there was, there wasn't particular specification as to what the herbaceous crops would be in... it's just that there is land available, not productive that could be converted that could provide quite a bit of biomass, that was a finding form that particular study, you could look for that study to see the details. I: thanks so much. You mentioned in one of your publications that while there are many other advanced alternative, cellulosic ethanol has the potential to be a major biofuel, what do you think about algae for example, is algae the future of fuel or do you still believe in cellulosic ethanol? P: I have no expertise concerning the technologies that may produce fuels from

Participants	Interview transcription
	algae so… I don't know, course I mean it would be reasonable for somebody to compare the economics of the production of fuels from algae to the economics to produce from other feedstocks but I am, I have not done such a study, I am not aware of such studies and that's the sort of thing you need to look at to answer the question you posed. I: And what do you think about, I mean how much government support does the biofuel need in the US, do they need any governmental support? P: Well I think the support that has been forthcoming has been for research and development and initial commercialization, is it needed, well the extent to which it is needed is determined by I guess the uncertainty and the level of fossil fuel prices. If the fossil fuel prices go up to 200 dollars a barrel we wouldn't need any support I mean you'd have, I mean the current state of technology we could probably support production from biomass competitively, but it's in a zone where the fossil fuel prices are, you know hovering around 100 dollars a barrel and there, there is uncertainty as to whether or not as to whether they could go down or… that is impairing investment. So in this zone a certain degree of government support is required to make advancements, I guess what the government support is doing is… trying to ready the technologies, the feed stocks, the supply systems so that when the economics are sounder the adoption can be fairly rapid. I don't think we can expect the government to support… production that is, well I mean I guess we are supporting production of ethanol with the subsidy indefinitely, I guess there… it's the degree to which I guess, I guess I am backing up here, as to whether or not there are other national interests I mean like national security, reducing the amount of oil imports, so if that is judged to be a high enough priority then there could be subsidies to favour production of bio fuels to reduce the requirements from imported oil. And right now there is, there is some recognition of that security interest by the subsidies for ethanol and there would be subsidies that would be given for bio fuels, other bio fuels production as well. So there is that recognition, there is that support I mean you can see the support in these subsidies per gallon. Are they needed, well I guess they are needed in order for the… for the markets, for the bio fuel to take off sooner rather than later, I guess the government, or at least the legislators have decided that it's in the national interest to get them off, get them going sooner rather than later. I: And in the first question you mentioned about the environment and environmental impact, what do you think, are you optimistic or pessimistic about the environmental impact of biofuels? P: I think it is very important to eval… to look at the sustainability issues of using wood biomass, particularly I think there have been a lot, there has been a lot of attention, continual attention paid to amounts of materials that could be taken without harming ecosystem function, a number of states in the US have developed guidelines for how much logging residue be taken for instance. There's an organization now I understand, I can't remember the name of it that is developing sustainability criteria for biofuels production, what kinds, types of biomass can be used without providing environmental harmful effects. So I think those are all appropriate I think there are a number of scientific issues still to be sorted out and I think they are being sorted out over time. So yes it's important, I think work is being done, there is recognition of that in some

Participants	Interview transcription
	regulation at state level as I mentioned. I: And my last question in general, should other options other than biofuels or biomass be considered for future? P: Oh yes, that's a hugely important question, from point of view of a person like myself, I mean I am a forester, I am a forest economist, we are interested in you know kind of the contribution that forest resources can make to, to, energy development I guess is one category then there's providing all sorts of ecosystem services, ecological functions, of course all that sort of stuff has high interest an importance, but on the energy side I think it is critically important to compare the effectiveness of using (?? 17:15), and here I am talking about I guess efficiency of using wood materials to produce biofuels versus electric power, versus thermal energy and I guess the literature I am seeing is that that the conversion efficiency, in other words the amount of energy output that you get per unit of wood energy is much, much higher for combined heat and electric power systems than it is for biofuels systems so I think the interest in policies favoring biofuels are very much ones that are looking at policy concern like… replacing imported fuels I mean it's, that's a concern that's driving support for biofuels, but if there is an interest in actually making the most efficient use of wood resources then we ought to be giving equal, if you know a balanced sort of support for use of wood resources to, very highly, very highly efficient conversion systems like combing power. I: thanks so much for your time, I appreciate it, sorry to interrupt you. Thanks so much indeed and, thanks for your time. P: Right, good luck. I: Thanks bye.
Participant H	1-Is there any prospect for biofuels? Yes 2-What are your views on the advantages and disadvantages of Biofuels compare to traditional fuels? Advantages: the value added is spread on more actors as the cultivation issues are more "democratic" and could be performed almos all over the world. Disadvantages: production costs and neo-colonialism attitude 3-What do you think about advantages and limitations of different generations of biofuels? 4- Can algae overcome the limitations? Is Algae the future's fuel? No i do not think so, algae needs other 20 yrs of research 5- Is the current projection achievable or not? yes 6- Should other options than biofuels be considered for future? Energy saving 7- Do the current regulations support the biofuel production across the world in future? yes 8- What are the main factors favouring the development of biofuel use in the EU? What are the main obstacles? Factors: regulatory issues. Obstacles: raw material cost 9- How much government support does the biofuels sector need? Now is predominant, in the future could be absent 10- How developed world demand affects poor countries policy?

Participants	Interview transcription
	Poors countries barely has strategies, but this generalization is not clear, what do you mean for poor countries? Environment: 11- What are the environmental Impacts? If not on marginal lands biofuel production will put in to cultivation large areas with high biodiversity 12- What are the potential impacts on food prices and lands? Do we have enough land? No impact. Yes we have, expecially marginal 13- What are the real advantages or disadvantages of biofuels in terms of reducing Green House Gases? It has a 0 balance
Participant I	1-Is there any prospect for biofuels? P: I am not quite sure what you mean with tis question. In Sweden, biomass is a major component of the energy system, mainly used in the pulp industry and the district heating sector. Maily heat, but also some CHP. See http://webbshop.cm.se/System/TemplateView.aspx?p=Energimyndigheten&view=default&cat=/Broschyrer&id=b4cea7b00212456b9bdbdbe47a009474 -What are your views on the advantages and disadvantages of Biofuels compare to traditional fuels? P: Mainly advantages since they are renewable and at least some have low net emissions of CO2. The net CO2 emission in LCA-perspective depends on what kind of biofuel, and what processes. If there is little reduction in CO2 compared to the LCA of traditional fuels, the advantages are also low. 3-What do you think about advantages and limitations of different generations of biofuels? P: Much depends on the production potential, energy efficiency in the production chain, and GHGs from cultivation. To use woody biomass in biorefineries appears quite promising. 4- Can algae overcome the limitations? Is Algae the future's fuel? P: Can´t answer that. Among other things, it depends on the energy efficiency in a LCA perspective. 5- Is the current projection achievable or not? 6- Should other options than biofuels be considered for future? P: Do you mean biofuels for the transport sector, or bioenergy in general? My opinion is that bioenergy / biofuel is an important contribution to the climate work, but other renewables and increased energy efficiency is needed as well. 7- Do the current regulations support the biofuel production across the world in future? 8- What are the main factors favouring the development of biofuel use in the EU? What are the main obstacles? P: Some parts of EU´s sustainability criteria may turn out to be obstacles. 9- How much government support does the biofuels sector need? 10- How developed world demand affects poor countries policy? 11- What are the environmental Impacts? P: That depends on how the biomass is produced. In Sweden, we use much industrial residues, and residues from forestry such as felling residues (mainly for heat and electricity). Much research has been done, and we now know quite well how to combine biomass extraction from forestry with consideration to biodiversity, soil and water. For perennial energy crops, the environmental impact is smaller than for traditional crops, and there are also some environmental benefits. 12- What are the potential impacts on food prices and lands? Do we have

Participants	Interview transcription
	enough land? P. Land may be limiting in the future. My opinion is that we must consider the energy issue together with other land use. Do cultivate feed for meat production is not a very effective land use. 13- What are the real advantages or disadvantages of biofuels in terms of reducing Green House Gases? P: See above, it depends on what biomass, and what emissions occur from the cultivation and the conversion processes. 14- Interaction of green energy sources with biofuels? Have other green energy sources affected the biofuels expanding? P: I don´t know. My opinion is that all renewable and sustainable energy sources are needed. 15- As a result of biofuel production, will habitat fragmentation occur and will the ecosystem change? P: It depends of course on how the cultivation and production areas are designed, and which environment considerations that are taken.
Participant J	I: Sorry to bother you and thank you so much for your time for this interview. P: No problem. I: I will keep this interview as short as possible but before starting, I just want to let you know that I am going to record this interview for using, parts of it in my final theis and any publications related to that, so if you are happy please let me know on the record or send me the signed consent form which I will send you. P: Have you send me already, ok. I: Yes, or either you can tell me right now on the record, it's fine. Thank you so much. P: It's ok for me so yeah. I: Thanks so much, thank you so much. So lets start, lets start with the future of the biofuels. Will you please tell me about the long term prospect of liquid biofuels, any forcast or scenarios for 1st, 2nd or 3rd generation of biofuels up to 2050 for example? P: Well, I think, if you look at biofuels as a way of converting solar energy into chemical energy, if you look at the efficiency it is relatively low, for most crops it is maybe, 2, 3 percent, these are really good crops with micro algae in the lab you can go to maybe 8 percent but is very unlikely you will ever achieve that in large scale systems, so I think it's not the most efficient way of converting solar energy into another form of energy. Most solar panels are more efficient, have efficiencies for 15 percent of higher so that is why I am a bit sceptic about biofuels, skeptical. So I don’t really believe that they will make a very big contribution to our energy. That is my opinion. I: Yes. If you, if you, I mean, when the fossil fuels finish actually, actually they'd never finish, but when the price will go up, there is a point that the search for alternative energy will begin, so you think it's going to happen for biofuels when the prices of oil going very high? P: Prices of oil will go up probably but they will always find new oil and cheaper ways to exploit it. So that is… a good example, in the 1800s there was a big discussion in the British parliament that all coal was finished, would be finished in the next 10 years, that was in the 1800s, so they had a really intense discussion, they said we have only coal left for 10 years, and but of course with the methods they had available at that time, they had indeed had coal left for only 10 years but they found ways to dig deeper to find other sources of coal, so we still have coal today. In the 1960s they had oil for about, up to about maybe 10 years ago, and then it would be finished but of course we keep

Participants	Interview transcription
	finding new oil and, and it's not finished yet. But as an alterate… oil will run out, prices will increase, but at the moment we are seeing a cheap supply of liquid, liquefied natural gas which is booming at the moment in the United states it's… shale gas fracturing, or fracking. So gas prices in the united states are now about 5 times cheaper than they are in Belguim, and it's a real, it's a clean source of fuel, it's cleaner than coal, cleaner than oil, it doesn't emit as many pollutants and it emits less CO2 per unit energy, about 2 times less CO2 per unit energy so, I think this is for me in the coming up to 2050 this will, we will see a shift from oil and coal towards natural gas. I: So you think that the future of fuel will be natural gas? P: In the near term future I think so yes. I: Ok, thanks. P: But that's what European policy makers want but they are at beginning avoided in Europe so there has been some explorative drilling in the UK I think, there has been explorative drilling in france which has been blocked by the government almost immediately, and there is explorative drilling I think in Norway and Poland. I think as soon as they discover that it's cheap, that it is plentiful available and then it will be, that will be. I: And if it goes back, come back to, to biofuel, what is your view on EU regulations, current regulations on biofuel? Do the regulations support the biofuel production across the EU? P: I think, I think without these EU regualtions there wouldn't be any biofuels on the market, it's been subsidized so much that biofuels are so expensive compared to fossil fuels that without subsidies nobody would use it, so EU regualtions support these subsidies so I think they are essential for biofuels, without EU regulations there wouldn't, nobody would be talking about biofuels I think. So it's important yes. I: And the main factors favouring the development of biofuels use in the UK or in EU as a whole, what are the main factors? P: It's regulation by the governments, 2020 idea that your government has, this is really pushing biofuels, they want I think replace 10 percent of the transport fuels by biofuels by 2020 so that means there has to be production so that is what is pushing companies to produce biofuels. I: And what do you think about the future regulation in the EU, they are going to go up in terms of the mandatory biofuel cap? P: That depends on, yeah, as long as we have money to waste on this we can, we will do it, but we will see with this crisis how it resolves and you'll have less and less money to spend on these kind of things, like rapeseed oil or canola oil, it's all over the place but that doesn't, we cannot transport our stuff around the continents with canola seed oil I think. I: And biofuels, has been, have been very controversial regarding to food prices, what do you think about this issue? P: It's very different, there's a lot of discussion, I think, probably in the united states it has led to increases in corn prices. But I think the increase in food prices is also due to the fact that fossil fuels got more expensive because agriculture is basically conversion of fossil fuels into food, it's conversion of fossil energy, you need fossil energy to produce the, the fertilizer for your agriculture, you need fossil fuels for the harvesting and the culturing, you need it to produce pesticides, you need it to transport your food. So if fossil fuel prices go up, food prices go up also. And then, that is one thing, and then also if you use more land to produce biofuels, so you produce food to produce to produce biofuels, probably prices will go up as well. So I think it is these two things, you cannot blame everything on the competition between biofuels and

