Towards advanced biofuels

OPTIONS FOR INTEGRATING CONVENTIONAL AND ADVANCED BIOFUEL PRODUCTION SITES

(RES-T-BIOPLANT)

February 2016
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The International Energy Agency’s Implementing Agreement for Renewable Energy Technology Deployment (IEA-RETD) provides a platform for enhancing international cooperation on policies, measures and market instruments to accelerate the global deployment of renewable energy technologies.

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ACKNOWLEDGEMENTS

The Authors would like to thank the Project Steering Group as well as the interview partners and experts filling in the written survey:

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<tr>
<td>1G</td>
<td>First Generation</td>
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<td>2G</td>
<td>Second Generation</td>
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<td>APR</td>
<td>Aqueous Phase Reforming</td>
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<td>AT</td>
<td>Austria</td>
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<td>ATJ</td>
<td>Alcohol to Jetfuel</td>
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<td>ASTM</td>
<td>American Society for Testing and Materials</td>
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<td>bbl</td>
<td>barrel</td>
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<td>BioFPR</td>
<td>Biofuels Bioproducts and Biorefining</td>
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<td>bl</td>
<td>billion liters</td>
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<td>BR</td>
<td>Brazil</td>
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<td>BTL</td>
<td>Biomass to Liquid</td>
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<td>CA</td>
<td>Canada</td>
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<td>CARB</td>
<td>California Air Resources Board</td>
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<td>CAPEX</td>
<td>capital expenditure</td>
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<td>CPO</td>
<td>crude palm oil</td>
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<td>DDGS</td>
<td>Distiller’s Dried Grains and Solubles</td>
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<td>DK</td>
<td>Denmark</td>
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<td>DSHC</td>
<td>Direct Sugars to Hydrocarbons</td>
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<td>EBTP</td>
<td>European Biofuels Technology Platform</td>
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<td>EEA</td>
<td>European Environment Agency</td>
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<td>EPA</td>
<td>US Environment Protection Agency</td>
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<td>EtOH</td>
<td>Ethanol</td>
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<td>European Union</td>
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<td>FAME</td>
<td>Fatty acid methyl ester</td>
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<td>Finland</td>
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<td>FR</td>
<td>France</td>
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<td>FT</td>
<td>Fischer-Tropsch</td>
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<td>FTJ</td>
<td>Fermentation to Jet</td>
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<td>GHG</td>
<td>greenhouse gas(es)</td>
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<td>GJ</td>
<td>Gigajoule</td>
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<td>HDCJ</td>
<td>Hydrotreated Depolymerised Cellulosic Jet</td>
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<td>HEFA</td>
<td>Hydro-processed Esters and Fatty Acids</td>
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<td>HTL</td>
<td>Hydrothermal Liquefaction</td>
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<td>HVO</td>
<td>Hydrotreated Vegetable Oils</td>
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<td>IEA</td>
<td>International Energy Agency</td>
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<td>IINAS</td>
<td>International Institute for Sustainability Analysis and Strategy</td>
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<tr>
<td>ILUC</td>
<td>indirect land use change(s)</td>
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<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<tr>
<td>IT</td>
<td>Italy</td>
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<tr>
<td>JRC</td>
<td>Joint Research Center of the European Union</td>
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<tr>
<td>LCA</td>
<td>Life-cycle analysis (or assessment)</td>
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<tr>
<td>LCFS</td>
<td>Low Carbon Fuel Standard</td>
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<tr>
<td>M</td>
<td>million</td>
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<tr>
<td>MFSP</td>
<td>Minimum Fuel Selling Price</td>
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<td>MI</td>
<td>million litre</td>
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<td>MSW</td>
<td>Municipal Solid Waste</td>
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<td>NL</td>
<td>The Netherlands</td>
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<td>NREL</td>
<td>National Renewable Energy Laboratory</td>
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OECD  Organisation for Economic Cooperation and Development
OPEX  operation expenditure
PPP  public-private partnership
R&D  research and development
RED  Renewable Energy Directive
REN21  Renewable Energy Network for the 21st Century
RFS  Renewable Fuel Standard
RIN  Renewable Identification Number
RJF  Renewable Jet Fuel
UCO  Used Cooking Oil
UNCTAD  United Nations Conference on Trade and Development
US  United States of America
EXECUTIVE SUMMARY

The IEA Implementing Agreement for Renewable Energy Technology Deployment (IEA-RETD) has commissioned this scoping study to serve the members of the IEA-RETD. The aim of this study is two-fold:

- Get a better understanding of the scale of the opportunity for adapting existing sites to produce advanced biofuels; and,
- Analysing the potential role of government policy to incentivise site conversion.

The key findings from the scoping study can be summarized as follows:

Feasibility of integration

Advanced (2nd generation / 2G) biofuel plants can be implemented as stand-alone units or integrated with conventional (1st generation / 1G) biofuel plants\(^1\). There are cases where significant synergies between 2G and 1G plants exist, while in other cases, integration options are very limited. Integration strategies can refer to: co-location (installing a separate 2G entity adjacent to an existing 1G facility), retrofitting (altering the existing 1G production line for producing 2G biofuels alongside 1G biofuels) or repurposing (adjusting the production process of an existing (mothballed) facility to produce 2G biofuels). “Energy integration” of electricity/process heat demand (through existing CHP plants) is an additional key option used in several cases. Integration strategies are also a basic approach for 2G plant implementation at the pilot and demonstration stage to minimize cost and investor risks, with co-location as the dominant strategy.

1G bioethanol sites are technically and economically more suitable for conversion into, or integration with 2G sites than biodiesel. Co-location is the most used integration strategy and the easiest to implement as well. Retrofitting is more challenging and more sensitive to economic feasibility. Repurposing of 1G bioethanol sites is seldom used. Eventually, 2G integration will become mainstream in the bioethanol industry increasing resource efficiency in the production of bioethanol, and increasing GHG emission saving potential in the resulting mix of 1G/2G bioethanol.

Technical difficulties for integrating 2G technologies into 1G biodiesel sites leave the possibility of co-location of plants (rather than the integration or re-purposing of 1G biodiesel plants) as the only technically feasible option. However despite the technical restrictions, business considerations to meet customer preferences (e.g. specific niche markets for 2G biodiesel) may become more relevant factors for making such investment decisions.

Integration of 2G bioethanol in pulp and paper industry sites and 2G renewable diesel into existing fossil refineries are further options to advance 2G biofuels, but were outside of the focus of this scoping study.

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\(^1\) This study classifies biofuels on basis of the feedstock used in their production. See Box 1 in chapter 1 for a full definition
Cost savings and other benefits
The variety of conceptual and design studies identify cost-savings from co-location for all 2G conversion pathways in the order of 5-10%, which most probably will drive respective integration strategies further, unless there are significant local barriers. Site-specific optimization can yield much higher cost reductions, especially for investment costs.

Only few sources identified GHG emission reductions, and those were mainly due to the (assumed) 2G operation, i.e. not related to integration.

Very few literature sources concerned land use impacts, although integration can deliver (small) direct land use savings, compared to greenfield stand-alone plants.

Employment and regional economy impacts are typically addressed only qualitatively, except a few cases giving overall figures, but lacking a baseline for comparison.

Policy instruments for the integration of sites
Three types of policy instruments that can incentivize the transition towards advanced biofuels were found: i) Command and control instruments such as production quota and blending or emissions mandates; ii) economic instruments such as a variety of tax exemptions and mechanisms for direct financial help to R&D, conversion of facilities, production of feedstock, etc., and iii) collaborative instruments, especially in the R&D field.

All researched policy instruments would bring different advantages and disadvantages for the conversion of 1G plants or integration of 2G plants. However, the sequence of implementation of instruments is crucial. A market start-up will only happen if stable support to technology development and technology commercialization is given (by way of economic incentives) for a reasonable timeframe reflecting investment lifetimes. Blending mandates would cause more harm than benefits if they were applied in an immature market where biofuel prices have not yet reached stability and fossil fuel prices remain low.

Conclusions and recommendations
Based on evidence compiled from the literature and the qualitative stakeholder survey, this report makes the following research-related recommendations for integrating 2G biofuel technologies into 1G biofuel plants:

1. Conduct an analytical study on the economic feasibility and other benefits of specific co-location and retrofitting strategies for 1G bioethanol sites, including ATJ for the aviation sector.

2. Include integration of 2G bioethanol in pulp & paper industry sites and 2G biodiesel into existing fossil refineries in follow-up work.

3. Carry-out market research for determining conditions for which 1G biodiesel sites could be of interest to 2G biodiesel plants investors, especially regarding access to market niches, product distribution strategies and feedstock supply possibilities rather than only the technical feasibility for conversion.

4. Due to limited information on 2G integration in the public domain (conference proceedings, journal articles, PhD theses etc.), it is recommended that further analytical work should include a panel of key industry stakeholders to discuss what approach will allow access to “in-house” data and what level of access might this be.
5. **Consider an in-depth policy study for proposing a specific mix of policy instruments for specific relevant countries and the EU.** This should respond to questions such as:

- How much economic support is needed for R&D, for what specific technology pathways, for how long and with which indicative results as targets?
- What have been the most effective economic instruments and incentives for realising new infrastructure? How much money should be budgeted for those instruments and when should they be stopped?
- What are the right signals before volumetric or blending mandates can be implemented safely? Do they need to be accompanied with economic incentives such as tax credit for production, tradable certificates or feed-in-tariffs?

This in-depth study should also aim to establish recommendations for a policy strategy that delivers international coherence and policy parity between different sectors using biofuels.
1. INTRODUCTION

Production capacity of conventional or first generation (1G) biofuels boomed during the last decade in the United States, the European Union and in some emerging economies such as Brazil (see Box 1 for the definition of conventional biofuels). The reason behind this boom was the expected growth in demand for biofuels supported by policies aiming to decarbonise the transport sector, reduce greenhouse gas (GHG) emissions, and reduce the dependence on imported fossil fuels. In e.g. Brazil and Germany, the promotion of the agricultural sector was also an important factor for the capacity boom.

Box 1: Definition of conventional and advanced biofuels for this study

This study classifies biofuels on basis of the feedstock used in their production

**Conventional or 1st generation (1G) biofuels**: 1G biofuels are produced from food crops (sugar, starch, oil). Examples of 1G biofuels are:
- **Biodiesel**, also referred as FAME in North America, from edible vegetable oils (palm, rapeseed, soybean, and sunflower oils, etc.).
- **Bioethanol** from sugars (sugarcane, sugar beets, etc.) or from cereal-based starches (corn, wheat, etc.).

**Advanced or 2nd generation (2G) biofuels**: 2G biofuels are produced from lignocellulosic feedstocks (i.e., agricultural and forestry residues, e.g., bagasse, corn stover, wheat straw, wood harvest leftover, etc.), non-food crops (i.e. grasses, miscanthus, algae), or industrial waste and residue streams. 2G biofuels cause zero or low Indirect Land Use Change (ILUC) impacts, and they usually reduce the carbon-intensity of transport fuels more than 1G biofuels. Examples of 2G biofuels are:
- **Cellulosic bioethanol** produced by hydrolysis and fermentation of lignocellulosic agricultural wastes such as straw or corn stover or from energy grasses or other energy crops. The end product is the same as conventional bioethanol.
- **Alcohol-to-Jet Fuel (ATJ)** with aid of thermo-chemical reactions and when alcohol is produced from feedstock for 2G biofuels.
- **Hydrotreated Vegetable Oils (HVO) or Hydroprocessed Esters and Fatty Acids (HEFA)**, also called renewable diesel or green diesel, when produced from feedstock for 2G biofuels. HVO is chemically closer or identical to fossil diesel, and hence allow the use of current fuel infrastructures (pipe, storage, engines) without technical limitation (Janssen et al. 2013).
- **Esterification of waste grease**, such as category 1 & 2 animal fats, grease trap waste, flotation fat or used cooking oil (UCO).
- **Fischer-Tropsch (FT) or Biomass-to-Liquid (BtL)** fuels produced via gasification of lignocellulosic feedstocks, non-food crops or wastes, followed by fuel synthesis via Fischer Tropsch process.

*Note: ATJ or HVO produced from feedstock for 1G biofuels are not considered 2G biofuels in this study.*

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2 Similar classification as of the European Industrial Bioenergy Initiative (EIBI) http://www.biofuelstp.eu/eibi.html
However, whilst production capacity boomed, the demand for biofuels did not grow as expected due to a variety of reasons:

- A general reduced growth of energy demand or even contraction of demand due to the economic crisis since 2007. As biofuels are usually blended with fossil fuels, less demand of fossil fuels, therefore, also means less demand of biofuels.
- Demand in the USA was affected firstly by volatility of corn prices due to increased drought events, and second by challenges related to the amount of ethanol blended into gasoline. Ethanol already accounts for about 10% of the US gasoline consumption, which is the limit that many car manufacturers accept within their liabilities. When the gasoline demand contracts, blending liability constrains further demand of ethanol. This constraint is called the “blend wall”.
- In Brazil, costs for land and labour increased and margins from sugar and ethanol production fell.
- In the European Union, doubts on the sustainability of 1G biofuels, especially biodiesel, also caused strong debates on the real potential of any 1G biofuel to reduce GHG emissions and on their possible negative impacts on biodiversity, land use, food prices and food security. These debates have led to establishing a cap on 1G biofuels, and the debates have halted investments until clear policy directions are taken.
- In addition, the reduction of oil prices in 2014 and 2015 apparently ended a period of 8 years with high oil prices. Biofuels are hardly cost competitive with fossil fuels, and low oil prices make it more difficult for biofuels to compete in the market.

