IRENA
International Renewable Energy Agency

ADVANCED BIOFUELS

What holds them back?

November 2019

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The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that serves as the principal platform for co-operation, a centre of excellence, a repository of policy, technology, resource and financial knowledge, and a driver of action on the ground to advance the transformation of the global energy system. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. **www.irena.org**

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ABBREVIATIONS

1G	First generation (biofuel)
2G	Second generation (biofuel)
ASTM	American Society for Testing and Materials
BCAP	Federal Biomass Crop Assistance Program (US)
BETO	Bioenergy Technology Office (US)
BEV	Battery electric vehicle
BNEF	Bloomberg New Energy Finance
CAA	Clean Air Act (US)
CAD	Canadian dollar
CAPEX	Capital expenditure
CARB	California Air Resources Board
CFS	FAO Committee for World Food Security
CNG	Compressed natural gas
CO_2	Carbon dioxide
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CWC	Cellulosic waiver credit
DME	Dimethyl ether
DOA	Department of Agriculture (US)
DOE	Department of Energy (US)
ECA	Emission control area
ECP	Energy and Climate Package (EU)
EISA	Energy Independence and Security Act (US)
EJ	Exajoule
EPA	Environmental Protection Agency (US)
EU	European Union
EU ETS	EU Emission Trading Scheme
EUR	Euro
EV	Electric vehicle
FAME	Fatty acids and methyl esters
FAO	Food and Agriculture Organization of the United Nations
FFV	Flex-fuel vehicle
FSA	Farm Service Agency (US)
GHG	Greenhouse gas
Gt	Gigatonne
HEFA	Hydroprocessed esters and fatty acids
HVO	Hydrotreated vegetable oil
ICAO	International Civil Aviation Organization
ICE	Internal combustion engine
ICT	Information and communication technologies
IEA	International Energy Agency
ILUC	Indirect land-use change
IMF	International Monetary Fund

IMO	International Maritime Organisation
IRENA	International Renewable Energy Agency
ISCC	International Sustainability and Carbon Certification
LCA	Lifecycle assessment
LCFS	Low-carbon fuel standard
LDV	Light-duty vehicle
LNG	Liquefied natural gas
LUC	Land use change
MAD	Ministry of Agricultural Development (Brazil)
MARPOL	International Convention for the Prevention of Pollution from Ships
MDF	Medium density fibreboard
MSW	Municipal solid waste
NGO	Non-governmental organisation
NGV	Natural gas vehicle
NO_x	Nitrogen oxide
NREL	National Renewable Energy Laboratory (US)
OECD	Organisation for Economic Co-operation and Development
OEM	Original equipment manufacturer
OPEX	Operational expenditure
PHEV	Plug-in hybrid electric vehicle
PKS	Palm kernel shell
QAP	Quality Assurance Plan
R&D	Research and development
RED	Renewable Energy Directive
RFS	Renewable Fuel Standard
RIN	Renewable Identification Number
RSPO	Roundtable on Sustainable Palm Oil
RTRS	Roundtable on Responsible Soy
RVO	Renewable Volume Obligation
SAF	Sustainable aviation fuel
SDS	Sustainable Development Scenario (of IEA)
SFS	Social Fuel Seal (Brazil)
SO_x	Sulphur oxide
UCO	Used cooking oil
UK	United Kingdom
UNEP	United Nations Environment Programme
US	United States
USD	United States dollar
VC	Venture capital

KEY MESSAGES

Advanced liquid biofuels play an important role in the low-carbon pathway for the transport sector laid out by the International Renewable Energy Agency (IRENA). Liquid biofuels require little change in fuel distribution infrastructure or the transport fleet and can therefore be rapidly deployed, leading to much-needed reductions in greenhouse gas (GHG) emissions. They also provide a practical alternative to fossil fuels for aviation, shipping and heavy freight trucks. While a variety of renewable energy sources must be employed to reach the goals of the Paris Agreement, advanced biofuels address key issues within the transport sector and will be needed for decades in order to meet long-term climate targets.

IRENA's low-carbon pathway to 2050 calls for a fivefold increase in consumption of biofuels, from 130 billion litres in 2016 to almost 650 billion litres in 2050. This means that new and growing markets will need to emerge in Africa, Asia and South America, in addition to the present major markets of Brazil, Europe and the United States (US). The needed increase is an achievable and realistic level of growth, given that investments in first-generation (1G) biofuels have in the past exceeded the level worth 15 billion litres of additional production capacity – which corresponds to the average growth rate toward 650 billion litres of production in 2050 – two years in a row. Despite this, worldwide investments in advanced biofuels production have been on a declining trend since 2011.

This IRENA report analyses barriers to advanced biofuel investments. Essential data presented in this report were obtained through a survey of 14 high-level business executives and decision makers in the advanced biofuel industry. The purpose is to understand the barriers from the project developers' perspective. Therefore, the analysis excludes views of advocacy groups, planners, policy makers and academia. The study also draws on public reports and other surveys identifying barriers to advanced biofuels. Unlike many past studies, this study does not limit itself to identifying impediments but also explores the levels of importance of the barriers. The resulting analysis shows a complex business environment, where barriers to investment include an array of infrastructure-related, environmental, social and political issues, but also points towards possible means of addressing these issues.

Regulatory uncertainty stands out as the most important impediment to investments.

The survey responses strongly reflect the fact that the regulatory framework for transport biofuels has been in flux and investment activity has consequently been stagnant for the last ten years, particularly in Europe.

Since 2009, three major legislative changes have taken place with the enactment of the Renewable Energy Directive (RED) I (2009), the Indirect Land-Use Change (ILUC) Directive (2015) and approval of the political agreement on RED II in 2018. Each major legislative milestone was preceded by two to three years of fierce public debate as the Commission's proposal proceeded through the European Parliament and the Council. Major pieces of legislation are then followed by associated lower-level legislation. These too, however, may be of crucial importance for biofuels producers. Finally, project developers must adapt to the varying speeds and ways in which the European Union (EU) legislation is transposed into Member States' national legislation.

Visibility regarding future markets has been poor and changes have been frequent. Half of the respondents think that investments are hampered by worries that, for example, sustainability criteria may change and become more stringent in the future. Project developers need to make decisions on the basis of assumptions, which extend beyond 5 to 12 years, on future feedstock and fuel markets. Bringing novel technologies to commercial maturity, in particular, takes time.

The US Renewable Fuel Standard (RFS) under the Energy Independence and Security Act (EISA) has provided a more predictable (14 years from 2009 to 2022) framework for biofuel companies to operate in, and the country has risen to become the leading biofuel producer, covering nearly half of the world's production of bioliquids. However, attempts to amend or refute the EISA legislation in Congress, and legal processes against the US Environmental Protection Agency (EPA) on various aspects of the RFS and the EPA's use of its right to certain waivers, have created uncertainty regarding future market rules.

Even though regulatory instability is regarded as a major barrier, the survey revealed that the recast Renewable Energy Directive – EU RED II, which enters into effect in 2021 – is deemed conducive for the industry. The new 3.5% target for advanced biofuels by 2030 is considered realistic but appropriately ambitious. Seventy-five percent of survey respondents agree the European targets under RED II will encourage investments.

The creation of an enabling environment for advanced biofuel deployment requires much more nuanced and multifaceted regulation than for other forms of renewable energy.

The advanced biofuel industry is still rather small, with only about 30 companies running refinery operations if sustainable waste-based biodiesel (fatty acids and methyl esters, FAME) producers are not counted. It is also rather fragmented, in that some feedstocks and conversion pathways are represented by very few companies. This fragmentation leads to what was observed in the present analysis: that the issues, concerns and opinions vary depending on the feedstock(s) or end-product(s) of the business in which the respondent is involved. A clear dividing line in the survey responses was observed between producers of cellulosic ethanol, which is primarily used as a blend with gasoline, and hydrotreated vegetable oils (HVO)-based drop-in biofuels.

Drop-in fuels are a key element in transport sector decarbonisation because ethanol and conventional biodiesel both have limitations on the amount that can be mixed with petroleum fuels. HVO production technology provides one proven avenue for drop-in fuels, which are required for decarbonising heavy transport, shipping and aviation. HVO plants are large-scale and already commercial, but their long-term business expansion is somewhat constrained by the global availability of the currently used waste oils and fats-based feedstock.

Now that the European industry in particular is looking to move away from using high indirect land-use change (ILUC)-risk feedstocks, waste-based feedstock collection needs to be intensified. At the same time, sustainable alternatives identified for growing oily energy crops as well as lignocellulosic conversion pathways for advanced fuels need to be pursued. These may include co-farming with other crops, seasonal (winter) farming, short rotation woody crops-based agroforestry, growing on degraded lands, land made available by more intensified agriculture, and land freed up by reduced waste and losses in the food chain.

The survey indicated that while issues relating to higher blending obligations, deployment of flex-fuel vehicles (FFVs) and E85, or promoting bio-economy co-products from the biorefineries do not appear important for HVO producers, they are most relevant for producers of lignocellulosic ethanol. In the industry segments producing lignocellulosic ethanol and thermochemical pathways (pyrolysis and Fischer-Tropsch), many facilities in operation today are the first of their kind. Businesses are often driven by innovation-based start-ups. Therefore, many of the refinery project sponsors representing these technology pathways are concerned about securing financing and reliable operations for their facilities.

There are many ways to effectively promote advanced biofuels.

Technology-neutral fuel standards, such as those in California (US) and those planned for Brazil, are favoured by most industry executives. The Californian experience has been a positive one, in that state legislation has created continued stability and project developer confidence. It has also clearly diversified transport fuel sources, such that there has been a substantial increase in the deployment of ethanol, renewable diesel, biomethane and electricity. A fuel-neutral carbon intensity-based mandate system provides a fair platform for advanced biofuels to compete.

However, even more straightforward tax- or obligation-based regulatory systems can be effective and applicable, particularly for countries just starting to promote advanced biofuels. By 2017, the share of bioenergy in Sweden's transport sector had reached 20%, much higher than the European average. This rapid switch from fossil fuels to biofuels was driven by tax exemptions on biofuels, and high carbon and energy taxes on fossil fuels.

Transport sector decarbonisation calls for accepting several fuel alternatives simultaneously rather than resorting to one encompassing solution.

Industry representatives provided a balanced view of transport sector decarbonisation with varying opinions on the relative importance of electric mobility, biogas and bioliquids. Most executives acknowledged that the total share of advanced biofuels will remain relatively small.

Aviation represents an emergent market for advanced biofuels, and half of the respondents counted on the sector being a major customer in the future. However, aviation fuel is not a stand-alone product of a refinery process but rather one fraction. When asked about the likely breakdown of product sales in 2030, the few providing such estimates saw the expected aviation sector share in their sales ranging from 4% to "possibly up to 50%".

Unless regulators devise specific promotional measures for the cellulosic ethanol segment, it will face uneven cost competition from first-generation ethanol producers in a declining market.

Ethanol made of sustainable cellulosic feedstock is standard fuel ethanol and currently used primarily as a blend with gasoline. Ethanol demand should be progressively untied from fossil fuel consumption, which will decline in the future due to the higher fuel efficiency of conventional engines and increasing electrification of road transport. Regulators should therefore stretch blending obligations and promote high ethanol blends and FFVs. Securing sustainable demand for the nascent production of cellulosic ethanol, however, will require price incentives within the mandated fuel pool or through a separate quota.

Even though not all respondents agreed, current levels of subsidies as well as the cost and availability of financing were viewed as important barriers.

Advanced biofuel conversion technologies are very close to commercialisation. Many innovative process concepts are being demonstrated in operational refineries. Over half of the respondents consider technology to be ready for the large-scale deployment of advanced biofuels. However, direct support for selected technologies, in particular risk financing for first-of-a-kind pre-commercialisation projects using lignocellulosic and thermochemical pathways, is crucial.

Executives of the advanced biofuel industry acknowledged that the food-vs.-fuel debate has advanced their cause but doubted the accuracy and reliability of methods to estimate GHG emissions, land-use change and indirect land-use change.

Executives perceive too much confusion in how lifecycle GHG emissions, land-use change (LUC) and ILUC are estimated. They also hope to see a more harmonised certification system verifying the sustainability credentials of their products. Yet, some of the respondents consider the introduction of sustainability standards and certification schemes to have been a positive development, boosting markets for advanced biofuels.

While more than half of respondents see that advanced biofuels are viewed positively by the public, the respondents acknowledge that the overall understanding of the issues surrounding advanced biofuels is low among the public, politicians and media, a view also confirmed by other surveys and opinion polls.

The core message of this report is that policy makers must be prepared to establish clear best-practice policies for long-term support for the deployment of advanced biofuels with targets high enough that the end-use and vehicle markets are incentivised to adapt to the existence of advanced biofuels as part of the fuel mix.

Governments outside the current main biofuels markets can avoid past mistakes by establishing bold, long-term and effective policies to stimulate sustainable growth of advanced biofuels based on careful attention to the barriers identified.

Policy measures, including blending obligations, mandates of different kinds, carbon taxes and the promotion of biofuels-friendly vehicles, are shown to be effective when they are applied rigorously and provide long-term certainty to project developers and consumers.

Advanced biofuels offer opportunities not only for climate change mitigation but also for harnessing waste, energy crops, co-farming and degraded lands, thus creating employment and wealth and increasing energy independence.

1. INTRODUCTION

1.1 BACKGROUND

The transport sector is on the verge of an exciting transition to clean mobility. At its current point in this process, however, it still lags significantly behind in the energy transition required to align with the goals of the Paris Agreement. Shipping and aviation have made comparatively little progress toward decarbonisation, and globally the share of renewable energy in the transport sector is very small, just 3% in 2016. Vehicle fleets remain dominated by reciprocating internal combustion engines using gasoline or diesel oil. As such the still very limited use of renewables involves mainly biofuels, with the largest markets in Brazil, Europe and North America. These biofuels consist mostly of bioethanol and biodiesel produced from crops, which are also grown for food or feed. While the adoption of electrification – one of the technologies that can help to decarbonise the sector when associated with renewable power generation – is growing, it remains quite limited with its current share in the transport sector at just above 1%.

To fulfil the goals of the Paris Agreement, a concerted effort is needed to substantially increase the levels of renewable energy sources in transport. This will mean embracing the new technologies already beginning to permeate the transport sector, from electrification to a wider variety of biofuels. IRENA's analysis for the REmap Case – a scenario to generate a global energy transformation that is aligned with the Paris Agreement goal of holding the global temperature increase to well below 2 °C – offers us a concrete picture of the energy transition and the role of biofuels within it. Through a combination of low-carbon technologies, transport emissions can be cut to under 2.4 gigatonnes (Gt) of carbon dioxide (CO_2) annually by 2050 from 2016 levels, which exceeded 8 Gt. This would represent a 70% reduction compared to current policies detailed in IRENA's Reference Case.

Biofuels represent an important aspect of the roadmap for transport decarbonisation. Meanwhile, electrification, together with information and communication technologies (ICT), is already starting to change the transport industry. As performance improves and battery costs fall, sales of electric vehicles (EVs), electric buses and electric two- and three-wheelers are growing. In 2017 around 6 million EVs were on the road. Under the REmap Case, the number would increase to over 1 billion by 2050. However, to meet our sustainable energy goals, we may also anticipate the need for increasing deployment of many kinds of biofuels. These include not only ethanol, biodiesel and biogas, but also other types of alcohols, such as methanol or butanol, as well as renewable diesel (HVO) and other so-called drop-in fuels that meet the fossil fuel quality standards.

New types of transport models in growing cities will help shift both public and private vehicle fleets from their low utilisation rates and use of fossil fuels towards less polluting, more flexible, decentralised and optimised vehicle management modes. The REmap Case also assumes the introduction of hydrogen, produced from renewable electricity, as a transport fuel as well as a 26% decrease in transport sector energy consumption due to the higher efficiency of conventional engines, optimised new modes of transport and electrification of the sector. The combination of technologies and new fuels would lead to a drop of over 75% in oil consumption by 2050, compared to 2016. The share of electricity in all of transport sector energy would rise from just above 1% in 2016 to 43% in 2050, over 85% of which would be renewable. Alongside all of these improvements, the contribution of biofuels to the total final energy consumption of the transport sector in 2050 is projected to increase from 3% in 2016 to 20%.

Reaching the projected goal would call for a fivefold increase in total liquid biofuel production and consumption, from 130 billion litres in 2016 to over 650 billion litres in 2050. Nearly 70% of this total would be conventional biofuels, whose production would almost triple, requiring significant upscaling particularly outside the current main markets. The other part would be advanced biofuels, which can be produced from a wider variety of feedstocks than conventional biofuels, but which supply less than 1% of biofuels today. The steep increase in biofuel production requires careful planning, taking into full consideration the sustainability of biomass supply.

While careful use of biomass is required, the necessary feedstock for such an increase does exist. IRENA (IRENA, 2019a) has estimated available primary biomass at 287–549 exajoules (EJ) in 2050, which would allow for 125 EJ to cover extended modern use of biomass for transport and other sectors including a gradual shift from petroleum-based materials and chemicals to bio-based ones. In accordance with other global feedstock potential estimates (IRENA, 2016a), the estimated primary biomass resource for second generation (2G) biofuel production would not represent a barrier for the targeted 16 EJ of biofuel consumption in 2050 needed to meet the projected 18% of transport sector total energy consumption.

The growth in global biofuel consumption during the analysis period would require that 80 to 100 refineries be developed annually, with a total annual investment cost of approximately USD 20 billion (US dollars) on average. This level was reached and exceeded during the two-year period of 2006–07 (Figure 1) through investments in first generation (1G) biofuel facilities, proving this to be realistic target if the market is attractive and stable enough for project developers in advanced biofuels.

The biofuel markets in Brazil, Europe and the US would continue to expand, albeit at a saturating rate, but new and growing markets are expected to arise in the developing countries. Biofuels markets are currently emerging in large countries such as Argentina, Canada, China, India, Indonesia, Malaysia, Mexico and Thailand.

In the southern hemisphere, much of the planned biodiesel production today is based on vegetable oils (soy, palm oil and related waste, and used cooking oil [UCO]) for biodiesel and on molasses and cassava for fuel ethanol. After a period of low interest in energy crops, however, the role of energy crops such as jatropha and canola should be re-evaluated for their use as more sustainable, albeit more demanding, biofuel production in tropical countries.

While the pathway to a renewable energy future is complex, biofuels can play a vital role in the energy transition if scaled up significantly. Although biofuels production has grown in recent years, the current growth is clearly insufficient to support the requirements of the energy transition. A much stronger and concerted effort is needed, particularly in demand-side sectors such as shipping and aviation, for which biofuels could provide key solutions.

This report seeks to provide policy makers with an understanding of the complex business environment around and current barriers to the expansion of investment necessary for biofuels to play their role in the transport sector's energy transformation.

1.2 GLOBAL TREND OF INVESTMENT IN BIOFUELS

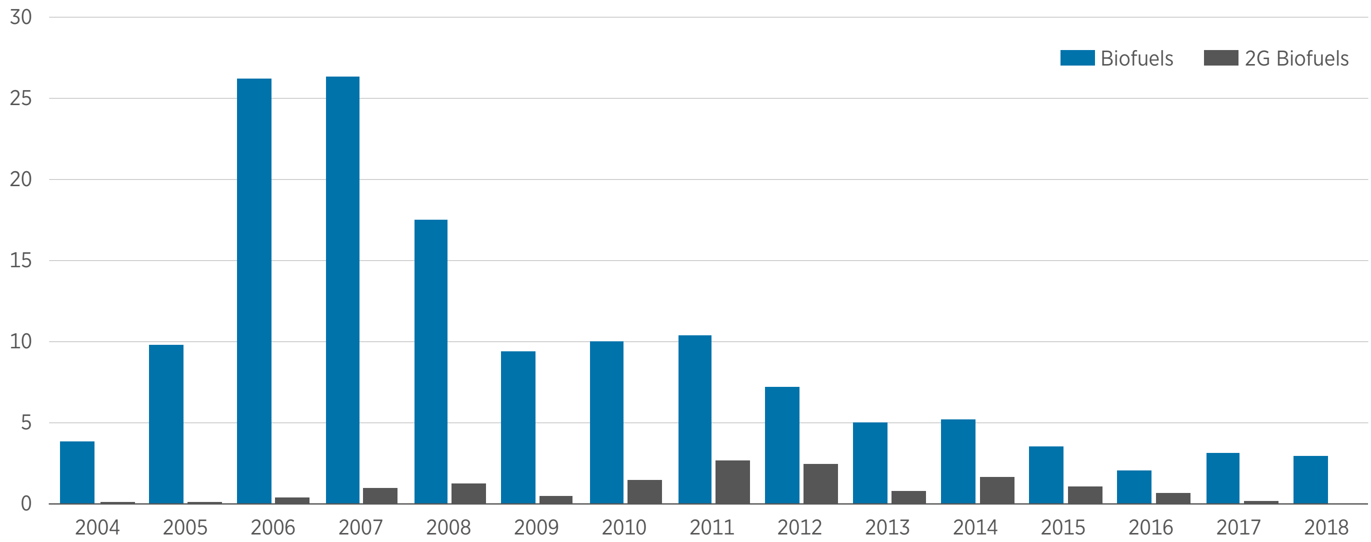
Liquid biofuels have a long history in transport, energy and climate policies in Europe, Brazil and North America. Governments have created supporting policies for biofuels driven by an array of objectives relating to the fight against climate change, energy security, oil import reduction, and agricultural and rural development.

Managing agricultural overproduction and sustaining prices for key crops in Europe and the US became a growing concern in the 1980s and 1990s to which ethanol blended with gasoline provided one solution. Pursuance of a modest share of ethanol in gasoline was not against the interests of the oil industry as it provided a solution for knock resistance replacing lead, when countries started banning, one by one, the use of lead in gasoline for environmental and health reasons.

Over the last two decades, climate concerns have become an increasingly strong motivation for policies promoting biofuels. This has resulted in growing support for biofuels and the production of biodiesel and fuel ethanol. These policies triggered a substantial investment boom, which peaked in 2007 when several sustainability concerns relating to the impacts of biofuels on food security, food and feed prices, and direct and indirect land use became an integral part of the international climate and energy debate.

The food-vs.-fuel debate, particularly, mobilised the scientific community, governments and non-governmental organisation (NGOs) and led to studies on the carbon intensity of various types of liquid biofuels. Studies now take into account the lifecycle emissions of the supply chains and emissions due to LUC and ILUC caused by growing feedstock for biofuels. Consequently, regulators in the largest markets, particularly in the US and the EU, reset their biofuels targets, blending mandates and support policies considering fuel distinctions by feedstock and associated carbon intensities.

Figure 1. Annual investments in biofuels (USD billion)



Note: 2G 2018 data not available.

Source: UNEP/BNEF (2019)

This discussion brought to the fore the need to develop advanced biofuels, or 2G biofuels, which are made of lignocellulosic feedstock such as corn stover, straw, wood waste, rapidly growing grasses and short rotation trees, municipal waste, and waste oils, fats or algae, all of which have few non-energy uses, and some of which can be grown on less productive and degraded lands or in seawater (algae), thus involving a smaller impact in terms of land-use. The desired shift from 1G biofuels to advanced biofuels was then reflected in the Renewable Energy Directive (RED) of 2009 and its revisions of 2015, and the US's Energy Independence and Security Act (EISA) of 2007 in their specific support mechanism for advanced biofuels.

The degree to which high expectations were placed on advanced biofuels is illustrated by the volume standards set forth in the EISA (2007) for biofuels. The EISA sets a cap for the volume standard of conventional biofuels for 2015 at 15 billion gallons a year, after which there would be no growth, whereas the volume standards for advanced biofuels were set to grow from a meagre 0.6 billion gallons in 2009 to 21 billion gallons in 2022. However, the plans for rapid expansion of advanced biofuels supply did not materialise. The volume standard set now by the US Environmental Protection Agency (EPA) in its annual ruling for 2019 is only 4.9 billion gallons for advanced biofuels (and just 0.4 billion gallons for cellulosic ethanol), a far cry from what was projected in 2009.

Investments in biofuels started to decline after the peak year of 2007 for 1G biofuels and 2011 for 2G biofuels. The production of biofuels has continued to grow, however, utilising the existing biofuel refinery capacity and its annual increments. The industry as a whole, however, including both conventional and advanced biofuels, demonstrates a limited, or at best moderate, appetite for new investments. This can seem paradoxical, given the fact that 68 countries have already enacted biofuel blending mandates (at the national or subnational level), showing a substantial increase from 36 in 2011 (IRENA, IEA and REN21, 2018).

Barriers affecting investments in advanced biofuels are numerous and reflect the complex nature of the business environment. Not only is the technology immature, reflected in the operational problems of the first-of-its-kind projects and high costs, but the challenges also include an array of environmental, infrastructure-related, social and political issues.

1.3 OBJECTIVE AND METHOD OF ANALYSIS

After observing a continuing decrease in liquid biofuel production investments, at a time when investments in other forms of renewable energy were growing and becoming immensely popular, it became clear that an analysis of the barriers to investment was needed. Consequently, the objective of this report is to clarify the factors explaining the stagnating investment activity in advanced biofuels.

The report relies on literature and a survey carried out during the second half of 2018, collecting views from companies active in the sector, representing mostly the private sector, and by recording and analysing their experiences of the various barriers encountered in their pursuit of day-to-day business and investments.

Many barriers to advanced biofuels have been identified by qualitative studies and surveys that are often quoted in industry and policy maker meetings. However, the industry and the transport fuel markets are constantly changing. The introduction of electric mobility, for example, was not prominently featured in global energy discussions ten years ago. Furthermore, many past studies did not explore the levels of importance of the industry's different constraints, limiting themselves to identifying and discussing the impediments. This study therefore aims to update the understanding of these barriers and to identify the currently prevailing and most pressing factors, helping to set priorities for those involved in planning and enabling technology, innovation and policy environments for advanced biofuels.

A review of past literature led to the choice of the main categories of the questionnaire and helped identify critical issues. Available in paper form and online, the questionnaire includes statements evaluated on a five-point agreement scale (the Likert Scale) under the five following groups:

1. feedstock (8 statements)
2. technology and financing (7 statements)
3. markets through mandates and targets (16 statements)
4. trends in consumer demand (12 statements)
5. environmental and social concerns (11 statements).

In addition, respondents were asked to make high-level projections about four topics:

1. the level of crude oil price which would enable sustainable business operations without subsidies or mandates
2. technology learning by 2030 (reduction % of capital expenditure [CAPEX])
3. the projected breakdown of the end uses for their product now and in 2030 (road transport, maritime, aviation, other)
4. ranking of minimum three most important barriers (from 14 options).

This study focuses exclusively on the views of industry representatives. Unlike several other surveys, there were no policy makers, planners, advocacy groups, international agencies or academia among the respondents. The feedback includes completed questionnaires from 14 biofuel industry executives in companies that have invested in or are currently investing in 2G biofuel production, including five chief executive officers or chief financial officers, five biofuel business line directors, and four high-level executives in charge of marketing, sales, innovation and government relations.

Chen and Smith (2017) observed in their extensive study on a very similar topic that the particularities of the field of a respondent's activity (say feedstock, conversion technology, policy, etc.) created a certain bias reflected in the responses. The economics/business experts seemed to provide a much broader and more balanced view of the barriers than did other professional groups. The respondents' higher-level professional statuses of this survey therefore hopefully provide a basis for a more general view on the business environment and helps avoid the identified expertise-related bias.

This survey, however, targeted only companies that had already invested in advanced biofuel business. The views of other companies that had considered investing but not moved forward successfully could be different from those seen in the survey results.

Five respondents were interviewed through in-depth 1–2-hour interactive sessions. Responses were received from Brazil, Canada, China, Europe and the US. The combined annual operating capacity of the responding companies amounts to 4 300 million litres of mainly hydroprocessed esters and fatty acids (HEFA)-based drop-in fuels (~86% of the total HEFA capacity), 210 million litres of advanced ethanol, and 130 million litres of other advanced biofuels such as pyrolysis oil and Fischer-Tropsch products, the latter two representing about half of the respective industry capacity.