Participants	Interview transcription
	food. But it's probably part of the story. I: Speaking about lands, do you think if biofuel is responsible for any direct or indirect land use change? P: Maybe in tropical countries, I think probably there have been more by the race for biofuels and that there have been polar bears killed by climate change, that is what I believe, that is my opinion, I think in Indonesia tropical rainforest cuts for production of palm oil, but I think the whole frenzy for biofuels has been stopped early enough to avoid really major environmental damage, I know for instance in Belgium, in Belgium the government, or one of the government parties before the elections they wanted to close our nuclear power stations and replace all the energy with energy from palm oil and when you ask where are you going to get the palm oil, they said from Congo in central Africa, of course that would have meant massive destruction of rain forest. Fortunately they didn't win the election and the whole thing didn't go through. And also green peace changed sides and turned against palm oil instead of being supporting. I: Yeah. And, lets talk about the environmental impacts for instance, what do you think about the impacts on climate change using biofuels, is there any positive or negative impacts? P: Well I think it doesn't emit fossil CO2 so probably the net effect is that is positive, but that's, the gains are not so big, what I read in life cycle analysis you have a gain and you emit less fossil CO2 that's not huge because you need fossil energy to produce biofuels, you need it to produce fertilizers to produce pesticides which is almost consuming as much energy as production of fertilizers. So, but there is a gain in CO2 emissions. I: So if we find a way to reduce the cost of producing biofuels, do you think is a good method or not? P: Yes, if you can do that but it's going to be a challenge because the cost is strongly related to energy costs so energy prices are going up so it's, it's going to be difficult, unless you use waste that is a, if you can convert cellulose to energy, that could be a solution probably but there have been, 5 years ago they said in 3 years we will be able to do it, but past that date and I don't see… it's not market yet so. I: and those who are very keen about using biofuels, most of them talking about algae right now, do you think if the… and third generations, do you think algae is the final answer for biofuels or not? P: Well I do research on algae so… if I would like money from the government to support my research I would say yes, but I am also skeptical there, so 5 years ago there was a boom in algae biofuels, it started when the oil prices started increasing up to 150 dollars a barrel and at the same time greenpeace turned against the biofuels. So all these, every body started looking in the direction of microalgae, but 5 years later there's not really, not an enormous progress in that field. So, production is still very low, there is nothing on the market available, algae are now, are already being produced but for really high value applications, for dietary supplements, when I… I want to buy, because we do research sometimes we need to extract oil, when I need a few kilograms of algae biomass I have to look really hard in Europe, a few kilograms. I'm not talking about a truckload of algae, just a few kilograms. And I pay, if I pay €50 for a kilogram, it's cheap. So that is the price we are talking about. To make biofuels you have to go down, not to €5 a kilogram but to 50 cents a kilogram, so that's two orders of magnitude. That is in any industry an enormous challenge and… everything is possible, but many things are not possible and I think this is one of the things that is not going to be possible. I think the… it will always be more expensive to produce algae than to produce other crops,

Participants	Interview transcription
	that is my opinion because it's more complicated, you need a much more complicated cultivation system, so I think algae have a future and have useful applications but I don't think biofuels will be, will be it. I: Is there any way to keep the cost of producing algae low? P: You can reduce it and there have… progress has been made, but not… it has not been reduced to the point, or we are still far from the point that it's… cheap enough to produce biofuels because biofuel, fuel is still a cheap product. A barrel of oil is now maybe 100 dollars a barrel, there are few things that you pay 100 dollars for a barrel full of the stuff, that is, it's still cheap, just go to the supermarket and look at where you pay only half a dollar for a litre, that is about the price of crude oil, these are cheap products, what is maybe cheaper, coca cola maybe. So that's, it's very difficult to produce oil at a price that it's on the market because, to produce oil, just put a pipe in the ground and it's… coming out of the ground like nothing, you just put in barrels and sell it. If you want to make biofuels you have to make biomass and extract the oil, convert it to fuel, it's much more, it's difficult to compete with the fossil fuel industry. I: And one last question, is there any prospect for 4th or 5th generation of biofuels which overcome the limitations? P: I think it's… maybe cellulose ethanol, but as I said, it's something they've been talking about for a long time, anaerobic digestion of biomass is relatively simple, I think there will be, there will always be biofuels, the first diesel motor it run on animal fats, so that was the first diesel motor, it didn't run on crude oil, though on pig fat. So there is a lot of waste oil and that can be converted into fuel so… and there is also a lot of waste biomass that can be converted easily into biogas, so biomethane but anaerobic digestion, so there will be biofuel but really growing something to make fuel out of it, I don't know, maybe use waste products over food production or whatever, to produce fuel ok, but to really grow a crop just with the goal for producing fuel, I don't know, biofuel.
Participant K	1- The future of biofuel, are you optimistic or not? Yes, I am optimistic. i think the fact is that we must have liquid fuels to keep a modern society running, and biofuels are the only sustainable option i know of to provide liquid fuels. my "ten reasons why" editorial gives more details. 2- The potential impact on environment? That is far too broad a question. biofuels can of course be "done wrong" and cause environmental problems, but with a little bit of thinking we can design biofuel systems to provide very large environmental benefits. the attached paper "biofuels done right…." gives one example of how we might design biofuel systems to achieve large benefits. there are other such approaches, but they require us to make large changes in how we are doing things. 3- The regulations? Are they smart enough? No, in general they are not. they need to become much more tuned to the actual differences between biofuels and petroleum fuels, they need to properly compare biofuels and petroleum fuels (see my editorial above on good science and good policy) and they also need to account for the great differnces in how biofuels might be produced, both good and bad.
Participant L	1-Is there any prospect for biofuels? Yes! 2-What are your views on the advantages and disadvantages of Biofuels compare to traditional fuels? Advantages: renewability, and in the future cheaper than fossil fuels, and reduced dependency on a few (politically unstable) suppliers. Disadvantages: Difficulties to be competitive in markets dominated by

Participants	Interview transcription
	traditional fuels, not least for "soft" issues like institutions, rules-of-the-game, access to media, and education. In addition, resources for technology (both new and improved) are much smaller than for traditional fuels. 3-What do you think about advantages and limitations of different generations of biofuels? My vision for biofuels is "bio-refineries", e.i. large scale production units for biofuels, heat, electricity, fibre products, etc. based primarily on lingo-cellulose. It is still too early to be sure of which type of biofuels will be the "winner" (methanol????, ethanol, biodiesel, or biogas) 4- Can algae overcome the limitations? Is Algae the future's fuel? In theory, yes! However, production of raw material can probably be carried out cheaper on the vast areas of abandoned agriculture or grazing land that can be used for biomass production. Competition with food crops can be handled by more intensive agriculture/animal husbandry including agro-forestry. One major problem with the "algae" vision is that many big players use the vision as an excuse for doing nothing with more immediate and concrete options. 5- Is the current projection achievable or not? Yes! 6- Should other options than biofuels be considered for future? Yes! Electrical vehicles for city travel and for rail transport. 7- Do the current regulations support the biofuel production across the world in future? No! See below 8- What are the main factors favouring the development of biofuel use in the EU? What are the main obstacles? The directives and 20/20/20 visions are favouring. The main obstacles are the strong stake holders in the traditional business, they prefer to protect their traditional business (oil companies) or secure as much benefit as possible from the predicted change (Farm associations in Germany, France, etc) 9- How much government support does the biofuels sector need? In my view, it is more important to create long term credibility for biofuels, and to make strong player to act positively in favour of biofuels ("to be good citizens") Economic incentives would be necessary in the beginning, but they should be clearly related to purposes and targets. 10- How developed world demand affects poor countries policy? To a large extent, the development of the biofuels business is not a governmental issue but a company- supply chain issue. Policies could be needed in for of sustainability rules, protection of investments, etc. The general answer is that poor countries should apply pro-active policies for the new "biofuels era" (internal markets, and export) 11- What are the environmental Impacts? There are numerous potential positive and negative impacts; an enormous challenge to promote the positive and to reduce the negative impact. However, it could be done. 12- What are the potential impacts on food prices and lands? Do we have enough land? Several recent studies report that there is land available that can support more than 100% of future energy need based on biomass. Also in this point the key issue is institutions, organization, and long term planning. It is likely that food prices in the short run can be effected (all other factors equal) In the longer perspective one could even predict lower and more stable food prices (more money flows into rural areas, opens opportunities for technology, knowledge, and market development) with higher intensity and efficiency in the production processes. 13- What are the real advantages or disadvantages of biofuels in terms of

Participants	Interview transcription
	reducing Green House Gases? Some biofuels production of today is very ineffective related to the green house issue. See my suggestion above; the bio-refinery concept. 14- Interaction of green energy sources with biofuels? Have other green energy sources affected the biofuels expanding? No! 15- As a result of biofuels production, will habitat fragmentation occur and will the ecosystem changeAlas, today most habitats are heavily disturbed/destroyed. With intelligent planning and implementation, habitats can be significantly improved (example STORA-Enso´s Brazilian project "jaguar and *Eucalyptus*")The REDD program can have a positive impact.
Participant M	-Is there any prospect for biofuels? Yes, especially in heavy duty vehicles where electric batteries cannot store enough energy. 2-What are your views on the advantages and disadvantages of Biofuels compare to traditional fuels? Adv.: somewhat lower ghg emissions. Disadv.: they transfer emissions from vehicles to agriculture and industry, and to developing countries. 3-What do you think about advantages and limitations of different generations of biofuels? 1st gen biofuels compete with food and land 2nd gen biofuels are better but sustainable potential is still limited. 4- Can algae overcome the limitations? Is Algae the future's fuel? They might be much better but it may be too early to assess. There shoulbe more studies on their limitations. 6- Should other options than biofuels be considered for future? Yes, also other options in addition to biofuels, a) improvement of fuel efficiency n vehicles, b) electric vehicles, c) improvement on transport systems and infrastructure. 7- Do the current regulations support the biofuel production across the world in future? Framework of regulations is developing but not yet good. 8- What are the main factors favouring the development of biofuel use in the EU? What are the main obstacles? EU-policy. Main obstacle is still the weak sustainability of biofuels. 9- How much government support does the biofuels sector need? The support should be directed to improve the sustainability framework, not the biofuel production or use. 10- How developed world demand affects poor countries policy? There can be serious impacts. Therefore the development should slow and controlled. 11- What are the environmental Impacts? Transfer of emissions from vehicles to land use sector and fuels manufacturing. Competition on land and water. 12- What are the potential impacts on food prices and lands? Do we have enough land? Certainly there are not land enough for vast biofuel use penetration. 13- What are the real advantages or disadvantages of biofuels in terms of reducing Green House Gases? The net emissions might not decrease at all, or the decrease is minimal compared with other damages and costs. 14- Interaction of green energy sources with biofuels? Have other green energy sources affected the biofuels expanding? Other green energy sources should be considered and expanded also. They can often be more beneficial.
Participant N	1-Is there any prospect for biofuels? Yes, but the biofuels alternatives must be carefully selected based on sustainability criteria, land and water demand and costs.

