Assessment of successes and lessons learned for biofuels deployment

Report on workshop results

IEA Bioenergy TCP
Intertask project of Task 39, Task 40 and Task 45

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Report on Workshops results

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1. Introduction

The intertask project “Lessons learned biofuels” examined the technical, economic, societal and political reasons underlying the past and ongoing booms and busts cycles of biofuel technologies development, demonstration, deployment and replication. The aim was to identify key factors for technology successes and the best policy framework conditions as well as the measures for stimulating increased future markets for production and consumption of sustainable transport biofuels.

The work was carried out from 2020 to 2022 in collaboration with the IEA TCP Bioenergy Tasks (T39, T40 and T45) in various work packages. In addition to the different work package also workshops were held on various topics and including different stakeholders along the biofuels value chains. A summary of the workshop results is given in this additional report.

2. Workshop on guidelines, 25 November 2021

2.1 Workshop frame

A workshop with the title "Guidelines to overcome barriers for commercialization of advanced biofuels" was organized by the Swedish Bioenergy Association (SVEBIO) on November 25, 2021 to gather expertise from industry and academia partners and discuss the topics addressed in the project. The workshop was joined by some 65 delegates. The invited speakers and panelists contributed with presentations and panel discussion blocks with the following topics:

- First of its kind projects – how to get to market
- Learnings in biofuel developments
- Advanced biofuel projects – accelerating development to large scale

The workshop discussed aspects to overcome the technical, economic, societal and political barriers in past and ongoing booms and busts cycles of biofuel technologies and to stimulate increased future markets for production and consumption of transport biofuels.

The key queries were addressed through diverse presentations, panel discussions and breakout sessions that could offer insights for the project. In addition, in relation to overcome barriers it was also discussed how to increase investments in new biofuels production plants.

2.2 Topics, discourse and main results

First of its kind projects – how to get to market

This block was composed by the presentation of experts from the projects BioDME (Chemrec project: Black liquor to clean biofuels) and Gobigas (Gobigas project: Wood gasification to biomethane). In both cases, it was clear that the operation of the demonstration facilities based on gasification of waste residues had firstly technical challenges that, due to experience gathered during project, were overcame. Although the technical feasibility of the demonstration facilities was confirmed and there were ongoing projects for the further scale-up of the technologies, it was decided not to go on the investments. The decision was made due the not fulfilment of the commercial break-even. Furthermore, it was expected that the production costs could be reduced through success of first-of-a-kind, but there was not clarity on long term regulations that could support a long-term investment of a first-of-a-kind facility.

Learnings in biofuel developments.

In this block the development of the ethanol market was shown. The majority of biofuels utilized in Europe still comes from crop-based biofuels and the biggest part of new car registrations comes from petrol (47.5%) and diesel (28%) vehicles. From the different quotas established in Europe, the majority of bioethanol is sold as E5 (84.2%), the remaining market share is divided in E0 (4.2%), E10 (11.5%) and E+(Mixture above E10, 0.2%). The European bioethanol certifications shows that the GHG emissions savings increased from 50.7% in 2010 to 75.5% in 2020 compared to fossil values. Also, regarding bioethanol, the company Raizen brought the perspective of bioethanol from the biggest bioethanol supplier from Brazil. The possibility of producing advanced biofuels in Brazil is accessed mainly from the by-products of the already established sugarcane industries. Owning an operational facility of biogas from vinasse and advanced bioethanol from bagasse, the company is already building further facilities, having therefore succeeded in overcoming difficulties from first-of-a-kinds. The strategy of the company is to expand further the product portfolio with advanced fuels as second generation ethanol, biomethane and sustainable aviation fuels.

Advanced biofuel projects – accelerating development to large scale.

In this block the insertion of a first-of-a-kind in market can bring diverse risks, from technology, product quality, feedstock availability to financing. For the building of a first-of-a-kind, a complete study of all these factors have to be realized, having a clear analysis of the risk management process. Technologies for production of advanced biofuels as HVO and co-processing could be able to supply a large fuel demand, as they are easier to be implemented. Technologies as Fischer-Tropsch and second-generation bioethanol are still limited due to lack of non-food biomass value chains.

A summary of the different breakout session is given as follows.

Boom and bust of (Swedish) biofuels projects

The markets for biofuels are largely influenced by political decisions. The political driving forces have been several, for example to reduce the dependency on oil imports, create new jobs and reduce CO_2 emissions from the transport sector. As biofuel markets are international, strategy changes in individual countries or regions also affect the national market.

The main rule has been that fuel is subject to energy tax, and for some countries CO_2 tax and VAT, as well as fees. Energy taxation is frequently revised and must exceed the minimum tax on fuels (fuel and heating oils) set by the European Union in the Energy Taxation Directive. In certain circumstances tax exemption can be made. Sweden has for a long time applied for state aid approval for tax exemption for biofuels.

As an example of a reduction obligation, Sweden has had a quota system since July 1, 2018, a reduction obligation to reduce CO_2 emissions for gasoline and diesel. This system has been introduced by the Parliament regarding the reduction of greenhouse gas emissions by mixing biofuels into petrol and diesel fuels. The duty means that greenhouse gas emissions must be reduced compared to the emissions from the equivalent energy amount of fossil petrol or fossil diesel fuel.

The European market is greatly influenced by the European policy which is mainly laid down in the Renewable Energy Directive II (RED II) which applies from 2021-2030. The directive will affect which raw materials will be used for biofuels. Above all, food crop-based biofuels will not be able to increase, and so-called advanced biofuels will receive a mandatory minimum quota going forward. Palm-based biofuels must also be phased out by 2030. An annex categorizes which raw materials may be used to qualify as advanced biofuel.

In the frame of its Green Deal, the European Union has presented a package of measures to reduce emissions by 55% by 2030, which also implies that several directives will be further updated. These measures in the package are given in more detail in the following table.

Table 1. 'Fit for 55' Proposals of directives from the European Commission in July 2021.

Abbreviation	Initiative	Content
EU ETS	Revision of the EU Emission Trading System, including revision of the EU ETS Directive concerning aviation, maritime and CORSIA	Revision of the EU's carbon trading scheme in line with the new GHG emissions reductions targets. The revision will create parallel systems to include emissions from new sectors (transport and buildings)
ESR	Revision of the Effort Sharing Regulation	Revision of the ESR in line with the EU ETS. Maintain national objectives for GHG emissions reduction in sectors not covered by the EU ETS
ETD	Proposal for a Council Directive restructuring the Union framework for the taxation of energy products	Revision of the ETD from 2003 to align tax rates with the current economic situation and climate objectives. The proposal aims to end tax breaks for fossil fuels (notably aviation) and provide

