INITIATIVE TOWARDS SUSTAINABLE KEROSENE FOR AVIATION

FINAL REPORT

FINAL PUBLISHABLE SUMMARY REPORT. CAPABLE OF BEING DIRECTLY PUBLISHED BY THE EC AND AIMED AT THE GENERAL PUBLIC

EXECUTIVE SUMMARY

Alternative fuels for aviation panorama has significantly changed along the last four years. More technologies have been accepted by the aviation fuel standards, but still the volume available is extremely limited and farther than cost parity than we expected by today. During this period, adapting the program to the context changes, the faced challenges and the findings, the ITAKA consortium has accomplished important milestones and goals.

The main milestone achieved has been to demonstrate, by the first time, the **use of the biojet blend in the conventional airport fuel systems** (tanks, pipelines, hydrants). This logistics mode is economically advisable, feasible and fully compliant with airport operations and users. Since the end of 2015, all flights departing from Oslo airport (Gardermoen) are using biojet fuel, what would account for about 60,000 flights and about **6 million of passengers**. Also, and no less relevant, this operation has allowed for the very first time the **demonstration of the claim of the use of biojet fuel in the ETS (Emissions Trading System)**, from the supply in a country (Norway) to the claim in another country (Germany, Nabisy system).

Later in 2016, a smaller volume of fuel entered in a similar way the Amsterdam airport (Schiphol) to demonstrate by first time, the administrative procedure for generating bio-tickets from biojet under the Renewable Energy Directive (RED). This demonstration event has been complemented with a study about how this mechanism could be applied quite easily in other Member States and it could help to reduce the current price gap between the conventional and biojet fuels.

Such experience has been possible thanks to a **biojet fuel production 100% made in the EU,** with the camelina oil being produced in Spain (accumulated for three seasons, more than 1000 t), later refined to biojet fuel in Finland. In the process, consortium has learnt that even at this small scale the **availability of sustainable European feedstock is a clear bottleneck:** new crops require a long time to expand and being significant and currently available feedstock is limited and demanded by other sectors or uses. Studies performed within ITAKA have shown that available used cooking oil (UCO) in the EU [~1-1.5 million t] is not sufficient for the current RED targets (10% share of renewable energy for transport in 2020). Currently in Europe there is about 2 Mt/y installed refining capacity for HVO (that could be used, partially, to produce HFP-HEFA biojet).

UCO is challenging to be used in technologies like HVO that use catalysts, because the high risk of contamination and high variability in composition of the feedstock. The project has developed a pre-treatment using pyrolysis that could serve to create an intermediate or complete pathway to solve those hurdles.

The **camelina oil production** has reached a **large, commercial scale** (more than 15,000 hectares in total) that has allowed optimizing the cultivation protocol and the crop's expansion strategy. Both elements are key to accelerate and properly address the expansion process. The two main regions considered in the project, Spain and Romania, offer two very different strategies and performances, representing different options across Europe. Camelina introduction in **Spain has been performed in dry land as a rotation alternative to fallow land**. Although camelina yields are usually low in such scheme, it does not interfere with food production, while providing environmental and socioeconomic benefits. **Romanian** plantations provide **higher yields**, while increasing development and socioeconomic benefits, with the **potential of using polluted lands**. It has been demonstrated that **sustainable camelina oil can be produced in Europe, in large amounts**, with low risk of displacing crops (ILUC), generating additional social and economic benefits for the farmers and saving up to 66% carbon emissions (GHG).

Two series of flights where completed. First in 2014, **18 long haul lights** from Amsterdam to Aruba, using an Airbus A330-200, transported circa 4,500 passengers that were informed about the project. The produced dataset confirmed positive results about reducing the maintenance frequency and costs using biojet. Later, another series of **80 short haul lights**, from Oslo to Amsterdam, on an Embraer 190, carrying about 8,000 passengers, also confirmed the **no detrimental effects** on operation with **similar or slightly better fuel consumption and, no variation in fuel gauging systems**. The flight series were complemented with lab tests and with Auxiliary Power Unit (APU) tests on emissions. The use of APU is a key safety element on the long haul flights with two engines while use significant less fuel per hour than a conventional aircraft engine while producing similar results on emissions. An **APU was tested** with the two batches, showing a **fuel consumption decrease up to a 1%** and that the emitted **particulate matter (PM) can be decreased up to a 50%** compared with conventional jet fuel. PM emissions are one of the major concerns on local pollution, causing a high number of premature deaths across Europe, what indicates that synthetic fuels as the HEFA biojet can significantly help to reduce this pollution impact at airports. The information obtained has been supplied to the International Civil Aviation Organization for the development of future standards for aircraft engines.

SUMMARY DESCRIPTION OF PROJECT CONTEXT AND OBJECTIVES

The overall objective of ITAKA has been to **develop a full value-chain in Europe to produce sustainable Synthetic Paraffinic Kerosene (SPK)** at large scale enough to allow testing its use in existing logistic systems and in normal flight operations in Europe. ITAKA will **assess its sustainability, economic competitiveness and technology readiness**, in order to identify and address **barriers to innovation**.

Being the first of its kind collaborative project in the EU, ITAKA targeted to **link supply and demand** by establishing a relationship under guaranteed conditions between feedstock grower, biofuel producer, distributor and final user. Therefore, ITAKA addressed challenges in two main areas:

- Development of commercial scale production and study implications of large-scale use.
- Research on sustainability, economic competitiveness and technology readiness.

Beyond this main technological and research objectives, **ITAKA was also able to contribute to the achievement of a further EU objective: The need to coordinate efforts and complementarities among European Initiatives** on sustainable aviation fuels, what has been highlighted during the EU Advanced Biofuels Flightpath definition[1] and identified in SWAFEA[2] recommendations: "Setting up a knowledge and test capability network within the EU to provide an EU based fuel evaluation capability". ITAKA has been built aiming to engage key stakeholders participating in different EU initiatives in the field, to **make a first significant step in the establishment of such European network**.

The project proposal that follows is framed in the implementation of the EU policies, implementation of the European Industrial Bioenergy Initiative (EIBI) of the Strategic Energy Technology Plan (SET-Plan) and specifically aims to be a contribution to the fulfilment of some of the **short-term (2015) EU Flightpath objectives[3].**

The biojet used in aviation was already standardized[4] for a maximum blend of 50% with fossil Jet-A1 fuel (FT and HEFA biojet) allowing its use in the existing infrastructures and aircraft, but there was also a need to investigate environmental, social and economical side effects and barriers, to be fully understood, as identified in EU FP7 funded projects **DREAM[5]** and **SWAFEA**.

1 DG MOVE- European Workshop on Sustainable Alternative Fuels for Aviation. Madrid, June 2010; EC Workshop on "The role of a European Civil Aviation Network in the promotion of aviation sustainable fuel". Brussels, Dec 2011.
2 SWAFEA-Sustainable Way for Alternative Fuels and Energy for Aviation (2011) is a EC study to investigate the feasibility and the impact of the use of alternative fuels in aviation: www.swafea.eu
3 Objectives by 2015: A clear and effective **communication strategy from the aviation industry** towards the European passenger concerning the advantages of using sustainable biofuels without any compromise on safety; Full development of quality standards, **certified use of biofuels and on flight testing**; Supply **of sustainably produced vegetable oils or fats for at least one existing HVO plant and 2 new HVO plants**.
4 ASTM 7566-11 and DEF STAN 91-91.7
5 DREAM-Validation of radical engine architecture systems(2011) is a large multinational FP7 R&T: www.dream-project.eu

The integration and organization of the whole aviation biofuel value-chain must be optimised to reduce fuel cost. This goal will require research and engineering/logistics breakthrough in all sectors involving the production and deployment chain.

FEEDSTOCK PRODUCTION

The specific objectives in the feedstock production phase were the following:

1. To **implement the first of a kind large-scale camelina plantations in Europe** and verify its compliance with **EU RED and RSB Standard criteria**, in order to supply **sustainable** feedstock oil and provide as expected results:
    - Production of certified sustainable camelina oil for conversion into biojet.
    - Field crop knowhow under real planting agronomic conditions.
    - Promotion of the crop among EU farmers.
    - Identification of the main barriers for the deployment of sustainable large scale camelina production in Europe.
    - Experience on the commercialization of the generated co-products (mainly camelina meal) as a high protein animal feed.