Global investment in biofuels production capacity reached a near 10-year low of US$ 5.1 billion in 2014 (REN21 2015). Investment in biofuels only grew where there was little production capacity installed. Investments in China grew 23% in 2014 (REN21 2015). Oil-importing economies in Southeast Asia and Africa have increased their policy support to biofuels as an option to lower their subsidies to imported fuels and to improve the economy of their agricultural sectors. In this context, the forecast of global biofuel production for the next five years has slowed down (see Figure 1).

**Figure 1  Comparison of global biofuel production and oil prices 2007-2020**

Note: Forward assumption for IEA crude oil average import price based on 65 day average of forward contract prices for Brent crude oil


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An overcapacity of 1G biofuel production has become evident in those regions that saw a capacity boom in the last decade (see Figures 2-5).

**Figure 2**  Development of biodiesel in the EU

![Development of biodiesel in the EU](image)

*Source: Data extracted from the USDA GAIN Report: EU-28 Biofuels Annual 2015*

**Figure 3**  Development of bioethanol in the EU

![Development of bioethanol in the EU](image)

*Source: Data extracted from the USDA GAIN Report: EU-28 Biofuels Annual 2015*
In the European Union (Figures 2 and 3) and in the United States (Figures 4 and 5), the excess capacity for biodiesel production is about 100%, with countries like Spain reaching 200% over capacity. The situation for bioethanol is more even, but still about 30% overcapacity exists in Europe.

Figure 4  Development of biodiesel in the US

![Graph showing development of biodiesel in the US]

Source: Statistics from the US Energy Information Administration (https://www.eia.gov/)

Figure 5  Development of bioethanol in the US

![Graph showing development of bioethanol in the US]

Source: Statistics from the US Energy Information Administration (https://www.eia.gov/)
However, the long term trajectory for the global decarbonisation of the transport sector is unlikely to change. Policies in the US and the EU are designed to be robust against oil price fluctuations and technology pathways. The Renewable Fuel Standard (RFS2) in the US, and the Renewable Energy Directive (RED) in the EU will remain [the] driving forces for the decarbonisation of the transport sectors here. Worldwide, bioethanol production is much larger than biodiesel production (about three times). This situation is expected to continue for the foreseeable future.

There is a significant role in the market for sustainably produced advanced biofuels. The potential greenhouse-gas (GHG) savings from 2G biofuels, compared to a fossil reference, range from 60 to 85 % in most cases, making a significant contribution to climate and decarbonisation goals.

While 2G technologies are close to being commercial, they will still require economic incentives. They will require policy certainty and a minimum price sustained in time. A steady transition from 1G to 2G biofuels is expected in the near- to mid-future even when some technical, economic and commercial challenges remain.

**However, 1G and 2G biofuels are produced with different technologies.** The development of their production pathways should not be considered in isolation, but acknowledging possible interactions and co-dependencies. The technical conversion of 1G into 2G biofuel sites, or the integration of both type of sites are in general difficult. Nonetheless, from both technological and economic perspectives there are several potential advantages for integrating 1G and 2G biofuel sites. With respect to technology, some steps, processes and services might be shared using the same equipment, infrastructure, know-how, etc. or trading by-products (e.g., materials or energy). In the economic side, advantages can influence both the capital cost and operating costs.

In 2014, 94 billion litres (bl) of bioethanol⁴ were produced worldwide; 61% from sugar crops and 39% from grains (REN21 2015). The US, Brazil and the EU are expected to remain the three major producers. Global biodiesel production was 30 bl globally in 2014 (REN21 2015) and it is estimated to reach 41 bl in 2022. The EU is the major producer of biodiesel⁵ with 45%, followed by the US and Brazil with 15 and 8%, respectively (UNCTAD 2012). The production of cellulosic bioethanol and renewable diesel from 2G feedstock is nowadays only marginal.

For these reasons the IEA Renewable Energy Technology Deployment (IEA-RETD) has commissioned the scoping study “Options for evolution of first generation biofuels production sites (RES-T-BIOPLANT)” with a two-fold aim:

- Getting a better understanding of the scale of the opportunity for adapting existing sites to produce advanced biofuels; and,
- Analysing the potential role of government policy incentivising sites conversion.

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⁴ Total gasoline production in 2012 was 1,3 trillion litres according to the US Energy Information Administration

⁵ Total diesel production in 2012 was 1,54 trillion litres according to the US Energy Information Administration
The analysis for this study has been based on factual evidence from recently published work and from written and oral interviews with relevant stakeholders acknowledged in this study. Information found in published work has been limited and mostly theoretical. Interviews were designed for the collection of qualitative information to complement the limitations of published information. Twenty written interviews were collected in a survey format. This survey was not intended as an opinion poll because the number of relevant stakeholders for this study is small.

The final report of this scoping study is structured as follows:

Section 2 discusses integration options and the technical feasibility of integrating different 1G and 2G technologies.

In Section 3, cost and benefits associated with the various integration strategies are analysed. This includes the analysis of GHG emissions and savings as well as the potential impacts on land use.

Section 4 presents business considerations, while Section 5 gives an overview of supporting policies.

Section 6 proposes a set of recommendations and next steps.
2. TECHNICAL FEASIBILITY

2.1. TECHNOLOGY PATHWAYS AND ASSOCIATED FEEDSTOCK SUITABLE FOR CONVERSION

This study focuses on the following technology pathways:

First generation (1G) technologies

- Bioethanol from starch (e.g. from corn, wheat) and sugar (e.g. sugarbeet, sugarcane)
- Biodiesel from vegetable oils (e.g. rapeseed, sunflower and soybean oil)

Second generation (2G) technologies

- Lignocellulosic ethanol (mainly by enzymatic hydrolysis and fermentation)
- Alcohol-to-Jetfuel (ATJ) from non-edible feedstocks
- Renewable biodiesel from transesterification of residual/waste fats, oils and grease (FAME), Hydrotreated Vegetable Oils (HVO), Hydroprocessed Esters and Fatty Acids (HEFA)

Figure 6 summarises the various technological pathways considered in this study according to the main feedstocks categories.

Figure 6  Feedstock technology combination in the current scope

Source: Adapted from Mawhood et al. (2015). All routes are commercially available except the lignocellulose and alcohols to 2G bioethanol routes for which commercial demonstration is ongoing.

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6 Fischer-Tropsch (FT) diesel – also known as “Biomass-to-Liquids” (BTL) - is excluded from this study due to early stage of (commercial) development, and low integration opportunities (only in pulp & paper plants, and petroleum refineries).
2.1.1. First generation (1G) pathways

Bioethanol

First generation (1G) bioethanol is produced with two different processes, either from starch-based (Figure 7) or sugar (Figure 8) feedstocks.

Bioethanol from starch uses grains, enzymes and yeast as main inputs. In this process, hydrolysis is needed prior fermentation, and animal feeds in the form of distiller’s dried grains with solubles (DDGS) which are nutrient-rich coproducts and very important to the economic performance of the process. Starch-based 1G bioethanol is commercially available and extensively used in, for example, the US and EU.

Figure 7 Block Diagram representation of starch to ethanol pathway

![Block Diagram representation of starch to ethanol pathway](image)

Source: Adapted from Lennartsson et al. (2014). DDGS = distiller’s grains and solubles

Sugarcane ethanol is predominantly produced in Brazil and other tropical countries. There are several differences in the sugarcane ethanol process with respect to starch ethanol, as shown in Figure 8.

In the sugarcane process, the whole cane is processed to obtain the sugar juice and bagasse and hydrolysis is not needed. Bagasse is an intermediate product of the process and generally it is used with sugarcane trash to cogenerate heat and electricity for the process.
Figure 8  
Block Diagram representation of sugarcane to ethanol pathway

Source: Adapted from Dias et al. (2013)

Biodiesel

1G biodiesel can be produced with different production methods from different raw material such vegetable oils or animal fats. A synthesis of the general production process is presented in Figure 9.

Figure 9  
Block flow diagram of the 1G biodiesel production process

Source: own elaboration
The feedstock used is one of the key technical and economic factors of the process (Talebian-Kiakalaieh, Amin & Mazaheri 2013). Using a lower cost feedstock such as used cooking oil (UCO) can decrease biodiesel production costs. However, the thermal processing has negative influences on oil properties, can create different types of impurities and increase free fatty acid (FFA) and water content in the oil, which requires costly purification and separation in the downstream processing to biodiesel (Talebian-Kiakalaieh, Amin & Mazaheri 2013).

The transesterification with alkali catalysts is the conventional method for biodiesel production (Talebian-Kiakalaieh, Amin & Mazaheri 2013). However, this method causes serious problems in the purification part. The acid catalysed process is not sensitive to FFA and water content like base catalysts but the production process is much longer. Other processes such as enzymatic catalysts, non-catalyst methods or supercritical methods might show good results, but they are more expensive.

Some advances in heterogeneous catalysis have also been reported and this might be a promising technology to conventional catalysts (Aransiola et al. 2014). Recent innovations of biodiesel processes are focused on using a variety of oil feedstocks (e.g. virgin and waste oils), the development of more efficient catalysts and in the utilization of novel reaction media (Nasir et al. 2013).

2.1.2. Second generation (2G) pathways

2G biofuels can be produced via thermochemical or biochemical processes, or a combination of both, and make use of non-edible feedstocks such as agricultural and forestry residues (e.g. corn stover, unused forest harvest material, straw) and wastes (e.g. used cooking oil - UCO), as well as lignocellulose from e.g. perennial grasses (e.g. miscanthus, switchgrass) and short-rotation coppices (e.g. poplar, willow).

Bioethanol

For bioethanol, enzymatic fermentation of hemicellulose (e.g. from bagasse, corn stover, straw) is close to commercial application, while enzymatic fermentation of lignocellulose (e.g. from wood) is less developed. Global production capacity of 2G bioethanol has been reported as about 620 Ml/yr (Mizutani 2015), while an own survey based on published industry data gives a total of 690 Ml/yr (Figure 10), and the study by UNCTAD (2016) indicates a substantially higher capacity of more than 1,600 Ml/yr.

Most of the installed capacity is located in the US, as shown in Figure 10. In the US there has been particular progress for cellulosic ethanol facilities and in May 2014, the first production of EPA-qualifying cellulosic bioethanol7 was delivered (E2 2014), and several more plants became operational since then.

There are also facilities operating in Brazil (total capacity about 122 Ml/yr), China (approx. 100 Ml/yr), Germany (1.25 Ml/yr) and Italy (76 Ml/yr), as recent overviews indicate (Mizutani 2015; Hailong 2015). UNCTAD (2016) reports higher figures of about 177 Ml (Brazil), 300 Ml (Canada), 340 Ml (China), 296 Ml (EU), and 490 Ml (US).

Most of the production capacity is concentrated in large facilities but there are as well some small facilities – e.g., Janssen et al. (2013) reported in their global overview for IEA Bioenergy Task 42 nine small 2G bioethanol plants totalling 25 Ml of capacity.

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7 The US Environmental Protection Agency determines which fuel/pathway types qualify as “advanced” biofuels.
**Figure 10**  
Global map of large 2G bioethanol sites

![Global map of large 2G bioethanol sites](Image)

Source: Mizutani (2015) and Hailong (2015); data given for annual production capacity of 2G ethanol

A schematic of a 2G biochemical ethanol process is represented in Figure 11.

**Figure 11**  
Block flow diagram representation of 2G ethanol pathway

![Block flow diagram representation of 2G ethanol pathway](Image)

Source: adapted from Eggert & Greaker (2014)
In this route, cellulosic biomass is hydrolysed, fermented and distilled to produce ethanol and the solid fuel generated from the residual lignin and solid syrup (waste) can be used for generating the energy needed in the process. Cellulosic biomass can be virgin material (e.g., wood residues) or processing residues such as bagasse that come from other industries, e.g., from sugarcane processing to 1G ethanol. During feedstock pre-treatment, it is at least partially fractioned into its main components (cellulose, hemicellulose and lignin), and cellulose accessible surface area increased (Albernas-Carvajal et al. 2014). The hydrolysis allows obtaining a liquid rich xylene.

The fermentation of C6 sugars (hexoses) to ethanol is a consolidated process carried out by yeast. However, the fermentation of C5 sugars (pentose) is more challenging (Albernas-Carvajal et al. 2014), and ongoing efforts aim at processes to ferment pentose and xylose with satisfactory yields.

Most 2G ethanol facilities use agricultural crop residues (corn stover, corn cobs, wheat straw), depending on local availability (Janssen et al. 2013).

