Future Fuels for Flight and Freight Competition – Feasibility Study

Final Report

E4tech (UK) Ltd and Ricardo Energy & Environment for Department for Transport, delivered through Arup AECOM

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Executive Summary

The UK's Department for Transport is supporting the demonstration of advanced biofuels through an Advanced Biofuels Demonstration Competition (ABDC), providing £25m of matched capital funding to underpin significant private sector investment in the development of these facilities in the UK. The Department is now seeking to further support advanced renewable fuel options, particularly for production of fuels that can displace diesel and jet in HGVs and aviation.

The aim of this feasibility study is to support DfT in designing a follow up competition to the ABDC. It provides information on:

- the current status of the fuels that could be targeted, including an assessment of their ability to be used in aviation and HGVs
- the business case in terms of UK value from UK plants and exports, and UK jobs
- likely interest of companies to enter the competition
- potential funding structures and eligibility requirements

The study draws on the lessons learned from the ABDC to date, as well as updated information on the status of the advanced renewable fuel technologies, policy developments and changing State Aid funding requirements.

The study has shown that:

- There are a wide range of technologies that could produce advanced renewable fuels suitable for use in aviation and HGVs. Of 15 routes to renewable fuels assessed, twelve were considered to be suitable for support through a competition, given their potential for future widespread use in aviation and HGVs, technology development status, potential for UK deployment and expected deployment level in the absence of further support. Those excluded were all based on technologies that are already commercially available, with some also being likely to happen without this additional support.
- The list of technologies considered suitable includes those that produce a diesel or jet fuel directly, those with intermediate fuels that require further processing to produce jet or diesel, and those producing another type of fuel that could be used in HGVs to displace diesel. For those that do not produce jet or diesel directly, it is important that the competition ensures that the fuels are used to displace jet or diesel, for example through including an end-use partner.
- The proposed funding option is a £20m competition aiming to support demonstration-scale projects producing an advanced renewable fuel, over 3 years. A smaller pot of £5.5m funding over FY 17/18 could be used for add-on funding for existing projects, and seed funding. All funding would be subject to State Aid Regulations, and a notification to the European Commission would be made ahead of the launch of the competition. However, some larger scale projects with longer timescales for development would require front-loaded CAPEX grant funding.
- The number of applications to the competition is likely to be around 25 to 30. This estimate is made on the basis that the seed funding will increase the number of applicants compared with the ABDC, and whilst the scope of fuels considered is narrower than in the ABDC in some cases (use of ethanol and butanol to displace gasoline is excluded), it has been expanded in others

(waste-derived fossil fuels). It is also based on a review of the known technology developers in each route, and a judgement on their likely interest in the UK compared with other regions, given their stage of development and capacity to conduct projects in multiple regions.

- The competition could lead to the demonstration of 3-5 technologies, depending on the final mix of plant sizes. Small-scale demonstration plants would apply for grants between £1m-£5m, while others may apply for up to £10m. Rather than specifying a required plant scale, it would be more appropriate to require bidders to propose a scale of plant that is appropriate to progress the technology and demonstrate the production of fuel.
- The value to the UK would derive both from plants deployed in the UK, and from the potential for building high value UK capabilities that could be exported to other regions. Given the very early stage of development of nearly all advanced routes to diesel and jet, value estimates made based on currently planned plants are small, particularly in 2020, given plant lead times. If a competition was successful in supporting demo plants such that these led to 3-5 commercial plants being built in the UK by 2030, the net annual UK benefit would be £100m. If rapid progress could be made, both in technology demonstration at scale and in policy support, deploying advanced diesel and jet at the levels envisaged by the IEA 2 degree scenario in 2030 would give a global market of up to £75bn by 2030, with UK net value added from UK deployment and global exports of £600m.
- The competition would guarantee UK benefits by requiring the plants to be sited in the UK. Whilst the competition could not include eligibility criteria to add to the UK value further, it would be beneficial to include assessment criteria asking applicants to describe the value to the UK from the proposed projects, as in the ABDC. The success and environmental benefits of the competition would rely on projects meeting the eligibility criteria set out covering technology scope, status of development, sustainability and project planning & financing.

1 Introduction

1.1 Background

The Climate Change Act 2008 set an 80% decarbonisation target for 2050. Meeting this target will require a radical reduction in transport emissions, which currently account for 24% of the economy-wide total. Cutting emissions to the extent required demands a multi-faceted approach including electrification and increased deployment of low-carbon liquid fuels.

Renewable fuels have been shown to make a potentially large contribution to the greenhouse gas (GHG) savings achievable by 2030[1], through partially displacing fossil fuels across all modes of transport. In the longer term, liquid renewable fuels, including biofuels and those of non-biological origin, are seen as the principal decarbonisation option available to the aviation and marine sectors, who rely on high density fuels. Similarly, there is interest in renewable fuels for HGVs, where the prospects for electrification are uncertain.

However, there is a desire to promote a shift from biofuels made from food crops to biofuels made from wastes and residues. The latter are not yet being produced in commercially significant volumes (with the exception of hydro-treated waste oils and fats, and biogas from wastes). Currently, biofuels based on wastes and residues count double towards compliance with the UK's Renewable Transport Fuel Obligation (RTFO) targets. European Directive (EU) 2015/1513, the "ILUC Directive", agreed in 2015, set a cap of 7% on the contribution of biofuels produced from food crops towards 2020 targets, and set a non-binding sub-target for advanced biofuels based on waste and residue feedstocks of 0.5%. Member States must transpose this into national legislation by 2017, including justifying the sub-target set for advanced biofuels. The UK consulted on the approach to transposition of this directive in December 2016 (see below).

There is as yet no EU or UK level policy to support renewable fuels after 2020. At European level, some form of policy support for advanced biofuels is expected to be put in place, accompanied by a removal of support for food-based biofuels. As part of the RED II the EC is proposing a 6.8% renewable and low carbon fuel target of which 3.8% would need to be met by advanced biofuels. The UK DfT consultation on the RTFO is proposing a "development fuels" sub-target of 1.2% by 2030 (double counted to 2.4%). Despite the uncertainty over the exact form that policy will take, there is still confidence that advanced biofuels and other renewable fuels of non-biological origin (both these types of fuels being referred to in this report as "advanced renewable fuels"), and potentially waste-based low carbon non-renewable fuels will form part of the strategy for decarbonising transport. This raises the question of how their production and use can be encouraged.

There are a number of advanced biofuel pilot and demonstration plants in the EU, the US, Brazil and China, as well as a few first-of-a-kind commercial plants in operation in some of these regions. As advanced renewable fuels are not being produced in significant volumes, there is pressure on governments to facilitate and speed up their progression to commercialisation. It is widely accepted

[1] Staff working document accompanying the European Commission Communication on A European Strategy for Low-Emission Mobility
https://ec.europa.eu/transport/sites/transport/files/themes/strategies/news/doc/2016-07-20-decarbonisation/swd%282016%29244.pdf

that one of the key aspects limiting the progression from pilot to demonstration plant, and from demonstration to commercial plant is the scale and risk associated with the required investment. Developers have also been unable to raise this finance because of the uncertainty around renewable fuel policy and the size of the future market. This is the principal barrier to further expansion of the fuels nearest to commercialisation, where a number of commercial scale plants have been built. For several technologies at an earlier stage, the component processes for making a fuel have now been proven, but the remaining risks and costs associated with developing integrated demonstration and first commercial plants, as well as the uncertainty in market uptake and value of the output fuels, remain a significant barrier to realising commercial production.

The UK’s Department for Transport has started supporting the demonstration of advanced biofuels through an advanced biofuels demonstration competition. The Department is seeking to provide further opportunities for supporting advanced renewable fuel options, especially for production of diesel, heavy fuel oil and kerosene displacement. The UK government believes it can play an important role demonstrating and deploying advanced renewable fuel production in the UK, and unlocking the potential environmental and economic benefits of a hi-tech domestic industry, and the jobs and growth that would bring.

1.2 The first advanced biofuel demonstration competition (ABDC)

To address many of the challenges discussed above, DfT announced in August 2013 that it would make £25m of capital funding available for an advanced biofuel demonstration competition (ABDC), which would underpin significant private sector investment in the development of such facilities in the UK.

The ABDC was launched in 2014, and is contributing matched grant funding to UK SMEs to help build first-of-a-kind plants in the UK. Their goal is to produce 1m litres of advanced biofuel by the end of 2018, with GHG savings of at least 60% compared to conventional fuels and economic benefits in terms of revenues and jobs linked to future technology deployment.

The ABDC was executed in two stages, a first phase requesting consortia to submit expressions of interest and a second stage where shortlisted project consortia were asked to submit full proposals. A DfT selection panel comprising experts from academia, industry, finance and policy provided recommendations on the proposals at both stages based on their technical, economic, and environmental merits, and benefits to the UK advanced biofuel industry.

A number of lessons have been learnt from the previous competition, which will inform the feasibility and design of the new competition:

- It takes a long time to secure private sector investors, which is critical to the success of the project. So, certainty or very high confidence over private sector funding should be required before public sector funding is committed.
- Imposing requirements on scale or product output could limit the ability of developers to bid, or lead them to propose projects that are not appropriate in terms of technical progression. The former because of the impossibility to build and commission plants within the period stipulated by the grant award, and the latter because the proposed scale is too large for some earlier, albeit

interesting, technologies. So, greater flexibility or a lower minimum capacity or production scale may be appropriate as long as the objectives of the competition are met (see Section 6 for suggestions for this new competition).

- Setting high GHG savings thresholds for demonstration plants may not be appropriate as these are designed to demonstrate the technical viability of the concept, but may not be designed to optimise energy or environmental performance so to limit costs and added complexity. So, while a robust estimate should be provided for the emissions from the demonstration plant, what is more important is that a convincing case is made for high GHG savings from commercial plants. However, GHG savings below a certain threshold for demonstration plants would mean that the fuel produced would not be eligible for support from advance renewable fuel policy schemes. Different GHG thresholds may also be appropriate for different TRL levels.
- Offtake agreements for produced fuels need to be robust. The objective of the next competition being to displace conventional fuels in HGVs and aviation means that even greater importance may need to be given to offtake agreements.
- The eligibility criteria need to be absolutely clear. For example, if a certain volume of production is set as a requirement it must be absolutely clear whether it refers to plant capacity or actual production by a certain time.
- The evaluation criteria need to be clear externally and internally (equally important at all stages of the competition), but should be limited to few critical criteria that bear the greatest relation to competition objectives. It should be clear to both bidders and evaluators what elements the proposal needs to address in relation to the criteria, and if needed the relative importance or weighting of those elements. The descriptions provided to the bidders and evaluators should be the same.
- A clearly defined approach to scoring evaluation criteria, with in-built QA stages, provides an auditable record of all assessment outcomes and decisions, which fully supports DfT in case of challenge.
- The proposed projects should aim to give maximum benefits to the UK. So, checks should be made that agreements with project partners and investors do not unduly limit the benefits to the UK e.g. by imposing procurement of equipment from abroad. DfT should be aware of such situations and push for negotiations to maximise benefit to the UK, and should ensure that the IP generated as a result of the project is retained in the UK even if the concept ends up being licenced further afield.
- Appropriate time should be allowed for bidders to prepare proposals and for the assessment process between stages such as the Selection Panel, Project Board, ISE IB and Ministers. The Selection Panel should be kept manageable by recruiting between 6 and 8 members.
- Some bidders lack resources and certain capabilities to address all requirements of the competition. There could therefore be an argument to provide support to them during the bidding process.
- Internal procurement routes should be investigated as early as possible, to be aware of any potential issues or processes that may add delays to contracting a Delivery Partner and launching the competition. This is especially the case for small start-ups where even a delay in decisions of two months could lead to bankruptcy.
- Government should not to feel obliged to allocate all of the grant funds if there is insufficient interest from companies that can prove they meet all of the requirements and have been

evaluated by the Selection Panel, Project Board and the ISE IB as having a good chance of succeeding

Further lessons learnt are described in the specific sections of the report to which they are relevant.

1.3 Aims of the Future Fuels for Flight and Freight Competition, and this study

There is a desire from DfT to maintain the momentum around advanced renewable fuels support through establishing a second competition, covering advanced renewable fuels (biofuels and renewable fuels of non-biological origin) capable of decarbonising aviation and HGVs. The aim of the competition would, once again, be to pave the way for first-of-a-kind commercial scale plants in the UK by proving technical and economic viability, and providing government support to help de-risk the investment climate. The competition will have a funding level of £20m over three years, and could be similar to the first competition, though potentially with a revised approach to take account of any lessons learned in the first competition.

The DfT considers that it may be appropriate to focus a second competition on fuels that can be used sustainably at high levels in transport modes that have few other decarbonisation options, in particular aviation and HGVs, as this could be of strategic importance to the UK. These fuels may need more support to reach the market than other advanced renewable fuels that are closer to commercial readiness, and therefore may not be brought forward by advanced renewable fuel targets alone. This focus and objective is shared with the ‘development fuels’ sub-target (described below) that is currently under consideration for inclusion under the RTFO.

The aim of this feasibility study is therefore to equip DfT with the information necessary to design and launch a follow up to the ABDC that specifically focuses on fuels of strategic importance to the UK. This includes providing information on:

- the current status of the fuels that could be targeted, and an assessment of their strategic importance to aviation and HGVs
- the business case – UK value and jobs, fuel demand, etc.
- feasibility of inclusion in the competition - likely availability and interest of companies to enter the competition given the readiness of technologies
- potential funding structures

Although several of these areas were assessed in the feasibility study for the first competition[2], developments in technology and market players, the focus towards aviation and HGVs, and the learning from the first competition mean that updated information is required.

Options for the use of a smaller, more time-limited funding pot (£5.5m over one year) are also considered.

[2] E4tech and Ricardo-AEA, Advanced Biofuel Demonstration Competition Feasibility Study, February 2014, under contract to Arup URS, commissioned by DfT https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/383577/Advanced_Biofuel_Demonstration_Competition_-_Feasibility_Study_FINAL_v3.pdf

1.4 Definitions

Several definitions are provided below to facilitate understanding within this study. It is important to note that these definitions are those needed for clarity in this study, and do not represent the eligibility criteria for the competition, which are proposed later in this report. The Competition must provide a clear definition of eligible fuels to ensure it attracts appropriate applications that meet the Department's objectives.

Advanced

There is no industry-wide agreed definition of the term "advanced" biofuels and other renewable fuels. The term is generally used to describe biofuels from technology pathways that have not yet reached commercial status, biofuels produced from residues, wastes or non-food feedstocks considered to be more sustainable than the biofuel crops commonly used today, "drop-in" biofuels whose molecules fit the existing fuels infrastructure, or some renewable fuels of non-biological origin.

At EU level, the term 'advanced' is generally used to refer to biofuels made from feedstocks listed in Annex IXa of the ILUC directive 2015[3]. Note that this definition and list will be revised by the Proposal for a revised renewable energy Directive[4]

Biofuels

Liquid or gaseous fuel for transport produced from biomass. 'Biomass' means the biodegradable fraction of products, waste and residues of biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste;

Renewable fuels of non-biological origin

"Renewable liquid and gaseous transport fuels of nonbiological origin" means liquid or gaseous fuels other than biofuels whose energy content comes from renewable energy sources other than biomass, and which are used in transport

Development fuels (definition under consultation)

A 'development fuel' is a fuel made from a sustainable waste or residue* or a non-biological renewable fuel, and would be one of a specified fuel type:

- Hydrogen
- Biomethane
- Aviation fuel (kerosene and avgas)
- Biobutanol
- HVO (hydro-treated vegetable oil)
- Fuel that can be blended at rates of at least [x]% and still meet the relevant fuel standard i.e. EN228 for petrol, EN590 for diesel

[3] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015L1513&from=EN
[4] 'Proposal for a revised renewable energy Directive' and annexes https://ec.europa.eu/energy/en/news/commission-proposes-new-rules-consumer-centred-clean-energy-transition

*Subject to waste hierarchy test and excluding used cooking oil (UCO) and tallow

Waste-based fossil fuels

The proposed revised RED includes a definition for ‘waste-based fossil fuels’: liquid and gaseous fuels produced from waste streams of non-renewable origin, including waste processing gases and exhaust gases.