Participants	Interview transcription
	2-What are your views on the advantages and disadvantages of Biofuels compare to traditional fuels? The right alternatives of biofuels can offer a significant GHG emission reduction in the transport sector, that associated with gains in efficiency in the vehicles (hybrid vehicles for instance) can have a large impact on the effort to reduce global GHG emissions. 3-What do you think about advantages and limitations of different generations of biofuels? Biofuels, either first (1G) or second generation (2G), will have to be evaluated in terms of GHG emissions reduction potential, land/water demand, production costs as a minimum. There should be no prejudice with respect to 1G or 2G if they pass this screening. I think 2G is a decade ahead at lest and we cannot wait; also, in my opinion, sugarcane ethanol will survive in the long term (it is also the International Energy Agency [IEA] opinion). 4- Can algae overcome the limitations? Is Algae the future's fuel? Algae at a first sight seems to have a tremendous potential to produce large amounts of biofuels with small land requirement, however the costs are high. The US Department of Energy (USDOE) sponsored an 18 years program on biofuels from algae (1978-1996) but it did not lead to a commercial alternative. To me, the potential is high but the future very uncertain due to the production costs. 5- Is the current projection achievable or not? There are several projections for biofuels production and use and they differ broadly. The Reference Scenario of the IEA (World Energy Outlook 2008) estimates in 118 million tons of oil equivalent (Mtoe) the biofuels production and use in 2030; this seems to be quite feasible for it represents, if all this amount will be in ethanol, some 220 billion liters of ethanol, or around two and a half times the present production (requiring less than 20 million hectares of land in 2030 if produced from sugarcane). I am not so certain about biodiesel. 6- Should other options than biofuels be considered for future? Yes, We need to be always open for other alternatives, but I cannot see now anothing better than sugarcane ethanol and palm oil biodiesel. 7- Do the current regulations support the biofuel production across the world in future? The most important ones are the US Renewable Fuel Standards (RFS2) and the EU Directive 2009/28/EC due to the magnitude of the transport fuel demand in these two regions. There are several other regulations mandating the use of biofuels such as in Brazil, India, China, Colombia, Thailand, Canada and several others. 8- What are the main factors favouring the development of biofuel use in the EU? What are the main obstacles? The need to reduce GHG emissions in transport and energy security seems to be the main drivers. However, there may be a support to local agriculture inserted in the act. The main obstacle are the production costs, land demand and ability of the EU produced biofuels to meet the GHG reduction limits. 9- How much government support does the biofuels sector need? At the first stages of market introduction some government support in terms of mandates, tax incentives, low interest loans and other types of subsidies are need. However, the subsidies must have o reasonable period of existence to minimize the risk of supporting the wrong alternative. 10- How developed world demand affects poor countries policy? What is happening now is that the developing countries are establishing biofuel programs aiming at firs to reduce the dependence on imported oil, but there are high hopes that the export to OECD countries will materialize in the future. 11- What are the environmental Impacts? First, the positive ones: GHG emission reduction, tail pipe emission reduction and lower risk of catastrophic accidents with oil spills like the recent Gulf of Mexico case and the Exxon

Participants	Interview transcription
	Valdez many years ago. On the negative side: damage to biodiversity (if proper measures are not taken) and increase in land use. 12- What are the potential impacts on food prices and lands? Do we have enough land? We do have enough land if the adequate alternatives of biofuels are selected (see 5 above). The impacts on food prices are dependent on the alternatives also; in the case of sugarcane ethanol in Brazil, there was a long term reduction in sugar costs due to improvements in sugarcane production and processing driven by the necessity to reduce ethanol costs to compete with the gasoline. 13- What are the real advantages or disadvantages of biofuels in terms of reducing Green House Gases? As explained above, it depends very much on the alternative. Sugarcane ethanol has reduction potential of 71% compared with gasoline according to the Directive 2009/28/EC default values. For wheat ethanol this value is in the range of 32 to 69% depending on the production path. 14- Interaction of green energy sources with biofuels? Have other green energy sources affected the biofuels expanding? Biofuels are and will be always competing with biofuels as alternatives to abate GHG emissions. In the EU Directive, it is estimated that more than a third of the transport energy demand by 2020 will be supplied by other alternatives to biofuels. 15- As a result of biofuel production, will habitat fragmentation occur and will the ecosystem change? It is possible, but it can be minimized with proper attention to biodiversity issues. It is a matter of comparing impacts of GHG mitigating alternatives.
Participants O, P, Q Discussion	1-Is there any prospect for biofuels? The national Renewable Action Plan (nREAP) has been published in December 2010 fixing indicative targets for renewable energy deployment in Belgium in view of reaching the targets of the Renewable Energies Directive 2009/28/EC (RED). To reach the national objectives for renewable energy in transport, the nREAP plans a biodiesel consumption of 698 ktoe and a bioethanol consumption of 91 ktoe in 2020. 2-What are your views on the advantages and disadvantages of Biofuels compare to traditional fuels? Advantages: - Biofuels contribute to climate change mitigation - Biofuels lower the energy dependence of Europe - Biofuels create jobs in the agricultural, automotive and industrial sectors (6 to 20 new jobs created for 1000 toe) - Biofuels reduce the dependence on imported proteins for feed Disadvantages: - Current raw material used for biofuel production is limited. Resource diversification is necessary. - A significant consumption of biofuels requires adaptation in fleet and fuel infrastructure, implying modifications in habits and mentalities of the larger public. - The higher production of biofuels in comparison with conventional fuels - Harmful emissions – in particular particulate mass - are in some cases substantially increased for biofuels through inclusion of the agricultural process in the fuel production pathway. All together the Ecoscore performance of vehicles running on biofuels is generally in the same order as for fossil fuel1. 3-What do you think about advantages and limitations of different generations of biofuels? Second generation biofuels enable the diversification of raw

Participants	Interview transcription
	material and thus the enhanced of the biomass potential. These fuels also present interesting potentials in terms of GHG performance. The main limitation for the development of second generation biofuels is currently the high investment and production costs and remaining technical uncertainties regarding these advanced technologies. 4- Can algae overcome the limitations? Is Algae the future's fuel? On the long term, algae could contribute to the national biofuel targets. This technology is however still in the Research & Development phase and still needs to be optimized to be economically viable. 6- Should other options than biofuels be considered for future? Electric mobility and energy saving in transport are equally important in reducing the climate impact of the transport sector and reaching national renewable objectives. 7- Do the current regulations support the biofuel production across the world in future? Yes 8- What are the main factors favouring the development of biofuel use in the EU? What are the main obstacles? The mandatory objectives for renewable energy in transport fixed by the RED favours the deployment of biofuels in the EU. The main obstacles are the progress in European quality standard publications for biofuel blending with conventional fuel and the implementation of high biofuel blends implying adapted fleets and fuel infrastructure and requiring major changes in habits and mentalities in the larger public. 9- How much government support does the biofuels sector need? Until biofuels become competitive with fossil fuels, governments support is needed. This support should translate into a biofuel blending obligation for fuel suppliers. High biofuel blends require financial support, especially for ethanol which has a lower energy content than gasoline. Support also has to be given to stimulate the deployment of vehicles and fuel infrastructure adapted to these high blends. 10- How developed world demand affects poor countries policy? Biofuel production for export could theoretically offer an opportunity for rural development in poor countries; however local policy is essential to develop local consumption of biofuels in parallel to export, to ensure food security and protection of smallholders (subsistence farming). 11- What are the environmental Impacts? The sustainability criteria fixed by the RED ensures environmental sustainability of biofuels consumed in Europe. The impact related to indirect land use changes of biofuels remains however uncertain at this point. 12- What are the potential impacts on food prices and lands? Do we have enough land? The by-products (animal feed) should be kept in mind when estimating the impact of biofuels on food prices and lands. These animal proteins are significant in quantities and partially replace imported soy proteins. 13- What are the real advantages or disadvantages of biofuels in terms of reducing Green House Gases? If no deforestation occurs for the cultivation of raw material, all biofuels perform at least as well as conventional fossil fuels and much better than no conventional fossil fuels such as Coal-To-Liquid or CTL (which according to Mr. Faaij of the University of Utrecht presents life cycle greenhouse gas emissions twice as important as conventional diesel). Uncertainty remains regarding emissions generated by indirect land use change; this however is also valid for fossil fuels. 14- Interaction of green energy sources with biofuels? Have other green energy sources affected the biofuels expanding? With the predicted biofuel expansion, some competition will probably appear between different bioenergy sectors for

Participants	Interview transcription
	biomass resources.
Participant R	2-What are your views on the advantages and disadvantages of Biofuels compare to traditional fuels? Some biofuels might reduce GHG emissions compared with "traditional fuels". However, biofuels have worse impacts on land-use, water use, food, habitat, the nitrogen cycle, and more. 6- Should other options than biofuels be considered for future? Wind, water, and solar power should be used in place of biofuels. 11- What are the environmental Impacts? Increased use of land, water, and nitrogen; increased habitat fragmentation; increased perturbation of the nitrogen cycle; increased water pollution; increased erosion; increased nitrogen pollution. 13- What are the real advantages or disadvantages of biofuels in terms of reducing Green House Gases? Biofuels made from conventional agricultural commodities generally will not reduce GHG emissions. Biofuels made from waste material probably will reduce GHG emissions significantly. Some second-generation biofuels made from cellulosic materials also probably can reduce GHG emissions. 15- As a result of biofuel production, will habitat fragmentation occur and will the ecosystem change? Yes, almost certainly.
Participant S	1-Is there any prospect for biofuels? • Lot of countries all around the world set biofuel blending mandates to diversify energy supply, e.g. the EU 10% biofuels till 2020. So probably demand for biofuels is going to rise in the next years if political targets on biofuels are not going to be changed. • What will happen after 2020 depends on the sustainability of biofuels in all aspects (social, economic, ecologic) as well as on development of other innovative and renewable energies as for example second and third generation biofuels (as for liquid fuels) and of development of transport sector and energy consumption patterns. 2-What are your views on the advantages and disadvantages of Biofuels compare to traditional fuels? • Advantages: in papers that are fostering or explaining biofuel promotion the mentioned reasons are greater energy autonomy, diversification of energy resources and the development of rural areas and the agricultural sector. Furthermore, depending on the crop and the production area and country, biofuels are able to contribute to a reduction of greenhouse gas emissions compared to fossil fuels (also depending on the method of Life Cycle Assessment). • Disadvantages: as for now, there are still some technical problems of biofuels regarding the usability for engines and regarding the efficient production of second and third generation biofuels. As for sustainability (social, economic, ecologic) biofuels still have to prove that advantages are greater than disadvantages – competition in between food and fuel production, landgrabbing issues and the displacement of local farmers have to be mentioned. The rising dominance of agrobusiness, that means monocultures and intensive as well as expansive growing methods could also threaten biodiverse areas, are displacing more suitable intercropping systems – only to mention a few conflicts. • The question is not so much about the advantages and disadvantages of biofuels compared to fossil fuels – it is more a question of future substitution possibilities for fossil fuels which are a finite resource. Otherwise or additionally it should be thought about a change of the

Participants	Interview transcription
	energy system or consumption behaviour all around the energy and transport system. 3-What do you think about advantages and limitations of different generations of biofuels? • Till now, second and third generation biofuels are still not technically mature enough to support the energy sector with large supply. So therefore till now technology is a limitation – but a lot of research is done in this area and the first second generation plants are already working. The advantage would be a better input-output-balance of raw materials and energy. 4- Can algae overcome the limitations? Is Algae the future's fuel? • The current trend in third generation energy development is quite interesting, but impacts and role of algaes till now not assessable. 5- Is the current projection achievable or not? • The current projection of the European Unions biofuels demand will probably only be achievable if biofuels from other regions of the world are going to be imported into the EU. International trade is probably rising in this sector – trade regulations on agricultural products will probably have to be rethought. 6- Should other options than biofuels be considered for future? • All possible options for future energy supply should be considered – especially other renewable energies like water, wind and solar power. Car technology will have to be adjusted on other kinds of energy supply. Regulations and directives: 7- Do the current regulations support the biofuel production across the world in future? • The current regulations around the world are supporting biofuel production in the coming years - in the EU up to 2020 if not changed meanwhile because the political decision process is always dynamic. For the time afterwards there can only be made estimations. 8- What are the main factors favouring the development of biofuel use in the EU? What are the main obstacles? • The main factors favouring the development of biofuel use in the EU are: greater energy autonomy to be less dependant on oil-producing countries, diversification of energy resources with regard to limited fossil fuel resources to secure energy supply which is a key factor for the economic sector and the development of rural areas and the agricultural sector. Europe is also interested in a sustainable use of resources and production structures; therefore there is the hope for a more carbon-friendly fuel, which could be biofuels. • Main obstacles in favouring the development of biofuels use: Insecurity of outcomes of the biofuels promotion in ecological and social spheres, especially in other parts of the world. 9- How much government support does the biofuels sector need? • The biofuels sector still needs political support in order to be able to compete with traditional fuels. Structures, technology, production systems etc. of biofuels still have the potential to improve. After decades of biofuels production, e.g. the Brazilian bioethanol market, dependant from sugar-prices, ethanol is also able to compete with petrol. 10- How developed world demand affects poor countries policy? • As mentioned in the answer on question 5, the current projection of