Abbreviation	Initiative	Content
	and electricity	exemptions/fiscal support to sustainable energies
LULUCF	Revision of the Regulation on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry	The proposal integrates emissions and GHG removals from land use (forestry, agriculture) into the climate policy framework (i.e. ESR), to protect and encourage carbon sinks.
RED III	Amendment to the Renewable Energy Directive to implement the ambition of the new 2030 climate target	The revision increases the EU target of renewable energy share in energy consumption from 32% to 40% by 2030. The proposal also increases objectives for the transport, building heating & cooling sectors, and sustainability for biomass requirements.
EED	Amendment of the Energy Efficiency Directive to implement the ambition of the new 2030 climate target	The revision modifies the energy efficiency target from 32.5% to achieve a reduction of 36% for final and 39% for primary energy consumption by 2030 and annual national energy savings target for Member States.
AFIR	Revision of the Directive on deployment of the alternative fuels infrastructure	The revision of the AFID transforms it into a Regulation with binding quantitative targets for the roll-out of public recharging/refueling infrastructure as well as interoperability, concerning road vehicles, stationary aircraft, and maritime and inland waterway vessels.
CO_2 for cars and vans	Amendment of the Regulation setting CO_2 emission standards for cars and vans	The revision of the Regulation sets sanctionable CO_2-reduction targets for manufacturers of cars and light commercial vehicles at 55% and 50% respectively by 2030, and 100% by 2035 – amounting to an effective ban on petrol and diesel cars and vans.
ReFuel EU Aviation	Proposal for a Regulation on ensuring a level playing field for sustainable air transport	New proposal to address the uptake of sustainable aviation fuels (SAF), with binding incorporation targets for 2025 and 2030, complementary to existing initiatives aiming to reduce GHG emissions from the aviation sector (EU ETS, AFIR, ETD).
Fuel EU Maritime	Proposal for a Regulation on the use of renewable and low-carbon fuels in maritime transport	New proposal similar to RefuelEU Aviation aiming to increase the share of sustainable maritime fuel, supplementing other initiatives of the Fit for 55 Package (EU ETS, AFIR, ETD).
CBAM	Proposal for a Regulation establishing a Carbon Border Adjustment Mechanism	New proposal establishing a carbon levy on certain goods entering the EU (electricity, cement, steel among others) to address carbon leakage risks coming from the EU ETS. This mechanism will be gradually phased in while free-allocation on the EU ETS will be phase out.
Climate Action Social Facility	Proposal for a Regulation establishing a Social Climate Fund	New proposal to support a fairer and just energy transition, financed by the EU long-term budget and revenues of the newly created parallel EU ETS for transports and buildings.

It is very positive that the EU Commission is focusing on the pricing of CO_2 emissions by tightening emissions trading and expanding it to more sectors. It will provide large reductions in CO_2 emissions in a cost-effective manner and create markets for sustainably produced biofuels.

Unfortunately, the commission has also made some proposals that create unnecessary obstacles to the utilization of bioenergy from, for example, forest biomass. The restrictive approach to biofuels from field crops also remains. This means that Europe risks missing out on fully exploiting the large bioenergy potentials that exist.

Bioenergy today accounts for 60 % of renewable energy in the EU, or around 12 % of total energy use. In Sweden, the proportion of bioenergy in total energy use is 39 %, and bioenergy is Sweden's largest energy source. Sweden has the exceptionally highest share of renewable energy of all EU member states thanks to a large supply of bioenergy, hydropower and wind power.

The workshop participants regarded the Fit for 55 proposals overall positive with these comments:

- Tightened legislation on renewable energy. It is about what %age of energy use by 2030 should come from renewable energy sources. The new goals are set high but achievable. The renewable energy target of 40 % [1]could be set significantly higher with a more positive view of bioenergy. Increased targets for renewables in heating and district heating are also good, although Sweden has already reached far beyond the proposed targets.

- The EU Commission's proposal for further tightening of the ETS emission rights trading will result in major reductions in emissions. Already today, the price of emission rights is high, which together with a relatively high price of fossil fuels makes it profitable to convert to renewable fuels in the industries and power plants covered by the ETS and to implement efficiency measures.

- The extension of the ETS to the transport sector and the heating sector, as well as the inclusion of shipping, creates a uniform minimum price on carbon dioxide emissions in the main part of the European economy. A carbon tax solution would be preferable because it would provide a fixed and predictable price for emissions, but expanded emissions trading is also good. The measure will lead to extensive conversion of heating plants, away from fossil fuels such as coal, heating oil and natural gas.

- A reform of the energy tax directive so that the tax is set according to energy content instead of according to volume is a welcome reform, which will provide a fairer taxation of, for example, ethanol and methanol.

- The proposed carbon tariff on certain industrial products sends a signal to other countries that they need to start putting a price on their carbon emissions from heavy industry. It could be a first step towards an international pricing of carbon dioxide emissions. Without such pricing, it will be difficult to reach the global climate goal in the Paris Agreement.

- A separate target for renewable fuels for aviation is excellent, although the level is far too low. While Sweden has decided on 30 % by 2030, the EU Commission is content with proposing 5 %.

- A very positive proposal in the transport area is to abolish double counting for certain types of biofuels and electricity. The double counting has given an incorrect picture of the share of renewable energy as well as of the share of fossil fuels in the transport sector.

The workshop regarded the proposal could have negative effects:

[1] Note: Now (09/2023) agreed at 42.5 %

- The target for greenhouse gas reduction in the transport sector of 13 % by 2030[2] is completely insufficient and has its basis in the EU Commission's negative view of biofuels. Here, the contrast with Sweden is great with our goal of 70 % reduction.

- The remaining restrictive attitude towards biofuels from field crops ("food and feed crops"), despite the fact that there is great potential for the cultivation of energy crops within the EU and the EU's neighbouring countries. A modest requirement that 2.2 %[3] of the energy in the transport sector in 2030 should come from advanced biofuels including biogas shows that they do not see biofuels as a central part of the transformation of the transport sector. Instead, the commission focuses unilaterally on electrification and hydrogen as well as recycled fossil waste products.

- The regulation on measuring emissions from exhaust pipes instead of valuing emissions during a vehicle's life cycle lays the hook for the entire climate work. It unilaterally favors electric and hydrogen vehicles, even though vehicles powered by biogas, ethanol or renewable diesel can have an equal or greater overall climate benefit. The proposal for the phasing out of internal combustion engines must therefore be revised so that it refers to the phasing out of hazardous or fossil emissions. Phasing out certain technical solutions also goes against the principle of technology neutrality.

- Proposals to extend the sustainability criteria for biofuels from forests, extend the reporting requirements also to smaller facilities, and proposals to regulate the use of stem wood for energy create new administrative costs without providing climate or environmental benefit. It also creates uncertainty among investors when there are time and again proposals for changed rules of the game in the market. In addition, an assessment and control of how materials are used in a cascading principle is proposed, assessed on, among other things, used land area, which makes it wrong for wood-based raw materials that they cannot be used directly for energy products. This means that the changeover takes longer.

- Proposals that involve prioritizing carbon storage in forests over the production of renewable raw materials for materials and bioenergy provide less climate benefit already in the short term and, in the long term, greatly reduced sequestration of CO_2 in growing forests and less substitution benefit.

Carbon tax / pricing – lessons and successes for biofuels?

Projects for investment in scalable biofuels which do not compete with food production and can be produced from EU-feedstocks (Herein referred to as advanced renewable fuels), which have successfully demonstrated technology, mitigated and allocated all risks (technology, commercial etc.) have still not been able to secure financing for commercial-scale rollout.