2. To **improve key aspects of camelina oil production**, including economic (productivity), social/land use and sustainability, through research activities aiming to:
    - Maximize plant quality, and oil content to improve the **productivity of camelina** oil per hectare.
    - Test **camelina plantations in degraded and polluted land** to explore an increase in the potential crop area in Europe while improving environmental benefits and generating growth in less developed rural areas.
    - **Improve (reduce) greenhouse gases emissions, through agronomic best practices**: Minimization of fertilization requirements and implementation of **no-tilling or minimal-tilling** agricultural procedures, as well as biofertilization (sludge) procedures.
3. To investigate the **feasibility of using waste vegetal oil** (UCO) as a sustainable alternative feedstock.

CONVERSION TECHNOLOGY

The innovation objective for the conversion technology was to improve existing technologies and processes for refining camelina oil and waste vegetable oil through the adaptation and novel integration of an existing plant and technology (Neste's renewable products plant in Porvoo) to build up the first-of-its-kind plant in the EU able to produce biojet fuel at a large enough scale to reduce production cost beyond the state of the art. The specific objectives of ITAKA in this area included:

1. Improvements in **process control, safety and optimization**.
2. Improvements in existing plant **production logistics**. The plant logistics and availability of skilled research and development (R&D) staff is crucial, for instance to develop the fuel analysis systems and for quality assurance on the blending process.
3. Development of **renewable jet fuel analysis methodology** needed for the fuel certification.
4. **Production of the required volume of Hydrotreated Vegetable Oil (HVO)** renewable jet fuel for ITAKA testing tasks. Development of process chain starting from camelina oil provider to production plant, testing, blending, transporting and storage of the fuel and ending to the delivery to the end customer.
5. **Provide the necessary data for the assessment** tasks (social, economic and environmental performance).

The main expected result of the conversion technology improvement was a more safe, efficient and fluent production process of renewable aviation fuel. The modifications to the refinery would also ensure the fulfilment of tight aviation fuel product quality requirements, especially in product density. Environmental, safety, healthy and quality aspects should be taken into careful consideration in every step of the production, transport and storage of the fuel.

LOGISTIC AND SUPPLY MANAGEMENT

ITAKA addressed all downstream logistics (i.e. blending, transport, storage and airport supply operations) at large scale, both through a dedicated and a non-dedicated system. The use of a non-dedicated system (i.e. co-mingled system) is the current practice/infrastructure at almost all the airports in the world as the most cost efficient fuel logistic system. The dedicated system adds significant costs, but it was necessary to carry out biojet flight testing programs. ITAKA studied logistic and supply management implications of large scale use of biojet fuel through:

1. **Enabling large scale testing of biojet fuel on specific flights**, through the use of a segregated logistic (dedicated system).
2. **Investigating thresholds** to the cost effective distribution and commercialization of biojet fuel through existing infrastructures. Focus will lie on:
   - Feasibility of transporting neat biojet fuel (i.e. 100% pure) as close as possible to its point of us, to insert it into the airport existing fuel system (non-dedicated system) saving cost and emissions.
   - Detect if operators are reluctant to accept the recertified biojet fuel and what is needed to make them accept the product without demanding additional tests.
3. Carrying out a **first of its kind trial on biojet fuel distribution through a full non-dedicated airport fuel system** (i.e. existing fossil jet fuel infrastructure), aiming to:
   - Identify the technical and administrative barriers associated with large scale use of biojet fuel in conventional infrastructure
   - Check the influence of the product on infrastructure (e.g. gaskets) and operations (e.g. interface detection and segregation when transported by pipeline)

4. **Improving** (and suggesting improvements for) **technical practices, mapping possible health & safety issues** during handling along the supply chain and administrative processes related to the delivery of biojet fuel (In both dedicated and non-dedicated systems).
   - Getting all paper work for a credible and accepted mass balance accounting system in place for delivery of bio jet through co-mingled airport infrastructure.
   - Optimizing the administrative work load associated with this new fuel (i.e. quality insurance, traceability).

TESTING AND LARGE SCALE USE

ITAKA targeted evaluation of impacts on aircraft operations with dedicated airlines in typical passenger flights in Europe, involving key actors of the value-chain. Flight-testing shall be carried out and relevant datasets shall be collected for the final assessment. The ITAKA objectives on this field are summarized hereunder:

1. **Perform commercial flights** using the produced alternative drop-in fuel in typical European passenger flight operations.
   - The involvement of significant European airlines would ensure the use of the produced sustainable biojet in commercial flights, in compliance with the volumes capacity and quality defined, and the availability of relevant data for future evaluation and testing activities.
2. **Assessment of engine and fuel system**, analysing data from flight to perform gauging fuel systems test and engine performance analysis (after each flight), checking:
   - That different aircraft fuel gauging systems functionality is not affected by the different fuel properties.
   - If alternative drop-in fuel has long-term improvement regarding emissions.
3. Investigate relationships between fuel blend composition, **combustion and air pollutant emissions**.
   - Using a fully instrumented Auxiliary Power unit (APU) test bed engine, key parameters would be monitored to assess engine performance when running on conventional and bio drop-in jet fuel at a number of blend ratios.
4. Collect **relevant and structured data** to enable the final assessment (social, economic and environmental performance).

SUSTAINABILITY

An **assessment of the maturity** of the technologies at-hand, **using the ICAO and CAAFI[6] approved Technology Readiness Level scale** was targeted, to achieve the following specific objectives:

6 **Commercial Aviation Alternative Fuels Initiative**: CAAFI is a U.S. coalition of airlines, aircraft and engine manufacturers, energy producers, researchers, international participants and U.S. government agencies. Aims to enhance energy security and environmental sustainability for aviation by exploring the use of alternative jet fuels.

1. Assess the current Fuel Readiness Level (FRL) at a given time, based on pre-defined criteria and give the route to next FRL until project completion.
2. **Collect the information relative to the Value Assessment** (VA) (LCA, Economics and Fuel quantity) as an input to develop Gate Reviews (GR) during the project execution, and check the coherence with the corresponding EU 2020 Flightpath objectives.

Another objective was to provide **guidelines for further commercial scale-up** of this production chain. With this aim, and based on the input from all stakeholders involved in the value chain, ITAKA targeted to **develop a scale-up model** to study the economic, social, environmental and regulatory implications of large-scale biofuels utilisation in aviation, for the expected situation of 2020 to analyse the results obtained in order to **provide recommendations to solve potential barriers to large-scale commercialisation**.

The work execution was planned according to the following specific objectives:

1. Evaluate the **economic viability and the social impact** of large scale production of biojet fuel based on information acquired from activities within ITAKA.
2. Evaluate the **impact** that the use of biojet fuels shall have on the **airlines operations and economics**, as in maintenance, ETS scheme, flight and ground operations.
3. **Estimate the emissions reductions** from aircraft engines that can be achieved through the use of biojet fuel related with the fuel consumption (% of blend, charasteristics).
4. Analyse the **feasibility for up-scaling the production** of camelina following the ITAKA processes.
5. Study possible **ETS market regulatory changes** for the achievement of the Flightpath objectives.
6. Perform sensitivity **analysis study and the evolution of biojet fuel price versus fossil fuel price** for year 2020.
7. Implement a scale up model and scenario variables into a software program to be able to assess different case studies proposed.
8. Assessment of the biofuel sustainability along the value chain and greenhouse gas (GHG) calculation for the biofuel according the EU RED and RSB criteria. Assessment of land use impacts and indirect impacts of camelina oil production.
9. Full Life Cycle Assessment of camelina biojet according to well accepted life cycle impact assessment method (LCIA). And assessment of land use impacts and indirect impacts of camelina oil production.
10. Identification of gaps, barriers and improvement areas across the sustainability certification processes. Identification of gaps and improvement areas in the RSB EU RED Standard to strengthen it as an international standard for certification of biojet sustainability.

DESCRIPTION OF THE MAIN S&T RESULTS

The ITAKA project supports the development of aviation biofuels in an economic, social and environmental sustainable manner, improving the readiness of existing technology and infrastructures. This has been achieved through a first of its kind collaborative project in the EU, which has developed a full value chain in Europe to produce sustainable drop-in biojet fuel based on the HEFA pathway at industrial scale.

During the implementation the project faced some issues related with the feedstock yield and the refinery capacity that prevented a conventional connection of all the steps of the value chain as planned. However, the value chain was demonstrated by testing the use of the biojet fuel in existing logistic systems and in normal flight operations in the EU. ITAKA linked supply and demand by establishing a relationship under specific conditions between feedstock grower, biofuel producer, distributor, airports and final user (airlines), encompassing the entire supply chain.

The generated knowledge is aimed to identify and address barriers to innovation and commercial deployment.

The following sections provide further details regarding the scientific and technical foreground of the project for each of the sections mentioned above. This foreground includes the identification of barriers which need to be solved in the future to foster large scale biojet fuel production in Europe.

