REPORT

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A REVIEW OF NORTH AMERICAN BIOFUEL PRODUCTION, POLICIES AND RESEARCH

Report from an f3 project

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THE SWEDISH KNOWLEDGE CENTRE
FOR RENEWABLE TRANSPORTATION FUELS

PREFACE

This report is the result of a collaborative project within the Swedish Knowledge Centre for Renewable Transportation Fuels (f3). f3 is a networking organization, which focuses on development of environmentally, economically and socially sustainable renewable fuels, and

- Provides a broad, scientifically based and trustworthy source of knowledge for industry, governments and public authorities,
- Carries through system oriented research related to the entire renewable fuels value chain,
- Acts as national platform stimulating interaction nationally and internationally.

f3 partners include Sweden's most active universities and research institutes within the field, as well as a broad range of industry companies with high relevance. f3 has no political agenda and does not conduct lobbying activities for specific fuels or systems, nor for the f3 partners' respective areas of interest.

The f3 centre is financed jointly by the centre partners, the Swedish Energy Agency and the region of Västra Götaland. f3 also receives funding from Vinnova (Sweden's innovation agency) as a Swedish advocacy platform towards Horizon 2020. Chalmers Industriteknik (CIT) functions as the host of the f3 organization (see www.f3centre.se).

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SUMMARY

The following report provides a brief overview of the development, production, policies and trends promoting biofuels in Canada and the U.S. in addition to some key contacts for collaboration with the f3. Information for the report was collected through literature reviews and interviews with leading researchers in Canada and the US during a research trip to attend the Advanced Biofuels Symposium in Montreal.

The production of biofuels has increased dramatically in North America in recent years. The United States (U.S.) is leading this development and has promoted biofuels through a number of policies and mandates through the Renewable Fuels Standard to drive production, research and innovation in the area. Canada has also intensified the promotion of biofuels in recent years through the Renewable Fuels Regulation, in addition to a number of provincial policies and mandates to promote biofuels. Ethanol is currently the dominant fuel in both countries, with blend rates in petrol between 5-10 percent, but with even higher blends in some areas in development, depending upon the region. The promotion and policies for ethanol fuels help to drastically increase their production and use in the past 10 years. The U.S. is currently the largest producer of ethanol in the world, with nearly 55 billion liters of ethanol produced in 2014. Canada has also seen a large increase in biofuel production during the last 10 years, with production increasing by a factor of 10. Currently Canada produces roughly 1.7 billion liters of ethanol per year. Other biofuels, such as biodiesel, have only marginal volumes in comparison, although roughly 300 million liters of biodiesel were produced in 2014 in Canada and 6 billion liters in the U.S.

Despite the dramatic increases in the past 10 years, Canada and the U.S. have seen stagnation in conventional biofuel production. This is due in part to a saturation of the market and incentives for current plants, but also due to a large focus on advanced biofuel. Nonetheless, the growth of advanced biofuels has been inadequate to meet mandates. For example, the U.S. set mandates to produce 60 billion liters of advanced biofuels per year by 2020. The U.S. EPA has since deemed these volumes to be unreachable with current technologies and have thus adjusted the mandate to only 2 billion liters per year. Nonetheless, in both countries, large innovative advanced biofuel production facilities have recently been opened and are producing cellulosic ethanol and other advanced biofuels which may drive developments of further plants.

The research on biofuels in the U.S. and Canada has also seen a large focus on advanced biofuel production. Both nations have set large focus on the new processes for advanced biofuel production and logistics for supplies of biomass for production plants. Furthermore, many of the research topics mirror those of the f3. Accordingly, a list of prominent research groups has been provided to allow for increased cooperation with North American biofuel researchers.

SAMMANFATTNING

Följande rapport ger en översikt över utveckling och produktion av biodrivmedel i Kanada och USA. Rapporten ger också en summering av de styrmedel som främjar en ökning av biodrivmedel. Rapporten bygger på en litteraturgenomgång samt intervjuer med ledande forskare i Kanada och USA, vilka genomfördes under en forskningsresa.

Det kan konstateras att produktionen av biodrivmedel har ökat kraftigt i Nordamerika under de senaste åren. USA leder utvecklingen och har gynnat biodrivmedel med hjälp av ett antal styrmedel inom programmet *Renewable Fuels Standard* vilka har syftat till att stimulera produktion, forskning och innovation inom området. Kanada har också intensifierat främjandet av biodrivmedel under de senaste åren genom förordningen *Renewable Fuels Regulation* så väl som ett antal regionala styrmedel. Det dominerande biodrivmedlet i både USA och Kanada är idag etanol, vilken blandas i bensin med en inblandningsgrad på mellan 5-10 procent, ännu högre inblandningsgrader förekommer dock i vissa utvecklingsområden, beroende på region. Styrmedel som främjar vissa etanolbränslen har bidragit till att drastiskt öka produktion och användning under de senaste 10 åren. USA är för närvarande den största producenten av etanol i världen, med en produktion av nästan 55 miljarder liter etanol år 2014. Kanada producerar för närvarande cirka 1,7 miljarder liter etanol per år men har sett en stor ökning av produktionen av biodrivmedel (till stor del etanol) under de senaste 10 åren, då produktionen ökade med en faktor 10. Andra biodrivmedel, såsom biodiesel, produceras endast i jämförelsevis, marginella volymer i Nordamerika, även om cirka 300 miljoner liter biodiesel producerades i Kanada och 6 miljarder liter biodiesel producerades i USA år 2014.

Trots den dramatiska ökningen av biodrivmedelsproduktionen under de senaste 10 åren, ser den konventionella produktionen av biodrivmedel i Kanada och USA ut att ha stagnerat. Detta beror delvis på en mättnad av marknaden och avtagande stimulansåtgärder riktade mot nuvarande anläggningar, men också på ett ökat fokus på avancerade biodrivmedel. Trots ökat fokus har tillväxten av avancerade biodrivmedel hittills varit otillräcklig för att möta de mål som satts upp för området. Till exempel har USA satt upp ett mål om att producera 60 miljarder liter avancerade biodrivmedel per år från 2020. Det amerikanska EPA har dock sedan dess gjort bedömningen att dessa volymer är omöjliga att nå med dagens teknik och har därmed justerat målet till endast 2 miljarder liter per år. Dock har stora innovativa produktionsanläggningar för avancerade biodrivmedel nyligen öppnat i både Kanada och USA, vilka producerar etanol från cellulosaråvara samt andra avancerade biodrivmedel. Detta skulle kunna driva på utvecklingen av ytterligare anläggningar och således ge bättre förutsättningar att nå de uppsatta målen.

Forskningen på biodrivmedelsområdet i USA och Kanada har också stort fokus på avancerad biodrivmedelsproduktion. Båda nationerna har satt stort fokus på nya processer för avancerad produktion av biodrivmedel samt logistik för leveranser av biomassa till produktionsanläggningar. Många av forskningsområdena har beröring med den forskning som bedrivs inom f3:s forskarnätverk. I slutet av rapporten återfinns en lista över framstående forskargrupper som tagits fram med syfte att möjliggöra ett ökat samarbete med nordamerikanska biodrivmedelsforskare.

CONTENTS

1 INTRODUCTION

In recent years, biofuel research and production has increased dramatically in North America. In the mid-2000s, Canada and the U.S. drafted policies and mandates to promote biofuels which has led to a significant increase in the use and production of biofuels in the two countries. Canada and the U.S. have also invested heavily in research and development for biofuels in order to speed up the commercialization of the biofuel industry. The U.S. is currently the largest producer of ethanol in the world, surpassing Brazil in 2005. Canada has also increased their production of ethanol by a factor of 10 in the last 10 years (GAIN, 2014).

The two countries have seen stagnation in conventional biofuel production with much focus on the production of advanced biofuels. Despite the promise of the production of advanced biofuels in these countries, growth has been inadequate to meet mandates; although development is continuing to drive production to become more economic. In both countries, large innovative advanced biofuel production facilities have recently been opened and are producing cellulosic ethanol and other advanced biofuels. It is therefore interesting to follow the policies, development and research on the North American continent with focus on Canada and the U.S.

This report therefore aims at providing a brief overview of biofuel policies, production and research in Canada and the U.S. As such this report aims at providing:

- a brief review of current policies promoting biofuels,
- a review of the production of biofuels and new developments,
- current research outlook and needs,
- information on relevant research institutes which may provide future networking and collaboration opportunities to f3 partners.