The lesson learned is the need for regulators to focus on how to handle price and volatility risks, which are the most challenging risks to handle in renewable fuels production and the need to provide grandfathering for projects as subsequent projects move down in cost on the learning curve – this so that projects can be made financeable. The key underlying risk is political risk – a large portion of the value of renewable fuels is politically created and is therefore extremely sensitive to changes or

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[2] The Approved RED III now mentions either a target of 14.5% GHG reduction or a target of 29% renewables (incl. multiple countings).
[3] In the approved RED III the target for advanced biofuels is increased to 5.5%, but also contains RFNBOs.

uncertainty in policy.

We use price risk to mean the risk that general market price level is or becomes permanently insufficient to permit a viable business. By volatility risk we mean the risk of prices fluctuating between periods due to market forces or, importantly, to political context or actions; this may make debt service uncertain and lead to default in given periods even if the price level were to be adequate as a long-term average.

What is required to enable investments in large production plants for advanced renewable fuels?

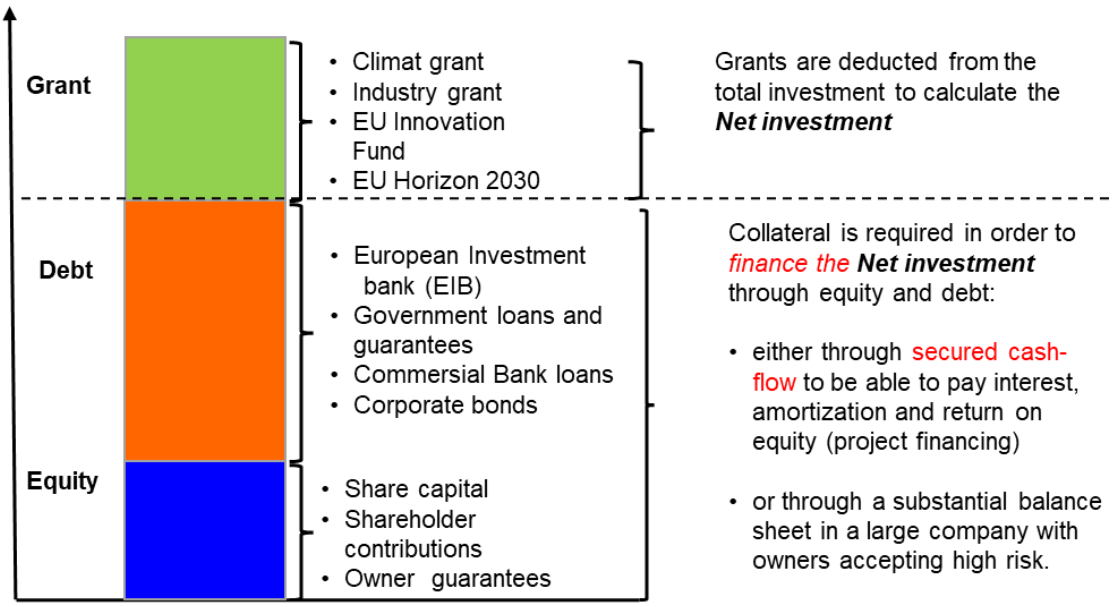

Figure 1. Examples of various components of an investment in project financing for a biofuel production plant. The components can vary in size depending of circumstances (ref. VINNOVA, 2021).

Note: In order to secure cash-flow required for project finance we propose implementation of Contracts for Difference (CFD) with off-take obligations for advanced renewable fuels.

A contract for difference is typically a civil law contract between two parties under which one or both parties commit to pay the other party the difference between a set price (strike price) and a market price or value.[4]

CFDs are instruments which are well-known by capital markets and which, after in 2014 having been ruled compatible with the internal market, have been very successful, for example in developing and securing finance for off-shore and on-shore wind in the UK and in Denmark. Proposal: In the context of advanced renewable fuels projects and proven policy instruments, this would allow investment in production capacity.

[4] See https://www.svebio.se/wp-content/uploads/2019/11/White-Paper-A-policy-and-support-regime-for-investment-in-renewable-fuels-1.pdf

Biofuels in aviation and marine

There are now good opportunities to coordinate and increase quotas for biofuel aviation. Norway has already decided on a quota and Sweden and the EU have a proposal[5]. This could go beyond the voluntary commitments that currently exist in some countries and among airlines. This can provide impetus for commercial facilities.

In shipping globally, approximately 11 billion tons are handled each year (2017) and 80-90 % of all international freight transport by sea. At the same time, shipping accounts for approximately 3 % of global emissions of carbon dioxide. In 2017, the global emissions from shipping amounted to 7.8 million tonnes of carbon dioxide equivalents. That is 15 % more than the year before and 246 % more compared to 1990. Shipping is thus a very energy-efficient but historically strongly increasing transport sector. A report from the European Environment Agency EEA shows that shipping could account for as much as 17 % of the world's carbon dioxide emissions in 2050 if no measures are taken.

Each year, the Baltic Sea and the North Sea are trafficked by around 10,000 ships. The most common ship type in the sea areas around Sweden are cargo ships, which include container ships, RoRo ships, dry bulk ships, and other ships with dry or packaged cargo. This is followed by tankers (crude oil tankers and product tankers), fishing vessels and passenger vessels, including combined cargo and passenger vessels and cruise ships. The scope of sea traffic has grown and today there are always around 2,000 ships in the Baltic Sea at the same time. At the same time, there are at least around 1,000 container ships that consume an average of 10,000 tons of marine diesel per year, making that market alone more than 10 million tons of fuel.

As of 1 January 2016, the world merchant fleet comprised 91,000 vessels over 100 gross tonnage (a measure of size). There are over 50-55,000 merchant ships trading internationally and transporting all kinds of goods on all major seas. The volumes of fuel consumed by the world fleet were around 257 million tonnes of oil per year (IMO, 2014). The World Navy is registered in over 150 nations and is manned by over a million sailors. The ships are technologically sophisticated, high-value assets (larger high-tech ships can cost over $200 million to build), and the operation of merchant ships generates an estimated annual income of over half a trillion US dollars in freight rates.

For 10 years, the Baltic Sea, parts of the North Sea and the English Channel have been a Sulfur Control Area (SECA). This means requirements for lower sulfur contents in ship fuel and emissions than the requirements that apply outside SECA. According to sales data for 2015/2016 from the major fuel suppliers in Sweden, around 1.5 million cubic meters of fuel were delivered to shipping in Swedish ports and on Swedish waters. The Swedish market consists of a few major players who together supply the majority of these volumes. According to Statistics Sweden, the volumes were higher, over 2 million cubic meters of fuel.

However, the official statistics in the field are associated with standardization and quality problems. Fuels are primarily classified based on sulphur content. In shipping, other concepts and terms are used to describe and classify marine fuel, heavy oil (Heavy Fuel Oil, HFO), as well as cleaner distillates, gas oil (Marine Gas Oil, MGO), diesel oil (Marine Diesel Oil), and low-sulphur fuel oils (Ultra Low Sulphur Fuel Oil, ULFSO).

In the same way as for aviation, shipping can and will change, initially with a directive in the EU on the reduction of emissions. However, it must be supplemented with more control instruments to really give impetus to a changeover and that advanced biofuels can become successful investments in the

[5] ReFuelEU aviation and FuelEU Maritime are now approved; for a short overview cf. here https://www.consilium.europa.eu/de/infographics/fit-for-55-refueleu-and-fueleu/ (last access: 09/2023)

long term.