This report will lead to a better understanding of the key issues affecting project developers' behaviour and decision-making regarding investments in advanced biofuels. The report advises policy makers on how project developers evaluate business opportunities and how current policies and regulations might be recalibrated to catalyse a change in project developer behaviour in the pursuit of the transport sector's energy transformation.

1.4 REPORT STRUCTURE

This report is divided into five main sections.

Chapter 1 begins by explaining the need for more investments in advanced biofuel production in the framework of a global transition to a low-carbon transport sector. The declining trend of investments in contrast to the required level of investments to reach the REmap 2050 target for biofuels explains the importance of analysing barriers to investments. The chapter then proceeds to setting the objective and describing the method of the analysis.

Advanced biofuels offer opportunities to mitigate climate change, harness waste and energy crops, create new jobs and strengthen energy independence

Chapter 2 briefly describes the current state of global advanced biofuel production and explains how the business differs from other renewable energy businesses in regard to the complexity surrounding its value chain, which involves several stakeholders. The chapter also reviews literature, including key studies and surveys regarding barriers to advanced biofuels from 2011 to 2018 in the US, Europe and globally.

Chapter 3 explains the context and background issues in a more detailed account of the hypothetical barriers in the fields of feedstock supply, technology readiness and availability of financing, regulatory setting, demand-side, and social and environmental issues.

Chapter 4 provides the results of the survey. The survey responses to the rating questions are then commented on in relation to the described context. Each statement of the survey is based on a hypothesis about a possible barrier.

Chapter 5 summarises the survey results. Observations are made on how the responses are dependent on the respondent's technology pathway. Barriers are listed and ranked by the level of importance in light of the survey responses.

2. BARRIERS TO ADVANCED BIOFUELS

The core distinction between conventional (1G) and advanced (2G) in this study biofuels relies on the sustainable sourcing of feedstock. Advanced biofuels are those that make use as feedstock of non-food and non-feed biomass, including waste materials (such as vegetable oils or animal fats) and energy-specific crops capable of being grown on less-productive and degraded land. They thus have a lower impact on food resources and should have a lower probability of causing LUC and ILUC.

Despite the advantages of a transition to producing and using 2G biofuels, the emergence of the advanced biofuel industry has been sluggish due to early stage technological development and numerous barriers such as high production costs, immature supply chains, dependence on government support schemes that are subject to political influences, and consequent uncertainty around market size.

2.1 THE STATE OF THE ADVANCED BIOFUEL INDUSTRY

Advanced liquid biofuel producers can be generally categorised by their production process in the following four groups:

1. **Microbial conversion of lignocellulosic biomass (*e.g.* stalks, corn stover) to bioethanol or biobutanol**. The process starts with pre-treatment of the feedstock followed by enzymatic hydrolysis that converts cellulose and hemicelluloses into sugars. Yeast or bacteria convert, through fermentation, these sugar molecules to alcohols such as ethanol or butanol. Such processes are at demonstration and early commercial stage.

2. **Transesterification of sustainably sourced FAME (*i.e.*, biodiesel).** The production process is conventional and used widely in the production of 1G biodiesel. FAME are typically used as a biocomponent and mixed with ordinary diesel fuel.

3. **Hydrotreatment of sustainably sourced vegetable oils or animal fats followed by alkane isomerisation and cracking to produce drop-in fuels (HVO/HEFA)**. The quality of these fuels, most commonly renewable diesel, equals or surpasses the specifications for equivalent petroleum fuels. Hydrotreatment is mostly used for vegetable oils; hence, the term “hydrotreated vegetable oils” (HVO) is commonly used to describe this fuel. However, the term “hydroprocessed esters and fatty acids” (HEFA) is increasingly being used because it encompasses feedstock fractions in addition to vegetable oils. In this study the two terms are used as synonyms.

4. **Thermochemical pathways starting with pyrolysis to produce biocrude or gasification of biomass for syngas**. Biocrude can be used for selected end uses, such as in oil-fired boilers, or refined further to produce drop-in fuels. Feedstocks can also be converted to syngas from which alcohols and/or Fischer-Tropsch drop-in fuels can be refined.

In addition to the above (ethanol, FAME diesel, renewable (HEFA/HVO) diesel and various drop-in fuels refined through thermochemical processes), the biofuels realm produces several intermediate, parallel and final products with varying pros and cons as transport fuels compared to the more standardised biofuels and fossil fuels.

These include, among others, methanol and butanol, farnesane (currently being tested for use as jet fuel), and dimethyl ether (DME) as a substitute fuel for diesel. While these are not represented in the survey material as such, many of the barriers pertaining to their development and commercialisation are similar to other biofuels. On the other hand, some of the biofuels are in competition with each other. For example, methanol can be catalytically converted from methane, but methane itself, for instance as biogas, can be used with minor modification in road vehicles. As for DME, following its approval by the State of California (US) as a transport fuel, it is being promoted and has gained a foothold in a few markets.

Production processes (1) and (4) are still under active technological development whereas (2) and (3) are mature and in fully commercial operation. The highest expectations are set for (1) and (4), because of their ability to use low-quality, low-cost and abundantly available feedstock such as agricultural and forest residues. Technological immaturity, however, translates to high capital cost which counterbalances the benefit of low feedstock cost.

The specific investment cost per annual production capacity is USD 45 per litre for cellulosic ethanol and thermochemically produced drop-in fuels, whereas it is between USD 0.7 and USD 1.3 per litre for biodiesel and HVO, and only USD 0.5–0.6 per litre for conventional ethanol.[1] Cellulosic ethanol technology is however expected to mature rapidly as it progresses along its learning curve, bringing the specific investment cost below USD 2 per litre by 2030 (S&T[2] Consultants Inc., 2018).

The development of cellulosic ethanol production has been slow and fraught with setbacks, with the first wave of investments resulting in many technical and commercial failures both in the US and Europe. Over 50% of advanced biofuel projects, which were started as a result of the 2005 Environmental Protection Act (EPAct) and the EISA/RFS of 2009, failed by 2015 (Withers, 2016). Many companies in the industry went bankrupt, idled their plants or diverted to other businesses. Among them were refineries built by majors such as Abengoa Bioenergy, DowDuPont (idled) and KiOR, who intended to produce cellulosic diesel and gasoline. In Italy, the bankruptcy of Beta Renewables/BioChemtex, at the time the developer of Europe's only commercial-scale cellulosic ethanol plant, dampened the hopes for commercial success among many investors and observers.

In 2018, worldwide, 12 refineries with an annual production capacity of 10 million litres or more could be counted as producing advanced cellulosic ethanol at a commercial level, according to the authors' records. In the US, the EPA recorded Renewable Identification Numbers (RINs, tradable credits awarded to domestic biofuel producers) in the cellulosic ethanol category (D3) to the amount of about 25 million litres from 11 projects in 2018, which is on average 2.2 million litres per project (EPA, 2019). Based on the modest production levels, most of the 11 projects can be categorised as demonstrations.

Thermochemical processing also remains a relatively marginal part of the biofuel sector at this time. There are seven biofuel refineries in the world applying thermochemical processes, some of which produce biocrude without refining it to transport fuels. Some, however, intend to do that in the future or may send biocrude for co-processing in a petroleum refinery.

If installed capacities for FAME and HVO are excluded, the total global production capacity for advanced biofuels can be estimated at about 0.6 billion litres per annum. Around 0.4 billion litres per annum is under construction, and about 60% of its total capacity is for biochemical ethanol (Sipilä *et al.*, 2018).

1 Note the specific cost is expressed for investment cost per 1 litre of the plant's annual capacity. This should not be confused with the production cost of 1 litre of annual output from the facility, for which the investment cost must be considered in annualised form. Annualising CAPEX of USD 5 per litre, for example, by using weighted average cost of capital of 8% and life of 20 years results in USD 0.51/litre capital cost component.

In contrast to these still developing technological processes, the production of FAME biodiesel, HVO-based renewable diesel and biojet fuel is already fully commercial. The market for biojet fuel is, however, still nascent. Sourcing of sustainable feedstock for FAME and HVO production is more problematic than for lignocellulosics-based processes, allowing the FAME and HVO industry segments to produce both 1G and 2G fuels or their mixtures.

While there are about 500 FAME biodiesel plants in the world, only a small share of these can be classified as 2G: producing biodiesel from entirely non-food and non-feed related raw materials such as cotton seed or jatropha oil. There are a good number of plants producing FAME from waste-based fats, UCO or oily wastes from palm oil processing, which have been promoted in Europe under RED with supporting policies until 2020. UCO and animal fats have alternative uses in the food industry, however, as an ingredient of animal feed and in oleochemistry. Using these oils and fats for biofuel therefore causes a substitution effect in these sectors, which may create the need to grow oil seeds as a replacement, thus resulting in a risk of ILUC emissions. Consequently, regulators in Europe and the US have constrained support for biofuels from these feedstocks.

The HVO/HEFA production pathway uses similar kinds of raw materials to those of FAME but produces higher quality fuels. These can be used in ordinary diesel engines without modifications or limits and can even be further processed for biojets, offering huge potential for HVO producers in the aviation subsector. Currently there are 15 HVO refineries in the world (Greenea, 2017), of which one was under construction as of the end of 2018. The total HVO capacity in 2018 was about 5 billion tonnes (5 500 million litres). In addition, two refineries in Spain co-process HVO so that the resultant conventional fuels have a biocomponent.

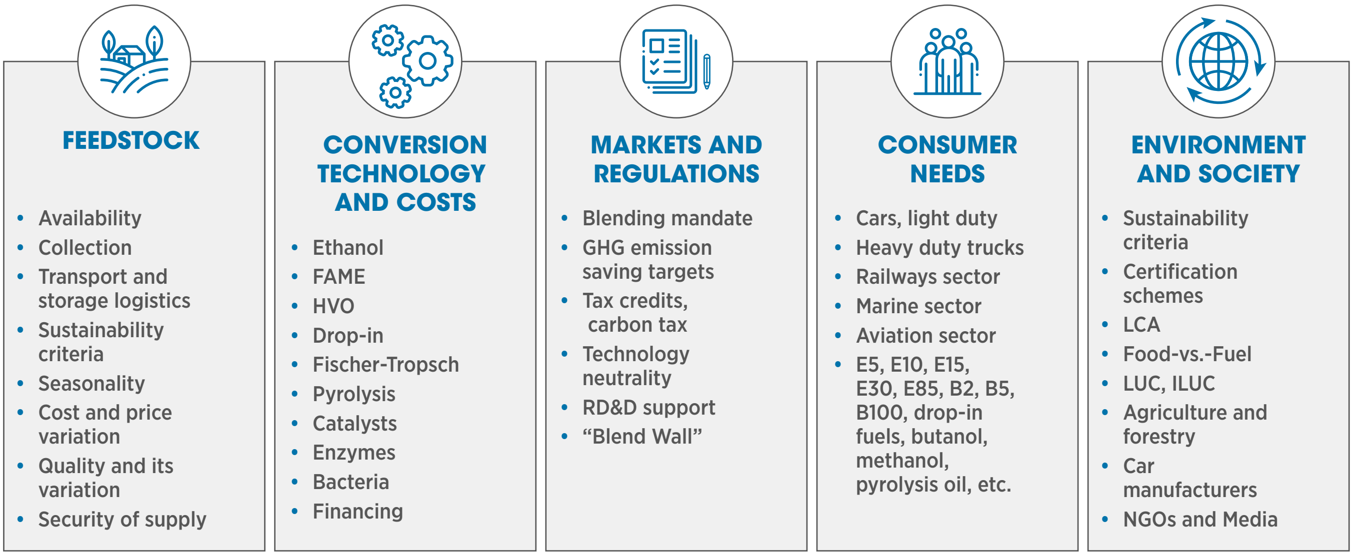
The scale of HVO/HEFA production plants is substantially higher, more than tenfold, than that of cellulosic ethanol. Capacities of various refineries range from 20 000 tonnes at Sinopec's plant in China to the typical range of a few hundred thousand tonnes, up to a million tonnes annually, at Neste Corporation's two refineries in Singapore and the Netherlands. While some of today's HVO refineries use virgin palm oil wholly or partly (making them essentially 1G producers), many of the refineries strive to replace palm oil and are in the process of shifting gradually to completely non-food and non-feed feedstocks. The high demand for HVO presents challenges for expanding supply capacity due to the limited amounts of sustainable waste-based feedstock. This may result in increasing interest in oil crops among HVO producers, such as jatropha or industrial forms of canola. The Finnish company UPM, for instance, is planning a facility of 500 000 tonnes per annum, for which one key feedstock option includes cultivation of *Brassica carinata* for winter cropping in Uruguay.

2.2 THE COMPLEXITY OF THE BIOFUEL VALUE CHAIN

The biofuel business is highly diverse and linked to many sectors of the economy and society in a more complex manner than, for example, today's petroleum or electricity generation industries, which have an established position in the economy. This diversity means that an array of options are available for a project developer for each step of the value chain.

Feedstock alternatives include, among others, food crops, energy crops, agricultural residues, forestry residues, waste oils and fats, as well as municipal waste, each with its own technical, social, economic and environmental characteristics. In the biofuel business, the resource is rarely in the hands of the project developer, and therefore the industry must connect with the primary biomass producing sectors, from farmers to food and forest product industries and their stakeholders. Establishing and maintaining the supply chain for feedstock is a central element of the typical biofuel producer's business management.

Figure 2. Stakeholders with competing interests across the value chain



Potential **conversion technologies** are also numerous, including several pathways within which there are alternatives for subprocesses. Selection of the targeted product market (ethanol, butanol, biocrude, FAME, drop-in fuels, etc.) sets the principal premise for choosing the conversion technology. Different conversion pathways each have particular feedstock quality requirements, yield and production economies, and technical and operational challenges as well as potentially a set of by- and co-products, the marketing and sales of which may form an essential part of the business model.

Biofuel markets are politically instituted and, in many countries, lack stability and maturity. They are formed in a political interplay of policy makers, stakeholders throughout the biofuel value chain and end-users. The market is not solely driven by consumer demand, but created on the basis of GHG emission savings targets, agricultural and rural development policies, and energy independence aspirations. The building blocks for creating the markets include government support for research and development (R&D), grants and loans for first-in-kind investments, fuel taxation and tax credits, blending obligations, and mandates of different kinds. These mandates may be set on the basis of transport sector emission reductions, the share of renewable energy, carbon intensity, or volumetric biofuel supply. The sustainability and fuel quality criteria for biofuels, and certification of those, also play an important role in the sector's regulation. The complex and political process surrounding the creation of national biofuel markets is therefore subject to influences from the international energy debate, NGOs and civil society in general.

On **the end-use side**, consumers' fuel choices for light vehicles (passenger cars, two-wheelers), heavy-duty trucks, public transport, marine ships and airplanes are driven by varying motives. Biofuel producers must choose their customer segment and ensure that product quality matches with corresponding consumption and engine types (gasoline and diesel, different degrees of blends and drop-in fuels) as well as consider the medium- and long-term impacts of competing energies such as petroleum, methane, hydrogen and electricity. Car manufacturers are among the key decision makers and stakeholders in forming biofuel market policies and regulation and play an important role in influencing consumer fuel choices as enablers, promoters or inhibitors of biofuels.

2.3 IDENTIFIED BARRIERS

Biofuel markets have evolved substantially from the end of the last decade, which marked a turning point in investments in 1G biofuels but also a starting point for increasing interest in 2G technologies (Figure 1). Interest in the specific barriers for the 2G biofuel industry has grown only recently as experience of the successes and failures of the first refineries has started to accumulate.

A review of the studies and surveys on advanced biofuel investment barriers reveals that many important issues identified in the late 2000s, during the initial hype around the emerging advanced biofuel business, remain relevant. Nor do 2G fuel industries necessarily escape the issues pertinent to 1G industries. The barriers identified in 2011 in the IEA's *Technology roadmap - Biofuels for transport* (IEA, 2011) and the consensus study report on the US RFS by the National Academies of Sciences, Engineering and Medicine in the US (National Research Council, 2011), remained relevant for subsequent studies and very few potential barriers identified then have proven to be non-issues now.

Both of these high-level reports – the former with a global view and the latter focusing on the US RFS – pay attention, among other things, to the feedstock supply chain infrastructure, the high costs of conversion technologies, the blend wall, and uncertainties relating to government policies. They both identify estimation methods of lifecycle emissions and associated methodologies – including for the estimation of ILUC emissions and sustainability certification requirements – as barriers because in the context of rapidly evolving science surrounding these issues, project developers cannot be certain that the biofuels they plan to produce will meet the thresholds set by regulators.

Barriers to advanced biofuels identified by the studies carried out to date are summarised in Table 1.

US context

Two US-based studies, Miller, Christensen and Park (2013) and Jones *et al*. (2017), see the blend wall (the risk of ethanol demand saturating at the point when fuel ethanol production reaches the volume needed to blend 10% ethanol in gasoline in the total car fleet) as a major impediment for investments in advanced ethanol. Miller, Christensen and Park (2013) take a corporate analysis instead of a project analysis perspective to the advanced biofuels sector. They present a systematic financial evaluation of stock-listed companies with a large stake in advanced biofuel production. Studies generally tend to provide qualitative reasoning for the slow commercialisation of 2G technologies, but this study can offer a quantitative risk analysis across the sector.

The study by Miller, Christensen and Park (2013) observes an elevated risk in 2G biofuel companies that likely contributes to unsteady and insufficient investment. This implies that additional policy measures are needed to reduce risk and build confidence in advanced biofuel companies in the early stages of commercialisation. They recognise that commercialisation barriers are complex and specific to each company, but list the blend wall, RIN pricing, oil prices and political uncertainty as common barriers contributing to the slow commercialisation and elevated risk levels of advanced biofuel companies. Biofuels must compete against oil-based fuels to break the blend wall and penetrate the market, while oil prices have not increased as many expected they would. The RIN price volatility at the time of the study is considered to result in heavy discounting of the revenue streams of advanced biofuel projects from RINs, perhaps 50% or more, making the cost of financing higher and availability more uncertain.

In analysing policy uncertainty for the US ethanol industry, Jones *et al.* (2017) identify the blend wall, flexible mandates and feedstock security as the main issues for the US advanced ethanol producers.

They also describe the much-debated flexible mandate as a chicken-and-egg problem: flexible advanced biofuel mandates enable the EPA to maintain low mandates for cellulosic ethanol when the available production capacity is low, but when mandates are low, project developers are not incentivised to expand capacity, thus maintaining the status quo.

Feedstock availability, particularly with energy crops, presents a similar problem. As the market is limited for biofuels, farmers will not grow dedicated crops until ethanol plants move in and provide guaranteed off-take. However, if farmers do not grow the required crops, project developers will consider that the feedstock supply is not guaranteed.

While both of these studies identify a set of complex issues facing the ethanol fuel industry, the blend wall is agreed to be significant. Notably, in 2016, the US ethanol industry actually broke the blend wall when the gasoline volume consumed nationally contained an average of 10.02% fuel ethanol. The ethanol industry, including producers of cellulosic ethanol, consider that the government should act on measures which would stretch the wall by inciting oil blenders and distribution companies to invest in blender pumps, storage tanks, and infrastructure for E15, FFVs and higher ethanol blends such as E85 (RFA, 2018a).

Two survey-based analyses of barriers impacting US advanced biofuel projects in 2015 provide us with a complimentary picture that also highlights a collection of policy issues. Among other research questions, Withers (2016) – also reported in Withers, Quesada and Smith (2017) – explores the most impactful barrier categories from among 23 pre-screened alternatives that “strongly impeded biofuel project success” since the outset of the industry in the US. The questionnaire was completed by 43 respondents from the total target group of 84 and included 16 respondents from the industry. The barrier categories in order of importance were funding, Renewable Volume Obligation (RVO), the EPA pathway approval process, RFS and RINs.

The second survey, on the US cellulosic biofuels industry and its commercialisation drivers and barriers (Chen and Smith, 2017), was sent to a total of 678 experts from a variety of fields throughout the biorefinery supply chain, and 228 responses were gathered. One of the merits of this study is that it not only lists important barriers but also quantifies the relative importance of factors driving and constraining the industry. This was achieved by including not only rating questions but also ranking questions, thus forcing respondents to highlight relative degrees of importance of various issues.

Both of these surveys have at the heart of their results the importance of government policies. Excluding the first barrier category from Withers (2016), which is funding, the other four top-ranked barriers are all policy-related, because each of them is a subset of the EISA, and three out of four of the highest ranked are subsets of the RFS. Similarly, the main drivers Chen and Smith (2017) identify are government policies followed by added value from co-products, carbon emission reduction and volatile oil prices. The most important barriers ranked are production costs, policy uncertainty and competition with petro-fuels.

Although both surveys highlight policy uncertainty as the second most important barrier, these two, almost simultaneous, surveys do not seem to agree on what ranks highest. Withers (2016) ranks funding in first place, whereas in Chen and Smith (2017), high production costs get the top spot. Withers (2016), however, separates internal and external barriers, and cost related issues are categorised as internal ones. Conversion rate and technology high-titre and yield were rated by all respondent groups as the most important internal barriers but funding as the most important external barrier. In this context, funding is defined as “not having enough financial resources to move forward and pressure to provide profits to maintain investor longevity and strength of company credibility”.

Withers (2016) is interested in understanding the problems encountered specifically by failed projects, and this focus is possibly reflected in the composition of the respondent group. Most, if not all, advanced biofuel start-ups in the US market are known to have received federal and state support. Funding drying up is the last stage in any failing project, and it may appear to be a crucial factor in failure. However, the root cause of this is hard to track. Project developers' patience coming to an end can be merely a consequence of many other impediments, in essence the straw that broke the camel's back.

The third most highly ranked barrier by Chen and Smith (2017) – competition with petro-fuels – is also mentioned as an important barrier in other studies (*e.g.*, by Biofuture Platform). When biofuels are promoted through tax incentives, not through blending obligation, an actual competitive situation between biofuels and petroleum may arise. However, in most countries, biofuel markets are based on obligations and strict policies in terms of business drivers relatively independent from petroleum markets, despite a connection between the two businesses in that blended products and distribution networks are a shared interest. The authors speculate about whether the timing of the survey, which followed a year (2014) of highly fluctuating oil prices (from around USD 100 per barrel to USD 45 per barrel) and led to a collapse, had influenced the respondents' views.

Additionally, Chen and Smith (2017) make an important observation that the points of view and ratings of experts in different fields were influenced by their fields of expertise. Feedstock experts, for example, rated fuel logistics as a significantly higher factor impeding the industry scale-up than, for example, refinery process experts. The latter in turn regarded high production costs as significantly more important. The authors therefore suggest that the relative ranking of scale-up factors can be influenced by an individual's expertise and knowledge, which further underscores the importance of examining issues from multiple perspectives.

European context

In 2014, the European Biofuels Technology Platform – Support for Advanced Biofuels Stakeholders (EBTP-SABS) sent a short questionnaire to governments, ministries, agencies and associations in EU28 countries and Energy Community Contracting Parties, compiling a commendable summary on barriers to biofuels deployment in Europe (EBTP SABS, 2015). Detailed feedback was received from 14 countries. Questions were categorised under several topics and themes, including (i) feedstock availability, (ii) national funding, (iii) impact of the EU policy, (iv) promotion of market uptake, (v) consumer confidence and (vi) investor confidence. The resulting report offers concise findings in each category and provides recommendations for corrective policy measures.

While the report lists the main issues pertaining to the European advanced biofuel market, it notably preceded the RED amendment through the so-called ILUC Directive (European Union, 2015). The respondents generally confirm abundant feedstock availability but recognise that supply chains for UCO and animal fats are challenging by being wide and dispersed. This highlights the potential competition between biofuels and other sectors of the bio-economy for feedstock and policy support, which could deter the biofuel industry from the biofuels segment. The report also examines several shortcomings in EU and national policies and support schemes for advanced biofuels, as perceived by the interest group, and underlines the need for continuity and regulatory stability.

Interestingly, where Chen and Smith (2017) ranked the food-vs.-fuel issue as the least important driver for cellulosic ethanol in the US context (in 2015), the EBTP survey reveals that the food-vs.-fuel dichotomy is still an important issue for advanced biofuels stakeholders in Europe (in 2014) (EBTP SABS, 2015). This may reflect a difference in the intensity of the debate between 2014 and 2015, as well as differences between European and US contexts.

In 2016, the Sub-Group on Advanced Biofuels (SGAB) of the Sustainable Transport Forum, operating under the auspices of the European Commission, surveyed SGAB members' and observers' opinions through open questions asking the respondents to name the most important barriers hampering the development of sustainable renewable fuels and renewable electricity use in transport. Fifteen questionnaires were returned (SGAB, 2017).

Much like the US-based studies and the EBPT survey, the SGAB questionnaire respondents highlighted the changing, insecure and fragmented policy environment in Europe as a key impediment. Poor cost competitiveness was also seen as a reason for slow commercialisation of advanced biofuels. The respondents also noted that support for non-bio low-carbon fuels (for instance CO_2 to ethanol) is non-existent under RED. Furthermore, the absence of common targets for the aviation and shipping sectors was raised as an issue for the industry.

A consulting study by E4tech UK (2017) advising the UK government on the production outlook for advanced drop-in biofuels by 2030 also highlights a lack of decarbonisation drivers for aviation and marine fuels as an important barrier.

Project AdvanceFuel under the European Union Horizon financing carried out a survey in 2018 among 100 stakeholders of the project and received 31 responses, of which 7 were from industry representatives (Uslu, 2018). The presumed barriers were categorised under feedstock supply, conversion and end-use following the biofuel value chain.

The most notable barriers reported, in order of priority, were:

1. dedicated policy support and stability for the industry
2. structural financial mechanisms to bridge the price gap between renewable and fossil-based fuels
3. high production cost of renewable fuels in comparison to fossil fuels
4. cost of renewable hydrogen production
5. fossil fuels still receiving subsidy
6. cost of capital
7. access to project finance
8. lack of clarity about environmental constraints.

The barriers seen as least significant related to feedstock, current agricultural practices and investments required for feedstock harvesting. Once again, policy stability was a key point of concern.

Global context

IRENA's *Innovation outlook: Advanced liquid biofuels* (IRENA, 2016b) describes the key conversion technologies of advanced biofuels and their technical barriers. The study also explores non-technical barriers, various policy development needs and strategies to support commercialisation. It presents a structure for 13 barriers in five categories (technical and economic, investments, environmental, social and infrastructure) and tables opportunities, needed actions and key actors to tackle each barrier.

The *Innovation outlook* report adds the following to the list of many oft-cited, predominantly technoeconomic and market and policy-related barriers: resources and costs associated with sustainability certification (environment), lack of assurance on socially responsible practice in advanced biofuels supply chain (social), lack of capacity in certain countries (social) and negative public perception (social).

In late 2018, the Biofuture Platform – a government-led, multi-stakeholder initiative of 20 countries designed to promote international co-ordination on advanced low carbon fuels and bioeconomy development – launched an assessment of the state-of-play of two key bioeconomy sectors: biofuels and nonenergetic bioproducts. The resulting report on the state of the low-carbon bioeconomy covers the platform member countries and selected countries and regions from the Sustainable Biofuel Innovation Challenge from Mission Innovation (SBIC/MI) (Biofuture Platform, 2018a).

The analysis includes the results of a survey to assess various barriers limiting the development and deployment of biofuel and bioproduct markets. This was distributed to Biofuture Platform member governments and SBIC/MI countries. The European Commission and 19 out of 22 countries responded. The survey found financing and fossil-fuel competition to be the two greatest barriers (from among six alternatives and an "other" category). The concern for limited financing relates to all stages of development, whether for R&D, demonstration or investment support. While fossil fuel competition is less pertinent to mandated markets, the regulatory environment in many countries makes biofuels and bioproducts face a competitive challenge from fossil alternatives. The barrier is highly relevant when fossil fuel prices are supported via subsidies.

Interestingly, the countries and regions where biofuel regulation is well established and most intricate (North America, Brazil, different EU countries, India and Indonesia) highlight in the survey that policies and regulation have negatively affected some sectors of the bioeconomy, raising unfavourable policy frameworks as the third most powerful barrier. Mozambique, the EU, Mexico, Uruguay and North American countries indicate there are limitations around feedstock supplies, which can be insufficient, expensive or inadequate. Finally, technical barriers and a lack of qualified human resources are ranked as less relevant (Biofuture Platform, 2018a).