2 METHODOLOGY

As the project aims to review the current focus, policies, technologies and research, literature reviews and interviews with biofuel researchers were conducted to gather appropriate information and data.

The literature review focused on the production and state of current policies related to biofuels in Canada and the U.S. Interviews were conducted with leading biofuel researchers in both countries. These were conducted during a field trip to North America to attend the Advanced Biofuel Symposium in Montreal, Canada and thereafter visit with researchers at Michigan State University in Michigan, U.S. during July 2015. Table 1 below lists the researchers interviewed for the study whom provided valuable input about current production plants and policies.

Table 1: Researchers interviewed

Canadian Biofuel Researchers	**American Biofuel Researchers**
• Don Smith, Executive Director for BioFuelNet • Warren Mabee, Associate Professor & Director-Queen's Institute for Energy & Environmental Policy • Julian Cleary, Assistant Professor-University of Regina	• Doug Gage, Ass. Vice President for Research and Graduate Studies & Director-MSU BioEconomy Network • Allen Julian, Chief Business Office, MBI • Bruce Dale, Professor, Professor of Chemical Engineering and Materials Science and Editor in Chief of Biofuels, Bioproducts and Biorefining

The interviews were conducted following an interview guide with each respondent and questions addressed the policies, state-of-the-art technologies, trends, research areas and challenges of biofuel production and development in Canada and the U.S., respectively. Questions included:

1. What are the most important/influential policies and initiative, at the moment, that are promoting biofuels?
2. What are the key challenges facing the Canadian/U.S. biofuel industry?
3. What future technologies for biofuels are currently being developed?
4. What are the most recent production plants coming online?
5. What are the current research trends in Canadian/U.S. biofuel research?
6. What are the key research challenges and who are undertaking this research?

Finally, current research focus areas were explored through the use of a literature review and development of a word cloud to find general research trends. More information is provided in Section 5 below.

3 POLICIES

The following sections will review the policies and initiatives in place in Canada and the U.S. to promote the use, development and research for biofuels with a focus on both national and regional developments.

3.1 CANADA

3.1.1 National Policy

In December 2006, the Canadian government announced its Renewable Fuels Strategy (RFS), which introduced national renewable fuel mandates for ethanol and biodiesel and provided resources to stimulate the domestic production of renewable fuels. The RFS was designed to 1) reduce GHG emissions resulting from fuel use, 2) encourage greater production of biofuels, 3) accelerate the commercialization of biofuel technologies and 4) provide new market opportunities for producers and rural communities.

The RFS is based around four primary actions: 1) increasing retail availability of biofuels through the **Renewable Fuel Regulation**, 2) supporting Canada's production capacity through the **ecoENERGY for Biofuels Initiative**, 3) assistance to farmers through the **ecoAgriculture Biofuels Capital Initiative**, and 4) the acceleration of new technologies through the **NextGen Biofuels program**.

1) Renewable Fuel Regulation

In December 2010, the Renewable Fuel Regulation introduced blending mandates for renewable fuel contents in the national gasoline pool and the diesel fuel and heating distillate oil pools with the objective of reducing greenhouse gas emissions.

The regulation set a 5% renewable fuel mandate (ethanol) for the national gasoline pool. A 2% mandate for renewable fuel content in diesel fuel and heating distillate oil was also established in the Renewable Fuel Regulation, but no commencement date was established. This was due to the fact that the demonstration of the technical feasibility for Canadian conditions had not been completed. In July 2011, the mandate was implemented with a permanent exemption for renewable content for diesel fuel and distillate oil in Newfoundland and Labrador due to logistical challenges. Amendments to the Renewable Fuels Regulations in 2013 introduced a permanent exemption from the mandate for heating oils. Responsibility to meet the blending mandates is at the point of production or importation.

The Renewable Fuel Regulation does not include any environmental sustainability standards, such as the European Union's Renewable Energy Directive which requires that the use of biofuels to contribute to minimum GHG reductions (compared to a fossil fuel reference value) of 35% by 2013, 50% by 2017, and 60% by 2018 and that biofuels not be made from biomass growing on land with high carbon stock or high biodiversity (Council Directive, 2009). However, Natural Resources Canada in cooperation with the provinces and the Canadian Renewable Fuels association have developed a set of non-binding 'Guiding Principles for Sustainable Biofuels in Canada' (Natural Resources Canada, 2013), which mentions legal, environmental and social concerns (Mondou and Skogstad, 2012).

The USDA Foreign Agricultural Service has noted that the "Federal and provincial blend mandates are not forecast to increase beyond current levels in the short or medium term." (GAIN, 2014) All Canadian Biofuel researchers interview noted that the mandates for biofuels are the single largest driver for biofuel development from policy in Canada, and without any development in the area little change in the industry is forecast. Furthermore, there is no mandate for advanced biofuels.

2) ecoENERGY

The ecoENERGY for Biofuels Program (administered by Natural Resources Canada) is a €1 billion[1] programme over 9 years which provides a per-liter incentive to biofuel producers from 2008-2017. Fixed declining incentive rates for ethanol and renewable/biodiesel production are detailed in Table 2. Sixteen ethanol plants have signed onto the programme. The federal production incentives will not be provided beyond the 31st of March 2017 and are not expected to be extended. (GAIN, 2014)

Table 2: Federal production incentive rates

Fiscal Year*	2008 -2009	2009 -2010	2010-2011	2011 -2012	2012 -2013	2013 -2014	2014 -2015	2015 -2016	2016 -2017
Renewable Alternatives to Gasoline (€/L)	0.07	0.07	0.06	0.06	0.05	0.04	0.03	0.03	0.02
Renewable Alternatives to Diesel (€/L)	0.18	0.17	0.14	0.12	0.10	0.07	0.06	0.04	0.03

* April 1 of a year to March 31 of the following year.

3) ecoAgriculture Biofuels Capital Initiative

The ecoAgriculture Biofuels Capital Initiative (administered by Agri-Food Canada), launched in 2007, was a 4 year €138 million scheme providing repayable grants up to €17 million. The objective of the initiative was to assist farmers in seizing new opportunities in the biofuels sector and it was seen as a vehicle to encourage the increased domestic production of ethanol. In November 2013, the scheme was extended by two years, until March 2013, to compensate for the poor economic conditions in 2008/2009.

The *Evaluation of ecoAgriculture Biofuels Capital Initiative* (Office of Audit and Evaluation, 2011), undertaken before the completion of the programme, reported that as of December 2010 six projects has contribution agreements signed and two had been approved, with a total contribution value of €55 million. The review forecast eight to 12 new facilities, or expansion of existing facilities, resulting in an additional 929 million liters of biofuel capacity.

[1] All economic figures are provided in equivalent Euros, with 1 CAD = € 0.689 and 1 USD = € 0.907 (based on exchange rate of October 25, 2015). Volumes have been provided in equivalent liters based on the conversion 1 gallon = 3.78 liters.

4) NextGen Biofuels program

Sustainable Development Technology Canada (SDTC), a non-for-profit organization funded by the federal government, was provided € 345 million in 2007 to fund commercial scale demonstration project for advanced biofuels over an eight year period.

Public support for biofuels and biofuel mandates are strong. In 2009, a poll commissioned by the Canadian Renewable Fuels Association showed that 84% of Canadians surveyed support the promotion of renewable fuels, 74% approved the federal blending mandate and 87% would support federal policies to promote the development of second generation biofuels (Mondou and Skogstad, 2012). A more recent survey commissioned by the Canadian Renewable Fuels Association, in July 2015, showed that 88% of respondents surveyed believed that more renewable fuels should be produced in Canada and that the government should do more to promote renewable fuels (Canadian Renewable Fuels Association, 2015). Furthermore, 67% of respondents said that they would support increasing the biodiesel mandate compared to only 10% opposed (Canadian Renewable Fuels Association, 2015).

3.1.2 Provincial Policy

Provincial biofuel policies play a significant role in Canada, as they were forerunners to federal policies. Canada's western provinces (British Columbia, Alberta, Saskatchewan and Manitoba) and Ontario have blend mandates; see Table 3. Quebec has an aspirational 5% mandate but has put significant effort into the development of cellulosic ethanol. Several provinces (Alberta, Saskatchewan, Manitoba, Ontario and Quebec) have production and/or consumption incentives for renewable fuels; more detail can be found in GAIN (2014).

Provincial ethanol blend mandates require that with the fuel producer or supplier replace the mandate percentage of gasoline available for sale with ethanol. For biodiesel, fuel producers or suppliers are required to blend the mandated amount of biodiesel in their overall sales of both on- and off-road diesel fuels.