2 Potential advanced renewable fuel routes

2.1 Introduction

There are a large number of conversion technologies under development for the production of advanced biofuels and other renewable and low carbon fuels. Conventional biofuels production operates at commercial scale, with widespread deployment (trans-esterification of oils and fats to produce FAME biodiesel, and fermentation of sugars (from sugar or starch crops) to produce ethanol). However routes that use waste and residue, or non-biomass feedstocks are typically at an earlier stage, as are those that produce fuels that have greater fungibility with jet and diesel fuels used in aviation and HGVs.

Given that there is as yet no agreed definition of the type of fuels that will be additionally supported in the UK through development fuels targets, this study has taken the approach of including a wide range of fuels in this section, assessing which of them are likely to meet the requirements of a competition, in terms of:

- Potential for future widespread use in aviation and HGVs
- Suitable technology development status for a competition – sufficiently advanced to allow production of a sufficient volume of fuel for engine testing, but not already widely commercially available
- Potential benefits to the UK – in terms of deployment potential, which principally depends on feedstock availability, or in terms of UK technology export possibilities
- Additionality to expected support through the RTFO – the competition should only support projects which would not be commercially viable with existing market based support

This section also includes other information on the routes, such as benefits (GHG and air quality impacts) and barriers to the technologies.

The development status is expressed in terms of the technology readiness level (TRL). TRL was first introduced by NASA, and is a relative measure of the maturity of evolving technologies on a scale of 1 to 9. As shown in Appendix A, TRL 1 indicates basic research on a new invention or scenario, while TRL 9 represents a fully commercialised technology.

TRL definitions are not necessarily inferred by plant capacity, because of the enormous potential difference in markets. For example, at the same capacity a small demonstration plant in one market could count as a first commercial plant in another. Annual production or production capacity for a specific product is therefore only an indicator for the level of commercialisation.

Note on air quality impacts

Engine out emissions are not only a function of the fuel used, but also of the combustion process (Compression Ignition – diesel cycle vs Spark Ignition – gasoline cycle) and a significant number of engine technology control parameters. Exhaust gas aftertreatment systems are widely used (and can be very effective as demonstrated by heavy duty EURO VI compliant vehicles) to control **tailpipe** emissions to “within” the required limits set for the application.

Introducing a new fuel into an existing fleet could therefore have certain effects, whereas introducing the same fuel with dedicated technology would typically be homologated to the governing emissions legislation of the region into which it is sold. The air quality impacts given in these sections are generalised statements of the potential effect of a fuel for indicative purposes only.

2.2 Gasification-based routes

Technology status

Gasification converts lignocellulosic feedstocks to syngas under high temperature and pressure. The syngas, composed of carbon monoxide and hydrogen, is then cleaned and conditioned to meet specific requirements of the subsequent catalytic process. In the six main catalytic synthesis technologies Fischer-Tropsch (FT) leading to diesel and jet fuel, DME, hydrogen, methane (often called bio synthetic natural gas or bioSNG), methanol and mixed-alcohols, the conditioned syngas is reacted over different catalysts with a variety of pressure and temperature conditions to produce different fuels.

The technology development status varies strongly with each upgrading technology. Methanol synthesis using biomass for gasification is currently the only upgrading technology operating at commercial scale (TRL 8). Methane and FT-synthesis are at a lower development level of TRL 6-7 and 5-6. There is most activity in FT-Diesel, but this is limited to operations mainly at pilot scale, with a few first-of-a-kind commercial and demonstration scale projects are planned for 2017 onwards. Few operational or planned projects currently exist globally for methane and mixed-alcohol synthesis. Projects on catalytic synthesis to DME from biomass have been cancelled. The UK has one player, Advanced Plasma Power (APP, an ABDC awardee) operating one pilot plant and planning a demonstration scale plant to produce bioSNG from waste, using technology from Outotec. The UK also has leading technology providers including BP, Johnson Matthey and Velocys.

There has also been work on anaerobic fermentation of syngas by micro-organisms into ethanol or other products. However, there is currently little high TRL activity in this route: the main developer above pilot scale INEOS Bio is aiming to sell their plant by the end of 2016. Lanzatech, whose syngas fermentation technology is currently being demonstrated based on CO-rich steel mill waste gases, could also potentially use biomass-derived syngas, and have done tests in the US on this approach, although this is not their current focus.

Benefits

Gasification with catalytic synthesis offers a variety of fuels that can be used to decarbonise both HGVs and aviation.

- Aviation – jet fuel from FT process
- HGVs – diesel from FT process can be used as a drop-in replacement for diesel. DME, methane and hydrogen can be used in modified HGV engines, and potentially hydrogen in fuel cells in the future. Methanol and other alcohols would require a further conversion step to produce diesel or jet, or blending with additives for use in a dedicated HGV. Scania have investigated using methanol in dedicated HGV engines and further investigations are ongoing by VTT in Finland.

GHG intensity values are not available for all the different gasification and catalytic synthesis routes based on operational projects. However, typical values for GHG savings are given in the RED:

- FT-Diesel using waste wood: 4gCO_2e/MJ which leads to GHG savings of 95% (RED).
- Methanol and DME using waste wood: 5gCO_2e/MJ which leads to GHG savings of 95% and 94% (RED).

The air quality benefits depend vary for the three main fuel types:

- Methanol: Methanol can potentially be utilised as a diesel substitute either with an ignition enhancer (similar to ED95) or in a dual fuel application where a small quantity (pilot injection) of diesel is used to ignite the methanol. Both are expected to demonstrate lower NOx and particulate emissions
- Methane: Methane can be used in a spark ignition engine where due to the lack of carbon to carbon bonds it will demonstrate negligible particulate emissions, but potentially higher NOx emissions that the after treatment system will be able to abate. Methane can also be used in a diesel engine as a dual fuel application where a small quantity (pilot injection) of diesel is used to ignite the methane. This is expected to demonstrate lower NOx and particulate emissions.
- FT-Diesel is likely to demonstrate similar emissions to diesel. Particulate emissions could be reduced if the fuel was designed to have shorter chains and/or less double carbon bonds.

Barriers to deployment (financial, technical, supply chain, demand)

Technical challenges and the difficulty of raising finance for capital intensive projects have led to a lack of biomass gasification and catalytic synthesis projects at commercial or large demonstration scale. Consistent syngas quality, produced reliably and efficiently from different biomass and waste feedstocks, meeting the syngas requirement of the catalytic synthesis upgrading steps needs to be achieved. This will improve reliability, reduce the production costs and improve overall economics.

Given the expected high costs of fuel production from these routes, policy support will be needed to encourage deployment of these gasification-based routes. As several are at an earlier stage of development and have higher projected costs than other routes that are included in the same policy support categories, they may not be developed as a result of these targets.

Gasification based plants typically have large economies of scale, driving larger projects with greater feedstock needs than other routes. This means that careful choice of location and feedstock options is required.

Commercialisation potential

For most catalytic synthesis routes, apart from commercial-scale methanol synthesis, the next step for commercial deployment is the successful operation of full-scale demonstration plants. This includes Advanced Plasma Power in the UK, a technology developer now constructing a demonstration plant for the production of bioSNG using MSW, a widely available and low-cost feedstock in the UK. Overall, only catalytic synthesis to methanol has currently a high potential for commercialisation in the short term as the technology operates at first-of-kind-commercial scale and uses low-cost feedstocks.

2.3 Pyrolysis and upgrading

Technology status

Pyrolysis is the controlled thermal decomposition of (typically dry) biomass at moderate temperatures, in the absence of oxygen, to produce liquid oil, gas and charcoal (biochar). Catalytic fast pyrolysis maximises the production of the liquid pyrolysis oil fraction (instead of char). Crude pyrolysis oil can be upgraded by directly blending with fossil vacuum gas oil within an existing refinery fluid catalytic cracker (FCC) unit or by undergoing hydro-deoxygenation before hydrocracking. Both upgrading options produce a combination of light, medium and heavy products, which can be distilled to produce diesel, jet and gasoline streams.

Conventional fast pyrolysis technologies for making food flavourings and bio-oil for heat and power applications have already been commercialised in a few plants[5], so fast pyrolysis is currently at TRL 8. However, upgrading is less developed at around TRL 5-6, with 5-20% short blending campaigns conducted at demonstration scale in a few oil refineries, but no dedicated upgrading facilities operational globally. Hydro-deoxygenation of pyrolysis oil is at an earlier lab and pilot scale (TRL 4-5).

The UK has strong capabilities in pyrolysis generally; however the focus to date has been on producing pyrolysis oil for use in heat and power applications. Fuel-focused fast pyrolysis UK actors include Future Blends (now bought by Next BTL LLC), who operate a pilot plant near Oxford using a modified fast pyrolysis platform, and Torftech Energy, who have multiple waste-to-energy plants and are researching biofuel production[6].

Benefits

Fast pyrolysis with upgrading has the potential to produce both jet and diesel that can be used to decarbonise both HGVs and aviation. No GHG intensity values are available for the pyrolysis and upgrading routes based on operational projects. The air quality impacts of upgraded pyrolysis oil to a drop-in diesel or gasoline will be similar to conventional diesel and gasoline.

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[5] Jones *et al*. (2016) "Fast Pyrolysis and Hydrotreating: 2015 State of Technology R&D and Projections to 2017", Pacific Northwest National Laboratory (PNNL). Available www.pnnl.gov/main/publications/external/technical_reports/PNNL-25312.pdf

[6] Bridgwater, T. & I. Watkinson (eds.) (2016) "Biomass and Waste Pyrolysis A Guide to UK Capabilities", Aston University European Bioenergy Research Institute (EBRI), Aston University. Available at: www.pyne.co.uk/Resources/user/UK%20Biomass%20and%20Waste%20Pyrolysis%20Guide%202015%20081015.pdf (17 Nov 2016)

Pyrolysis oil can be fractionated to produce pyrolytic lignin and sugars which can both be used as intermediate chemicals to produce resins for example

Barriers to deployment (financial, technical, supply chain, demand)

The main barriers relate to pyrolysis oil upgrading step. The use of hydrotreating in this step contributes significantly to fuel production costs. Catalyst lifetime, deactivation, stability and cost are the main technical barriers for the upgrading process which slow-down further deployment. Full integration of fast pyrolysis with upgrading in a single facility has also not yet been demonstrated at scale, and presents a significant challenge.

Policy support will be needed to encourage deployment this route. Whilst these processes are not the most commercialised routes that would fit within an advanced/development fuels category, leading to some uncertainty over the effectiveness of targets in promoting their deployment, several barriers are reduced compared with gasification based routes. Pyrolysis plants could be economically viable at smaller scales, entailing lower capital costs, and the costs of the whole process can be reduced by integration in existing processes such as refinery upgrading.

Commercialisation potential

To achieve commercial scale pyrolysis oil upgrading requires continuous demonstration over a larger timeframe in existing oil refineries or the demonstration in an integrated facility. The former has been tested for short periods with existing oil refinery actors while the latter is only at early pilot stage. The UK has very limited prospects to achieve a demonstration scale integrated facility before 2030. Integration in a UK refinery could be more achievable in the timeframe of the competition, but this would depend on availability of pyrolysis oil, willingness of refiners to participate, and on the level of policy support available. The value of the competition supporting UK refinery upgrading alone would need to be carefully evaluated.

2.4 Sugars to hydrocarbons

Technology status

These routes produce hydrocarbon fuels from sugars. For routes based on lignocellulosic feedstock, technologies developed for lignocellulosic ethanol plants are used to extract fermentable sugars from the starting waste and residue feedstocks. Two routes exist to transform LC sugars to hydrocarbons. The first route consists of biological conversion by aerobic fermentation (with air, at atmospheric pressure), to generate specific hydrocarbon precursors, before product recovery, purification and upgrading to diesel, gasoline and jet fuels. This includes routes via biological catalysts, heterotrophic algae fermentation and modified yeast. Aerobic fermentation of LC sugars is currently at TRL 5 based on tests by Global Bioenergies and Amyris. In the second route, aqueous phase reforming (APR), an aqueous solution of sugars is converted by a high temperature reforming process using a chemical catalyst to produce a mixture of acids, ketones, aromatics and cyclic hydrocarbons, plus hydrogen and water. Further processing steps are then required to produce gasoline, diesel and jet fuel, as this requires a series of condensation reactions to lengthen the carbon chains in bio-crude, before hydrotreating and isomerisation. The APR process using LC sugars is currently at TRL 4-5 based on trials by Virent (now Tesoro) at lab scale. Besides Johnson Matthey (catalyst developer) and Shell working with Virent, there are no other known UK companies involved in sugar to hydrocarbon routes.

Benefits

Sugar to hydrocarbon routes have the potential to directly decarbonise HGVs and aviation through the direct production of diesel and jet fuel. No GHG intensity values are available for Sugar to hydrocarbon routes based on operational projects. The air quality impacts of sugar to hydrocarbon routes to drop-in diesel or gasoline will be similar to conventional diesel and gasoline. Sugar to hydrocarbon routes have a wide scope for biorefining and different biochemicals depending on process and company. For example, Virent focuses on paraxylene used in PET bottles while Amyris has a focus on farnesene that can be used to make solvents, coatings and many others products.

Barriers to deployment

For the APR conversion route, catalyst challenges such as deactivation and coking and low selectivity to hydrocarbons are among the main technical barriers. For aerobic fermentation routes, the variability of hydrolysates from real-world LC feedstocks and the presence of inhibitors from the integrated pre-treatment process are main technical challenges[7].

There is also an economic barrier related to using the same feedstocks as more developed routes to fuels: for example, more expensive routes to hydrocarbons will not be commercially viable as long as ethanol produced from the same sugars has a similar market value to the hydrocarbon fuel product that would be produced.

Commercialisation potential

The progress towards commercialisation is expected to be low as there is limited activity on using LC sugars by existing companies in this route. Further, besides the involvement of Johnson Matthey and Shell with Virent, no UK actor is involved which limits the commercialisation potential in the UK in the short and medium term significantly.

2.5 Lignocellulosic ethanol

Technology status

Lignocellulosic ethanol is the most advanced biochemical conversion process. It involves the pre-treatment and hydrolysis of lignocellulosic feedstock to C5 and C6 sugars and the consequent fermentation of these sugars to ethanol. There are several technology providers operating first-of-kind commercial plants and a similar number having plants in planning or construction status in Europe, the US, China and Brazil. In addition there are a comparable number of technology developers at pilot and demonstration scale. The UK has one first-of-kind commercial lignocellulosic ethanol plant in the early development stages. Danish technology developer Inbicon is cooperating with UK project developer Vireol on this project which is at the initial feasibility stage. At pilot scale Fiberight is working in the UK on two IB catalyst funded projects testing parts of their MSW to sugars process. Nova Pangaea, an ABDC awardee, uses a pyrolysis-based process to convert forestry

[7] J. Holladay *et al*. (2014) "Renewable routes to jet fuel". Available at http://aviation.u-tokyo.ac.jp/eventcopy/ws2014/20141105_07DOE%EF%BC%BFHolladay.pdf

residues into LC sugars for subsequent conversion to ethanol. In addition, the UK has acitivty in research, pre-treatment, biocatalysis and process development.

Benefits

Ethanol cannot be used in jet fuel, or in diesel directly. However, options exist for supplying these markets via

- an alcohol to jet route (ethanol to jet or diesel, covered below), or
- to fuel HGVs through blending with additives and use in a dedicated HGV engine. For example ED95 is an ethanol based fuel consisting of 95 percent ethanol with the addition of ignition improver, lubricant and corrosion protection. Particulate levels can be expected to be very low. There are Scania HGVs and buses operating currently in the UK on ED95.

No actual GHG intensity values are available from any of the operating first-of-a-kind commercial plants. From the data used in the Renewable Energy Directive (RED), wheat straw-derived ethanol has typical GHG emissions of 11 gCO_2e/MJ which leads to GHG savings of 87%[8]. Ethanol as a blend into gasoline typically lowers NOx and particulate matter (both particulate mass and number). Non-regulated but carcinogenic aldehyde emissions should be expected when combusting ethanol in spark ignition engines.

Lignocellulosic ethanol production can be combined with other uses of the sugars produced as an intermediate in the process, with the biorefinery producing a large variety of chemical building blocks such as lactic or acetic acid. However, the competition from other food-based sugars routes in these markets is likely to be significant and so would require policy support for lignocellulosic sugar-based biochemicals.