Participants	Interview transcription
	the European Unions biofuels demand will probably only be achievable if biofuels from other regions of the world are going to be imported into the EU. International trade is probably rising in this sector – trade regulations on agricultural products will probably have to be rethought. On the one hand, the rising demand for biofuels could be a chance for poor countries to establish a new export product, because their economies are mainly based on the primary sector. On the other hand, the higher biofuels demand from industrialized countries should be combined with further value-adding-production processes and industries in the poorer countries, in order to keep financial and knowledge increases in the countries. Otherwise there will be the risk of degrading the poorer countries on the level of mere raw-materials suppliers. Additionally the "black box" poor country has to be opened as well as defined. Conditions in Mozambique are probably not the same as in Ethiopia or Peru. The national growth of income devises has to be perceived independently from local and regional effects and outcomes in the biofuels producing countries, e.g. a local farmer does not profit automatically from an increased ethanol export. Environment: 11- What are the environmental Impacts? • There are a lot of environmental impacts concerning biofuels as well as the increasing demand on agricultural sector such as soy and meat. Impacts are diverse depending on the production system, the used land, climate and practices. Water, soil, biodiversity issues have to be considered. 12- What are the potential impacts on food prices and lands? Do we have enough land? • The potential impacts of biofuels on food and land are not easy to assess because there are a whole bunch of other factors such as demographic change, speculation on agricultural goods, climate change, droughts, volatile fossil fuel prices which have a large impact on prices for agricultural goods. In general land use and land availability is going to be an increasingly important topic, because of biofuels, but also because of the other mentioned factors. 13- What are the real advantages or disadvantages of biofuels in terms of reducing Green House Gases? • Depending on the crop and the production area and country, biofuels are able to contribute to a reduction of greenhouse gas emissions compared to fossil fuels (also depending on the method of Life Cycle Assessment). While corn ethanol from the US will probably not have a great effect on the reduction of GHG, sugarcane ethanol from Brazil is supposed to have great GHG reduction potentials. But this also depends on possible side effects that have to be taken into account as for example GHG emissions that occur due to land use conversion or indirect land use change. It is very difficult to measure these effects. 15- As a result of biofuel production, will habitat fragmentation occur and will the ecosystem change? - This depends on governance instruments and their implementation and controlling possibilities. If expanding areas for a larger energy crop production as well as other agricultural goods is managed in a sustainable way there will be

Participants	Interview transcription
	the option to save biodiversity hotspots and ecosystems. Brazil implemented for example an agrozoning instrument for sugarcane in order to use the land which is most appropriate for sugarcane cultivation in terms of soil compatibility, climate, biodiversity, food production. Besides a lot of countries are fostering certification schemes in order to avoid negative ecological and social effects in the producer countries. The question remains, how viable these certification and controlling schemes are. Due to a higher demand on biofuels, pressure on biofuels supply will increase and therefore also the pressure on land use questions – which multiply with earlier mentioned trends and processes.
Participant T	1-Is there any prospect for biofuels? yes 2-What are your views on the advantages and disadvantages of Biofuels compare to traditional fuels? + Emission reduction of THG + diversification of resources + tailormade design of molecules in 2nd generation + biofuels + long term availability of resources - land use conflicts 3-What do you think about advantages and limitations of different generations of biofuels? 6- Should other options than biofuels be considered for future? Yes, HEV, modal split, public transport 7- Do the current regulations support the biofuel production across the world in future? I think so 8- What are the main factors favouring the development of biofuel use in the EU? What are the main obstacles? Favouring: policy targets 9- How much government support does the biofuels sector need? Long term support for investors to join, stable conditions. This is more important than quantity… 10- How developed world demand affects poor countries policy? Strong, sustainability criteria (inc. social aspects) have to be defined 13- What are the real advantages or disadvantages of biofuels in terms of reducing Green House Gases? Depends on the biofuel and resource used
Participant U	Is there any chance for biofuel to be "the future's fuel"? The initial surge of biofuels in industrial economies was driven by energy security and rising fossil fuel prices; but market forces alone were not sufficient to drive the process, which required heavy policy support (subsidies, mandates and tariffs for imports) targeting few domestic-based feedstocks (corn, rapeseed, soybeans); meanwhile research and development of new feedstocks to support future biofuel expansions took off, including high-yielding (sweet sorghum) and more versatile crops (jatropha), as well as dedicated energy crops for second-generation biofuels. Yet the expected large gap between future demand and potential domestic supply in the North required expanding biofuel production in developing countries, which had the land and the climate needed to produce raw feedstocks on a large scale. 2-Your views on long term prospect for liquid biofuels-up to 2050? Future biofuels are likely to be produced from a much broader range of feedstocks including the lignocelluloses in dedicated energy crops, such as perennial grasses, and from forestry, the co-products from food production, and domestic vegetable waste. Advances in the conversion processes will almost certainly improve the efficiency and reduce the environmental impact of producing biofuels, from both existing food crops and from lignocelluloses

Participants	Interview transcription
	sources. A significant advantage of developing and using dedicated crops and trees for biofuels is that the plants can be bred for purpose. This could involve development of higher carbon to nitrogen ratios, higher yields of biomass or oil, cell wall lignocellulose characteristics that make the feedstock more amenable for processing, reduced environmental impacts and traits enabling the plant species to be cultivated on marginal land of low agricultural or biodiversity value, or abandoned land no longer suitable for quality food production. Several technologies are available to improve these traits, including traditional plant breeding, genomic approaches to screening natural variation and the use of genetic modification to produce transgenic plants. Research may also open up new sources of feedstocks from, for example, novel non-food oil crops, the use of organisms taken from the marine environment, or the direct production of hydrocarbons from plants or microbial systems. 2-a: Forecasting Scenarios for First Generation Biofuels? It is increasing understood that first generation biofuels (produced primarily from food crops such az grains, sugar, beet and oil seeds) are limited in their ability to achieve target for oil product substitution, climate change nitigation, and ecanemic growth. 2-B: Forecasting Scenarios for Second Generation Biofuels? Many of the problem associated with first generation biofuels can be adressted by the production of biofuels manufactured from agricultural and forest residues and from non-food crop feedstocks. Where the lignocellulosic feedstock is to preduced from specialist energy crops grown on arable land, several concerns remain over competing land use, although energy yields are likely to be higher than if crops grown for first generation biofuels (and co-products) are produced on the same land. Second generation biofeuls are relatively immature so they should have good potential for cost reductions and increased production efficiency levels are more experience is gained. Dependent partly on future oil prices, they are therefore likely ti became a part of solution to the challenge of shifting the transport sector towards more sustainable energy sources at some stage in the medium-term. 2-c: Forecasting Scenarios for Third Generation Biofuels (algae)? The most accepted definition for third-generation biofuels is fuels that would be produced from algal biomass, which has a very distinctive growth yield as compared with classical lignocellulosic biomass. Several fuels can be derived from microalgae. These include hydrogen, methane, biodiesel/oil and ethanol. Methane can be effectively generated from algae produced in wastewater treatment ponds. While ethanol could be produced from algal starches and sugars, not much effort has been devoted to producing ethanol from algae. Most recent work has focused on the development of biodiesel from lipids/fatty acids that can be produced by certain species of microalgae. Production of biofuels from algae usually relies on the lipid content of the microorganisms. Usually, species such as Chlorella and Nannochloropsis are targeted because of their high lipid content and their high productivity. There are many challenges associated with algal biomass, some geographical and some technical. Lipids obtained from algae can be processed via transesterification by the previously described biodiesel process or can be submitted to hydrogenolysis to produce kerosene grade alkane suitable for use as drop-in aviation fuels. 3- Is there any way for algal fuel to be cost competitive with first and second generations?

Participants	Interview transcription
	Algae offer advantages over terrestrial plants for biofuel production. Algae have short generation cycles and fast population growth that also support genetic advances. Using algae for biofuel production would spare corn and soybeans for consumption as food by humans. While there is commercial potential for microalgae, technological and other obstacles related to algae species, environmental conditions and production logistics must be met for practical large-scale production. Algae biofuels provide a viable alternative to fossil fuels; however, this technology must overcome a number of hurdles before it can compete in the fuel market and be broadly deployed. These challenges include strain identification and improvement, both in terms of oil productivity and crop protection, nutrient and resource allocation and use, and the production of co-products to improve the economics of the entire system. Regulations and directives: 4- What is your view on global biofuel regulations? Do the current regulations support the biofuel production? Forecasting scenarios for future regulations and directives? Among the factors currently limiting the development of regional and global biofuels markets, the lack of comprehensive and generally adopted international standards is most important. The International Standards Organisation (ISO) is currently working on developing certain biofuels standards, and the outcomes of this effort are eagerly awaited. The subsequent International Standards will help the broad development of biofuels worldwide. The proposal for ISO standards on liquid biofuels has been reviewed by ISO members and their stakeholders, and follows on the work done under the International Biofuels Forum (IBF), a tripartite group involving Europe, USA and Brazil. ISO has established a committee on liquid biofuels under ISO/TC 28/SC 7 and the group met for the first time in January 2009 in Brazil. The discussions at the meeting served to confirm a number of conclusions of the IBF white paper. In this respect, ISO/TC 28/SC7 has focused on a role of information collection and monitoring he work of other standards bodies. As this is not the usual objective of an ISO committee developing International Standards, this role may be reviewed in the future. To address the need for common sustainability criteria, the ISO members from Germany and Brazil (DIN and ABNT respectively) circulated a proposal for a new Project Committee to develop a single ISO standard. The voting results among the ISO members were successful and a committee was established in this area. The Committee's work is at an early stage, and so far the following has been agreed. Scope Standardisation in the field of sustainability criteria for production, supply chain and application of bioenergy. This includes terminology and aspects related to the sustainability (e.g. environmental, social and economic) of bioenergy. ☐ Inventory of initiatives; ☐ Terminology; ☐ Greenhouse gases; ☐ Environmental aspects; ☐ Social aspects; ☐ Economic aspects; ☐ Verification and auditing; ☐ Indirect effects. 5- What are the main factors favouring the development of biofuel? What are the main obstacles?

Participants	Interview transcription
	The main factors favouring the development of biofuels are: - Security of supply - Reducing Greenhouse gases - Waste disposal is a large cost for companies and communities - Development of new and more efficient technologies 6- How much government support does the biofuels sector need? What kind of support needed? Full support is needed in form of: -Updated Road Map, -Regulation and Directives -Financial Support. -infrastructure and training of skilled labour -Environmental impact: 7- What are the environmental Impacts (agriculture, biodiversity, Climate Change, water and Soil)? Positive or negative? One of the primary justifications for a shift to biofuels as an alternative energy source has to do with the climatic benefits that are anticipated to occur from the substitution of fossil fuels, whose combustion results in large net CO2 emissions, to fuels whose combustion releases gases sequestered through cultivation and which are therefore considered greenhouse gas (GHG) neutral. Current energy policies address environmental issues including environmentally friendly technologies to increase energy supplies and encourage cleaner, more efficient energy use, and address air pollution, greenhouse effect, global warming, and climate change. Renewable energy sources that use indigenous resources have the potential to provide energy services with zero or almost zero emissions of both air pollutants and greenhouse gases. Biofuels are expected to reduce dependence on imported petroleum with associated political and economic vulnerability, reduce greenhouse gas emissions and other pollutants, and revitalize the economy by increasing demand and prices for agricultural products. 8- What are the potential impacts on food and commodity prices? Short-term/cyclical factors i. Adverse weather conditions affecting agricultural production in many parts of the world explain some of the recent commodity price increases. ii. Reductions in stocks due lower than expected harvests have put upward pressure on prices due to the induced volatility and higher risk premium that lower stocks imply. iii. International commodity trade has been limited due to the imposition of export restrictions in various countries, putting upward pressure on commodity prices. iv. There is some debate about the impact of the influx of speculative investment on agricultural commodity prices. Whilst some analysts argue that this influx had no impact on prices, others think that it has contributed to recent price rises. Longer-term/structural factors v. Growing demand from emerging economies has increased demand for agricultural commodities. vi. Rising biofuel production, mainly in the US has had a discrete impact on commodity prices and most notably the maize market. vii. Higher oil prices have an impact on the agricultural industry. viii. Historically low levels of investment in agriculture and agricultural research have slowed down improvements in productivity with a negative impact on the supply potential.