**Biodiesel**

Biodiesel can be obtained from advanced acid esterification or from oleochemical processes of all type of non-edible oils and fat wastes containing free fatty acids (FFA). Acid esterification of FFA requires high grade materials to handle the challenge of corrosion compared to conventional esterification used in the production of 1G biodiesel. Processing low quality fat waste may require additional final treatments such as distillation to increase biodiesel’s purity and quality.

Oleochemical processes, such as the hydropressuring of lipid feedstocks from oil crops, algae or tallow (Karatzos et al. 2014) are used to produce advanced biodiesel. Technology for oleochemical processes for the production of drop-in biofuels is well developed and close to commercial competitiveness. It entails low capital expenditure, compared to other emerging production routes. These processes require a simple hydropressuring step to catalytically remove oxygen from the fatty acid chains to convert them into diesel-like hydrocarbon mixtures such as Hydroprocessed Vegetable Oils (HVO) or Hydrotreated Esters and Fatty Acids (HEFA) using a wide range of waste fats and oils as feedstocks.

The HVO process produces biofuel from vegetable oils. Chemically, it entails direct catalytic hydrogenation of vegetable oils, which are triglycerides, into the corresponding alkanes. The glycerol chain of the triglyceride is hydrogenated to the corresponding C3 alkane, propane — there is no glycerol side stream. This process removes oxygen from the oil, i.e., the diesel produced is not an oxygenate like conventional 1G biodiesel (FAME). Unlike transesterified FAME, HVO diesel (or renewable diesel or green diesel) is a colourless paraffin, with a high cetane number (85 to 99). HVO renewable diesel has an easier ignition and more efficient combustion, lower cloud point, better storage stability, better cold properties, and less tailpipe NOx emissions than FAME biodiesel.

HEFA are straight chain paraffinic hydrocarbons that are free of aromatics, oxygen and sulphur. HEFA diesel offers a number of benefits over FAME, such as reduced NOx emission, better storage stability, and better cold properties. HEFA renewable diesel can typically be used in all diesel engines and its properties are similar to BTL diesel®. HEFA has also been approved for use as an aviation (bio jet) fuel (EBTP undated).

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8 See footnote 6
Alcohol to Bio-Jetfuel

Complementary to 2G ethanol and diesel, there are processes to produce bio-jetfuel, with various levels of fuel readiness. Figure 12 shows the level of fuel readiness for 2G biofuels suitable for jetfuels (Mawhood et al. 2015). Alcohol to jetfuel (ATJ) refers to the family of conversion pathways that produce jetfuel from biomass via an alcohol intermediate. Both drop-in and neat jetfuels are being targeted by ATJ developers, with some attention being paid to the potential of butanol as a jetfuel end-product, rather than an intermediate. Drop-in fuels under development include synthetic paraffinic kerosene (ATJ-SPK) and synthetic kerosene with aromatics (ATJ-SKA). A wide range of processes can be used to synthesise alcohols, depending on the characteristics of the feedstock. Once the alcohols are obtained from the biomass, they undergo a four-step upgrading process to create hydrocarbons in the jet fuel range. In general, technologies to synthesise alcohol intermediates are better developed than those to convert the intermediates to jet fuel (Mawhood, Rodriguez Cobas & Slade 2014).

Other thermochemical processes and “hybrid” thermochemical/biochemical technologies exist but are beyond the scope of this report (for more information see Karatzos et al. 2014).

Figure 12 Current fuel readiness of 2G biojet fuel conversion technologies

Fuel Readiness Level

9 Fuel Readiness level provides a descriptive hierarchy of “toll gates” designed to enable consistent comparison of technological maturity between different types of technology. This index reflects the specific range of risks affecting the development of fuels (as opposed to equipment), specifically the fuel’s chemistry and its compatibility with fuelling infrastructure and aircraft.
2.2. **INTEGRATION OPTIONS**

At a first glance, it seems possible that in the expansion of different 2G biofuels processes and facilities, synergies with 1G biofuel sites can be created. There are several options for the evolution of 1G biofuel sites. Based on de Jong (2015), this report uses the following options for the modification of sites. These options are compared with building a new stand-alone 2G facility at a new industrial site (“greenfield”) as a baseline:

- **Co-locate 1G and 2G processes.** Co-location involves installing a separate entity adjacent to an existing facility which uses part of the feedstock, feedstock infrastructure and/or utilities of the existing facility (i.e. producing 2G biofuel alongside 1G biofuel without changing the existing production line).

- **Retrofit an existing 1G process with 2G components.** This option involves altering the production line of an existing facility (e.g., by adding a ‘bolt-on’ unit), such that by-products or unutilized components of the feedstock can be used for producing 2G biofuel alongside 1G biofuel;

- **Repurpose 1G into a 2G biofuel site.** This option involves adjusting the production process of an existing (mothballed) facility to produce a different output (i.e., altering the production line to produce 2G biofuels instead of 1G biofuels).

The following figure presents the different degrees of integration.

*Figure 13  Different degrees of integration*

![Diagram showing different degrees of integration](image)

- **Co-locating:** installing a separate entity which uses part of the feedstock, feedstock infrastructure and/or utilities of the existing facility
- **Retro-fitting:** adding a ‘bolt-on’ or ‘add-on’ unit which uses by-products or unutilized components of the feedstock for alternate purposes
- **Repurposing:** adjusting the existing production process to produce a different output

*Source: De Jong et al. (2015). The figure give a schematic example of possible coproduction strategies. In some cases, a coproduction strategy may also require e.g., additional storage facilities.*
Several 2G biofuel facilities (e.g., in Brazil, Finland, US) are already co-located with 1G biofuel production facilities (see Box 1), especially for 2G bioethanol (Janssen et al. 2013), and an increasing number of US 1G biofuel companies are exploring how to retrofit their processes to incorporate cellulosic feedstocks into their production lines (E2 2014). Furthermore, 2G renewable diesel from residues and wastes (a.k.a. "green diesel") increasingly comes from HVO plants integrated into existing refineries, with either partial or complete conversion to green products.

As illustrated in Box 2, the integration strategy depends on the feedstocks used and respective processes. For bioethanol routes, many companies choose co-location strategies with 1G plants since they can share infrastructure and by-products (e.g. excess electricity and steam). Nonetheless, there are as well stand-alone 2G bioethanol facilities. Integrated strategies for other 2G routes (e.g., HVO and HEFA) are more challenging since fewer synergies might be created in the process.

### Box 2 Stand-alone vs. integrated plants

<table>
<thead>
<tr>
<th>Feedstocks and processes</th>
<th>Stand-alone</th>
<th>Integration by</th>
<th>Biorefineries</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Co-location</strong></td>
<td><strong>Retrofit</strong></td>
<td><strong>Repurpose</strong></td>
<td></td>
</tr>
<tr>
<td>Agricultural residues to 2G bioethanol</td>
<td>Abengoa, Hugoton, Kansas (US); Beta Renewables Crescentino, (IT)</td>
<td>DuPont, Nevada, Iowa (US) &amp; POET-DSM, Emmetsburg, Iowa (US): corn stover, co-located to 1G corn plant</td>
<td>Inbicon (Dong Energy) collocated with CHP plant</td>
</tr>
<tr>
<td>Sugarcane to 2G bioethanol</td>
<td>Granbio (BR)</td>
<td>Raizen – Costa Pinto (BR): collocated with 1G bioethanol plant (see Box 2)</td>
<td>Biocarburantes de Castilla y León (ES), integrated with 1G bioethanol plant</td>
</tr>
<tr>
<td>MSW to bioethanol</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woody residues to 2G diesel</td>
<td>UPM: Lappeenranta (FI): crude tall oil, co-located with pulp&amp;paper mill (see Box 3)</td>
<td></td>
<td>ENI Venice (IT) and Neste Oil, Rotterdam &amp; Singapore: conversion of oil refinery</td>
</tr>
<tr>
<td>Waste oil to HVO</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources: own elaboration based on Janssen et al. (2013) and companies’ websites
2.3. **INTEGRATION STRATEGIES**

Processes for the production of bioethanol are different than processes for biodiesel production so the implications of integration of 1G and 2G processes are quite different as well. The chosen integration strategy is a key factor for success and it may combine different plant or process modifications depending on the specific characteristics of the technology and facility.

Taking into account technical and economic factors, participants in the study survey deemed the conversion of bioethanol sites more favourable than the conversion of biodiesel sites, as illustrated in Figure 14. The expansion of starch bioethanol sites to include cellulosic bioethanol is perceived as the most favourable option followed by a similar expansion of sugar bioethanol sites.

*Figure 14*  **Suitability of various 1G biofuels sites conversion into 2G biofuels plants**

Under the classification of other options for integration, a participant considered that modification of 1G biofuel sites to be able to accommodate Biomass to Liquid (BtL) technologies is not a favourable option. Some participants also mentioned that 2G technologies can be integrated in other industries such as the pulp&paper industry. The integration of 2G biofuel processes into 1G sites can especially benefit from using common logistics systems and potentially co-using existing infrastructure. However, there are significant differences in these benefits depending on the particular technology pathways chosen.

**2.3.1. Bioethanol sites**

*Co-location*

Integration strategies involving co-location options for sugar and starch bioethanol sites with cellulosic bioethanol might bring synergies and economies of scale in terms of logistics, energy, fermentation, wastewater treatment, and biomass use. In the case of 1G bioethanol sites, the possibilities to take advantage of the product distribution system, the logistics system for feedstock supply and storage, the common use of auxiliary energy systems (steam and electricity), and the re-use of some ancillary equipment were considered high by the survey respondents (see Figure 15). The product distribution system is the element considered to have the largest synergies.
The primary change required for conversion will be to the primary feedstock being converted in the bioethanol process. However, it is also typical that longer processing/fermentation times and lower final product concentrations mean that the core fermentation and distillation assets will need to be expanded to maintain overall bioethanol production rates.

As a case study, **Box 3** illustrates the strategy followed by Raizen for a 2G sugarcane plant in Brazil.

**Box 3: Sugarcane 2G bioethanol co-located Raizen plant in Brazil (Commercial)**

The Raizen Plant co-located with the Costa Pinto sugar/ethanol mill in Piracicaba uses bagasse and sugarcane residues (straw) as feedstock. In 2012 the demonstration activities started, and in 2014 the construction of the co-located Costa Pinto 2G ethanol facility started. The investment in the plant was about 56 M€ and a production capacity of 42 Ml/yr was expected. In October 2014 the fermentation of hexoses was completed and in October 2015 completion of process for fermentation of pentoses was expected. The plant has already validated the pre-treatment technology for biomass and also the enzymes supply. Still, there are challenges with logistics and supply of primary sugarcane residues and fermentation of pentoses sugars.

The Raizen group expects to continue working in the 2G bioethanol sector and plans to produce 1 bl/yr of 2G bioethanol, sell the technology to other industries, optimize the process to maximize economic performance and integrate with the chemical industry.

**Retrofitting and partial repurposing**

Integration strategies involving retro-fitting and partial re-purposing have two ways of integrating starch-based 1G and 2G bioethanol technologies, as shown in Figure 16 (Lennartsson et al. 2014):

- **Retrofitting and integration at the fungal cultivation stage.** In this case, the core of the 1G process remains untouched, thus minimising pentose-rich process streams and risks of contamination.
- **Partial repurposing with integration at the fermentation stage.** In this case, lignin and undigested cellulose will pass through the entire process.

As shown in the Figure 16 and Figure 17, production of 1G and 2G bioethanol implies different processes and different feedstocks so the joint use of equipment is challenging.

*Figure 16 An integrated 1G and 2G bioethanol process*

**Source:** Adapted from Lennartsson et al. (2014); integration could occur at the fungal cultivation step (alternative 1) or at the fermentation step (alternative 2)

**The pre-treatment of lignocellulose is key in all the integration processes.** Chemicals and enzymes used here require attention in order to prevent negative influences on the quality of the DDGS used as animal feed product (Lennartsson et al. 2014).

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10 Lennartson et al. (2014) propose food-related fungi (filamentous Zygomycetes and Ascomycetes) for this, and to produce fungal biomass as a high-grade animal feed from the residues after the distillation (stillage).
An important challenge in 2G ethanol processes is obtaining sufficiently high sugar concentrations after the hydrolysis. To a large extent, this is solved by integrating 1G and 2G processes, since sufficiently high concentrations are easily reached in 1G processes (Lennartsson et al. 2014). However, a potential integration of 1G and 2G bioethanol processes does not solve the problem of how to ferment pentoses (Lennartsson et al. 2014). Co-fermentation of pentoses and hexoses is not yet commercially proven. However, the pentoses could also be used for the production of compounds other than ethanol at later stages in the process.

The integration of sugar-based 1G and 2G bioethanol processes can adopt retrofitting strategies as well, as shown in Figure 17.

**Figure 17**  Block flow diagram of integrated sugarcane 1G and 2G bioethanol production process

Source: own elaboration from Dias et al. (2013). Note: double lines represent alternatives for pentose use

A key characteristic of the sugarcane bioethanol production process is that all plant matter of sugarcane is processed when delivered to the mill (note that in 1G mills leaves are not harvested).

The cane juice obtained is processed to obtain ethanol, while the bagasse can be used for cogeneration of heat and electricity or production of 2G bioethanol (see Figure 17).