Barriers

The lack of policy certainty at EU and UK level is the main barrier for the development of further commercial scale lignocellulosic ethanol projects. Developers consider that advanced biofuels sub-targets that include LC ethanol would be sufficient to drive commercialisation of this technology in Europe. In the UK, ethanol is not currently included in the proposed development fuel list, and so LC ethanol is unlikely to be produced in the UK and sold in the UK, as developers will focus on other countries with targets that support LC ethanol. In addition, ethanol would not be converted into fuels that can be used in aviation or HGVs without additional policy support, given the additional costs compared with selling the fuel directly for gasoline blending in another market.

The feedstock resources of some feedstocks such as straw available in the UK may not make it an attractive proposition for multiple plants which may reduce the attractiveness to producers. The first commercial plants are expected to have higher production costs than first generation ethanol making policy support a necessity, but technical improvements such as co-fermentation of C5 and C6 sugars to improve yields are important to further improve the economics of the process.

[8] DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 as amended by Directive 2015/1513 of 9 September 2015.

UK commercialisation potential

The first early commercial LC ethanol plants globally are based on agricultural residues such as straw, which is a limited feedstock resource in the UK. Technologies that allow a wider feedstock variety such as including wood or MSW would be preferable in the mid-term to avoid feedstock limitations. Lignocellulosic fermentation and further bio-refining provide synergies for the UK due to strong research capabilities and several players at earlier stages of development in different parts of the value chain. There may be value in supporting the development of such technologies, in particular where value to the UK could be realised through IP development, improved efficiency, reduced production costs and the potential for further bio-refining activities.

2.6 Lignocellulosic butanol

Technology status

Lignocellulosic butanol technologies convert second generation feedstocks into butanol in a similar way to lignocellulosic ethanol (see above). Most butanol developers, including those closest to commercialisation, are focusing on scale-up and yield improvements using food-crop based sugars. Very few players currently work on the commercialisation of lignocellulosic butanol and some of these are currently on hold or have been mothballed. Green Biologics and Celtic Renewables are engaged in pilot plant activities in the UK, but Butamax's UK pilot plant in Hull has been mothballed, with Butamax continuing development outside the UK.

Benefits

Butanol can be blended with gasoline at higher proportions than ethanol within the same oxygenate limit, for example 16% butanol by volume is equivalent to E10. Butanol cannot be used in jet fuel, or in diesel directly. However, options exist for supplying these markets via an alcohol to jet route (butanol to jet or diesel, covered below). No information is available on testing of butanol for use in HGVs.

Actual GHG savings are not yet known, but are expected to be similar to those from lignocellulosic ethanol. Butanol displays similar characteristics as ethanol in a spark ignition engine, see ethanol section. In addition, butanol represents an attractive intermediary building block for bio-based chemicals. The air quality characteristics of butanol are very similar to ethanol, please see above.

Barriers to deployment

In comparison to lignocellulosic ethanol, the separation process is more energy intensive and the fermentation technologies are less mature making the process less cost competitive. It is currently more attractive for butanol developers to convert first generation ethanol plants to butanol (for example to overcome the US ethanol blending limits) which limits the interest in lignocellulosic butanol development. Butanol is included on the draft development fuels list, but it is not yet known whether the value of this support would be enough to make lignocellulosic butanol more attractive than alternative markets. In addition, butanol would not be converted into fuels that can be used in aviation or HGVs without additional policy support, given the additional costs compared with selling the fuel directly for gasoline blending in another market.

UK commercialisation potential

The potential for commercialisation will depend on the successful scale-up of first generation butanol and lignocellulosic ethanol. Players currently operating at pilot scale could deploy demonstration scale plants by 2020 if yields can be increased and policy incentives exist. As with LC ethanol, the feedstock resources of some feedstocks such as straw available in the UK may not make it an attractive proposition for multiple plants which may reduce the attractiveness to producers. However, given the existing UK butanol players there is a case for global deployment of UK IP.

2.7 Hydrogen

Technology status

Renewable or low carbon hydrogen can be produced via a range of routes:

- Renewable hydrogen from biomass – covered in the gasification and catalytic upgrading section.
- Renewable hydrogen from water electrolysis using renewable electricity – covered in this section
- Low carbon hydrogen from fossil fuels with carbon capture and storage - not considered further here given the focus on renewable fuels, and current lack of UK carbon capture and storage infrastructure
- Renewable hydrogen from novel routes such as photoelectrochemical watersplitting, thermochemical cycles etc. – not considered further given their early stage of development

The most promising near-term electrolytic technologies (alkaline and PEM electrolysis) are already available today (TRL 9). However, given the earlier stage of renewable hydrogen transport systems as a whole, this option is considered further in this section, rather than being excluded at the start.

For transport applications, small scale electrolysis is considered most feasible in the near term, given that the electrolyser can be sited at a refuelling stations, and the system sized to meet the transport demand. However, there is also UK interest in deploying electrolysers close to sources of renewable generation, or at constrained nodes on the electricity grid, to enable greater use of renewable electricity[9]. Some or all of the hydrogen produced by these systems could be used for transport applications.

Hydrogen could be used in road transport (cars, buses, light duty vehicles, HGVs), marine applications and trains, but not in aviation, due to its low energy density. Hydrogen use in cars is in the early stages of commercialisation, with buses at the fleet demonstration stage. Use in HGVs requires further work to develop the technology and improve economics. Use in marine is at the early demonstration stage, with activity and interest from several UK companies in use of fuel cells and in engine conversions[10]. Use in rail is at demonstration stage globally, with university research in the UK.

Benefits

Hydrogen produced using renewable electricity can have very low well-to-tank GHG emissions, down to zero if renewable electricity is also used for compression and dispensing. Note that if the WTT

[9] Ref roadmap

[10] Roadmap appendix

GHG intensity is non-zero, use in a fuel cell vehicle has an increased efficiency compared with a conventional vehicle, which means that well-to-wheel GHG savings are reduced. This factor is set at 0.4 in the FQD and RED, meaning that hydrogen can have a WTT GHG intensity 2.5 times higher than the GHG threshold, or 83.8 $gCO2e/MJ_{H2}$. It is important to consider the well-to-wheel emissions of the system proposed in order to make a valid comparison with conventional fuels and the RED GHG saving requirements. Policy support may depend the requirements for electrolysers that are not directly connected to a renewable electricity source, which are currently being consulted on.

When used in a fuel cell, hydrogen has zero air pollutant emissions. In internal combustion engines, there are emissions of NOx only, which are low[11].

In addition, production of hydrogen can have energy systems benefits, such as allowing the use of 'stranded' renewable energy resources, and providing services to energy networks, such as balancing and avoiding grid constraints.

Barriers to deployment (financial, technical, supply chain, demand)

For hydrogen from electrolysis, high electricity costs represent the major barrier to market competitiveness compared with hydrogen produced from natural gas. Technology development and economies of scale could also reduce costs, improve performance and improve commercial competitiveness. Inclusion of hydrogen from renewable electricity in the RTFO from 2017 will be the first market based policy support available in the UK to promote renewable hydrogen over fossil-hydrogen in transport. In addition, for electrolysers at refuelling stations to offer attractive economics, it is essential to secure low cost electricity, by operating electrolysers to take advantage of fluctuations in electricity prices and also providing balancing services to the grid. This requires work on business models, as well as an appropriate market framework for electrolysers to generate value from system services.

However, overall, the main barriers to use of hydrogen in transport are high system costs compared with conventional fuels and vehicles, availability or maturity of vehicles (see above), and lack of supporting hydrogen infrastructure. Particularly for hydrogen systems fuelling heavier vehicles, the performance and cost of the electrolyser itself is not the principal barrier to deployment. As a result, it may be more appropriate to support renewable hydrogen in transport systems through other funding mechanisms that are more appropriate to the main challenges faced, such as through the Hydrogen for Transport Advancement Programme (HyTAP), which funds hydrogen refuelling stations, through vehicle development and trials funding, and/or regional funding for integrated projects.

Commercialisation potential

The electrolyser industry consists of around 30 SMEs. The UK has a leading actor in PEM electrolysis (ITM Power), currently targeting small and medium scale applications, up to half a tonne of hydrogen per day. There is also UK experience in using electrolysers: Pure Energy Centre have installed an operated electrolysers for a number of UK and overseas clients. Other UK players are working in the value chain, and the UK has relevant capabilities to develop advanced materials and processes in this area. On the vehicles side, there are UK players in small vehicles and parts of the supply chain for cars and heavier vehicles, with the UK's hydrogen and fuel cell roadmap proposing targeting UK vehicle

[11] Ref roadmap report

development efforts at buses and larger vehicles (vans, trucks, HGVs) and small vehicles. On the marine side, the UK has the potential to take a leadership role given the history of ship-building, the number of inter-island ships in operation and globally leading demonstration projects.

2.8 Hydrotreated oils routes (HVO and HEFA)

Technology status

Hydrotreatment of oils involves the conversion of vegetable or waste oils into diesel and jet fuel, generally referred to as hydrogenated vegetable oil (HVO) when converted to diesel and hydroprocessed esters and fatty acids jet (HEFA) when converted to jet. There is also testing on the use of HVO in jet applications, where it is referred to as HEFA+. Under the development fuels definition under consultation, HVO and HEFA would only be included if produced from qualifying waste oils not including UCO and tallow. The process of hydrotreatment consists of a thermal decomposition process, a hydrogenation and isomerisation reaction to produce HVO, and an additional selective cracking process to produce HEFA. Depending on the plant configuration, it can be a dedicated HVO plant or a co-production plant with different shares of HEFA and HVO as products, as well as other co-products such as naphtha and propane. The plant can either be a separate unit at an existing oil refinery (allowing for co-usage of hydrogen) or be built as a dedicated standalone plant.

HVO production is at TRL 9, as production is underway in several countries, with multiple active plant technology developers. HEFA production is at an earlier stage commercially: it has been produced at several plants, and is in use in aviation, but this is not widespread. However, there is considered to be no technical barrier to production at TRL9, if the business case for production and use in aviation were viable for a wider range of users.

Benefits

Hydrotreating routes produce fuels that can be used directly in diesel or jet, at up to 100% for HVO in diesel, 50% for HEFA in jet, and potentially 10% for HEFA+ in jet. GHG savings vary widely depending on the feedstock used, but are very high from waste feedstocks. HVO has been shown to reduce particulate matter emissions significantly, depending on the blend percentage with diesel and after treatment systems used. NOx emissions have been shown to be similar.

Barriers to deployment (financial, technical, supply chain, demand)
The principal barrier to supply of HVO and HEFA from waste oils aside from UCO and tallow is the availability of those waste oils themselves. There is no technology barrier to their production. HEFA has additional barriers compared with HVO, in that the economics of the route are not competitive with jet fuel, and aviation biofuels are only included within policy support for biofuels in a small number of countries.

Commercialisation potential
Given that the supply of HVO/HEFA from waste oils aside from UCO and tallow is constrained by the waste oils availability, and a greater HVO plant capacity exists than the current supply of these materials, further supply of waste oils is likely to be converted in existing plants, displacing vegetable oils. The support available to this route in several countries (development fuels support in the UK, double counting in many Member States) is likely to be sufficient to support further use of these

feedstocks for HVO today (given that this route is economically viable) and HEFA if included in biofuels and/or aviation policy, and potentially to support further plants in the future if the sustainable feedstock base increased.

2.9 RFNBOs

Technology status

Renewable fuels of non-biological origin (RFNBO) include in this feasibility study the production of synthetic fuels such as methanol, FT-Diesel and methane, but exclude hydrogen production, which is covered above. These RFNBOs involve the electrolysis of renewable electricity to hydrogen and converts the hydrogen with carbon dioxide through catalytic synthesis into synthetic fuels. The most advanced player in this technology is currently at TRL 8: the Carbon Recycling Initiative (CRI) plant in Iceland producing methanol from geothermal electricity. There are two other pilot projects, a Sunfire/Audi project in Germany producing synthetic diesel and the SOLETAIR project in Finland[12] undertaken by VTT/KTI and others to test the production of methanol, synthetic diesel and higher alcohols. Audi is involved in three other pilot projects: a cooperation with Joule in the US to produce ethanol and two P2G projects to produce methane in Germany[13]. The TRL of these routes is currently at 5-6. Besides ITM Power focusing on synthetic gas and academic research, for example at the University of Sheffield (TRL 4) the UK does not have any significant players working on synthetic fuels from hydrogen.

Benefits

For the fuel applications and air quality, see section 2.2 on gasification which covers the same fuels. The GHG emissions can be very low, for example, for CRI in Iceland based on geothermal electricity the GHG intensity is 8.5gCO_2e/MJ which represents a 90% saving[14]. However, this depends strongly on the route and source of electricity, and the way in which the GHG methodology will be applied to RFNBOs. It would be important to consider the well-to-wheel emissions of the system proposed in any proposal in order to make a valid comparison with conventional fuels and the RED GHG saving requirements. Policy support may depend on the requirements for electrolysers that are not directly connected to a renewable electricity source, which are currently being consulted upon.

Barriers to deployment

Increasing life times and operating efficiencies of electrolysers, improving the catalyst and reaction design for fuel production and the more efficient capture of CO_2 are the main technical development needs[15,16]. Developing a robust business case will require matching low cost renewable electricity

[12] Green Car Congress, 2016. Compact pilot plant for solar to liquid fuels production. Available at: http://www.greencarcongress.com/2016/11/20161109-soletair.html

[13] Audi, 2016. Synthetic fuels: Audi e-fuels. Available at: http://www.audi.com/corporate/en/sustainability/we-live-responsibility/product/synthetic-fuels-Audi-e-fuels.html

[14] Boulanger, P. 2015. Power-to-Methanol: Green transport fuel, renewable energy storage and grid balancing service. Available at: https://ec.europa.eu/energy/en/events/workshop-using-bioenergy-energy-storage-and-balance-grid

[15] E4tech, Study on development of water electrolysis in the EU (2015).

[16] Styring. P, Daan Jensen, Heleen de Coninck, Hans Reith, Katy Armstrong, Centre for Low Carbon Futures, Carbon Capture and utilisation in the green economy (2011)

with a high plant utilisation in order to cover the capital cost. Even though there is little cost data available due to the early stage of development, the production costs of synthetic fuels from hydrogen are likely to be higher than from other renewable fuels. This means that even though they are planned to be included in support from the RTFO, they are unlikely to be supported through policy aimed at a wider category of fuels (such as development fuels) alone. Policy support may also depend on the requirements for electrolysers that are not directly connected to a renewable electricity source, which are currently being consulted upon. In the proposed RED II, RFNBOs are included in the proposed 2030 target, but not the advanced biofuels and biogas sub-target.

Commercialisation potential

The UK is unlikely to be an ideal place for synthetic fuel plants as it requires cheap renewable electricity, co-located with CO_2 sources. In addition, most companies working on synthetic fuels are not based in the UK and are unlikely to build their first plant in the UK. However, a potential scenario for deployment of these technologies in the UK is the interest of a UK region with considerable renewable power resources and sources of CO_2. This could change in the medium term (around 2030) with a higher penetration of renewables in the UK.

2.10 Waste-based fossil fuels

Technology status

'Waste-based fossil fuels' is defined here as liquid and gaseous fuels produced from waste streams of non-renewable origin, including waste processing gases and exhaust gases. Lanzatech's process uses a waste fossil source of carbon such as steel mill carbon monoxide. Other fuels could include the use of mixed MSW, waste plastics or tyres as feedstock in pyrolysis, hydrothermal liquefaction or gasification to produce liquid fuels. A few European companies offer pyrolysis plants for waste tyres to produce pyrolysis oils, such as Metso who have tested 32t of waste tyres for 800h of continuous operation in a pilot plant[17]. Others include Enviro Systems, but currently their main aim is the recovery and sale of black carbon[18]. In addition a few Chinese companies and US offer pyrolysis plants for waste plastics and tyres, but it is unclear whether any plants are operational, at which scale and if any upgrading to liquid fuels is undertaken[19,20]. The TRL can be estimated at 8, similar to the pyrolysis process, while the upgrading is only at TRL 4-6 (see chapter 2.3). In the UK Recycling Technologies works on a waste plastic pyrolysis process to produce naphtha, slack wax and heavy fuel oil and will test their first plant with a council in the UK. However, their current focus appears to be heavy fuel oil[21]. Another UK company, 2G BioPower works on waste tyre pyrolysis, but their status and intent to produce liquid fuels is unclear.