Participants	Interview transcription
	• Second generation biofuel production has the potential to reduce land requirements and increase productivity. 9- Direct and indirect land-use change? Direct land use change (DLUC) In the context of biofuels, direct land-use change (DLUC) refers to the conversion of land from some other land-use category to the production of bioenergy crops. DLUC can provide environmental costs or benefits. For example, re placing row crops with perennial grasses will often increase soil carbon sequestration, reduce nutrient and pesticide run off, and improve biodiversity. When crops replace pasture or forest, DLUC can result in substantial greenhouse gases (GHG) emissions. The greenhouse gases (GHG) emissions of biomass feedstock production result ing from crop cultivation and conversion as well as direct LUC can be determined from a comparison of the carbon balances of the previous land use with those aft er t he land has been used to produce biomass crops. This relates to the above-ground carbon content of the existing vegetation (if any), as well as the below-ground carbon levels, including soil carbon. Each balance might be negative or positive, so that the total direct carbon balance could also be negative or positive. Biofuel GHG emissions increase if carbon-rich land (such as peat under, rainforest) is converted for cultivation of the biomass crop. But if feedstocks are grown on low-carbon soils, the impact can be positive. For example, perennial plants, such as oil palm or short-rotation willow coppice, store carbon in their root system so that biological seques tration takes place and total GHG emissions are usually reduced when direct LUC is factored in and cultivation takes place on former arable land. indirect land-use change (ILUC) When biofuels are produced on existing agricultural land, the demand for food and feed crops remains, and may lead to someone producing more food and feed somewhere else. This can imply land use change (by changing e.g. forest into agricultural land), which implies that a substantial amount of CO2 emissions are released into the atmosphere.The proposal sets out indirect land-use change (ILUC) factors for different crop groups. These factors represent the estimated land use change emissions that are taking place globally as a result of the crops being used for biofuels in the EU, rather than for food and feed. Simply put, all biofuels that use land will get an ILUC factor. Feedstock that do not require agricultural land for their production (i.e. waste, residues, algae) and those that cause direct land use change (i.e. in which case operators need to calculate their actual emissions) are exempt from the factors. 10- What are the real advantages/disadvantages of biofuels in terms of reducing Green House Gases? Advantages of Biofuels Many countries are depending on fossil fuels of other countries so biofuels reduce Dependance on Foreign Oil. Since biofuels can be made from renewable resources, they cause lesser pollution to the planet. They release lower levels of carbon dioxide and other emissions when burnt, which means they pollute the environment in lesser amounts. To reduce the impact of greenhouse gases, people around the world are using biofuels. The fossil fuels or it s products, when burnt, produce large amount of greenhouse gases and reduces greenhouse gases up to 65 persent by. carbon dioxide and other products like NOx in the atmosphere. These greenhouse gases trap sunlight and cause planet to warm. The burning of coal and oil increases the temperature and causes global

<table>
<tr><th>Participants</th><th>Interview transcription</th></tr>
<tr><td></td><td>warming
Disadvantages of Biofuels
With respect to the kind of biofuel generally biofuel are quite expensive to produce in the current market. As of now, the interest and capital investment being put into biofuel production is fairly low but it can match demand. Better to say many countries are far from this new technology.
However, the process with which they are produced makes up for that. Production is largely dependent on lots of water and lots of oil. Large quantities of water are required to irrigate the first generation biofuel crops and it may impose strain on local and regional water resources, if not managed wisely. In order to produce corn based ethanol to meet local demand for biofuels, massive quantities of water are used that could put unsustainable pressure on local water resources.but in case of second and third generation it is not so
Oil and gas industries:
11- Will biofuels be able to compete with crude oil? When it is going to happen?
Algae biofuels may provide a viable alternative to fossil fuels; however, this technology must overcome a number of hurdles before it can compete in the fuel market and be broadly deployed. These challenges include strain identification and improvement, both in terms of oil productivity and crop protection, nutrient and resource allocation and use, and the production of co-products to improve the economics of the entire system. Although there is much excitement about the potential of algae biofuels, much work is still required in the field.
12- Some researchers now say that with developing of Shale Gas resources, there would be no future for biofuels, what do you think? Is biofuel dead?
Shale gase have disadvantages including:
• It is difficult and expensive to transport.
• Because of those hefty transport costs, gas does not behave like a commodity. Only one-third of all gas is traded across borders, compared with two-thirds of oil.
• Gas has no global price.
• Gas prices in different parts of the world are set by quite different mechanisms, they vary wildly across the globe.
• Gas pipelines cost million of dollars a kilometre to build.

• Biofuels are becoming more viable. Although it's still trying to shake off past negative connotations with regard to raised food prices, the advanced biofuels industry is now pursuing strategies that bypass the need for a reliance on consumed feedstocks. Fuels and products can now be made from cellulosic sugars derived from non-competitive materials such as wood chips, switchgrass, and even municipal waste. More importantly, the fuels being made are looking more and more like true oil replacements with regard to energy content, cloud point, and other important characteristics.</td></tr>
<tr><td>Participant V</td><td>1-Is there any prospect for biofuels?
Biofuels have a role to play in renewable transport, being the only near term option to address carbon emissions from this sector.
2-What are your views on the advantages and disadvantages of Biofuels compare to traditional fuels?
Clearly an important advantage of sustainable biofuels is reduction in carbon</td></tr>
</table>

Participants	Interview transcription
	emissions in the transport sector. There are also socio-economic benefits (rural employment, rural economy, etc.), if properly implemented. On the other hand, there are risks of poor environmental and socio-economic impacts if the biofuels are not produced sustainably. Certification is an important aspect here to counteract this risk. 3-What do you think about advantages and limitations of different generations of biofuels? So called first generation biofuels have emission benefits which are often quite limited, although they do have the benefit of being familiar to the agricultural community. They also have quite low yield per hectare, although targeted research activity could improve this. Second generation biofuels offer the prospect of higher yield per hectare and significantly improved emissions benefits compared to most first generation biofuels. There is still much work to be done to produce second generation biofuels that are competitive and that do not require government support. 4- Can algae overcome the limitations? Is Algae the future's fuel? Tough question! Despite the enthusiastic headlines, there seems to be quite a way to go before the market can expect meaningful contributions from biofuels derived from algae. They have important benefits in terms of land demand (or absence thereof) and potential areal productivity, so they are worth pursuing. 5- Is the current projection achievable or not? Assuming this question refers to EU 2020 targets, the targets are definitely challenging. The scale of demand by 2020 would suggest that across the EU it will be very difficult to attain the 10% from renewables. Contributions from electric vehicles could be important, but are unlikely to be that significant. 6- Should other options than biofuels be considered for future? The development of electric vehicles could contribute something. Also some action on modal shift could alleviate the problem but have a positive impact on demand. 7- Do the current regulations support the biofuel production across the world in future? Achieving the European 2020 target for renewables in transport will require significant biofuels development. It is likely that large quantities of biofuels will need to come from other parts of the World, driving production in other countries, particularly developing countries. 8- What are the main factors favouring the development of biofuel use in the EU? What are the main obstacles? The main factor is the Renewable Energy Directive 2009/28/EC which mandates 10% renewable in transport by 2020. The main obstacle is the cost of biofuels compared to traditional fuels. 9- How much government support does the biofuels sector need? Government mandates are important to driving the development of biofuels; without these there would be very limited development. 10- How developed world demand affects poor countries policy? This is an issue that needs careful attention. On the one hane biofuels development could act as driver for income generation in poor countries. Alternatively it could lead to greater exploitation with little local benefit. Clearly strong certification schemes with an emphasis on socio-economic impacts for the producers are crucial. 11- What are the environmental Impacts? The environmental impacts depend crucially on the production pathway. For many first generation biofuels there is a positive benefit in terms of emissions and reduced inputs compared to traditional agricultural practice. There are some biofuel pathways where the benefits are questionable and these need to be properly evaluated and failed if

Participants	Interview transcription
	they do not match the minimum requirements stipulated in the EU Directive. 12- What are the potential impacts on food prices and lands? Do we have enough land? Despite the bad press for biofuels during the food price spike of a couple of years ago, the reality would seem to be that the biofuels contribution to that spike was quite small – other factors were much more significant. For current targets there is enough land, provided that it is properly exploited and that effort is maximised to use land that is out of use/underutilised. 13- What are the real advantages or disadvantages of biofuels in terms of reducing Green House Gases? Biofuels, properly applied, can reduce GHG emissions in the transport sector. While many first generation biofuels have limited capacity to reduce GHG emissions, the development of second generation biofuels offers significant potential for emissions reduction. 14- Interaction of green energy sources with biofuels? Have other green energy sources affected the biofuels expanding? Not sure what this question means. If it concerns biomass for heat and power versus biofuels for tramnsport, then I would say that there has been very limited impact of biofuels development on the development of heat and power. With current technology, biomass for heat and power is derived from different streams (wood fuels, straw, etc.). When second generation biofuels are commercial then this picture could change. 15- As a result of biofuel production, will habitat fragmentation occur and will the ecosystem change? This depends on how rigorously sustainability criteria are applied.
Participant W	1- Do you consider biofuel as future's fuel? Yes, we need all types of renewable fuels and liquid fuels are the hardest to get, as biofuels are liquid fuels they will need to part of the future solutions on energy 2-Your views on long term prospect for liquid biofuels-up to 2050? 2-a: Forecasting Scenarios for First Generation Biofuels? First generation biofuels ARE food, these need to phased out quickly, food is expensive and getting more expensive, we cannot exchange food for fuel 2-B: Forecasting Scenarios for Second Generation Biofuels? Cellulosic ethanol has not yet become economic viable, but if it can, then there is a very good market for ethanol as a fuel additive and as a feedstock for chemistry. Jatropha and other second generation biofuels also need to be expanded 2-c: Forecasting Scenarios for Third Generation Biofuels (algae)? To date this is one of the best option we can see for a scale of production that meets our needs (the world uses 1.2 trillion gallons of petroleum per year). Algae also offer the potential of being grown on non-arable land and using non-potable water, either waste water or salt water. Fuel from algae today is too expensive to compete with fossil fuel, but the energy return on investment (EROI) from algae is now projected to be 2.5 to 1, and a positive energy return like that means that it can compete with fossil fuel, we simply need to reduce the cost of the production systems with better engineering and better recycling of the non- hydrocarbon inputs, like water, nutrients and energy. 3- Is there any possibility for Algae/Lingocellolusic fuels to be competitive with first generation biofuels in near future? Yes, if near terms means the next 3 to 5 years. We need to go to large scale with a few of these systems and then see what prices are, it may be much closer than many people think. 4- What is your view on EU/UK regulations? Do the current regulations support the biofuel production in the UK in future? I don't know UK

Participants	Interview transcription
	regulations, but in the US we have very mixed regulations. Some are supportive many are not. Most regulations are the result of a single industry asking for some special treatment, this is NOT a very good way to regulate anything, but that is the way we mainly do it. We need a more reasoned long term approach to our biofuels regulation, and we need a carbon tax. If we actually taxed people for the pollution from their carbon output proportional to the cost that pollution has on society, we would reduce CO2 output, and have the money to fund reduced carbon fuels … but we don't do that right now. 5- What are the main factors favouring the development of biofuel use in the UK? What are the main obstacles? The main factor influence biofuels use is the rising cost of fossil fuels, period! Every thing else, like climate change, health problems from air pollution, wars over energy etc, would just be ignored if we had cheap energy. 6- How much government support does the biofuels sector in the UK need? What kind of support needed? A carbon tax equal to the real cost of fossil fuel use would be more than sufficient to drive full development of biofuels. In the mean time, keep research going, it is working. 7- Forecasting Scenarios for future regulations and directives in the UK/EU? When the cost of fossil fuels goes up another 25%, people will panic (again) and start to think about additional rules to support biofuels. By the time climate changes start to really get ugly, it will likely bee too late to really change much to impact that, so or best bet is increased fossil fuel cost. 8- What are the environmental Impacts (agriculture, biodiversity, Climate Change, water and Soil)? Positive or negative? This is a very complex answer and can not be stated simply. It is completely dependent upon how we deploy biofuel production. If we use traditional crops like corn or sugarcane the answer is very different than if we use cellulosic ethanol or algae. 9- What are the potential impacts on food and commodity prices? The price of food has gone up 240% over the last decade, any addition pressure on food crops could be very damaging to the world economy. If, and it's a big IF, we can use non-potable water and non-arable land, than this impact will be much less, and may actually push food prices down. 10- Direct and indirect land-use change? This is a big question no matter what we use, algae, cellulosic, corn or sugarcane. This needs to be monitored as we go to scale and unexpected consequences addressed. 11- What are the real advantages/disadvantages of biofuels in terms of reducing Green House Gases? For cellulosic ethanol and algae there is a dramatic reduction, for corn and sugarcane less, but all biofuels are better than fossil fuels, no matter what. 12- Looking into the short/medium term future, what will be the availability of oil in medium (up to 2030) and long term (up to 2050)? A lot has been written about fracking and how this will impact oil. It appears it will add about 9% to our total world reserves, meaning that we will be hard pressed to produce enough by 2030 to meet world demand. By 2050 the prospects are not good that we be able to meet anything close to demand. 13- Will oil demand continue to grow? Will it remain the world's single most important source of energy for the foreseeable future? Yes, for at least the next 30 years, we simply do not have a replacement. A new truck, train or plane purchased today will need fuel from oil in 20, 30 or 40 years, there is no way around that. 14- Any alternative to crude oil? Biofuel maybe? Algae seems to be the best, but almost any biomass has the potential to be a crude oil replacement