FEEDSTOCK

The ITAKA project has allowed implementing four large scale camelina campaigns (more than 15,000 hectares sown in total) from autumn 2012 to summer 2016, in semi-arid dryland regions in Spain as well as, two campaigns in a lower scale (200 ha), in Romania. These four harvests have been processed in existing agricultural infrastructure in Spain for the production of camelina oil.

The different large scale camelina campaigns have allowed drawing many conclusions and lessons learnt for the development of a sustainable camelina value chain in Spain and Europe. The following issues have been identified, mostly related to the agricultural expansion of the crop, but also to the industrial process for the oil production:

Technical issues

- Commercial herbicide approval for camelina plantations has been identified as one of the major barriers for camelina crop expansion from a technical point of view. Based on the ITAKA project results, Spain has initiated the approved different commercial herbicides, both for broad and narrow leaf weeds.

Industrial issues

Camelina production
- > 15000 hectares
- > 1719 R&D plots
- 20 tested camelina varieties
- 536 farmers , 16 regions, 38 provinces

- The excess of impurities in camelina harvest hampers the cleaning process, making it more time consuming and less efficient. It is highly recommended to keep such harvest impurities as low as possible, through an adequate weed control as well as proper combine regulation.

Crop introduction issues

- Camelina is a crop with high hardiness and adaptability produced with low agricultural inputs. However, as land quality is generally very poor in arid dryland regions, adequate fertilization becomes a key issue for the success of camelina plantations.
- Farmers in arid dryland regions in Spain are not always used to perform background fertilization due to climatic variability, minimizing this way the risk in case of drought. This habit becomes apparent when farmers cultivate a new crop, unknown to them.
- Farmers in arid dryland regions and are not used to cultivating new crops, especially oil crops. During the introduction of camelina in a new region, it is necessary to select professional farmers that understand the specificities related to camelina cultivation and are willing to follow recommendations regarding minimum land quality and fertilization protocols.

Large scale camelina plantations

Camelina is an oilseed crop that can be sustainably grown by farmers replacing fallow land in Europe. The crop shows better performance in semi-arid regions than other major oilseed crops grown in Europe (such as rapeseed and sunflower, that in those areas cannot substitute the fallow period), mainly due to its drought and frost tolerance.

Camelina production

- ~4500 t high protein feed
- ~1500 t husks (feed fiber)
- Camelina yield: 500-2,500 kg/ha
- Camelina proxy: ~50% barley yield

The ITAKA project has deployed large scale camelina plantations during 4 consecutive agronomic campaigns (2012-2016). During such period, there have been various weather conditions: winter and spring droughts as well as unusual rainy harvest conditions.

Camelina plantations have been cultivated in a wide range of climatic and soil conditions. Camelina yield has varied from 500 to 2,500 kg per hectare, depending on the cultivation and weather conditions.

Given such wide variation, the ITAKA project has closely monitored different camelina plantations, collecting both camelina data and barley data from the same farmer, in order to define a suitable correlation between both crops. Barley has been chosen as it is the crop most commonly cultivated in Spain in the areas where camelina has been introduced. Barley yields in these areas have varied from 800 kg/ha to almost 5,000 kg/ha, evidencing the difference in cultivation conditions between the areas and farmers.

As camelina is a hardy crop, this correlation increases for low yielding areas (below 2,000 kg/ha), where the expected camelina yield can increase up to 70% compared to barley yield.

The overall result is that a farmer, with barley yields from 2,000 to 4,000 kg/ha on average, following ITAKA's optimized camelina agronomic protocol can expect a camelina yield of approximately 50% that of barley yield in his farming plots. This means that a farmer harvesting 3,000 kg/ha of barley in a given year should expect a camelina harvest of 1,500 kg/ha.

Camelina oil value chain

The industrial process followed from the camelina harvest up to the crushing facility includes a cleaning process to separate camelina husks from camelina grain. The clean camelina is transported to the crushing facility for oil extraction, producing camelina meal or expeller, depending on the oil extraction technology.

Camelina production

- Camelina oil content: ~42% of grain
- Camelina husks: ~20% of total harvest
- Camelina meal: ~65% of grain

Camelina harvest has been processed mainly in cereal elevators (for the cleaning step) and oilseed, mainly sunflower, crushing facilities, leveraging on e xisting agricultural infrastructure.

The analysis performed to the camelina oil quality indicates that the main parameter to be taken into consideration in order to comply with biojet fuel specifications is basically phosphorus content. However, based on ITAKA results, it is generally not justified to pre-treat the crude camelina oil prior to the delivery to the HEFA biojet fuel production refinery.

ITAKA's camelina oil content has varied considerably depending on the climatic conditions during spring time (coinciding with the plant's grain production). Average camelina oil content in the harvest has varied from 40% to 44%.

Additionally, camelina oil production value chain in Spain has enabled producing other valuable by-products (camelina husks and camelina meal), employed as high quality animal feed.

Camelina meal or expeller is produced at the crushing facility, as a solid by-product of the oil extraction process. Camelina meal, containing up to 40% protein, is the vegetable raw material produced in Spain with highest protein content.
It is a raw material of great interest from a nutritional point of view, since there is no plant feedstock produced nationally in Spain with higher protein levels. Camelina meal or expeller produced during the ITAKA project has been commercialized targeting the animal feed industry. Indeed, camelina meal customers are interested in reducing their dependence on imports of soybean and rapeseed meal as feedstocks with high protein content. Camelina meal produced during the crushing step is roughly double the amount of camelina oil.

Camelina husks main destination is the animal feed industry too, due to its high fiber content. Camelina husks, containing high fiber content (~35%), have been employed as raw material in ruminants animal feed. A camelina farmer generates approximately an amount of camelina husks equal to 20%-25% of its total harvest (considering camelina grains and husks). However the overall level should be kept below 20% in order to allow optimizing processing costs. Depending on the cleaning efficiency the fat and protein levels can increase due to its camelina grain content.

The main alternatives for the management of the camelina straw consist of packing or chopping the straw after harvest. Camelina straw has higher levels of fiber and lignin than traditional cereal straw, so it is not particularly attractive for use in animal feed. However, these properties, in addition to the fact that the ash level is about half of the cereal straw, makes camelina straw a feedstock of great interest for energy applications, especially in boilers.

Camelina value chain optimization

Camelina Company España's (CCE) experience during the four large scale camelina plantations within the ITAKA project shows that the harvest's level of impurities is a critical factor for the efficiency of the industrial post-harvest process. In order to guarantee that the harvest logistics are optimized, it is necessary to have harvest impurities below 20%.

The harvest cleaning efficiency is, as the harvest transport, very much influenced by the amount of impurities that are introduced in the cleaning process. CCE technical staff has managed to reduce the level of impurities in farmer's camelina harvest, mainly through the adequate use of herbicides as well as increased monitoring and technical support to farmers at harvest stage. This way the impurity levels has decreased below 20%, allowing the cleaning process to reach the required efficiency (>98%).

Camelina meal valorization

Camelina meal quality analysis during the ITAKA project indicates that fiber, ash, starch and sugars content in the extraction by-product have not significantly varied along the different crush runs. Protein and fat levels, when measured as PROFAT (addition of protein and fat content in the meal or expeller), have been stable around 42%. Although camelina meal or expeller has more than 15% PROFAT content than rapeseed meal, there are several other factors that affect the sale of such by-product to the animal feed industry:

- Camelina meal and expeller are new raw materials that the animal feed industry is not used to employ from a nutritional standpoint.
- The amount of product available is limited and most nutritionists are willing to include a new raw material only if there is a guaranteed continuity in its supply.
- The storage and dosage space available for nutritionists in the animal feed factories are limited – and a very valuable asset which not all companies are willing to use in a new raw material.

It is expected that once the crop is fully established and there are large amounts of guaranteed product available on the market throughout the whole year, animal feed producers will be willing to pay for its nutritional value, which should be at least 10% rapeseed meal price.

Camelina husk valorization

Camelina husk commercialization has been performed basically on the basis of its fiber content for the animal feed industry. Such price is however very dependent on the market prices and, most importantly, the availability of other source of fiber.

New added value products

Camelina oil meal and husks are currently marketed due to their high nutrient content (protein, fiber, vitamins). However, these products also contain different groups of bioactive compounds with great interest in the nutraceutical and functional food industry.

Camelina Company España has successfully developed a process at lab and demo scale in order to produce both a camelina husk extract as well as camelina meal extract rich in camelina antioxidants.

FEEDSTOCK OPTIMIZATION RESEARCH

Camelina Company España (CCE) and Biotehgen have developed several camelina trials in Spain and Romania during 2012-2016, focusing on two main sustainability aspects of camelina plantations. On the one hand agronomic trials have been implemented in order to improve the social sustainability of the crop, focusing on agronomic protocol optimization trials as well as cultivation in alternative land: degraded and contaminated land. In addition, trials have been established in order to improve the environmental sustainability of camelina plantations, focusing on fertilization, biofertilization and sludge trials as well as no-tilling and minimal tilling trials.