[17] Metso, 2016. Tire pyrolysis – the true recycling solution. Available at: http://www.metso.com/products/pyro-process/tire-pyrolysis-sytems/
[18] Enviro Systems, 2016. Plants. Available at: http://www.envirosystems.se/technology/plants-2/?lang=en
[19] Bestongroup, 2016. Tyre pyrolysis process. Available at: http://tyrepyrolysisplants.net/tyre-pyrolysis-process.html
[20] Huayin Group, 2016. Waste tyre to fuel pyrolysis plant. Available at: http://www.huayinenergy.com/products/HY-6th_Waste_to_Oil_Pyrolysis_Machine/
[21] Williams, C. Is plastic-to-oil on brink of success in the UK? In MRW. Available at: https://www.mrw.co.uk/10012806.article

Benefits

Regarding the benefits of fuels and their air quality impact, please see section **Error! Reference ource not found.** for ethanol and the relevant chapters for pyrolysis, hydrothermal liquefaction and gasification. GHG emissions of waste based fossil fuels will vary widely depending on the process and feedstock. In particular, the counterfactual fare of the waste used, such as alternative disposal options is crucial. As a result any process would require a full lifecycle carbon intensity assessment including consideration of the counterfactual.

Barriers to deployment

For technical barriers please see the relevant chapters on gasification (2.2), pyrolysis (2.3) and HTL (2.12). For gas fermentation, the main challenges are yield and energy use in the process. Waste based fossil fuels are not currently supported by the RTFO, but would count towards requirements of the FQD, and so be supported by the proposed Motor Fuel Greenhouse Gas Emissions Reporting Regulations. In the proposed RED II, waste-based fossil fuels are included in the proposed 2030 target, but not the advanced biofuels and biogas sub-target.

Commercialisation potential

Lanzatech has previously expressed an interested in the UK and with policy support could develop a project in the near future to produce ethanol. Liquid fuel production via pyrolysis from waste tyres or plastics seems less likely in the near term as the UK does not appear to have any players working on liquid fuels for HGVs or aviation and it would require the interest of a UK refinery for the pyrolysis oil upgrading to liquid fuels. Swindon-based Recycling Technologies currently focuses on low-sulphur ship engine fuel.

2.11 Alcohols to jet and diesel

Technology status

Short chain alcohols (such as ethanol, methanol, n-butanol and isobutanol) can be catalytically converted to longer-chain hydrocarbon fuels, including gasoline, diesel and jet fuel. The conversion of ethanol or butanol molecules typically involves a combination of dehydration then oligomerisation reactions (combining molecules into longer-chains), followed by hydrogenation (adding hydrogen), isomerisation (branching to meet fuel specifications) and finally distillation into the required product streams. The process for methanol to gasoline (MTG) follows a different conversion pathway, which includes dehydration of methanol over a catalyst to form dimethyl-ether (DME), followed by further catalytic dehydration and hydrogenation reactions via light olefins to gasoline. As LC alcohols are (almost) chemically identical to their 1G alcohol or fossil alcohol counterparts, the TRL of catalytic conversion to drop-in hydrocarbons is largely unrelated to the origin of the alcohol. The first step, ethanol to ethylene is a commercial technology at TRL 9. The ethylene to fuels conversion step is not commonly used today, but industry players consider that it could be built if the market conditions were right to make it economically feasible. Overall, technologies from LC alcohol to hydrocarbon products are currently operating at TRL 5, but could progress quickly given prior experience. The first commercial plants, but not using lignocellulosic feedstocks, are planned by two players in the US for 2020. Pilot and lab scale activities are both ongoing in the US and Sweden.

Benefits

The fuel and air quality impacts are similar to the other routes producing drop-in diesel (EN590), see section 2.2 and 2.3. GHG impacts will depend on the emissions of the alcohol feedstock used, with a small increase related to the second conversion step.

Barriers to deployment

The biggest remaining technical challenge to alcohol-to-hydrocarbon technology is optimisation of the process conditions towards greater throughput and reduced recovery losses, whilst minimising the risks of runaway reactions[22].

As with other routes from sugars, there is also an economic barrier related to using the same feedstocks as cheaper routes to fuels: for example, ethanol to jet will not be commercially viable as long as ethanol produced from the same sugars has a similar market value to the jet fuel product that would be produced.

Commercialisation potential

Even though the integrated technology from feedstock to hydrocarbons is only at lab and early pilot stage, it is expected that, with existing technology, converting commercial scale operations alcohols to hydrocarbons could be achieved within a few years. There has been previous interest by some developers in plants in the UK. However, this would require a strong economic driver, including support from an end user and policy support under the RTFO.

2.12 Hydrothermal liquefaction and upgrading

Technology status

Hydrothermal liquefaction (HTL) is a process where biomass (plus a large amount of water) is heated at very high pressures to convert it into energy dense 'bio-crude'. The near- or super-critical water acts as a reactant and catalyst to depolymerise the biomass, although other catalysts can also be added. The characteristics of HTL oils make them easier to upgrade and more suitable for diesel production. HTL technology for producing bio-crude is currently at early demo scale (with continuous reactors), with an early demo in operation (TRL 5-6), but experience of upgrading HTL oils is limited to lab-scale[23,24] batch reactors at TRL 3-4 (and no integrated plant or refinery testing experience). The overall technology route is therefore at **TRL 4**. There are no commercial UK actors, but some academic research.

[22] Personal communication with technology developer
[23] Mullins, M. (2015) "Conversion of Biologically Derived Oils into Transportation Fuels", Michigan Tech. Available at www.svebio.se/sites/default/files/8.%20Michael%20Mullins%20-%20Conversion%20of%20Biologically%20Derived%20Oils%20into%20Transportation%20Fuels.pdf
[24] Lane, J. (2015) "Still algae, still fuels: The Digest's 2015 8-Slide Guide to Muradel", Biofuels Digest. Available at www.biofuelsdigest.com/bdigest/2015/11/10/still-algae-still-fuels-the-digests-2015-8-slide-guide-to-muradel/

Benefits

The benefits are similar to those of diesel, gasoline and jet from upgraded pyrolysis oils. However, HTL oils require less extensive upgrading than pyrolysis oils. This is due to their lower water and oxygen and higher energy contents. Also, HTL is well suited to process wet biomass.

Barriers to deployment

The most serious of the technical barriers currently facing this route is the lack of upgrading demonstration activities, with refineries in the real-world. Hydrothermal liquefaction plants face other challenges related to catalyst performance and efficiency, product quality, and disposal/treatment of high volumes of waste water. Other barriers are very similar to pyrolysis oil upgrading, see section 2.3. These include a lack of sufficient policy support.

Commercialisation potential

Developers claim that with further optimisation, it will be possible for the upgrading step to use standard refining processes to produce gasoline, diesel and jet fuel. It is expected that HTL oils could be used at high blend percentage in refinery FCC units, and with mild hydro-deoxygenation, it might be possible to co-process the bio-crude with fossil crude oil in the front end of existing oil refineries. The high energy density of the intermediate bio-crude provides the potential for economic transportation to a much larger off-site refinery. However, developers expect that HTL oil testing in refineries will be 5-10 years behind pyrolysis oils (as there are not sufficient volumes available yet to run testing campaigns), and hence the integrated technology may struggle to reach TRL 8 by 2030. In addition, there are currently no UK commercial actors.

2.13 Anaerobic digestion

Technology status

Anaerobic digestion (AD) is the decomposition of biological feedstocks by micro-organisms, usually in the absence of air (oxygen). The decomposition of the feedstock produces a gas comprising mostly methane and carbon dioxide. AD technology is well developed and mature technology (TRL 9), with thousands of plants in operation in Europe, generally using wastes including food, crop residues and manure.

Methane produced from biogas can be used in HGVs directly (see earlier section), or converted to other fuels, including hydrogen, methanol or liquid fuels, such as diesel and jet. Given the small scale of AD plants and large scale of liquid fuel production processes, there is most interest in addition of biomethane to the natural gas grid, with production of liquid fuel at a centralised larger plant. This is currently done in the Netherlands, where methanol is produced from natural gas from the gas grid, with contracts for biomethane supply at a different location.

Benefits

Biogas routes have typical GHG savings of over 80% according to the RED, when converted to CNG. GHG savings of routes with further conversion steps will depend on the route used.

Barriers to deployment (financial, technical, supply chain, demand)

Barriers to projects producing biogas through AD for use in the transport sector are typically related to the available returns, availability of project finance, and project-specific factors such as feedstock sourcing, infrastructure and siting[25]. However, developers of biogas projects not aiming at the transport sector have overcome many of these barriers to grow rapidly in the last few years under support from the Renewable Heat Incentive (RHI).

Commercialisation potential

For production of transport fuels to be attractive to developers and operators of AD plants, the production of the fuel needs to be more commercially attractive to them than electricity generation, use in a combined heat and power (CHP) plant or upgrading and injecting to the grid and receiving payments under the RHI. A comparison of these options in 2015[25] considered that, at under current levels of RTFC prices, and current levels of support available in the heat and power sector, that the supply of biomethane into the transport sector would be viable from existing plants, but would be unlikely to increase by 2020. However, this could change rapidly depending on on the future levels of support under these policies, and the potential inclusion of methane under the development fuels sub-target.

[25] Ricardo-AEA 2015 for DfT “Biomethane for Transport from Landfill and Anaerobic Digestion” https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/416002/biomethane-for-transport.pdf

2.14 Summary

The table below shows the extent to which each routes meets the criteria set out at the beginning of this section, based on the information given in the sections above. Entries in green meet the criteria fully, those in yellow would require further conditions to be made for inclusion in a competition, and those in red would not meet the requirements of the competition as envisaged here. Routes with entries in red are not considered further in this report.

Route	Application - could the fuel be used in aviation/HGVs?	Status - Is the level of development suitable for a competition?	Economic value – would UK resources allow further commercialisation? If not, are there technology export possibilities?	Additionality - Would this happen in the UK under proposed market support alone? If not, could there be other benefits?
Gasification to diesel or jet	Yes – as both a diesel and jet fuel substitute	TRL 5-6	Yes – can use a range of UK resources	Unlikely to happen – route is more expensive, capital intensive and risky than other development fuels proposed, and developers' first plants are unlikely to be in the UK
Gasification and catalytic conversion to ethanol, methanol	Ethanol can be used in ED95, or via ethanol to diesel or jet (E2D/E2J) To guarantee this would an end use partner/ offtake (HGV company, E2D/E2J company) would be needed. Little work on use of methanol in HGVs	TRL 8 – would have longer development time and capex requirements	Yes – can use a range of UK resources	Very unlikely to happen in the UK, if not in development fuels list, particularly given that it is likely to be supported in the US and other EU countries. Also would be very unlikely to be used in HGVs.
Gasification to methane, hydrogen	Yes – HGV partner needed. Methane HGV partners would be possible. For hydrogen this would be difficult.	TRL 6-7 for methane, with hydrogen expected to be similar	Yes – can use a range of UK resources	Potential for further production of methane given current UK demo activity. Hydrogen is unlikely as not a priority for either gasifier companies or hydrogen project developers

Route	Application - could the fuel be used in aviation/HGVs?	Status - Is the level of development suitable for a competition?	Economic value – would UK resources allow further commercialisation? If not, are there technology export possibilities?	Additionality - Would this happen in the UK under proposed market support alone? If not, could there be other benefits?
Gasification and fermentation to ethanol	As above for ethanol	TRL 7-8 based on one non-operational demo plant	Yes – can use a range of UK resources	Very unlikely to happen as there are few active players
Pyrolysis and upgrading to diesel/jet	Yes - both	TRL 8 for pyrolysis oil TRL 5-6 for upgrading in FCC in oil refinery TRL 4-5 Upgrading through hydro-deoxgenation	Yes – can use a range of UK resources	Unlikely to happen – route is at an earlier stage of development than other development fuels proposed
Sugar to hydrocarbons	Yes - both	TRL 4-5 from LC sugars	Yes – can use a range of UK resources	Unlikely to happen - only a few significant players who are unlikely to come to the UK
LC ethanol	As above for ethanol	For agricultural residues there are several commercial plants globally, but none in the UK - TRL 8 MSW and wood - TRL 6	Yes – can use a range of UK resources, although agricultural residues and MSW most likely in the near term	Very unlikely to happen in the UK, if not in development fuels list, particularly given that it is likely to be supported in the US and other EU countries. Also would be very unlikely to be used in HGVs.
LC butanol	Can be used via butanol to diesel or jet (B2D/B2J)	TRL 4-5 from lignocellulosic sources, TRL 5 from non-cellulosic wastes	Yes – can use a range of UK resources, although agricultural residues and	Very unlikely to happen in the UK, if not in development fuels list, particularly given that it is likely to be supported in the US and other EU

Route	Application - could the fuel be used in aviation/HGVs?	Status - Is the level of development suitable for a competition?	Economic value – would UK resources allow further commercialisation? If not, are there technology export possibilities?	Additionality - Would this happen in the UK under proposed market support alone? If not, could there be other benefits?
	Investigation of use in HGVs To guarantee this would need an end use partner/ offtake (HGV company, B2D/B2J company)		MSW most likely in the near term	countries. All players' main focus is not LC feedstocks or the UK. Also would be very unlikely to be used in HGVs.
Hydrogen from electrolysis	Possible for HGVs in the future but difficult now. Buses, vans are possible	Electrolyser at TRL 9 Other parts of the system are at an earlier stage	Yes – using UK renewable electricity resources	Unlikely to happen to a very large extent, as hydrogen transport projects are focused on siting near the user, not renewables
HVO/HEFA	Yes - both	Commercial (TRL9) for HVO, with HEFA at TRL8	Limited resource UK and globally from feedstocks that would count as development fuels	Development fuels support (when qualifying feedstocks used) would be enough to support this route.
Other RFNBOs **Power to methane** **Power to liquids**	Yes – both However, most existing players are not focusing on diesel	Apart from one developer at TRL 8, the TRL of others is at 5	Widespread UK deployment unlikely large sources of very cheap renewable electricity are required to make economics viable Export possibilities are limited as no known non-academic players in the UK	Would be unlikely to happen, unless a region has a particular interest to demonstrate the use of surplus renewable electricity

Route	Application - could the fuel be used in aviation/HGVs?	Status - Is the level of development suitable for a competition?	Economic value – would UK resources allow further commercialisation? If not, are there technology export possibilities?	Additionality - Would this happen in the UK under proposed market support alone? If not, could there be other benefits?
Waste-based fossil fuels	Yes – both if to diesel/jet	TRL 7-8 from waste gases. TRL of others as high as the corresponding bio route	Range of resources using waste carbon gases and MSW, though proof of sustainability required	Not known – depends on support for this fuel type
Alcohol to jet and diesel	Yes - both	Ethanol to ethylene is a commercial technology (TRL 9) LC alcohol to hydrocarbon at TRL 5, but could be scaled up quickly due to known commercial processes	The UK is not the ideal place to site a large plant – more likely to site in a region with multiple ethanol/butanol plants. However, smaller plants are possible, and there is UK interest in this route.	Would be unlikely to happen as the economics is currently prohibitive
Hydrothermal technologies	Yes – both	Production of HTL oil is at demo scale (TRL 6) Upgrading of HTL oil is only at lab scale (TRL 3-4)	Yes – can use a range of UK resources	Unlikely to happen – route is at an earlier stage of development than other development fuels proposed
AD	Can be used in CNG or LNG HGVs today Future options exist for conversion to liquid fuels or hydrogen	AD is commercial - TRL 9	Yes – can use a range of UK resources	Likely to happen under existing support mechanisms, depending on the relative benefits of use of biomethane in power, heat and transport and on inclusion in the development fuels sub-target

3 Business case

3.1 UK value and jobs analysis

Significant growth is expected in advanced renewable fuels markets globally. UK deployment of advanced renewable fuels facilities will support UK revenue generation and jobs, but innovation and demonstration support could also create additional economic value by helping UK-based businesses to develop competitive advantages and compete successfully in non-UK markets. We have therefore developed a simple set of calculations and assumptions to estimate the value to the UK of deployment in the UK, plus taking a small share of the global advanced renewable fuels market, using a similar approach to that used for the ABDC.