Table 1. Barriers to advanced biofuels identified by studies carried out to date

STUDY	YEAR	REGION/ COUNTRY	RESPONDENTS	IDENTIFIED BARRIERS
Biofuture Platform (2018a)	2018	Global	Online survey to country representatives of the platform	• Limited financial resource • Fossil fuel competition • Limitations for feedstock supply • Policy frameworks and technology
IRENA (2016b)	2016	Global	Authors	• High production costs compared to fossil fuels and conventional biofuels • Policy uncertainty • Finance availability and supply chain risk • Development of bio-based chemicals and biorefineries • Uncertainty about environmental requirements • Perceptions and uncertainty about social impacts • Development of infrastructure and logistics
IEA (2011)	2011	Global	Authors	• Fossil fuel subsidies • Lacking economic support mechanism, financial risks mitigation mechanism, mandates, feed-in tariffs, tax incentives • Stable and long-term policy framework • Sustainability certification • Trade barriers • Uncertainty regarding sustainability • Feedstock supply chain infrastructure • End-use infrastructure – blend wall
Uslu (2018)	2018	EU	100 stakeholders, 31 responses of which 7 industry representatives	• Dedicated policy support and stability/security for the industry • Structural financial mechanism to bridge the price gap between renewable and fossil-based fuels • High production cost in comparison to fossil fuel costs • Cost of renewable hydrogen production • Fossil fuels still receiving subsidy • Cost of capital • Access to project finance • Lack of clarity about environmental constraints
E4tech (UK) (2017)	2017	UK	Authors	• High capital cost and capital risk • Shortage of long-term strategic investors • Variable feedstock quality (lack of specifications and standards) • Lack of understanding of market size and value as a result of policy mechanism • Lack of clear, long-term policy signal • Uncertainty around policy attractiveness • Lack of a decarbonisation driver for aviation and marine fuels
SGAB (2017)	2016	EU	SGAB members and observers, 15 questionnaires were returned	• Changing policy environment, which results in the lack of long-term rules and support • Insecure and fragmented investment climate • Cost competitiveness of second generation (2G) biofuels • No support for non-bio low-carbon fuels in RED • Absence of targets for aviation and shipping sector • Absence of post-2020 targets for renewable energy in transport

STUDY	YEAR	REGION/ COUNTRY	RESPONDENTS	IDENTIFIED BARRIERS
EBTP SABS (2015)	2014	EU	Questionnaire to governments, line ministries, agencies and associations in EU28 and Energy Community Contracting parties -feedback from 14 countries	• Feedstock is available • Wide and dispersed chain of feedstock providers • Competition between several end-use options (for feedstock) could deter investors • Lack of coherent bio-economy plans • Uncertainty on EU regulation in the medium-term • Lack or inconsistency of national legislations and strategies • Heterogenous and sometimes contradictory non-governmental initiatives • Limited national support • Limited absorption capacity in some EU countries for EU funds • EU policies perceived as incoherent • Stable regulatory framework and standards needed • Lack of mechanism to improve market development • Food-vs.-fuel dichotomy still an issue • Car owners' confidence
Chen and Smith (2017)	2015	US	228 experts (of 678) throughout the biorefinery supply chain	• High production costs • Policy uncertainty • Competition vs petroleum fuels
Withers (2016), Withers, Quesada and Smith (2017)	2015	US	43 respondents from 84, including 16 industry representatives	• Funding • RVO (Renewable Volume Obligation) • EPA pathway approval process • Renewable Fuel Standard (RFS) • RINs (Renewable Identification Numbers - tradable credits for biofuel supply)
Miller, Christensen and Park (2013), Miller (2013)	2013	US	Authors	• Blend wall • Forward contracting (uncertainty on RIN pricing) • Oil prices • Political uncertainty (such as caused by attempts to amend or appeal the RFS)
National Research Council (2011)	2011	US	Authors	• Feedstock costs • Feedstock storage and delivery • Absence of price discovery institutions in bioenergy feedstock markets • Conversion technologies and costs • Infrastructure investments for biorefineries • Fuel distribution infrastructure • Blend wall • Uncertainties in government policies • Non-federal rules, regulations and incentives • Lifecycle GHG emissions • Air- and water-quality effects of biorefineries • Water use for irrigating feedstock and in biorefineries • Fuel certification requirements • Farmers' and forest owners' attitudes • Consumer knowledge, attitudes and values

3. CONTEXT AND RELEVANCE OF SURVEY QUESTIONS

3.1 FEEDSTOCK

Feedstock availability

The survey statement concerning feedstock availability is "there is not enough feedstock for advanced biofuels business expansion".

One of the most common justifications for shifting away from crop-based biofuels is the greater abundance of sustainably harvestable feedstock for advanced biofuels. Yet, the question about feedstock availability remains in the public discourse on advanced biofuels.

Considering global population growth projections and the inherent competition for agricultural land-use among biofuel feedstock, food and animal feed sectors, the sustainable production of 1G feedstock is a major challenge. Many crop-based feedstocks are also tainted by claims of undesirable monoculture and land-grabbing. Furthermore, to fulfil the aims set out by the Intergovernmental Panel on Climate Change's *Special report on global warming of 1.5 °C*, the United Nations Framework Convention on Climate Change through the Paris Agreement and the UN's Sustainable Development Goals, overall agricultural land-use needs to be reduced. This is essential to boost carbon sequestration and minimise habitat and biodiversity loss.

In contrast, advanced biofuels are produced using agricultural residues, woody residues from forestry and wood processing industries, municipal solid waste (MSW), short rotation woody crops, energy crops, oily seeds farmed on marginal land unsuitable for crop production, industrial and commercial waste such as UCO, waste oils, fats, tall oil, and algae. As these are all by-products, waste products or under-utilised side streams, they have minimal environmental and ecological impacts and have potential to improve economic efficiency.

Various organisations (IRENA, IEA, Greenpeace, EU) have concluded that sustainable biomass supplies are sufficient to exceed projected global demand. National, regional or global estimates depict resource availability in the context of pre-conditions of the biofuel industry as a whole. However, for an individual company considering investment in a lignocellulosic advanced biofuels refinery, especially when based on non-tradable residues, resource availability is a serious local level matter. Due to the low density of agricultural and forestry residues, the cost of road transport limits the feasible area for collecting and transporting feedstock to a radius of 50–200 kilometres from the refinery site, depending on the feedstock properties. Therefore, project developers seek as their first priority locations where feedstock concentrations are already sufficiently large, where by-products of industrial scale production are available and are based on existing supply infrastructure, such as at sawmills, pulp mills, rice mills and other agroindustrial plants.

Since securing feedstock is essential for the feasibility of an advanced biofuels business, yet long-term supply agreements are rare, project developers tend to minimise risk by seeking and maintaining a mixture of feedstock sources, in order to ensure a constant supply.

Feedstock quality

The survey statements concerning feedstock quality are "regulation of biomass feedstock quality is inadequate" and "feedstock quality variations disrupt our production".

Some advanced biofuel conversion processes are sensitive to feedstock quality variation. These processes are designed for a relatively narrow set of physical and chemical qualities, deviations from which can negatively impact conversion efficiency, stability of processing and operational costs.

At the same time, to manage price risk and sufficient volume of feedstock – and thus economy of scale in biorefinery operations – having a diverse portfolio of feedstock is desirable.

Although combining diverse feedstocks can cause quality variation, especially when different classes of resources (*e.g.,* herbaceous with woody materials) are combined, variation also occurs within a single feedstock. There is natural variation in the elementary composition of plants. In addition, variation can be due to differing farming practices, harvesting conditions and storage, resulting in varying degrees of degradation, moisture and ash content.

Feedstock storage and logistics

The survey statement concerning feedstock storage and logistics is "biomass transport and logistics are not available at volumes required by full-sized biorefineries".

Timely logistics and effective storage are necessary for maintaining the supply and quality of feedstock. Agricultural waste stems from crops harvested during relatively short time periods, which may occur one to three times annually, whereas a biorefinery needs a steady, year-round feedstock supply. Inadequate storage can result in low density, poor flowability or degradation. After collection (*e.g.*, straw baling), feedstock may need to be pre-processed to control its size (chipping, grinding, pelletising, briquetting) and moisture content (drying). The logistics system must also minimise dry matter loss and degradation. Transport and associated handling systems must be arranged to bring feedstock from fields through intermediate storage and pre-processing facilities to the refinery.

In developed countries, proven process concepts and technical solutions for biomass collection, storage, handling and transportation are available, but they come at a cost. Feedstock production and logistics in the US constitute over 35% of the total production cost of cellulosic ethanol, and logistics associated with moving biomass from fields and forestry sites to the biorefinery can make up 50–75% of this (Hess, Wright and Kenney, 2007). Reducing these costs is therefore indispensable to creating an economically sustainable biofuels industry, and best practices should be further developed.

In developing countries, smallholders tend to lack capital and space for establishing needed storage and logistics facilities, meaning they must rely on external capital, farmer co-operatives or private enterprises to undertake pre-processing, storage and other supply chain management. As the advanced biofuels industry expands, specialised companies are likely to manage the logistics of the value chain. In India, for example, a company already exists to manage feedstock supply for several bioenergy plants, including contracts with farmers to collect residues (with set timeframes and costs) and long-term contracts to supply feedstock with set quality requirements to bioenergy plants. Bringing together multiple feedstock suppliers for multiple biomass off-takers enables such companies to optimise storage and transport infrastructure and benefit from large-scale operations.

Competing uses of feedstock

The survey statement concerning competing uses of feedstock is "competing uses of biomass feedstock (such as heat, power and bioproducts) pose a major risk for our biofuel business".

Existing or emerging competing uses of biomass feedstock, such as use of agricultural waste by households, farmers and villages at sites of harvesting and collection, present risks for refinery operators relying on the long-term availability and cost predictability of feedstock.

Competing uses include residues as fertiliser, wood fuel for cooking and heating, straw or husk burning for drying vegetables, straw as animal bedding, agrowaste composting, biowaste for animal feed, and sale of easily tradeable chips, pellets and briquettes for heating and power. Industrial use of biomass for direct or indirect heat or power generation (*e.g.,* in pulp, saw, sugar, palm oil and other mills and agroindustrial processing facilities) is another usage that may increase demand for and competition over targeted biomass resources.

Furthermore, demand for methane biogas, produced via anaerobic digestion of biomass, may increase, for onsite heat or power generation, feeding into the natural gas network, or sale in bottles for cooking or in bulk transport.

In addition, biomass is used as raw material in the production of existing and novel value-added voluminous products, including particleboard, medium-density fibreboard and animal fodder, and specialised niche products such as food additives, emulsions, soaps, detergents, paint, varnish, resin, plastic and lubricants. The latter group may pose a competing demand to feedstock and intermediate products for bioliquids producers, due to their low price sensitivity.

Advanced biofuels offer minimal environmental impact and the potential to improve economic efficiency

Feedstock price

The survey statements concerning feedstock price are "better mechanisms are needed to monitor biofuel feedstock prices" and "feedstock price uncertainty hampers our business".

The cost of feedstock for 1G biofuels represents approximately 70% to 90% of total production cost and is higher for biodiesel than ethanol. High raw material costs and low CAPEX and non-fuel operational expenditure (OPEX) costs render the biofuel production industry extremely sensitive to changes in feedstock price (IISD, 2013). While the CAPEX of 2G advanced biofuel refineries is higher than that of 1G refineries for similar output, 2G feedstock is sought primarily from cellulosic and oily low-, no- or negative-cost wastes and residues. Feedstock cost for cellulosic ethanol production is estimated to constitute 35–50% of total production cost, depending on various geographical factors and supply chain characteristics from harvesting, collecting, storing, pre-processing and transportation to bio-refineries (Hess, Wright and Kenney, 2007).

Agricultural residues, MSW and lignocellulosic raw materials other than round wood, wood chips, pellets and palm kernel shell (PKS) are generally less expensive. With gate-fees for MSW, feedstock costs can even be negative. However, feedstock quality can vary, sometimes being dispersed or having low density or high moisture content, creating logistical challenges. Without adequate drying and storage capacity in the supply chain, agricultural waste availability and price varies seasonally.

Agricultural production, which must be relied on in feedstock supply, has its own culture of relatively short-term supply contracts. As there may not be a world market price serving as a reference, project developers of advanced biofuels face challenges with regard to feedstock supply security, price stability and predictability. Furthermore, although by-products, waste products and under-utilised side streams are low-value by nature, the growth in incentives for using biomass from these sources, including rising demand for biofuels, has led to competition and price hikes that amplify uncertainty.

Feedstock incentives

The survey statement concerning feedstock incentives is "incentives for farmers to grow feedstock for advanced biofuel plants are inadequate".

Farmers and non-industrial forest holders play important roles in supplying raw materials, such as energy crops, agricultural residues, short rotation woody crops, woody residues from forestry and oily seeds farmed on marginal lands, for advanced biofuels. The question therefore rises whether incentives to farmers and forest holders provided by governments to grow and supply feedstock could help deploy more advanced biofuels.

The bulk of government incentives for advanced biofuel production typically goes to fuel producers, as opposed to feedstock suppliers, due to an assumption that increasing demand will raise both the prices and quantities of feedstock and revenues for farmers, thus also benefiting feedstock producers. Nevertheless, an expectation of a positive price signal is not always enough to induce farmers to adopt new crops and practices.

Diffuse adoption of new farming practices, technologies and crops amongst farmer communities in different regions, agricultural systems and socio-economic contexts elicits additional challenges in encouraging the uptake of novel crop farming practices. Large-scale agriculture may take advantage of the adoption of the new practices required by biofuels production differently from smallholder farmers. Aside from farm economics – such as the feasibility and investment cost needed to initiate cultivation of a new crop or to start collecting, processing and transporting residues – potential barriers include: a lack of information about new opportunities regarding biofuel feedstock; a lack of associated farming skills; logistical barriers to harvesting and transporting feedstock; behavioural socio-cultural inertia; and uncertainties about the feasibility of advanced biofuel production, the continuity of government support, and the viability of nearby refineries purchasing feedstock (National Research Council, 2011).

In Brazil and the US, policies exist to overcome these challenges. To promote biodiesel production in Brazil, the Social Fuel Seal (SFS) is granted to biodiesel producers who acquire a minimum percentage of feedstock from family farms, sign a contract with these farmers and give the farmers technical assistance. In the US, the Farm Service Agency (FSA) manages a Federal Biomass Crop Assistance Program (BCAP) set up to help farmers grow advanced biofuel feedstock.

3.2 TECHNOLOGY AND FINANCING

Technology readiness and lignocellulosic ethanol

The survey statements concerning technology readiness and lignocellulosic ethanol are "technology is not ready for large scale advanced biofuels deployment" and "lignocellulosic (2G) biofuels will reach significant volumes by 2030".

Technology readiness is an oft-cited barrier to advanced biofuels. The boundary between technology and financial performance related barriers is, however, blurry. In many, while not in all cases, solutions exist to the technology related hurdles of biomass conversion to liquid biofuels, but their cost exceeds a limit tolerable by the market for the resulting product price. In such cases a barrier can also be characterised as an economic one and is ultimately policy related.

The first statement about whether advanced biofuel conversion technologies are ready for large-scale deployment, as policy makers have anticipated, is a debated topic. Many believe that public support for 2G biofuels is not warranted because the cost of the transition from 1G to 2G biofuels production has proved to be too expensive. Furthermore, the high expectations placed on advanced biofuels, which have been used to justify EU/federal and national/state-level subsidies, grants and loans, and measures in support of R&D, have not been met (Roche, 2018; Michalopoulos, 2018; Loris, 2017).

Many firstcomers in the industry indeed faced severe technology-related challenges and failed to operate their facilities to capacity or annual production targets. Technical hurdles, together with other factors, resulted in abandonment of facilities, with companies shifting to other products or even declaring bankruptcy. Most of the notoriously failed projects were for the production of lignocellulosic ethanol.

Despite the technical and operational hurdles encountered in the past, today several commercial-sized lignocellulosic ethanol refineries are operating. At least 12 lignocellulosic refineries are in commercial operation (excluding those of less than 10 million litres of annual capacity) including 2 in Brazil, 3 in China, 3 in Europe and 2 in the US, in addition to 2 ethanol plants in Europe using spent sulphite liquors from a pulp mill as feedstock. The current situation can be interpreted to show that the industry is moving ahead and passing the high-risk demonstration stage.

Drop-in biofuels

The survey statement concerning drop-in biofuels is "technology is mature enough to start marketing drop-in gasoline and diesel from lignocellulosic feedstocks".

Drop-in fuels are a key element of transport sector decarbonisation, as the most common biofuels – ethanol and FAME biodiesel – have limitations in terms of the proportions in which they can be mixed with petroleum fuels. Advancing beyond the ethanol and biodiesel blend wall and supplying for heavy-duty transport, aviation and marine sectors requires fuels that can power engines alone and/or in very high blends.

High-quality drop-in biofuels are currently produced from lipids from vegetable oils, oily wastes, UCO, tall oil and animal fats via an oleochemical processing route (HVO/HEFA). This has already become a thriving new business, which paves the way for drop-in fuels as part of transport sector decarbonisation. However, the feedstocks used may not be available in sufficient quantities to cover all the projected biofuel demand from the transport sector, especially the rising aviation sector. Therefore, other pathways for drop-in fuel production using lignocellulosic feedstocks, which are cheaper and more readily available, are under active development, with focusses on thermochemical, biochemical and hybrid pathways.

Thermochemical pathways turn biomass into pyrolysis oil (bio-oil) via pyrolysis, or syngas via gasification. Pyrolysis produces a gaseous mixture and solid char as by-products, which can be used for energy (heat and power production) in different applications. Bio-oil can then be further upgraded to liquid hydrocarbons via hydrogen-intensive hydroprocessing. In hybrid processes, bio-oil is fed to existing petroleum refineries, together with intermediate petroleum distillates, such as vacuum gas oil. Such co-processing is already under demonstration and has the potential to cut costs by utilising existing fossil fuel refining, distribution and storage infrastructure. However, the products are not 100% biofuels, but rather "lower" carbon drop-in fuels.

Syngas can be processed into renewable gasoline through methanol synthesis, followed by methanol-to-gasoline synthesis, or alternatively, via Fischer-Tropsch synthesis, followed by upgrading via hydrocracking into various fuels. Methanol from syngas can also be converted to DME, a fuel with several favourable properties for use in diesel engines but not yet fully commercialised in any market.

Numerous biological pathways, feedstocks and micro-organisms have been proposed for the production of drop-in biofuels and their intermediates (Karatzos and Saddler, 2014). Biochemical pathways use methods such as enzymatic hydrolysis into sugars, or fermentation into ethanol or other alcohols, followed by catalysis or bioforming into drop-in biofuels (*e.g.,* alcohol-to-jet). Advanced biocatalytic processes convert sugars to less oxygenated longer chain alcohols (butanol, butanediol) and higher molecular weight compounds, such as isoprenoids and fatty acids.

Several economic and technical challenges concerning improving yield and maintaining stable processing exist with some of these technologies. In some cases, particularly biochemical processing, the production of various chemicals and other non-fuel products – as opposed to biofuels – has proved more feasible.

Most plants in current operation may be classified as pilots or demonstrations, with only three commercial-scale projects being under construction or having reached an advanced stage of development. Commercial demonstration plants of US companies Gevo and Byogy represent the alcohol-to-jet technology. Gevo's process starts with butanol and Byogy's with ethanol, in which ethanol is led from their existing ethanol process to a bolt-on plant producing diesel and jet fuel.

Several pyrolysis plants exist, but most produce bio-oil for heating burners, and only a few aim to add hydroprocessing of crude oil to produce transport fuels. Envergent (a joint venture between HoneywellUOP and Ensys), with a rapid pyrolysis process, is actively promoting biocrude co-processing demonstrations in petroleum refineries (Brazil, US, Canada). Fulcrum Bioenergy (US) is developing a Fischer-Tropsch synthesis facility applying a thermochemical pathway to produce drop-in fuels from municipal waste. Redrock Biofuels (US) also has a project under construction to produce hydrocarbons from woody biomass, and Total is developing a demonstration unit in France. Maverick Synfuels (US) is operating a syngas-methanol demonstration plant, and Shell's catalytic thermochemical process, IH2, is being demonstrated in India. Finally, Virent (US) has an operational demonstration plant based on a combination of Aqueous Phase Reforming technology with modified conventional catalytic processing.

Algae (3G) biofuels

The survey statements concerning algae (3G) biofuels are "algal (3G) biofuels will reach significant volumes by 2030" and "the biggest challenge for algal biofuel is in growing and harvesting algae at scale".

The potential benefits of algae-based biofuel production are unlikely to go unnoticed among project developers, considering that researchers have claimed that algae could be 10 to 100 times more productive than traditional feedstocks (DOE, 2018). Expectations concerning the performance of algal biofuel production and the time needed to reach commercialisation have, however, proved overly optimistic. Hype around algae, as measured by internet search activity on the topic, has tempered since reaching a peak in 2008. Despite reducing enthusiasm, progress is being made, and from time to time the media publish reports of breakthroughs concerning certain aspects of micro-algae cultivation, harvesting and oil extraction. The survey therefore tests the hypothesis that algae breaks through and leads to significant production by 2030.

Algae is advantageous in that it can be grown in highly diverse environments. Tens of thousands of microorganisms exist under the informal definition of "algae" that can accumulate lipids suitable for biofuel production, many of which are salt tolerant and can be grown in seawater, removing competition for land use applicable to crop-based feedstocks. Some can be cultivated in the harsh conditions of non-arable land, while others can be fed by industrial or municipal wastewaters. Furthermore, algal photosynthesis can be integrated to use secondary CO_2 sources, such as flue gases from industrial or power boilers or wastewater plants.

Growing algae in open ponds is the simplest and cheapest method. However, such ponds expose algae to varying environments, non-sterilised water and other organisms, which may contaminate or destroy the crop. Greenhouse covers or closed photobioreactors help solve the contamination issue but increase the overall cost of the process. In terms of yield, artificial photobioreactors are the most effective cultivation method. Mass cultivation represents over 40% of the total cost and is considered the key obstacle to commercial realisation of microalgae (Oh *et al.*, 2018). There is also a trade-off between expected growth of algae and its lipid productivity. Stress (*e.g.*, that caused by nutrient deprivation, salt, pressure or hormones) triggers accumulation of algal lipids essential for biofuels, but also reduces photosynthetic activity and hence overall productivity (Oh *et al.*, 2018; Flynn, 2017). Depending on the cultivation method, concerns also exist about the resource usage and carbon footprints of algae cultivation, in terms of use of water, fertilisers (nitrogen and phosphorous) and space (Flynn, 2017).

Overall, micro-algae cultivation systems are still under development, the efficiency of solar-to-organic energy conversion remains low, and the cost of oil production is high (IRENA, 2016b). While many companies – including corporations, such as ExxonMobil – are working on algae-based feedstock, several have gone bankrupt, closed the line of business or moved on to other businesses. As with other biomass resources, the discourse on future perspectives for algae increasingly revolves around the biorefinery concept, which produces not only biofuels but also proteins and nutrients, various value-added speciality chemicals, biogas and/or electricity (Cheng and Timilsina, 2011). This concept has the potential to improve the economics of algae-based feedstock, but also faces challenges. For example, the operating conditions for maximising lipid extraction can induce losses and negatively impact the quality of other bio-products (Oh *et al.*, 2018).

Transport infrastructure

The survey statement concerning transport infrastructure is "inadequate transport infrastructure will constrain the marketing of advanced biofuel products".

Issues relating to transport infrastructure are more prominent when a geographic dislocation of biofuel supply and demand necessitates long-distance transport to deliver products to market. The most common biofuels (FAME and ethanol), as well as crude-type bio-products, (*e.g.*, pyrolysis oil), have properties which require specific attention in transport, storage and handling. The survey seeks to understand whether this is seen as a barrier for advanced biofuels deployment.

Vegetable oils and animal fats have higher viscosities, making them more difficult to pump and store, and are more unstable, making them susceptible to degradation during storage, handling and end-use. FAME tends to oxidise, risks microbial growth and has degraded low temperature flow properties, and deposits material on exposed surfaces, such as filter elements, creating various challenges concerning its storage.

Furthermore, FAME products have unique challenges depending on source (*e.g.*, palm oil-derived products can solidify under Northern European winter conditions, whereas rapeseed-derived products remain liquid). Switching storage container usage from FAME to jet fuel therefore requires particular care (*e.g.*, three intermediate FAME-free cargoes, plus a hot water wash) (The UK P&I Club, 2017).

Pyrolysis oil requires acid-proof loading, unloading and handling equipment, requiring additional infrastructure investment (Laihanen, 2014). FAME, bioethanol, bioethanol-gasoline blends and pyrolysis oil are hygroscopic and soluble in water, and therefore susceptible to irreversible phase separation once a critical threshold of water contamination is exceeded. In bioethanol blends, water causes formation of an alcohol-rich water/ethanol aqueous phase on top of an alcohol-poor gasoline phase, which collects at the bottom of the storage tank (The UK P&I Club, 2017).

Oxidative susceptibility can be beneficial from an environmental perspective, as it renders a fuel biodegradable, potentially mitigating environmental risks in case of spillage. Despite oxidation risk, experiments with biodiesel, B20 and B5 demonstrated reasonable stability up to three years under well-maintained, underground storage conditions. The addition of antioxidants after oxidation onset has proven effective in restoring stability (Christensen and McCormick, 2014).

Practical experience in transporting and storing ethanol and biodiesel is already abundant, as these commodities are traded globally, and in the main markets (Europe, the US, Latin America) storage and handling facilities are located near major ports. The dislocation issue is particularly pertinent to the inland US, where ethanol and FAME production are concentrated in the Midwest, whereas consumption is highest in coastal areas.

According to the US Department of Agriculture (DOA), 90% of ethanol is transported by train or truck. Ethanol could be transported by pipe, but because of its affinity to water, this would require either dedicated pipelines or clean-ups of existing pipelines. The first experiences of piped ethanol are from the Central Florida Pipeline from Tampa to Orlando, which has transported commercial batches of ethanol along with gasoline shipments (US Department of Energy, 2018a).

Dislocation has not resulted in insurmountable challenges or cost increases in the US market. However, should traded volumes of biofuels rise as expected in global and regional projections, substantial investment in storage and transportation infrastructure will be required. Such expansion calls for a stable policy environment, enabling co-ordinated investments by all relevant stakeholders, including producers, blenders, dealers, transporters, fuel distribution companies and consumers.

Availability and cost of financing

The survey statement concerning availability and cost of financing is "availability and cost of financing is a major barrier to investment in advanced biofuels".

Sponsors of advanced biofuel projects focus on the opportunity presented by the emerging industry, which is supported by favourable policy drivers and megatrends, and devise strategies in their business plans to mitigate and allocate known risks. The availability and cost of external financing are two major challenges identified by past studies as affecting advanced biofuel investment prospects. The questionnaire therefore surveys how crucial project developers regard this aspect to be in their investment planning.

Members of the financial community, in turn, consider the investment through a sectoral- and company-specific risk analysis. They identify and quantify individual risks and the overall risk level to establish the certainty of repayment of any financing and the expected return on capital.

In their evaluation, they must consider the realities of an emerging industry, characterised by supply chains with a relatively low level of establishment, a multitude of potential conversion processes, relatively new technology, and a market for end-products that is subject to changes in public sentiment and political trends. On the other hand, they consider the merits and financial standing of the project developers in relation to the size of the project as well as the merits of the business plan.

The properties of the sponsor(s), project developer(s) and targeted source(s) of financing for advanced biofuel investments can be briefly characterised as follows:

» **Strategic developers: providing equity**

- Many early developers in advanced biofuels are large companies strategically positioned to benefit from fuel diversification, such as oil companies (BP, ENI, Neste, Preem, Shell, Sinopec, Total), resource companies (Fibria, UPM), agro-energy corporations, large 1G producers (Little Sioux Corn Processors, Raizen, REG), and chemical and process technology companies (Dupont, Honeywell). These companies have a higher-than-average risk tolerance to carry out R&D for identifying and developing suitable conversion technologies and building demonstration plants for use before scaling up. The backbone of financing is equity funding, which may be supplemented by corporate loans, or grants, loans or guarantees from public sector R&D support mechanisms.