Social sustainability results

The establishment of an agricultural protocol to obtain an optimal development of the crop has been one of the most important targets of the ITAKA project regarding feedstock development. Different camelina trials have been carried out in order to optimize the agronomic protocol. These tests include:

- Seeding date
- Seeding density
- Effect of the distance between rows on the camelina development
- Use of roller harrow
- Use of herbicides on camelina plantations
- Effect of residual herbicides on the camelina development
- Shattering
- Crop rotation
- Fauna attack

In semi-arid climates, camelina autumn seeding favors the adequate development of the plantation. This planting date allows the crop to germinate promptly and reach winter in a rosette stage; above all, camelina plantations can this way profit from autumn and winter rainfall, allowing the crop to thrive under such harsh climates. This planting date also enables farmers to have enough time to clean their lands of weeds and minimize the need of herbicide application, increasing this way their economic benefit and improving the environmental footprint of the crop.

Once the strategy to limit weed competition is set, determining the adequate seeding density is necessary to avoid competition within camelina plants. Depending on several external factors (machinery, type of land etc.), sowing density may vary. CCE has initially determined as optimum seeding density a range of 7-8 kg/ha. However, and in the same way it has occurred with other oilseed crops such as rapeseed, it is expected that such seeding density decreases over time, as the crop is further developed. Additionally, trials focused on the optimum distance between sowing rows have been conducted. The results show that a smaller distance between rows (12.5-17.5 cm) enables greater productivity, mainly due to the fact that such plantation frames enables minimizing competition with weeds.

CCE has not found benefits in the use of roller harrow just after sowing, as it does not favor the crop's germination. However, this activity is usually extended in ITAKA's growing regions and its advantages in connection to harvest are recognized. The trials performed indicate that the use of roller harrow is useful before seeding (facilitating the seed depth regulation during sowing) or after germination (in cotyledons or rosette).

On the other hand, CCE has performed camelina herbicide trials in order to select commercial products for weed control in camelina plantations. The trials have been performed with several commercially available herbicides, applied both in pre and post emergence. Initial results show that there are commercial herbicides that control weeds effectively, including dicotyledonous and monocotyledonous weeds.

Additionally, CCE has performed a trial in order to evaluate the effect of Chlorsulfuron, Diflufenican, Pendimethalin and Triasulfuron as residual herbicides in camelina plantations in semi-arid areas. Results show that there are negative effects on camelina plantations if a minimum recommended residual period is not respected, or if some farming conditions are met (meteorology, tilling,…).

Shattering trials have been developed in order to determine the dehiscence of two camelina varieties. Both varieties have shown tendency to shatter (around 25% of the pods) in a period of two-three weeks after reaching maturity, which indicates the time frame the farmer has to harvest without suffering high production losses.

CCE has determined the advantages of introducing camelina as a crop rotation alternative in regions with fallow land periods and barley production. The overall objective is to minimize fallow land periods while increasing the economic benefit of farmers and the overall sustainability of their farms. The results indicate that the Barley/Camelina/Barley rotation has shown better yield and economic performance than the other crop rotation alternatives analysed.

CCE has studied the damage produced by local fauna in camelina plantations. Indeed, this kind of damage is an extended problem in some regions in Spain and it affects mainly sunflower and cereal crops. Results have shown that camelina is not an attractive crop for cervids and rodents in case there are other surrounding plantations.

Finally, CCE has carried out trials on degraded land in Spain and Biotehgen on contaminated land in Romania. Results show that camelina cultivation shows good potential in certain types of degraded soils as well as some contaminated soils for sustainable production.

Environmental sustainability results

One of the main objectives of the ITAKA project is to develop agronomic practices to ensure sustainable and respectful farming activities with the environment. Camelina plantations present better Green House Gases (GHG) emission results than most traditional oilseed crops, due to its lower use of fertilizers and fossil fuels for agronomic labors. CCE and Biotehgen have conducted trials focused on mineral fertilization as well as biofertilization and tillage trials in order to maximize the GHG emission reduction.

Mineral fertilization trials have shown that Nitrogen in background fertilization greatly favors the crop development. On the other hand, camelina crop has not shown an interesting response to Phosphorus fertilization on soils with concentrations of this nutrient higher than 15 ppm. Also, Nitrogen application in dressing fertilization has shown a very positive effect on crop yields.

Additionally, camelina trials with different biofertilization products have been conducted. The biofertilization study includes commercially available products, based on amino acids and oligopeptides, microorganisms, fertilizers with high water absorbing capacity, plant extracts as well as sludge, slurry and compost. The most outstanding results have been obtained through sludge fertilization.

Finally, minimal or no tilling trials performed present yield results similar to those of conventional tillage production, further corroborating the expected improvements linked to the reduction of GHG. Also, cultivated as second culture in Romania, with or without a starter irrigation, the yields reach 1,200 kg/ha.

Other developments performed in Romania

The ITAKA partner Biotehgen performed different experimental camelina trials in Romania, on alternative lands and under different technological schemes. Biotehgen also developed a breeding program for increased oil content and productivity.

This research clearly demonstrated the potential to cultivate camelina on heavy metal polluted lands (average of 1900 kg/ha of seeds) and sterile dump (average of 1,200 kg/ha) with moderate fertilization input (N60P60K30).

Romanian recommendation
• 8 kg/ha seeding rate
• Less than 1 cm seeding depth
• Fertilization (UF/ha): N 50-60 and P 30-40
Yield ranges 1,000-2,700 kg/ha

The technology for camelina cultivation in Romanian climate condition (continental temperature) has been optimized. Now there is a national recommendation on autumn and spring cultures, respectively.

Application of medium fertilization was found to increase the winter resistance. Depending on weather, irrigation, weed and mildew attack productivity ranges between 1,000 – 2,700 kg/ha.

Camelina varieties screening and development

Variety screening trials have identified that there are, among the pool of varieties tested within the ITAKA project (20 varieties), both long cycle and short cycle varieties. Long cycle varieties are most suited for autumn planting in arid dryland regions (late October-late November), while short cycle varieties allow farmers that have not the time to sow to perform a late sowing camelina plantation (December-January).

Results indicate that variety V13 has best performed independently from the sowing date and is hence recommended as the chosen variety for European dryland semi-arid sowing conditions. Additionally, variety V1 has been identified as a short cycle variety, especially recommended for farmers that, due to difficult sowing conditions, require a late sowing variety.

A new camelina variety line was developed by Biotehgen in Romania and after two years testing is under homologation process at the end of the project (October 2016). The new variety line is resistant to heavy winters, strong winds and mildew attack. It has registered an average of 9.5% increase in yields and 2.4-4% increase in oil content when cultivated under continental temperature conditions, with heavy winters.

Commercial scale plantations

Camelina is an oilseed crop that can be sustainably grown by farmers replacing fallow land in Europe. The crop shows better performance in semi-arid regions than other major oilseed crops grown in Europe (such as rapeseed and sunflower, that in those areas cannot substitute the fallow period), mainly due to its drought and frost tolerance.

The ITAKA project has deployed large scale camelina plantations during 4 consecutive agronomic campaigns (2012-2016). During such period, there have been various weather conditions: winter and spring droughts as well as unusual rainy harvest conditions.

Camelina plantations have been cultivated in a wide range of climatic and soil conditions. Camelina yield has varied from 500 to 2,500 kg per hectare, depending on the cultivation and weather conditions.

Given such wide variation, the ITAKA project has closely monitored different camelina plantations, collecting both camelina data and barley data from the same farmer, in order to define a suitable correlation between both crops. Barley has been chosen as it is the crop most commonly cultivated in Spain in the areas where camelina has been introduced. Barley yields in these areas have varied from 800 kg/

ha to almost 5,000 kg/ha, evidencing the difference in cultivation conditions between the areas and farmers.

The overall result is that a farmer, with barley yields from 2,000 to 4,000 kg/ha on average, following ITAKA's optimized camelina agronomic protocol can expect a camelina yield of approximately 50% that of barley yield in his farming plots. This means that a farmer harvesting 3,000 kg/ha of barley in a given year should expect a camelina harvest of 1,500 kg/ha.

As camelina is a hardy crop, this correlation increases for low yielding areas (below 2,000 kg/ha), where the expected camelina yield can increase up to 70% compared to barley yield.

ITAKA's camelina oil content has varied considerably depending on the climatic conditions during spring time (coinciding with the plant's grain production). Average camelina oil content in the harvest has varied from 40% to 44%.