Sugarcane mills are flexible and can deliver bioethanol and/or sugar depending on the market condition. At present, the market for sugar is limited so facilities need to produce 1G bioethanol from sugarcane, which favours 2G integration.

While the most used integration strategy in Brazil is the co-location of 1G and 2G facilities in one site, there is the industrial vision to progress to a more integrated process also using retrofitting strategies.

This is illustrated in the following Figure 18, where the different stages (“waves”) of development for sugarcane bioethanol in Brazil are shown (Leite 2015).
The Brazilian industrial vision for the integration of 1G and 2G bioethanol technologies allows also the integration of heat and water supply and a higher surplus of electricity production (Albarelli et al. 2014), which could also be options for non-sugarcane ethanol plants. Yet, feeding solid biomass to reactors continues to be a challenge and the commercially available equipment does not necessarily integrate easily into new processes (Leite 2015).

Despite this, fermentation of all biomass matter is technologically feasible. The key issue is to increase existing production with cost effective technology that would allow proper fermentation of the combined feedstock.

### 2.3.2. Biodiesel sites

#### Co-location

The most promising technology pathway for the conversion of 1G biodiesel sites to allow renewable (green) 2G diesel production is the HVO process. Yet, even HVO diesel plants may take advantage only of ancillary equipment existing in a 1G biodiesel site. This is because both production processes are very different in their technology, so that equipment and facilities of a 1G facility has little utility for 2G HVO/HEFA renewable (green) diesel production. Both type of processes use oils as feedstock though, therefore most of the logistical infrastructure can be used jointly. Also, the product distribution infrastructure could be of common use.

The conventional transesterification process requires lower temperatures and pressures compared to HVO, i.e. the equipment used in the core process of 1G FAME biodiesel production cannot be used for HVO. Therefore, an integration strategy using co-location options is the most suitable strategy for the modification of 1G biodiesel sites.
Accordingly, respondents to the study survey rated the re-use of ancillary equipment, logistics and distribution systems in biodiesel sites lower than for bioethanol (see Figure 19).

**Figure 19  Possibilities to re-use 1G biodiesel plant equipment, logistics, and distribution systems for 2G integration**

![Chart showing possibilities to re-use 1G biodiesel plant equipment, logistics, and distribution systems for 2G integration.](image)

Note: 0: unfavourable – 5 very favourable. Number of responses: 12

*Source: own elaboration from the survey*

**Retrofitting and partial repurposing**

It is possible to retrofit or partially or fully repurpose current conventional biodiesel plants by turning them into feedstock flexible plants that can co-process waste fats. The conversion must be tailor made and has several complexities. The modification of a single unit in an existing plant will influence other units, therefore a high level of expertise and understanding of the chemistry of biodiesel production is required. Successful biodiesel retrofit projects are characterised by enlarging feedstock flexibility and improving product quality, as well as by avoiding unstable process operations, off-spec products and extended down-times. An example of

**Box 4: Retrofitting Elin biofuels 1G biodiesel plant of 33 ktonnes/year to co-process waste fats.**

BDI – BioEnergy International AG - has specialised in biodiesel retrofitting projects. One of them is the Elin biofuels plant in Volos, Greece. The aim of the RetroFit optimisation project was to increase both raw material flexibility and the quality of the final biodiesel product via the remodelling, expansion and process optimisation of an existing biodiesel plant that was based on outdated German technology.

The retrofitted plant has a capacity of 33,000 tonnes/year and can co-process 1G vegetable oils with raw materials of lower quality, such as used cooking oil and animal fats. The quality of the distilled biodiesel satisfies the quality requirements set by the standard EN 14214. Cost-wise, the retro-fitted plant represented an investment of the order of 3.6 M€, while a brand new 2G biodiesel plant of similar production capacity processing animal fat would require an investment of 21 M€.

*Source: Interview with BDI*
Another option for the evolution of 1G biodiesel sites mentioned by some of those interviewed is retrofitting with plastic production processes. This option is not analysed in this report, but could be an interesting subject to conduct research on.

2.3.3. Integration of 2G biofuels in other types of installations

Both 2G bioethanol and 2G biodiesel can also be integrated in the pulp & paper industry and in refineries.

UPM’s 2G renewable diesel plant (see Box 5) is integrated into an existing pulp & paper mill, and many wood processing industries are interested in using advanced Fischer-Tropsch processes to convert their residues into BTL fuels, although this development is in an early stage.

In Canada, the Woodlands Biofuels demo plant\textsuperscript{11} uses gasification to convert wastes into 2G bioethanol, and Tembec in Quebec\textsuperscript{12} extracts chemicals from spent sulphite liquor of a pulp & paper mill for conversion to bioethanol.

\textbf{Box 5: Wood residues (tall oil) to 2G renewable diesel. Lappeenranta Biorefinery, UPM (Commercial)}

This UPM first-in-class biorefinery is located on the same site as the UPM Kaukas pulp and paper mill. The technology used is based on UPM innovation. The crude tall oil used as feedstock is a residue of chemical pulping process containing natural extractive components of wood. During the pre-treatment the crude tall oil is purified. After that it is hydrotreated with the supply of water. Reaction water is separated and directed to water treatment. During the fractioning, remaining hydrogen sulphide and non-condensable gases are removed. The remaining liquid is distilled to separate 2G diesel. The total UPM investment raised 175 M€ and the diesel production is 120 Ml/yr. Total direct and indirect jobs sum up to 200 persons.

\textit{Source: http://www.upmbiofuels.com/biofuel-production/biorefinery/Pages/Default.aspx}

HVO diesel is already integrated in several oil refineries for its blending with fossil diesel, e.g. Total in France, Preem in Sweden, ConocoPhillips in Ireland, Cepsa and Repsol in Spain or Galp in Portugal. The process is referred to by oil refineries as “co-processing”, a technique allowing for HVO production using the desulfurization unit of oil refineries. Vegetal oils are directly mixed with fossil diesel in these units. Co-processing is much easier to implement than pure HVO production and has also lower CAPEX. It mainly uses the hydrogen produced on site in the fossil refining units, thus limiting the sourcing needs. However, it requires the use of already refined oils which, in turn, increases the feedstock price. At the same time, the HVO is already blended into the final product so it cannot be sold as pure HVO or used for improving the diesel quality by blending in higher amounts.

Apart from the reasons connected to the HVO’s superior quality over regular fossil diesel, the investments in co-processing are also caused by financial and social reasons.

\textsuperscript{11} \textit{See http://www.woodlandbiofuels.com/process-overview.html}

\textsuperscript{12} \textit{See http://www.tembec.com/}
Fossil oil refineries especially in Europe are facing overcapacity and liquidity issues which limit the profitability of the plants. Co-processing HVO allows them to become profitable and compete more successfully on the market. Co-processing of HVO in no-longer-profitable oil refineries has saved workplaces by preventing closures. It results in an improved social image of oil companies and gives them some political advantage. This phenomenon is especially visible in projects implemented in the south of Europe (ENI in Italy, Total in the south of France, Repsol in Spain, see Box 6).

**Box 6: Co-processing HVO at Repsol’s oil refineries in Spain**

Repsol has been co-processing HVO in its Spanish refineries since 2012. The main reasons for implementing co-processing are to obtain a quality blend that works better in the existing automotive park while also improving the cost competitiveness of their refineries.

Their plan is to replace 1G vegetable oils with used oils and animal fat. This step will require some modifications in their refineries and extra pre-treatments for the new feedstock. Some uncertainty exists with respect to the specific fractions of products from the reactor after changing feedstock. Ongoing research is supposed to give the answer and will allow them to plan the best course of action. Their longer term goal is to use pyrolysis oil from lignocellulosic residues (forestry/agricultural).

*Source: Interview with Repsol*

### 2.4. BOTTLENECKS

Aside from the already identified technical bottlenecks in the analysis of integration strategies, economic bottlenecks also exist. Main economic bottlenecks are related to the fact that high investments are required to produce 2G biofuels, while their final price remains the same as 1G biofuels.

Key bottlenecks identified by survey participants are:

- **Raw material costs and security of supply** (primary economic bottleneck) – here, the price stability and availability of raw material are important. Costs to overcome logistical restrictions such as road, rail and waterway infrastructure may constrain development.
- **More expensive and complicated technology** (e.g., enzymes are critical in the bioethanol biochemical processes) - this also implies additional investment for technology change and this investment cost is high. Particular attention has to be paid to erosion/corrosion of high-wear equipment (Mizutani 2015).
- **Higher energy demand** – this can be met at least partially by using unconverted residues such as lignin, though.

Several 2G processes are based on not yet fully mature technologies so there might be unwillingness to take an active 1G facility producing biofuels with a known value offline for conversion, and 2G biofuels have currently unclear market value.

### 2.5. ONGOING AND PLANNED SITE CONVERSIONS

From the technology point of view, in the case of bioethanol and AJF, most process facilities already exist in the 1G site and the installation of pre-treatment units needed for 2G bioethanol production are technically feasible.
There are ongoing activities on the integration and conversion of starch bioethanol sites and cellulosic bioethanol, e.g., the commercial activities of DuPont and Abengoa\textsuperscript{13}.

Also, there is a limited number of ethanol plants being retrofitted to produce biobutanol and/or adding on small elements of cellulosic processing, e.g., Gevo\textsuperscript{14}, Green Biologics and Butamax. There are as well operational demonstration plants producing cellulosic ethanol from municipal solid waste (e.g., Biocombustible de Castilla y León and Enerkem\textsuperscript{15}, and INEOSBio in Florida USA making syngas from MSW and fermenting it to ethanol).

There are refineries in Italy\textsuperscript{16}, France\textsuperscript{17} and USA\textsuperscript{18} that are being adapted to the production of biodiesel and jet fuels. Box 7 illustrates the activities carried out in La Mède refinery in France.

**Box 7: La Mède refinery by Total (France)**

An investment of €200 million to transform the La Mède refinery is planned by Total to convert existing units to produce HVO. Even if some petroleum product refining operations will be maintained, a biorefinery with a capacity of 500,000 t/yr will manufacture renewable diesel primarily from used oils. The HVO process selected by Total is a French technology developed by Axens.


### 2.6. CURRENT R&D ACTIVITIES

R&D efforts focus on the different stages of production processes, but do not generally aim at tackling issues related to conversion or integration of 1G biofuel sites for 2G biofuel production. R&D efforts address optimising 2G processes rather than to integrate 2G biofuels into already existing facilities. 2G research activities are not only carried out in North America and Europe, but also in other emerging economies such as Brazil, China, Thailand and Mexico (UNCTAD 2014).

The 1G biodiesel industry constantly develops their ability to use lower-cost feedstocks, such as used cooking oil, in addition to the traditional rapeseed or soybean oils. HVO producers, especially Neste Oil, have a strong focus on using waste and residue fats and oils in addition to traditional (virgin) vegetable oils. Renewable jetfuels and HEFA are products under development and R&D, but their introduction to large-scale production requires additional demand from the customer side.

\textsuperscript{13} http://www.abengoabioenergy.com

\textsuperscript{14} http://www.gevo.com/about/our-business/production-sites/

\textsuperscript{15} http://enerkem.com/


\textsuperscript{18} AltAir Paramount facility: http://altairfuels.com/
Particular research is performed around bottlenecks such as:

- Lignocellulosic biomass logistics: Even if this is not limited to 2G processes, biomass supply is a key concern in most 2G facilities. Research has shown that there are opportunities to optimize the costs related to lignocellulosic feedstock logistics (Lamers et al. 2015).
- Enzymes production (and respective efforts to reduce this cost) by Abengoa (see Abengoa Bioenergy New Technologies 2015), Novozymes, and DuPont.
- Lower-cost and higher efficiency Fischer-Tropsch processes to convert residues and wastes in the pulp & paper industry – especially black liquor – into synthetic BTL diesel.

Furthermore, research indicates that multiple benefits could be obtained from integrating biodiesel/renewable diesel and bioethanol production processes in the oilseed processing industry (Granjoa, Duarte & Oliveira 2014).
3. COSTS AND BENEFITS

There is high variability in production costs of biofuels, depending on feedstocks and technologies. In general, 1G production costs are quite high in developed countries, while in Brazil and other developing countries, their costs are lower than in the OECD countries\(^\text{19}\) and might be competitive with fossil fuels. There are several reasons for this, such as lower feedstock production costs or lower labour costs.

**Production costs of 2G biofuels are highly variable** depending on technologies and feedstocks, and there is very limited information about commercial production costs for 2G bioethanol. The uncertainty in cost estimates is higher for 2G than 1G biofuels, and very limited data exists on commercial plant performance for 2G biofuels. Some cost categories depend on local conditions, so variability occurs between regions, but convergence of cost can be expected when the industry matures (de Jong et al. 2015).

In comparison with 1G biofuels, 2G pathways depend on more high-cost technologies so that even if they use lower-cost feedstocks, their total costs are higher (UNCTAD 2014). However, there are promising costs reduction potentials for 2G technologies, while 1G biofuels are in general well optimized (IPCC 2012).