Table 3: *Provincial Blend Mandates*

Province	**Ethanol Blend Mandate**	**Renewable diesel/Biodiesel Blend Mandate**
British Columbia	5%	4%
Alberta	5%	2%
Saskatchewan	7.5%	2%
Manitoba	8.5%	2%
Ontario	5%	2-4%*

* Depending on GHG reductions

3.2 THE UNITED STATES

The U.S. has promoted the production of biofuels as a method to provide jobs, greater economic vitality in rural areas, increase energy independence, increase technological innovation and to reduce global warming impacts from fossil fuels (White House, 2014). Federal and state policies and initiatives have thus been created to promote biofuels, as outlined below.

3.2.1 Federal Policies

Although previous government initiatives were instrumental in building biofuel policy and regulations, see Table A in the Appendix, the ***Renewable Fuel Standard***, introduced through the Energy Policy Act of 2005, is the single largest policy instrument for the promotion of biofuels in the U.S. This document, often referred to as the **RFS-1**, mandated an annual blending target of 7.5 billion gallons (roughly 28.4 billion liters[2]) of renewable fuels in gasoline and diesel by 2012 (Environmental Protection Agency, 2010). This target drove a large increase in corn-based ethanol, estimated at a 5-fold increase, from approximately 5 billion liters in 1991 to 25 billion liters in 2007.

As the U.S. looked to increase biofuels in the transportation sector, quantitative mandates were included and expanded in the Energy Independence Security Act (EISA) of 2007, which were set in place through the revised Renewable Fuels Standard (denoted as **RFS-2)**. In the RFS-2, greenhouse gas emissions thresholds and a target of roughly 121 billion liters of biofuels were set for 2020. Furthermore, the mandate called for certain portions of advanced and conventional biofuels from a number of sources. These included conventional ethanol (corn), cellulosic biofuels, biomass based biodiesel and other advanced fuels. For the different fuels, blend mandates are outlined and adjusted annually by the EPA based on predicted annual fossil fuel consumption figures.

Box 1: Definitions for different fuels and their environmental impacts (US Government, 2007; Section 201)

- ***Conventional biofuel*** is ethanol derived from corn starch. Conventional ethanol facilities that commence construction after the date of enactment must achieve a 20 percent greenhouse gas (GHG) emissions reduction compared to baseline lifecycle GHG emissions. The 20 percent GHG emissions reduction requirement may be adjusted to a lower percentage (but not less than 10 percent) by the U.S. Environmental Protection Agency (EPA) Administrator if it is determined the requirement is not feasible for conventional biofuels.

- ***Advanced biofuels*** is renewable fuel other than ethanol derived from corn starch that is derived from renewable biomass, and achieves a 50 percent GHG emissions reduction requirement. The definition — and the schedule — of advanced biofuels include cellulosic biofuels and biomass-based diesel. The 50 percent GHG emissions reduction requirement may be adjusted to a lower percentage (but not less than 40 percent) by the Administrator if it is determined the requirement is not feasible for advanced biofuels. (Cellulosic biofuels that do not meet the 60 percent threshold, but do meet the 50 percent threshold, may qualify as an advanced biofuel.)

- ***Cellulosic biofuels*** is renewable fuel derived from any cellulose, hemicellulose, or lignin that is derived from renewable biomass, and achieves a 60 percent GHG emission reduction requirement.

[2] 1 U.S. gallon roughly equates to 3.8 liters

The 60 percent GHG emissions reduction requirement may be adjusted to a lower percentage (but not less than 50 percent) by the Administrator if it is determined the requirement is not feasible for cellulosic biofuels.

Mandates required that conventional biofuels (i.e. corn based ethanol) stagnate and that there is an increase in cellulosic ethanol. This is outlined as an expected growth from 0.4 billion liters in 2010 to 11 billion liters in 2015 and thereafter 61 billion liters in 2022. Furthermore, biomass-based diesel is required to increase from 1.9 billion liters in 2009 to over 3.8 billion liters 2012; no increase is outlined thereafter (OLA Minnesota, 2009; Rajcaniova et al., 2015). Table 4 and Figure 1 below depict the targets and different biofuels outlined in the RFS-2.

Table 4: Biofuel Production Targets under the RFS2 in billion liters

(Source: http://www.ethanolrfa.org/pages/renewable-fuel-standard/#sthash.p1jJVh8N.dpuf)

Year	Renewable Biofuel	Advanced Biofuel	Cellulosic Biofuel	Biomass-based Diesel	Undifferentiated Advanced Biofuel[3]	Total RFS
2008	34.1	0.0	0.0	0.0	0.0	34.1
2009	39.7	2.3	0.0	1.9	0.4	42.0
2010	45.4	3.6	0.4	2.5	0.8	49.0
2011	47.7	5.1	0.9	3.0	1.1	52.8
2012	50.0	7.6	1.9	3.8	1.9	57.5
2013	52.2	10.4	3.8	3.8	2.8	62.6
2014	54.5	14.2	6.6	3.8	3.8	68.7
2015	56.8	20.8	11.4	3.8	5.7	77.6
2016	56.8	27.4	16.1	3.8	7.6	84.2
2017	56.8	34.1	20.8	3.8	9.5	90.8
2018	56.8	41.6	26.5	3.8	11.4	98.4
2019	56.8	49.2	32.2	3.8	13.2	106.0
2020	56.8	56.8	39.7	3.8	13.2	113.6
2021	56.8	68.1	51.1	3.8	13.2	124.9
2022	56.8	79.5	60.6	3.8	15.1	136.3

[3] Undifferentiated biofuels are biofuels that do not fit into the other categories (e.g. biogas) and can act as a buffer for "extra" biodiesel biomass based biodiesel

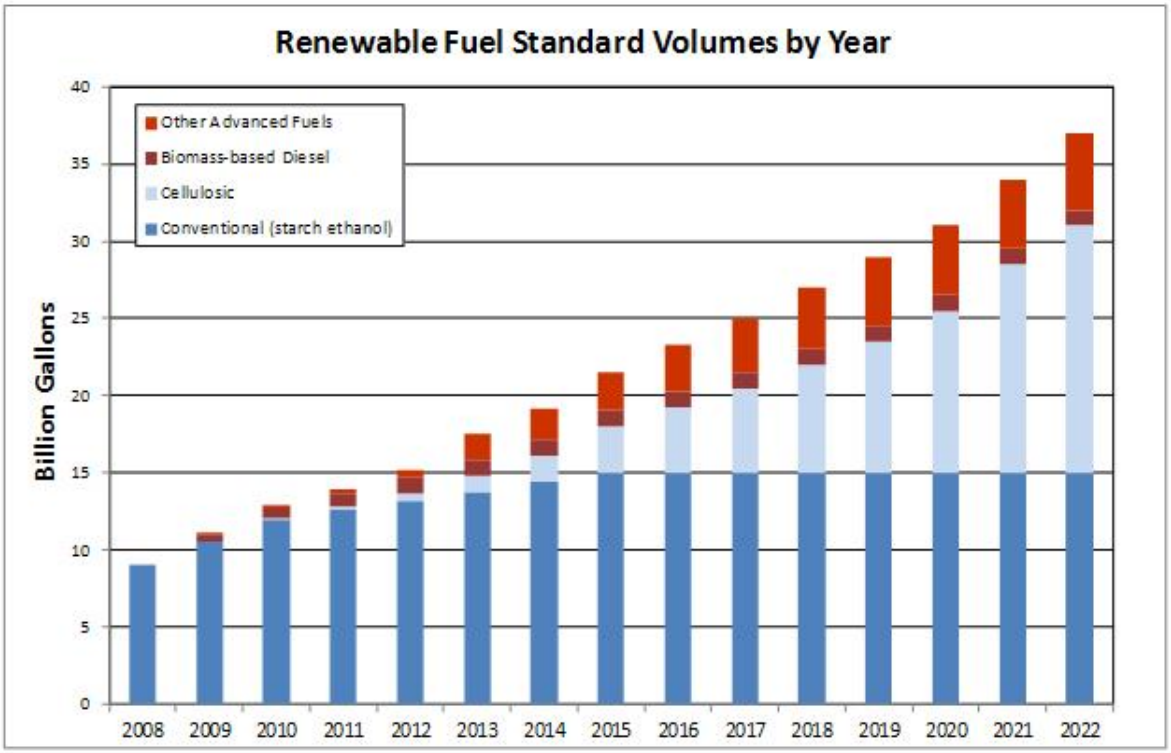

Figure 1: Renewable Fuel Standard Volumes by Year (in billion Gallons)