Two scenarios are given: a 'current planned plants' scenario based on plants that are currently planned, and potential subsequent plants from the same developers, taken where possible from parallel E4tech work for DfT on advanced biodiesel. A high scenario is also given, based on E4tech analysis for a 2016 study for the European Commission[26], which is derived from the IEA's 2015 Energy Technology Perspectives 2 degree scenarios. These scenarios vary by an order of magnitude in 2030, reflecting the difference between

- the small number of projects currently planned - for technologies that are mostly pre-TRL 8, with uncertain policy support, and given competing advanced fuel options, such as lignocellulosic ethanol and
- the volumes of fuel that are expected to be needed to contribute to emissions reduction sufficient to meet a 2 degree scenario. This would require a favourable policy framework is favourable, technologies to be rapidly proven and diffuse rapidly thereafter on a licensing basis

These scenarios include those routes where projections are available or can be estimated: gasification-based routes to diesel and jet, pyrolysis and upgrading, sugars to hydrocarbons, hydrothermal liquefaction, upgrading of alcohols, direct use of alcohols in HGVs, gasification to methane and hydrogen, and waste-based fossil fuels using waste carbon gases. The other routes in scope for which no projections are available or easily made are other RFNBOs, where the potential will depend heavily on electricity prices and grid constraints, and other waste-based fossil fuels, where the potential will depend heavily on the sustainability of individual projects. The potential for these routes would be additional to the figures given below. Note that the markets given are for these routes to diesel and jet substitutes, not for all advanced renewable fuels. This means that the figures are not directly comparable with those from the ABDC feasibility study. The figures given here are considerably lower in 2020, given the exclusion of LC ethanol (unless converted to diesel/jet) which is the main advanced route deployed today.

Global deployment figures are used to estimate the potential net value added (NVA) contribution to the UK economy across the various supply chain options, from feedstock, through technology construction and operation, to downstream distribution of finished fuels. In the Current planned

[26] Prospective for Future Production of Non-Crude Liquids November 2016, Nexant and E4tech, https://ec.europa.eu/energy/sites/ener/files/documents/ec_noncrude_liquids_publishable_executive_summary_final_1nov2016.pdf

plants scenario 46 commercial-scale plants are built by 2030 producing the fuels via the routes in scope above, producing 4 mtoe/yr of fuel. In the High scenario this increases to 500 commercial-scale plants, producing 60 Mtoe/yr of fuel.

Global turnover figures are calculated by using estimated advanced renewable fuel prices (£25-35/GJ in 2020 falling to £20-30/GJ by 2030). This ranges from **£3 – 75bn** a year by 2030, with feedstocks accounting for around 40-45% of this value, technology capex and opex 42-50%, and downstream distribution 10-13%.

The methodology for calculating the value to the UK and jobs is adapted from the Bioenergy TINA for Carbon Trust, as in the previous feasibility assessment for the ABDC.

Development of a domestic industry will provide significant value to the UK. UK deployment figures in the absence of the competition are based on plants currently planned to be in the UK in the Current planned plants scenario, which are zero in 2020. In the high scenario, it is assumed that the competition, as well as a favourable policy environment and global technology success, leads to plants from several developers being built in the UK, using the same approach as in E4tech's work for DfT on advanced biodiesel. These estimates give between 4 and 21 commercial-scale advanced fuel plants built in the UK by 2030, at a range of scales, producing 0.35 – 2.0 Mtoe/yr of fuel (providing 1-4% of UK transport demand, ignoring any multiple counting). UK turnover figures are then calculated to range from **£300 –2,600m** a year by 2030. Based on these assumptions, the successful establishment of a domestic UK advanced renewable fuels industry could generate a NVA of **£47 – 400m** a year by 2030 (including displacement effects).

The successful capture of global advanced biofuel business opportunities could generate millions of GBP in value for the UK. The UK net value added of global exports from the different possible technology choices is estimated at between **£8 and 195m** a year by 2030 (including displacement effects), with the large majority of the value found in the design and development of conversion technology components – since these are more exportable, protectable through IP and well-aligned with the UK's academic and commercial strengths. Combined with the NVA from UK deployment, the total size of the prize for UK advanced renewable fuels could reach **£55 – 600m** a year by 2030.

The successful establishment of a domestic UK advanced renewable fuels industry could generate **900 – 7,700** new jobs within the UK by 2030, with a strong focus on feedstock supply. Increased exports for the accessible global market could generate another **90 – 2,100** UK jobs by 2030, leading to a total employment opportunity of **1,000 – 9,810** UK jobs within the advanced renewable fuels sector by 2030.

3.2 Impact of the Competition

The above analysis gives possible ranges for the deployment of advanced renewable fuels in the UK and globally. However, whether the UK values are realised depends on whether a handful of planned projects go ahead, and which developers are successful in demonstrating their technology, raising finance and scaling up.

The value of the proposed Competition is therefore framed around the successful UK demonstration of one technology in the 2020 timeframe, additional to those funded through ABDC. After 2020 2-4 further demo scale plants are built, with these demo plants leading to 3-5 commercial scale plants by 2030 in the UK.

Based on an unknown technology choice, one demonstration plant (producing 1.3 ktoe/yr) could lead to turnover of up to £2m a year by 2020. Adding 2-4 new demo plants of varying scales by 2030 increases the cumulative deployment unlocked by the Competition to 4 – 20 ktoe/yr. 3-5 new commercial plants based on these demo plant increases the cumulative deployment unlocked by the Competition to 250 – 430 ktoe/yr, and turnover to approximately £210 – 545m a year.

The NVA and employment impacts potentially resulting from the Competition are shown in Table 2, based on only considering non-tradable UK portions (and no global export figures), due to the deployment being assumed to be in the UK.

Table 1: Summary of the potential UK value and jobs from the advanced renewable fuels industry (Currently planned plants – High)

	2020	2030
Global deployment (Mtoe/yr)	0.1 – 0.5	3.6 - 60
UK deployment (Mtoe/yr)[27]	0 - 0	0.4 – 2.0
UK deployment (% of transport fuel demand)	0 - 0	0.7 – 3.8
Global number of plants[28]	8 - 30	46 - 500
UK number of plants[28]	0 - 0	4 - 21
Global turnover (£m/yr)	110 - 780	3,000 – 75,000
UK turnover (£m/yr)	0 - 0	300 – 2,600
UK NVA from exports (£m/yr)	0.3 – 1.9	8 - 195
UK NVA from domestic (£m/yr)	0 - 0	47 - 400
UK NVA total (£m/yr)	0.3 – 1.9	55 - 600
UK jobs from exports	3 - 20	90 - 2100
UK jobs from domestic	0 - 0	920 – 7,700
UK jobs total	3 - 20	1,000 – 9,800

Table 2: Summary of potential Competition impacts (Currently planned plants – High)

	2020	2030
Deployment (ktoe/yr)	1 - 1	250 - 430
Number of plants	1 demo	Additional 2- 4 demo and 3-5 commercial
Turnover (£m/yr)	1.3 – 1.9	210 - 545
NVA domestic (£m/yr)	0.2 – 0.3	38 - 98
Domestic jobs	Cannot be estimated by this methodology. Expected to be around 50	690 - 1750

[27] NB This is deployment from commercial plants only, and does not include demo plants funded through the ABDC

[28] NB Plant scales vary over time and by developer

4 Feasibility of supporting these technologies

This sections consider whether a competition could feasibly support projects based on these technologies, in terms of:

- Whether the technologies are at the appropriate stage of development for support by a demonstration competition, and whether they could deliver a fuel product at a suitable scale for fuel testing
- What type of prospective applicants there might be for each technology
- Whether there are significant risks to a competition focused on these routes

4.1 Technology status

As shown in Section 2, the technologies considered suitable for a demonstration competition have a range of technology readiness, with the most advanced players being at TRL 8 – first commercial plants. However, for some routes the most advanced players are at a much earlier stage, and for all routes there are players at earlier stages, with variations in technology or with a different feedstock focus. The table below summarises the progression that could be expected via the competition for each route. For each route, progression at an earlier TRL could also be possible for players at an earlier stage of development.

Progression via competition	Route
Within TRL8: e.g. UK deployment of a technology with a first commercial plant elsewhere, operation on different feedstocks, use in different vehicle types	Fermentation of waste or LC sugars to ethanol
	Gasification and catalytic conversion to ethanol, methanol
To TRL 8: First of a kind commercial system	Waste-based fossil fuels
	Gasification to diesel or jet
	Gasification to methane, hydrogen
To TRL 7: Demonstration at pre-commercial scale	Fermentation of waste or LC sugars to butanol
	Alcohols to diesel/jet
	Pyrolysis and upgrading to diesel/jet
To TRL 6: Small scale demonstration plant	Sugar to hydrocarbons
	Other RFNBOs
	Gasification and fermentation to ethanol
To TRL 5: Pilot plant	HTL with upgrading
	Any route

The number of potential bidders to this competition may be lower than in the ADBC, as a result of the narrowed range of transport applications targeted, the focus of many developers on regions other than the UK, and uncertainty over the European policy landscape and impacts of Brexit. In order to maximise the number of potential bidders, the range of TRLs targeted should be kept as broad as possible, with the exception of a minimum TRL level and scale. This is for two reasons:

- A minimum scale is desirable such that enough fuel can be produced to enable testing for the targeted applications. The volume of fuel required depends on the scale of testing (fuel properties, engine testing, on and off-road vehicle testing) and on the application, but as an example, engine testing on an HGV would typically require at least 1000l of fuel – meaning that a pilot plant (TRL5) is the minimum acceptable scale. For other fuels a larger scale may be appropriate – for example testing pyrolysis oil in a refinery would require at least 8000l of pyrolysis oil. Rather than setting a value for the minimum scale, it would be better to require applicants to state what testing is appropriate and that the scale proposed matches the requirements of that testing
- A minimum TRL (progress to TRL 6) ensures that the selection criteria and monitoring criteria for the competition can be common to all bids. Earlier stage RD&D may be more appropriate for funding via an alternative mechanism, such as through research council, Innovate UK and EU Horizon 2020 funding. Allowing bids at lower TRLs reduces the business case for the investment itself, in terms of near term numbers of jobs, and value to the project developer, but widens the range of potential bidders. This may result in an increase in the number of UK bidders, thus potentially increasing the UK benefits in the longer term. See section 5.1 for a discussion of relevant State Aid considerations for bids with lower TRLs, including rules around aid intensity and maximum grant awards.

Supporting plants moving to TRL 8, or that are already at TRL 8 outside the UK, moves beyond what was envisaged in the ABDC. According to TRL definitions, TRL 8 plants would not be considered a ‘demonstration’. However, considerable challenges remain to the commercial success of advanced biofuel plants globally, not only linked to future policy uncertainty, but also to the challenges of establishing feedstock supply chains, proving new technologies at scale, and ensuring reliable operation. Demonstrating that a TRL 8 plant can be built successfully in the UK could pave the way for future UK deployment, with associated GHG saving and economic benefits. These plants will have higher investment costs and longer timescales for development than TRL 6-7 plants, which are considered further in section 5.

4.2 Prospective applicants

There are a variety of potential types of bidder, which depend on the route, the degree of existing UK activity, and the attractiveness of the UK compared with other locations. Most bids are likely to require a consortium with representation across the supply chain. These could be led by:

- Technology developers. This is more likely for technologies at earlier TRLs
- Feedstock company-led, such as waste management companies
- Other stakeholders with an interest in developing the conversion technology such as a fuel user

Since the number of technology pathways that may be delivered entirely by UK technology providers is limited, it is therefore expected that consortia will include (if not be led by) non-UK companies.

The likelihood of bidders from each of the routes considered, and the geographical origin of those bidders is indicated below. This is based on a review of the know technology developers in each route, and a judgement on their likely interest in the UK compared with other regions, given their stage of development and capacity to conduct projects in multiple regions.

Likelihood of bidders	Technologies and regions
High	Fermentation of waste or LC sugars to ethanol – UK and EU
	Waste-based fossil fuels - UK and ROW
	Gasification to methane, hydrogen – UK and ROW
Medium	Gasification and catalytic conversion to ethanol, methanol - ROW
	Pyrolysis and upgrading to diesel/jet - UK, EU and ROW
	Fermentation of waste or LC sugars to butanol – UK and ROW
	Gasification to diesel or jet – EU and ROW
	Alcohols to diesel/jet – UK and ROW
Low	Sugar to hydrocarbons – EU, ROW
	Other RFNBOs – EU
	Gasification and fermentation to ethanol - ROW
	HTL with upgrading

5 Funding structures

This chapter reviews the existing State Aid Regulations which determine the types and amounts of Government funding that are permissible within the European market in order to identify the most appropriate category of aid for a potential new competition.

The study then reviews possible options for structuring this aid in line with the Regulations and to maximise the number of high quality applications and eventual successful projects.

5.1 Review of updated State Aid Regulations

Regarding the use of State Aid routes for grant funding, much depends on the timescale for development and launch of a scheme. Longer term programmes (such as those run by the Carbon Trust, TSB and ETI) have all applied for a specific full State Aid exemption using the full notification procedure which allows for maximum control over the design of the scheme, but requires in-depth justification of the requirement for market intervention. Within UK Government Departments, DECC, Defra, BIS and DfT have all used State Aid General Block Exemption Regulations to deliver grant funding schemes with a shorter lead-time.

The European Commission's State Aid regulation is designed to prevent Government funding from causing unfair competitive advantages within a given market. In designing a funding scheme to support demonstration projects, there are a number of routes available that will comply with State Aid legislation, including block exemptions and a full notification procedure, which is known as an individual exemption.

General Block Exemption Regulations (GBERs) provide a list of specific conditions under which Member States may launch a funding scheme without being required to complete the full notification procedure. Provided the block exemption conditions are met, the programme manager may simply notify the Commission via a retrospective transparency notice. In the event of a very large individual award being made, a notification must still be made to the Commission – even when the scheme under which the award has been made satisfies all of the requirements of GBER.

If it is not possible to comply with all the conditions of a block exemption, the program manager must apply for an individual exemption using the full notification procedure which can take at least 3-6 months.

5.1.1 Background on update of Regulations

The Commission launched a consultation on the 18th December 2013 on the implementation of updated State Aid Guidelines for assessing public support projects in the field of energy and the environment. The General Block Exemption Regulations were formally updated on 17th June 2014 which expanded the number of exemptions from 26 to 33. The updates focused on ensuring Member States have adequate safeguards in place to limit distortions of competition and to avoid subsidy races between Member States.

5.1.2 Relevant General Block Exemption Regulations (GBER)

Continuing from the GBER used for the first round of the ABDC, Article 41 (Investment aid for the promotion of energy from renewables) remains the most relevant GBER for a new round of the competition. The table below summarises the key points of Article 41. In particular, Article 41 contains specific provisions for biofuel production from sustainable feedstocks and covers other renewable fuels.

Article and title	Scope & Eligible Costs	Maximum aid intensity	Aid intensity bonuses	Maximum Threshold
Article 41 – investment aid for the promotion of energy from renewables	For new installations only. **Eligible Costs** – the extra investment costs to promote the production of energy from renewable source. Restrictions apply regarding biofuels which must use sustainable feedstocks that are non-food-based.	Aid intensity may be set by the funder subject to the process being a competitive application	+ 20% for small undertakings; + 10% for medium-sized undertakings. + 15% for Assisted Area (a); 5% for Assisted Area (c).	15m Euros per recipient, per project.

The table in Appendix A provides an overview of all the exemptions under the Regulations that could potentially be relevant to projects funded by a new competition. An individual project could rely upon any combination of the exemptions, subject to the accumulation rules.

Accumulation rules

Aid granted under one GBER exemption may be accumulated with aid under a different GBER exemption in relation to the same identifiable Eligible Costs, partly or fully overlapping, only if such accumulation does not result in exceeding the highest aid intensity or aid amount applicable. This multiple GBER approach is taken in current funding schemes such as the Scottish Government's Local Energy Challenge Fund, which allows a large range of different project types to utilise the eligible technologies and costs for 11 different GBERs to determine the best 'fit' for their projects.