Technical and economic analysis of biofuels

For the technical and economic analysis, the group discussed questions such as:

- Driving factors for success - What are the reasons a technology needs to be a success?
- R&D focus related to the technology itself - What are the technology challenges to focus / overcome?
- Time period - Which time period take to scale-up the TRL a biofuel?
- Involved actors (from academia and industry) and their role - Which responsibilities have them?
- What is the role of public funding?

Key messages were: Start with fuels that have a high TRL like HVO/HEFA (or biomethane) and also use the potential of co-processing to reduce overall GHG emissions. These options are also associated with the lower investment risks within the advanced biofuels options. Establish proper value chains and improve them. Use all options in a broader context of biobased economy incl. biomass/energy crops as carbon source.

Moreover, start doing and establishing a transparent monitoring system to continuously check regulative frame, standards and norms and adapt them if necessary. Infrastructures should be developed in a transnational way (not each country is able to build up infrastructures for many different options). Last but not least, strengthen the awareness of risk, consolidated total cost of ownership and challenges of investments and plant operation along the value chain.

The challenge of biofuels with electrification

The means for biofuels to co-exist with electric vehicles was discussed. Biofuels are less being considered in public discussions on how to decrease emissions of the transport sector. Excellent numbers are shown for the use of biofuels in passenger cars; however, electricity is considered as replacement instead of a complement. The extent to which biofuels and battery electric vehicles are sustainable is debated and differ across markets due to different biofuel production and electricity generation methods.

Two areas which deserve attention are: Where/when does electric mobility make sense, and where will we see biofuels gaining further ground? Opinions are in part based on emotions instead of science "it is not about data". Biofuels are connected to discussions on palm oil, food vs fuel. The overall efficiency speaks in favour of electrification of road (and air and rail) transport. However, electro-mobility does not have the negatives on display as it is considered as 'zero-emission solution', thereby only considering the tailpipe instead of the life cycle. There are emerging markets with large potential to increase low carbon fuels. Electrification is not feasible on its own. There are many obstacles for electrification of mobility as well, such as critical materials, mining, energy density (particularly for long distance traffic such as heavy-duty trucks, aviation, marine etc).

The banning of new sales of cars with combustion engines (ICEs) from 2035 in the EU seems to bring with it a reduction of demand for biofuels. However, the legacy fleet of existing vehicles on the road will need fuels for a long time past 2035. A trend to the contrary is the current deployment of production and fueling stations for liquid biogas, supplying heavy long-haul vehicles in the Nordic countries. This potential could be explored on additional markets.

Biofuels can reduce the GHG of fossil fuels by increased blends. There are opportunities for win-win alliance with fossil fuel industry (which will be around for many decades as the current energy crisis indicate) and with the emerging bioeconomy. Regarding air pollution, clean biofuels decrease pollution in cities while existing vehicles can be used. If there is a prejudice against blended and neat biofuels, there is a need to break barriers and decrease misinformation. Combining biofuels with plug-in hybrid vehicles may be an excellent solution. Are regulators forcing the market towards electric vehicles?

Current policy changes are not necessarily turning to renewable fuels. The EU and USA have stringent policies for tail-pipe emissions in vehicles, which in future will be hard to meet with combustion engines. Older engine technologies profit most from blending. Internal combustion engines still have room for improvements and can be combined with hybrid solutions. Recommendation is to increase research to develop biofuels, concurrently with electric vehicles.

Proven benefits of biofuels are less acknowledged (reduction of GHG emissions when replacing fossil fuels, well established industry in place, job generation, benefits for air quality etc). While the negative aspects of biofuel production on food production, availability and pricing have received more attention, there are also positive indirect effects from increased biofuel production on food production, by e.g. helping to improve rural infrastructure and rural development. Also less acknowledged is the potential for improvements in IC engines or hybrid vehicles using biofuels.

There is also another option: Electro-fuels, a collective name for fuels and chemicals made from electricity, water and carbon dioxide or nitrogen. They can result in a variety of end products (for example, hydrogen, jet fuel, diesel, gasoline, methanol, methane, and ammonia). Briefly, electro-fuels are produced by combining hydrogen, which is produced by the electrolysis of water in an electrolyzer, with carbon dioxide or nitrogen. The carbon dioxide can have different sources; it can come from, for example, flue gases, side streams of liquid biofuels, upgrading of biogas or captured from the air. Nitrogen is captured from the air.

Depending on how an electro-fuel such as hydrogen or methanol is produced, it has a different carbon footprint and is sometimes referred to by different colours. Most hydrogen and methanol produced today is derived from fossil fuels such as natural gas and coal. Significant resources are now being invested in developing alternative routes to electro-fuels, where forecasts suggest production costs competitive to today’s fuels.

In the revised Renewable Energy Directive II, it is stated that electro-fuels are a renewable liquid and gaseous transport fuel of non-biological origin if the energy content is renewable. The EU Commission will come back with a more detailed description of how greenhouse gas emissions from electro-fuels are to be calculated. As for biofuels, electro-fuels are particularly interesting for sectors such as shipping and aviation that are difficult to directly electrify and where liquid fuels with high energy density are difficult to replace.

The production of electro-fuels can be combined with production of biofuels. The addition of H2 in gasification processes or in biogas can boost the production of fuel through the combination with CO2 in the process, In this way, a larger amount of fuel is produced from the same amount of biomass. The amount of captureable biogenic carbon dioxide is not the main limiting factor for large-scale production of electro-fuels in Sweden and Scandinavia. However, available electricity throughout the year is a limiting factor.

The challenge for electro-fuels initially is their low energy conversion efficiency and high production costs. Decisive for the costs of electro-fuel is the price of renewable electricity, as well as the cost of equipment, specifically the electrolysers. Production costs are currently estimated to be high but can gradually decrease if the producers become more efficient and if the price of renewable electricity and electrolysers and other equipment, such as carbon dioxide capture, can be reduced. One of several examples of companies developing electro-fuels is Perstorp at Stenungsund with Project Air, which is a collaboration between Uniper (Germany) and Fortum (Finland) for the production of 200,000 tons of methanol.

3. Swedish workshop on new investments and risks on 13 April 2021

3.1 Workshop frame

SVEBIO organized a national (Swedish) workshop in Stockholm on April 13, 2021 to discuss what forms the basis of new investments which then lead to either successes or lessons learned and how to extrapolate that development curve into new advances. This workshop was centered on how to manage risks.

3.2 Topics, discourse and main results

The participants in the workshop were divided into six groups. The groups were created to get good working groups with different backgrounds and experiences. All group members had to choose five factors based on the project group's hypothesis: which are the factors that you consider to play an important role in the investment process for biorefineries? The factors that were identified as the central factors of the group became the ones that received the most marks. At the group level, the seven most central factors were in descending order.

1. The long-term nature of the energy legislation – the reduction obligation curves determined,
2. Financing of first-of-its-kind, form of financing – project financing versus own balance sheet,
3. Offtake agreement with GHG performance, price and volume,
4. Raw material availability, competition/raw material quality, price and volume,
5. The state aid rules,
6. Technology maturity,
7. Other means of control.