- Other developers are typically from technology and process companies, which have often developed proprietary technologies for commercialisation and scaling up (Enerkem, Gevo, Sundrop Fuels). They typically stem from start-ups which have formed strategic partnerships with non-competing technology partners, financiers and venture capital (VC) firms. Availability and cost of financing can be major issues for these companies.

» **Financial investors: providing equity, semi-equity and credit**

- Early-stage investors in start-ups include innovators and entrepreneurs themselves, angel investors, VC firms and merchant banks, each bringing private equity and semi-equity. VC firms typically seek a 15–45% shareholding, often wishing to be represented on the board of directors or in management. Start-up failure rate is very high, meaning early-stage investors look for returns exceeding ten times their original investment.

- Commercial banks have low risk tolerance and require collateral for loans. Their role is therefore limited when companies do not yet own tangible assets for security. Until a biorefinery is operational and generates sales, advanced biofuel developers often depend on unsecured loans with flexible repayment schedules or that are convertible to equity.

- Traditional project finance structure, in which cash flow and contractual set-up are considered sufficient to secure debt repayments (*i.e.*, no recourse against sponsors' assets) is uncommon in the advanced biofuel business. Unlike in the power generation sector, neither the fixed assets nor the contractual arrangement (primarily for feedstock supply and product off-take) are considered secure enough for project financing.

» **Public sector: providing equity, credit, grants and guarantees**

- Many countries (Brazil, Canada, Europe, India, the US) promoting advanced biofuels in their energy and climate strategies offer co-funding (grants, loan guarantees, low cost loans, tax incentives) towards the capital costs of pilot, demonstration and first commercial plants. In addition to EU programmes, many European governments have equivalent incentive schemes. In the US, the DOE, DOA, Department of Transportation and some federal agencies (*e.g.*, the EPA), administer such schemes.

- Some sovereign wealth funds, as well as international funding agencies (public investment and international development banks) provide financial support for advanced biofuel production as part of their sustainable development strategies.

Financial actors are attracted to the advanced biofuel sector by potentially high future returns, as there is the possibility of start-ups achieving temporary dominance in the market by successfully developing new technology. On the other hand, if the failure rate of the sector's companies proves exceptionally high or returns remain low compared to expectations, investors lose confidence in the sector and financing becomes scarce.

According to a study by Miller, Christensen and Park (2013), 2G biofuel companies in the field of cellulosic and algal biofuels in the US market posed a significant risk for investors between 2010 and 2013 and had difficulty in generating adequate returns to attract investment under the policy and market conditions of the time. Cavka and Vahlström (2014), however, observed that the advanced biodiesel sector did not seem to carry higher systematic risks than the conventional biofuel sector between 2012 to 2014, nor the market in general, though the returns were also not significantly higher than in the conventional biofuel sector, nor the market in general. They hypothesised this may have been because the analysed firms had established multi-product refineries and diverse product portfolios and noted that several different internal factors were also in play.

3.3 MANDATES AND TARGETS

Legislative landscape

The survey statement concerning the legislative landscape is "policies affecting our business are stable and clear".

The apparently unstable policy environment for biofuels stands in contrast with the long development period of advanced biofuel production facilities. A biofuel refinery typically takes five to ten years to develop. The time needed is dependent on the readiness level of the conversion technology, the characteristics of project sponsors and the source of financing, amongst other factors. Pre-project stages of an investment include business planning and feasibility analysis, conceptual and engineering design, permitting, contracting feedstock, setting up supply chains, and mobilising financing. Several years precede a conclusive investment decision, which is then followed by detailed design, construction and commissioning. The latter requires a further two to four years, or longer, if a technology has not yet been piloted and demonstrated. Investors look forward to returns that pay back the investment during an operational period of 10–30 years thereafter.

Meanwhile, policies tend to remain in force for roughly the period needed to develop one or two biofuel investments. In unfortunate cases, the policy environment can change and void key assumptions from the original investment analysis before the plant begins operations.

Regarding the duration of the main policy frameworks, the US RFS2 under the EISA of 2007 represents the longest prevailing regulatory framework. It pre-set volumetric biofuels targets for the country for 14 years from 2009 to 2022. The EU "winter package" of 2009 determined renewable energy development for a ten-year period until 2020. In Brazil, RenovaBio plans to set rules for the biofuels market for an eight-year period of 2021–2028.

Policy uncertainty is consistently ranked as a major barrier to the commercialisation of advanced biofuels (Chen and Smith, 2017; Miller, Christensen and Park, 2013; National Research Council, 2011; EBTP SABS, 2015; Biofuture Platform, 2018a). This uncertainty arises partly because biofuels involve an exceptional number of stakeholders with conflicting interests, and partly because markets are entirely politically instituted and based on high-level objectives concerning GHG emissions, energy independence, and agricultural and rural development and employment – all matters which divide along political lines.

With regard to feedstock, the market is dependent on agricultural and forestry primary production; consequently, the interests of those sectors are of importance. European and US farming sectors battled for decades with overproduction and declining prices of certain crops, meaning that biofuel feedstock cultivation and local ethanol/biodiesel refinery businesses were traditionally viewed as positive alternatives to setting aside lands, an opportunity to create new farming revenue streams, and an option for revitalising rural areas. Partly due to these interests, 1G biofuel producers (*e.g.*, sugarcane-/corn-based ethanol, rapeseed-/soy-based biodiesel) have grown.

However, these sectors have traditionally been viewed negatively by some environmental activists due to the sustainability concerns raised by modern forestry and agricultural practices (*e.g.*, logging, monoculture, biodiversity concerns, use of pesticides/chemical fertilisers). Relations between environmentalists and natural resource sectors became further polarised during the food-vs.-fuel debate of 2007–2009, and the almost parallel and related discussion about the risk of indirect land-use change caused by biofuels production. Both controversies triggered global debate on the sustainability of biofuels amongst scientists, media, politicians, advocacy groups and citizens, rendering biofuels a controversial and sensitive topic on the political agenda.

The three major biofuels markets (Brazilian, European, US) have been instituted through an array of policy measures involving blending mandates, farmer subsidies, tax incentives, grants, loans and loan guarantees for R&D and refinery development. Such an intensive government involvement is criticised by another side of the political spectrum, namely conservative groups representing economic liberalism and/or the interests of oil and gas industries, which wish to abolish all subsidies and minimise government involvement in economic activities to avoid market distortion, reduce the tax burden and maintain low fuel prices.

Additional dividing lines of the biofuels discourse are drawn around end-uses of biofuels and preferred solutions for low-carbon transport. EVs tend to dominate opinions on solutions for future low-carbon transport, while another focus is on the promotion of public transportation and car-free cities, with reducing attention paid to biofuels as a solution for decarbonisation. The end-use perspective also brings in car manufacturers, ship owners and airliners individually and collectively through their advocacy organisations in important roles to affect future fuel choices.

Policy uncertainties

The survey statement concerning policy uncertainties is "regulatory uncertainty impedes investments in advanced biofuel production".

Biofuel producers typically have short-term supply contracts for feedstock and biofuels off-take, lending them a greater risk profile than the wind and solar electricity sectors, which are characterised by problem-free immaterial feedstock, and off-take guaranteed by long-term supply agreements or feed-in tariffs. In this context, biofuels policy stability is of the utmost importance. Examples from the three major biofuels markets have shown how legislative and regulatory changes can alter the business outlook and prompt rapid shifts to either a boom or a suppressed market. Along with final legislative acts, the gestation period during which an issue is debated matters greatly to project developers. When the market knows that a critical piece of regulation is under a jurisdictive process, commercial operators must weigh the risk of unfavourable outcomes and may refrain from critical investment decisions until the certainty of their outcome is achieved.

The US biofuels policy has brought about commendable success in increasing the country's overall supply of biofuels, albeit its achievement with advanced, and especially lignocellulosic biofuels, is modest. Many politically motivated acts in the US legislature have caused uncertainty among project developers, including serious attempts to amend or eliminate the whole RFS in Congress.

Overall, perceptions of the EPA's role as the administrator of RFS are increasingly politicised, and lawsuits have deemed that proposed volume obligations are either too low or too high, or not in accordance with the EISA. In addition, the EPA has also been criticised for missing some deadlines in its rulings.

The EPA has exercised its right to issue two types of waivers, leading in both cases to criticism from biofuels lobbying groups, which considered that to be a major source of uncertainty in the market. Cellulosic waiver credits (CWCs) allow the EPA to manage deficits in advanced cellulosic biofuels supply by resetting the obligation level closer to the foreseen *de facto* production capacity, taking into consideration that the capacity for cellulosic ethanol has not ramped up as was expected in 2007.

However, ethanol producers have argued that with fewer waivers, there could have been more incentive for project developers to install higher capacity, which would have led to a smaller supply deficit. Secondly, small refinery waivers allow the EPA to grant waivers to smaller oil refineries, or to force larger ones to make up the difference when smaller ones have considerable difficulties or encounter hardship in fulfilling their blending obligation. Ethanol advocacy groups and the National Farmers Union have sued the EPA for allegedly abusing its authority by allowing undue waivers to small refineries, especially in 2017.

The EPA's time-consuming approval process of new fuel pathways for advanced biofuels has also been considered a cause of uncertainty for project developers. Furthermore, renewal of critical legislation is also a concern for project developers looking for continuity in regulation. Tax credits for biodiesel, renewable biodiesel and 2G biofuel expired in 2017. The bipartisan Biodiesel Tax Credit Extension Act of 2019 seeks to extend these tax incentives for 2018 and 2019. Finally, advanced biofuel producers and advocates in the US have started lobbying for the higher level of ambition for post-2022 volumetric targets under the RFS, which will be a topic for a new political agreement and legislative process.

In Europe, the first major game-changing policy shift took place in 2006, when Germany, as the dominant European biodiesel producer at that time, halted its 1G biodiesel boom by gradually subjecting biodiesel to fuel tax and introducing blending mandates as the primary policy measure for biofuels. This caused a shift from rural entrepreneurship-driven tax-free biodiesel business amongst independent petrol stations to managing biofuels supply by traditional oil distribution companies through their obligation to blend biofuels. Since this change in policy, a series of changes every few years in EU-level policies, legislation and regulation have caused a profound impact on the perceived investment environment within the industry in Europe.

The EU Energy & Climate Package (ECP) of 2009 was foundational and established a framework for Member States to set national emission reduction and renewable energy targets. This led to enactment of the Renewable Energy Directive (RED, 2009/29/EC), requiring the EU to fulfil at least 20% of total energy needs and 10% of transport using renewables by 2020, through attainment of individual national targets.

As soon as the overall target was established for the transport sector, the focus turned to ensuring the sustainability of the fuels that are counted as renewable components in the transport sector fuels, considering also the ILUC impact of growing feedstock for biofuels. Food-vs.-fuel concerns led policy makers to want to limit the consumption of 1G biofuels and introduce advanced biofuels to the mix.

Soon after RED was enforced, and national targets were set, the directive to reduce indirect land use change for biofuels and bioliquids of 2015 (ILUC Directive amending Fuel Quality Directive, 2015/1513) as well as appropriate amendments to RED, were enacted. The EU also defined a set of sustainability criteria for biofuels production to ensure carbon savings and protect biodiversity, requiring achievement of GHG savings on a lifecycle basis of at least 35% in comparison to fossil fuels. This rose to 50% in 2017 and 60% (for new production plants only) in 2018.

Legislative and regulatory changes can alter the business outlook and prompt a rapid shift to either a boom or a suppressed market

In 2016, after the Paris Agreement, the Commission published a proposal to revise RED to make the EU a global leader in renewable energy and ensure that a target of at least 27% renewables in final energy consumption by 2030 was set. By the end of 2018, the Council, European Parliament and Commission came to an agreement on RED II for 2021–2030, setting an overall target for the share of renewable energy in the EU at 32% by 2030, and 14% for the transport sector. The cap for crop-based biofuels is maintained at 7%, allowing a slight increase in the production of 1G biofuels.

A binding target of 3.5% is set for advanced biofuels, taking into account the double-counting principle (the Member States can count the energy content of consumed advanced biofuels twice towards their renewable energy target). The agreement limits high-risk ILUC biofuels to 2019 levels and obligates their complete phase-out by 2030, most notably impacting palm oil usage.

Since 2006, EU legislation has evolved in rapid sequence. This was driven mostly by the need to ensure ever-improving sustainability performance of biofuels brought to the European market. However, the process of achieving this target created continual uncertainty amongst project developers. The features of the legislation included soon-to-follow amendments to recently enacted legislation so that legislative packages were partly incomplete once issued.

The legislative process on biofuels was a generally non-consensual and politically charged one, in which environmental NGOs and industrial lobby groups had a particularly prominent role. Finally, the European policy environment is affected by the variations in policy measures adopted by Member States, and the different time frames for Member States transposing EU regulation to national legislation.

Key policy measures

The survey statements concerning key policy measures are "mandates and blending obligations for advanced biofuels should be replaced by price mechanisms like rebates, tax credits, reduced taxed rates and a market value for carbon" and "technology neutral fuel standards (as in Brazil or California) are better than fuel specific mandates (as in EU)".

The most common forms of support for renewable energy in the transport sector are mandates and blending obligations, often combined with a variety of fiscal incentives and public financing for early-stage technologies. Renewable fuel mandates and blending obligations are recognised as effective ways of creating a market for biofuels. At least 68 countries have now enacted biofuel blending mandates at national or subnational levels, up from 36 in 2011 (IRENA, IEA and REN21, 2018).

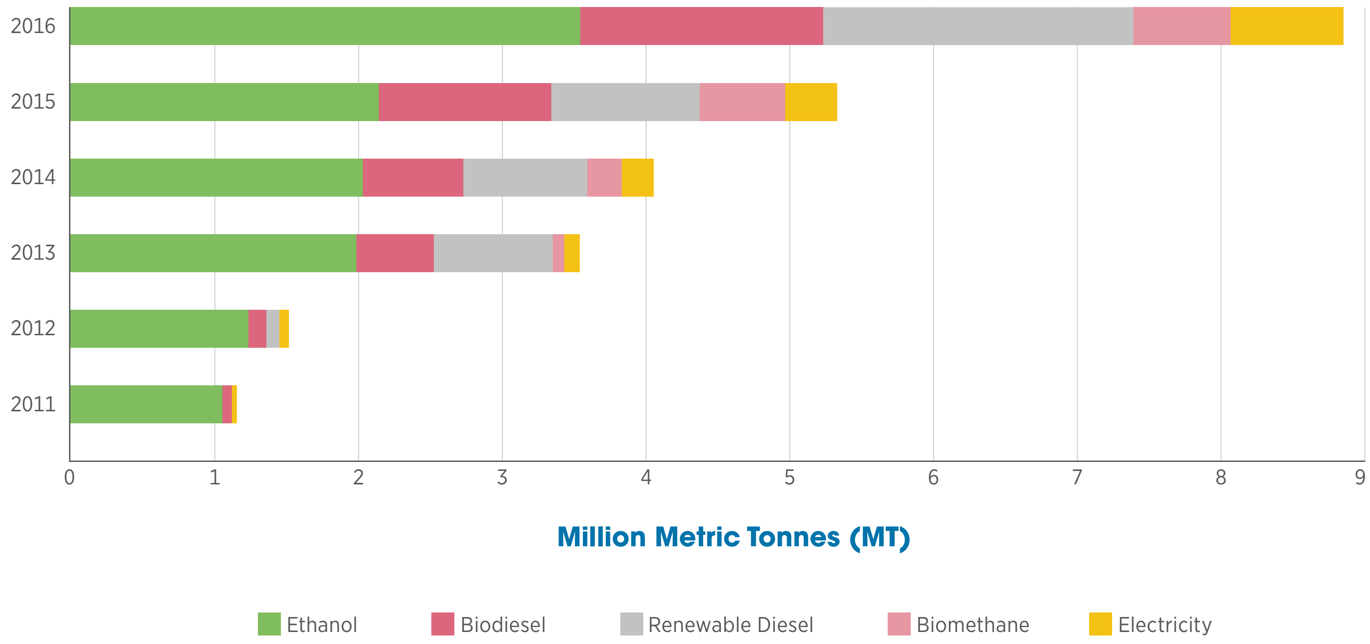
Mandates have the benefit of being in line with the "polluter pays principle". Under mandate schemes, the cost of introducing more expensive but less polluting fuels to the total fuel mix is carried by fuel consumers rather than by taxpayers, some of whom may contribute very little to transport emissions. Secondly, enforcing and administering mandates do not require intensive government interference, and the administrative burden remains reasonable. Mandates do not, however, automatically credit production of advanced biofuels unless a separate mandate within the fuel pool, or another such mechanism such as double counting within the EU, is created to reward producers of lignocellulosic ethanol and other advanced biofuels.

While mandates have become popular, tax incentives have also proved effective even as the sole regulatory measure, if the incentive level is strong enough. Tax cuts, rebates and credits are ways to improve the price competitiveness of renewable fuels. Fuel and/or carbon taxes imposed on fossil fuels can be used for the same by making fossil fuel alternatives more expensive.

A universal and revenue-neutral carbon tax is often seen as the most advanced and fair tax measure for promoting deployment of low-carbon fuels, as it is completely fuel technology-neutral, and as it is not fiscal in the sense that tax revenues are returned to the taxpayers. According to a World Bank report on the state and trends of carbon pricing (The World Bank, 2018), not counting the Canadian provinces, 21 national jurisdictions had carbon taxes in 2017. The highest emission price, EUR 26 per emitted CO_2 tonne, was applied in Sweden, where the tax was instituted in 1991. This was gradually increased to EUR 120 per tonne in 2018 (Government Offices of Sweden, 2018).

The next highest carbon values are in Switzerland and Liechtenstein (USD 101 per tonne) (The World Bank, 2018) and Finland (EUR 62 per emitted CO_2 tonne) (Vero [Finnish Tax Authority], 2018). Industries under the EU emission trading scheme (EU ETS) have been exempt from the tax in Sweden and Finland. In October 2018, Canada enacted a Federal Greenhouse Gas Pollution Pricing Act implementing a genuinely revenue-neutral carbon tax, starting in 2019. The tax will be CAD 20 (Canadian dollars) per CO_2 tonne in 2019, rising by CAD 10 per tonne per year until it reaches CAD 50 per tonne in 2022 (Nuccitelli, 2018).

Figure 3. Sources of credit under the Low Carbon Fuel Standard, California



Source: Vergara (2017)

The Low Carbon Fuel Standard (LCFS) in California (and the somewhat similar Clean Fuels Program in Oregon), Canada's British Columbia Renewable & Low Carbon Fuel Requirements Regulation, the German GHG reduction mandate, and Brazil's RenovaBio represent the new gold standard of mandates.

The LCFS requires a reduction in carbon intensity for the transport sector and is completely fuel-agnostic. Credits for the supply of biofuels and other advanced transport fuels are granted only on the basis of reduced carbon intensity in comparison to fossil fuel alternatives.

The lower carbon intensity of advanced fuels will then lead to more credits for their suppliers, hence making them competitive and accelerating deployment. The LCFS has proved effective in increasing the share of low-carbon fuels in the total transport energy mix and in diversifying the fuel pool of California. LCFS has created continued stability and confidence for producers of a variety of low-carbon fuels.

Target levels

The survey statements concerning target levels are "European renewable fuel targets are insufficient to encourage investments in advanced biofuel production" and "targets for expansion of advanced biofuels production are not sufficiently ambitious".

The survey asks opinions about the ambition level of advanced biofuel targets. In Europe, where the advanced biofuel targets are typically less than 1% or nil, they can be instinctively seen as low.

The adequacy of biofuel deployment targets can be evaluated based on economic or environmental perspectives, but the two statements of the survey on this topic will leave the respondent's perspective open. The economic perspective asks whether targets for renewable transport fuels aim for a large enough market share so that willing project developers fully exploit the potential of advanced biofuels, but also avoid excessive supply-demand imbalances.

The environmental perspective is concerned with whether targets are sufficient to accomplish transport sector decarbonisation in line with the Paris Agreement, seeking to limit average global temperature rise to well below 2 °C compared to pre-industrial levels within the present century.

The promotion of cellulosic ethanol production encounters specific regulatory challenges because under the conditions of purely volumetric obligations or blending rate obligations for ethanol, 2G ethanol is not cost-competitive with 1G ethanol. The EU has set a specific target for advanced biofuels, and it enables double counting of advanced biofuels towards the target. In the US and in several EU Member States, the solution has been to set distinctive mandates for cellulosic ethanol or advanced fuels in general. Within the EU, such sub-categories are in place in Bulgaria, Denmark, France, Germany, Italy, the Slovak Republic and the UK.

The advanced fuel obligations in Europe are generally small, ranging from 0.05% in Germany to 1% in Italy for 2020 (GAIN, 2018a). The EU's double counting principle – adopted by half of Member States in national legislation – adds opportunities for advanced biofuel producers. Double counting, especially under conditions of short supply or high 1G prices, incentivises blenders to pay a premium for advanced biofuels.

Under the US RFS, advanced fuel volume targets are based on annual rulings based originally on the EISA. However, advanced biofuel supply has been continually insufficient considering the EISA levels, which has led the EPA to adjust the annual volumetric targets dramatically down using its right to waiver, close to the existing capacity. Therefore, there has not been a situation in which a price signal has been strong enough for advanced fuels to boost the investment activity to a level that could provide volumes outlined in the EISA.

Market fragmentation

The survey statement concerning market fragmentation is "EU and US biofuel markets are too fragmented, more coherent central regulation is needed".

Market fragmentation has sometimes been presented as a potential barrier impacting the production and trade of advanced biofuels. The US states retain the right to make laws covering anything not pre-empted by the federal constitution, federal statutes or international treaties. Provinces in Canada also have wide legislative autonomy in many matters relevant to climate and fuels policy regulation (as well as states in Brazil). Indeed, there exist very distinct state-/province-level regulations. However, in the US and Brazil, the federal regulation is strong and detailed, and biofuels businesses are run primarily with national and international biofuel markets in mind rather than within the state/province boundaries.

In Europe, the fragmentation is more striking. EU Member States pursue the agreed goals as they deem appropriate from their national perspectives, in consultation with the Commission. This has resulted, for example, in considerable variation in the target levels, the calculation basis of the targets, and the ways by which policies pursue these targets. Mandates may have been set for fuels in total or separately for gasoline and diesel. Targets may be volumetric, based on renewable energy in the energy content of selected fuels, or GHG reduction of the total pool of transport fuels. Member States' policies may include blending obligations, mandates, tradable credits, tax rebates or taxation of fossil fuels in differing variations and combinations.

Some countries set specific targets for the use of advanced biofuels and have adopted the double-counting principle of RED, but other countries do not have these elements in their national legislation. The speed at which Member States adopt common regulation in their legislation also varies. The last country to adopt a biofuel mandate as a response to the RED legislation of 2009 did so in 2017, for the legislation to be in force in 2018, when the target year is 2020 (ERR.ee, 2016).

Blend wall and fuel ethanol demand

The survey statements concerning blend wall and fuel ethanol demand are "blending limits discourage investment in advanced biofuel production" and "governments should promote E85 and flex-fuel vehicles to maintain market pull for lignocellulosic ethanol".

"Blend wall" refers to technical constraints that limit increased ethanol use in gasoline, which may be based on vehicle technology, physical environment (*e.g.*, cold weather), or lack or high cost of fuel transport and distribution infrastructure. Technical limits for ethanol or biodiesel use in vehicles are reflected in fuel and vehicle standards. When markets reach blend target levels, policy-based blending obligations start limiting growth for biofuel demand. There is no incentive for obligated blenders and distributors to increase the supply of biofuels beyond the mandatory level. Outside the Brazilian and US markets, mandates and blend rates for ethanol remain mostly under 10%.

In Europe, E10 can be used in about 90% of petrol cars used (99.7% petrol vehicles produced since 2010). The availability of E10 blend is increasing, accounting for 32% of petrol sales in France and 63% in Finland. In Germany, the E10 market share remained low in 2016, at 12.6% (ePURE, 2018). E10 is available in the US, Australia and New Zealand. In Brazil, the ethanol use mandate is currently 27%. Now that the US has reached a record average blend rate of 10.08% (in 2017) (REN21, 2018), the biofuel industry is lobbying to introduce E15 as the new standard.

Diesel fuel blending mandates typically range from 0% to 7%, with Brazil leading, having increased its B8 standard to B10 in 2018 (Biofuels International, 2018). Production technology for 1G fuels is mature and the CAPEX requirement of ethanol and biodiesel plants is not high, enabling rapid investment response to short supply.

International experience shows that under enabling policy environments 1G producers can indeed catch up to blend target levels very quickly and occupy space reserved for biofuels. Therefore, there is no motivation for investments in the production of cellulosic ethanol or non-crop-based biodiesel without additional incentives and/or distinct mandates for advanced biofuels. 1G producers could potentially invest in 2G biofuel because the feedstock often comes with lignocellulosic material. A limited and risky market for advanced ethanol, however, discourages them from developing cellulosic ethanol production in bolt-on facilities, because any market share to be gained from the investment would come at the cost of their conventional production (Bio, 2016).

Creating more space for additional biofuels supply is possible by stretching blending limits to E15, E20 or E25 for ethanol, or up to B20 for biodiesel (*e.g.*, Indonesia). Additional demand for ethanol, unconstrained by technical or administrative limits, can be created by promoting and enabling FFVs optimised to run on any mix of E10–E85 gasoline and up to 100% hydrous ethanol fuel (E100) (*e.g.*, Brazil). However, each addition of a new blend creates a need to develop adequate distribution infrastructure, requiring large investments.

Tariffs and trade

The survey statements concerning tariffs and trade are "import tariffs are needed to protect domestic investments in advanced biofuels" and "import tariffs have a negative impact on our business operations".

Import tariffs on biofuels or feedstock represent an additional factor causing uncertainty in the market, and those have been applied from time to time by most major biofuel trading parties. In addition to regular duties, anti-dumping and countervailing duties for ethanol and biodiesel have existed amongst trading partners in Europe, North America and South America.

Given the close link between agriculture and biofuels, countries and trading blocs set import tariffs to protect their farming sectors and producers within the rules of international treaties. Without these tariffs, countries with higher production efficiency and more favourable feedstock endowment would be able to supply biofuels to the protected markets and drive down prices, with consequences for local feedstock markets.

Trade restrictions are imminent when such developments are perceived as contrary to the policy objectives of supporting domestic biofuel production. Furthermore, most biofuels markets are characterised by subsidies or support schemes for feedstock supply and/or biofuel consumption, causing market distortions in both importing and exporting countries. Domestic political justification therefore exists for anti-dumping duties and other defensive actions, or to accuse other countries of using them.

Not only import tariffs but also export tariffs are used. Argentina's export tax on soy oil is meant to pursue the export of biodiesel instead of raw soy oil. The tax increases soy oil supply in the domestic market, lowering its cost and improving its feasibility as a feedstock for domestic production of biodiesel for export.

With no incentive to increase the supply of biofuels beyond the mandatory level, policy-based blending obligations can limit demand growth

A lack of consistent labelling and customs practices surrounding biofuels also have an impact on their import and trade. Cellulosic ethanol has no customs code of its own but it is treated the same as other equivalent ethanol products. Duty rates in Europe are set for biodiesel (FAME) and different biodiesel blends separately. HVO is, however, categorised in Europe and the US as diesel, despite being renewable. The EU has duties for FAME, B30 and below, and ethanol, plus anti-dumping duties and countervailing duties on FAME on US and most Canadian companies.

European imports of ethanol have declined over recent years, such that fuel trade is currently almost balanced. Ethanol imports (mainly from the US) represented 3.9% of fuel ethanol consumption in 2017 (GAIN, 2018b). Biodiesel imports to the EU take place mainly from Malaysia and Argentina, with around 32% market share each. They accounted for 8.7% of biodiesel consumption in 2017 (GAIN, 2018b). In response to a World Trade Organization ruling on a trade dispute over biodiesel imports from Argentina and Indonesia, the EU abolished anti-dumping duties in 2018. Biodiesel exports amount to only 1% of production.