Regarding the definition of Advanced Fuels as discussed in Sections 2 and 5 of this study, the new competition could be open to applications to produce waste-based fossil fuels: a fuel that is derived from non-biological waste and therefore not a biofuel. Initial indications from the Regulations are that State Aid for waste re-use or recycling contributes to environmental protection when the materials treated would otherwise be disposed of, or be treated in a less environmentally friendly manner (paragraph 66). It would be the responsibility of any applicant to the new competition to determine their compliance with State Aid Regulations if the potential project fell outside the scope of Article 41 (Investment aid for the promotion of energy from renewable sources).

Other GBERs of note are Article 22 (Aid for Start-Ups) and Article 25 (Aid for research and development projects). Aid for Start-Ups can potentially cover a range of seed-funding style funding activities, and start-ups did apply to the ABDC. Aid for R&D would be highly relevant if technologies with lower TRLs were eligible to apply. These GBERs are discussed in more detail in sections 5.2.3 and 5.2.4.

5.2 Funding Options for a new competition

5.2.1 Existing scheme structure for the Advanced Biofuels Demonstration Competition

The first round of the ABDC was exempted from State Aid notification under Article 41: Investment aid for the promotion of energy from renewables. Grant awards were for a maximum of 50% of eligible capital cost (uplifts applied of 10% for Medium Enterprises, 20% for Small Enterprises, 15% for Assisted Area (a) and 5% for Assisted Area (c)). Grants were capped at EUR 15 million, which equated to £10,958,194 at the 5th September 2015.

Grants were awarded via a 2-stage competitive process and notification letters were sent to successful bidders. Carefully crafted bespoke special conditions were negotiated and included in Grant Offer letters to minimise risks to DfT of projects spending money which was later found to be abortive. For example, some of the Grant Offer letters included stage gates before any funds could be released, and conditions were incorporated so that even if the second and subsequent follow on plants were to be built outside the UK the profits for any licences would be taxed in the UK. Accountable Grant Arrangement (AGA) letters were issued in due course, coinciding with a Ministerial Announcement of the awards. Signed AGA letters were returned to DfT for countersignature.

AGAs set out award conditions specific to each project and the grant claim schedule as determined during AGA negotiations. Grant was paid on the basis of submitted evidence of defrayed costs, combined with achievement of progress milestones. Stage gates were defined for each project to form major go / no go decision points for the project and for DfT as the funder. Claim frequency varied from monthly to 6-monthly depending on the complexity and desired claim approach of each project.

5.2.2 Assumptions for a new competition

A new competition will involve £20m of capital to be spent over 3 years (FY 18/19 – 20/21).

Options for how to use £5.5m of additional capital funding to be spent over 1 year (FY 17/18) are also considered, although the main focus will be on the options for the £20m.

Regarding the number of projects that DfT would look to support, we have made suggestions of a likely project pool for each of the options reviewed.

It is assumed that the DfT prefer to seek a Delivery Partner with appropriate experience of scheme design for the overall management of the new competition, rather than develop the scheme in-house.

It is assumed the new competition will follow the best practice of using defined eligibility criteria to complete an initial screening of applications, scored assessment criteria to determine an overall ranking of applications, and make use of an Expert Selection Panel and Project Board to confirm final award recommendations to Ministers.

Where ‘demonstration-scale‘ is referred to in the following sections, this refers to any technology ranging from TRL 5 (very small demonstration) to TRL 8 (early commercial plant).

5.2.3 Options for £5.5m of funding over 1 year FY 17/18

This section reviews options for short turn-around projects that have the potential to complete spend by March 2018. It is feasible for more than one of these options to be taken forward.

No.	Description	Pros	Cons	Grant per project	Potential applications and relevant GBER
1	Add-on funding for existing projects. The rationale being that the change in the exchange rate since September 2015 would allow grantees to receive more GBP funding under the EUR 15m cap, plus existing projects have seen cost increases for additional items. The current exchange rate gives £12.6m as the maximum award under Article 41. At the time of grant award, the maximum cap was £10.9m.	Existing projects have seen cost increases that exceed the limits of their existing matched-funding and risk project failure. Applicants would need to provide evidence of these cost increases, showing clearly how they are in addition to the projected costs from their original plans. An addendum to the original grant offer would be needed to increase the value of grant being offered.	Other biofuel players may see this as unfair and complain that funding should be open to new bidders if this is the only option taken up. DfT may face questions of additionality when funding existing projects although the evidence of cost increases should mitigate this risk.	Between £0.7m and £1.6m, up to a total of £2.3m within the permitted aid intensities.	High Article 41: as an additional add-on cost
2	Funding for modifications to an existing plant to process advanced biofuel	Allowances for upgrades or add-ons are within State Aid Exemptions. These projects should spend earlier than new-build projects as they are working with existing or part-built plants	There may still be specialist equipment orders with very long lead times. Projects could be funded up-front in FY17/18 and continue while the main fund is still functioning, thus reducing the risk that projects will run into issues after FY17/18 without any oversight.	Potentially £2-4m	Medium Article 41

3	Accept applications from pilot plants (TRL4-5)	A much smaller plant could feasibly begin construction within 1 year	Risks around matched funding, planning permission and other delivery challenges. Applicants would need to be well-developed in their plans. Projects could be funded up-front in FY17/18 and continue while the main fund is still functioning, thus reducing the risk that projects will run into issues after FY17/18 without any oversight.	Potentially £1m	Low Article 41
4	Seed funding to enable project concepts to develop e.g. funding over 6-9 months for FEED studies, project costs development, partnering arrangements, feedstock and off-take arrangements, full and detailed GHG calculations, full Life Cycle Assessments, and building the business case evidence for future commercial potential. Delivery Partners could provide access to expertise that the project concepts wouldn't otherwise have (access to engineering and design expertise,	Increases quality of competition for CAPEX grant funding. All deliverables would increase the chances that other investors will react positively to the project, and may mean that some projects progress without the need for grant funding at the CAPEX stage. Successful examples of seed funding can be found in both the Local Energy Challenge Fund (Scotland) and ETI Waste Gasification Fund, where a number of projects proceeded	Funding would be spent without any guarantee that CAPEX projects would be developed and advanced fuels delivered. Additional risk that the actual plant is developed outside the UK For seed funding for renewables with a £20m grant awarding up to £100k over 6 months, the Scottish Government received 66 applications for seed funding, and supported 23 projects. Applications for full funding were then received from 18	This option could potentially fund 3-10 projects. The size of the grant awards would be limited by the ability to deliver work by March 2018.	High Article 21 *(up to £0.8m Euro as 'innovative enterprises')* Article 22 *(up to £7.5m Euro for 50% of the costs of a Feasibility Study)* De Minimis State Aid *(if*

	commercial expertise, GHG expertise, access to investor networks etc). Applicants could propose their own level of grant request, along with a justification of how the money would be spent by March 2018, with a cap of around £2m to avoid spending all of the budget on a small number of projects. This is larger than in other seed funding projects in the UK, which have typically been at up to £300k, but in the same range as projects recently awarded by the US DoE[29]. There would be likely to be a range of projects from £50k upwards.	to completion without the need for further grant funding after support to develop the project to an investment-ready state.	projects, and 9 were awarded grants totalling £20m. The outputs of the 23 projects were viewed as having added value to the initial concepts. The ETI typically supports a ratio of 3 projects seed funded for every 1 project that gets full funding support, stating that seed funding brings added value in attracting other investors to have an impact larger than the original investment from ETI.		*the grant is under 0.2m Euro)*

[29] A US Department of Energy (DoE) fund for project development and planning for advanced biofuel plants has been announced (http://www.bioenergy-news.com/display_news/11598/us_doe_announces_plan_to_back_biofuels_and_biopower_projects/) with grants of USD 0.8 – 4.0 m per project for the project definition phase. Initial information seems to indicate that this budget needs to be spent before a Phase 2 decision is made in Oct 2017-Sept 2018 (US Fiscal year 2018). This will be followed by Phase 2 funding at a 50% cost share for pilot and demo scale facilities, with funding levels of up to $15m and $45m USD respectively.

Recommendation for £5.5m funding over FY 17/18: The two options most likely to produce applications and successful projects within the timescales are options 1 and 4. The application window could be short (3 months) and decisions made in a single evaluation stage, thereby awarding grants during late-spring 2017 and giving grantees up to 9 months to deliver their projects, complete all spend, and claim the grant monies before March 2018.

5.2.4 Options for £20m of capital funding over 3 years FY18/19 – 20/21

Options for a new competition build on the successes of ABDC and the lessons learned through that process. Each option has been examined for its advantages and disadvantages, and the likely impact on the number and quality of applications.

1. **Standard CAPEX grant** for demonstration-scale advanced fuel plants, paid in arrears on a milestone basis, with an update that grant offers are not countersigned by Government until all matched-funding is in place. The grant offer would also include a request for DfT to be party to other investor due diligence meetings/activities, in order to give them comfort that the investment is going to be placed, be aware of the timescales for due diligence completion, and so that they are aware of any implications of other T&Cs that the project may be being asked to comply with. This is a direct learning from ABDC.

- <u>Pros:</u>
  - DfT is protected from spending money on failing projects as grant is only paid out once capital has been expended and progress milestones achieved.
  - This puts pressure on projects to finalise matched-funding arrangements as the grant offer would contain a time limit that cannot be breached, and the funds would then transfer to a reserve project. The grant offer is often the conditional trigger point for other investors confirming their commitment. Ministers may be uncomfortable with the uncertainty of holding a grant offer but this approach will put them in a strong position for any audits by the NAO and keeps the pressure on other investors to commit. Specific time limits would have to be negotiated with each grantee on the basis of the status of their matched funding arrangements.
- <u>Cons:</u>
  - The milestone approach tends to lead to delays in grant spend as progress can easily be held up by a variety of issues. Very difficult to accurately forecast grant spend. However, this can be managed if money is transferred to a third party or bank that the DfT can authorise payment from.
- <u>Number and quality of applications:</u>
  - Likely to receive between 10 and 20 applications due to the wider definition of advanced renewable fuels and current levels of activity in the advanced fuels market. This is a constrained estimate given the proposed requirement for advanced biofuel applications to include committed off-take partners (for specific routes). It is likely that many applications will have some development needs and will be project concepts rather than well-developed plans (as was seen in ABDC Stage 1 applications).

- £20m could support between 3 and 5 projects, depending on the final mix of plant sizes. Due to the wider scale of this new competition, small-scale demonstration plants would apply for grants between £1m-£5m, while others may apply for up to £10m. The major determining factor in the number of projects in the new competition will be which scale of plant is appropriate to progress the technology and demonstrate the production of fuel. The lesson learned from ABDC was that a plant that can produce at least 1m litres of biofuel per annum was larger than was needed for technology demonstration in all 3 cases. We would therefore expect to see a larger number of smaller projects in the new competition.

2. **Standard CAPEX grant plus seed funding**: Standard CAPEX grant following the structure of (1) above, but with up to a maximum of £2m (expected average of around £100k) awarded to each shortlisted bidder after a competitive Stage 1 application process to be spent over 6-9 months on background research or work that will develop the strength of the offering (i.e. being investment-ready by Stage 2) e.g. FEED studies, project costs development, partnering arrangements, feedstock and off-take arrangements, full and detailed GHG calculations, full Life Cycle Assessments, and building the business case evidence for future commercial potential. The grant would only be released on the production of valid evidence of work delivered supported by invoices, although monitoring would be light touch oversight. When the shortlisted bidders are invited to present their proposals at Stage 2 they should be asked to provide an update on how the money has been spent, what has been learnt, and what added value has been achieved with the seed funding.

- Pros:
  - Because the time from being selected for the shortlist to grants being offered was 9 months on ABDC, grantees were immediately challenged to deliver their completed plants by March 2018 as they had not been able to progress with activities such as FEED or detailed cost specifications as this could only start once the grant was awarded. A grant between Stage 1 and Stage 2 would allow for vital project development activities to take place which would maintain momentum towards project deadlines.
  - As some of the shortlisted bidders may not be selected, the smaller grant may enable these companies to have proved a concept possibly enabling them to be financed by other routes. The ETI is particularly supportive of this approach as they have demonstrated how other investors can be attracted by a project that has received seed funding to develop a marketable concept into an investment-ready project.
  - Announcing a number of seed grants would give the message to bidders that the DfT is proactive. It should also result in much stronger bids as evidenced in the Local Energy Challenge Fund[30] where 80% of the Stage 1 applications that were short-listed for seed funding were not investment ready, compared to an average 115% increase in assessment scores at Stage 2 for those projects that progressed.
- Cons:
  - As some of the projects may drop-out after receiving seed funding then it is possible that some of this seed funding does not provide added value. However, in practice, the determination of project viability still provides valuable lessons for both the funders and the potential project delivery partners. The potential advantages for most projects receiving seed

[30] http://www.localenergyscotland.org/funding-resources/funding/local-energy-challenge-fund/

funding would outweigh this and the light touch monitoring supervision with evidence-based payments would prevent any fraudulent spending of government money.

- Number and quality of applications:
  - Likely to receive a higher number of initial applications (potentially 25-30) due to the allowance for project development between Stage 1 and Stage 2 of the application process. This is likely to increase the quality of applications at Stage 2 and improve the likelihood of strong investor commitment. It is unlikely that the new competition will see the level of applications from the Local Energy Challenge Fund (115 in the first competition and 66 in the second competition) as the scope of eligible technologies for this fund was much wider than renewable fuels.
  - We would still expect to fund 3-5 projects at Stage 2, given the reflections in option (1) above, but the funding would be at lower risk of project failure given the additional development work in place before final funding awards are made.

3. **Front-loaded CAPEX grant funding for long-term (4-5 year) projects:** A higher risk option, we would recommend this would be applicable only for projects producing over 5 million litres of fuel per annum that need a longer development timeframe (e.g. 4-5 years).

- Pros:
  - Allows DfT to fund large-scale projects which could produce high volumes of biofuels with the UK (e.g. 3 good quality projects were excluded from Stage 1 of ABDC due to the completion date being beyond March 2018)
- Cons:
  - Exposes DfT to the high risk of projects failing after the first 3 years, with little protection against spending Government money on a project that does not complete, other than a claw-back clause in the grant offer if the project does not go on to completion. This would require DfT Legal involvement up to 2-3 years after the end of the competition. For example, many gasification plants have failed at the commissioning stage after experiencing technical difficulties that require further capital injection into the project. As commissioning is one of the final stages of project completion, a high level of due diligence and scrutiny of the project risks would have to be undertaken by evaluators and the Project Board.
  - Applications would likely be for the maximum state aid limit under Article 41 (15m Euros) as the scale of plant would lead to eligible project CAPEX over £20m and so a single application could take up over half of the grant fund. This may be more risk than DfT is willing to take to fund a single large project. One possible solution is to limit any applications to £5-8million.
- Number and quality of applications:
  - Likely to receive a small number of applications from some of the original ABDC applicants that were excluded due to delivery timescales, and from market players that did not apply to ABDC because of their expected construction timescales.
  - Some of these applications may be quite advanced as plants of this size may have been in discussions without a funder for a number of years.

4. **Repayable CAPEX grant**: This would be paid as a low interest loan (repayable once the plant is producing fuel) that can be written off as a grant if the company fails to have sufficient cash flow to repay the loan once the project is complete. An example would be for every £1 of net operating

profit, 5% has to be repaid to the funder. The Energy Technology Institute (ETI) makes all of its investments on this basis, with the view that this funding model acts as an incentive for people to exploit the technology they have developed.

ETI Repayable Grant Funding Model

The ETI's grant conditions state that in return for their investment in the project, the ETI will own any foreground or arising Intellectual Property (IP) from delivery of the project. Grantees must then pay the ETI a license fee to use that IP over a period of 5-10 years. The license fee is generally based on an appropriate indicator of performance, such as product sales or units of electricity generated. The founding principle is that IP should not be left unused.

It is important to note that Return on Investment (RoI) is not a key driver for the ETI's investments (e.g. ETI expect to invest over £30m in 2016/17 with incoming license payments of £0.5m). The ETI typically funds TRL 2-4 activities and combines Government funds with private sector funding, allowing up to 100% of the investment costs to be covered by a single source.