Based on the collective experience and reflection of the project participants, a new set of factors for enabling positive development was drawn up, see below. The number of central factors has also been limited to those judged to be the most central. It turns out that several project participants are aware of significantly more essential factors in their decision-making processes. During the analysis, factors have been combined and some factors perceived as similar have been removed. A hypothesis about which factors are central to investment in Swedish biorefineries can be grouped and described as follows.

- Financial factors:
    - The management's experience
    - The project's calculated profitability
    - Funding: First-of-its-kind
    - Form of financing – project financing, financing against the balance sheet

- Political orientation and regulatory factors:
    - Long-termism, strength and credibility of the energy legislation - the reduction obligation curves determined
    - Share of the reduction obligation from non-food raw materials - forest raw materials
    - Energy and carbon dioxide tax
    - Other control instruments – feed-in tariff, bonus/malus, guaranteed minimum price level
    - State aid rules

- Market factors:
    - Offtake agreement, GHG performance, price and volume

    - Access to raw materials – the energy situation/quality, price and volume

- Technology factors:
    - Technology maturity, Refinery technology TRL scale (how technically mature the technology is)
    - Potential of the product for increased added value.

4. IETS workshop on industrial use of biofuel on 13 March 2022

4.1 Workshop frame

Members of the Lessons Learned project participated in a seminar organized by the IEA IETS (Industrial Energy-related Technologies Systems) Technology Collaboration Programme, held March 13, 2022. Lessons were learned from larger Swedish industrial projects aimed at reducing climate emissions. The purpose of the seminar was to highlight experiences of major industrial projects in Sweden and to identify opportunities for continued R&D and interaction to facilitate the necessary transition and finally to initiate Swedish networking in the area, both nationally and internationally.

4.2 Topics, discourse and main results

Industry may offer a significant savings potential at low or even negative cost. Depending on sector and location, industry increasingly see demand for and a transition towards greatly reduced greenhouse gas emissions. The need for knowledge about experiences of how obstacles can be solved is crucial for a rapid changeover to be achieved. This applies to experiences from the entire chain of planning, implementation and operational stages.

There are significant changes in the industry underway, including but certainly not limited to electrification, development of (sustainable or not) hydrogen gas production distribution and use, carbon capture (CCUS/BECCS), biorefineries, process integration (including energy efficiency), industrial symbiosis, Artificial Intelligence and Machine Learning, digitization, new business models, circular economy and lastly, changes due to evolving changes in consumer behaviour.

Among the projects presented were "Experiences of heating steel with hydrogen", "From forest residue to new industrial business in the pulp industry", "Collaborative projects and alliances for sustainable transition", "Transformative changes towards circular economy in the petrochemical industry" and "Sustainable industrial transition – Reflections on Swedish biorefinery development". The experiences and lessons are incorporated in this report.

The most important aspects to consider as discussed were changes along the different value chains and on different markets with complicated technological or market shifts, several new techniques/systems (partly untested), the time aspect, managing the market given new/more actor constellations, unpredictable future changes in policy instruments, financing and means and methods for risk sharing.

References

[ADVANCEFUEL 2020]
ADVANCEFUEL (2020). How can Europe develop a market for advanced renewable fuels? June 2020, Available online: http://www.advancefuel.eu/contents/files/advancefuel-media-briefing.pdf (last access July 2022)

[E4tech 2015]
Feasibility studies for first of a kind commercial sustainable biofuel projects: A guidance document, Final report for the European Commission Directorate-General Energy, No ENER/C2/2013/626, August 2015, Available online: https://energy.ec.europa.eu/document/download/81bdd9b3-2f2d-4b2d-94bf-2557d4c6530f_en?filename=FeasibilityStudyBiofuelProjectsGuidanceDocument_Final.pdf (last access: July 2022)

VINNOVA 2021
Ekbom, T., Gavelius, M., Rudberg, J. “Styrmedel för nya svenska biodrivmedel”, VINNOVA, September 2021
https://www.svebio.se/wp-content/uploads/2021/09/Styrmedel-fo%CC%88r-nya-svenska-biodrivmedel-SVEBIO.pdf

Appendices

A proposed policy scheme and instrument: Contract for Difference (CFD)

Excerpt from "White Paper – A policy- and support regime motivating investment in production of truly sustainable and scalable advanced renewable fuels"

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1. Scope and objective

This White Paper is intended as a guide to policymakers, expert agencies and promoters of renewable fuels to a meaningful policy and support regime permitting investment in advanced renewable [6]fuels production.

The guide focuses on how to handle price and volatility [7] risks in renewable fuels production and the need to provide grandfathering for projects as subsequent projects move down in cost on the learning curve – this so that projects can be made financeable. The key underlying risk is political risk – a large portion of the value of renewable fuels is politically created and is therefore extremely sensitive to changes or uncertainty in policy.

The guide does not cover numerous other production project risks such as technology, feedstocks etc., which also have to be allocated and mitigated to secure financing. It is the authors' experience from hands-on development and financing of advanced renewable fuels technology and projects as well as power projects that the price and volatility risk is the most challenging risk to handle in this context.

The document does not analyze EU competition and state aid law in detail. Based on the authors' practical experience in successfully obtaining DG competition clearance and given the below

- Policy and support regimes similar to that proposed herein have already well served the renewable electricity market
- State aid law and competition has significant provisions allowing state aid provided the societal benefit outweighs the cost of market distortion

[6] The term advanced renewable fuels is used herein to encompass both "advanced biofuels" and "2G" and fuels such as "2G electrofuels" (for example, the conversion of renewable power to liquid or gaseous fuels)
[7] We use price risk to mean the risk that general market price level is or becomes permanently insufficient to permit a viable business. By volatility risk we mean the risk of prices fluctuating between periods due to market forces or, importantly, to political context or actions; this may make debt service uncertain and lead to default in given periods even if the price level were to be adequate as a long-term average.

- EU regulation explicitly recognizes the needs and exceptional nature of advanced renewable fuels productions[8], we certainly believe a meaningful policy and support regime is implementable in Sweden.
- A previous, government-commissioned study, Fossilfrihet på väg (Fossil free road transport) has found that similar schemes are implementable under EU law[9]. The scheme proposed herein also adds an auction mechanism to further increase a competitive element.

Lastly, we note that there is nothing new under the sun, advanced renewable fuels promoters and researchers have in various forms and forums identified and communicated all issues and proposals herein during the last decade. [10]

Encouragingly, the last 5 years have seen a number of Swedish Government-commissioned studies or other reports which have correctly analyzed requirement for advanced biofuels production, the impediments to investment and, in some cases, meaningful solutions supporting advanced biofuels production. [11][12]

2. What is a Contract for difference?

A contract for difference (CFD) is a typically a civil law contract between two parties under which one or both parties commit to pay the other party the difference between a set price (strike price) and a market price or value.

CFDs are instruments which are well-known by capital markets and which have been very successful, for example in developing and securing finance for off-shore and on-shore wind in the UK and in Denmark.

CFDs also avoid the obvious and inherent shortcomings described in this document of general quota- and mandate based systems such as the current Swedish system, the US RFS System, the EU advanced renewable fuels or aviation renewable fuels targets, or trading of green certificates – all of which have proved unsuccessful in driving significant investment in advanced renewable fuels plants.