> 2.1 million hectares of fallow land could be used to sustainably grow camelina to produce ~700,000 tons of biojet yearly (1% EU jet fuel consumption)
>
> Saving > 1.7 Mt of CO_{2eq}
>
> Creating up to 100,000 jobs

Additionally, camelina oil production value chain in Spain has enabled producing other valuable by-products (camelina husks and camelina meal), employed as high quality animal feed.

Camelina husks, containing high fiber content (~35%), have been employed as raw material in ruminants animal feed. A camelina farmer generates approximately an amount of camelina husks equal to 20%-25% of its total harvest (considering camelina grains and husks). However the overall level should be kept below 20% in order to allow optimizing processing costs.

Camelina meal, containing up to 40% protein, is the vegetable raw material produced in Spain with highest protein content. ITAKA camelina meal has been employed by large Spanish animal feed producers, reducing this way protein imports, mainly from soybeans. Camelina meal produced during the crushing step is roughly double the amount of camelina oil.

REFINING

For the completion of the project, ITAKA partner Neste was responsible for the conversion of oil to biojet fuel. Several modifications were required at Neste's renewable products production plant in Porvoo, Finland. This plant was designed to produce renewable diesel, therefore the modifications were necessary to improve the plant's capability to produce also biojet fuel. The improvement process included building a new recirculation line, which was implemented in the summer of 2013.

This modification targeted to improve the safety process. The changes also aimed at ensuring that the product quality would comply with the aviation fuel standard (Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons, ASTM D7566). The project execution started in June 2012 and mechanical completion was achieved by January 2013.

Furthermore, an additional purification process was carried out for the fuel. The target was to study the behaviour of jet fuel monitor filters before and after the purification step. This was required to ensure the product quality and to study the behaviour of jet fuel filters when filtering biojet.

After the production run, the used filters were analysed. The conclusion was that the inspected used elements turned out to be functional. This indicates that with Neste Renewable Jet Fuel, a filtration set-up used in this production run, will not be needed in future production runs. It should be noted that the above results represent only one filter type and one renewable jet fuel type. Therefore, any general recommendations to the industry cannot be provided based on this test.

Currently in Europe there is about 2 Mt/y installed refining capacity for HVO (that could be used, at least partially, to produce HFP-HEFA biojet if the process gets approved). This capacity is concentrated in Neste's plants in Finland and The Netherlands where 1.5 million tonnes of renewable biofuel, including an option for renewable jet fuel, can be produced. The European capacity is planned to be enlarged by 2018 in 1 Mt/y more.

PRODUCT ANALYSIS AND CERTIFICATION

Newly-introduced aviation fuels must have certain physical and chemical properties so that they can serve as drop-in fuels: they must have sufficient density, remain liquid at very cold temperatures, be compatible with the materials used within the current infrastructure, as well as within the aircraft (e.g. elastomer compatibility to provide o-ring seal swelling and to prevent engine/component wear), etc. In order for these synthetic fuels to be used in aircraft, their certification against certain fuel specifications is required.

ASTM D1655 outlines the specifications for petroleum-derived jet fuels (Jet A and Jet A1), such as those produced from crude oil, tar sands or shale oil. D1655 is not sufficient for the certification of synthetic fuels produced from non-conventional sources, primarily because it does not define a minimum aromatic content (conventional jet fuels already have aromaticity), and it does not test the fuel for lubricity or for detailed distillation properties. h ence, in 2009 a set of new practices and specifications were defined for synthetic fuels from coal, natural gas and biomass under the standards of D4054 and D7566. D7566 specifies performance properties and compositional requirements for individual alternative jet fuel synthetic blending components. D4054, on the other hand, provides a guideline for the evaluation of new aviation fuels specifying detailed requirements for their testing.

In ITAKA, four analytical methods required for ASTM D7566 based on standard methods were successfully developed and implemented at Neste during 2013-2015. The aim of the methods was to analyse trace metals and halogens, fatty acid methyl esters (FAME) and hydrocarbon distribution in renewable fuels. The standard methods are ASTM D7111, ASTM D7359, Ip585 and ASTM D 2425.

Neste Renewable jet fuel was successfully produced during the year of 2015 within the ITAKA project. The fuel was certified at Neste laboratories and its blend with fossil Jet A1 at Saybolt laboratories, Denmark. The ASTM D7566 fuel standard specification was met by the final product.

SUSTAINABILITY CERTIFICATION OF THE ITAKA BIOJET BATCHES

While the ASTM D7566 standard refers to the quality of the fuel blend, a recognized sustainability certification has typically also been accomplished. The Life Cycle Analysis (LCA) of the pathway needs to be carried out according to an 'internationally' accepted methodology. ITAKA has followed the sustainability standards recognized by the Eu Directive on Renewable Energies (RED), mostly the RSb Eu RED, but also the ISCC and other sustainability checks from the parties.

Neste Renewable Jet fuel was also registered in German Emission Trading System (ETS) Nabisy[7]. proof of Sustainability was issued stating that the fuel is product is 100% derived from biomass and Eu RED certified.

7 https://nabisy.ble.de/nabima-web/app/locale;jsessionid=1b131AC0C813Cb498D4E7D6463244A3A?set=en

LOGISTICS

Within ITAKA, different supply chains of biojet fuel were developed. Segregated supply chains were put in place for biojet fuel supply for flight testing programs by Airbus and Embraer on KLM flights from Schiphol and Oslo airports. ITAKA also demonstrated for the first time ever for commercial aviation that biojet fuel supply through an airport's existing infrastructure system is possible, with the supply of biojet fuel via Oslo's tank farm and hydrant system.

Setting up the supply chains within ITAKA provided interesting results and useful insights, not only on the logistics, but also on the certification processes of the bio-component of the biojet fuel (HEFA jet) and the biojet fuel blend.

A segregated biojet fuel supply chain was put in place for deliveries for Airbus flight testing program at Schiphol with KLM. This supply chain included 400 t of 47% blend UCO based biojet fuel delivered for 18 flights. The supply was executed via dedicated transport and transfer into dedicated refueler truck at the airport.

Likewise, a segregated biojet fuel supply chain was put in place for deliveries for Embraer flight testing program at Oslo with KLM Cityhopper (Embraer E190). This supply chain included 213 t of 47% blend camelina based biojet fuel delivered for 80 flights. The supply was also executed as for Airbus, via dedicated transport and transfer into dedicated refueler truck at the airport.

An additional supply chain was established in ITAKA. For the first time ever, a non-segregated supply of biojet fuel via an airport's common fuel system was implemented at Oslo Gardermoen Airport. The supply chain and fuel supply was set up in accordance with JIG/EI 1530 requirements. The camelina based biojet fuel was delivered and supplied via the airport's commingled storage and hydrant system.

ITAKA allowed the partners to acquire new knowledge and lessons learnt which regarding logistics may be summarized as follows: SkyNRG, as responsible for the logistics of the value chain provided some insight regarding the barriers and ways to improve ASTM D7566 HEFA certification, as indicated below.

Biojet fuel neat and blend certification processes

- End–of-life catalyst used in HEFA production can produce aromatics that can end up in HEFA Jet Fuel, which can result in off-spec HEFA jet.
- Strict aromatic content limits in D7566 specification complicate the certification process and seem to conflict with aromatics being indispensable for final jet fuel blend. A request to ASTM to change the specifications was submitted.
- The prescribed method for aromatic content measurement (D2425) is very uncommon and limitedly available, causing long analysis times, resulting in additional costs, for instance for storage of the product.
- Removal of aromatics in relatively small batches without affecting other parameters (such as trace metal content) is very difficult; hydrogenation was found as the only suitable option.
- Sourcing fossil jet fuel with the required aromatic content needed to create a blend that meets the specifications (min. 8% of aromatics) can be challenging because high aromatic fossil jet fuel seems to be scarce.
- The ASTM D7566 Table 1 minimum of 8% aromatics complicates the supply chain; it can cause delays in blending processes and can imply additional costs when the fossil jet cannot be sourced locally. Review of this requirement should be considered.

Biojet fuel Segregated Logistics

Supplying biojet fuel via a segregated system is necessary to carry out biojet fuel flight testing programs, to ensure the biojet fuel molecules are fuelled on designated aircrafts

The **implementation of sustainability standards** can increase 7-9% the cost the camelina oil, **increasing the cost of the biojet over 12%**

The flight program (100 flights, 376 hours) with high blends (>20%), the APU and lab tests (50% blend) confirm that no negative impacts from bio-jet were found, but positive effects like better energy efficiency or less maintenance needs.