Brazil has advocated free trade for ethanol; however, as the EU and China have effectively closed their biofuel markets via import duties, Brazil has remained one of the few markets open to receiving excess ethanol supplies from world markets. Brazil was a net exporter of fuel ethanol until 2016 and turned net importer in 2017, when imports accounted for about 6.8% of consumption of fuel ethanol. Ethanol exports represent about 1.7% of domestic production. Brazil does not trade with biodiesel (GAIN, 2018c).

China increased its tariffs from 5–30% in 2017 (EIA, 2018), and as a response to the rapid rise in ethanol imports, introduced a duty-free quota for an amount representing an approximate average of imports from 2014–2016, and an import duty of 20% for volumes above that amount (150 million litres per quarter) (Phillips, 2018).

The US has been a net exporter of fuel ethanol from 2010 onwards, mainly to Brazil, Canada and India (EIA, 2018). Fuel ethanol imports have reduced since their peak in 2012–2013. US biodiesel imports account for 19.8% of consumption, and exports make up 5.7% of production. Imports of ethanol, biodiesel and HVO are largely driven by California's LCFS and other West Coast states.

In addition to import tariffs, sustainability criteria for feedstock and biofuels have sometimes been presented as setting technical trade barriers.

3.4 TRENDS IN BIOFUEL DEMAND

Electric vehicles and the role of biofuels

The survey statements concerning EVs and the role of biofuels are "advanced biofuels will remain a niche and represent only a tiny share of the future energy mix", "EVs pose a serious threat for biofuels business in the coming 5 to 15 years", "biofuels should be targeted primarily for shipping and aviation, and light vehicles should be electrified" and "multiple fuels, feedstock and technology pathways make the advanced biofuels market too fragmented to effectively promote their large scale deployment".

Worldwide, enthusiasm for EVs is growing rapidly. According to the IEA's *EV outlook for 2018* (OECD/IEA, 2018), the number of electric passenger cars on the road globally shot up from 1 million to 3 million between 2015 and 2017. EV growth is being driven by favourable policies and tangible incentives, ranging from lower taxes to EV drivers' right to use bus lanes. The influx of new EV models by many car manufacturers – including battery (BEVs) and plug-in hybrids (PHEVs) – has raised hopes and demand for accelerated deployment of EVs as a solution to transport sector decarbonisation. Under the IEA's New Policies Scenario, the EV stock will reach 125 million units by 2030, when the estimated share of light-duty vehicles (LDVs) will be 12%. Projections by the IEA and IRENA indicate that electric LDVs will reach the 1 billion milestone by 2050, contributing – together with electrification of buses and two- and three-wheelers – to a total 43% share of electricity in the final energy use of the global transport sector (IRENA, 2019b).

These positive projections are matched by an IMF working paper, in reference to past technology transitions (*e.g.*, replacement of horses by motor vehicles, or the increase of US market penetration of mobile phones and microwaves), that suggests that oil and motor vehicles could have a much shorter remaining lifespan than commonly assumed (Cherif, Hasanov and Pande, 2017).

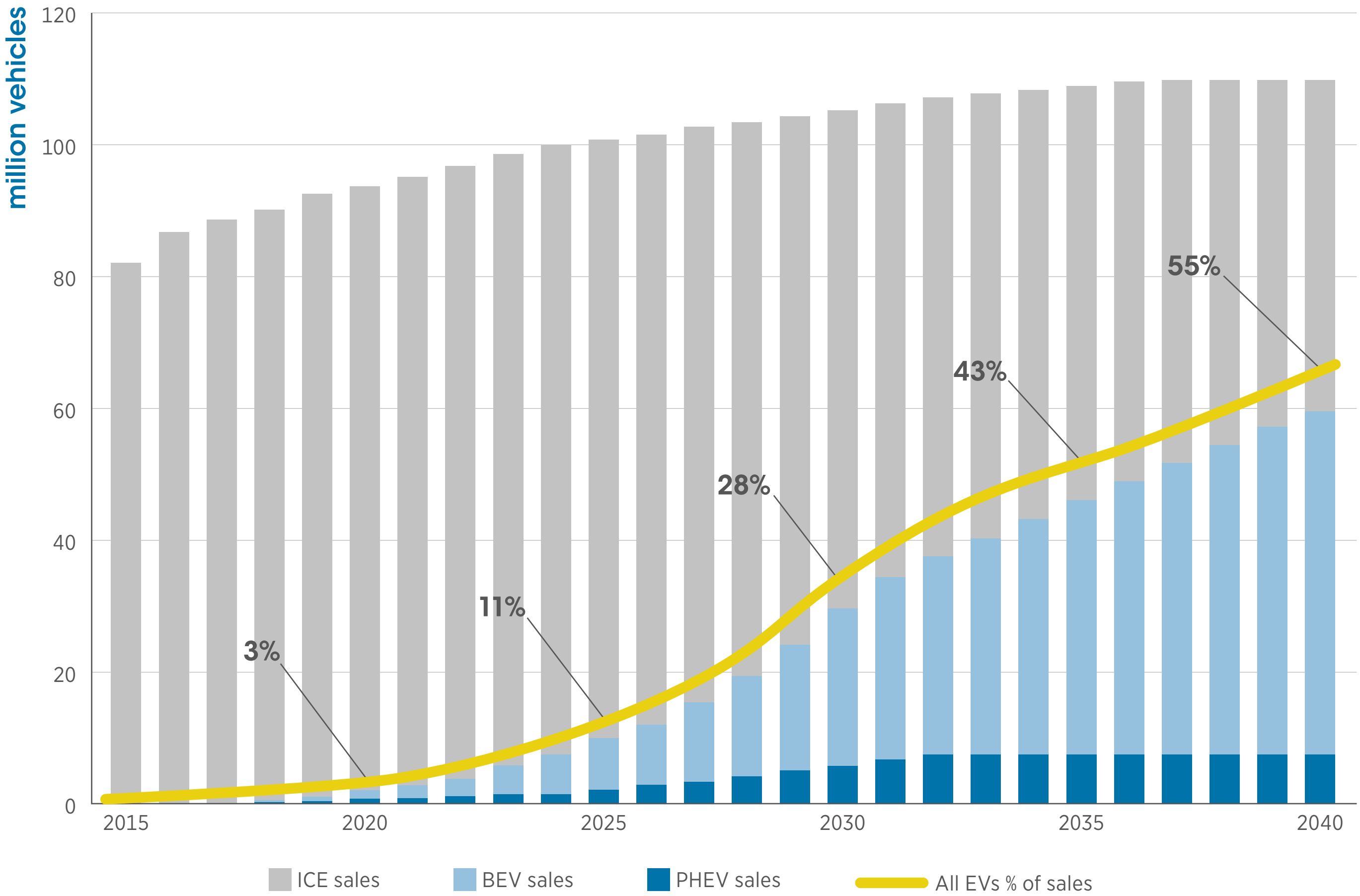
In the study's fast adoption scenario, EVs would effectively replace motor vehicles at a 93% displacement rate by the early 2040s. Indeed, while the range of estimates for displacements in various diffusion models for 2030 to 2050 is very wide, newer projections are more aggressive for EVs and forecast significant reduction of internal combustion engines (ICEs) in LDV fleets.

These views are underpinned by media reports about cities refusing access for ICEs and governments pledging to end their sale. Countries announcing ICE sales bans (in particular, diesel) or targets for 100% BEV/PHEV fleets include France, Ireland, the Netherlands, Norway, Scotland, Slovenia, Sri Lanka, Sweden and the UK as a whole, scheduled between 2025 (Norway), 2040 (France, UK, Sir Lanka) and 2045 (Sweden) (OECD/IEA, 2018).

Concurrently, several car manufacturers have announced their intention to halt development of ICEs and launch new EV models (OECD/IEA, 2018), including Volkswagen, which recently announced the launch of its last generation of ICE car models in 2026 (Reuters, 2018). Previously, the company had announced plans to invest USD 48 billion into electrification transition by 2030.

Light-duty vehicles with internal combustion engines could remain in service until the 2050s despite EV market uptake

Figure 4. Annual global light duty vehicle sales



Source: BNEF (2018)

Even the most positive assessments of the rapid uptake of low- and zero-emission vehicles, however, must address an array of important issues, both from the consumers' and policymakers' perspectives, including:

- overall costs of all LDVs, including purchase price and operation cost
- availability of infrastructure for charging, hydrogen and advanced liquid fuel distribution
- future increased efficiency of ICEs
- modal shifts and behavioural changes in transport
- well-to-wheel environmental performance of different kinds of vehicles, including the environmental impact of battery production and electricity production.

The rapid adoption of EVs as the core of transport decarbonisation will be a complex process but there is significant energy behind the movement. Environmental groups such as Transport & Environment in Europe are demanding a rapid shift, from 2030 to 2035 onwards, entirely to zero-emission vehicles.

Referring to the limited resources of sustainable feedstock, the T&E Roadmap to 2050 assumes that the RED II target for advanced biofuels in 2030 will be reached, but that thereafter, all sustainable advanced biofuels would be diverted to the aviation subsector (Transport & Environment, 2018a).

The apparently imminent dominance of low-/zero-emission new vehicle sales will challenge decision-makers to consider how much and for how long to invest in promoting low-carbon advanced biofuels for LDVs. Measures such as introducing higher blends (E15/E20), FFVs or aggressive biofuel mandates will then be weighed against the option of investing entirely in the transition to electricity in light duty transport.

Project developers in advanced liquid biofuels production must face the possibility of ICE-LDVs becoming side-lined, and the consequent effects of EV market uptake on future demand for bioliquids, but even under aggressive displacement assumptions ICE-LDVs will still hold until the 2050s. Markets for 2G liquid and gaseous fuels, albeit strongly reduced, will therefore be present in most projections of the future transport energy mix. A prudent approach will therefore embrace advanced biofuels as contributors to transport sector decarbonisation in parallel with EVs, considering that increasing amounts of advanced biofuels are needed in heavy freight, ships and aviation. This, in turn, will likely have consequences for the types of fuels produced from biomass with preference for drop-in fuels, particularly renewable diesel, biojet, methanol and options other than ethanol and FAME biodiesel, which now dominate the biofuels supply.

Flex-fuel vehicles and the future of advanced fuel ethanol

The survey statements concerning FFVs and the future of advanced fuel ethanol are "FFVs are necessary for decarbonising the transport sector" and "Brazilian experience with ethanol and FFVs dominating light vehicle markets is unlikely to be achieved elsewhere".

Advanced ethanol has four principal major future markets. One is to continue using ethanol blended with gasoline. This market is expected to shrink in tandem with the improved fuel economy of vehicles and reduced sales of ICE-LDVs. The second is to break blend walls, extend them and promote E85 or 100% ethanol fuels for FFVs. The third is to use ethanol as an intermediate chemical to produce drop-in fuels, *e.g.*, for aviation. Finally, ethanol can also be further refined to other chemicals which would replace their fossil fuel-based equivalents.

FFVs are able to flexibly run on gasoline blended with ethanol or methanol at various degrees. They typically utilise E85 but can also run on any medium-/high-ethanol blend. Factory-made FFVs are not significantly more expensive than equivalent gasoline-powered vehicles (USD 100–200), and most petrol-powered ICE cars can be retrofitted with a conversion kit (USD 500–800). If the availability of dispensing infrastructure for medium-/high-ethanol blends for consumers can be ensured, the relatively low cost of increasing the share of renewables in transport through FFVs might offer a shortcut to rapidly decarbonising a large share of LDVs.

The current reliance of ethanol production on food or feed crops, however, presents a significant social barrier to their uptake, except where governments have taken active measures to pursue FFV deployment. Brazil, in particular, has made a concerted effort to promote FFV deployment, with the result that E100 and FFVs together represent 28 million vehicles or 77% of the total car fleet, and 90% of 2018 vehicle sales were FFVs.

In the US, similarly, there are nearly 20 million FFVs and over 3 000 E85 stations offering high-level ethanol blends, because the DOA's Biofuels Infrastructure Partnership programme funded the installation of new ethanol infrastructure and at least 1 400 stations between 2016 and 2018. The Brazilian model has raised interest across South America and in many developing nations with feedstock potential for higher ethanol production.

In Europe, there are around 4 000 E85 stations (Miljö Fordon, 2018), the greatest density being in Sweden, but they are also increasing in popularity in France, where there are nearly 1 000 (Barbaux, 2018). In both countries, E85 fuel is supported by tax exemptions, making it cheaper at the pump than baseline fuels (E5, E10). Other countries have been pulling back their support for E85 and FFVs, however, based on LUC concerns (GAIN, 2018b; US Department of Energy, 2018a).

The advocacy organisation Advanced Biofuels USA has argued to the investment community that the market success of FFVs is clearly linked with the method of incentivisation of 2G ethanol production. They encourage the industry to persistently pursue its long-term goal of building a high-blend (greater than 30%) ethanol market. Cellulosic ethanol is seen as the primary fuel for cars and light-duty trucks in North America. Therefore, rather than relying on short-term fixes, such as pursuing acceptance of E15, FFVs and E85 are seen as key prerequisites for increased advanced ethanol demand (Advanced Biofuels USA, 2011). The relative ease and low cost of converting conventional gasoline-powered cars to FFVs with conversion kits offers possible solutions even where the FFV models manufactured by car manufacturers do not sell well and are not widely available, as in Europe.

The market success of flex-fuel vehicles is clearly linked to incentives for 2G ethanol production

Shipping sector

The survey statements concerning the shipping sector are "maritime biofuels are impeded due to the cost of changing ship engines and fuel storage infrastructure" and "international agreements should eventually limit sulphur, NOx and GHG emissions in ships, forcing them to use biofuels".

Maritime fuel is currently dominated by the dirtiest fuels sold by oil refineries, and the sector has only relatively recently faced significant governmental or public pressure to reform. GHG emissions from international shipping were omitted from the 1997 Kyoto Protocol, and despite the Paris Agreement, the sector has lacked mandatory targets for GHG reductions. Pressure has begun to mount, based on concern over climate change, resulting in a number of agreements that will significantly reduce shipping emissions.

A binding international agreement (the 2008 revision to the 1997 Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL), by the International Maritime Organisation [IMO]) limits sulphur oxide (SOx) and nitrogen oxide (NOx) emissions of ships to a degree that necessitates an extensive shift to new fuels (IMO, 2018). In addition, a global cap for sulphur, reducing sulphur emissions from 3.5% to 0.5% from 2020, has also been introduced (IMO, 2018). Finally, a breakthrough agreement was reached in 2018, when members of IMO approved a Vision and an Initial Strategy, for the first time envisaging a targeted 50% reduction in total GHG emissions from international shipping by 2050 compared to 2008 (IMO, 2018).

The shipping sector is thus under significant pressure to act on sulphur and GHG under concluded agreements, as well as by public concern about climate change. Several efficiency-improving measures (*e.g.*, optimising vessel size, load, speed) have been identified and are under discussion amongst industry players that may help address these issues. Still, the IEA estimates that sulphur regulations necessitate modification or changing of 70% of fuels currently used by the sector (IEA Bioenergy, 2017). Drop-in diesel (HVO), biofuels blends (*e.g.*, with biodiesel or ethanol) or even 100% vegetable oil are technically feasible in ships (whereas pyrolysis oil is not viable). For liquefied natural gas (LNG)-powered machines, DME and bio-LNG are valid substitutes (Ecofys, 2011; IEA Bioenergy, 2017).

In this arena, advanced biofuels have great potential, especially considering that biofuels are almost sulphur-free (below the 0.1% content in fuel required since 2015 in emission control areas [ECAs], mainly in coastal North America and Northern Europe) and that the shipping industry is highly concentrated. Large and very large oceangoing ships, for instance, represent 20% of the total roughly 85 000 vessels and 80% of the gross tonnage. The bulk of international seaborne freight passes through a few well-established routes to a limited number of major ports, at which bunkering takes place (IEA Bioenergy, 2017).

Infrastructure and engine changes necessary to accommodate advanced biofuels could thus be deployed in a relatively concentrated set of locations and vessels while producing a significant reduction in emissions.

Ships are long-lifetime assets, and changes in storage, bunkering and engine infrastructure are expensive. The shipping industry is highly competitive and its future fuel choices will be driven and constrained by a multitude of factors, the management of which calls for co-ordination between ship owners, port operators, engine manufacturers, service providers and fuel suppliers. One industry viability assessment found that ship owners are ready for no more than a 10% capital cost increase, competitiveness at a USD 50/ tonne CO_2 carbon price, and negligible upstream emission (Lloyd's Register and UMAS, 2017).

None of the zero-emission options analysed fulfilled these criteria, though advanced biofuels appeared to be the most attractive solution currently available, outperforming alternatives economically in terms of capital cost implications for machinery and storage, and with low fuel and voyage costs.

For all their promise, there are some significant challenges to overcome in deploying advanced biofuels to the shipping industry. Implementation and enforcement of sustainability standards on a global shipping network represent a significant challenge. A recent road-mapping study identifies regulators' ability to control the application of strict sustainability criteria, given that sustainable and non-sustainable biofuels have similar physical properties and bunkering takes place in the global port network, as a key concern with the implementation of biofuels for shipping. For this reason, that study completely ignores biofuels among potential choices for shipping, instead recommending battery-electric and hydrogen technologies from sustainable renewable sources for decarbonisation (Transport & Environment, 2018b). If biofuels are to be used for shipping they must address the coupled challenges of ensuring sustainability and availability in ports around the globe.

Aviation sector

The survey statement concerning the aviation sector is "we count on aviation sector being a major customer".

The aviation industry has seen very high passenger traffic growth during recent years. Airlines face stiff competition and have passed savings from low fuel prices and efficiency improvements on to customers. The growing middle class of emerging economies has sustained the increase in demand for tourism and business travel. IRENA's REmap Case 2050 projects that this growth will continue in the long term, with a 3.3-fold increase from 2015 to 2050 in annual passenger kilometres, with consumption of biojet growing from negligible levels to 105 billion litres, almost equivalent to current global biofuel production (130 billion litres in 2017) (IRENA, 2019b).

Airlines are now coming under increasing pressure by corporate clients, individual passengers and governments to reduce carbon emissions. Aviation is difficult to decarbonise, however, due to a lack of technically feasible options and the highly competitive sector's sensitivity to fuel price.

Airports and passenger flows have major economic impacts on cities, regions and countries, requiring unilateral action for improved sustainability to be feasible. Governments agree on common rules for international aviation through the International Civil Aviation Organization (ICAO). The specialised agency's 191 member countries only agreed on the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) in 2016, before which only initiatives for sustainable aviation by airlines, companies, governments, airports and civil society existed (ICAO, 2018a). ICAO considers biofuels to be sustainable aviation fuels (SAF), representing a central element of CORSIA, along with a broader package of measures to achieve the global aspirational goal of carbon-neutral growth from 2020 onwards.

In 2017, ambitious targets of 2%, 32% and 50% SAFs in international aviation fuels by 2025, 2040 and 2050, respectively, were presented but rejected by ICAO, which instead opted for vaguer wording that conventional jet fuels will be substituted with SAF "to a significant percentage" by 2050 (ICAO, 2018b; GreenAir Online.com, 2018). This agreement also has not been without opposition, however, as civil society groups led by Friends of the Earth International objected strongly on the grounds that such biofuel volumes may lead to more land-grabbing, food price volatility, deforestation, biodiversity destruction, agrochemical use, pollution of freshwater and limited climate impact, culminating in the suspicion that the sustainability criteria and their enforcement mechanism were too weak to prevent the use of palm oil (Biofuelwatch, 2018).

Despite the opposition, some tangible government policy support for SAF producers exists. CORSIA enables ICAO member states to generate GHG reduction units for off-set schemes from the use of SAF. In Europe, the RED II includes a 1.2 multiplier for biofuels use in aviation and demands competition with the road transport sector. The RFS2 supports aviation biofuels on an "opt-in" basis by granting producers RIN credits, despite the aviation sector not being obligated to do so. Furthermore, California is expected to amend the LCFS to include SAF as opt-in fuels by 2019, whereby the incentive value under the LCFS could be combined with the RIN credits for US producers (Pavlenko and Kharina, 2018).

The need to decarbonise aviation presents growing opportunities for biofuel producers to bring new blends to market

Only drop-in biofuels (or advanced low-carbon liquid fuels) capable of being blended with standard jet fuel (according to American Society for Testing and Materials [ASTM] D7566) and maintaining the standardised quality for aviation are currently a feasible decarbonisation option for existing aircraft. However, CORSIA has resulted in 21 initiatives for increasing SAF usage, with five airports distributing regularly blended fuels and over 150 000 commercial flights flown using them so far (ICAO, 2018c).

More importantly, however, the supply of biofuels for aviation has increased due to new conversion processes being approved as annexes to ASTM D7566 (five processes allowing 10–50% blending), proposed by AltAir Fuels, Amyris, Byogy, Dynamic Fuels, EERC, Gevo, Honeywell UOP, Fulcrum Bioenergy, Kaidi, LanzaTech, Neste, Red Rock Biofuels, Sasol, Shell, SG Preston, Swedish Biofuels, Syntroleum and Total. The approval process, including aircraft and engine Original Equipment Manufacturer (OEM) testing, is costly and can take two years to complete (ICAO, 2018c).

A further five pathways are pending approval, involving Applied Research Associates, Blue Sun Energy, BP, Boeing, Chevron, Chevron Lummus Global and Phillips 66. These processes include HEFA diesel, alcohol-to-jet using ethanol and butanol (pending), and isobutanol and co-processing of bio-oil with conventional middle distillates in existing refineries, which would open a new market for pyrolysis oil (approved).

The deployment of new blends in aviation has just begun but is already expanding opportunities for advanced biofuel producers to sell their products. Some airlines have shown a commitment to sustainable fuels, as manifested by 15 announced off-take agreements with biofuel producers, spanning mostly from three to ten years, with production estimated to range from 0.8 to 1.1 billion litres annually (ICAO, 2018c). Further deployment is necessary for a higher economy of scale and cost reductions. The aviation sector thus offers strong potential for growth to producers of drop-in biofuels but is not accessible to the entire biofuel industry.

Role of co-products

The survey statements concerning the role of co-products are "sales of biofuel by-products and co-products is a necessary part of our business case" and "rising demand for high-value-added bio-based materials diverts investment from advanced biofuels".

The biofuels business is often integrated with the production and sales of other bio-based materials, chemicals and polymers, as well as heat and power. The feasibility of a traditional biorefinery is based on the production of biofuels in large volumes for mandated transport fuel markets, along with low-value side-products (*e.g.,* animal feed), on-site energy generation (heat, power) and selected high-value co-products enhancing overall economic performance. The questionnaire's results indicate that these co-products may represent an increasingly important part of most non-HEFA producers' businesses, but the perceived importance of these products is highly dependent on the respondent's conversion pathway and associated feedstock.

Corn-based ethanol production, for example, enables the supply of distillers grains for animal feed, corn oil as biodiesel feedstock, and carbon dioxide. Global increase in biodiesel (FAME) production has brought large volumes of by-product glycerine, used as a food sweetener or pharmaceutical humectant, to the market. Lignocellulosic feedstocks of 2G biofuels have diverse co-products, including cellulose, hemicellulose and lignin, all of which have unique downstream products and end-uses, enabling high raw material efficiency and zero waste, provided the products are in demand and competitive in their respective markets.

The combination of feedstocks, platforms and processes currently available would allow for the use of biomass to produce almost all petroleum products in biofuel refineries. In the petroleum industry, around half of refinery profits come from the refinement of chemicals from roughly 15% of the feedstock (Biddy, Scarlata and Kinchin, 2016). As the biofuel market expands, co-products are anticipated to contribute similarly to the biofuel industry's financial performance. In 2017, the co-product (distillers' grains, corn oil) contribution to US bioethanol refinery revenues was estimated at USD 6.7 billion (21%), when ethanol sales were USD 24.3 billion (RFA, 2018b). This can serve to help reduce the price of the accompanying biofuel. A recent study has estimated that co-production of bio-based chemicals and materials can result in about a 30% reduction of the minimum selling price of 2G biofuels such as bioethanol and biodiesel (Wageningen University & Research, 2018).

Following this path, the 2G industry is increasingly tapping into the biochemicals market, with many producers having diversified and intensified development, production and marketing of co-products. Some first-wave companies producing advanced biofuels in the early 2010s, which lacked financial feasibility with solely transport fuels or found them to be too risky, managed to continue by refocusing on other bio-economy products. We are seeing a global trend toward the expansion of biorefineries to produce food and feed ingredients, chemicals and materials, and bioenergy (electricity, heat, fuels) from sustainable resources.

Even with a high level of integration in biorefinery co-processing, however, the cost of some bio-based products remains higher than that of their fossil-based counterparts, depending on oil and gas prices. Diversity of production and value-added co-products are therefore highly beneficial. In a fully optimised refinery, fractions of feedstock, intermediate products (*e.g.,* C5/C6 sugars derived from cellulose/hemicellulose) and final energy products (*e.g.,* ethanol, pyrolysis oil) represent a starting point for further refining into speciality chemicals, polymers or high-value drop-in fuels. A highly integrated biorefinery may even result in biofuels representing a minority in the aggregate of revenue streams (*e.g.,* if a large share of the cellulose fraction is used as fibre for paper, board or textiles instead of being converted wholly to C6 sugars, or if a large share of C6 sugars is converted to bio-polymers, plastics and chemicals instead of fuels).

In the current social climate, plastics face increasing scrutiny, localised production and supply of materials and goods are becoming increasingly preferred over globally traded equivalents, and consumers are expressing a desire to shift to biodegradable products. Politicians, businesses and consumers are thus increasingly searching for renewable substitutes for fossil fuels in the face of climate change and the limited long-term availability of oil and gas. This opens a variety of opportunities for biofuel producers to increase, or stabilise, financial performance through value-added co-products related to their feedstock and conversion pathway.

Biogas

The survey statement concerning biogas is "biogas is one of the best options for decarbonising road transport".

Biogas and biomethane from medium- and large-scale facilities can be used to replace and decarbonise some natural gas consumption. They have a wide variety of end-uses including heat and power generation, injection into the natural gas grid, and transportation that are largely determined by local conditions, including the types and locations of production facilities, and presence of a natural gas grid, gas filling stations and Natural Gas Vehicles (NGVs). In this context, use as a transport fuel represents a relatively small share among the many feasible end-uses of biogas.

3.5 ENVIRONMENTAL AND SOCIAL CONCERNS

Sustainability criteria

The survey statements concerning sustainability criteria are as follows.

- There is too much confusion about how lifecycle GHG emissions, land use change and indirect land use change are estimated.
- Harmonisation of certification schemes would make it much easier to get advanced biofuels to the market.
- Methods used for estimating land use change impacts of various biofuels are accurate and reliable.
- Sustainability standards and certification schemes have boosted markets for advanced biofuels.
- Investments are hampered by worries that sustainability criteria may become more stringent.

The sustainability criteria of biofuels linked to fuel approvals in mandated markets play a key role in European and US legislation, extending beyond direct GHG reduction to include how the risks of LUC, ILUC and reduced biodiversity are managed along the biofuel value chain. In Brazil, the carbon intensity of a biofuel will be the main determinant for its value in the future market, and therefore a national biofuel certification scheme is also being developed for the upcoming RenovaBio programme (for 2020 onwards). Elsewhere in the world, sustainability criteria has played a lesser role in regulation, which does not mean that sustainability is not considered. In China and India, for example, the government has pre-established specific types of feedstock eligible for government-supported biofuel production.

In Europe, sustainability criteria include GHG emission reduction, protection of land with high carbon stocks, and protection of biodiversity in forests, grasslands, peatlands and wetlands. The methodology for calculating the GHG impact of biofuels, bioliquids and their fossil fuel comparators is presented in RED (2009/28/EC) Annex V.