- Pros:
  - Money can be paid upfront or in lump-sums to enable reliable grant spend profiles
  - A strong commercialisation and exploitation strategy is critical to funding awards and is closely monitored by the ETI to ensure their investment brings added value to the market
- Cons:
  - Only likely to be a viable option for demonstration-scale projects that will have a high likelihood of expecting a cash flow, or if DfT has a strong interest in owning and licensing IP up to 10 years in the future
  - Legal challenges and complexities with grantees attempting to make a case why the loan should be annulled, even if second follow on projects will be profitable
  - Each grant contract will be bespoke and require a number of months of negotiation. This is a recognised challenge for the ETI with many of their individual investment contracts taking over 3 months to negotiate.
  - Paying money in lump sums will not prevent other issues that may delay the project or cause failure, such as equipment delivery delays or planning permission
- Number and quality of applications:
  - This option could potentially see a reduced number of applicants compared to a non-repayable CAPEX grant, as applicants may struggle to make the case that their project will be able to expect a cash-flow sufficient to repay the grant. Applicants with a reasonable chance of revenues may struggle to identify equity investors who will have difficulties with a reduced return on their own investment during the lifetime of the repayment terms.

5. **A challenge competition**: A competitive approach throughout with a lump-sum prize payment for completion of a project that addresses the challenge(s) identified.

- Pros:
  - Generates competition and projects striving to adhere to their project plans to achieve completion within their original deadlines
- Cons:

  - All money is paid at the end of each project. DfT are unlikely to want to retain all £20m until FY20/21 as an extreme example, and as all the projects in the first ABDC round relied on angel investors and venture capital, it is very unlikely many bidders would be prepared to risk all the project cost with no guarantee of success.
- Number and quality of applications:
  - Unlikely to generate sufficient applications to run a competitive process.

Recommendation for £20m capital funding over FY 18/19 – 20/21: The option most likely to produce sufficient volumes of high quality applications and successful projects within the timescale is Option 2 (Standard CAPEX grant plus seed funding). If seed funding is instead supported by the £5.5m funding pot in FY17/18, we recommend the use of Option 1 (Standard CAPEX grant funding) from the start of FY18/19. The advantages posed by supporting bidders in the development of their proposals outweigh the potential drop-out rate of unsuccessful bidders at Stage 2, as the seed funding may enable these companies to have proved a concept possibly enabling them to be financed by other routes, as seen in other funding schemes.

Combining Options 2 and 3 would expose DfT to more risk, but the ultimate reward is a number of professionally-designed and planned projects that produce high volumes of UK advanced fuels. Exposure to risk would have to be a priority evaluation and decision-making criteria for the assessors and Project Board, but could open up the competition to be an example of high risk/ high benefit funding.

5.2.5 Options not considered suitable for £20m of capital funding over FY18/19 – 20/21

A number of additional options were considered for the £20m fund. These options were found not to be suitable for a number of reasons, many linked to the technology and commercial risks of demonstration-scale advanced fuel plants, and also the nature of the unique investment packages which are inevitable when demonstrating new technologies that traditional investors and banks will not fund (such as angel investors and venture capital funds). These options were:

1. **Setting up a scheme that is aimed at shared ownership or community ownership**: Due to the nature of the risks involved in demonstrating new technology it is unlikely that there would be many applicants for this type of scheme. Community ownership schemes are starting to gain traction in commercially available renewable technologies, but are unsuitable for non-commercial technologies and are very high risk for local or community investment.

2. **Government issuing loans at commercial rates**: It is highly unlikely that bidders will take up this option as there is no guarantee of revenue generation from a demonstration-scale plant.

3. **Government taking equity shares rather than paying a grant**: DfT could take a share of the company, with a requirement for a product to be sold in a fixed number of years' time. We understand DfT is not keen on taking equity shares due to potential conflicts with policymaking,

although a separate sub-government organisation could be set up. Other investors may also be deterred as they will end up with a lower proportion of the equity.

4. **Government bank guarantees**: This would only work potentially for TRL 8 and above, although funds would need to be ring-fenced until FY 20/21 to pay the guarantee if the project failed.

6 Summary and requirements for the competition

6.1 Synthesis of findings

This feasibility study provides the information necessary to design and launch a follow up to the ABDC that specifically focuses on fuels aimed at displacing fossil diesel and jet. The study has shown that:

- There are a wide range of technologies that could produce advanced renewable fuels suitable for use in aviation and HGVs. Of 15 routes to renewable fuels assessed in chapter 2, twelve were considered to be suitable for support through a competition, given their potential for future widespread use in aviation and HGVs, technology development status (TRL 5-8 typically), potential for UK deployment and expected deployment level in the absence of further support. Those excluded were all based on technologies already at TRL 9, with some also being likely to happen without this additional support.
- The list of technologies considered suitable includes those that produce a diesel or jet fuel directly, those with intermediate fuels that require further processing to produce jet or diesel, and those producing another type of fuel that could be used in HGVs to displace diesel. For those that do not produce jet or diesel directly, it is important that the competition ensures that the fuels are used to displace jet or diesel, for example through including an end-use partner.
- The proposed funding option is a £20m competition aiming to support demonstration-scale projects producing an advanced renewable fuel. A smaller pot of £5.5m funding over FY 17/18 could be used for add-on funding for existing projects, and seed funding. All funding would be subject to State Aid Regulations, and a notification to the European Commission would be made ahead of the launch of the competition.
- It would be appropriate for the competition to support developers moving to TRL 6-8, whereas the previous competition aimed at TRL 6-7 only, as considerable challenges remain to the commercial success of advanced biofuel plants globally, not only linked to future policy uncertainty, but also to the challenges of establishing feedstock supply chains, proving new technologies at scale, and ensuring reliable operation. Demonstrating that a TRL 8 plant can be built successfully in the UK could pave the way for future UK deployment, with associated GHG saving and economic benefits. However, the longer timescales for development of these projects would require front-loaded CAPEX grant funding (option 3 in section 5.2.3), which has higher risk for DfT.
- The number of applications to the competition is likely to be around 25 to 30. This estimate is made on the basis that the seed funding will increase the number of applicants compared with the ABDC, and whilst the scope of fuels considered is narrower than in the ABDC in some cases (use of ethanol and butanol to displace gasoline is excluded), it has been expanded in others (waste-derived fossil fuels). It is also based on a review of the known technology developers in each route, and a judgement on their likely interest in the UK compared with other regions, given their stage of development and capacity to conduct projects in multiple regions.
- The value to the UK would derive both from plants deployed in the UK, and from the potential for building high value UK capabilities that could be exported to other regions. Given the very early stage of development of nearly all advanced routes to diesel and jet, value estimates made based on currently planned plants are small, particularly in 2020, given plant lead times. If a

competition was successful, UK deployment would increase, with the UK benefit from plants stimulated by the competition being £100m. If rapid progress could be made, both in technology demonstration at scale and in policy support, deploying advanced diesel and jet at the levels envisaged by the IEA 2 degree scenario in 2030 would give a global market of up to £75bn by 2030, with UK NVA from UK deployment and global exports of £600m.

- The competition would guarantee UK benefits by requiring the plants to be sited in the UK. Whilst the competition could not include eligibility criteria to add to the UK value further, it would be beneficial to include assessment criteria asking applicants to describe the value to the UK from the proposed projects, as in the ABDC.

6.2 Purpose & Objectives of the competition

The **purpose** of the competition would be to promote the development of a UK advanced fuels industry, including supplier capabilities and skills in relevant technologies, while maximising value for money for the taxpayer.

The **objectives** of projects within the competition would be:

- To demonstrate successfully the proposed technology pathway.
- To show an understanding of the market context (size, readiness, target market, cost levels) with a clear view of where their product would fit.
- To develop a clear strategy for commercialising the technology and the products.
- To bring together a team with the necessary expertise and experience to deliver the Project to its objectives.
- To secure match funding of the project's costs (in line with State Aid rules).
- Deliver a clear strategy for communicating the successful delivery of the project, together with the technological advances, to the wider advanced fuels community and the public.

6.3 Application process

There would be a 2-stage application process, with funds made available for successful Stage 1 bidders to support the development of their project proposal.

- At **Stage 1** of the application process, bidders would submit proposals for:
    - ***Funding Stream A: Seed funding.***
      Applicants can apply for seed funding to cover activities such as FEED studies, project costs development, partnering arrangements, feedstock and off-take arrangements, full and detailed GHG calculations, full Life Cycle Assessments, and building the business case evidence for future commercial potential. The Stage 1 applications would also include details of the full capital project, and preliminary projections of project timescales and delivery partners.
    - ***Funding Stream B: Add-on funding.***
      Applicants from existing eligible projects can apply for a maximum of £2.3m of add-on funding for demonstrable additional costs, within the maximum allowable state aid award.
- At **Stage 2** of the application process, bidders from Stream A would submit and present detailed proposals for the full CAPEX project. The aid intensity of 50% in ABDC attracted bidders, and was not felt to be overly generous as the identification of matched-funding was still challenging for

many projects. The rationale of setting a 50% aid intensity is still relevant for a new competition. The State Aid maximum cap for this competition would be EUR 15 million[31], currently around GBP 12.6m. Bidders must pass Stage 1 to be eligible to apply for Stage 2.

Both Stage 1 and Stage 2 would be assessed via defined eligibility and evaluation criteria, subject to review by a Selection Panel, and final funding recommendations to Ministers would be made by a Project Board and/or Investment Panel.

In terms of updates required to the existing documentation, the majority of the existing materials can be reused. The major updates would be to the Stage 1 application form to allow applicants to outline how they would use the seed funding, and to the assessment criteria for evaluation of Stage 1 applications. Updates would also be needed for the guidance document to give clear definitions of eligible seed funding activities. The Stage 2 application form would need to allow applications to detail the activities and added value gained from the seed funding.

6.4 Eligibility criteria

Suggested **eligibility criteria**:

Technology scope

- The project must be based on one of the conversion technologies selected in section 2.13. In summary, these are listed below. Any other routes that fulfil the criteria listed in the table in section 2.14 could also be considered, although the onus would be on the applicant to prove their eligibility.
    - Gasification-based routes to diesel or jet, pyrolysis with upgrading, routes from sugars to hydrocarbons, hydrothermal liquefaction and upgrading
    - Routes based on production of alcohols, with direct use in HGVs, or upgrading to diesel or jet
    - Gasification-based routes to methane or hydrogen, with use in HGVs
    - RFNBOs (excluding hydrogen from electrolysis) with direct use in HGVs, or upgrading to diesel or jet
    - Waste-based fossil fuels, with direct use in HGVs, or upgrading to diesel or jet
- The project must either
    - Produce a fuel that when blended with diesel or jet fuel (at a reasonable blending level e.g. above 5%) meets the relevant specification i.e. EN 590 or ASTM D7566 annexes
    - Include a project partner who will use the fuel produced to fuel HGVs. This would apply to projects not producing a fuel that would be blended with jet or diesel, such as those producing methane, hydrogen, ethanol, methanol or butanol.

Technology status

- The bidder's technology must already be at at least TRL 5, i.e. have a pilot plant, and must successfully attain at least TRL ≥ 6 (small demonstration) by the end of the project
- The project must produce a quantity of fuel suitable for testing at a scale appropriate for the level of development of the fuel

[31] Under Article 41 Aid for the promotion of energy from renewables

Sustainability

- The technology used must have the potential to achieve > 70% GHG reductions from a commercial plant in comparison to a reference fossil fuel (given that this level is proposed in the proposed REDII). The project itself must deliver at least 60% GHG saving if receiving support through RTFCs is central to the plant's commercialisation plan.
- Any route based on waste feedstocks (biological or non-biological) should show no diversion from options higher up the waste hierarchy e.g. recycling
- Any application with a non-renewable waste as a feedstock must provide a full consequential lifecycle GHG assessment

Project details

- The demonstration-scale plant must be operational no later than March 2021.
- The demonstration-scale plant must be located in the UK.
- Under State Aid Rules, the amount of grant requested for the CAPEX project must be below the maximum grant limit of EUR 15 million.
- The applicant must have at least Heads of Terms in place with an off-take partner and evidence of match funding.

6.5 Indicative timescales

The following timescales are suggested for the key stages of the new competition. These timescales are subject to further change and are reflective of the assumptions used throughout this study.

Activity	Activity owner	Duration	Suggested timescales
Update existing documentation	ABDC Delivery Partner	1 month for review and approvals	January 2017
Launch Stage 1 application window (including Ministerial launch meeting)	ABDC Delivery Partner & DfT team	3 months	February - April 2017
Procurement of F4C Delivery Partner (assumed via SPaTS framework)	DfT	2 months	February - March 2017
Deadline for Stage 1 applications	F4C Delivery Partner	Set Date	Late April 2017
Assessment of Stage 1 applications	F4C Delivery Partner	3 weeks	May 2017
Selection Panel & Project Board for Stage 1 (Additional time will be	F4C Delivery Partner & DfT	1 day per meeting	May 2017

Activity	Activity owner	Duration	Suggested timescales
needed if the Investment Panel is required)			
Grant awards for Stage 1 (standard grant award wording)	F4C Delivery Partner & DfT Legal	2 weeks	Early June 2017
Delivery of seed funding activities, monitoring activities and grant claims	Grantees & F4C Delivery Partner	10 months	June 2017 – March 2018
Launch Stage 2 application window (in parallel to seed funding activities)	F4C Delivery Partner & DfT	3 months	January – March 2018
Deadline for Stage 2 applications	F4C Delivery Partner	Set Date	Early April 2018
Assessment of Stage 2 applications, including due diligence activities	F4C Delivery Partner	3-4 weeks	May 2018
Selection Panel & Project Board for Stage 2 (Additional time will be needed if the Investment Panel is required)	F4C Delivery Partner & DfT	2 days	May 2018
Grant awards for Stage 2 (including negotiation of project-specific conditions)	F4C Delivery Partner & DfT Legal	3-4 weeks	June 2018
Delivery of Stage 2 activities, monitoring, reporting and grant claims	Grantees & F4C Delivery Partner	33 months (2 years, 9 months)	July 2018 – March 2021

7 Key risks to successful delivery

A detailed risk assessment has been carried out relating to the delivery of the competition. The risks, impacts, level of impacts and potential mitigation measures are detailed according to the stage of the competition – from competition launch, funding award, project execution and legacy (Table 3 - Table 6).

Table 3: Assessment of risks associated with the competition launch

Risk	Impacts	Level of impact	Mitigation
Limited interest due to the competition scope not addressing industry needs	A low number of proposals	**High** Fewer applications reduce the likelihood of identifying a suitable project, but overall scheme objectives may still be achieved. May indicate that the appetite for risk is lower than expected. It could also indicate a lack of interest and commitment from organisations/partners required to deliver strong consortia and successful projects.	Implementing a two stage application process would allow DfT to review at an early stage, and possibly at lower expense, if sufficient numbers of strong proposals are being made.
Limited interest due to funding levels	A low number of proposals	**Medium** Fewer applications reduce the likelihood of identifying a suitable project, but overall scheme objectives may still be achieved. Previous competition's stakeholder workshop indicated that the proposed funding level was sufficient to support project(s) at the scales and TRL levels discussed.	The review of existing schemes has illustrated that the 'market standard' for grant support for demonstration projects is around 50%. This should be achievable for TRL 6 activities, but the budget is likely to be insufficient to support TRL 7 activities at this level. Options identified for supporting higher TRL projects in section 5.
Limited interest due to timescales/milestones.	A low number of proposals	**Medium** Fewer applications reduce the likelihood of identifying a suitable project, but overall scheme objectives may still be achieved.	Early communication of the competition allows prospective applicant to begin engaging with potential partners. It is important to ensure that realistic project milestones are set, and these may be set on a project-by-project basis to reflect the specific proposal activities. An experienced selection or advisory panel should facilitate the setting of appropriate milestones.