3.1. GENERAL COSTS FOR 1G AND 2G BIOFUELS

Several modelling exercises have been carried out to investigate production costs of biofuels in the short- to longer-term. [Error! Reference source not found.](#) shows current 2015 and expected 2020 costs for different biofuel pathways.

Festel et al. (2014) showed that total production costs of various 1G and 2G biofuels are primarily driven by feedstock prices.

Conversion costs are only of minor importance for 1G biofuels, while relevant for 2G ethanol, HVO, and especially BTL (Figure 20), particularly by 2020 assuming larger production scales. The competitiveness for 2G biofuels will additionally increase mid- to long-term due to learning curve effects. The Brazilian sugarcane experience deserves particular attention (see Box 8).

\(^{19}\) For example, the current cost of bioethanol production is about 0.18 US$\text{/l} in Brazil, 0.28 - 0.46 US$\text{/l} in China, and about 0.44 US$\text{/l} in India, roughly comparable to the pre-tax prices of gasoline and diesel in these countries (UNCTAD 2014). Variability of petroleum fuel prices are not considered in this report.
There are several variabilities in 2G sugarcane ethanol costs (Clariant 2015):
- Pre-treatment: supply costs of chemicals, steel quality and cost
- Hydrolysis: transportation & logistics cost of enzymes, process optimization
- Fermentation: sugar separation and concentration
- Distillation: waste water treatment and vinasse, sufficient energy production, quality of lignin.

A major challenge for 2G cellulosic ethanol is the cost reduction of enzymes (e.g. Lennartsson et al. 2014; Milanez et al. 2015). Additionally, transport and logistics cost and exchange rates are crucial for Brazil (Clariant 2015).

The current production cost of 1G sugarcane bioethanol is estimated to be about 0.27 €/l – 0.34 €/l\(^2\) (Milanez et al. 2015; Mizutani 2015).

In the medium- to long-term, costs of 1G sugarcane bioethanol are expected to be reduced, but the cost of 2G sugarcane bioethanol is expected to fall more sharply to become competitive with 1G bioethanol from 2020 onwards.

Results from other authors (Mizutani 2015) also expect that 2G sugarcane bioethanol is competitive with 1G from 2018 onwards when the price could reach 0.27 €/l.

\(^{20}\) Constant Exchange rate of Brazilian real/Euro considered in this study at 0.25 €/real
Figure 21  Estimation of production costs for 1G, 2G bioethanol in Brazil

Source: Own representation based on Milanez et al. (2015)

Production costs estimations for **renewable jet fuel (RJF) pathways** in greenfield plants also vary, depending on the technology, as shown by de Jong et al. (2015). In this analysis, HEFA performed well due to high yield and few chemical transformations required to convert oil feedstocks to RJF, while the Direct Sugars to Hydrocarbons (DSHC) pathway showed the highest cost\(^2\).

De Jong et al. (2015) showed clearly the importance of various costs categories (feedstocks, capital expenditure - CAPEX, and operating expenditure - OPEX) which highly varies among technologies, and also analysed the cost for plants based on mature technology and “pioneer” (first of its kind) plants, concluding that pioneer plants show significantly higher cost. Most relevant differences were found for capital intensive technologies (e.g., ATJ) and technologies with high technological complexity (e.g. BTL).

None of the conversion pathways investigated by de Jong et al. (2015) are expected to reach price parity with petroleum-derived jet fuel in the short term.

\(^2\) De Jong et al. (2015) used the “Minimum Fuel Selling Price” (MFSP) which represents the cost price at which products need to be sold to achieve a zero equity net present value. The authors found a MFSP of 30 €/GJ for HEFA, and 140 €/GJ for DSHC.
### 3.2. Costs of Site Integration

Integrating 1G and 2G technologies might have several economic benefits both in the capital costs and operation costs. For example, when co-locating plants CAPEX can be reduced by utilizing existing equipment and savings might be derived via labour, warehousing, site development and wastewater treatment facilities.

Several authors have analysed and modelled the costs of different degrees of biofuel plants integration for various feedstocks and conversion routes. For example, de Jong et al. (2015) modelled various RJF pathways in Europe, finding integration strategies to decrease cost by 4-8% compared to greenfield production for plants based on mature technology, and 5-8% for pioneer plants (See Figure 22).

**Figure 22**  Cost reduction by co-locating compared to greenfield RJF production

![Cost reduction by co-locating compared to greenfield RJF production](image)

*Source: de Jong et al. (2015). Note: data averaged over all production locations; FT: Fischer-Tropsch; ATJ: Alcohol-to-Jetfuel; DSHC: Direct Sugars to Hydrocarbons*

The reduction can largely be ascribed to a reduction of total capital investment and related costs (e.g. maintenance). Consequently, the most capital-intensive technologies (i.e. FT and ATJ) show the largest cost reductions. The reduction in MFSP for pioneer plants is on average 1.4 percent-points larger than for plants based on mature technology, mainly because pioneer plants are generally more capital-intensive. In absolute terms this represents a considerable reduction, since MFSPs for pioneer plants tend to be substantially higher than those for plants based on mature technology. Integration of process units and material and energy flows is expected to lead to further cost reductions. Whether energy is generated in the process and offers surpluses that might be sold to the grid is a key factor of the plant economy.

The benefits of integration in terms of CAPEX was also highlighted by most of the participants in the survey. When sharing utilities between 1G and 2G plants, some investments can be saved. However, additional investment in biomass pre-treatment and new process steps can offset the initial savings.
The costs also depend on local conditions (e.g. feedstock prices, labour costs), so sometimes integration strategies exceed greenfield production costs. Beyond integration strategies, site-specific optimization could yield much higher cost reductions given the immaturity of the technologies, i.e. there are options for a “technology learning curve”.

The cost of feedstocks was highlighted as a major bottleneck by some survey participants. These costs are highly dependent on the company’s supply strategy, i.e., whether they own land and have an integrated feedstock supply system, or rent land for their own cultivation, are supplied from trading in the market, or use by- or co-products (e.g. black liquor in the case of the pulp and paper industry or bagasse in the case of sugarcane ethanol). Depending on context, volumes of raw material required in a 2G facility might be large enough to compete with other uses that are able to pay more for the feedstock, and as a result, feedstock costs can escalate significantly, thus compromising the profitability of the plant.

The economy of dry mills for bioethanol from grains depend on their by-product DDGS, sold as animal feed. Therefore, in the integration strategy much attention has to be paid to not negatively influencing the value of the DDGS coproduct (Lenartsson et al. 2014; Wallace et al. 2015). This puts restraints on the choice of pre-treatment of lignocelluloses and utilizing the pentose sugars by food-grade microorganisms (Lenartsson et al. 2014).

For corn bioethanol, research showed that co-location might be a promising option: Ou et al. (2014) determined that bioethanol production costs in co-located mills can be reduced by 34 % with respect to 2G mills, depending on stover-to-grain mass ratios. This reduction in costs is because of sharing electricity and steam generation units. Participants in the survey reported that retrofitting and co-location could generate savings of 40 % CAPEX, which represents roughly a 20% total cost reduction.

The possibilities of producing integrated sugarcane bioethanol have been explored in Brazil. As discussed in the previous section, Brazilian 2G biofuels production costs are expected to be competitive with 1G production costs in the medium-term and commercial activities have already started. Overall figures of different sugarcane ethanol configurations are shown in Box 9.

**Box 9: Capital costs of stand-alone vs. co-located 2G sugarcane bioethanol plant in Brazil**

The experience from commercial 2G sugarcane bioethanol plants in Brazil demonstrates that the cost of building a 2G plant co-located with a 1G plant is much lower than building a 2G plant from scratch. The stand-alone Granbio 2G plant in Alagoas (cluster model, in the middle of a sugarcane region) required an investment of 237 M€ for an annual production capacity of 82 Ml. The investment in the Raizen 2G plant, co-located with the Costa Pinto mill in Piracicaba, was 56 M€ for a production capacity of 40 Ml. This results in an investment of 2.9 €/l capacity for a stand-alone and 1.4 €/l capacity for a co-located sugarcane ethanol plants. Even if the production capacity of the stand-alone plant was double that of the co-located plant, the capital cost per litre of stand-alone plant was double that of the co-located plant.


In integrated sugarcane facilities several operations can be shared between both plants, e.g., sugar concentration, fermentation and distillation, utilities and storage (Dias et al. 2013).
Modelling of production costs of integrated and stand-alone sugarcane mills has been conducted by Milanez et al. (2015).

The main factors playing a role in bioethanol production costs are CAPEX and feedstocks. CAPEX is higher for stand-alone 2G plant than for an integrated 1G-2G facility, while feedstock costs are higher for an integrated 1G-2G plant (0.15 €/l) than for a stand-alone facility (0.10 €/l). Milanez et al. (2015) also project a major reduction in enzymes cost over time (from 0.1 €/l to 0.05 €/l)22 which reduces 2G bioethanol costs both for stand-alone and integrated 1G-2G plants.

Another way to integrate 1G and 2G biofuels production is by means of the so called biorefinery. Joint production of biochemicals and biofuels in a biorefinery is more robust to market volatilities as these plants can serve both chemical and fuel markets (de Jong et al. 2015). The biorefinery concept can stimulate overall 2G biofuels development by enabling producers to gain experience with biofuel production while enjoying the higher profit margins of biochemical coproducts (de Jong et al. forthcoming). However, a biorefinery might have the basic strategy of maximizing the conversion of the biomass feedstock to specialty chemicals, leaving only minimal side streams to energy products (Rodsrud, Lersch & Sjode 2012). This approach has worked well for Borregaard (Norway) and could an interesting pathway for other investors in the future.

In summary, the production cost benefits of 2G bioethanol integration into 1G sites have been identified in the literature in a range of 5-10%, compared to a stand-alone greenfield plant.

Integrated biodiesel

As discussed in previous sections of this report, options to integrate 2G diesel technologies (biodiesel or renewable or green diesel) into 1G facilities are very limited from the technical point of view. Thus, as the HVO and HEFA processes are very different from the FAME process, a conversion of a FAME facility would be about as costly as investing in a new HVO or HEFA facility.

However, there are opportunities to integrate HEFA production into current petroleum refineries. For example, ENI in Italy reports 80% investment cost reduction for their renewable diesel facility due to utilization of existing refinery assets.

In the case of pulp and paper industries that apply integrated strategies for the production of 2G biofuels, participants in the survey have reported savings of up to 50 % of CAPEX (without further specification, though).

3.3. EMISSIONS SAVINGS

The impact of integration strategies on emissions – especially those of greenhouse gases (GHG) – have not been subject to analysis in the current literature, as the key reasons for integration are cost savings and reduction of investment risks (see previous section). Yet, integration improves the opportunities for 2G biofuel plants so that the GHG balance compared to 1G biofuels are of interest.

22 Data provided in USD. Exchange rate €/US$ considered at 0.8
Typically, emission savings of 1G and 2G biofuel plants are determined vis-à-vis conventional (fossil) fuels such as gasoline, diesel, and jet fuel as reference systems. There is a huge variety of scientific work on general life-cycle analysis (LCA) concerning overall emission impacts (e.g. acidification, eutrophication), and even more LCA work focusing on GHG emissions.

3.3.1. Overall emission balances

The literature on the overall emission balances of biofuels is exhaustive, but in general, 1G biofuels show higher potentials for acidification, eutrophication and photochemical oxidation than fossil fuels, while residue- and waste-based 2G biofuels perform significantly better (Karp et al. 2015). This is exemplarily shown in Figure 23 for the case of sugarcane-based bioethanol.

For crop-based 2G biofuels, respective results depend much on the cultivation system, but perennial crops such as grasses and short-rotation coppices tend to have lower acidification and eutrophication potentials than their fossil competitors (Morales et al. 2015).

![Relative environmental impacts of flex-fuel vehicles using butanol, ethanol, and gasoline](image)

Source: Pereira et al. (2014). Note: 1G2G ethanol: integrated 1G-2G ethanol; 1G2G-B butanol: integrated 1G and 2G ethanol production process with butanol production using all anhydrous ethanol as feedstock.

3.3.2. GHG emission balances

The GHG emissions of 1G biofuels in comparison to fossil fuels depend mainly on the biomass feedstock, while for 2G biofuels, key impacts come from the operation of conversion plants23.

Key issues for crop-based biofuels – both 1G and 2G – are potential effects from indirect land use changes (iLUC) which can be significant (Ahlgren & Di Lucia 2014; CARB 2015; JRC 2015; Searchinger et al. 2015), but there are also interesting options to prevent iLUC, especially by using underutilised or marginal land, and intercropping (IEA Bio 2015; Wicke et al. 2015).

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23 This assumes that 2G feedstocks are mainly residues and wastes. If dedicated energy crops such as perennial grasses and short-rotation coppices are used as 2G biofuel feedstocks, the GHG balance depends on the type of land use change (if any) associated with the cultivation of the crops.
For 2G biofuels using forest-based feedstocks, potential carbon changes in the forest (“C debt”) are relevant (Buchholz et al. 2015; Gaudreault & Miner 2015; JRC et al. 2014). Withers, Malina & Barrett (2015) showed that depending on forest operations, GHG emissions of wood-based 2G biofuels can be significant. Yet, low-GHG emission feedstocks from forests exist, especially unused harvesting residues, and – in temperate and tropical forests – pre-commercial thinnings (Matthews et al. 2015; Ter-Mikaelian, Colombo & Chen 2015).