The ILUC directive (2015/1513) sets a cap on food and feed-based biofuels in the target setting, and introduces biofuels and bioliquids in different feedstock categories, depending on their ILUC impact. Annex IX gives provisionally estimated ILUC emissions from 1G biofuels and lists those feedstocks for which the ILUC emissions are set at zero, and advanced feedstock and fuels, mainly waste-based, which can be double-counted against renewable energy targets.

The EU also requires Member States to respect the Principles for Responsible Investment in Agriculture & Food Systems, approved by the FAO Committee on

World Food Security (CFS) (2014), and encourages implementation of Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries & Forests in the Context of National Food Security, adopted by CFS in 2013 (European Union, 2015). Compliance with these criteria is followed up by certification bodies operating under Member States' national verification or voluntary schemes, each with differing focuses, rules and standards. Some schemes focus on particular crops or parts of the value chain, whereas the most popular ones, such as the International Sustainability and Carbon Certification (ISCC), have broad coverage of biofuels and bioliquids.

The number of approved schemes dropped from 67 to 19 between 2009 and 2016 (Stattman, *et al.*, 2018). Schemes are obligated to report to the Commission on their activities, and the Commission approvals are valid for five years. Schemes are broadly categorised as roundtable/multi-stakeholder initiatives (*e.g.,* Roundtable on Sustainable Biofuels (RSB), Roundtable on Sustainable Palm Oil (RSPO), Roundtable on Sustainable Soy (RTRS)), those established by industries (*e.g.,* Bonsucro for global sugar cane industry), and government-supported schemes (*e.g.,* ISCC, supported indirectly by the German government). RED sustainability criteria have been criticised by many stakeholders (Erixon, 2013). Some NGOs believe the regulation is too lax and encourages industries to apply only minimum compliant sustainability performance.

Harmonised certification schemes are needed, along with consistent assessment methods for emissions and land-use impact

NGO involvement in certification is associated with more rigorous definitions but it is declining (Stattman *et al.*, 2018; Kemper and Partzsch, 2018). Others in the industry lobby claim the methodologies used to calculate the emission savings are arbitrary and applied unevenly in Europe.

Administrators of the RFS and the LCFS, the EPA and the California Air Resource Board (CARB), respectively, conduct sustainability analyses of all feedstocks and fuel conversion pathways for fuel standards. The EPA's analysis determines whether fuel pathways meet GHG reduction thresholds required by the Clean Air Act (CAA), while in California, analysis results in fuel- and pathway-specific carbon intensity factors. The EPA encourages voluntary Quality Assurance Plans (QAPs), where independent third parties audit and verify the compliance of RINs.

In general, the RFS is based on a "buyer beware" liability and compliance approach, in which regulated parties are expected to conduct their own due diligence to confirm that purchased RINs are valid and compliant (EPA, 2018a). Lifecycle assessment (LCA) – or "well-to-wheel" analysis – is used to assess the overall GHG emissions of a fuel, including each stage of its production and use. The EPA's LCA pays substantial attention to indirect emissions of fuel pathways (*e.g.,* pressure on water resources, air and water pollution, increased food costs, ILUC emissions), as required by the CAA (EPA, 2018b).

ILUC emissions have become an integral part of the sustainability assessment in Europe and North America. Application of the concept in regulation is special in the sense that it creates economic consequences for a fuel producer based on actions of unrelated producers (of feedstock, feed or food) elsewhere in the world. While this would be unusual in other economic sectors (it could theoretically be applied, say, in the food industry or forest sectors too), ILUC is essential due to the global nature of climate change mitigation.

The GHG reduction credentials of biofuels would not be complete without land-use impacts, which extend beyond sites of production and national borders. The global climate policy context is the major driver of mandate schemes, other subsidies and public support to biofuels. Therefore, ILUC impacts require distinct consideration.

A vast stock of peer-reviewed articles, dissertations and other scientific literature focusing on various aspects of ILUC associated with biofuels production, consumption and related policies exists. Because ILUC effects are often difficult to observe or measure directly, they are simulated using a combination of macro-economic and environmental models. Highly discrepant simulations (sometimes varying from negative to positive) arise due to the varying assumptions for key parameters between models (*e.g.,* treatment of co-products, yield developments, sub- and top-soil carbon stocks, displacement of other commodities).

The EC, EPA and CARB have all developed and refined their models, attempting to reduce uncertainties for more accurate ILUC estimations. Sensitivity (Monte Carlo) analysis is conducted on results based on a random variation of key parameters.

Models used include: the International Institute for Applied Systems Analysis' global model for assessing competition for land use between agriculture, bioenergy and forestry (GLOBIOM), used by the EC; the GREET model, developed by Argonne National Lab to estimate carbon intensities (used by California); and a combination of two partial equilibrium models, the Food & Agricultural Policy Research Institute (FAPRI) model and the Forestry & Agricultural Sector Optimization Model (FASOM), used by the EPA (Pavlenko and Searle, 2018). Estimation of ILUC emissions relies on the Global Trade Analysis Project (GTAP) model, developed and supported by researchers at Purdue University (CARB, 2019).

An example of the evolution in the ILUC emissions estimation process is the 2018 EPA ruling on the GHG emission savings of the Grain Sorghum Oil Pathway (ICCT, 2018; EPA, 2018c).

The new ruling considers the indirect GHG emissions caused by the additional production of corn or vegetable oils needed to replace the use of sorghum waste for biodiesel, which waste could potentially also be used as feed for livestock. The ruling represents an example of a fair shift to a more stringent requirement in sustainability criteria, which could, however, potentially materialise into a risk for biodiesel producers counting on the Grain Sorghum Oil Pathway.

Sustainability debate and the NGOs

The survey statements concerning sustainability debate and the NGOs are as follows.

- Food-vs.-fuel debate continues to push advanced biofuels business forward.
- Environmental advocacy groups have helped advance second generation biofuels.
- Advanced biofuels production leads to land grabbing and monoculture by large agricultural companies.

Environmental NGOs have played an important role in raising and maintaining discussion on the sustainability credentials of various biofuels, and in the creation of legislation that considers ILUC emissions among other sustainability standards. While the food-vs.-fuel discussion was sparked by a debate in scientific fora, it was quickly popularised through environmental NGO campaigning, particularly between 2007 and 2009, thematically focusing on rainforest destruction, biodiversity loss and risk of exacerbated poverty through increased food prices.

These arguments joined together in the discussion of the use of palm oil for fuel production, and this issue has been a steadfast target of NGOs' activity since then. However, campaigning slogans do not always differentiate among various kinds of biofuels. The specifics of feedstocks, fuels and co-produced biomaterials are not always considered in the sustainability debate, which is one driver towards negative public perception on biofuels in general and has a potentially detrimental impact on advanced biofuel producers.

Environmental NGOs have differing positions on advanced biofuels. While almost all categorically oppose 1G biofuels, positions on advanced fuels vary. Greenpeace, for example, allots a role for biofuels from woody feedstock, waste or algae that is not produced on existing agricultural land (Greenpeace, 2008). However, the role of biofuels is generally decreasing in NGO strategies due to emerging EVs (Greenpeace, 2015).

European Transport & Environment – representing many European environmental transport sector NGOs – used to perceive the role advanced biofuels can play in transport sector decarbonisation positively. In a debate prior to the ILUC Directive, it demanded placement of a cap on the contribution that "land-based" biofuels can make towards the renewable energy target in transport; inclusion of accounting for ILUC in legislation; and allocation of appropriate support for advanced biofuels while securing their sustainability – which all became elements of the final ILUC Directive, including support to advanced biofuels through double-counting.

Except for the cap for 1G biofuels, which was set at 7% instead of the advocated 5%, all its policy goals were achieved (Dahlman, 2017). Nonetheless, the NGO's recent statements reveal that there is no longer room for advanced biofuels in their strategy, not even in the aviation sector (Transport & Environment, 2018a and 2018d). Instead, decarbonisation is sought almost exclusively through electricity, hydrogen and electro-fuels.

NGOs have also proved sceptical about the position of energy crops amongst advanced biofuels feedstocks, despite fuel pathway approvals being part of biofuel regulation and LCA modelling on GHG savings having become more sophisticated and nuanced. Energy crops have substantial potential when grown sustainably on degraded or set-aside land, or under agroforestry. However, NGOs allege that they are associated with human rights abuses, including mass land clearances in developing countries (*e.g.,* Kenya, Guatemala), and land-grabbing for large companies to plant fuel crops (An Taisce, 2013a and 2013b).

The rapid growth of interest in energy crops (*e.g.,* jatropha, miscanthus, switchgrass) in the early 2010s and its almost equally rapid decline soon thereafter was possibly due to poor publicity, which resulted in economic losses and frustration in places where biofuel developers had started to grow feedstock but withdrew and did not finally purchase the yields from the local partners (*e.g.,* Africa). Interest in energy crop cultivation has somewhat faded in major biofuel markets, but may arise again, especially driven by the aviation sector demand and developing countries considering biofuels as part of their own decarbonisation efforts.

Public perceptions

The survey statements concerning public perceptions are as follows.

- The difference between conventional and advanced biofuels is understood by the public, politicians and media.
- The public and the media do not understand the potential synergies between food and non-food portions of crops.
- Advanced biofuels are viewed positively by the public.

Public perceptions have particular value for biofuel markets, because they are instituted through political processes and are therefore exposed to the influence of a complex set of social and political forces, including political parties, economic interest groups, the scientific community, civil society, NGOs, media and citizens. Citizens' perceptions about the favourability of biofuels are an important precursor influencing decision makers and form the basis of consumer acceptance for various biofuel products. The biofuels debate – which peaked in 2008 and was particularly strong in Europe – has focused mainly on the assessment of the sustainability credentials of 1G biofuels, considering not only GHG emission savings, but also their impact on food security in developing countries, preservation of biodiversity, land-use rights, human rights, land-grabbing and deforestation, amongst other issues, primarily through LUC and ILUC.

The initial scientific debate sparked various environmental groups to target lobbying to turn the public, media and politicians against biofuels policies supporting 1G biofuels production and use of palm oil for fuels. Promoting the deployment of 2G biofuels with low or non-existent ILUC impacts comes in as a societal response to sustainability concerns regarding 1G biofuels.

The development of the 2G market is, however, somewhat linked to 1G markets, since end-products (ethanol, butanol, biodiesel, HVO, drop-in fuels) and market players across the value chain (farming sector feedstock suppliers to the pump) are the same. Bolt-on refineries allow for production of 1G and 2G biofuels on the same sites, enabling much of the feedstock supply and end-product delivery chain to be jointly managed, and benefiting from the sharing of some process units and greater economy of scale. 1G producers are therefore logical candidates as developers of 2G biofuels production. Negative opinions and publicity covering 1G biofuels can potentially also harm the advanced biofuel sector, since differences between conventional and advanced biofuels are not typically understood by the public, politicians and media.

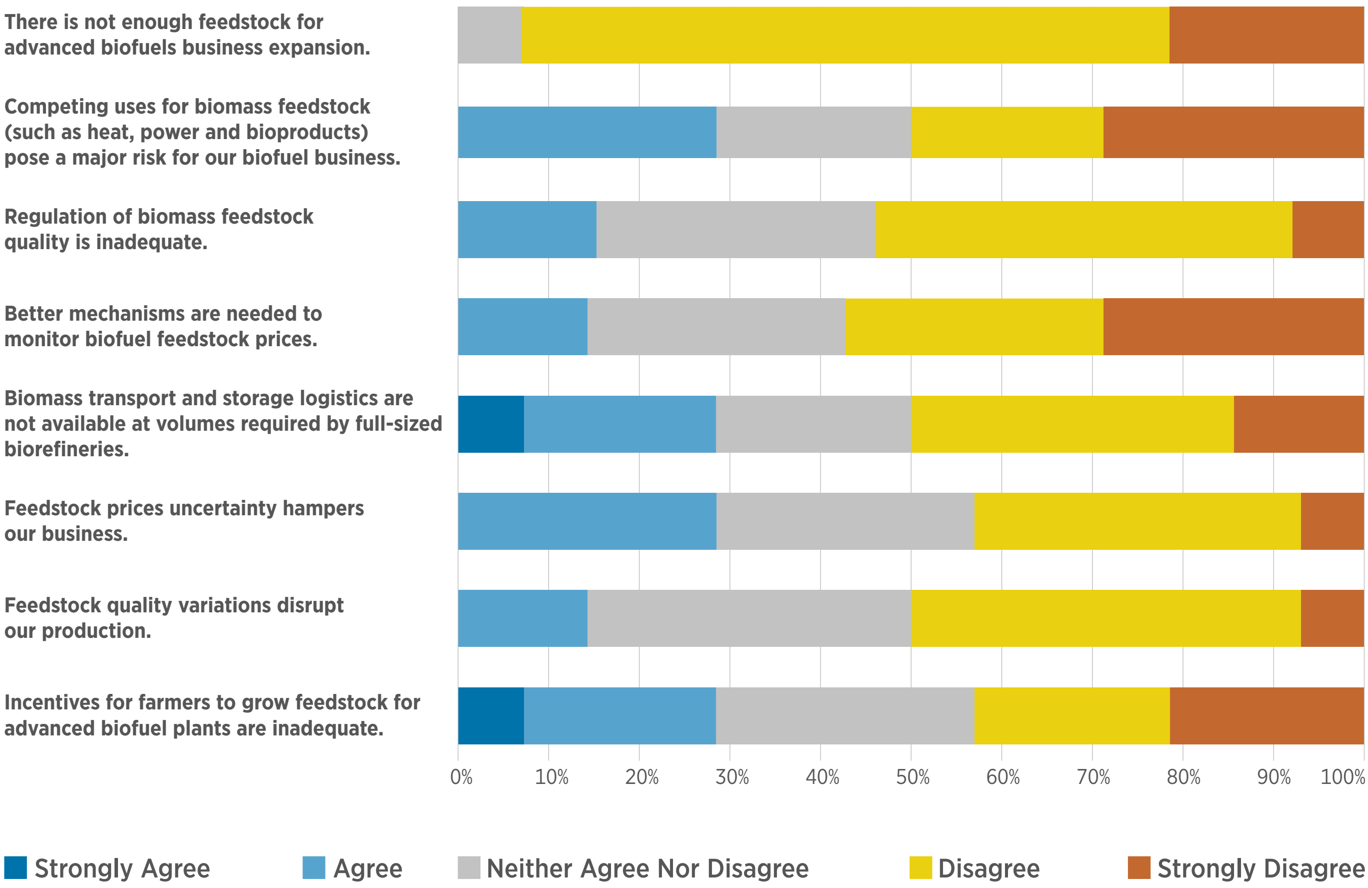
Literature on public opinions of biofuels and their policies clearly shows that the level of knowledge about biofuels in diverse global markets is low and that there is a fair amount of ambivalence (Wegener *et al.*, 2014; Jäger *et al.*, 2017; Moula, Nyári and Bartel, 2017; Balogh *et al.*, 2015; Van de Velde *et al.*, 2009; Zhang *et al.*, 2011; Savvanidou, Zervas and Tsagarakis, 2010). However, this ambivalence diminishes as a result of gained knowledge (Delshad *et al.*, 2010). Furthermore, despite limited evidence in support, public perceptions of biofuels appear, based on several surveys, to be overwhelmingly positive (IBB Netzwerk, 2017; Cropenergies, 2017).

The distinction between 1G and 2G fuels has become more notable recently (IBB Netzwerk, 2017; Jäger *et al.*, 2017). However, attitudes are also susceptible to change upon exposure to anti-biofuel information (Dragojlovic and Einsiedel, 2015). Continuous use of palm oil for biodiesel has been the most persistent topic in the biofuels debate. In an Ipsos poll surveying EU citizens across nine Member States, only 18% were aware of the existence of palm oil in diesel blends, and 69% supported a palm oil ban, while only 14% opposed it (Transport & Environment, 2018c).

4. SURVEY RESULTS

4.1 FEEDSTOCK

Figure 5. Questionnaire responses to statements concerning feedstock



Responses to statements concerning **feedstock** are illustrated in Figure 5 and interpreted in this section.

The responses clearly indicate that overall the business operators do not see the feedstock issues, *i.e.,* availability (quantity), quality and price, and their variation, as major impediments to advanced biofuels expansion. Those expressing concerns in this area represented nil to less than 30% of responses. Generally, feedstock issues appear more crucial for producers of lignocellulosic ethanol than representatives of other technology pathways. Even though the cost is lower for lignocellulosic producers, their projects are often based on very local sourcing and a limited number of feedstock suppliers, which makes the project subject to some risks.

Respondents overwhelmingly deny that feedstock availability limits the expansion of advanced biofuels businesses. The fact that the total output of the industry is still relatively small and all respondents represent firstcomers to the industry may be one factor behind this opinion. As firstcomers they have had the strategy of occupying the most favourable space in the value chain including in terms of feedstock sourcing.

Some of the interviews reveal that feedstock supply issues are important concerns particularly for HVO/HEFA producers, who may face long-term availability issues if the business expands substantially in global scale. Chapter 5 shows that despite the ratings listed here, some respondents rank feedstock availability and price among the three most important barriers.

Half respond that their businesses' production is not disrupted by feedstock quality variation, though one who uses UCO for biodiesel and another cellulosic ethanol producer had faced challenges with variable quality.

Business operators do not see feedstock availability, quality or price variations as major impediments to the scale-up of advanced biofuels

Most respondents do not consider competing uses of biomass feedstock (*e.g.,* heating, power or bioproducts) to be a major risk to their business. Some feedstock, such as MSW, is clearly "captive" and even paid for through gate fees.

With regard to oils and fats, HVO producers often have a global or regional supply of traded feedstock which provides a buffer against many feedstock-related risks. Possible competing uses for traded commodities reflect the price of feedstock rather than availability. Those with most concerns about competing uses are advanced ethanol producers, whose feedstock, such as wood residues, typically has potential for heating and power generation close to the place where the feedstock is collected. Regarding the growth in the circular economy and bioeconomic concepts, which are increasingly receiving political support and may receive economic incentives and R&D funding in future, competition for bio-based materials may increase in the future. Some biochemicals may draw resources from biofuels. However, in most cases a broadening of biorefineries' product offering is considered positive for the overall business.

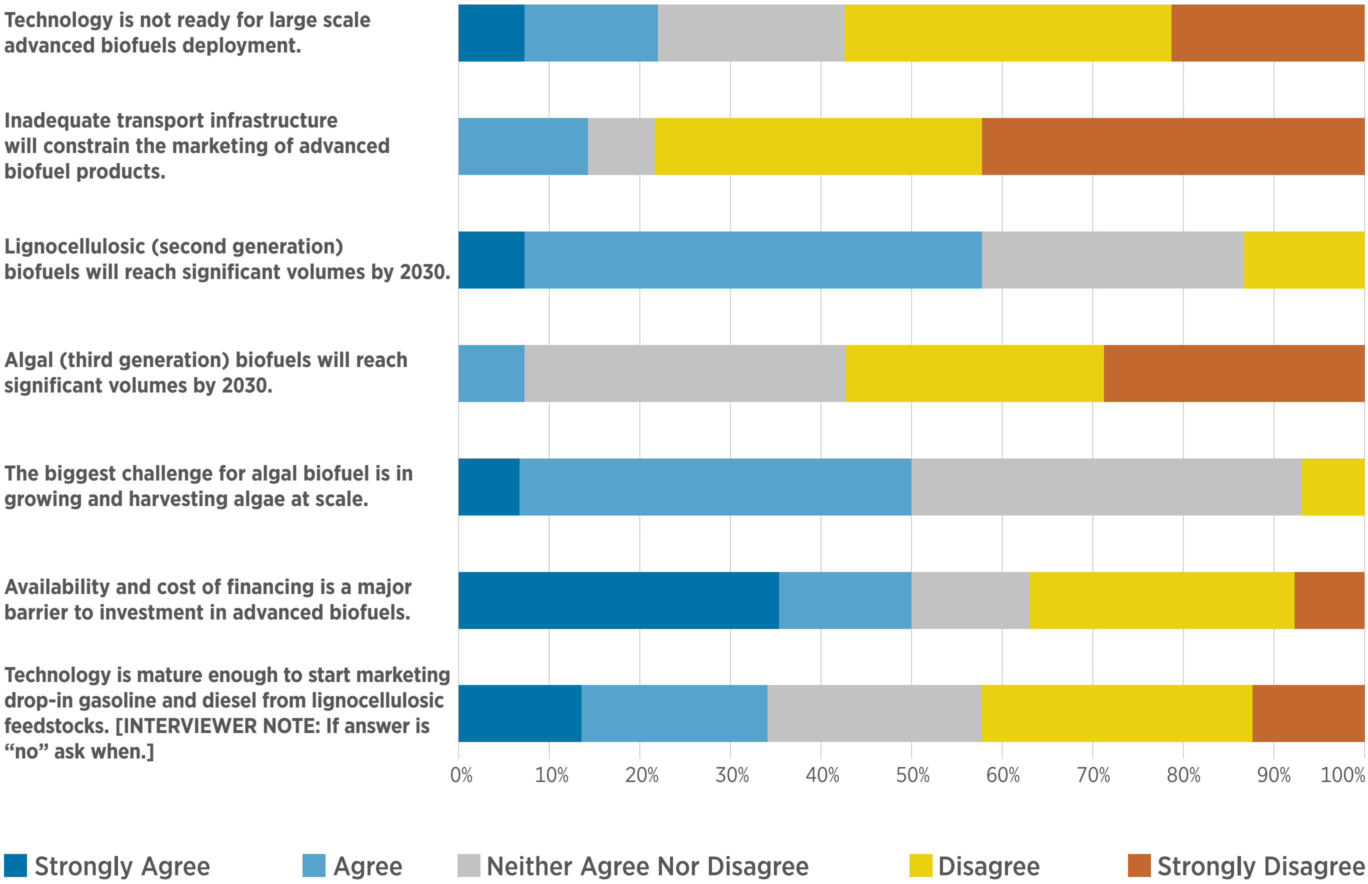
A small majority believe that biomass transport and storage logistics volumes sufficiently serve full-sized biorefineries.

Opinion amongst respondents is divided over whether feedstock pricing uncertainty hampers business. This suggests that pricing is a manageable risk that advanced biofuels businesses have come to accept and learned to mitigate, for example through incorporating multiple sources of biomass into the supply chains. Institutions (exchanges, consultants, auditors, etc.) have developed around some feedstock, especially those traded internationally, whereas some feedstocks are highly local by nature and managed through tailored supply contracts with local industries, cities (MSW) and farmers.

Questionnaire respondents are split in their opinions regarding the adequacy of farmers' incentives for growing feedstock for advanced biofuel plants. This is likely due to the fact that most respondents do not source their feedstock directly from farmers or their co-operatives.

4.2 TECHNOLOGY AND FINANCING

Figure 6. Questionnaire responses to statements concerning technology and financing



Responses to statements concerning **technology and financing** are illustrated in Figure 6 and interpreted in this section.

In response to a very broad set of statements about technology readiness, over half of respondents say they consider advanced biofuels technologies ready for large-scale deployment. A 20% minority do not see technology ready for large-scale deployment. There is no common factor to be identified between those agreeing and disagreeing.

Narrowing the results down to lignocellulosic technologies, over half of respondents believe that lignocellulosic 2G biofuels will reach significant volumes by 2030. Some respondents, however, underlined in the interviews that their projects are effectively first-of-kind, and entail some technology risk manifested in extended installation periods and process instability. Given the overall small number of projects globally, problems are encountered and can be attributed to limited engineering and operational experience (including with enzymes and catalysts) and immature supply chains for contractors' services and equipment supply. There is no global industrial ecosystem yet in support of advanced biofuel investments.

Most respondents do not agree, or do not express an opinion on, the matter of whether algal biofuels (3G) will reach significant volumes by 2030. A similar proportion consider the growth and harvesting of algae on a large scale to be the greatest challenge to their widespread adoption.

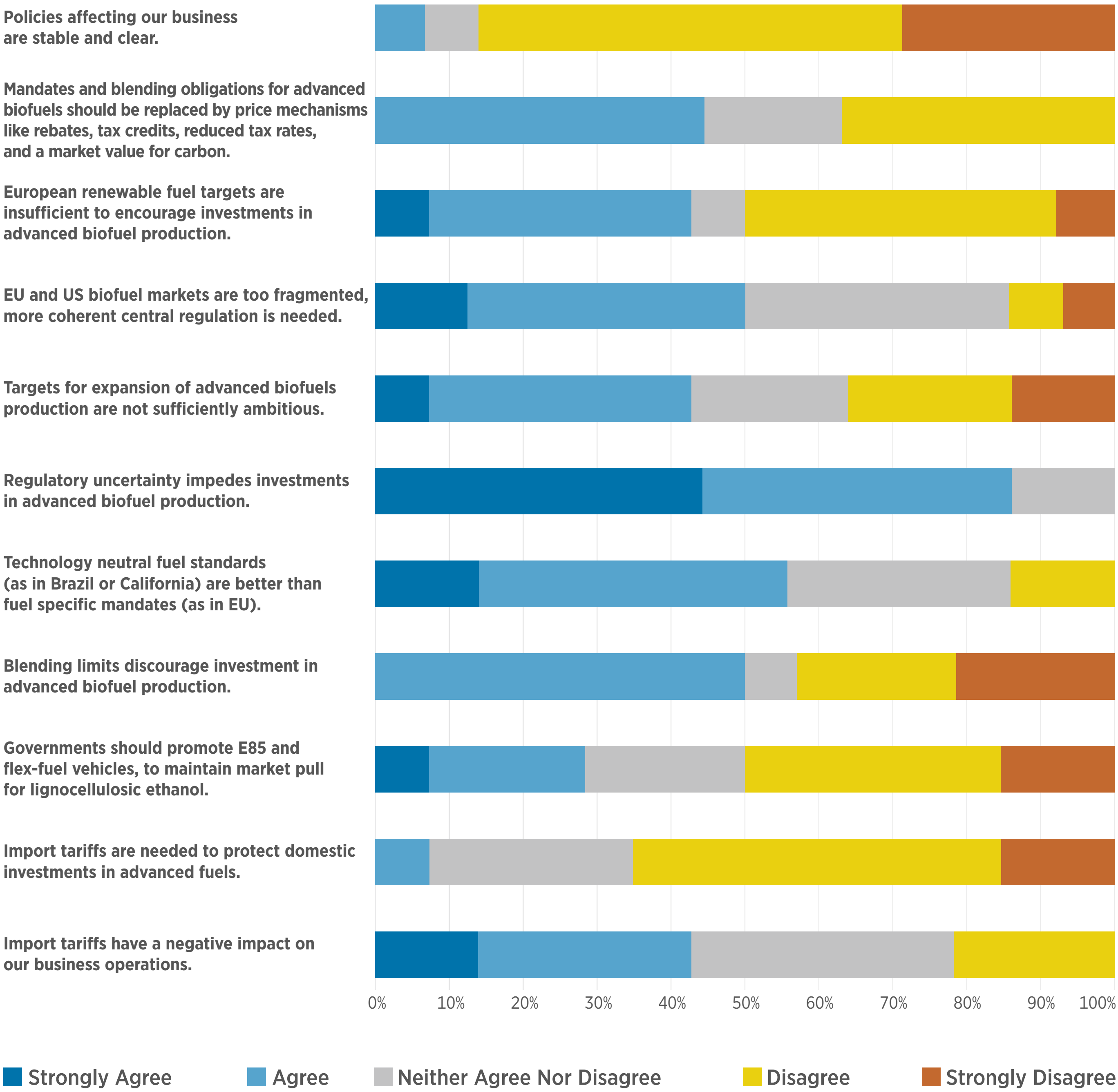
Even though technology pathways from lignocellulosic feedstock to drop-in fuels are evolving rapidly, this industry sub-segment has not yet reached full commercial maturity. Close to half have doubts about technology readiness which would enable marketing drop-in gasoline and diesel from lignocellulosic feedstocks, whereas one-third believe that that technology is ready. The background of the respondents can be seen in their responses: those who are already in the business of producing drop-in fuels from lignocellulosic feedstock are also more positive about their prospects than others.

A clear majority disagrees with the statement that inadequate transport infrastructure will constrain the marketing of advanced biofuels products, indicating that issues reported on this front are not commonly shared but are rather local and/or fuel specific.