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[8] EUROPEAN COMMISSION Guidelines on State aid for environmental protection and energy 2014-2020 (2014/C 200/01): "(114) In addition, the Commission will consider that the aid does not increase the level of environmental protection and can therefore not be found compatible with the internal market if the aid is granted for renewable fuels which are subject to a supply or blending obligation (60), unless a Member State can demonstrate that the aid is limited to sustainable renewable fuels that are too expensive to come on the market with a supply or blending obligation only."

[9] SOU 2013:84 Fossilfrihet på väg (Fossil free transport) p. 840

[10] For example, Chemrec AB formal answer including proposal for CFD instrument to DG Energy on EU SET plan "How to close the risk finance for advanced renewable fuels projects" June 2013

[11] For example, but not limited to: SOU 2013:84 Fossilfrihet på väg (Fossil free transport); Energimyndigheten: Kontrollstation 2019 för reduktionsplikten. (Mid-term review 2019 for the reduction obligation); SOU 2019:11 BioJet för flyget (Aviation renewable fuels)

[12] For example, "Development and analysis of a durable low-carbon fuel investment policy for California" by the International Council of Clean Transportation (2016). This extremely well-written white paper also proposes a CFD-type instrument.

Proposal: In the context of advanced renewable fuels projects and proven policy instruments, the following would allow investment in advanced biofuels production capacity and meet the criteria:

Advanced renewable fuels production projects bid for, and winners are awarded, CFDs in so called reverse auctions (lowest bid wins). These pay out the difference between an uncertain or insufficient market price and the price required to finance the project (strike price). Auctions are held on a recurring basis according to set categories each for a different type of route to renewable fuels, with specific maximum administrative strike price and specific terms.

These parameters can change according to policy needs, technology and cost reduction, leaving the Government in control - the key feature is that they do not change for a project once offered and awarded, providing the required long-term stability needed to finance.

Key benefits for the Government and for consumers include:

- Plants which make target achievement possible can actually be built
- The cost of the support regime is minimized through reverse auctions
- The maximum cost imposed on consumers is known up front and can be controlled. Each auction can have different conditions, for example a maximum price which is typically lowered over time to reflect technology improvement. (An example from offshore wind is that CFD strike prices have drastically gone down between different years' auctions).

3. Implementation and structuring of a CFD program13

We believe a Government agency such as the Energy Agency could administer and manage a CFD program. This process and program could take the below form:

3.1 Implementation of regulatory framework and targets

- **Definition of auction categories and pre-qualification requirements.** Categories can provide for differing routes and sizes of projects for the production of advanced renewable fuels, but all require high GHG-savings performance and sustainability:
  - GHG performance, e.g. at least some 85% reduction versus fossil fuel baseline.
  - Environmental and social sustainability criteria
  - Scalability and indirect effects
  - Technologies and categories (for example electro-fuels, biomass gasification, pyrolysis)
  - Routes definition – from energy source to usable fuel incl. energy efficiency
  - Auction process, Time lines and decision on frequency of auction. An illustrative example is given in section 10.
  - Energy volumes – the volumes in TWh or MJ to be auctioned in each category.
  - The categories can change from year to year as technologies, costs and/or target achievement change.

- **Development of the CFD contract structure.** This is described below.

[13] Significant credit for the structure and completeness of this section is due to ICCT "Development and analysis of a durable low-carbon fuel investment for California" (2016)

- **Definition of obligated parties.** Distributors of fuels subject to energy tax shall be required to distribute advanced fuels per below quotas and according to the rules herein. It should be noted that a project promoter or other party may set up or contract with a third party for the distribution and/or creation of a distributor for a given project. This distributor may then become an obligated party. An example is setting up a distributor for a fuel for which current distributors do not yet handle the product, such as for DME.

- **Setting of quotas for obligated parties** for each category with penalties for non-achievement equal to the non-compliance fee ("reduktionspliktsavgift"). This is intended to provide additional incentives for obligated parties to distribute the fuels.

    - We recommend that quota-fulfilments may be traded between obligated parties.
    - One may note that the Government commissioned study "Fossil free transport" concluded that high-blend and pure renewable fuels should also fall under quotas but, as noted above that this was not sufficient to generate investment in advanced biofuels plants.[14] Furthermore, it is implicitly recognized in EU regulations that advanced renewable fuels of the type considered herein can be subject to both quotas and specific support as only one of the instruments may be insufficient.[15]

- **Definition and implementation of framework for allocating costs of CFDs to obligated parties**. The cost of the CFDs is allocated to obligated parties in proportion to their share of total distribution of fuels subject to energy tax. This is in line with recommendations in the Fossil Free Transport study. An alternative would be to allocated these costs only to the fossil fuel pool, which would be more consistent with the polluter pays principle but which could have more extreme impacts on fossil fuel prices.[16] Allocation can be done either through excise taxes on fuels the revenue of which are earmarked for financing CFDs or through the obligation to purchase certificates generated at production of the fuels at a price sufficient to finance the CFD costs. Other mechanisms, including a partial Government subsidy could be envisioned to accelerate implementation and mitigate impacts on consumer fuel prices.

[14] SOU 2013:84 Fossilfrihet på väg 14.7 p.705 and 14.7.2 p.733-734
[15] EUROPEAN COMMISSION Guidelines on State aid for environmental protection and energy 2014-2020 (2014/C 200/01): "(114) In addition, the Commission will consider that the aid does not increase the level of environmental protection and can therefore not be found compatible with the internal market if the aid is granted for renewable fuels which are subject to a supply or blending obligation (60), unless a Member State can demonstrate that the aid is limited to sustainable renewable fuels that are too expensive to come on the market with a supply or blending obligation only."
[16] SOU 2013:84 Fossilfrihet på väg p733

Creation of a Government contracting party to CFD, administering agency, legal contracts

- Please refer to below description of key terms of the CFD
- The key terms of the CFD and the energy volumes on offer in each auction makes the maximum cost of the program quantifiable.

- **Ongoing and pre-launch validation of program with capital market parties.** Typically, renewable fuels policies and support schemes have been launched without formal and structured validation with neutral capital market parties De minimis, an entity such as the EIB needs to be requested to confirm to the Swedish Government that *"the proposed scheme which is intended to give more certainty on the revenue, volume and price risk faced by a renewable fuels producer (whatever its form) will allow EIB to provide non-recourse financing to promoters. This provided that all other project risks (e.g. technology, feedstock, are mitigated and allocated in a satisfactory and customary manner)".* If such assurance cannot be given, the designer of the scheme needs to solicit tangible modifications to the scheme from, in this case, the EIB. This is the acid test, without such validation, policies are likely to be unfit for purpose.