2G biofuels based on residues and wastes in the EU typically perform much better in terms of GHG reduction than crop-based pathways, achieving up to 95% GHG reduction compared to fossil fuels (Baral & Malins 2014). Recent analysis by Plevin & Mishra (2015) found similar results for the US. For sugarcane-based 2G bioethanol in Brazil, GHG emissions also appear very low (Cremonez et al. 2015).

De Jong et al. (2015) indicate that, depending on the specific pathway, integration of 2G with 1G biofuel technologies can lead to 40-60% GHG emission savings for bioethanol compared to fossil gasoline (but excluding iLUC effects)

### 3.4. IMPACTS ON LAND-USE

Integration strategies of 1G to 2G biofuel sites will deliver different impacts on land use depending on the integration strategy and the feedstock used. Assessing implications on land is a complex exercise that depends on a list of factors such as the feedstocks (and replaced feedstocks), the biofuel integration strategy, the technology applied and the methodology of the analysis.

A qualitative systemic approach to this is given in Table 1. Given the lack of data, impacts on land use by different technologies has not been considered in this analysis.

The system boundaries are important when assessing impacts on land-use and need to be the same among the different feedstocks/conversion strategies analysed.
Table 1  Land implications of different biofuel integration strategies depending on feedstock type

<table>
<thead>
<tr>
<th>Categories</th>
<th>Example</th>
<th>Overall implications on land use</th>
<th>Co-location</th>
<th>Retrofitting</th>
<th>Repurposing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not related to land use</td>
<td>Wastes (e.g., UCO) and residues (e.g., MSW)</td>
<td>No major implications (if no displacement)</td>
<td><em>Ceteris paribus</em>, no major direct implications other than for greenfield separate 1G and 2G plants</td>
<td>No major impacts on land since waste/residues are used (important to define system boundaries)</td>
<td>No major impacts on land since waste/residues are used (important to define system boundaries)</td>
</tr>
<tr>
<td>Primary residues (from harvesting)</td>
<td>Straw from corn or wheat</td>
<td>Depending on the current use of the residues and respective displacement effects</td>
<td></td>
<td>Could deliver positive impacts, depending on grains/residue use balance and displacement of (current) residue use (e.g., for livestock feeding and bedding)</td>
<td>Potentially benefits on land use if corn and grains are not used</td>
</tr>
<tr>
<td>Secondary residues (from processing industry)</td>
<td>Bagasse from 1G ethanol processing</td>
<td>Depending on alternative scenarios for current use of e.g. bagasse</td>
<td></td>
<td>Potentially positive impacts if sugarcane leaves are used</td>
<td>This is not a suitable alternative for 1G bioethanol</td>
</tr>
<tr>
<td>Dedicated lignocellulosic crops</td>
<td>SRC (e.g., poplar, willow), energy grasses (e.g., sorghum)</td>
<td>Depending on the type and amount of land used</td>
<td></td>
<td>Additional land is needed</td>
<td>Potentially benefits on land use if corn and grains are not used</td>
</tr>
</tbody>
</table>

Source: own elaboration

The potential of waste feedstocks is limited (they depend on other principal supply chains) and might also lead to indirect effects if these materials were already used in other sectors. Waste feedstocks might occur in smaller amounts and be unequally distributed. On the other hand, new production sites might need a larger size to benefit from economies of scale.

When primary residues (either agricultural or forestry residues) are used, the impacts on land use will depend on the integration strategy. The highest potential benefits on land use could be obtained when 1G plants using corn or wheat as feedstock are repurposed to use the residues of the cultivation of the main product (straw from grains). Different implications on land would be found if these plants were retrofitted to use lignocellulosic energy crops.

In any case, the use of residues should take into account sustainability considerations such as the amount of residues to be left on the ground to protect soil properties.

Retrofitting options also can deliver potential benefits. Displacement effects of using these residues (e.g. thinning used by the pulp and paper industry) have to be taken into account. Again, the methodology used in the calculations (e.g. whether straw is considered as a by-product or co-product) and system boundaries might deliver different results.
In the case of sugarcane ethanol, benefits on land use could be obtained when using sugarcane leaves in co-located or retrofitted plants.

In the case of using lignocellulosic energy crops, impacts on land use will depend on the type of land used (whether abandoned land is used) and the energy crop’s productivity. As indicated by one of the participants in the survey, iLUC effects are significantly reduced when using non-food lignocellulosic crops. *Ceteris paribus* the higher the productivity of energy crops the lower the amount of land needed. In this case, again, the assumptions about the biofuels inclusion/replacement are important on the results.

3.5. OTHER ASSOCIATED BENEFITS

The conversion of sites seem to bring some benefits, but the responses from the qualitative stakeholder survey gave no clear trend. This might be attributable to the different outcomes for the different feedstocks, pathways and integration strategies, as discussed in previous sections.

Some survey participants indicated that the primary benefit that conversion should bring is to improve plant economics and respective commercial sustainability, because profitability is one of the key elements in the decision-making process.

Integration might bring a more efficient use of feedstocks. In the case of sugarcane, e.g. the use of bagasse for 2G biofuel production can enable a better performance of the whole process. This might be true as well when straw from grain cultivation is used without causing displacement effects.

Employment and local economy could be positively impacted by integration strategies. Thus, some stakeholders indicated that local employment (due to construction and operating activities, including the supply of feedstock) is a relevant impact category.
4. BUSINESS CONSIDERATIONS

Decisions for the integration of 1G and 2G biofuel sites do not depend only on the technical feasibility or the costs of integration. Business considerations are as important and sometimes the only deciding factor for modifying a 1G biofuel site. Business considerations for the integration of 1G and 2G bioethanol plants for the production of fuels for dedicated fleets or for aviation, and the co-location of 1G biodiesel and HVO production sites are explained in the next sections.

4.1. BIOETHANOL FOR DEDICATED FLEETS OR FOR JET FUELS

The US produces a very large amount of 1G bioethanol. The ability to absorb more bioethanol in the road transport sector is questionable due to “blend wall” restrictions. Integration of 1G and 2G bioethanol sites for the production of bioethanol with larger GHG emission reduction potential for its not-blended use in dedicated fleets is also a business possibility.

The integration of 1G bioethanol plants with Alcohol-to-Jet fuel (ATJ) technologies could be an interesting option in the US market and in other markets close to the saturation of local demand for 1G bioethanol and with plans to promote the use of more biofuels in the aviation sector.

4.2. MARKET SYNERGIES FOR THE CO-LOCATION OF 1G BIODIESEL AND HVO

Technical restrictions in the conversion of 1G biodiesel sites to 2G sites leave the possibility of co-location of plants as the only technically feasible option. Co-location of 1G and 2G biodiesel plants could potentially share energy services, logistics infrastructure and human resources. This possibility could be interesting if niche markets for 2G biodiesel or renewable diesel are created, the decision mainly a demand-driven business decision to meet customer preferences.

The profitability of the HVO diesel plant business model is driven by the fact that the quality of the renewable diesel produced is higher than the EU biodiesel standard EN14214. This is achieved with cheaper feedstock such as crude palm oil (CPO), palm fatty acid distillate (PFAD) or high free-fatty acids (FFA) animal fat. In order to achieve the EU standard requirements the producers of 1G biofuels need to process a mix of vegetable oils with at least 50% of rapeseed oil while a 2G HVO plant can run fully on PFAD and still reach the European Union standards. A 1G plant using the same low quality feedstock from palm would be able to produce biodiesel with a cold filter plugging point (CFPP) out of the EU standard even for summer conditions.

The CAPEX of a HVO plant is much higher than the CAPEX of a 1G biodiesel plant because of the expensive equipment required for the hydrogenation process. However, OPEX may be lower as the price of waste material feedstock for 2G HVO can be significantly lower than vegetable oil feedstock for 1G processes. The by-products from the HVO process are bio-propane, bio-LPG and bio-naphta. These by-products are usually more valuable than glycerine produced in conventional 1G esterification processes.

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24 The maximum quantity of bioethanol that can be sold each year given legal or practical constraints on how much can be blended into each litre of gasoline

25 Lowest temperature, expressed in degrees Celsius (°C), at which a given volume of diesel type of fuel still passes through a standardized filtration device in a specified time when cooled under certain conditions
The hydrogen consumption for HVO is also much lower than the consumption of methanol in the regular biodiesel production - yet, the price of methanol is lower. (Greenea 2015).

Thus, integration options for 1G and 2G HVO biodiesel plants are quite limited. The decision for co-location is basically a business decision for locations with niche markets for 2G renewable diesel. Stakeholders interviewed for this study informed of cases of US investors interested in buying (running or mothballed) 1G biodiesel sites in Germany to co-locate HVO plants next to them because of the business value of an existing site with full licensing to operate, existing infrastructure for feedstock supply and product distribution, and the existence of a niche market for higher quality HVO renewable diesel. For these potential investors, the biggest challenge is not the technical conversion itself or the cost of this conversion, but securing the best strategy for feedstock supply and product distribution next to a niche market for their new product.

With large oil companies continuing to invest in HVO production sites or co-processing HVO renewable diesel in their own refineries, their need to externally source renewable diesel for blending will reduce. Oil refineries prefer HVO diesel for blending over conventional 1G (FAME) biodiesel because of HVO’s higher quality properties. 1G biodiesel producers and traders would be directly impacted as the demand for their products will also be reduced. This situation can improve the business case for the co-location of 1G or 2G HVO plants with conventional 1G biodiesel plants.

Investors interested in HVO are also studying new markets. One of these potential new markets is HVO biojet fuel. While the current business model for incipient biojet fuel supply to airports is centralised, some interviewed stakeholders are of the opinion that this business model could very well evolve towards a decentralised model with HVO biojet fuel production sites closer to airports. This consideration makes the location of some 1G biofuel sites interesting for co-location with HVO biojet fuel plants.

4.3. EVOLUTION OF HVO SITES

While HVO renewable diesel plants can use any sort of oil as feedstock, at present they are mostly using edible vegetable oils and therefore they do not qualify as 2G sites under this scoping study. The evolution of HVO sites into HVO sites using 2G feedstock (waste oils, or pyrolysis oils from lignocellulosic material) is not considered a good business idea at the moment by most stakeholders interviewed. The few HVO plants operating at present are brand new plants that are already profitable using conventional vegetable oils. The use of waste oils in these plants would require more costly hydrogen for feedstock pre-treatment and corresponding process modifications. Stopping the production of current HVO plants to make these technical modifications and change their market strategy for allowing the use of generally scarce waste oils is not considered a sensible business idea while these plants are already profitable.
5. SUPPORTING POLICIES

5.1. POLICY RATIONALE

Many 2G biofuel technologies are close to being commercial. After two decades of rapid developments in enzymatic hydrolysis, the first few commercial-size cellulosic ethanol facilities are operating in the US, Brazil and Europe. HVO diesel facilities are gaining popularity in the European and global markets with an increasing number of companies investing in them, including oil refineries for blending. The next step is to replicate success cases around the world.

The modification of 1G biofuel sites to accommodate 2G technologies, either by co-location, retrofitting or repurposing, is an alternative to the construction of new dedicated (stand-alone) 2G biofuel sites. This alternative may offer in some cases interesting savings and other benefits. But 2G biofuels are significantly more expensive and their commercialisation is being held back by policy uncertainty.

It is the role of policymakers to create policy certainty to foster innovation and to ensure that environmental, economic and energy objectives are achieved. Full lifecycle accounting of emissions should be the tool that underpins the mitigation of CO₂ from transport fuels. In comparison to 1G biofuels, well performed 2G biofuels have larger potential to reduce emissions and reduce impacts on biodiversity, land use change, food security and food prices.

Policy instruments can help to bridge current limitations in this transition. They can support building new 2G biofuels production sites, but also they can support the integration of 1G and 2G biofuels production sites.

Experiences in 1G biofuels show that most countries started with the introduction of economic instruments supporting R&D and demonstration plants. This helps with bringing technologies to a mature stage. Economic and financial instruments can then be introduced to make the whole economically viable, which are maintained until up-scaling of technologies. Finally, instruments to grant market access can be implemented.

Some combinations of instruments have proven more effective than others to incentivise investments and to narrow the price gap. In all cases, the order of implementation of policy instruments is crucial. The risk of any combination of instruments is that they may develop a market that is not economically sustainable in the end.

Policies must make clear what the maximum amount of money needed is, in the form of economic instruments to create an economically viable market and for how long those instruments will remain in the market.