Source: Alternative Fuels Data Center, U.S. Dept. of Energy http://www.afdc.energy.gov/laws/RFS.html

As mentioned previously, the RFS-2 also included sustainability criteria for biofuels, i.e. environmental sustainability, with limits seen in Box 1 above. This includes environmental impact reduction criteria of different biofuels in comparison to fossil equivalents (similar to the EU Renewable Energy Directive). In order for the different fuels to be considered sustainable, they are required to have GHG emissions reductions of 20% for conventional fuels, 50% for advanced biofuels and 60% for cellulosic biofuels. Furthermore, as many ethanol plants were in operation before 2007, a "grandfathering" rule was applied to those plants operating pre-2008, which allowed these to be included as conventional fuels but not required to meet the 20% GHG emissions reductions. Furthermore, land use was also addressed in the RFS2, with requirements that raw materials be used from agricultural land that is cleared or cultivated prior to 2007 and must be actively managed, non-forested land (US Government, 2007; Section 201). If raw materials are produced outside of the U.S., the producers must provide tangible evidence that land was not cleared after December 2007. The EPA has also issued guidelines on calculating indirect land use change emissions from biofuels, which has been highly contested by biofuel producers, especially corn ethanol and biodiesel producers for the potential negative implications it may have on their production processes (Mondou and Skogstad, 2013). Biofuel policy is a hotly debated topic in the U.S. Mondou and Skogstad (2013) outline many of the controversies surrounding the mandates provided in the RFS-2 and the EPA's modelling of indirect land use change effects.

Several of the interviewed researchers discussed the implications of life cycle assessment in policy for the biofuel industry. One researcher suggested that

> "It is the apparent conflict between GHG reduction and some biofuels that is the current major policy impediment to biofuels since it splits the constituencies."

Another statement included,

> "The key national initiative is the Renewable Fuel Standard, which is being hotly debated right now. If it is overturned or sharply limited, it is likely we will not see a large biofuel industry in the U.S. within my lifetime. The private sector, having spent billions, will walk away and will not come back until a new generation of leaders emerges."

Besides mandates for certain shares of biofuels in the transportation sector, the federal government has provided credits for blended fuels. The credit has ranged from €0.1-0.14 per liter of ethanol from 2005-2009, and after 2009 this was set at €0.11 per liter of ethanol. Cellulosic ethanol credits are set at €0.24 per liter. In 2004, incentives were provided for the biodiesel industry. A $1.00 credit was provided for biodiesel produced from virgin oils, i.e. those such as oil commodities and animal fats, while €0.450 was provided for biodiesel produced from waste oils. In 2009, this credit was set at $1.00 per gallon of any type of biodiesel. Tax credits are also provided for producers based on their production figures. €0.02 was provided per liter of ethanol and biodiesel on the first 56.8 million liters (only applicable for plants with a capacity of less than 227 million liters). Finally, the government also has tariffs for imported fuels in order to support biofuels in the U.S. and to prevent cheaper fuels from being imported and taking over the market share, e.g. from South America (OLA Minnesota, 2009; Rajcaniova et al., 2015).

Grants have also been provided to develop biofuels in the U.S. from the federal government. These include €450 million between 2008-2015 for production of advanced biofuels, €22.5 million between 2008-2010 for research and development projects and commercial application in states with low output of ethanol (both traditional and cellulosic) and € 180million between 2008-2014 for infrastructure to allow for E-85 to be sold at the pump (Renewable Fuels Assosiation, 2014; U.S. Government, 2007, Sec. 207, 223 and 244).

In addition to federal incentive programs, in the 1970s and 80s, many states initiatives were developed to help revive the ethanol industry in the U.S. These came in the form of tax exemptions and credits for producers in addition to grants and loan programs for land and facilities. By 2004, over 36 states had ethanol support programs (California Energy Commission, 2004). States such as Minnesota have made many incentives for the promotion of fuels, including providing tax exemptions for only E85 fuels and increasing blending walls. Currently, Minnesota has a 10% blending cap for biodiesel and is expected to increase this to 20% later in 2015, although some delays may be expected in order to upgrade blending facilities (OLA Minnesota, 2009; Solomon et al., 2014) which gives it a unique position as a leading proponent of ethanol in the U.S.

4 PRODUCTION

4.1 CANADA

4.1.1 Bioethanol

The 5% ethanol mandate requires approximately 2.2 billion liters of bioethanol to be put on the Canadian market per year. However, it is suggested that, in 2014, the national blending rate has reached 7.1% of the gasoline pool, higher than the national 5% renewable fuel mandate, with a similar forecast for 2015. Canada has not reached a domestic production capacity that would allow its blend rates to be met by domestic production. Hence, the balance of ethanol is imported, currently from the U.S. (GAIN, 2014).

Canadian biofuel production has increased by a factor of 10 within the last 10 years. Bioethanol production capacity rose by a marginal 1% from 1,730 million liters in 2013, to 1,745 million liters in 2014. In 2015, production is forecast to remain at 1,745 million liters. Increases have been attributed to increases in operation efficiency with no increase expect in domestic production capacity between 2014 and 2015. It is suggested that unless there is substantial economic change, production capacity will remain at current levels (GAIN, 2014).

There are 17 bioethanol production facilities located in Alberta (Edmonton, Hairy Hill and Red Deer), Manitoba (Minnedosa), Ontario (Aylmer, Chatham, Havelock, Johnstown, Sarnia and Tiverton), Quebec (Varennes and Westbury) and Saskatchewan (Belle Plaine, Lanigan, Lloydminster, Unity and Weyburn), see Figure 2. Half of Canada's bioethanol production is in Saskatchewan, Manitoba, and Ontario (GAIN, 2014).

Primary feedstocks for bioethanol are corn (77%) and wheat (23%), which has mainly been driven feedstock availability. Ethanol plants in Ontario, Manitoba and Quebec utilize corn due to its availability in the vicinity, whereas plants in Alberta and Saskatchewan process mostly feed wheat due to the limited availability of corn (GAIN, 2014).

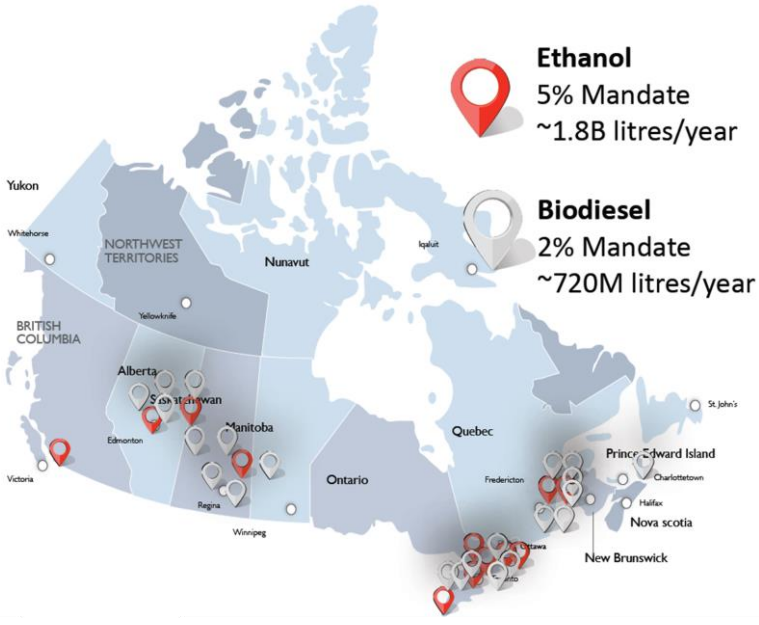

Figure 2: Biofuel production sites in Canada. Source: Canadian Renewable Fuels Association (2015)

4.1.2 Biodiesel

Biodiesel production is forecast to reach 395 million liters in 2015, up from an estimated 300 million liters in 2014. In 2014, production is estimated to have more than doubled due to a new canola facility in Lloydminster, Alberta. However, this is below the level required by the 2% biodiesel mandate, approximately 650 million liters, the balance of which is met by imports. Statistics on total diesel use suggest that a blend rate of 1.9 is forecast for 2015 (GAIN, 2014).