Participants	Interview transcription
	15- Will biofuels be able to compete with crude oil? When it is going to happen? Yes, biofuels will be competitive in 5 years if oil price rise at the rate they have for the last decade (five fold increase in the last decade), longer if oil prices stabilize at $100 barrel, which they may for the next few years. IN that case it may take 10 years to get biofuels to $100 a barrel.
Participant X	1-What will be the future's fuel? If by 'future's fuel' we mean 'liquid motor fuel', we need to carefully look at the technologies and processes which are currently available and also look at the prospects of new and advanced technologies which are being developed to see how all of these could meet the demand for liquid fuel for the foreseeable future. I will put my bet and money on Second Generation Biofuels for the short to medium term demand and Third Generation Biofuels for the long term demand. 2-Your views on long term prospect for liquid biofuels-up to 2050? 2-a: Forecasting Scenarios for First Generation Biofuels? First Generation Biofuels are a dying species, especially the bioethanol from cereal crops (e.g. wheat, maize, etc.). A lot of large wheat bioethanol plants are on the verge of closure or have already closed down due to high prices of cereal crops. The only First Generation bioethanol process that might survive for a longer period is bioethanol from sugar beet and sugar cane. 2-B: Forecasting Scenarios for Second Generation Biofuels? Quite a few Second Generation Biofuels technologies are close to commercialisation and with the right investments in these technologies, they will enter the market within the next 5-10 years and could play a major role in providing liquid motor fuels for the whole world. 2-c: Forecasting Scenarios for Third Generation Biofuels (algae)? Algal fuels technologies are being developed at a rapid pace and attracting a lot of investments into these projects. These technologies will be commercialised within the next 10-15 years and together with Second Generation Biofuels will play a major role in the fuels market. 3- What other options than biofuels be considered for future? 'Biosynthetic gasoline and kerosene'; Bio-methanol; Hydrogen fuel. 4- Can biofuels compete with crude oil? What is this turning point price for petroleum and when it is going to happen? With 1st generation biofuels, it is becoming increasingly difficult to compete with fossil fuels as long as the prices of raw materials and feedstocks are quite high and therefore the biofuels prices have to be subsidised to be competitive with fossil fuels. However, 2nd generation biofuels could compete with crude oil and other fossil fuels in the long term as long as the price of, for example gasoline, does not drop below $3.00 per gallon. 1st generation bioethanol price is currently hovering around $3.50 to $3.70 per gallon, but 2nd generation bioethanol price will surely be lower than that and closer to $3.00 with emerging technologies. 5-Algae or lingocellusic biofuel? Which one is the future's fuel? Both alongside each other and it depends how fast each of them could take a good niche in the fuel market. Algal technology is still quite a few years behind lignocellulosic biofuel.
Participant Y	1-Is there any prospect for biofuels? EU obligations will make them in EU, EU's traffic fuel directive (2003/30/EY) 2-What are your views on the advantages and disadvantages of Biofuels compare to traditional fuels? Pros: extending supplies of feedstock, new suppliers and new production areas, better security of supply, new business possibilities for industry (forest, agriculture etc.), Cons: economy: higher prices, sustainability and certification issues, eg. food vs. fuel competition,

Participants	Interview transcription
	biodiversity risks, process efficiency (how much feedstock/ biofuel) still unclear, Intensive biomass logistics to conversion sites, different conversion processes require different feedstocks and fragmented & highly heterogeneous (in quality and quantity) supply of biofmass feedstocks across world 3-What do you think about advantages and limitations of different generations of biofuels? Feedstock flexibility and/or new biofuels with higher compatibility with existing infrastructures are the preferred options for advanced conversion routes to be implemented in complement/synergy with current biofuels, to meet the 2020 targets, strong activities are needed to improve sustainable feedstock availability (including logistics), as well as rational criteria on how best to allocate biomass when different uses are possible 4- Can algae overcome the limitations? Is Algae the future's fuel? Partly yes, since no competing use and high availability per area, still under development 5- Is the current projection achievable or not? The 2020 target (10%) is achievable, partly because double counting (2nd generation biofuels), higher shares very challenging – both feedstock availability and demand side 6- Should other options than biofuels be considered for future? Yes, electrical car (hybrid, full), gas operated car (biogas and natural gas), later hydrogen operated car 7- Do the current regulations support the biofuel production across the world in future? There are strong domestic markets in world (Brazil, US, Asia), EU has some regulations but they have only effect on the international trade. It seems that EU favour more 2nd generation biofuels and biodiesel whereas the biggest producer US and Brazil concentrates more on 1G ethanol 8- What are the main factors favouring the development of biofuel use in the EU? What are the main obstacles? Main factors behind the commitment are: prevention of climate change, securing availability of fuel, supporting regional development, main obstacles are: cost-effectiveness, compatibility to current car fleet and distribution logistics (max share) and convenience in use, and feedstock availability 10- How developed world demand affects poor countries policy? In the same way as with other commodities (ore, agriculture products, fossil fuels etc.) (i.e. raw material source for developed world) 11- What are the environmental Impacts? Changing cropping patterns (biodiversity, conversion of natural ecosystems), land use changes (LUC, iLUC) increased water stress, soil quality, changes in carbon stock 12- What are the potential impacts on food prices and lands? Do we have enough land? Theoretically we have enough land, but it is a question of species and their cultivation practises and land ownership situation in different areas, in many cases food and fuel crops are competing with each other for the best areas 13- What are the real advantages or disadvantages of biofuels in terms of reducing Green House Gases? GHG-reduction have to be monitored very carefully, using LCA methodology, there are a large variation between feedstocks and conversion routes, ethanol from sugarcane (Brazil) and from cellulose feedstock are the best options, EU has put some regulations for biofuels to be valid in this sense (-35% GHG vs. fossil fuels, later -60%) 14- Interaction of green energy sources with biofuels? Have other green energy sources affected the biofuels expanding? They will compete with the same feedstock, cellulose 2G biofuels, normally other green energy is cheaper option to reduce GHG, therefore biofuels will have their own target and commitment 15- As a result of biofuel production, will habitat fragmentation occur and will the ecosystem change?

Participants	Interview transcription
	Changing cropping patterns will definitely change the ecosystem but we should keep the development within sustainable limits, certification is one tool for this
Participant Z	1-Is there any chance for biofuel to be "the future's fuel"? It depends on what type of biofuel is of interest i.e first, second or third generation biofuels. Either sugar crops (such as sugar cane or sugar beet), or starch (like corn or maize) can be fermented to produce ethanol, a liquid fuel commonly used for transportation. Or natural oils from plants like oil palm, soybean, or algae can be burned directly in a diesel engine or a furnace, or blended with petroleum, to produce fuels such as biodiesel. Some countries are using Wood and its byproducts which can be converted into liquid biofuels, such as methanol or ethanol, or into woodgas. In a countries like brazil, Malaysia I think the future fuel could be biofuel from plants. But in countries which have ocean or seas I definitely think from algae or a combination of algae and salt water tolerant plant. 2-Your views on long term prospect for liquid biofuels-up to 2050? If we look at it globally the answer for biofuels-up to 2050 it definitely grow up despite the limited importance of liquid biofuels in terms of global energy supply. Which effects in terms of agriculture and the use of more land for fuel production rather than the availability of food and feed may become significant, at least at the current state of our technology. It will certainly have adverse effects on the food security of the poor and the food-insecure if food prices were to rise again as a result of resource diversification specially water scarcity towards the production of feedstock crops for biofuels. For example, in a country like Iran or similar geographical and land in Asia, model simulations that project that continuing along the trend suggested in current scientific plans of future expansion in various key biofuel-producing regions in country (from water point of view), prices of grains, oils would be at least 20 times higher by 2050. Since we are in water scarcity situation. But if we plan to use algae of Persian Gulf or Caspean sea along with other biofuel technologies like agricultural waste or salt water tolerant plant I think it will work. 2-a: Forecasting Scenarios for First Generation Biofuels? Since the first generation biofuels are directly related to a biomass that are edible and we are now in water scarcity hence no definite forcast. 2-B: Forecasting Scenarios for Second Generation Biofuels? We need to keep in mind that every country needs to improve biofuel production processes. Before bioenergy can make a larger contribution to the energy economy, feedstocks, agricultural practices, and technologies that are efficient in their use of land, water and fossil fuel must be developed. Hence the second generation biofuels has a better forcasting scenarios in Asian countries and Worldwide because that can be produced suatainabily by using biomass consisting of the residual non food parts of agricultural crops. 2-c: Forecasting Scenarios for Third Generation Biofuels (algae)? Which one has the edge; fresh water algae or marine algae? Third generation biofuels, has similar effect like second generation biofuels since it is made from non food p;ants and specially if algae is of use. Specially in countries with oceans and seas. The resulting fuel is id distinguishable from other biofuel counterparts since they are green environmental friendly and with less or no foot print. Is there any way for algal fuel to be cost competitive with first and second

Participants	Interview transcription
	generations? Sure if we find a strain of good algae with short generation time which produces extracellular biofuel. 4- What is your view on global biofuel regulations? Do the current regulations support the biofuel production? Forecasting scenarios for future regulations and directives? At present we do not have biofuel regulations but in order to have that we need to first design a biofuel road map. In Eur. Since 2003 the regulation and directives were issued but in most of Asian countries there is no regulation and directives. 5- What are the main factors favouring the development of biofuel? What are the main obstacles? The main factors favouring the development of biofuel should be with a view to contributing to objectives such as meeting climate change commitments, environmentally friendly security of supply and promoting renewable energy sources. In Asian countries biofuels hold out the prospect of new economic opportunities for people. Encourages new market outlets for agricultural waste if we plan for second generation of biofuel or the third generation. The importance of security of supply has been underlined as the cost of conventional transport fuels has more than 6 times in Iran as compare to 8 years ago. The obstacles are land, biodiversity and CO2 emission. Biofuels' advantages in terms of greenhouse gas emissions and security of energy supply can be obtained at lower cost through other technology like algal production provided appropriate algal strains. The produced biofuel should meet sustainability criteria, in particular • On land with high biodiversity value (protected areas and areas that are important for species reproduction); sould not see any biofuel plants and should be in a way that protects soil, air, water and forestry; nevertheless the biofuel must reduce CO2 emissions. 6- How much government support does the biofuels sector need? What kind of support needed? Full support is needed in form of: -Updated Road Map, -Regulation and Directives -Financial Support. -infrastructure and training of skilled labour -Environmental impact: 7- What are the environmental Impacts (agriculture, biodiversity, Climate Change, water and Soil)? Positive or negative? Biofuels affects on ecosystems and species within them (including humans), and also on geophysical systems such as water and climate. Impacts may be direct, like tailpipe emissions from burning biofuels, or indirect, like soil emissions of carbon dioxide from biomass? production. Biofuels can have positive and negative ecological and environmental impacts, and the overall net impact can be either positive or negative.In First Generation Biofuels the environmental impact is mostly negative in all aspects with larger foot print as compare to biocapacity even for a country like Brazil. But in second and third has less impact if scientifically planned. 8- What are the potential impacts on food and commodity prices? Again depends on which kind of biofuel is planned the first generation has surely large negative effects on food and commodity prices.. 9- Direct and indirect land-use change? Similarly if the first generation is the objective it has negative effects 10- What are the real advantages/disadvantages of biofuels in terms of reducing Green House Gases?