Opinion is more divided over whether the availability and cost of financing is a major barrier to investment in advanced biofuels. Amongst respondents, a majority considers financing a crucial issue to the advanced biofuels industry. Raising capital for business occupies a good deal of management resources in innovation-based start-ups. However, some project developers among the respondents represent large companies that are strategically positioned to benefit from diversification into advanced biofuels and are able to use equity and corporate loans to finance investment.

4.3 MANDATES AND TARGETS

Figure 7. Questionnaire responses to statements concerning mandates and targets



Responses to the statement concerning **mandates and targets** are illustrated in Figure 7 and interpreted in this section. The set of opinion statements includes three statements about stability and fragmentation of advanced biofuel policies and regulation, four statements exploring opinions about the preferred types of policy measures, two statements on whether the regulation reflects ambition level high enough, and two statements about import tariffs.

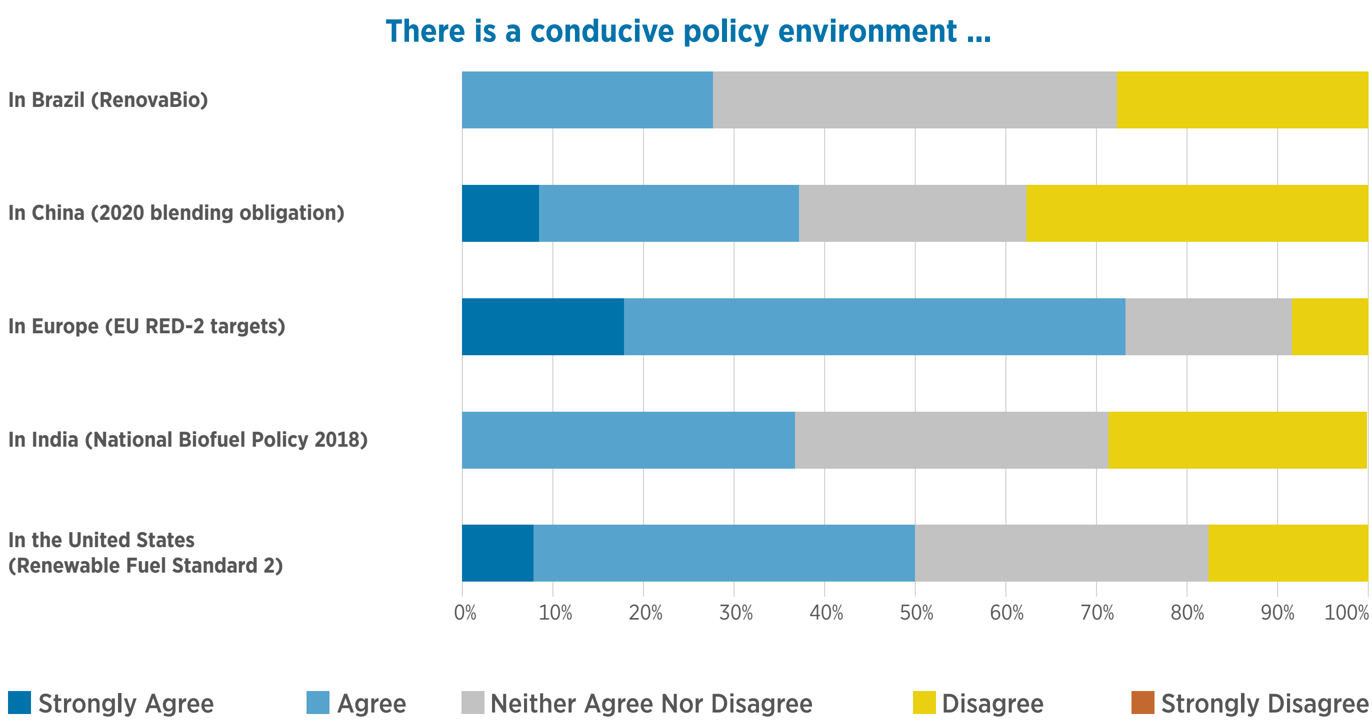
Opinions on the stability or lack of stability of advanced biofuel policies, and associated risks and barriers, were tested through a twin-statement, one positive and one negative. Both resulted in a very clear messages – given by about 85% of respondents – that regulatory uncertainty impedes investments. This is consistent with other surveys and literature analysis. The policy uncertainty therefore stands out as the most prominent barrier to investments.

Half think that the EU and the US biofuel markets are too fragmented, and that more coherent central regulation is needed, although a further 36% are unsure. The fragmentation of targets and promotional mechanisms is particularly notable in Europe, where EU Member States have highly varying ambition levels for liquid biofuels and policy measures for their deployment. The US is overall more uniform although some state-level fuel standards are in place. Fragmentation is manifested also by the main markets applying differing sustainability criteria for fuels and systems for their certification.

Only a small majority (43%) of respondents sees the targets for expansion of the sector as insufficient, with 36% of respondents disagreeing, indicating that the impediments in policy areas are not primarily related to target levels but more to how policies are enacted and implemented.

The perceived policy uncertainty is clear but may be a matter of the past. There is therefore a set of questions asking respondents' opinions about whether the current or upcoming policy environments are favourable for their business. The results are shown in Figure 8.

Figure 8. Questionnaire responses to statements concerning regulatory environment in different markets



In contrast to the consistent belief that policies have been unstable and lack clarity, the opinions of respondents are divided. Many neither agree nor disagree about how conducive policies are today and in the near future. The most striking result is for Europe, as an overwhelming majority has a positive view of RED II as creating a conducive market for advanced biofuels. A total of 50% see the US markets favourably. For Brazil, China and India, opinions are roughly equally split, but many respondents also do not actively trade in these markets.

Because criticism of policy uncertainty/lack of clarity and simultaneously positive views of current policy environments are in clear contrast, responses must be influenced by the time referred to in the statements. The referred US RFS is in force, as are the Indian and Chinese policies and biofuel targets, whereas RED II and RenovaBio are still on paper and scheduled to come into effect in 2021 and 2020, respectively.

Positive feedback by nearly 75% of respondents on the European policy environment under RED II can be seen as resulting from the long-sought agreement of June 2018, which established clear numeric targets for biofuels for the ten-year period 2021–2030. The RED II decision includes continuation of double-counting and a mandatory share for advanced biofuels, which is obviously regarded as sufficient by the industry representatives.

Policy uncertainty is undoubtedly a barrier that will delay the overall deployment of advanced biofuels. It may, however, not necessarily be a prohibitive barrier for an individual company. All the companies that responded to the survey had made a major investment in advanced biofuels under prevailing circumstances during the past ten years. There are also companies that, after careful consideration, decided not to invest in advanced biofuels.

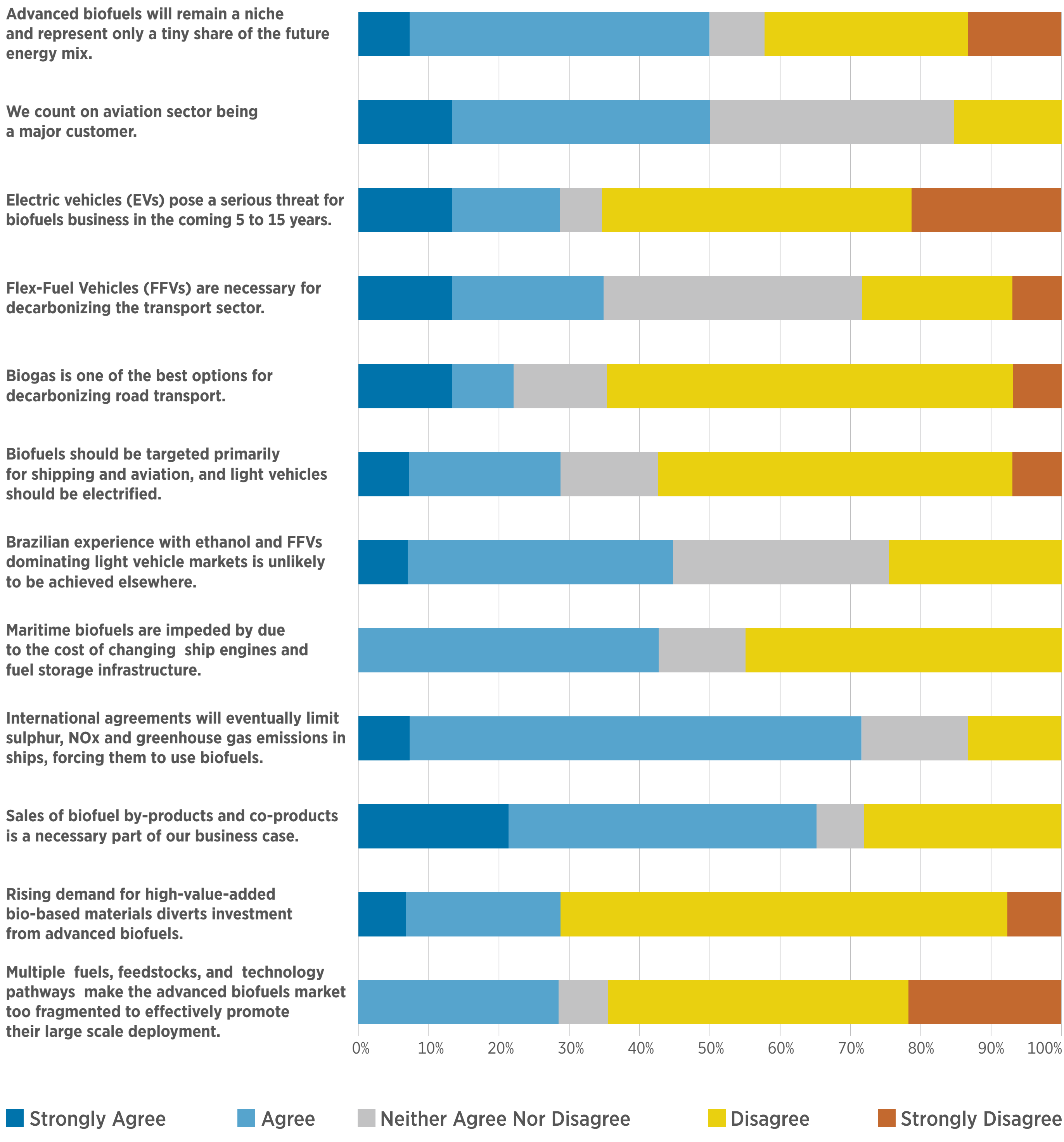
Investments can still prove viable for an individual actor operating under policy uncertainties who has taken risks into consideration. Policy risks can be effectively mitigated if a refinery a) operates serving a well-defined country market with a stable policy or LCFS; b) operates on a global scale and has a well-established supply chain for feedstock that fulfils strict sustainability criteria; or c) has a scale that enables product sales to many alternative markets.

Opinions and preferences are mostly split on the various types of policy measures, depending mainly on the respondent's main technology pathway. Almost half say that mandates and blending obligations for advanced biofuels should be replaced by price mechanisms, such as rebates, tax credits and reduced tax rates, or by a market value for carbon, with just under 40% disagreeing. Here, for example, all those representing less mature technology pathways prefer tax incentives. About one-third think that governments should promote E85 and FFVs to maintain market pull for lignocellulosic ethanol, with around one-third disagreeing. About half think the blending limits discourage investments. In the latter two questions, all representatives of advanced ethanol production agree with deployment of E85 and FFVs and oppose low blending limits.

Technology-neutral fuel standards are preferred by most over fuel-specific standards, which are supported by only a few. A majority answers that import tariffs are not needed to protect domestic investment in advanced biofuels, with only a few believing they would be needed. About 40% acknowledge that such tariffs have a negative impact on their business operations.

4.4 TRENDS IN BIOFUEL DEMAND

Figure 9. Questionnaire responses to statements concerning trends in biofuel demand



Responses to the statement concerning **trends in biofuel demand** are illustrated in Figure 9 and interpreted in this section.

The future of advanced liquid biofuels is often presented as being in a competitive situation with other low-carbon solutions for road transport. The set of statements in this section explores how the project developers see the role of advanced biofuels in road transport vis-à-vis the entry of EVs and other transport sub-sectors such as shipping and aviation. The specific role of ethanol is also of interest assuming that ethanol production volumes will decline in the future, if it is used mainly in blended form with gasoline.

The first statement, however, tests broadly the overall role of advanced biofuels in the future energy mix. The surprising result is that half of respondents agree that "advanced biofuels will remain a niche market, representing only a 'tiny' share of the future energy mix". This may reflect pessimism due to the many barriers encountered in the day-to-day running of an advanced biofuel business, or it may simply reflect realism, with respondents seeing the energy market as a whole and biofuels supply as limited to advanced biofuels, excluding 1G. Advanced biofuels today have a share of less than 1% of total biofuels. Those not sure about this statement were few. Almost half of the other respondents disagreed with it.

The biofuel and EV industries are often assumed to be in direct competition, but the surveyed members of the biofuels industry see room for growth in both industries with the decarbonisation of the transport sector. This is indicated by over 60% of respondents who disagree with the statement that EVs represent a serious threat over the next 5 to 15 years and the nearly 60% who denied that biofuels should primarily target the shipping and aviation sectors, leaving light vehicles to electrification.

Advanced ethanol producers most consistently support E85 and FFVs, but their views are not shared by the industry as a whole. Some 35% of respondents see FFVs as a necessity for decarbonising the transport sector, and 23% see that the dominance of FFVs and ethanol in the light vehicle market, as seen in Brazil, could be repeated elsewhere.

Views on the future role of shipping in the biofuels market seem less clear. A total of 43% of respondents believe that the cost of changing ship engines and fuel storage infrastructure is significantly impeding the adoption of biofuels within the maritime market, while another 43% disagree. At the same time, 71% think that international agreements and environmental legislation targeting the sulphur and GHG emissions of ships will eventually force the adoption of biofuels in shipping.

Half of all respondents see the aviation sector as becoming a major customer in the future. The drop-in fuel producers, in particular, anticipate expansion in the aviation sector.

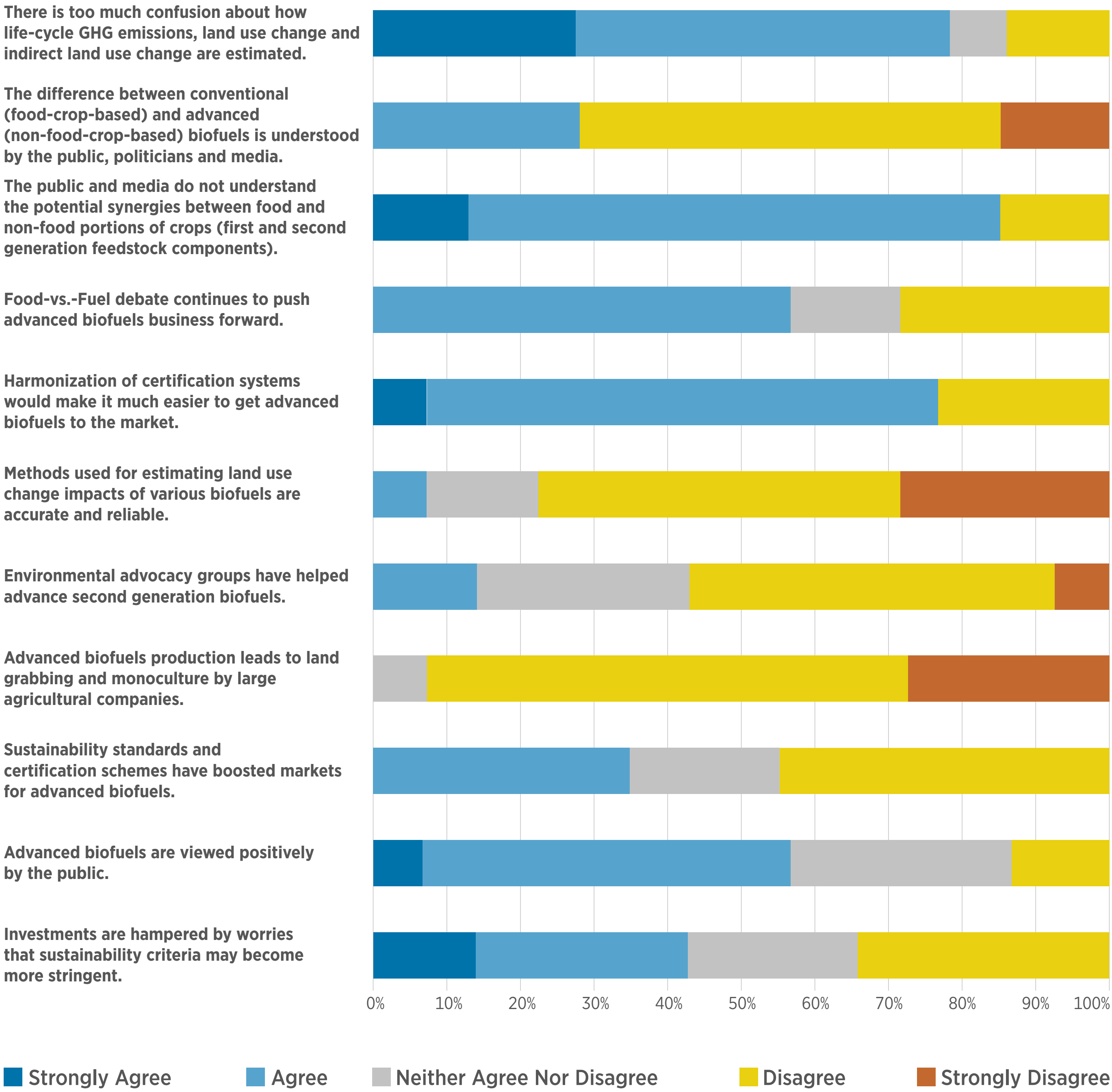
Co-production is seen in a positive light: 64% responded that the sale of by- and co-products is a necessary part of their business and 21% within it strongly agree with such statement. Over 70% do not feel that rising demand for high-value-added bio-based materials diverts investment from advanced biofuels.

According to the questionnaire responses, diversity in pathways, products and markets appears to be viewed largely positively in the biofuels industry. Although the biogas industry has been evolving and scaling up globally, respondents do not appear to consider it to be a significant part of the transport sector energy transition.

While the biofuel and EV industries are often viewed as competitors, the decarbonisation of the transport sector offers space for both to grow

4.5 ENVIRONMENTAL AND SOCIAL CONCERNS

Figure 10. Questionnaire responses on environmental and social concerns



Responses to statements concerning **environmental and social concerns** are illustrated in Figure 10 and interpreted in this section.

The survey statements in this section examine the project developers' views on the importance of sustainability criteria, the food-vs.-fuel debate, environmental NGOs, certification schemes, and public perceptions of advanced biofuels deployment. In this area, opinions are less divided than in the previous chapters, and the respondents' technology pathways and fuels reflect less in their opinions.

Almost 80% of respondents express that there is confusion over how lifecycle GHG emissions, and both direct and indirect land-use change, are estimated. The reliability and accuracy of LUC impact estimations were doubted by most. The distrust of respondents in estimations of GHG emission savings, LUC and ILUC emissions likely arises from the variability of different models, which in turn results from the high complexity of estimating combined global values through modelling.

The multitude of certification systems appears not to be in the interest of the industry, but nearly 80% of respondents support harmonisation. Although about 40% of respondents think that investments are hampered by potentially increased future stringency, the rest disagree or decline to answer, suggesting that the science around biofuel sustainability may be converging and consensus may be increasing, resulting in a more stable environment. Opinions are split over whether sustainability standards and certification schemes have helped to boost the market overall.

Almost 60% of respondents think the public perception on advanced biofuels is positive, which is also confirmed by the results of several opinion polls. A different view is, however, also represented among responses. In line with other polling, over 70% of the present questionnaire's respondents doubt the public's ability to distinguish between 1G and 2G biofuels. Although the 1G biofuel industry has been a driving force for the creation of ethanol infrastructure and markets, upon which 2G lignocellulosic ethanol is also dependent, these issues seldom reach public attention, a view held by most respondents and reflected in the literature.

The roles of the food-vs.-fuel debate, environmental NGOs, and sustainability standards and certification schemes are presented in the questionnaire statements as positive forces which promote the deployment of advanced biofuels. Advanced biofuels emerge in the results as a counterforce to 1G biofuels, and the debate in this respect is seen as more positive than negative. However, 40–60% of respondents do not agree that environmental NGOs and the introduction of sustainability standards and related certification have had a similar positive role.

5. KEY FINDINGS

This chapter summarises the survey results and is broken down into three sections. The first section reports on the observations made through the process of interviews and the analysis of questionnaire responses that the opinions presented on many, but not all, statements, are influenced by an individual respondent company's technology and product (type of biofuel). The typical differences of HEFA producers and cellulosic ethanol producers are highlighted. The second section provides a brief on selected issues arising from views expressed on the rating questions on the Likert Scale. This is therefore a summary of the previous chapters. Rating questions are classified under five areas, namely feedstock, technology and financing, mandates and targets, trends in biofuel demand, and environment and social issues. Finally, the third section reports the results of the questionnaire's ranking question about the level of importance of various potential barriers to the respondents' businesses and identifies the three most important risk areas or barriers ranked from among 14 categories.

5.1 OBSERVATIONS

As noted in Chapter 1, Section 3, the target group of the questionnaire is relatively small. The total number of commercially operating advanced biofuel producers (excluding engineering, process technology companies, labs and chemical companies selling enzymes and catalysts, etc.) in the world may not be much larger than 30 but determining the actual number depends on the definition of "advanced biofuels" and "commercial scale production", and how many of the FAME producers are included as 2G producers based on their sustainable waste-based feedstock.

The field is not only small but also fragmented with some conversion technology pathways currently represented by only a handful or less of operational plants in the world. The 14-respondent pool is thus enough to allow us to draw some general conclusions concerning the sector.

Even with a limited number of respondents, we sometimes need to consider subgroups to understand the dispersion of responses. Clearly, some issues and concerns are highly dependent on the conversion technology and associated end-product that the respondent company represents. This appears most starkly in the observed division of responses between producers of cellulosic ethanol and HEFA-based drop-in fuels. Some companies are positioned midway between these categories, such as those representing thermochemical pathways from lignocellulosic feedstock to drop-in fuels, pyrolysis or biochemical pathways from the sugar platform to drop-in fuels, which all could be seen to form a third group.

Cellulosic ethanol producers build on the existing ethanol market and infrastructure, making the promotion of blending obligations and the standardised gasoline blends (sold as E5, E10 and E85, for instance) important for them. On the other hand, questions related to "blend wall", refinery co-products or promoting FFVs (E85) clearly had little relevance for HEFA-based drop-in fuel producers. These companies are much more concerned about having stations selling 100% renewable diesel or incentivising captive markets for drop-in fuels, such as by public bus operators, ferries, trucking companies and airlines.

Two other important factors follow this division by fuel production which also influence the responses. One is that most HEFA producers are large companies with an oil-refining background. Of the 15 HEFA refineries in the world, only four are not owned by petroleum-refining companies (AltAir, Emerald Biofuels, UPM and REG).

Unsurprisingly, barriers related to the availability and cost of funding, for instance, seem different from the big companies' perspective compared to the relatively small technology companies' perspective.

Secondly, the technology for HEFA production is mature, whereas lignocellulosic ethanol producers as well as many in the third group representing thermochemical pathways are still battling with the risks and barriers associated with the early stage of commercialisation.

The existence of the three distinct groups within the advanced biofuels industry tends to create a wide dispersion of responses and reduce the skewness of results on the Likert Scale to a number of questions. The following table summarises some key differences between cellulosic ethanol and HEFA/drop-in groups.

Table 2. Differences in business environment for cellulosic ethanol and HEFA producers

ISSUE	CELLULOSIC ETHANOL	DROP-IN FUELS (HEFA)
Feedstock	Agricultural, forestry and municipal waste and residues Mainly solid	Oils and fats, used cooking oil, oily energy crops Mainly liquid
Feedstock sourcing	Local	Up to global (traded)
Availability	Abundant	Constrained
Main constraints	Local circumstances	Sustainability criteria, ILUC emissions, displacement effect
Sponsors	A mix of technology start-ups to large resource companies	Mainly large companies, oil & gas companies
Scale of conversion	Small	Medium to large
Bioeconomy co- and by-products	Important	Not important
Car engine realm	Gasoline	Diesel
Main focus	Personal vehicles	Personal vehicles, trucks, public transport, ships and aviation
Transport technology issues	Blend wall, E15, E85, FFVs	Go it alone with the current fleet technologies

5.2 RATING OPINIONS

Feedstock: The respondents do not take a unified stand on the various issues related to feedstock availability, cost, quality and infrastructure.

While respondents denied the statement that there is not enough feedstock for expansion of the advanced biofuels business, when asked to rank different barriers, the availability of feedstock was ranked third by a significant margin. This may be partially due to the phrasing of the two questions leading to different perspectives on the issue. The barrier ranking question highlights any "barrier you have encountered in planning investments .." which focuses the issue on the company's own business. In contrast, a respondent may take a broader view of the issue when the rating question asks more generally if there is ".. enough feedstock for advanced biofuels business expansion."

This does not, however, mean that availability of feedstock is not an issue for many responding companies. During interviews one respondent noted "supply chain management is a central part of our work," while another indicated that "waste streams in Western Europe are pretty well used already, but there are pockets where there is no local market for waste, with regional imbalances", and this is where they saw their opportunity. Similarly, the data suggest that almost 30% of respondents – predominantly advanced ethanol producers – actively consider competing uses of biomass to be a serious threat to their biofuel business. This may also have a bearing on those who ranked biomass availability as a concern. As one interviewee pointed out, "biomass competition takes place in sourcing, not in end-products."

For the majority of respondents, feedstock availability, price and quality (and their variations) do not stand out as significant issues. Most respondents are operating a successful advanced biofuel business and have therefore solved problems in the feedstock supply for their existing refinery, if there have been any.

Technology and financing: More than half of the respondents regard technology as ready for the large-scale deployment of advanced biofuels.

Technological issues do not stand out as strong concerns in the responses. As one respondent said, "processes are efficient and high-yielding – not much room for improvement. There are no tech issues in making jet fuel. It is all about the future price point..." Likewise, most respondents do not see the infrastructure for transporting, storing and distributing biofuels as problematic.

The availability and cost of financing, on the other hand, comes out as a major barrier to investments in advanced biofuels. Raising capital for business occupies considerable management time in innovation-based start-ups. Even in cases of big, "deep-pocketed" companies, the proponents of advanced biofuel investment may face internal competition for investment money. One respondent regarded the need for public support to realise firstofkind commercial-level refineries as the most critical financing related issue.

When asked to consider the future of algal (3G) biofuels, however, responses were almost unanimously negative. The technological and practical challenges of large-scale algae production have not yet been overcome, and respondents do not see algae-based biofuels as playing a significant role by 2030.

Mandates and targets: Regulatory uncertainty stands out as a barrier to investments.

There is almost complete unanimity on this issue. Regulatory uncertainty impedes investments in advanced biofuel production, and policies affecting the respondents' businesses are not stable and clear. Developing a refinery for advanced biofuels production requires a minimum time frame of approximately five years, unless a company can replicate an engineering and business concept. With pilots or demonstrations of novel processes the time needed until a full-scale refinery is in commercial-scale operation can exceed ten years. A stable regulatory environment is essential to planning biofuel refinery investment given this time scale.

The rapid pace of major regulatory changes relating to biofuels in Europe has been highly counterproductive for those who have been planning or implementing investments during the last ten years. This period included three major milestones consisting of the enactment of RED I in 2009, the ILUC Directive in 2005 and approval of the proposal for RED II by the European Council in December 2018. Every enactment has been preceded by some years of legal process and associated public debate as the Commission's proposal has proceeded through the European Parliament and the Council.