There are 12 biodiesel production facilities located in Alberta (Lethbridge and West Lloydminster), British Columbia (Delta – two plants), Ontario (Hamilton, Mississauga, Springfield, Sombra and Welland), Quebec (St-Jean d'Iberville and Montreal) and Saskatchewan (Foam Lake), see Figure 2. Half of Canada's bioethanol production is in Saskatchewan, Manitoba, and Ontario. The majority of Canadian biodiesel is exported to the United States due to the blenders' credit (GAIN, 2014).

Primary feedstocks are canola, animal fat, and recycled oils. By the end of 2015 canola is expected to account for approximate 66 % of the feedstock, due to the large abundance of canola. Only the two largest plants in Welland (canola and soybean) and Lloydminster (canola) have been consistently able to operate at capacity over the last five years (GAIN, 2014).

4.1.3 Advanced biofuels

Canada is making progress toward the full-scale operation of facilities. In 2004, the Iogen Corporation, an Ottawa (Ontario) based company, built the world's first commercial scale demonstration plant to convert wheat straw fiber to ethanol. The plant has produced more than 2 million liters of cellulosic ethanol in its €69 million demonstration plant using agricultural residues such as wheat straw, corn stover and bagasse as feedstocks (Lane, 2013). In 2002, Shell invested in developing Iogen cellulosic biofuel technology, however, in 2012 Shell announced the termination of its pursuit of a cellulosic ethanol project in Canada. Following a 2012 joint venture announcement, in October 2012, between Iogen and Raízen, Brazil's third largest energy company, the production of cellulosic ethanol on schedule at Raízen`s newly expanded Costa Pinto sugar cane mill in Piracicaba, São Paulo, commenced in December 2014 (Lane, 2015).

Enerkem has completed the construction of a 38 million liter, cellulosic ethanol plant in Edmonton using Enerkem's proprietary thermochemical technology. A 25 year agreement with the City of Edmonton will supply the plant with 100 tonnes of dry municipal solid waste (MSW) per year. The facility will have a capacity 38 million liters per year (Labrie, 2015).

Future plans for a full-scale, cellulosic ethanol plant in Varennes, Quebec have also been announced. The project would be a joint venture between Enerkem and Greenfield Ethanol Inc. converting MSW into 38 million liters of ethanol per year (GAIN, 2014).

4.2 THE UNITED STATES

The production of biofuels has increased rapidly in the U.S. between 2000 and 2014; see Figure 3. The majority of this comes from ethanol and biodiesel, although other biofuels are also produced and used to a lesser extent in the U.S., including e.g. methane, methanol and butanol. The following subsections outline some of the developments and production in the different fuels.

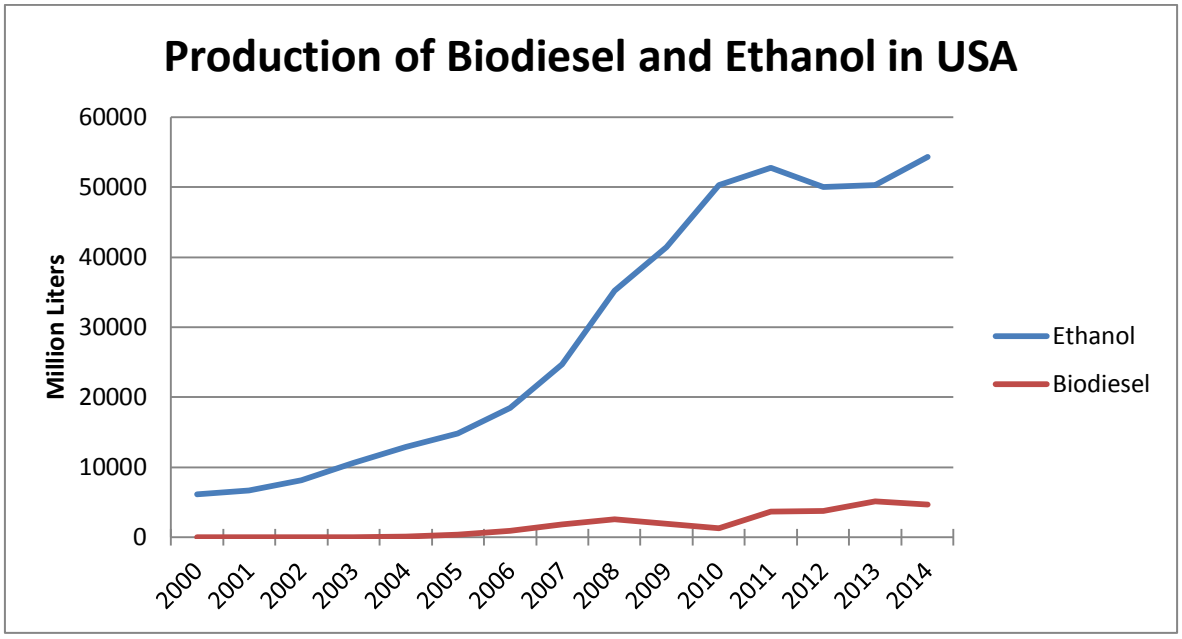

Figure 3: Production of Biodiesel and Ethanol and in the U.S. (in Million liters) Source: www.eia.gov

4.2.1 Ethanol

The U.S. is currently the largest producer of ethanol worldwide, having overtaken Brazil in 2005. As seen in Figure 4, a rapid increase can be seen starting roughly 2005. The increase is primarily a result of the promotion of ethanol through the RFS-1 and 2 programs and a phase-out of methyl tertiary butyl ether (MTBE) as a fuel additive to gasoline (Solomon et al., 2014). In 2014, the U.S. produced roughly 54 billion liters of ethanol, which is used both as E85 and low blends. Currently, the majority of the ethanol produced in the U.S. comes from corn-based ethanol although sorghum and other cereals are also used to a lesser extent. In the RFS-2 program corn, or starch based, ethanol will saturate at 56 billion liters/year after 2011 and the amount of cellulosic biofuels production in the U.S. will rise as high as 60 billion liters/year.

Nearly 95% of all gasoline (blend) sold in the U.S. contains up to 10% ethanol. This is done to increase the octane levels, meet air quality requirements and targets set by the RFS-2 (Alternative Fuels Data Center, 2015). In response to a waiver submitted by a cooperation of ethanol producers under the Clean Air Act, the EPA has allowed for the use of E15 to be used in the vehicle fleet produced after 2001 (EPA, 2015). There is also work being pursued by ethanol producers to introduce so called “Blender pumps” where flex-fuel vehicle owners can choose to fuel with E15, E20 and E85 (Alternative Fuels Data Center, 2015).

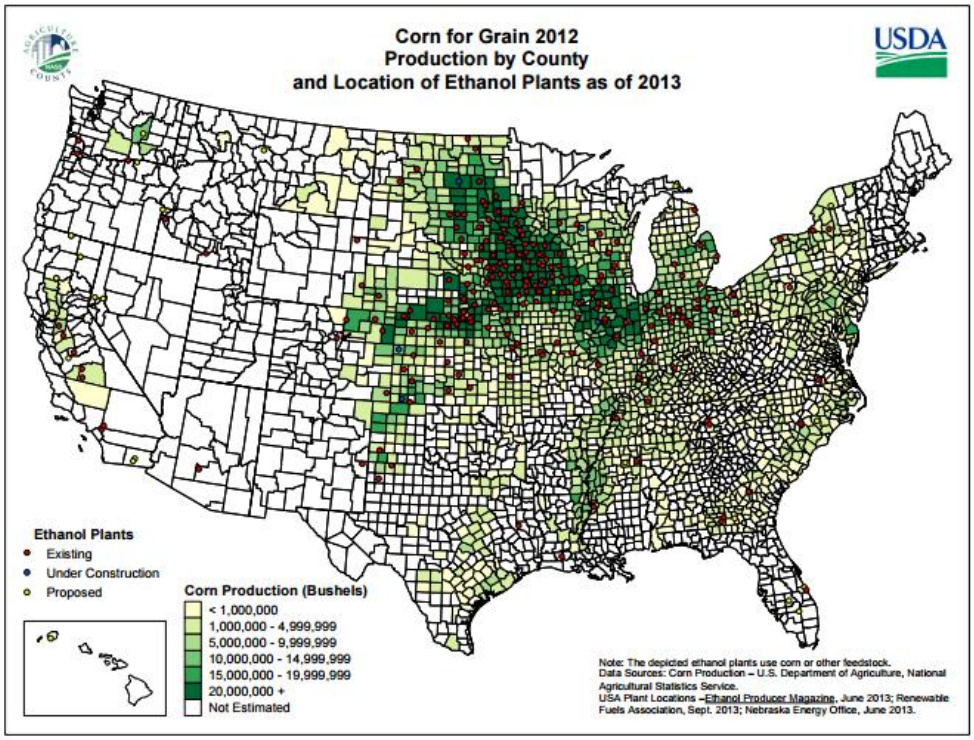

Figure 4: Ethanol Production Plants in the U.S. Source: http://www.nass.usda.gov/Charts_and_Maps/Ethanol_Plants/U._S._Ethanol_Plants/index.asp

4.2.2 Advanced Ethanol

Despite the promotion of cellulosic ethanol production in the U.S., there has been inadequate development of advanced ethanol plants (Solomon et al., 2014); see Table 5 below. In 2013, the Renewable Fuels Association listed many of the current projects under construction for commercialization for cellulosic ethanol production. Several of these projects have unfortunately been abandoned or put on hold due to costs and changes in economic climate. However, recently several advanced bioethanol plants have come online (CRS, 2012).