3.2 Bid phase and CFD contract

A pro forma civil law CFD contract for each category is provided to potential bidders as part of the invitation to bid process. This should be identical to the final CFD contract awarded. It needs to set out the CFD terms with high precision in order that financing institutions and promoters can incorporate it in investment and credit analysis:

- The CFD contract characteristics include:
  - **Maximum energy volume on offer in the category and for a project**, needs to be sufficient for a plant of sufficient scale. Sample of order of magnitudes per year of production: for biomass gasification 1 TWh (3.6 PJ,~120 000 m3 diesel eqv); for an electrofuel project, 0.25 TWh or 0.9 PJ per year. These yearly volumes times the duration of the CFD gives the maximum total volume supported.
  - **CFD maximum administrative strike price** (this is the maximum possible value of the CFD on offer, which, multiplied by the volumes above give the maximum costs). This could be set either based on analysis and understanding of the various routes for production of advanced biofuels or at the current level of non-compliance penalty ("Reduktionspliktsavgift"), which is 5 SEK/kg CO2 for diesel and 4 SEK/kg CO2 or Gasoline or, expressed per MJ using the regulatory standard values for energy content, respectively
  - **CFD market price proxy**. Given that renewable fuels markets are small, less transparent, very volatile and subject to large political risk, it is proposed that market price proxies similar to the following are used (on an energy equivalent basis):

- Diesel substitutes: Market price proxy is the lower of:
    a. Average of Rotterdam EU compliant FAME prices from Platts and Argus or equivalent agency for the closest period, and
    b. Average prices for the closest period Rotterdam EU Diesel prices per Platts and Argus

- Gasoline substitutes: Market price proxy is the lower of:
    a. Average of Rotterdam T2 ethanol prices from Platts and Argus or equivalent agency for the closest period, and
    b. Average of EU wholesale gasoline prices per Platts and Argus.

       Alternatively, a market price proxy could be an arms-length contract with an obligated party; however, this will require more complex evaluation and comparison of bids as less transparent.

- Adjustment components, for example for tax impacts (including a possible tax imposition of CO_2 and energy tax also on pure biofuels), unfavorable regulatory or legislative decisions/change of law and incremental distribution costs. Incremental distribution costs may be applicable if a fuel is not drop-in and requires additional distribution arrangements and infrastructure, and where it is appropriate to break this out as opposed to bundling it in the strike price bid. The distribution component may be indexed according to an appropriate CPI or PPI price index.
- The value of the CFD during operation will thus vary while the net revenue to the producer will be close to stable, but be according to the following formula:
    - CFD Payout per MJ produced of qualifying fuel =

      MAX [Strike price bid – (Market price proxy + tax impacts + adjustment for non-passthrough change-of-law unfavorable impacts + adjustment for incremental distribution costs), 0]
    - The CFD proposed only pays to the producer if the sum of market price plus adjustments is below the strike price. Should the market price be above the strike price, no claw back is proposed, i.e. the producer does not have to pay the CFD counterparty. We believe this additional potential reward for risks is warranted for not yet de-risked first plants and risky renewable fuels markets. (CFDs used for some offshore wind projects do have payments going both ways.)

- **Duration**, maximum 3 years development and construction followed by 15 years of operation. The project, after win of CFD but before start of construction, is assured of 15 years of predictable revenues. This permits the project to demonstrate capacity for equity and debt service, required to raise finance.

- **Counterparty**. It is proposed that the CFD counterparty be a Government entity so as to minimize the counterparty credit risk. However, we propose that the counterparty is funded by allocating the cost of the CFD in line with the approaches discussed in *Implementation of regulatory framework and targets*

- **Bid requirements** – to ensure that winners will actually go ahead and build plants, the below types of items need to be provided. It should be noted that for a large project using a technology not previously commercialized, the cost of provision of these items can, depending on the accuracy of estimates and risk accepted in the underlying contracts, run into low 10s of millions of EUR and require significant time; this needs to be taken into account in the invitation to bid and auction process in order to allow new entrants:
  - Promoter presentation and consortium agreement demonstrating a solvent and competent promoter and or consortium
  - Financing term sheets for equity and debt conditional on CFD win
  - Financing plan
  - Conditional rights to suitable site and site analysis demonstrating likelihood of permits /Construction and environmental permits
  - Construction/EPC agreement conditional on CFD win
  - Project plan
  - Lifecycle GHG analysis and ESIA (Environmental and Social Impact Analysis)
  - Offtake or distribution agreement conditional on CFD win
  - Possibly, bid bond which is forfeited if bid is successful but is not followed through
  - CFD counterparty, the entity which develops, finances, builds and operates the plant

3.3 Auction and award phase

Bids are submitted, including:

- The bid requirements documentation
- The strike price and volume bid. The volume may be for all or part of a project's production and may be for part of the quota in the category bid for.

Bids are evaluated for meeting the qualitative requirements.

Bids are then evaluated for minimum expected CFD cost, probably weighted for GHG savings.

This can, depending on the exact CFD structure, market price proxies and production profiles, be done using a levelized cost projection over the 15 years (NPV of CFD costs over 15 years / NPV of MJ produced over 15 years, at appropriate discount rate) or by comparison to a reference market price per the date of the invitation to bid.

CFDs are then awarded to the lowest CFD cost bidder(s) in respective categories. At the time of acceptance of the award, the bidder will have to post a performance bond to provide assurance that the project will be implemented. Should winning bidder not accept the award, the bid bond will be forfeited.

4. Example of advanced biofuels project and CFD

Financials and financing of an advanced biofuels production project

Below are highly simplified financials for a type of advanced renewable fuels plant. The example is based on a type of biomass gasification plant (Black liquor) producing synthetic gasoline and reflects a first plant of commercial size.

Figures are based on 28,000 hr pilot plant experience, significant engineering studies and design, and budgetary estimates from Engineering Procurement and Construction contractor (EPC). The EPC provided customary EPC wrap performance and completion guarantees and liquidated damages, reflecting an acceptable technology risk

One may note that for subsequent de-risked plants, as the unit, in addition to producing renewable fuels, replaces a so-called recovery boiler in a pulp mill, CAPEX can be reduced by an avoided cost from 490 MEUR to 250 MEUR – another reason for a support scheme allowing the first plants to be built.

MEUR except where indicated **Plant financials**	**Renewable energy (Ethanol lge eqv)**	**Fossil energy price (Gasoline)**
CAPEX: 490 MEUR		
Production: 185 million litres gasoline equivalent per year		
EUR/lge Biofuels price	0.90	0.60
Revenues	166	111
Opex	(65)	(65)
EBITDA	101	46
Debt service and dividends		
Debt service, 70% debt	(49)	(49)
Dividends, 30% equity	(35)	(35)
Total capital service (10 years)	(84)	(84)
Base case debt service coverage and break-even price points. Prices in EUR/lge		
Simple debt service coverage (EBITDA/debt service)	2.1	0.9
Min price allowing capital service (OPEX + Capital)/Volume	0.81	0.81
Min price after debt repayment allowing 20% ROE (OPEX + Dividends)/Volume	0.54	0.54
0 EBITDA Break-even price after debt service (rational to produce above this price)	0.35	

Assuming financing by: 70% debt over 10 years @7% and 30% equity @20% return, the project:

- Can service debt and equity at renewable fuels prices above 0.81 EUR per liter gasoline equivalent (LGE).
- Cannot service debt and equity at current fossil prices, Debt service coverage ratio at 0.9 at 0.60 EUR/LGE
- After debt is reimbursed, can pay dividends at prices above 0.54 EUR/LGE, approaching competitiveness with fossil
- Can generate positive EBITDA above 0.35 EUR /LGE. This is relevant post debt-reimbursement as it means the plants will likely stay in production after the support scheme terminates.
- For subsequent or n^{th} plant where avoided cost can be credited, the plant production cost approaches parity with fossil.