Participants	Interview transcription
	Advantages of Biofuels Many countries are depending on fossil fuels of other countries so biofuels reduce Dependance on Foreign Oil. Since biofuels can be made from renewable resources, they cause lesser pollution to the planet. They release lower levels of carbon dioxide and other emissions when burnt, which means they pollute the environment in lesser amounts. To reduce the impact of greenhouse gases, people around the world are using biofuels. The fossil fuels or it s products, when burnt, produce large amount of greenhouse gases and reduces greenhouse gases up to 65 persent by. carbon dioxide and other products like NOx in the atmosphere. These greenhouse gases trap sunlight and cause planet to warm. The burning of coal and oil increases the temperature and causes global warming Disadvantages of Biofuels With respect to the kind of biofuel generally biofuel are quite expensive to produce in the current market. As of now, the interest and capital investment being put into biofuel production is fairly low but it can match demand. Better to say many countries are far from this new technology. However, the process with which they are produced makes up for that. Production is largely dependent on lots of water and lots of oil. Large quantities of water are required to irrigate the first generation biofuel crops and it may impose strain on local and regional water resources, if not managed wisely. In order to produce corn based ethanol to meet local demand for biofuels, massive quantities of water are used that could put unsustainable pressure on local water resources.but in case of second and third generation it is not so 11- Will biofuels be able to compete with crude oil? When it is going to happen? Sure it will 12- Some researchers now say that with developing of Shale Gas resources, there would be no future for biofuels, what do you think? Is biofuel dead? Certainly yes in First Generation but in second and third generation there is a vast future.
Participant AB	1-Is there any prospect for biofuels? Yes, biofuels account for 1/3 of the Swedish primary energy (125 TWh) and use is increasing at a rate of 2-3 TWh (=1-1,5 Million m3 solid) every year 2-What are your views on the advantages and disadvantages of Biofuels compare to traditional fuels? This is a very comprehensive question and can't easily be answered in brief. But, biofuels from sustainably managed systems can provide coal based energy and material feedstocks that are GHG neutral, energy efficient, clean and economical. Further they provide employment and income in rural areas due to the dispersed nature of production. A disadvantage can be that, presently, heat sinks are necessary for economical conversion to high-end forms of energy such as electricity or liquid/gaseous fuels. A risk is employment of poor operations and systems that are not sustainable, but instead detrimental to environment biodiversity and long term yield. 3-What do you think about advantages and limitations of different generations of biofuels? The question is too complex to answer and must be specified in much greater detail. Also it is not clear if you are asking about the (bio)fuel feedstock (nut shells, algae, bark, foliage, wood, fat, grass…), or about converted fuels (pellets, brickettes, DME, FT Diesel, Hydrogen, methanol….) that is converted into energy (heat, electric, kinetic etc) or if you are asking about the energy that results from conversion of biomass. 4- Can algae overcome the limitations? Is Algae the future's fuel? It can possibly be developed, but I know too little to have a strong opinion. 5- Is the current projection achievable or not? Current projection? I feel

Participants	Interview transcription
	confident that Sweden will comply with the EU 2020 goal of 49 % renewables (we are presently at ~47 %), but less confident that some other countries in EU27 will manage. Sweden has good opportunities and started this development already in the 1970s. It is hard and takes time. 6- Should other options than biofuels be considered for future? Of course 7- Do the current regulations support the biofuel production across the world in future? Not entirely. Regulations are patchy and often reflect national or business branch perspectives. Especially protectionistic parts of national agricultural politics influence in a bad way. Further, regulations must be adapted to the regional conditions. It is almost impossible to formulate sustainability rules in detail, they must be generic and then interpreted and implemented in each country besaed on the local social and ecological conditions. Further standardisation, protection against spreading harmful orgnisms and diseases etc must be put in place. 8- What are the main factors favouring the development of biofuel use in the EU? What are the main obstacles? The RES Directive is the most positive, the inertia of the energy system and the lobbying of "non-renewable" stakeholders and of national agricultural interests are the main obstacles. It varies tremendously from country to country. 9- How much government support does the biofuels sector need? It varies depending on the maturity of the bioenergy business in each country. Initially infrastructure and legal framework must be built up, also fossil CO-taxation and simliar initiatives may prove important. 10- How developed world demand affects poor countries policy? Hard to say what will happen and also probably varying from country to country. A risk is that biomass feedstocks will lead to proletariation of rural inhabitants and to decrease of food production. A possibility is that a new business will emerge where sustainable income will help lift the welfare in poor countries and alleviate the pressure on the atmosphere through fossil CO2 11- What are the environmental Impacts? An incredibly large and complex question which will also have different answers depending on what bioenergy system you are asking for. Impossible to answer briefly. If sustainable systems are developed, bioenergy has the potential to deliver large volumes of fuel with very limited negative effects. If carried out improperly, the biodiversity can suffer, soil productivity decrease, water quality deteriorate and local population can be empowerished… So it can be "good" or "bad" depending on HOW it is carried out. 12- What are the potential impacts on food prices and lands? Do we have enough land? We have enough land. The question is if we have the foresight to develop the possible systems in time. This is dependent on questions such as "who have the power over the land today and what are their interests?" "will landowners profit from doing 'the right thing*" etc. Are you asking a global question or a EU27 question? Land prices will rise as it becomes clear that it is the ONLY sustainable sources of biomass. Fossil biomass is an ending resource and also a resource that clearly creates problems when utilised in the current way. 13- What are the real advantages or disadvantages of biofuels in terms of reducing Green House Gases? Bioenergy is positive if NET emmisions due to harvesting and energy conversion from the ecosystem (soil, plants, animals over a rotation period) and from all the operations (harvesting, tranports, energy conversion etc) involved in utilisation is lower than the corresponding emmissions from use of a similar amount of fossil fuel. Further, if the net emissions from use of bio is near zero, bio is GHG neutral. If more carbon is

Participants	Interview transcription
	tied up by the eco system than what is emitted through bioenergy activities (asi in Finland and Sweden) then bio is actually helping to mitigate GHG stress. In principle, it is possible to create GHG neutral energy ssytems based on bioenergy, but to also "clean the atmosphere" from already emitted fossil GHG (mostly CO2) we must also apply carbon capture techniques. 14- Interaction of green energy sources with biofuels? Have other green energy sources affected the biofuels expanding? Are you referring to solar? Wind? Hydro? I do not understand the question… 15- As a result of biofuel production, will habitat fragmentation occur and will the ecosystem change?If the global mean temperature rises we are certain to see such negative development, as population and consumption grows we also see these risks. An improper and irresponsible development of bioenergy can certainly also have such negative effects, but it is my opinion that it need not happen to any great extent if bioenergy is developed with responsibility and foresight.
Participant AC	1-Is there any prospect for biofuels? Yes, biofuels can play an important role at least in the transition phase. They can provide between 5-20% of transport fuel needs without affecting food production. On the contrary, if properly managed, biofuels can help to increase food production. 2-What are your views on the advantages and disadvantages of Biofuels compare to traditional fuels? Biofuels offer the advantage that can be produced in many countries and thus will be difficult for anybody to have a monopolistic control. They offer the possibility for rural development and provide energy locally, energy diversification, etc The disadvantages are the high costs of most feedstocks and their lower calorific value. While oil is relatively easy to handle, the biofuels chain is far more complex (e.g. land use, productivity, social and economic implications, potential climate impacts, etc). It is not possible to have an efficient biofuel industry without a modern and dynamic agricultural sector and this is difficult given the huge disparities in agricultural development around the world. 3-What do you think about advantages and limitations of different generations of biofuels? Biofuels offer many local advantages e.g. local rural development, diversification of supply, social benefits, etc. But it is wrong to think that biofuels are the panacea to solve our energy problem. They can simply assist a bit because it is unrealistic to use biofuels in a large scale simply because the many competing uses for land and biomass. Biofuel are part of the problem and part of the solution. As 2G and 3G biofuels are developed, the negative impacts could be reduced significantly while improving benefits 4- Can algae overcome the limitations? Is Algae the future's fuel? Some companies, including some large ones, believe so, but I have very strong reservations. We need to think of a diversified energy matrix in which oil will continue to play a key role but with renewable energy sources (all types) playing far bigger role. There are still many unanswered questions with regard to algae e.g. costs, contamination, water and land use, etc. Algae may play an interesting role as substitute of kerosene in the aviation industry. 5- Is the current projection achievable or not? Most projections are over optimistic. I think in some cases e.g. ethanol from sugarcane because it is well developed and the major advantages this crop offers, some of the projections are achievable (i.e. 10% global substitution of gasoline by ethanol). 6- Should other options than biofuels be considered for future? Yes, because demand for energy is projected to increase considerably. All other possibilities, including nuclear, should be pursued. What is really important is

Participants	Interview transcription
	to develop clean energy technologies 7- Do the current regulations support the biofuel production across the world in future? Yes, in most cases. Biofuels are driven mostly by policy rather than market forces. This however needs to change with market forces playing a much greater role in the future. Historically all energy sources have received government support in one way or another. 8- What are the main factors favouring the development of biofuel use in the EU? What are the main obstacles? Policy support (for reasons we all know). The main obstacles are costs and availability of feedstocks in large scale. It is unrealistic to think the EU will ever be self-sufficient in liquid biofuels. Although technically this may be possible, from an economic point of view will make more sense to import a large proportion. 9- How much government support does the biofuels sector need? As indicated, currently the main driver is policy and this is necessary in the short and perhaps to medium terms. In the longer term, biofuels need to compete with other sources. What is needed is a “fair playing field” for all energy sources. 10- How developed world demand affects poor countries policy? Poorer countries (the so-called developing countries) have the greatest potential for biofuel production and also the greatest competitive advantage and hence see biofuels as an opportunity in most cases. Biofuels policy needs greater cooperation between producers and consumers. For example, the development of sustainability criteria has been mostly driven by EU policy with little participation from poor countries, though this gradually changing. 11- What are the environmental Impacts? The environmental impacts can be many and varied. Much will depend on the specific crop, circumstances, agricultural practices, etc. Generally, however, the potential benefits of biofuels, if properly managed, far outweigh the potential negative environmental impacts 12- What are the potential impacts on food prices and lands? Do we have enough land? This is a complex issue which has been overblown by the Media. The reasons for food prices increase are many and diverse and biofuels are just one. Biofuels have been blamed for most of the food increases but this is far from the truth- even The World Bank was forced to admit that the impacts of biofuels were overstated. 13- What are the real advantages or disadvantages of biofuels in terms of reducing Green House Gases? Depending on the crops and management practices, biofuels have been shown to reduce GHG by 10 to 80%. However, biofuels are not the answer to GHG they simply can help a bit 14- Interaction of green energy sources with biofuels? Have other green energy sources affected the biofuels expanding? One of the difficulties is lack of cooperation with other renewable green sources/technologies. The greater impacts seem to have been investment e.g. wind power has taken a good proportion of investment in recent years. When you compete to scarce resources, this is bound to have an impact somewhere. 15- As a result of biofuel production, will habitat fragmentation occur and will the ecosystem change? No necessarily. Intrinsically biofuels are not better or worse than any other crop; it depends on policy, management practices, etc.

Appendix F: Interviews consent form

UNIVERSITY OF WESTMINSTER
SHOOL OF LIFE SCIENCES

CONTRIBUTOR CONSENT FORM
(Agreement for Use of Contribution)

School Address/Telephone No.	115 New Cavendish Street, W1W 6UW, London UK, Phone: (+44)207911 5807
PhD Dissertation Title	Long-term Projections for Biofuel in the UK/EU
PhD Student	Payman Moayedi-Araghi
Description of Contributions	Interview
Contributor Name	

Thank you for agreeing to contribute to the above research programme. This form gives the UNIVERSITY OF WESTMINSTER the right to use the whole or part of your contributions in all media and publications throughout the world and, in so doing, will help the UNIVERSITY OF WESTMINSTER to maintain its position as a leading educational institution. We very much hope to use your contributions, but we cannot guarantee to do so.

- You assign to the UNIVERSITY OF WESTMINSTER the copyright and all other rights in your contributions for use in all media/publications now known or which may be developed in future and you confirm that your contributions will not infringe the copyright, or similar rights, of any third party.
- In the light of the need of research for flexibility, you agree that the UNIVERSITY OF WESTMINSTER may summarize, adapt, or translate your contributions and you agree not to exercise any "moral rights"[2] you may have against the UNIVERSITY OF WESTMINSTER in respect of any uses of your contributions pursuant to this Agreement or against any third parties who have been authorised by the UNIVERSITY OF WESTMINSTER.

If you agree with the terms set out above please sign the form below and return it.

Thank you once again for your assistance.