Table 5: RFS Mandates for Cellulosic Ethanol and EPA Projections on Actual Production (Measured in Billion Liters). Source: www.eia.gov/forecasts/archive/aeo13

	RFS Mandate	EIA Projection
2013	0.0	0.9
2014	6.6	1.0
2015	11.4	1.2
2016	16.1	1.4
2017	20.8	1.5
2018	26.5	1.6
2019	32.2	1.7
2020	39.7	1.8
2021	51.1	1.9
2022	60.6	2.1

POET in a venture with DSM opened their Project Liberty plant in 2014, which produces cellulosic ethanol from corn residues with a 78 million liter capacity in Emmetsburg, Iowa in 2014; see more at POET-DSM (2015). Iowa is also home to another cellulosic ethanol plant from Quad County Corn Processors using corn kernel fibers to produce roughly 7.6 million liters of ethanol in a co-located conventional ethanol plant to provide more value to the by-products. Abengoa also opened a 94.6 million liter capacity cellulosic ethanol plant in Hugoton, Kansas using crop residues with an enzymatic hydrolysis process. The plant also produces 21 MW of electricity. Finally, Dupont also is completing a 113.6 million liter cellulosic ethanol plant in Nevada, Iowa using crop residues (Renewable Fuels Association, 2014).

The Advanced Biofuels USA group also keeps an updated directory of advanced biofuel producers and interest groups on their website, with a database/spreadsheet including information such as the company, type of feedstock, technology/process, co-products, classification of process and other information (ABUSA, 2015).

4.2.3 Biodiesel

Biodiesel production has increased dramatically during the last decade; see Figure 5. Biodiesel is produced from many different types of oils and fats in the U.S. These include soybean oil, animal fats, yellow grease, camelina, canola and corn oil. However, the most common feedstock is soybean oil and animal fats. Soybeans are commonly grown, in a rotation with corn, and primarily limited to the Midwest states (Carriquiry and Babcock, 2008; Weber, 2012).

The production outputs of the nearly 100 biodiesel plants in the U.S. vary widely from 189,000 liters to 302.8 million liters per year/facility. However, most plants produce less than 113.6 million liters per year (BRDB, 2008); see Figure 6 for locations of biodiesel plants in the U.S.

The production of biodiesel, however, has been volatile during the period. Tax credits helped to stimulate the production, though a crash in biofuel production was seen in 2009-2010. Recently the biodiesel industry has rebounded and the output from biodiesel producers has increased. However, high prices for soy production and mandates which only require a production of roughly 3.8 billion liters per year may not allow for a large increase in biodiesel in the future (Solomon et al., 2014; (BRDI, 2015; Carriquiry and Babcock, 2008).

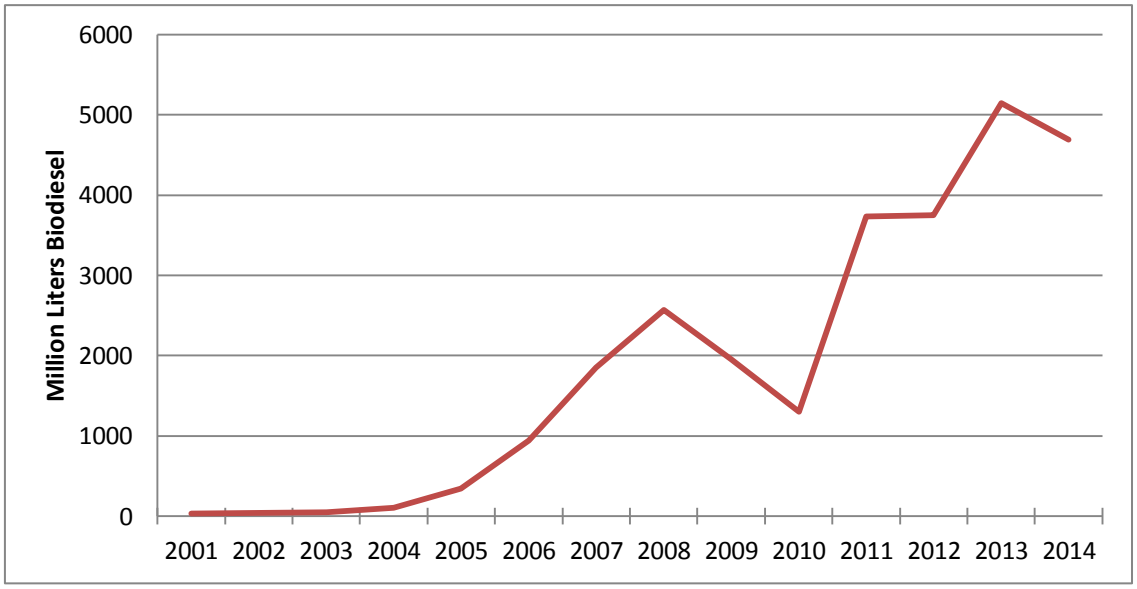

Figure 5: Biodiesel Production in U.S. 2001-2014 shown in Million Liters of Biodiesel. Source: http://www.eia.gov/totalenergy/data/monthly/pdf/sec10_8.pdf

Figure 6: Biodiesel Production Plants in U.S. Source: http://www.bls.gov/green/biofuels/biofuels.htm

4.2.4 Other fuels

Ethanol and biodiesel are dominant fuels in the U.S. market for biofuels. Despite the potential for producing other fuels, e.g. biogas, methanol and hydrogen, there is limited supply and demand for these fuels; see Figure 7.

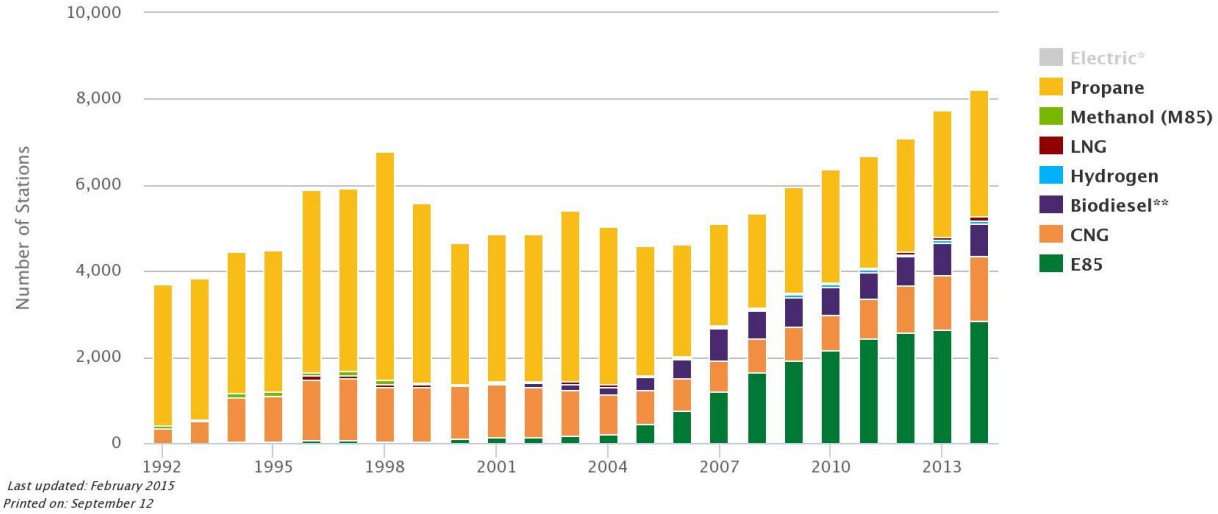

Figure 7: Fueling stations offering alternative fuels in the U.S. (excluding electricity stations) Source: (AFDC, 2014)

There is a large potential for renewable gaseous fuels in in the vehicle fleet, see Figure 7. Nonetheless, biogas (i.e. biomethane) is primarily used in the U.S. to produce electricity (and sometimes heat). Despite the large potential from waste water treatment plants, anaerobic digesters installed for organic waste (e.g. dairy farms and municipal wastes), much of the produced biomethane in the U.S. comes from landfills (DOE, 2015a), see Table 6.