In contrast, the US RFS under EISA has provided a predictable (14 years from 2009 to 2022) framework for biofuel companies to operate within, and the country has risen to become the leading biofuel producer, covering nearly half of the world's production of bioliquids. Political turbulence around the act, however, has caused some uncertainty for project developers. There have been many efforts to amend or refute the RFS in Congress, and the EPA, as its administrator, has taken criticism from a variety of directions. Multiple lawsuits have also targeted the EPA in which plaintiffs claim the EPA's established renewable fuel obligations are either too low or too high. In addition, the EPA's use of its authority to use waiver credits to adjust the obligations to certain market realities has been much criticised, and the biofuels industry has been discontented with the duration and meticulousness of the fuel pathway approval process.

In looking at the latest and upcoming policy environments, however, most respondents saw the targets and foreseen regulations under the EU RED II for the period from 2021 to 2030 in a positive light. The advanced biofuel industry has generally consented to the RED II and agreed that the 3.5% target for advanced biofuels by 2030 is realistic. In this questionnaire, 75% of respondents regarded the European target level as sufficient to encourage investments.

At the same time that Europe and the United States seem to have passed the state of flux, biofuels are being boosted by lawmakers in Brazil, China and India. Brazil is now entering a new era with the recently enacted Brazilian National Biofuels Policy – RenovaBio for 2020 to 2028, which will be fuel-neutral and based on carbon intensity mandates. The government is currently drafting more detailed regulations including what is needed for certifying fuels and accrediting the certifying companies.

In China, the National Energy Administration (NEA), in its 13th Five-Year Plan for Biomass Energy, set new and higher targets for fuel ethanol and biodiesel by 2020. In 2017, a plan was issued for nationwide use of E10 gasoline by 2020, expanding from the current 11 trial provinces. India's National Policy on Biofuels – 2018 encourages the use of renewable energy in every possible way in the transport sector. It aims at increasing the ethanol blending rate in petrol from the current 2% to 20%, and a biodiesel blending rate of 0.1% to 5% by 2030. China and India have also been targets of notable foreign investments in advanced waste-based fuels production, such as LanzaTech and Enerkem in China, and Shell and Chempolis in India.

There is no unanimous perspective from the respondents on what regulatory mechanisms are best for promoting biofuels, but some general agreements are evident. Technology-neutral fuel standards, as for instance in California and planned in Brazil, are favoured by a narrow majority of the respondents, and most of the responding business executives oppose import duties on biofuels.

Views on individual policy measures, on the other hand, such as public support for E85, FFVs and breaking the blend wall, see respondents divided along product lines, with ethanol producers supporting these measures whereas others are rather indifferent to them.

Trends in biofuel demand: Transport sector decarbonisation calls for accepting the deployment of many fuel alternatives at the same time rather than resorting to one encompassing solution.

The respondents were more down-to-earth than anticipated in their expectations about the speed and volume of advanced biofuels deployment. Every fuel and end-use in the survey had its proponents and opponents, but half of the industry executives accepted that the share of advanced biofuels in the future energy mix will remain small. Electric mobility, for instance, is not seen as a significant threat to biofuels by two-thirds of the respondents, although there are strong opinions on both sides. The general expectation appears to be that there is room for the growth of multiple energy alternatives to fossil fuels.

The aviation and shipping sectors are particularly seen as loci of growth for the biofuels industry. Biofuels are seen as offering a way to meet the need for better fuel options created by international agreements aiming to limit shipping sector emissions. When asked about the likely breakdown of product sales in 2030, a couple of respondents provided estimates for the expected aviation sector share in their sales, ranging from 4% to “possibly up to 50%”.

With efficient, high-yielding processes already available, improving bio-jet production depends on finding the future price point

The aviation shares of 20% to 25% given by two respondents are realistic because the hydrocracking of renewable hydrocarbons to biojet results in a higher share of lower-value naphtha and refinery gas at the cost of higher-value renewable diesel. Unless the aviation sector provides a high premium in the price of renewable jet fuel, HEFA producers will likely continue serving heavy-duty trucks and shipping with renewable diesel.

Selling co-products is an essential part of the business case for most, but not so for the HEFA producers. One respondent advocated a gradual shift in focus from the energy use of biomass to higher value-added use of biomass and called for optimising the refinery concept without pre-set targets for biofuel output. The majority (over 70%) did not anticipate the rising demand for high-value bio-products to divert investments from advanced biofuels.

Environment and social: Executives of the advanced biofuel industry doubt whether the methods used to estimate GHG emissions, land use change and indirect land use change are accurate and reliable.

Similar to the responses concerning policy issues, matters of stability, clarity, and accuracy and reliability stand out as central concerns in sustainability standards and certification schemes. Doubts about how sustainability credentials are established for biofuels were expressed by around 80% of respondents. Only 36% of the respondents believe that the introduction of sustainability standards and certification schemes has served to boost the markets for advanced biofuels.

At the same time, over 40% of the respondents think, with 14% strongly agreeing, that worries over increasingly stringent sustainability criteria in the future are currently hampering investment. However, the split on this issue and others may reflect increasing confidence that the science around sustainability criteria is evolving toward more convergent results and that regulators are taking a prudent approach to changing rules, offering a degree of stability.

Even as matters stand, however, 80% of respondents believe there is too much confusion in how lifecycle GHG emissions, LUC and ILUC are estimated. Currently, the European certification is based on the EU Member States' national verification schemes or voluntary schemes approved by the Commission. In the United States and the state of California, the verification is performed by the EPA and CARB for the RFS and the LCFS, respectively, as the administrators of the schemes. A step toward better harmonisation is that CARB plans to introduce third-party verification to supplement CARB's own staff work in 2019, and one of the selection criteria will be that a third-party verifier is already recognised under the EU RED (Lai, 2017). The majority of respondents believe that a more harmonised, and more accurate, certification system to verify the sustainability credentials of their products would aid in bringing biofuels to market.

Business representatives acknowledge the role of the food-vs.-fuel debate in setting the advanced biofuels business in motion and continually pushing it forward. However, they are more dubious about the current role of environmental advocacy groups and levels of public understanding of biofuels. Indeed, environmental NGOs have increasingly shifted from moderate support for the role of advanced biofuels in the transport sector's decarbonisation strategies to almost exclusive support of the electrification, hydrogen and electro-fuels sector, which leaves little or no role for advanced biofuels.

Respondents also seem to have accurately judged the level of public knowledge concerning biofuels. While more than half of respondents believe the public has a generally positive view on advanced biofuels, 70% do not think that the public, politicians and media have a clear understanding of the differences between 1G and 2G biofuels. This aligns with several recent opinion polls that indicate the public in many countries clearly supports the idea of biofuels, but has a generally low level of knowledge about them. Public understanding may be growing, however, as two recent polls (in Austria and Germany) do show an increasing awareness of the differences between 1G and 2G biofuels and indicate that attitudes to biofuels are somewhat guided by this distinction. Similarly, a recent poll by the environmental advocacy organisation Transport & Environment indicated strong opposition in Europe to using palm oil for fuel.

5.3 RANKING BARRIERS

The questionnaire includes a ranking question about the level of importance of various possible barriers to the respondents' businesses. The respondents were asked to rank a minimum of three of the most important areas of risk or barriers from among 14 categories (13 + "other"). Nine categories collected at least one score between 1 and 3. Some respondents ranked down to the seventh order, but rankings lower than the third are ignored in the analysis to make the responses consistent.

The ranking of each category is calculated by assigning an individual's highest scored barrier a value of three, the second two and the third one, then summing up the total values for each category. The ranking results are summarised in Figure 11, in which the area reserved for a risk or a barrier category is in relation to its total ranking.

Incentives like mandates, blending obligations and subsidies are only effective in a stable and predictable regulatory environment

Figure 11. Barriers ranked by the level of importance

The sector regulation and its stability as well as policy related subsidies and blending mandates stand out as the most important areas for biofuel policy planners. Internal techno-economics issues, such as technology risk, process reliability, conversion efficiency and CAPEX are in the second place.

The following categories were given zero-ranking: innovation and future cost reductions, lifecycle carbon intensity with LUC/ILUC, transport sector trends (EVs, aviation, etc.) and low price of crude oil.

Ranking according to upper-level categories.

Categorising barriers entails a risk of "comparing apples and oranges", especially when some risk categories represent only a narrow segment of the total business. One respondent underlined that cost competitiveness is about the total cost, not about the individual cost components (such as feedstock cost, CAPEX, etc.).

The scoring results are therefore also reviewed here by summing up selected lower-level categories to three upper-level categories with another three original categories remaining intact: regulation, production economy, feedstock related, technology risk, financing related, and public perceptions.

The following three categories are combined aggregates, whereas technology risk, financing related and public perceptions remain as in the original questionnaire. Two original categories (level of subsidies and feedstock price) are counted at the same time in two upper-level categories:

- **Regulation:** Stability of regulation, level of subsidies, and level of blending mandates
- **Production economy:** Conversion efficiency and CAPEX, level of subsidies, feedstock price, and availability and cost of financing
- **Feedstock:** Feedstock availability and feedstock price.

Figure 12. Ranking of barrier categories in relation to the most important one

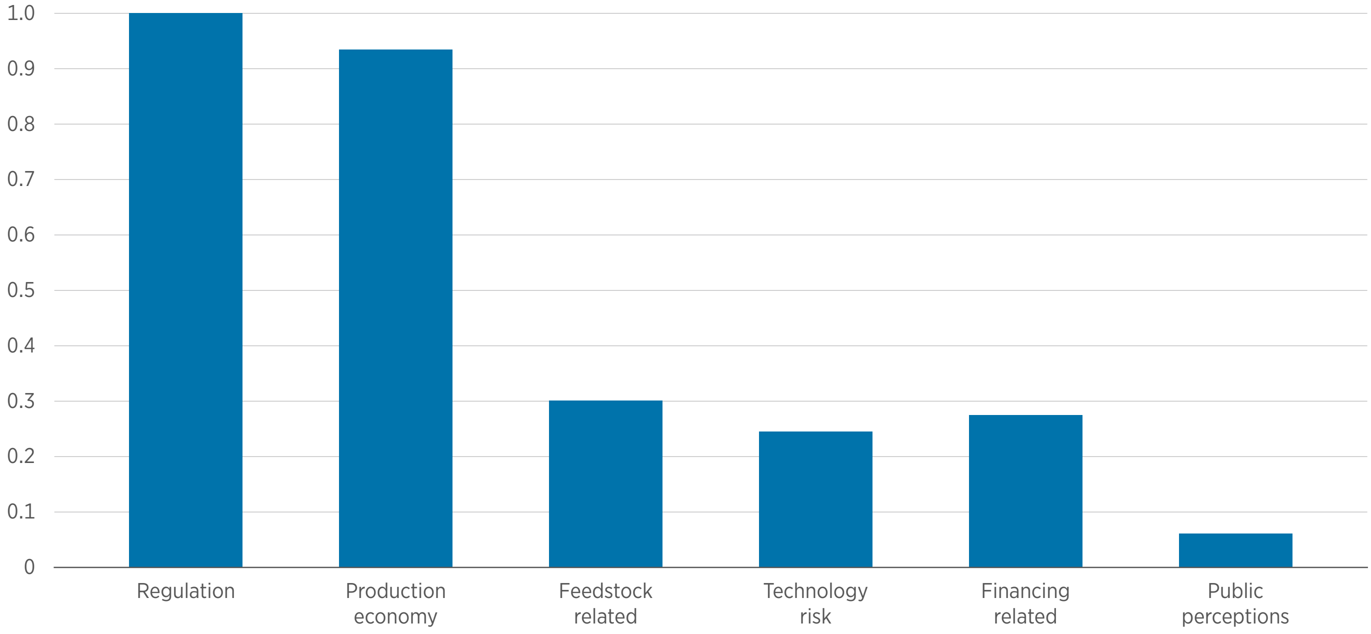
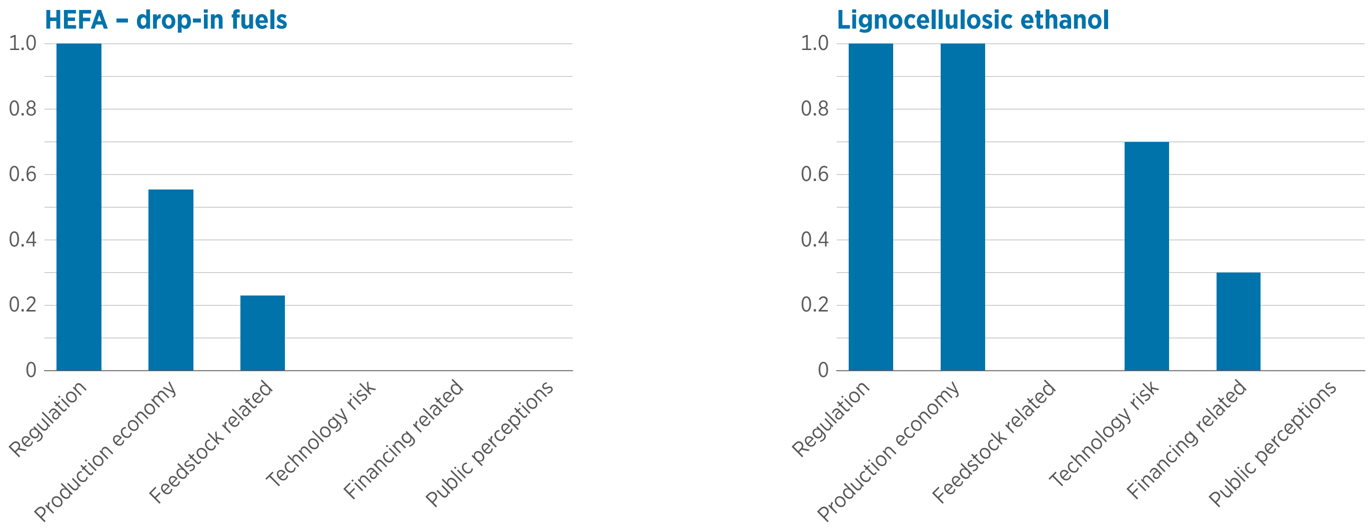


Figure 13. Rankings by HEFA and cellulosic ethanol groups



The most significant barriers to investment are related to regulation.

The importance of stability in regulation is overwhelmingly reinforced in both of these methods of parsing the ranking data. This result is consistent with other surveys and the literature reviewed in Chapter 2. This is further emphasised by the fact that in Figure 11 the regulatory category is valued at double that of the barrier categories ranked as second most important.

Regulatory issues concerning the level of blending mandates and level of subsidies are also ranked high. Examination of the higher-order categories in Figure 12 shows the result is still notable but somewhat less stark. Production economy also stands out as a significant issue, with all other barriers trailing these two significantly.

By reviewing ranking results for HEFA and cellulosic ethanol producers separately, the more immature technology of cellulosic ethanol pathway can be seen in the higher ranked production economy and technology risks. However, feedstock availability is not an issue for cellulosic ethanol producers whereas it ranks as third for HEFA producers, as can be expected.

Another barrier is also worth addressing, even if it does not currently register as a crucial concern for the biofuel industry. While low oil prices are often cited as a barrier to biofuel investment, they were not ranked as important by the respondents. The perception of price competition with oil is relevant in markets where advanced biofuels are supported primarily through taxation on fuels. The sudden drop in crude oil prices in the latter part of 2014, which have since remained at a lower level, caused ethanol to lose its competitiveness in some markets, which may be the reason low oil prices are regarded as a major barrier for advanced biofuels.

In market environments created through mandates, however, be they for renewable energy or fuel volumes, the price competition of advanced biofuels takes place primarily within the mandated fuel pool, and the costs of fuels outside the particular fuel pool have less significance. Under fuel-neutral markets, this is not the case, but the fuel pool includes all low-carbon fuels. Tradable credits generated by advanced biofuels' lower carbon intensity are then anticipated to render cost competition fair.

As the rankings of barrier categories make clear, the regulatory environment, including incentives in terms of mandates, blending obligations and subsidies, matters most, but only insofar as the environment is predictable and provides certainty on the market rules over a reasonable period of time. To achieve the decarbonisation of the transport sector will require the deployment of multiple alternative fuel sources, each of which has its own concerns dictated by its feedstock and technological pathway.

Advanced biofuels should not be treated monolithically, and this report indicates that there are multiple effective pathways for promoting their development. If advanced biofuels are to play their expected role in the reduced carbon pathway to 2050, however, regulation must remain stable enough to allow for adequate planning of investment and development.

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APPENDIX: QUESTIONNAIRE FOR INDUSTRY FEEDBACK

INDUSTRY FEEDBACK ON BARRIERS TO ADVANCED BIOFUELS – QUESTIONNAIRE

COMPANY

Name of the company:			
Name of respondent:			
Title of respondent:			
Email:		**Telephone:**	

FACILITY

Name:			
Location/country:		**City/State:**	
Status:	Choose one from the dropdown menu.		
Year of commissioning:			

Tick applicable feedstock, technology and product options, and give annual capacity per product

FEEDSTOCK		CONVERSION TECHNOLOGY		FINAL PRODUCT(S) SOLD		OUTPUT MILLION L/A
Sugar crops and residues	☐	fermentation	☐	ethanol	☐	
Starch crops and residues	☐	transesterification	☐	methanol	☐	
Oil seeds and residues	☐	enzymatic hydrolysis	☐	butanol	☐	
Other agricultural residues	☐	acid hydrolysis	☐	drop-in gasoline	☐	
Wood crops and residues	☐	enzyme onsite production	☐	FAME biodiesel	☐	
Grass crops and reisudes	☐	gasification for syngas	☐	drop-in diesel	☐	
Used cooking oil	☐	pyrolysis	☐	HEFA	☐	
Animal fats	☐	methanol to gasoline	☐	DME	☐	
Tall oil	☐	Fischer-Tropsch synthesis	☐	drop-in kerosene (biojet)	☐	
Municipal Solid Waste MSW	☐	hydroprocessing	☐	pyrolysis oil (biooil)	☐	
Algae	☐	biochemical ethanol	☐	biogas	☐	
other, what..	☐	ethanol-to-drop-in fuels	☐	other, what..	☐	
		other, what..	☐			

REGULATORY CONTEXT

Please consider the key market(s) of your plant and mark the market(s) by number in the business priority order (maximum five jurisdictions).

European Union	☐		U.S.A. Federal	☐	
Country 1	Choose Country.	☐	State 1	Choose State.	☐
Country 2	Choose Country	☐	State 2	Choose State.	☐
Country 3	Choose Country	☐	State 3	Choose State.	☐
Brazil	☐		Indonesia	☐	
Canada	☐		Thailand	☐	
China	☐		Other, what..		☐
India	☐		Other, what..		☐

HIGH LEVEL PROJECTIONS

We encourage you to estimate or guesstimate.

1. Markets for advanced biofuels cannot be sustained without subsidies and mandates, if the crude oil price does not exceed click to key-in the price USD per barrel continually.
2. Advances in biofuel conversion technologies and plant operations will result in production cost (capital and O&M) reduction of at least key-in percentage figure % by 2030, if innovation and investments in the sector continue at least on the level of the previous ten years.
3. Give an estimate and forecast about the end-use of your product sales

OUR ADVANCED BIOFUELS WILL GO TO...	END USE	2018 %	2030 %
PLEASE USE VOLUMETRIC BASIS (LITRES/GALLONS) FOR THE PERCENTAGE SHARES	Road transport		
	Maritime sector		
	Aviation		
	Other uses than transport		
	Total	**100 %**	**100%**

4. It is understood that a successful business requires all parts of the value chain function properly. Please rank at least three most important areas of risk or barrier you have encountered in planning investments, below, in order of importance.

CATEGORY OF IMPACT TO BUSINESS SUCCESS	NRO		NRO
Availability of sustainable feedstock		Level of subsidies in key markets	
Feedstock price		Stability of regulation in key markets	
Feedstock quality		Availability & cost of financing	
Conversion efficiency and cost (capex)		Life-cycle carbon intensity with LUC/ILUC	
Technology risk and process reliability		Transport sector trends (EVs, aviation, etc.)	
Innovation & future cost reductions		Low price of crude oil	
Public perceptions		Other, what	
Level of blending mandates in key markets		Other, what	

QUESTIONNAIRE

ISSUES, RISKS AND BARRIERS (CLICK YOUR RESPONSE)	RESPONSE				
	STRONGLY DISAGREE	DISAGREE	NEITHER AGREE NOR DISAGREE	AGREE	STRONGLY AGREE
	1	2	3	4	5
FEEDSTOCK:					
There is not enough feedstock for advanced biofuels business expansion.	☐	☐	☐	☐	☐
Competing uses for biomass feedstock (such as heat, power and bioproducts) pose a major risk for our biofuel business.	☐	☐	☐	☐	☐
Regulation of biomass feedstock quality is inadequate.	☐	☐	☐	☐	☐
Better mechanisms are needed to monitor biofuel feedstock prices	☐	☐	☐	☐	☐
Biomass transport and storage logistics are not available at volumes required by full-sized biorefineries.	☐	☐	☐	☐	☐
Feedstock price uncertainty hampers our business.	☐	☐	☐	☐	☐
Feedstock quality variations disrupt our production.	☐	☐	☐	☐	☐
Incentives for farmers to growfeedstock for advanced biofuel plants are inadequate.	☐	☐	☐	☐	☐
Please type below your comment (if any) on feedstock related barriers: What do you see as the most promising feedstocks for advanced biofuels? What do you see as the main logistical challenges to amassing required feedstocks at scale, and how cope with them?					
COST OF TECHNOLOGY AND FINANCING:					
Technology is not ready for large scale advanced biofuels deployment.	☐	☐	☐	☐	☐
Inadequate transport infrastructure will constrain the marketing of advanced biofuel products .	☐	☐	☐	☐	☐
Lignocellulosic (second generation) biofuels will reach significant volumes by 2030.	☐	☐	☐	☐	☐
Algal (third generation) biofuels will reach significant volumes by 2030.	☐	☐	☐	☐	☐
The biggest challenge for algal biofuel is in growing and harvesting algae at scale.	☐	☐	☐	☐	☐
Availability and cost of financing is a major barrier to investment in advanced biofuels.	☐	☐	☐	☐	☐
Technology is mature enough to start marketing drop-in gasoline and diesel from lignocellulosic feedstocks. [INTERVIEWER NOTE: If answer is "no" ask when.]	☐	☐	☐	☐	☐
Please type below your comment (if any) on technology and financing related barriers: • What do you see as the greatest technical and economic challenges to marketing advanced biofuels? • In what time frame (if any) do you see advanced biofuels being marketed at large scale?					

ISSUES, RISKS AND BARRIERS	RESPONSE				
	STRONGLY DISAGREE	DISAGREE	NEITHER AGREE NOR DISAGREE	AGREE	STRONGLY AGREE
	1	2	3	4	5
MARKETS THROUGH MANDATES AND TARGETS					
Policies affecting our business are stable and clear.	☐	☐	☐	☐	☐
Mandates and blending obligations for advanced biofuels should be replaced by price mechanisms like rebates, tax credits, reduced tax rates, and a market value for carbon.	☐	☐	☐	☐	☐
European renewable fuel targets are insufficient to encourage investments in advanced biofuel production	☐	☐	☐	☐	☐
EU and US biofuel markets are too fragmented, more coherent central regulation is needed.	☐	☐	☐	☐	☐
Targets for expansion of advanced biofuels production are not sufficiently ambitious.	☐	☐	☐	☐	☐
Regulatory uncertainty impedes investments in advanced biofuel production.	☐	☐	☐	☐	☐
Technology neutral fuel standards (as in Brazil or California) are better than fuel specific mandates (as in EU).	☐	☐	☐	☐	☐
Blending limits discourage investment in advanced biofuel production.	☐	☐	☐	☐	☐
Governments should promote E85 and flexi-fuel vehicles, to maintain market pull for lignocellulosic ethanol.	☐	☐	☐	☐	☐
Import tariffs are needed to protect domestic investments in advanced biofuels.	☐	☐	☐	☐	☐
Import tariffs have a negative impact on our business operations.	☐	☐	☐	☐	☐
There is a conducive policy environment in the market for investments in advanced biofuel production:					
In Brazil (RenovaBio)	☐	☐	☐	☐	☐
In China (2020 blending obligation)	☐	☐	☐	☐	☐
In Europe (EU RED-2 targets)	☐	☐	☐	☐	☐
In India (National Biofuel Policy 2018)	☐	☐	☐	☐	☐
In the United States (Renewable Fuel Standard 2)	☐	☐	☐	☐	☐
Please type your comment (if any) on policy and regulation related barriers: • What are the specific policy related impediments for investments • What specific improvements would you suggest in the regulations affecting your market(s)?					

ISSUES, RISKS AND BARRIERS	RESPONSE				
	STRONGLY DISAGREE	DISAGREE	NEITHER AGREE NOR DISAGREE	AGREE	STRONGLY AGREE
	1	2	3	4	5
CONSUMER DEMAND:					
Advanced biofuels will remain a niche and represent only a tiny share of the future energy mix.	☐	☐	☐	☐	☐
We count on aviation sector being a major customer.	☐	☐	☐	☐	☐
Electric vehicles (EVs) pose a serious threat for biofuels business in the coming 5 to 15 years.	☐	☐	☐	☐	☐
Flex-Fuel Vehicles (FFVs) are necessary for decarbonizing the transport sector.	☐	☐	☐	☐	☐
Biogas is one of the best options for decarbonizing road transport.	☐	☐	☐	☐	☐
Biofuels should be targeted primarily for shipping and aviation, and light vehicles should be electrified.	☐	☐	☐	☐	☐
Brazilian experience with ethanol and FFVs dominating light vehicle markets is unlikely to be achieved elsewhere.	☐	☐	☐	☐	☐
Maritime biofuels are impeded by due to the cost of changing ship engines and fuel storage infrastructure.	☐	☐	☐	☐	☐
International agreements will eventually limit sulphur, NOx and greenhouse gas emissions in ships, forcing them to use biofuels.	☐	☐	☐	☐	☐
Sales of biofuel by-products and co-products is a necessary part of our business case.	☐	☐	☐	☐	☐
Rising demand for high-value-added bio-based materials diverts investment from advanced biofuels.	☐	☐	☐	☐	☐
Multiple fuels, feedstocks, and technology pathways make the advanced biofuels market too fragmented to effectively promote their large scale deployment.	☐	☐	☐	☐	☐
Please type your comment (if any) on consumer related barriers: • What are the specific policy related impediments for investments • What specific improvements would you suggest in the regulations affecting your market(s)?					

ISSUES, RISKS AND BARRIERS	RESPONSE				
	STRONGLY DISAGREE	DISAGREE	NEITHER AGREE NOR DISAGREE	AGREE	STRONGLY AGREE
	1	2	3	4	5
ENVIRONMENT AND SOCIAL:					
There is too much confusion about how life-cycle GHG emissions, land use change and indirect land use change are estimated.	☐	☐	☐	☐	☐
The difference between conventional (food-crop-based) and advanced (non-food-crop-based) biofuels is understood by the public, politicians and media.	☐	☐	☐	☐	☐
The public and media do not understand the potential synergies between food and non-food portions of crops (first and second generation feedstock components).	☐	☐	☐	☐	☐
Food-vs-Fuel debate continues to push advanced biofuels business forward.	☐	☐	☐	☐	☐
Harmonization of certification systems would make it much easier to get advanced biofuels to the market.	☐	☐	☐	☐	☐
Methods used for estimating land use change impacts of various biofuels are accurate and reliable.	☐	☐	☐	☐	☐
Environmental advocacy groups have helped advance second generation biofuels.	☐	☐	☐	☐	☐
Advanced biofuels production leads to land grabbing and monoculture by large agricultural companies.	☐	☐	☐	☐	☐
Sustainability standards and certification schemes have boosted markets for advanced biofuels.	☐	☐	☐	☐	☐
Advanced biofuels are viewed positively by the public.	☐	☐	☐	☐	☐
Investments are hampered by worries that sustainability criteria may become more stringent.	☐	☐	☐	☐	☐

Please type your comment (if any) on environmental and social issues:
- What are the specific policy related impediments for investments
- What specific improvements would you suggest in the regulations affecting your market(s)?

Anything missing?

Do you feel that some crucial issues are absent in the above questionnaire?
If yes, kindly describe them and provide your view on them by typing below.

Issue 1:
Issue 2:
Issue 3:

THANK YOU!

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