A segregated supply chain entails that the entire logistic chain is completely segregated from the fossil jet supply to an airport and aircraft: biojet fuel is transported separately, and transferred at the airport into a dedicated refueler truck (while conventional jet fuel mostly is distributed via pipeline system to and at the airport).

Segregated biojet fuel supply chains work, but they add significantly to the costs of biojet fuel and are less efficient than the existing supply chains for conventional jet fuel.

To move biojet fuel to a commercial-scale product, avoiding segregated downstream supply chains is a key element of reducing cost and increasing efficiency without compromising safety or performance.

Biojet fuel non-segregated Logistics

- Since 2012, both JIG and EI 1530, hence also the AFQRJOS[8], follow ASTM and DefStan regarding allowance of synthetic components to be blended with Jet A-1 for up to 50%. In other words, JIG allows biojet fuel to be used in existing jet fuel infrastructure leading to and at airports.
- The supply of biojet fuel to Oslo airport via its common fuel system demonstrated that supplying biojet fuel via existing jointly operated jet fuel systems appeared very feasible from both operational and organizational perspective.
- The biojet fuel supply to Oslo airport was still segregated using road tankers. When scaling up, efficiency improvements may be achieved by supplying the biojet fuel further upstream, via existing jet fuel infrastructures that are used for supplying fossil jet towards airports, e.g. the various pipeline systems that are in place. Most (international) airports are supplied with jet fuel by pipelines. These pipelines can be multi-product pipelines (e.g. for jet and diesel use) and, can be part of a network supplying multiple locations, including military airports. For example, the Central European Pipeline System (CEPS), owned by the NATO, is an international pipeline system supplying both civil and military airports in Central and Western Europe.

8 JIG: Joint Inspection Group defines international standards for aviation fuel handling. The most relevant for the ITAKA project is the AFQRJOS: Aviation Fuel Quality Requirements for Jointly Operated Systems.

AVIATION

Within the ITAKA project, Airbus and Embraer acted as the interface with Koninklijke Luchtvaart Maatschappij N.V. (KLM) and KLM Cityhopper (KLC) respectively, which were the airlines using the biojet fuel in regular revenue flights campaigns. A long-haul campaign was launched with Airbus aircraft and a short-haul one with Embraer fleet.

AIRBUS CAMPAIGN

In order to use an Airbus A330-200 aircraft for the test flights, in conjunction with KLM, the long-haul route was agreed, departing from Schiphol Airport (The Netherlands) to Aruba and Bonaire islands (Dutch Caribbean) for about 10 hours-duration flights. To obtain comparable test data, it was desirable to use the same aircraft for each flight. Hence, for that reason, KLM proposed the use of PH-AON, an Airbus A330-200 (MSN0925 version KLM04 Standard ST7) with CF6-80E1A3 engines. This aircraft entered service with KLM in April 2013. Since the schedule of the PH-AON registration was not clear until very shortly before this aircraft would actually fly from Schiphol Airport to Aruba/Bonaire, it required strict planning between SkyNRG (responsible for the delivery process to Schiphol) and KLM. It also implied that always enough biojet fuel was to be stored at Schiphol Airport to facilitate the variable and unknown schedule. The KLM team together with SkyNRG organized the frequency of flights according to their team capacities and aircraft allocation. Airbus agreed with this schedule, compliant with its task of data collection and analysis.

Final use of biojet

- > 1800 t CO_{2eq} saved
- Potentially > 70% GHG reduction
- > 6 million passengers
- ~ 60,000 flights on <3% blends
- 376 flight hours on blends over 20%
- 50% less PMs per ton of biojet fuel
- 1% better energy efficiency

A total of 18 flights took place from May 2014 to January 2015 and used an average of 23% of UCO-based biojet fuel (a HEFA fuel from Used Cooking Oil) supplied via SkyNRG. One wing (and consequently its engine) was fuelled with conventional fossil Jet A-1 and the other with the 47% UCO-based biojet fuel blend. In order to assess the performance of these commercial flights, KLM made available to Airbus the ACMS (Aircraft Condition Monitoring System) data download and fuel uplift quantities. ACMS data was recorded asynchronously and stored on the aircraft.

EMBRAER CAMPAIGN

The Embraer E190 flight campaign was defined in a three-phased period, operated by KLM Cityhopper. The first and third phases used only Jet A-1 fuel, while the second phase, used only biojet fuel (a HEFA fuel from Camelina sativa oil). There were 177 total short-haul flights performed from March to June 2016 (of which 80 flights on biojet fuel). All flights were strictly performed from Oslo Airport to Amsterdam Airport, being regular revenue flights. 29 Embraer E190 participated in this campaign, as the decision was to use the whole E190 fleet available to avoid any operational constraints for the airline.

Behind this flight campaign, a long and detailed work was done allowing KLM Cityhopper flights a correct aircraft refuelling, at the right time (respecting the turnaround time for each slot), collecting and recording all necessary data about the process. This allowed all partners involved, mainly Embraer, to make their assessments. The starting point for this successful campaign happened when ITAKA and Oslo Airport wrote a special operational procedure. This procedure included all technical requirements in order to guarantee the quality of the biojet fuel and its correct refuelling. Tasks from the biojet fuel truck tank operation to aircraft crew were defined and strictly followed.

The final biojet fuel blend, after aircraft refuelled, was 25% camelina based biojet (HEFA). This is the result of the fuel remaining in tanks from the previous flight (safety reserves) and the uplifted blend. Engine and E190 aircraft data collected during flight campaign was analysed by Embraer engineering. The EGT (Exhaust Gas Temperature), N2 (Core Speed) and FF (Fuel Flow) engine parameters were used to do the Engine Performance assessment as well as Fuel Volume and Density, to do the Fuel Gauging System accuracy assessment. The final assessment results showed no impact for Engine Performance degradation and Fuel Gauging System accuracy, when operating with the drop in biojet fuel produced to ITAKA Project.

The procedure of the ITAKA's flight campaign can be replicated for any new biojet fuel technologies and/or feedstock up-scaled in Europe or any other country. As well, the procedures performed by Embraer for the aircraft assessment, with no operational impact for the airline flight operations and mainly, no impact for the airline passengers.

FLIGHT CAMPAINGS RESULTS

The main results of the flight campaigns were the following:

- Feasible flight plans definition and performance evaluation:
  - 18 long-haul 10 hours flights fuelled with a 47% UCO-based biojet fuel blend in one wing (left), coming down to an approximately an overall of 23% UCO based biojet fuel per flight on average. 10 of the 18 flights were performed on one engine of the same aircraft. A total of 408 tonnes of biojet fuel blend was used.
  - 177 short-haul flights, with approximately 1h 45min block time, of which 80 were fuelled (both fuel tanks) with a 47% camelina based biojet fuel blend, coming down to approximately 25% camelina based jet fuel per flight. 29 aircrafts were used and a total amount of 213 tonnes of biojet fuel blend was fuelled on these flights.
- Logistics coordination for aircraft allocation and fuelling:
  - For the long-haul flights, one engine (left) was fuelled with the 47% UCO biojet blend to ensure the comparability of the performance against the other conventional Jet A-1 fuelled engine. The fuelling was done with a dedicated airport truck, which was filled from ISO containers containing the biojet fuel.
  - For the short-haul flights, the refuelling with the 47% biojet fuel blend at Oslo Airport was done by a dedicated airport fuel truck tank which was filled from a road truck. The E190 aircraft normally arrived at Oslo Airport with a remaining quantity of conventional fuel (Jet A-1) on both fuel tanks, resulting in a final biojet fuel blend in the aircraft of approximately 25%, on both aircraft fuel tanks.
- Engine performance data gathered, analysed and reported for both flight campaigns showed the following:
  - No fuel type effect was observed in the parameters that could impact directly on engine's lifetime or deterioration.
  - No detrimental effects. Similar or slightly better fuel consumption using the HEFA blend..
- Fuel gauging system performance and accuracy data were gathered, analysed and reported for both campaigns, showing that the gauging system responds acceptably to the biofuel blend and that the accuracy is within the aircraft certified limits.
- Airbus modelled the route from Amsterdam to Aruba to assess the water drain and validated it against KLM long-haul flights, showing that the conventional fuel absorbs 10 cm3 more water per flight than the biojet blend. This adds up to a significant amount between draining services, reducing the maintenance costs when using biojet blends.
- APU performance and emissions trends were assessed by MMU in a test rig, confirming the reduction of fuel flow, SAE smoke number, mass and size of non-volatile particles and CO_2 emission index, for increasing HEFA content.

EVALUATION, SUSTAINABILITY AND IMPROVEMENT

Using the specific methodology of the RSB EU-RED scheme, a greenhouse gas emission reduction calculation on the full value chain of ITAKA has shown that a significant improvement in GHG emissions can be reached.