Table 6: Current and Potential Biogas Systems/Plants in the U.S. Source: (USDA, 2014)

	Livestock Manure	**Landfill Gas**	**Water Resource Recovery**	**Total**
Currently Operational Biogas Systems	239	636	1,241	2,116
Total Potential Number of Biogas Systems	8,241	1,086	3,681	13,008

5 RESEARCH AND INNOVATION

5.1 CANADA

5.1.1 Research Networks

BioFuelNet (BFN) is the Canadian association for advanced biofuels. BFN has been funded for 5 years, from April 1 2012 to March 31 2017, by the Government of Canada through the Networks of Centres of Excellence programme under a €17 million grant and 24 € million from partner contributions. Phase I of the BFN ran from April 1 2012 to March 31 2015, funding 64 projects in the topics of feedstock, conversion, utilization and social, economic and environmental sustainability, organized across four regional platforms (West, Prairie, Central and East). Phase II will be comprised of 10 focused projects, each containing multiple work packages, in the areas of feedstock, conversion, utilization and social, economic and environmental sustainability. Currently the network is comprised of 27 universities, 142 partner organizations, 130 researchers, and 277 students.

The BFN has several task forces[4] to organize research between partner universities. These include 1) integrated biological biorefinery, 2) integrated thermal biorefinery, 3) low cost sustainable biofuel feedstock, 4) policy, 5) forestry, and 6) aviation. For the latter task force, the goal is to investigate the delayed deployment of biojet fuel in Canada. The task force consists of Transport Canada, Environment Canada, National Research Council, Air Canada, Airbus, International Air Transport Assoc., Commercial Aviation Alternative Fuels Initiative (CAAFI) and ASCENT (The Aviation Sustainability Center FAA Centre of Excellence).

5.1.2 Research Focus

At the Advanced Biofuels Symposium[5], in addition to comments provided from the interviewees, a large focus of current research is on supply chain management and logistics for the supply of biomass for advanced biofuel production. This is due to the fact that Canada has large supplies of biomass spread out across the country and very concentrated population areas along the border with the U.S. Therefore, supplying biofuel production facilities with biomass, and thereafter using the biomass efficiently for biofuels and other products is a major concern.

The task forces set up by the BFN, as mentioned previously, also offer a review of current research interests. These are primarily related to the treatment of biomass, sustainable forestry practices and an emerging research field related to biofuels in the aviation sector.

5.1.2.1 General Research Trends

Using a SCOPUS search for research from 2014-2015 and limiting the results to articles from authors in Canada, 62 articles were found. The search string included different biofuels and limited the search to articles published in the environmental sciences and energy fields with following terms:

[4] http://www.biofuelnet.ca/phase-ii/phase-ii-task-forces/

[5] http://www.biofuelnet.ca/news-and-events/advanced-biofuels-symposium-2015/

ethanol OR biodiesel OR biogas OR sng OR methanol OR hvo OR cellulosic ethanol AND (LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (AFFILCOUNTRY , "Canada")) AND (LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "ENER"))

A word cloud from the keywords and terms from the abstract and keywords of the articles was created in order to see the focus in the research; see Figure 8 below.

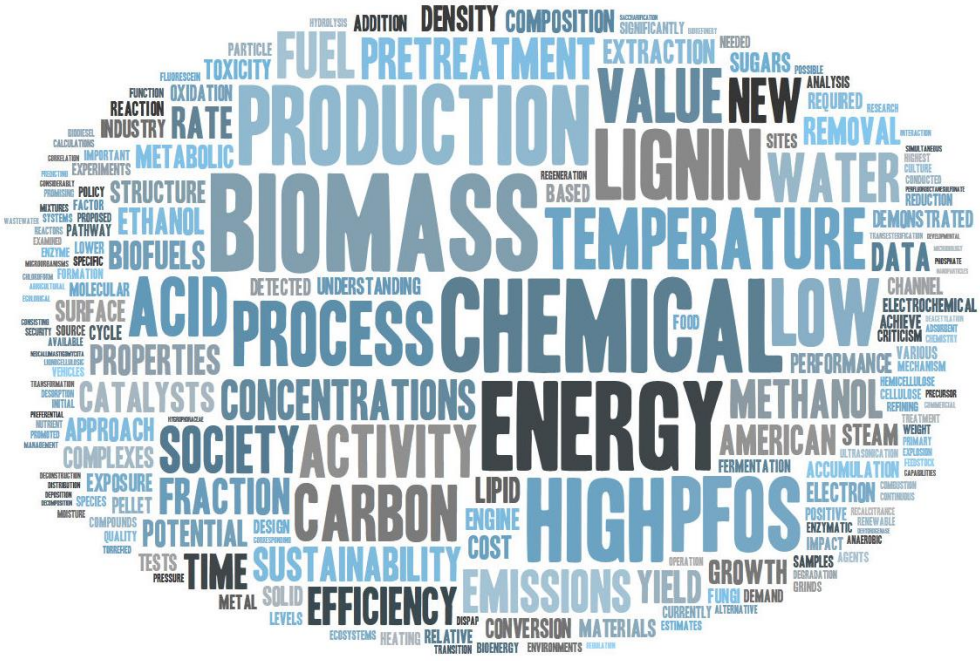

Figure 8: Keywords and terms from recent Canadian biofuel research

Reviewing many of the studies, and the keywords provided in Figure 8, a large focus has been set on advanced pretreatment options, added value products and sustainable production methods.

5.2 THE UNITED STATES

5.2.1 Research Networks

The U.S. Department of Energy (DOE) provides funding for many projects and programs which focus on biofuels and bioenergy. For example, the DOE supports research in the DOE Bioenergy Technologies Office. The following focus areas are included at each respective laboratory:

- Biorefinery R&D: National Renewable Energy Laboratory
- Feedstock Development: Oak Ridge National Laboratory
- Biomass Harvesting Technology: Idaho National Laboratory
- Syngas, Catalysis, and Bioproducts: Pacific Northwest National Laboratory
- Reaction Engineering and Separations: Argonne National Laboratory.

In addition to the DOE Bioenergy Technologies Office, the DOE has also funded Bioenergy Research Centers with different focus areas. These include:

BioEnergy Science Center is led by DOE's Oak Ridge National Laboratory and focuses on the resistance of plant fiber to breakdown into sugars. In addition the BioEnergy Science Center is reviewing the use of new energy crops such as poplar and switch grass.

Great Lakes Bioenergy Research Center is led by the University of Wisconsin and Michigan State University. The focus of the center is on reviewing plant fiber-breakdown in order to increase plant production of starches and oils to produce fuels. A major focus at the center is also sustainability, examining the environmental and socioeconomic implications of moving to a biofuels economy with prominent researchers in the field such as Prof. Bruce Dale.

Joint BioEnergy Institute is led by DOE's Lawrence Berkeley National Laboratory. The main focus of the center is to model crops of rice and Arabidopsis, in the search for game-changing breakthroughs in basic science, and is exploring microbial-based synthesis of fuels beyond ethanol.

5.2.2 Research Focus

Biofuel researchers in the U.S. outlined that, similar to Canadian research, advanced biofuels have begun to receive more focus. In a recent White Paper from the US Department of Energy (DOE, 2015b) the development, successes and areas for improvement and research were outlined to provide guidance for funding and support for future research.