All stakeholders interviewed for this study agreed that the most important aspect for any supporting policies is stability and predictability of any further update. Stakeholders agreed that policies must provide support in three areas:

1. Technology development and cost competitiveness
2. Infrastructure investments (including integration of sites)
3. Market access
5.2. AVAILABLE POLICY INSTRUMENTS

Policy instruments that can support the integration of first- and second-generation biofuel production sites can be classified into three types (see Table 2) (SQ Consult, 2014):

1. Collaborative instruments for R&D
2. Economic instruments either for infrastructure or for production (tax exemptions, subsidies, financial support)
3. Command and control instruments (quotas, blending mandates, procurement rules)

Collaborative instruments are often classified as "supply-push" (supporting research, development and demonstration of technologies) and "demand-pull" (changing market conditions like voluntary private procurement) instruments. Collaborative instruments may also happen between the private and public sectors with the so called public–private partnerships (PPP). The adoption of standards, codes of conduct and self-regulation by the industry is another form of collaborative instrument.

Economic instruments, also referred to as price-based instruments or market-based instruments, use market, price, and other economic variables to provide incentives for infrastructure investments, production and use of biofuels. These instruments seek to address the market failure of externalities by incorporating the external cost of infrastructure investments, production or consumption activities.

This is done through direct incentives, subsidies, taxes, or charges on processes or products, or by creating rights trading mechanisms (such as biofuel certificates trading or emissions trading mechanisms). The costs of economic instruments are mainly paid by taxpayers or end-consumers, depending on the instrument. Tax payers pay for direct incentives, subsidies, tax exemptions and tax reliefs for instance. End consumers pay (at least partially) in case of levying specific taxes and charges to the product that is promoted as long as (part of) the cost is passed through.

The application of economic instruments is in general beneficial for starting a market; however they may become expensive to sustain when the market engages and beneficiaries are reluctant to lose the economic advantages of receiving incentives or benefiting from tax exemptions or discounts.

Command and control instruments are defined as the regulation establishing what is permitted and what is not permitted in a specific industry or activity. The command part establishes the obligations to be complied with, and the control part establishes the sanctions that result from non-compliance.

Command and control instruments include direct regulation for the industry development via legislation. As the name implies, the command and control approach consists of a 'command', which sets a standard, a production obligation or consumption mandates (for example the minimum amount of second generation biofuel blended with fossil fuels) and a 'control', which monitors and enforces the standard.

Command and control instruments are mainly applied to grant market access. They may be linked to established national incorporation targets. Not all command and control instruments have the same effectiveness. Many of them are just accompanying measures to other more relevant instruments. Command and control instruments basically affect market access.
### Table 2 Types of policy instruments

<table>
<thead>
<tr>
<th>Collaborative</th>
<th>Economic</th>
<th>Command &amp; control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology development</td>
<td>Agreements for R&amp;D cooperation</td>
<td>Funding for R&amp;D</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Direct investment and incentives for the integration of 2G biofuel sites, including incentives for logistics and distribution infrastructure</td>
<td></td>
</tr>
<tr>
<td>Financing and de-risking</td>
<td>Financing schemes, tax exemptions or low-interest rate loans for integration of 2G biofuel sites</td>
<td>Emissions trading systems</td>
</tr>
<tr>
<td>Market access</td>
<td>Adoption of own production or consumption targets</td>
<td>Tax exemptions per unit of biofuel produced for reducing the price of biofuel production</td>
</tr>
<tr>
<td></td>
<td>Voluntary private procurement</td>
<td>Tariffs and duties for the trade of biofuels</td>
</tr>
<tr>
<td></td>
<td>Harmonisation and adoption of standards, certification and labelling</td>
<td>Trading of biofuels certificates (e.g. RINs in the US or Biotickets in NL)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Emissions mandates through fuel quality standards</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Authorisation quotas for biofuel producers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Regulations restraining import of biofuels or the feedstock</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Biofuels obligations</td>
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<tr>
<td></td>
<td></td>
<td>Specifying product blends that must be available in the market</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Blending mandates</td>
</tr>
</tbody>
</table>

Source: Own elaboration and SQ Consult (2014)

### 5.3. POLICY INSTRUMENT MIX SUPPORTING SITE INTEGRATION

Significant incentives, in combination with low feedstock prices, are expected to be necessary for 2G biofuels to be competitive until economies of scales effects have reached a sufficient level. However, rather than brand new policy proposals, a strategy of small changes to sustain support to R&D activities, financial help for infrastructure, volume/blending mandates, tax policies and environmental regulations will be more effective for the immediate future of 2G biofuels. A strategy of small changes is also preferred because it is the best way to ensure that existing production sites will continue to have a market for their products and the transition may happen in an orderly way.

The order of implementation of policy instruments is crucial. A market start-up will only happen if firm support to technology development and technology commercialisation is given (in the way of economic incentives). Blending mandates would cause more harm than benefits if they are applied in an immature market when biofuel prices have not yet reached stability and fossil fuel prices remain low.

Flexibility in the set-up of policy instruments is a very important characteristic to take into account. The combination of incentives, mandates, escape clauses, and implementation mechanisms should be well-designed, effective, and constantly monitored (e.g., on an annual basis). They should also be actively modified as needed to enhance their effectiveness.
The following mix of instruments and order of implementation are proposed:

### 5.3.1. Instruments for technology development and cost competitiveness

Bridging the gap between breakthrough research and commercialisation (usually referred as bridging the technological “valley of death”) for technologies in their pioneer status requires significant Research, Development and Demonstration (RD&D) efforts, mostly in the way of economic support. It is a matter of time for 2G technologies to reach further development and cost competitiveness.

Most of biofuel producers interviewed agreed that current level of public and private support to RD&D activities in Europe and the US is sufficient but longer term targets should be set, monitored and sustained. An illustrative example of European Public Private Partnership for demonstration projects in Europe is presented in **Box 10**.

An important warning regarding long term support to specific industries is that they run the risk of creating powerful lobbies that later hamper the withdrawal of support programs when the RD&D potential is exhausted. Today, we see signs that the support programs for 1G biofuels may have created such a political lock-in making it difficult to scale down support, even though 1G biofuels have proven less promising than originally thought. Hence, governments should strive to keep flexibility when crafting support programs for 2G biofuels.

**Box 10: European PPP under the H2020 Programme**

Public Private Partnership (PPP) in Europe to support bio-based industries has an estimated budget of €3.8 billion. The EU will contribute €1 billion from the Horizon 2020 programme budget, while industrial partners will commit €2.8 billion.

The PPP should help demonstrate the efficiency and economic viability of 2G biofuels and other bio-based products.

The PPP under Horizon 2020 is a starting point that needs to be complemented with other funding sources in order to support advanced, first-of-a-kind commercial scale biofuel plants. To do so, it would benefit from being combined with structural funds, particularly in Central and Eastern Europe. If such countries connect both funding opportunities, they will benefit from the innovation and economic opportunities while making use of structural funds that are currently underspent.

### 5.3.2. Instruments for infrastructure investments

Investments in new plants or in the integration of sites will still largely depend on government support for the medium term. This requires stable policy support in the form of grants, loan guarantees or tax exemptions.

Financial incentives that have fixed periods of validity are the most effective. The impacts of these financial incentives can be constantly monitored to decide on their extension and/or modification. Financial incentives should be specific in their objectives and target group. It is often presumed by the biofuel industry that incentives will be always extended, but extensions should never be automatic, but the result of a policy assessment exercise.
Experience shows that incentives applied in the EU are significant but insufficiently targeted to support specific objectives. If incentive measures are to be used then they should be differentiated in terms of their policy objectives. For example, if their objective is infrastructure investments aiming at GHG savings, then these incentives should be explicitly addressed to projects that can actually deliver against the stated policy objective as opposed to a blanket support mechanism available to a broad scope of projects. For illustration, the Netherlands had a specific subsidy for biofuel plants conversion in 2011, but it was later discontinued. No government support is given to production sites to achieve conversion to 2G biofuel production sites. Responsibility now lies with the industry itself.

In this respect, US incentives (see Box 11) target more specific objectives and beneficiaries and are sustained in time. To avoid abuse and ensure their effectiveness, they are usually implemented together with monitoring mechanism to assess their results (SQ Consult 2014).

**Box 11: US economic incentives for 2G biofuels infrastructure**

Examples of economic and tax incentives that are applied (or have been applied) in the US for the promotion of 2G biofuels infrastructure that could be considered for supporting the integration of 1G and 2G biofuel production sites:

**USDA Biorefinery Assistance Program:** USDA Rural Development is offering loan guarantees for the development, construction, and retrofitting of commercial-scale biorefineries to produce 2G biofuels derived from cellulose, hemicellulose, lignin and different waste materials. Eligible borrowers include individuals, entities, Indian tribes, state or local governments, corporations, farm cooperatives or farm cooperative organizations, associations of agricultural producers, National Laboratories, institutions of higher education, rural electric cooperatives, public power entities, and consortia of any of these types of entities. Financed entities must provide at least 20% of the financing for eligible project costs, and applications for funding must include an independent feasibility study and technical assessment. Eligible project costs include the purchase and installation of equipment, construction or retrofitting costs, permit and licensing fees, working capital, land acquisition, and the costs of financing.

**Special depreciation allowance for cellulosic biofuel plant property:** A taxpayer may take a depreciation deduction of the adjusted basis of a new cellulosic biofuel plant in the year it is put in service. Any portion of the cost financed through tax-exempt bonds is exempted from the depreciation allowance.

**Policy instruments at State level:** Several states have established additional incentives for de-risking the investment in new production facilities, tax exemptions, tax discounts to final users, credits and direct incentives for constructing and testing 2G biofuel plants.

### 5.3.3. Instruments for market access

Instruments that grant market access to 1G biofuels at the moment are not sufficient to also grant market access to 2G biofuels. Current policies predominantly focus on the use of biofuels in the road transport sector, and do not promote the use of biofuels in the maritime and air transport sectors. The major bottlenecks for establishing effective biofuel policies in the maritime and air transport sectors are the impact of fuel prices on the competitiveness of both sectors, and the international nature of their business. The latter makes it very difficult to establish coherent policies across borders. Policy parity and international policy coherence is required to broaden the markets for 2G biofuels.
As discussed in section 3, production costs for 2G biofuels are higher than for 1G biofuels. Market access can be achieved via significant direct economic help, high carbon prices or via blending mandates that are specific to 2G biofuels. With no market access granted to 2G biofuels, the integration of sites quickly becomes non-economically feasible. However, policy makers must consider that any form of mandate may cause more harm than benefits if they are applied in an immature market when biofuel prices have not yet reached stability and fossil fuel prices remain low. Volatile revenue imposes high risk for these investments. Stability of prices usually comes after learning and certain up-scaling has already happened. Mandates should therefore not be implemented as long as up-scaling and price stabilization have not occurred.

**Direct subsidies and tax credits**

Direct subsidies should be specific, with clear purposes and with clear target groups. They should be closely and permanently monitored to avoid unexpected loss in national budgets. For example, in the US from 1978 through 2004, the federal government provided payers of federal excise taxes on motor fuel with a tax credit for the amount of (1G) bioethanol blended with gasoline. This was a growing direct subsidy. Due to concerns about the loss of federal revenues for transportation purposes, the tax credit was replaced in 2005 with a federal tax refund to blenders of motor fuel. Then a tax credit for (2G) cellulosic ethanol was introduced and the ethanol tax credit was reduced. Still in fiscal year 2009, tax credits for biofuels reduced federal revenues by about 6 billion US$ (SQ Consult 2014). An illustrative example of successful tax credits for market access is presented in Box 12.

**Box 12: Successful US tax credits for market access**

Some examples of successful tax credits in the US are:

**Cellulosic biofuel producer tax credit:** A cellulosic biofuel producer that is registered with the US Internal Revenue Service (IRS) may be eligible for a tax incentive in the amount of up to 1.01 US$ per gallon of cellulosic biofuel when produced in the US and: a) Sold and used by the purchaser in the purchaser’s trade or business to produce a cellulosic biofuel mixture; b) Sold and used by the purchaser as a fuel in trade or business; c) Sold at retail for use as a motor vehicle fuel; used by the producer in a trade or business to produce a cellulosic biofuel mixture; d) Used by the producer as a fuel in trade or business. If the cellulosic biofuel also qualifies for alcohol fuel tax credits, the credit amount is reduced to 0.46 US$ per gallon for biofuel that is ethanol and 0.41 US$ per gallon if the biofuel is not ethanol. The incentive is allowed as a credit against the producer’s income tax liability.

**Alternative fuel mixture credit:** The alternative fuel mixture credit is the product of 0.50 US$/gallon and the number of gallons of alternative fuel used by the taxpayer in producing any alternative fuel mixture for sale or use in trade or business of the taxpayer.

**Volumetric and blending mandates:**

For blending mandates to be effective with 2G biofuels, they should be differentiated according to the GHG reduction potential and according to the likelihood of future cost reduction from increased experience (learning curve). This differentiation has occurred in the US but not so far in Europe where all types of biofuels have received the same treatment (see Box 13).
Blending mandates are better associated with GHG standards to benefit 2G biofuels. Some imported 1G biofuels also score well in terms of GHG-reducing potential, most notably sugar cane ethanol from Brazil, and these 1G biofuels will also benefit from a GHG standard. Increased support to 2G bioethanol, for instance reserving a share of the mandate for new technologies, can help ensure that blending mandates actually benefit 2G biofuels and the modification of 1G biofuel production sites. Tariffs to specific imported biofuels can also help, but tariffs are not as effective and as transparent as directly supporting 2G technologies (SQ Consult 2014).