The ITAKA pathway is currently at more than 50% GHG emission reduction compared to the fossil fuel reference (RSB EU RED), but a lot of improvement is possible especially regarding the crushing facility step. A completely mature process would bring the reduction over 60% (around 66%) so complying with the current policy targets. The November 2016 proposal for a new EU RED policy states a target for advanced biofuels over 70% reduction. The ITAKA project has assessed that considering only improvements during the camelina oil production value chain (none during the biojet phase) the savings could be of 73,4 %.

Just considering the state of the art at the end of the ITAKA project but with a restriction on dressing fertilizer (from nitrate NO_3 to ammonium sulphate (NH4) would allow to achieve 70% savings. A second scenario, which takes also into account potential short term improvements during the camelina cultivation and oil production phase (improving the camelina variety and the oil extraction process) could easily reach the 73,4 % savings.

SUSTAINABILITY CERTIFICATION

The ITAKA camelina oil value chain (from planting seed to camelina oil production) established by Camelina Company España has been the first camelina oil value chain worldwide to achieve Roundtable on Sustainable Biomaterials (RSB) certification.

On top of that ITAKA partner EPFL conducted a GHG LCA using the RSB certification process of the fuel delivered to the airlines. Also Airbus Group Innovations France performed a LCA using two LCIAs (Life Cycle Impact Assessment) to assess other environmental and ecosystem impacts. More description of the sustainability results will be indicated in the corresponding section below.

The ITAKA proposed camelina growing scheme provides a major advantage for further crop expansion: it does not compete with any other crop as it just replaces fallow land periods, thanks to the benefits offered by crops rotation. However, it has also been found that such equilibrium needs to be monitored to avoid unsustainable expansion.

Based on CCE's experience, the certification cost for such agricultural rotation schemes can impact between 7% and 9% depending on the feedstock sale price. Although it is expected that some costs can be optimized when scaling up production, feedstock price can increase by, at least 5% due to direct certification costs. Considering the refining yields, the effect in the biojet cost could be over the 12%, what could overshadow incentives like those from the RED. This on top of current standards do not discriminate advanced or no-ILUC feedstocks for the regulatory recognition. It is important to stand out that such impact does not include the initial cost of implementing the certification scheme. As consequence, it is very important to establish a market that is willing to pay a premium for certified sustainable aviation feedstock. Other bioproducts in Europe are currently not requested to have such demanding and costly sustainability schemes and certifications, which can be a clear barrier for the biofuel industry to access sufficient volumes of sustainable feedstock.

PROPOSED MEASURES FOR RISK REDUCTION

The current EU RED RSB GHG calculator does not take into account the amount of rainfall during the crop cycle. However, this is a critical parameter in the cultivation process, as it directly impacts the camelina yield level.

Indeed, the two most important factors influencing the GHG emissions during the cultivation step are camelina yield as well as nitrogen fertilization. Nitrogen fertilization also greatly affects camelina yield.

Oilseed crop cultivation in semi-arid regions usually suffer spring droughts. Under these circumstances, farmers obtain very low yields during harvest due to the lack of rainfall in springtime, although will have applied nitrogen dressing fertilization during February. The resulting GHG emissions are high, as the combination of low yields with average nitrogen fertilization penalizes the GHG performance of the crop.

However, the GHG calculator should take into account that for semi-arid regions (i.e. rainfall of 100 mm during the whole crop cycle when a spring drought occurs) the nitrogen fertilizer is not fully leached nor volatilized to the atmosphere.

Fertilizer GHG emissions assigned to such camelina harvest should be taken into account, allowing to compensate for the yield drop in the GHG calculator.

As mitigation measures, two different steps might be considered:

1. Further study the amount of nitrogen available for the next crop as well as the GHG emissions related to such drought conditions.
2. At least for semi-arid regions, consider the complete rotation cycle, including for example the barley+camelina cycle.

PROPOSAL TO REDUCE CERTIFICATION BURDEN

It is a key issue to reduce the certification requirements for certain Principles for European countries, in order to reduce the certification burden on operators.

Indeed, there are Principles within the certification scheme which compliance and monitoring rely more on national governmental institutions than private companies seeking certification. These Principles, mainly "Human & Labour Rights" and "Land Rights" are very time consuming and do not provide a clear certification benefit in European countries. Indeed, it is not easy to provide evidence that there is no child labour in Spain.

The proposal to reduce the certification burden is that a certification body designated by the Certifying scheme performs an assessment at country level, so that operators within such country do not have to provide documentation and evidence for certain Principles and Criteria.

This is already performed for some other Principles in Europe, such as "Local Food Security". The proposal is to include other Principles in such approach, in order to streamline the certification process, reducing its need of evidences and documentation to the minimum, in order to reduce costs.

SUSTAINABLE CAMELINA EXPANSION POTENTIAL

The expansion potential of the crop has been determined based on three different criteria in order to guarantee that it is sustainable from an economic, social and environmental perspective:

- Social: Only fallow land has been considered for the expansion potential, in order to guarantee that no other crops were displaced.
- Environmental: The amount of fallow land that can be replaced by camelina plantations has been limited (based on the Aridity Index) in order to guarantee a minimum level of moisture in the soil.
- Economic: Fallow land in high yielding areas (defined as areas with average barley yield higher than 5 tons per hectare) has not been considered, taking into account that for such areas camelina crop income could be less profitable for farmers than other oilseed alternatives.

> The supply using the conventional logistics channels and the claiming of the use of the biojet in the ETS and the RED policy schemes will provide practical insights to improve policy implementation

> **Emissions tests**
> High paraffinic fuels like HEFA biojet could contribute to a significant (>30%) improvement of the local air quality at airports

A study to determine camelina expansion potential under these assumptions has been carried out by ITAKA partners.The main conclusions are that there are more than 7.5 million hectares of fallow land in Europe, out of which more than 2.5 million hectares are located in Spain. Considering only the amount of fallow land that would enable sustainably producing camelina, the European acreage is as high as 2.1 million hectares, while Spain accounts for a lmost 25%.

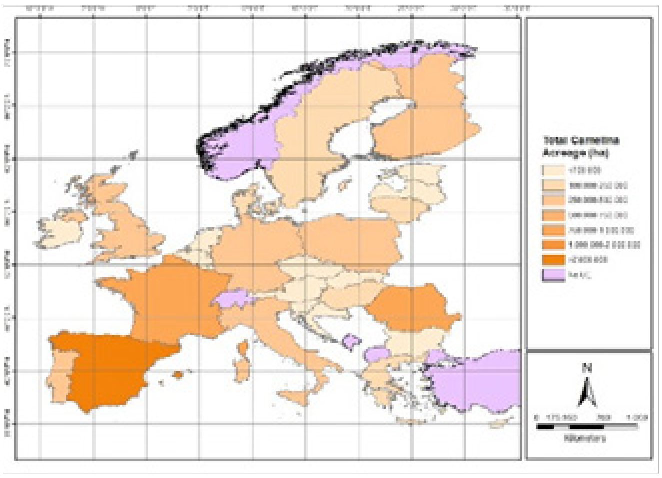
The analysis performed indicates that there is a high potential to produce sustainable camelina oil for the aviation biofuel industry in Europe. Indeed, there are more than 2.1 million hectares for sustainable camelina cultivation in Europe, which can contribute with more than 700,000 tons of camelina biojetfuel per year.

There is group of countries with high production potential, including Spain, France, Finland, Poland and Sweden. All these countries can sustainably produce more than 150,000 tons of camelina oil per year. In Spain, which has a more arid climate than most other European countries, the regions which have lower yield also present the larger acreage potential. Indeed, Spain alone presents a cultivation potential of 0.5 million hectares approximately.

SCALING UP

ITAKA partner and coordinator SENASA, was responsible for the execution of the ITAKA Scale-Up Model, which was first envisaged as a tool to identify the requirements and barriers that would encounter the camelina-based biojet fuel industry when trying to reach European wide commercial market. However, camelina is not the only feedstock that can be used, and the HEFA process is not the only process approved for its use in commercial flights. Furthermore, since the scaling up entails several years, there are more pathways expected to be approved in the near future and compete with HEFA. Therefore, an overall study of the biojet fuel industry in Europe was required, in order to estimate the possible scalability of the camelina-based biojet fuel industry.