I agree these terms

Signed ……………………………. Date ……………………………

Appendix G: Biofuel mandates in Canada, adapted from (Mabee and Saddler, 2010)

Region	**Mandate**	**Announcement/legislation**	**Regulation (approved)**	**Date (effective)**
Canada	Average 5% based on gasoline pool by 2010 – ~2.2 billion litres	Bill C-33, July 3, 2008	TBD	2010
British Columbia	Provincial annual average 5.0% renewable content in gasoline pool	Bill 16, April 18, 2008	08/12/2008	2010
Saskatchewan	Blend average 7.5% ethanol in gasoline pool	Ethanol Fuel Act, July 15, 2002	Updated over the years as below: 11/01/05–01/14/07: 1.0% ethanol 01/15/07 – 12/31/07: 7.5% ethanol 01/01/08 – forward: 7.5% ethanol	01/01/2007
Manitoba	Blend average 8.5% ethanol in gasoline pool	Biofuels Act, December 4, 2003	12/12/2007	01/01/2008
Ontario	Blend average 5.0% ethanol in gasoline pool	Announcement November 2004	7/10/2005	01/01/2007

Region	Mandate	Announcement/legislation	Regulation (approved)	Date (effective)
Quebec	Target: average 5.0% ethanol in gasoline pool	Target only, no regulation planned	N/A	2012
Alberta	5.0% ethanol content in gasoline by 2010	Provincial Energy Strategy, December 11, 2008	TBD	2010

Appendix H: Lipid content in the dry biomass of various species of microalgae, adopted from (Singh et al., 2011b):

Species	Lipid content (% dryweight)
Botyococcus braunii	25–80
Chlamydomonas reinhardtii	21
Chlorella emersonii	28–32
Chlorella protothecoides	57.9
Chlorella pyrenoidosa	46.7
Chlorella vulgaris	14–22
Crypthecodinium cohnii	20
Cylindrotheca sp.	16–37
Dunaliella primolecta	23
Dunaliella salina	6
Dunaliella tertiolecta	35.6
Euglena gracilis	14–20
Hormidium sp.	38
Isochrysis sp.	25–33
Monallanthus salina	>20
Nannochloris sp.	30–50
Nannochloropsis sp.	31–68
Neochloris oleoabundans	35–54
Nitzschia sp.	45–47
Phaeodactylum tricornutum	20–30
Pleurochrysis carterae	30–50
Prymnesium parvum	22–38
Scenedesmus dimorphus	16–40
Scenedesmus obliquus	12–14

Appendix I: History of crude oil prices, 1946-2011

2011

January	$84.47	July	$88.82
February	$81.32	August	$77.72
March	$94.72	September	$77.31
April	$102.15	October	
May	$92.92	November	
June	$87.92	December	
		2011 Average	$87.48

2010

January	$69.85	July	$67.91
February	$68.04	August	$68.34
March	$72.90	September	$67.18
April	$76.31	October	$73.63
May	$66.25	November	$76.00
June	$67.12	December	$81.01
		2010 Average	$71.21

2009

January	$33.07	July	$56.16
February	$31.04	August	$62.80
March	$40.13/$39.88	September	$60.98
April	$42.45/$42.20	October	$67.43
May	$51.27/$51.02	November	$69.43
June	$61.71/$61.46	December	$66.33
		2009 Average	$53.56/$53.48

2008

January	$84.70	July	$126.16
February	$86.64	August	$108.46
March	$96.87	September	$96.13
April	$104.31	October	$68.50
May	$117.40	November	$49.29
June	$126.33	December	$32.94
		2008 Average	$91.48

2007

January	$46.53	July	$65.96
February	$51.36	August	$64.23
March	$52.64	September	$70.94
April	$56.08	October	$77.56

May	$55.43	November	$86.92
June	$59.25	December	$83-46
		2007 Average	$64.20

2006

January	$58.30	July	$66.28
February	$54.65	August	$64.93
March	$55.42	September	$55.73
April	$62.50	October	$50.98
May	$62.94	November	$50.98
June	$62.85	December	$54.06
		2006 Average	$58.30

2005

January	$42.21	July	$52.13
February*	$42.91/$41.11	August	$58.07
March*	$48.55/$47.80	September	$58.56
April*	$46.63/$46.38	October	$55.12
May*	$43.27/$43.02	November	$51.18
June*	$49.56/$49.80	December	$52.31
		2005 Average*	**$50.04/$49.81**

2004

January	$30.87	July	$36.25
February	$31.03	August	$40.67
March	$33.48	September	$41.25
April	$33.08	October	$48.71
May	$36.31	November	$44.30
June	$33.80	December	$39.20
		2004 Average	**$37.41**

2003

January	$29.44	July	$27.39
February	$32.13	August	$28.33
March	$30.26	September	$25.14
April	$25.22	October	$27.07
May	$23.61	November	$27.66
June	$27.23	December	$28.83
		2003 Average	**$27.69**

2002

January	$16.65	July	$23.69
February	$18.88	August	$24.90
March	$20.97	September	$26.28

April	$22.83	October	$25.38
May	$23.79	November	$22.92
June	$22.16	December	$25.25
		2002 Average	**$22.81**

2001

January	$28.66	July	$23.58
February	$26.72	August	$24.08
March	$23.96	September	$20.82
April	$26.77	October	$19.04
May	$25.44	November	$16.45
June	$24.27	December	$16.21
		2001 Average	**$23.00**

2000

January	$24.11	July	$27.17
February	$26.54	August	$28.27
March	$27.44	September	$30.88
April	$22.99	October	$30.01
May	$26.06	November	$31.16
June	$28.57	December	$25.50
		Yearly total Average	**$27.40**

1999

January	$9.86	July	$17.43
February	$9.30	August	$18.55
March	$12.05	September	$20.94
April	$14.60	October	$19.93
May	$15.17	November	$22.26
June	$15.24	December	$23.33
		Yearly Average	**$16.55**

1998

February	$13.71	August	$10.20
March	$12.75	September	$12.44
April	$13.15	October	$11.88
May	$12.67	November	$10.36
January	$14.56	July	$11.52
June	$11.03	December	$8.64
		Yearly Average	**$11.91**

1997

January	$23.52	July	$17.57
February	$20.00	August	$17.82
March	$19.21	September	$17.63

April	$18.06	October	$19.20
May	$19.15	November	$17.99
June	$17.20	December	$16.31
		Yearly Average	**$18.97**

1996

January	$17.33	July	$19.73
February	$17.60	August	$20.38
March	$19.71	September	$22.25
April	$21.78	October	$23.34
May	$19.56	November	$21.99
June	$18.50	December	$23.38
		Yearly Average	**$20.46**

1995

January	$16.50	July	$15.50
February	$17.06	August	$16.32
March	$16.87	September	$16.40
April	$18.20	October	$15.72
May	$17.91	November	$16.37
June	$16.68	December	$17.47
		Yearly Average	**$16.75**

1994

January	$13.29	July	$18.26
February	$13.28	August	$16.89
March	$13.13	September	$15.79
April	$14.85	October	$16.07
May	$16.54	November	$16.47
June	$17.76	December	$15.63
		Yearly Average	**$15.66**

1993

January	$15.25	July	$16.27
February	$18.69	August	$16.40
March	$18.92	September	$16.13
April	$18.81	October	$16.54
May	$18.29	November	$15.22
June	$17.64	December	$12.83
		Yearly Average	**$16.74**

1992

January	$17.59	July	$20.45
February	$17.75	August	$20.02
March	$17.68	September	$20.62

April	$19.00	October	$20.32
May	$19.62	November	$19.00
June	$21.07	December	$17.92
		Yearly Average	**$19.25**

1991

January	$23.56	July	$20.31
February	$19.42	August	$20.48
March	$18.67	September	$20.43
April	$19.48	October	$21.98
May	$19.94	November	$20.91
June	$18.93	December	$18.28
		Yearly Average	**$20.19**

1990

January	$21.42	July	$17.47
February	$20.83	August	$25.69
March	$19.10	September	$32.52
April	$17.23	October	$34.69
May	$17.36	November	$28.38
June	$17.64	December	$26.00
		Yearly Average	**$23.19**

1989

January	$16.59	July	$18.50
February	$16.60	August	$17.35
March	$18.54	September	$18.18
April	$19.35	October	$18.85
May	$18.73	November	$18.71
June	$19.04	December	$19.50
		Yearly Average	**$18.33**

1988

January	$16.00	July	$15.00
February	$15.50	August	$14.25
March	$15.00	September	$13.50
April	$17.00	October	$12.50
May	$16.50	November	$13.34
June	$15.25	December	$14.65
		Yearly Average	**$14.87**

1987

January	$16.75	July	$19.00
February	$15.75	August	$18.50
March	$18.00	November	$17.50

June	$18.50	December	$16.00
		Yearly Average	**$17.50**

1986

January	$22.50	July	$11.00
February	$16.00	August	$13.25
March	$14.00	September	$14.00
April	12.50	December	$15.50
May	$13.00	**Yearly Average**	**$14.64**

1985

January	$26.00		
Feb. thru December	$27.00	**Yearly Averag**	**$26.50**

1984

November	$28.00		
December	$27.00	**Yearly Average**	**$27.50**

1983

January	$30.00		
Feb. thru Oct., 1984	$29.00	**Yearly Average**	**$29.00**

1982

February	$34.00	August	$31.00
March	$32.00	September	$31.00
April	$31.00	October	$32.00
May	$31.00	November	$32.00
June	31.00	December	$31.00
July	$31.00	**Yearly Average**	**$31.55**

1981

	Lower Tier - IL	Upper Tier - IL	Released & Stripper
January	$6.94	$15.07	$38.00
February	$6.99	$15.19	$38.00
March			$38.00
April	$		$38.00
April, 1981 thru Jan.,1982			$35.00

1980

	Lower Tier - IL	Upper Tier - IL	Released & Stripper
January	$6.34	$13.74	$38.00
February	$6.38	$13.83	$38.00
March	$6.42	$13.93	$38.00
April	$6.46	$14.03	$38.00

May	$6.51	$14.13	$38.00
June	$6.56	$14.24	$38.00
July	$6.61	$14.35	$38.00
August	$6.66	$14.46	$38.00
September	$6.72	$14.58	$36.00
October	$6.78	$14.70	$36.00
November	$6.84	$14.83	$36.00
December	$6.89	$14.95	$37.00

1979

	Lower Tier - IL	Upper Tier - IL	Released & Stripper
January	$5.87	$12.68	$15.95
February	$5.90	$12.75	$15.95
March	$5.94	$12.83	$15.95
April	$5.98	$12.91	$18.20
May	$6.02	$12.99	$19.20
June	$6.06	$13.08	$24.50
July	$6.10	$13.17	$26.50
August	$6.14	$13.26	$28.50
September	$6.18	$13.36	$31.00
October	$6.22	$13.46	$32.50
November	$6.26	$13.56	$35.00
December	$6.30	$13.65	$38.00

1978

	Lower Tier - IL	Upper Tier - IL	Released & Stripper
January	$5.46	$11.78	$14.95
February	$5.48	$11.83	$14.95
March	$5.51	$11.89	$14.95
April	$5.54	$11.95	$14.95
May	$5.57	$12.01	$14.95
June	$5.60	$12.08	$14.95
July	$5.63	$12.15	$14.95
August	$5.66	$12.22	$14.95
September	$5.71	$12.32	$14.95
October	$5.76	$12.43	$14.95
November	$5.81	$12.54	$14.95
December	$5.84	$12.61	$14.95

1977

	Lower Tier - IL	Upper Tier - IL	Released & Stripper
January	$5.33	$11.35	$14.00
March	$5.33	$10.90	$14.00

August	$5.33	$10.90	$14.95
September	$5.36	$11.16	$14.95
October	$5.39	$11.42	$14.95
November	$5.42	$11.68	$14.95
December	$5.44	$11.73	$14.95

1976

	Lower Tier - IL	Upper Tier - IL	Released & Stripper
February	$5.20	$11.28	$13.10
March	$5.23	$11.35	$13.10
April	$5.26	$11.42	$13.10
May	$5.30	$11.49	$13.10
June	$5.33	$11.55	$13.10
Prices froze at this level until January 1, 1977, except stripper (uncontrolled).			
September			$14.00

1975

	Lower Tier - IL	Upper Tier - IL	Released & Stripper
February	$5.20		$11.60
April	$5.20		$11.90
July	$5.20		$12.40
September	$5.20		$12.40
October	$5.20		$12.60
November	$5.20		$13.10

1974

	Lower Tier - IL	Upper Tier - IL	Released & Stripper
August	$5.20		$10.30
December	$5.20		$11.20

1973

	Lower Tier - IL	Upper Tier - IL	Released & Stripper
April	$3.60		
August	$4.20		
September	$4.20		$5.20
October	$4.20		$5.85
November	$4.20		$8.55
December	$5.20		$8.55

1970

November	3.60		
Beginning of Tier Prices	Lower Tier - IL	Upper Tier - IL	Released & Stripper
December	3.60		

1969 back to 1946

April 1, 1969	$3.35		
March 17, 1969	$3.30		
March 1, 1969	$3.25		
July 1, 1968	$3.20		
August 1, 1967	$3.15		
December 6, 1965	$3.10		
October 11, 1963	$3.00	Gravity pricing established	
August 29, 1960	$3.00	***OPEC was formed in 1960 with five founding members: Iran, Iraq, Kuwait, Saudi Arabia and Venezuela***	
June 20, 1960	$2.85		
December 13, 1957	$3.00		
January 9, 1957	$3.15		
June 12, 1956	$2.90		
October 15, 1955	$3.00		
October 20, 1954	$2.90		
June 15, 1953	$3.02		
November 28, 1947	$2.77		
October 15, 1947	$2.27		
March 10, 1947	$2.07		
November 15, 1946	$1.82		
July 25, 1946	$1.72		
April 1, 1946	$1.47		
March 31, 1946	$1.37		