**Box 13: US and European mandates**

Volumetric mandates applied in the US clearly promote investment and growth of 2G biofuels. The fact that the United States chose volumetric targets and the European Union chose percentage blending targets in part reflects the political economy of the biofuels policy in both regions.

By setting volumetric mandates, the United States reduces uncertainty faced by biofuels producers and farmers and promotes an investment environment. The US Environment Protection Agency (EPA) determines yearly the volume of cellulosic biofuel that will be produced for use in transportation in the following year. Each year, the obligated parties (refiners, importers of gasoline and diesel, and blenders) are required to meet volumetric targets. The RFS2 compliance program is based on the use of unique Renewable Identification Numbers (RINs) assigned to batches of renewable fuel by their producers and importers. RINs are used by obligated parties to demonstrate compliance with the applicable standard. They can be sold and traded within the US.

In the EU, setting blending targets in terms of percentages addresses the commitment of the sector in meeting the overall Kyoto limits, but does not create an environment especially favourable to investments in the sector. Setting those targets in terms of GHG emissions themselves would increase the effectiveness of European policy in this respect.

Yet, 2G biofuel blending mandates are valid only after required technological learning (and respective cost reductions) have taken place, as volatile revenue imposes high risk for investments. Technological learning requires investments to “drive down” the cost curve, i.e. policy must secure pioneer markets for approximately one decade.
6. CONCLUSIONS AND RECOMMENDATIONS

Based on evidence compiled from the literature and the stakeholder interviews, this report makes the following recommendations regarding the modification and/or integration of 1G biofuel sites with 2G production processes:

1. **Compared to 1G biodiesel, 1G bioethanol sites are technically and economically more suitable for conversion into, or integration with 2G sites.** Co-location is the most used integration strategy and the easiest to implement as well. Retrofitting is more challenging and more sensitive to economic feasibility. Repurposing of 1G bioethanol sites is seldom used. **Eventually, 2G integration will become mainstream in the bioethanol industry, increasing resource efficiency in the production of bioethanol, and increasing GHG emission saving potential in the mixed product.**

   It is recommended to conduct an analytical study on the economic feasibility and other benefits of specific co-location and retrofitting strategies for 1G bioethanol sites. This research could focus on specific case studies in different countries and different market conditions, including the integration of ATJ for supplying bio-jetfuels to the air transport sector.

2. **Integration of 2G bioethanol in pulp and paper industry sites and 2G renewable diesel into existing fossil refineries** are further options to advance 2G biofuels, but were outside of the focus of this scoping study. **It is recommended to include these options in follow-up work.**

3. **For 1G biodiesel sites, there are few technical options favouring their conversion to 2G diesel.** Yet, further analysis is required on the technical possibilities for partial repurposing to coprocess waste fat, and on that business- and market-oriented options that may favour the co-location of 1G biodiesel with 2G HVO/HEFA processes. Therefore, **it is recommended to conduct market research for determining conditions for which 1G biodiesel plants could be of interest to 2G diesel plants investors.**

   It is understood that this research would focus on market aspects such as access to market niches, value of existing sites with regard to product distribution strategies and feedstock supply possibilities rather than the technical feasibility for conversion.

4. Due to limited information on 2G integration in the public domain (conference proceedings, journal articles, PhD theses, etc.) either for bioethanol or for renewable diesel, **it is recommended that further analytical work should include a panel of key industry stakeholders to discuss which approach (and possibly incentives) will allow access to “in-house” data At what level of access**
5. An in-depth policy study is recommended for proposing a mix of policy instruments for relevant countries or supranational regions, e.g., the EU. This should respond to questions such as:

- How much economic support is needed for research, development and demonstration (RD&D), for what specific technology pathways, for how long and with which indicative results as targets?
- What have been the most effective economic instruments and incentives for realising new infrastructure? How much money should be budgeted for those instruments and when should they be stopped?
- What are the right signals before volumetric or blending mandates can be implemented safely? Do they need to be accompanied with economic incentives such as tax credits for production, tradable certificates or feed-in-tariffs?
- How policy instruments should be designed to avoid cross-subsidies in co-location and retrofitting setups?

This in-depth study should also aim to establish recommendations for a policy strategy that delivers international coherence and policy parity between different sectors using biofuels.
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QUESTIONNAIRE

A questionnaire was prepared and offered in an online platform to a selection of 118 experts in different fields that could potentially contribute with their views to this study and were asked to participate in this study. The distribution of experts per activity segment is shown in Error! Reference source not found. A total of 20 full interviews, either by written or by phone were realised (see the acknowledgments section).

Table 3 Number of experts selected for interviewing per activity segment

<table>
<thead>
<tr>
<th>Interviews per activity segment</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Producers and technology suppliers</td>
<td>43</td>
</tr>
<tr>
<td>Global (or regional) organisations</td>
<td>20</td>
</tr>
<tr>
<td>- Biofuel industry</td>
<td>8</td>
</tr>
<tr>
<td>- Other organisations</td>
<td>4</td>
</tr>
<tr>
<td>- IEA Tasks leaders</td>
<td>3</td>
</tr>
<tr>
<td>- Roundtables and Standards Committees for biofuels</td>
<td>5</td>
</tr>
<tr>
<td>Traders</td>
<td>4</td>
</tr>
<tr>
<td>R&amp;D, knowledge centres and consultancies</td>
<td>29</td>
</tr>
<tr>
<td>Policy design bodies</td>
<td>22</td>
</tr>
<tr>
<td>- European Commission</td>
<td>6</td>
</tr>
<tr>
<td>- National Regulators</td>
<td>16</td>
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<tr>
<td>Grand total</td>
<td>118</td>
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</table>

The content of the written questionnaire is presented next.
Questionnaire for:

Scoping Study “Options for evolution of first generation biofuels production sites (RES-T-BIOPLANT)”

We invite you to participate in this experts survey especially designed for the RES-T-BIOPLANT scoping study commissioned by the IEA Renewable Energy Technology Deployment (IEA-RETD).

The aim of this study is two-fold:

- Get a better understanding of the scale of the opportunity for adapting existing sites to produce advanced biofuels; and,
- Analysing the potential role of government policy to incentivise site conversion

For details, see the attached IEA-RETD Letter.

This questionnaire has 4 sections:

SECTION 1: Technical feasibility

SECTION 2: Infrastructure and logistics

SECTION 3: Benefits of conversion

SECTION 4: Supporting policies

The approximate time to complete this survey is 20 minutes.

Please respond to as many questions as possible and in the level of detail that you feel comfortable with. This can range from your own perception, to a higher level of detail/knowledge.

Contributors to this study will be thanked and recognised in the final report.

All info given will be published only in aggregated fashion, and no statement/information will be related to any specific contributor.

You are invited to share the link to this survey with colleagues that you consider appropriate.

Important note: We are not looking for technology sensitive information on processes (or any other sort of commercially secret information), but information that will help us understand the feasibility of converting conventional first generation sites into advanced biofuel sites.

DEFINITIONS

First generation (1G) biofuels plants include: Starch to ethanol, sugar to ethanol, biodiesel from vegetable oils and yellow grease

Advanced biofuels plants include: lignocellulosic ethanol (enzymatic fermentation pathway, pathways involving pyrolysis processes, etc.), Alcohol-to-Jet Fuel (ATJ), Hydrotreated Vegetable Oils (HVO) and Hydroprocessed Esters and Fatty Acids (HEFA)
Before you proceed with the survey, please tell us about yourself:

Name: _______________________________
Organisation: _________________________
Position: _____________________________
Country: _____________________________
E-mail address: ______________________

What is the activity that best describes our organisation?

__ Production of biofuels
__ Trade of biofuels
__ Policy design entity
__ Research and development, consultancy
__ Roundtable, industry association
__ Other (please specify): _____________________

Could we contact you for a more extensive interview?

__ Yes    __ No

If yes, please give us your phone number or skype address: __________
SECTION 1: Technical feasibility

**Question 1:** How suitable is the conversion of the following first generation biofuels sites into advanced biofuels production facilities? Please rank suitability from 1 to 5. One being not favourable at all, and 5 being very favourable. If possible explain the reason for your selection. Please keep in mind the conversions that you consider most favourable as you will be asked further questions on them later in this questionnaire.

<table>
<thead>
<tr>
<th>Option</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<tbody>
<tr>
<td>1. Sugar ethanol to cellulosic ethanol</td>
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<tr>
<td>2. Starch ethanol to cellulosic ethanol</td>
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<td>3. Alcohols to Jet fuels</td>
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<td>4. Vegetable oil to HVO or HEFA biodiesel</td>
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<td>5. Yellow grease to HEFA</td>
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<td>6. Other: ________</td>
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If possible, please share with us reasons (technical, economic, others) for your assessment:

**Question 2:** Are you aware of any conversion of sites already made, planned or in process? Could you briefly describe them (or give a reference, e.g. website, article, presentation etc.)?

**Answer:**
Question 3: Are you aware of any ongoing Research and Development (R&D) activities in this field, or respective R&D proposals likely to be financially sponsored and who the likely financial sponsor is? Please briefly describe these activities (or give a reference, e.g. website, article, presentation etc.)?

Answer:

SECTION 2: Infrastructure and logistics

Question 4: To what extent is it possible to re-use ancillary equipment, logistics, and distribution systems of first generation biofuel plants after site conversion?

Please rank suitability from 1 to 5, with 1 being not favourable at all, and 5 being very favourable. If possible explain the reason for your evaluation.

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</table>

Biodiesel plants:
1. Auxiliary energy (steam, electricity)
2. Ancillary equipment
3. Logistic system (feedstock supply, storage...)
4. Product distribution system

Bioethanol plants:
1. Auxiliary energy (steam, electricity)
2. Ancillary equipment
3. Logistic system (feedstock supply, storage...)
4. Product distribution system

Any comment on this topic that you would like to share?
SECTION 3: Benefits of conversion

**Question 5:** From the list of most suitable site conversions you provided in Question 1, Section 1:

- What is your perception or knowledge about the costs of site conversion?
- What is your perception or knowledge about the potential savings compared to the construction of new biofuel production sites?

We would appreciate in-depth information, but also aggregated data would help us in our aim. Again, feel free to give references (e.g. website, article, presentation etc.)

**Answer:**

**Question 6:** What are the economic bottlenecks that options for conversion face?

**Answer:**

**Question 7:** From the list of most suitable site conversions you provided in Question 1, Section 1, could you give an estimation of emissions saved, either total per year (indicate size of plant), or in percentage per ton produced?

**Answer:**

**Question 8:** What is the overall local and global impacts of site conversion on land-use?

**Answer:**
**Question 9:** Please rank potential associated benefits for site conversions (e.g. employment, local economic activity, use of local feedstock, knowledge transfer...). Please rank potential benefits from 1 to 5, with 1 representing no benefits at all, and 5 for being highly beneficial. If needed, specify it by technology and if possible explain the reasons for your evaluation.

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<tbody>
<tr>
<td>1.</td>
<td>Employment</td>
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<tr>
<td>2.</td>
<td>Local economic activity</td>
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<tr>
<td>3.</td>
<td>Use of local feedstock</td>
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<tr>
<td>4.</td>
<td>Knowledge transfer</td>
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<tr>
<td>5.</td>
<td>Other: ______________</td>
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Could you share your perception on which of above potential benefits are more relevant to the decision making process for these site conversions?

**Answer:**

**SECTION 4: Supporting policies**

**Question 10:** What government incentives are you aware of (and where they are applied) that support the conversion of first generation biofuel production sites?

**Answer:**

**Question 11:** What incentives from other industries, would you consider replicable as relevant to the biofuel sector and in particular for supporting the conversion of biofuel production sites?
**Question 12:** From the list below, what type of supporting policies do you think could be most effective? Please rank effectiveness from 1 to 5, with 1 representing not effective at all, and 5 for being most effective.

1. Financial support to R&D related to conversion
2. Financial support to conversion of existing sites
3. Other financial support to feedstock production and logistics for converted sites
4. Establishment of production quotas and blending mandates
5. Other: ______________

Could you share some reasons for your ranking?

**Answer:**
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- DANISH ENERGY AGENCY
- République Française
- Ministère de l'Écologie, du Développement durable et de l'Énergie
- SUSTAINABLE ENERGY AUTHORITY OF IRELAND
- NEDO
- Department of Energy & Climate Change
- enova

on the basis of a decision by the German Bundestag
The International Energy Agency’s Implementing Agreement for Renewable Energy Technology Deployment (IEA-RETD) provides a platform for enhancing international cooperation on policies, measures and market instruments to accelerate the global deployment of renewable energy technologies.

IEA-RETD aims to empower policy makers and energy market actors to make informed decisions by: (1) providing innovative policy options; (2) disseminating best practices related to policy measures and market instruments to increase deployment of renewable energy, and (3) increasing awareness of the short-, medium- and long-term impacts of renewable energy action and inaction.

Current member countries of the IEA-RETD Implementing Agreement are Canada, Denmark, France, Germany, Ireland, Japan, Norway, and United Kingdom.

More information on the IEA-RETD can be found at

www.iea-retd.org