From the document, many new research areas were identified. Some of these which may be interesting for the f3 include:

Sustainability

- Interaction of crops with biotic and abiotic environment, e.g. cycling of nutrients, soil erosion, water quality and pest/disease control
- Techno-economic evaluation of biomass-to-fuel technologies
- Predictive systems and management systems for biofuel crops and surrounding ecosystems

Feedstock Development

- Develop and enhance broader set of crops which are regionally viable and include improve yields, nutrient uptake, recycling and resilience

Lignocellulosic Deconstruction

- Improved enzymes for breakdown of cellulose and lignin
- More robust pre-treatment and separation systems

Specialty Fuel Production from Biomass

- Develop fuels with densities and handling properties more similar to gasoline, diesel and jet fuel through metabolic engineering of new, broad-based genetic and metabolic engineering and synthetic biology techniques

Bioproduct Development from Biomass

- Research on the methodologies, feedstocks, pathways and techniques needed to improve and increase the opportunities to produce bioproducts from biomass and biofuels

Aviation biofuels are also of interest to many research groups in the U.S. The U.S. military has set ambitious targets to use advanced biofuels to support energy security and replace a large share of their fossil fuel consumption (Li, 2014; Marsh, 2008; Su et al., 2015). The National Renewable Energy Lab, in addition to other partners, has therefore focused on the use and production of advanced biojet fuels for the U.S. military[6].

Figure 9: US Navy Jet which uses Biofuel. Source: http://www.americansecurityproject.org/

Furthermore, many of the U.S. researchers interviewed (similar to Canadian researchers) discussed logistic research and supply chain management as one of the main areas of focus. As the distribution of this resource has been a bottleneck for economically sound production, logistic research has been given priority at the moment. This includes e.g. how to transport, store and treat large quantities of biomass from their source to biorefineries. One group, MBI (see Allen Julian in the listing below), has developed an AFEX pretreatment process which they have developed for smaller distributed systems. They hope the technology will provide not only distributed biomass pretreatment for biofuels, but also a pretreatment option for biomass to be used as feed in developing countries.

[6] http://www.nrel.gov/defense/projects.html

5.2.2.1 General Research Trends

Using a SCOPUS search for research from 2014-2015 and limiting the results to articles from authors in the U.S., 2,085 articles were found. The search string included different biofuels and limited the search to articles published in the environmental sciences and energy fields with following terms:

ethanol OR biodiesel OR biogas OR sng OR methanol OR hvo OR cellulosic ethanol AND (LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (AFFILCOUNTRY , "United States")) AND (LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "ENER"))

A word cloud from the keywords and terms from the abstract and keywords of the articles was created in order to portray the focus in the research; see Figure 10 below.

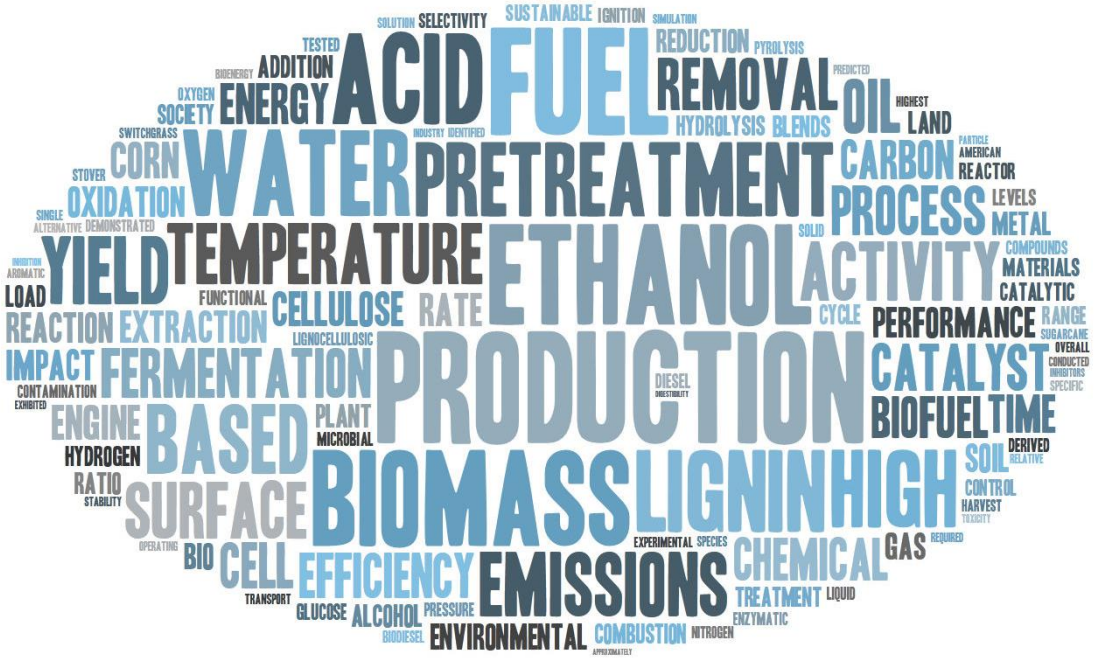

Figure 10: Keywords and terms from recent biofuel research from U.S.

Reviewing the articles found that the relevant areas of research included pretreatment of different biomass for advanced biofuel production. Similar to Canadian studies, added value processes and products were also of importance to cascade the use of biomass. There were also several articles focused on nutrient recycling and land use/soil carbon changes. However, there was a larger focus on lignocellulosic ethanol production in the articles from the U.S. in comparison to Canadian studies.

6 IMPORTANT RESEARCH GROUPS IN CANADA AND THE UNITED STATES

Table 7 provides a listing of important research groups in Canada and the U.S. that could be of interest for collaboration with f3 participants identified in this study. Nonetheless, as there are many institutes and researchers prominent in the biofuel research area in both countries, Table 7 does not provide a comprehensive listing.

Table 7: Biofuel research groups of interest for f3 researchers

Group/Researcher	**Affiliation**	**Notes**
Great Lakes Bioenergy Research Center (Bruce Dale, Prof.)	Michigan State University (U.S.)	• Professor of Chemical Engineering and Materials Science • Editor in Chief of Biofuels, Bioproducts and Biorefining
MBI (Allen Julian)	MBI/Michigan State University	• AFEX technology for biomass pre-treatment • Logistic “hubs” for biomass treatment • Focus on both fuel and feed
Barry Salomon, Prof.	Michigan Technological University (U.S.)	• Policy • Sustainability Assessments Bioenergy
Don Smith, PhD	BioFuelNet	• Director of BioFuelNet
Warren Mabee, Prof	Queen's University	• Director-Queen's Institute for Energy & Environmental Policy
Heather MacClean, Prof.	University of Toronto	• LCA expert in the biofuel field
Joint Bioenergy Institute	University of California-Berkeley	• Biomass research • New fuels
Amy Landis, PhD	Arizona State University	• Life cycle assessment of biomaterials • System integration and

		industrial ecology
Bioenergy Research Center	University of California-Davis	• Biomass Production Systems • Process and Systems Engineering • Resource Management and Environmental Quality
John Caspersen, Ass. Prof.	University of Toronto	*Caspersen Lab Research* • Biodiversity • Bioenergy/forest ecosystem services • Life cycle impacts and carbon cycling
National Renewable Energy Lab	U.S. Dept. of Energy	• Department of Defense Aviation Fuel Research

The Advanced Biofuels USA[7] group also provides a listing of many of the programs for undergraduate, graduate and research groups in the U.S. working with biofuels which may be interesting to build collaboration and exchanges.

[7] http://advancedbiofuelsusa.info/education/universitycollege-programs-in-us-by-state/

7 CONCLUSIONS

Government initiatives and policies have played a major role in the development and promotion of a biofuel sector in both Canada and the U.S. Coupled with regional initiatives and mandates, this has led North American producers to become leaders in ethanol production. Other biofuels, such as biodiesel and biogas, however have not received as much attention with production and demand for these fuels lacking in the market.

Despite the recent stagnation of conventional biofuel production, increased attention has been placed on advanced biofuels from biomass and wastes. Canada and the U.S. have opened large commercial production sites and continue to drive research, development and innovation in the area which will allow for more economic production in the future.

North American researchers also share similar research areas as researchers connected to the f3. It is therefore important to follow the development of biofuels in Canada and the U.S., to learn from the successes and failures and create collaboration which may benefit Sweden in the future.

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APPENDIX

Table A: Past US Legislation Promoting Ethanol Fuel (California Energy Commission, 2004)

Energy Tax Act of 1978
Energy Security Act of 1980
Crude Oil Windfall Profit Tax Act of 1980
Gasohol Competition Act of 1980
Surface Transportation Assistance Act of 1982
Tax Reform Act of 1984
Alternative Motor Fuels Act of 1988
Omnibus Budget Reconciliation Act of 1990
Energy Policy Act of 1992
Omnibus Budget Reconciliation Act of 1993
Transportation Efficiency Act of the 21st Century (1998)