Risk	Impacts	Level of impact	Mitigation
Industry is more interested in applying for other funding schemes	A low number of proposals	**Low** Projects may be supported by more than one funding scheme	Ensure that competition rules enable projects to be supported by more than one initiative at the same time. Fully understand the rules of wider EU block exemption.
Applicants do not understand the competition objectives and eligibility criteria	May result in either a higher or lower number of applications	**Low** Application process will reinforce the objectives and eligibility criteria.	Develop and disseminate clear competition scope, eligibility criteria, and evaluation criteria. And provide FAQs and contact details for queries. A two stage application process including an initial brief Expression of Interest would allow for DfT to select appropriate projects to take forward to full application, reducing the effort required by both DfT (or the selection panel) and applicants.
Limited interest or willingness to form consortia, or lack of suitable consortia	A low number of proposals, or weaker proposals	**Medium** The biofuels industry has a good track record of working well together in partnership. Consortia should ideally be positioned across the supply chains, limiting competition issues Need to form consortia with end users may limit interest from producers of some fuel types	The industry understands the need to partner with actors across the supply chain, and the strength of such partnerships in determining feedstock supply and fuel quality, etc. Suggested seed funding between Stage 1 and Stage 2 of the application process will enable businesses to use a positive response and funding of their time to attract partners into a consortium.

Table 4: Assessment of risks associated with the proposal selection and award

Risk	Impacts	Level of impact	Mitigation
Limited availability of experienced individuals for the selection panel	Unable to launch the scheme due to lack of assessors, or poor evaluation leads to inappropriate project selection	**High** Assessors are required to ensure that the selected proposals are credible	Early identification and engagement with experienced individuals. The responsibility may be passed on to an external programme manager, in which case they should demonstrate that their network of contacts will facilitate assembly of an appropriate selection panel.
Contract negotiations	Negotiations could result in costly delays to the project, delay project inception and place project milestones and objectives at risk.	**Medium** Risks are primarily to project schedules and costs	Early communication of detailed terms and conditions of grant award. Employ experienced contract managers, either internal or external.
Poor or inappropriate applications	Inefficient use of resource to sift out unsuitable applications.	**Medium** Poor or inappropriate applications would have minimal impact on the scheme objectives, but may increase the time spent at the evaluation stage.	Make the competition objectives clear and understandable to avoid possible misinterpretation. Develop and disseminate clear competition scope, eligibility criteria, and evaluation criteria. And provide FAQs and contact details for queries. Implementing an Expression of Interest stage will reduce the amount of time required to sift out unsuitable applications.

Table 5: Assessment of risks associated with the project implementation

Risk	Impacts	Level of impact	Mitigation
Unable to leverage match funding from the private sector or other sources	Project cancelled or scope/scale reduced	**High** Match funding will be required to reach competition objectives	Publicise selected projects, and possibly hold event(s) to facilitate networking between project developers and prospective funding bodies. This may be possible after the first phase of a two phase application process, as appropriate matched funding plans may be required for the second phase of applications
Unable to secure licence to build and operate (planning, environmental permitting).	Very long delays to project inception and build.	**High** Unless a suitable location has been identified, it will not be possible for the project to launch.	The DfT may require planning permission to have been sought and gained prior to proposal submission. However, this would limit the number of applicants. Or provide credible risk assessment on planning and permitting process. Higher priority may be given to projects that propose to build on an existing pilot scale demonstration project – where it could be feasible to extend operations.
Failure to secure feedstock in the quantity required for demonstration plant.	Project viability	**High** Feedstock supply will be vital to the performance of a project	Project proposals will be required to take feedstock supply into account. Ideally, the project consortium will feature industry players at all stages of the supply chain. Securing feedstock agreements may be facilitated by a two stage application process, which allows selected applicants in invest more time into the full application.
Technology/ IP ownership or licensing prevents use of technology	Impacts on project viability	**High** Project will be delayed if alternative technology has to be sourced.	EoI process may enable organisations to procure suitable technology in advance – or to ensure no barriers to use of technology. Funding call may encourage participation of the whole technology development process – e.g. include original technology innovators in the form of academic partners or entrepreneurs.

Risk	Impacts	Level of impact	Mitigation
“Scale-down” of commercially proven equipment for custom pilot and demo applications creates unforeseen difficulties	Financial and planned timescale impacts as the equipment is a necessary component for the project.	**High** Redesigns and/or retrofits would delay the project and can costly.	Proposals will be required to demonstrate and prove that specified technical equipment is available and has been proven. Where the equipment is not already available, the proposal should include detailed plans on how consortium will acquire/ develop the equipment and these plans (timescales/ financial/ administrative) should be included in the overall project plan.
Overspend on the project	Consortium partners may experience financial difficulty	**High**	Ensure proposals include accurate project cost estimates, cash flow forecasts, and adequate contingency. This may be assessed by the selection panel (and programme manager). Contracts to ensure that DfT are not accountable for additional costs. Expression of interest procedure may allow applicants to invest more time and resource into full application, and therefore produce more accurate plans. Regular progress reporting and review by scheme administrator (or program manager) in order to ensure that any issues are flagged, logged and mitigated early in the process.
Technology failure	Project delays may arise and result in missed objectives.	**High** One of the wider objectives as part of the scheme (may) be a need to enhance and develop existing technology in order to demonstrate or bring to commercial readiness.	Proposals will be required to provide evidence to demonstrate that their technology readiness levels meet the minimum eligibility criteria. Proposals will be assessed by technical experts with an understanding of the limitations of the technologies involved. Regular progress reporting and review by scheme administrator (or program manager) in order to ensure that any issues are flagged, logged and mitigated early in the process.

Risk	Impacts	Level of impact	Mitigation
Delayed build and commissioning	Impacts on project timescales with repercussions for the achievable plant outputs.	**Medium**	Proposals should include credible work plans, including the allocation of resources and project milestones. These may be assessed by an experienced selection panel. The appointment of a suitable engineering provider and appropriate contracts will ensure timely construction and commissioning, experienced advisors may provide guidance on these arrangements. Seed funding to develop the FEED would identify any further risks to project timescales prior to Stage 2.
Health and safety (H&S) issues	Licence to build and operate may be effected	**Medium**	Plant operators will be required to operate within all relevant H&S regulation. DfT can require that proposals demonstrate an understanding of these requirements.
Withdrawal of consortium members due to lack of engagement, shift in business priorities, or financial difficulty	Practical and administrative impacts to the project and outcomes. Delays while a suitable replace if found. Consortium morale.	**Low – High** The level of the impact could depend on the level of investment and/or the role of the partner	Proposal review process should assess strategic fit with future plans of consortium partners. Offering grant that is conditional on securing funding within a set time limit should reduce the risk of projects starting without matched-funding in place. The grant would be offered to a reserve project if the time limit is breached. Redundancy management plans should be required to be built into the consortium.
Availability of skilled workforce available to operate plant.	Delays in plant production, reduced plant availability, and increased costs	**Low** Appropriate site selection should consider labour force requirements Scale of the plant may not require full industrial workforce	Ensure proposed plant location has been carefully considered and discussed within the project proposal.

Table 6: Assessment of risks associated with competition legacy

Risk	Impacts	Level of impact	Mitigation
Limited dissemination of project results; successes and lessons learned.	Impact of the competition limited	**Low** Reporting requirements linked to funding award	Milestone reporting structure can be prescribed to ensure reporting is received throughout the project duration.
Failure to adequately demonstrate technology or meet demonstration targets (performance, availability, yield)	Reduce interest in investing in subsequent 1st of a kind commercial scale plant	**Medium**	DfT to ensure that proposal assessors have a high level of expertise in order to evaluate the readiness of technologies and experience and expertise of project personnel.
Failure to demonstrate a marketable product due to missing target production cost, or sustainability criteria	Limit potential for commercial scale development Potential negative impact on the investor confidence in advanced biofuels.	**High**	Project proposal will be required to demonstrate that outputs are in line with overarching government policy and the objectives of the scheme. Careful assessment of credibility of proposed targets.
Petroleum and conventional food-crop biofuel price fluctuations reduce the profitability of advanced renewable fuels.	Reduced interest in investing in the project – little desire to follow up on project successes.	**Medium** Policies to direct energy requirements away from fossil fuels will continue to help influence development of renewable fuels as an alternative.	Government national and international policies continue to promote the need for alternative fuel sources for environmental and energy security reasons.
Policy uncertainty weakens the investment case for future plants	Reduced interest in investing in the project – little desire to follow up on project successes.	**High** Policy has the potential to completely remove support for a route, or to support it less strongly than other routes	Clear UK policy signals, including coordination between competition and development fuels policy.

Appendix A TRL definitions

TRL	Definition	Explanation
1	Basic research	Principles postulated & observed, no experimental proof available
2	Technology formulation	Concept and application have been formulated
3	Applied research	First laboratory tests completed; proof of concept
4	Small scale prototype	Built in a laboratory environment
5	Large scale prototype	Tested in intended environment
6	Prototype system	Tested in intended environment close to expected performance
7	Demonstration system	Operating in operational environment at pre-commercial scale
8	First-of-a-kind commercial system	Manufacturing issues solved
9	Full commercial application	Technology available for consumers

Appendix B Relevant General Block Exemptions applicable to a competition for renewable fuels

Article and title	Scope & Eligible Costs	Maximum aid intensity	Aid intensity bonuses	Maximum Threshold	Examples of activities potentially within scope
Art 22 – Aid for start ups[32]	**Eligible recipients** are unlisted small enterprises up to five years following their registration, which have not yet distributed profits and which have not been formed through a merger.[33] Start up aid can take the form of: (a) **loans** with interest rates which do not conform to market conditions, with duration of up to 10 years. Maximum nominal amount of 1m Euros. A ratio is applied for loans of less than 10 years; (b) **guarantees** with premiums which do not conform to market conditions with a duration of up to 10 years. Maximum 1.5m Euros of amount guaranteed. A ratio is applied for guarantees of less than10 years. (c) **grants**, including equity or quasi equity investment. Interest rate and guarantee premium reductions of up to 0.4m Euros gross grant equivalent	N/A	For **loans**: - Maximum nominal amount of 2m Euros for Assisted Area (a) - Maximum nominal amount of 1.5m Euros for Assisted Area (c). For **guarantees**: - Maximum 3m Euros of amount guaranteed for Assisted Area (a) - Maximum 2.25m Euros of amount guaranteed for Assisted Area (c) For **grants**: - Interest rate and guarantee premium reductions of up to 0.8m Euros for Assisted Area (a) - Interest rate and guarantee premium reductions of up to	N/A	The loans, guarantees and grants can be used for any purpose. However, please note the rules relating to accumulation of this aid with other aid

[32] Please note that the provisions set out under Article 22 should only be used as a last resort to support eligible project costs which are not supported by any of the other GBER Articles covered under this Fund.

[33] Special rules apply where the small enterprise is not subject to registration – see Article 22(12)

Article and title	Scope & Eligible Costs	Maximum aid intensity	Aid intensity bonuses	Maximum Threshold	Examples of activities potentially within scope
	A recipient can receive support through a mix of aid instruments (i.e. loans, guarantees and grants) provided that the proportion of the amount granted through one instrument, calculated on the basis of the maximum aid amount allowed for that instrument, is taken into account in order to determine the residual proportion of the maximum aid amount allowed for the other instruments.		0.6m Euros for Assisted Area (c) **Small and innovative enterprises**[34]: The maximum amount under this Article may be doubled.		
25 – Aid for research and development projects.	The following categories of research could potentially be relevant: (a) industrial research (meaning planned research or critical investigation aimed at the acquisition of new knowledge and skills for developing new products, processes or services or for bringing about a significant improvement in existing products, processes or services. This may include the creation of components parts of complex systems, and may include the construction of prototypes in a laboratory environment or in an environment with simulated interfaces to existing systems); (b) experimental development (meaning acquiring, combining, shaping and using existing scientific, technological, business and other relevant	Industrial research: 50% Experimental development: 25% Feasibility studies: 50%	**Industrial research and experimental research:** increased up to a maximum aid intensity of 80% as follows: (a) + 10% for medium-sized enterprises; + 20% for small enterprises. (b) + 15% one of the following conditions apply: - if the project involves effective collaboration (see Art 25(6)(b)(i) for more details); or	Industrial research: 20m Euros per recipient, per project Experimental research: 15m Euros per recipient, per project Feasibility studies: 7.5m	Any stand-alone research project or any research element or feasibility study that is part of a larger project.

[34] An "innovative enterprise" (as referred to in Article 22) means an enterprise:
that can demonstrate, by means of an evaluation carried out by an external expert that it will in the foreseeable future develop products, services or processes which are new or substantially improved compared to the state of the art in its industry, and which carry a risk of technological or industrial failure, <u>or</u>
the research and development costs of which represent at least 10 % of its total operating costs in at least one of the three years preceding the granting of the aid or, in the case of a start-up enterprise without any financial history, in the audit of its current fiscal period, as certified by an external auditor.

Article and title	Scope & Eligible Costs	Maximum aid intensity	Aid intensity bonuses	Maximum Threshold	Examples of activities potentially within scope
	knowledge and skills with the aim of developing new or improved products, processes or services. This may include development of commercially usable prototypes); (c) feasibility studies (meaning the evaluation and analysis of the potential of a project, which aims at supporting the process of decision-making by objectively and rationally uncovering its strengths and weaknesses, opportunities and threats, as well as identifying the resources required to carry it through and ultimately its prospects for success). The **Eligible Costs**, to the extent relevant to the project, are: - personnel costs; - costs of instruments and equipment; - costs for buildings and land; - costs of contractual research, knowledge and patents; - additional overheads incurred directly as a result of the project.		- if the results are widely disseminated (see Art 25(6)(b)(ii) for more details) **Feasibility studies:** + 10% for medium-sized enterprises; + 20% for small enterprises	Euros per study	
Art 36 – Investment aid enabling undertakings to go beyond Union standards for environmental protection or to increase the level of environmental	**Eligible Costs** - the extra investment costs to go beyond the EU standards or to increase the level of environmental protection in the absence of EU standards. Special rules apply for the acquisition and retrofitting of transport vehicles for road, railway, inland waterway and maritime transport.	40%	+ 10% for medium-sized undertaking; + 20% for small undertakings. +15% for Assisted Area (a); +5% for Assisted Area (c).	15m Euros per recipient, per project.	This could apply to an entire project or to discrete elements of a project where levels of environmental protection are increased beyond European Union standards or where measures are put in place to increase environmental protection resulting from the recipient's activities and no such standards are in place.

Article and title	Scope & Eligible Costs	Maximum aid intensity	Aid intensity bonuses	Maximum Threshold	Examples of activities potentially within scope
protection in the absence of Union standards	Any costs not directly linked to the achievement of the higher level of environmental protection are not eligible costs.				
Art 37 – Investment aid for early adaptation to future Union standards	**Eligible Costs** - the extra investment costs to go beyond the currently applicable EU standards. Any costs not directly linked to the achievement of the higher level of environmental protection are not eligible costs.	Where the investment is more than 3 years before the standard in force: 20% for small undertakings; 15% for medium-sized undertakings; 10% for large undertakings. Where the investment is between 1 and 3 years before the standard in force: 15% for small undertakings; 10% for medium-sized undertakings; 5% for large undertakings.		15m Euros per recipient, per project.	This could apply to an entire project or to discrete elements of a project.
Art 41 – investment aid for the promotion of energy from renewables	For new installations only. **Eligible Costs** – the extra investment costs to promote the production of energy from renewable source, which shall be determined as follows:	30% for small installations (as referred to in the right hand box);	+ 20% for small undertakings; + 10% for medium-sized undertakings. + 15% for Assisted Area (a);	15m Euros per recipient, per project.	Any project that involves a new installation that promotes energy from renewables, including advanced biofuel plants.

Article and title	Scope & Eligible Costs	Maximum aid intensity	Aid intensity bonuses	Maximum Threshold	Examples of activities potentially within scope
	- where the costs can be identified in the total investment cost as a separate investment, e.g. a readily identifiable add-on component to a pre-existing facility, these costs; - where the costs can be identified by reference to a similar less environmentally friendly investment that would have been carried out without the aid, the difference between the costs of both investments; - for certain small installations, where no less environmentally friendly comparator exists, the total investment costs are Eligible Costs. Restrictions apply regarding biofuels which must be sustainable biofuels that are non-food-based.	45% in other cases. Note: A different intensity may be set subject to the process being a competitive application	5% for Assisted Area (c). Where open competitive bidding process aid intensity may reach 100%, subject to certain requirements regarding transparency and equal treatment.		