Note: Given perceived risk of first-of-their-kind projects, debt and equity providers may need to be assured of a price of at least 0.81 EUR / LGE during the debt tenure of 10 years plus a margin of safety. In the following CFD example, we have assumed a 15-year duration of the CFD contract.

CFD example for the advanced biofuels project

The following example assumes that the project has won a reverse auction in its category by offering a strike price equivalent to 0.81 EUR per LGE (or 0.025 EUR per MJ). A CFD has been awarded with a duration of 15 years. (For simplicity we ignore the adjustment terms).

A simulation using a set of random market prices gives the following: (DSCR: Debt service coverage ratio, here simplistically EBITDA / debt service)

	Period	Market price proxy	CFD Payout	Strike price/Break-even price	Total price	DSCR at mkt price	DSCR w. CFD
Construction	C1			0.81	-		
	C2			0.81	-		
	C3			0.81	-		
15 years of operation covered by CFD*	O1	0.90	-	0.81	0.90	2.08	2.08
	O2	0.70	0.11	0.81	0.81	1.32	1.72
	O3	0.90	-	0.81	0.90	2.08	2.08
	O4	0.50	0.31	0.81	0.81	0.56	1.72
	O5	0.40	0.41	0.81	0.81	0.18	1.72
	O6	0.70	0.11	0.81	0.81	1.32	1.72
	O7	0.80	0.01	0.81	0.81	1.70	1.72
	O8	0.70	0.11	0.81	0.81	1.32	1.72
	O9	0.50	0.31	0.81	0.81	0.56	1.72
	O10	0.90	-	0.81	0.90	2.08	2.08
	O11	0.30	*0.51*	*0.81*	*0.81*	*(0.19)*	*1.72*
	O12	0.70	*0.11*	*0.81*	*0.81*	*1.32*	*1.72*
	O13	0.40	*0.41*	*0.81*	*0.81*	*0.18*	*1.72*
	O14	0.70	*0.11*	*0.81*	*0.81*	*1.32*	*1.72*
	O15	0.60	*0.21*	*0.81*	*0.81*	*0.94*	*1.72*
Operation post-support**	O16	0.60		0.35	0.60		
	O17	0.50		0.35	0.50		
	O18	0.40		0.35	0.40		
	O19	0.50		0.35	0.50		
	O20	0.90		0.35	0.90		

* Example has 10-year debt but a 15 year CFD - this reflects an additional risk buffer. A bidder has a tradeoff between offering low risk to secure financing(longer period CFD support) and and minimizing the expected cost of the CFD to win the bid(low value CFD, short period support).
** Post support, and post debt repayment, the breakeven price is lower and on the order of being fossil-competitive

Per above and the below graphical representations.

- It is evident that the project exposed to volatile market prices cannot ex ante demonstrate a capacity for debt service
- The CFD kicks in and pays out whenever the market price goes below the strike price

- The cost of the CFD to fossil fuel consumers is represented by the red area times the volume.

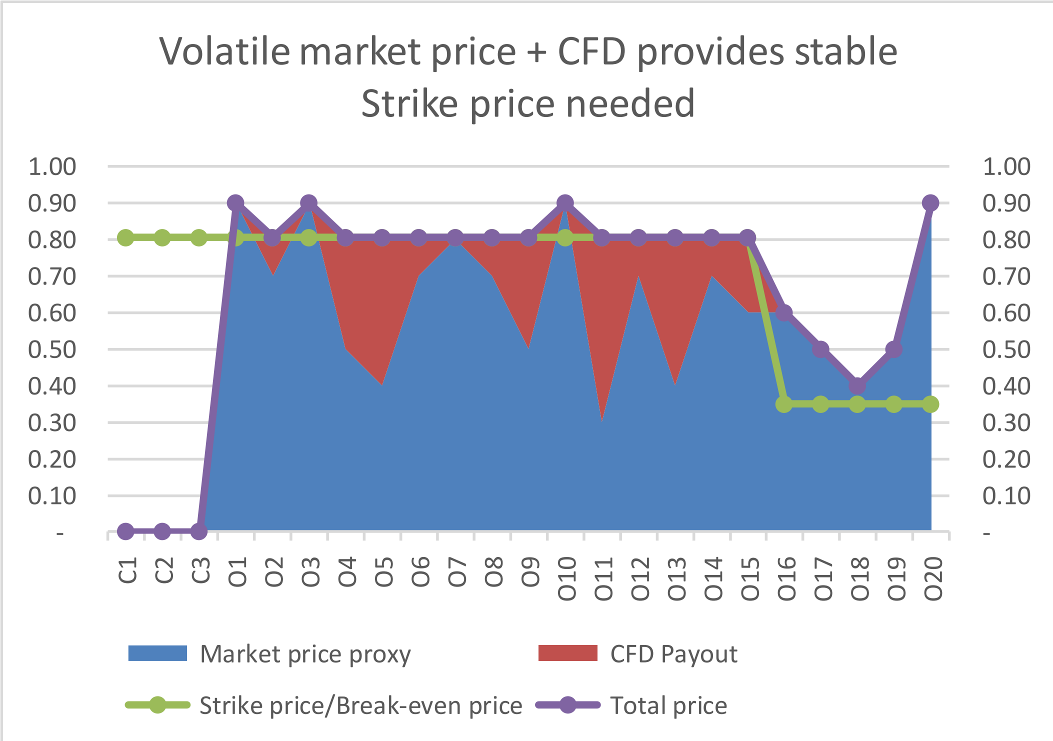

Figure 2. Graph of market price and the strike price for the project.

Appendix 2.

Colours of different types of hydrogen production

Below is an explanation of the colour codes for different hydrogen production methods.

- **Green hydrogen** is produced by electrolysis of water with renewable electricity. Green methanol is produced from either bio-based raw materials or hydrogen produced from renewable electricity that reacts with bio-based carbon dioxide.

- **Blue hydrogen** is produced from natural gas where carbon dioxide from this process is separated and stored (CCS) or further used (CCU) as in chemical processes. The blue hydrogen has therefore a low carbon footprint from a system perspective. Blue methanol is made from separated carbon dioxide from industry or power plants (or from the atmosphere) that reacts with green hydrogen.

- **Grey hydrogen or methanol** is produced from natural gas without separation or use of the carbon dioxide, which is therefore released into the atmosphere. This is the most common method today.

- **Brown hydrogen or methanol** is produced from lignite without separation or use of the carbon dioxide, which is therefore released into the atmosphere.

- **Black hydrogen or methanol** is produced from coal without separation or use of the carbon dioxide, which is therefore released into the atmosphere.

- Turquoise hydrogen is produced by pyrolysis of methane into hydrogen with solid carbon as a by-product which can either be used or stored and depending on use it therefore has a low carbon footprint from a system perspective.

- **Pink hydrogen** is produced by electrolysis of water with nuclear electricity.

- Yellow hydrogen is produced by the electrolysis of water with solar-based electricity, or as some advocates call it: of an electricity mix found on the electricity grid, which is partly renewable and partly fossil.

- White hydrogen is produced by separating hydrogen from industrial processes without higher emissions of carbon dioxide than before. White methanol is produced from white and green hydrogen with bio-based or fossil carbon dioxide separated from industry or power plants where the system does not produce higher emissions of carbon dioxide than before.

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