FALLOW



SUSTAINABLE

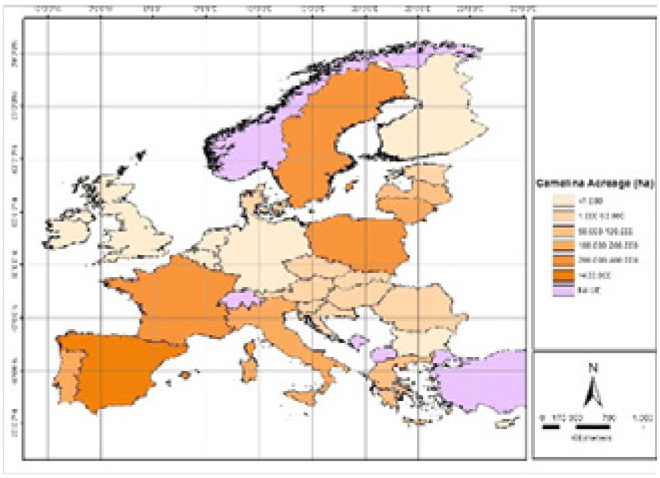


Figure. Fallow and sustainable land for camelina expansion in Europe.

The greater scope of the model allowed the researchers to study several aspects, which was not possible when assessing only camelina. Studying the overall value-chains allowed retrieving economic information of the different industries involved: feedstock production, alternative jet fuel production, logistics, and aviation. Furthermore, the socio-economic information at the different levels of the value-chain was calculated.

The results of the scale up model shows the impact of biojet European regulations on the stakeholders involved as well as on the airlines which are expected to buy the alternative jet fuel. This was achieved through the modelling and simulations of different regulations in 64 scenarios.

The conclusions obtained from the results show that in order to avoid a monopoly of whichever pathway becomes the most profitable in the near future, the EU should find the best way to foster the different pathways considering their potential in emissions' reductions, since while all of them would be validated according to a GHG LCA calculation, their potential in emissions savings may be quite different. Those pathways with greater potential in emissions savings should have priority to receive more funds from the EU to develop their pathway. However, other factors, such as cost efficiency, play an important role to maximise the emissions savings per euro spent.

The viability of this industry depends largely on exogenous factors, especially the price of fossil jet fuel; therefore, it is paramount to develop a long term framework for the development of the most economic and environmental efficient pathways.

OVERALL CONCLUSIONS

The need to fully explore the potential benefits of new fuel sources ensuring the sustainability and promoting the large scale use is one key target for all the final users, which have performed an analysis of the main results, achievements, barriers and opportunities encountered during ITAKA project.

The analysis of the data gathered during the two flight campaigns (the long-hauls flights performed with an A330-200 and the 80 short-haul flights performed with E190), using HEFA biojet blend in comparison to fossil Jet A1, showed that there is no fuel type effect observed on the engines' performance parameters, so there is no direct impact on the engines' lifetime or deterioration and, even more, there is a slightly better consumption identified using the HEFA blend compared to the Jet A1. Secondly, the fuel gauging system responds adequately to the biofuel blend and the accuracy is within the aircraft certified limits performance and accuracy. It was also calculated to accumulate less water between operations.

Tests performed on an Auxiliary Power Unit (APU) confirmed that the APU performance with the HEFA blend had lower fuel flow and emissions, lower SAE smoke number, mass and size of non-volatile particles (nvPM) and CO_2 emission index, for increasing HEFA content in the blend.

Besides the 80 KLM Cityhopper flights for the Embraer test series, the major part of the HEFA blend supplied at Oslo airport was supplied via the airport's common fuel system thanks to the collaborative work done by ITAKA (SkyNRG), AirBP, the airport's commingled aviation fuel storage provider (OLT) and the airport manager Avinor. This demonstrated for the first time ever that biojet fuel supply through an airport's existing infrastructure system is possible.

Although the biojet fuel supply to the airport fuel farm was still segregated using road tankers, receiving into existing jointly operated jet fuel systems appeared feasible from operational, organizational and administrative perspective.

There are some other positive factors to be taken into account linked to the aviation alternative fuels, such as the promotion of new activities in the area of the renewable energies, the emergence of new markets or services promoting innovation to face the environmental challenges, leading to a potential creation of socio-economic development at a regional, national or European scale.

However, an integrated strategy, framework and policy in Europe are still required to create the conditions of sustainable economic growth for the aviation alternative fuels (the price gap between sustainable and fossil jet fuel remains the biggest challenge to create a stable market).

THE POTENTIAL IMPACT

Singular projects such as ITAKA, in which the whole value chain is demonstrated, can provide significant impacts at multiple levels, given the broad spectrum of stakeholders involved, activities developed and outcomes achieved during the project development. Most relevant impacts, however, can be grouped in 3 main categories, namely environmental, socioeconomic, and politic impacts.

ENVIRONMENTAL IMPACT

With the ratification of the Paris Agreement on climate change (UNFCCC COP21), the signatory states will be required to publish binding action plans for decarbonisation, particularly, in the transport sector by 2020. At a global level, the decarbonisation of transport is one of the most effective ways for achieving the climate protection targets. Next to higher engine efficiencies and the simultaneous hybridization of engine technologies, biofuels will have to play an important role in terms of a bridging function.

The meeting concluded with the adoption of Paris Agreement and associated decision text, although it did not include any reference to international aviation. The fact that aviation was not covered under the Paris Agreement can be considered to be a vote of confidence in the progress that ICAO and its Member States have achieved so far. Indeed, as previously mentioned, an agreement was achieved on October 6th 2016, where most countries agreed to participate in the so-called Carbon Offset and Reduction Scheme for International Aviation, CORSIA.

The pact will be rolled out in two phases, first on a voluntary trial basis starting in five years, followed by full implementation and mandatory participation in 2027. The impact of such a global agreement is expected to be significant, being able to support green aviation practices and curb emissions related to aviation from 2020. The continuity of the activities performed in ITAKA will significantly contribute to offset and reduce the current carbon footprint of EU's aviation sector through the application of CORSIA scheme's accountability. The support of the European Commission would be crucial to develop the industry, as the CORSIA or the ETS, or even the RED incentives, by themselves, cannot balance the current price gap of the biojet.

ITAKA has demonstrated that the implementation and wide adoption of biojet fuel production would certainly have a relevant impact on the environment by contributing to air transport decarbonisation. This impact will be made possible through several axes, including contribution towards the CORSIA scheme (through carbon accountability), GHG reductions and promotion of low-iLUC practices.

The implementation of the full biojet fuel value chain has evidenced significant reductions in GHG emissions. The sustainability criteria stablished under the Renewable Energy Directive establishes that a biofuel's GHG emissions must be at least 35% lower than from the fossil fuel they replace. From 2017, this will increase to 50% and, the savings must be at least 60% for installations starting operation after 5th of October of 2015.

According to the work carried out by EPFL throughout the project's development, the camelina-based biojet pathway has achieved emissions reductions over 50% along the cultivation campaigns, applying the RSB EU-RED methodology. In addition, a further effort has been carried out extrapolating these results into the mid-term, where technology and involved processes will be more mature. As such, in a typical standard scenario, GHG reductions could reach 66%, exceeding the stringent targets set by the EU for the next coming years. This fact makes the camelina-to-biojet pathway to comply with future GHG reduction targets, thereby guaranteeing high sustainability standards for camelina cultivation.

At the same time, according to the LCA work performed by Airbus Group Innovation taking into account more environmental indicators, if camelina biojet brings an improvement regarding climate change and fossil fuels depletion, it does not for every impact categories taken into account into LCIA (ecosystems, biodiversity and soil) due to agricultural land and water use compared to fossil jet fuel. These results are also obtained for any biobased biofuels using agricultural lands when compared to fossil fuels.

ITAKA has shown other positive environmental impacts linked to camelina cultivation, which are related to the specific cultivation practices enabled by crop rotation and use of fallow land. According to the EU's CAP scheme, these agricultural practices result significantly beneficial for the climate and the environment and, as such, farmers applying them are favoured through the greening payments, a major innovation brought in under the 2013 CAP reform. This additional support mechanism has been established because market prices do not reflect the effort involved in providing these public goods. These practices contribute to the exploitation of land with low-iLUC crops such as camelina, and therefore, lower carbon footprint.

ITAKA has reviewed several feedstock-pathway combinations which are already certified in terms of fuel specifications, and which are expected to be sustainable from an environmental point of view; however, further research is needed to demonstrate such sustainability and economic feasibility. The use of Used Cooking Oil in the project has proven to be a valid option of feedstock, but limited by its quality and availability. ITAKA's scale up model (ISUM) has shown that the future of European alternative fuels for air transport will depend on several feedstocks and pathways.

SOCIOECONOMIC IMPACT

ISUM included socioeconomic impact analysis of introducing alternative fuels in Europe. The results show that 4% mandate of alternative fuels would represent from 35,000 to 50,000 direct jobs, primarily on feedstock production and logistics. Indirect employment would range from 60,000 to 100,000 jobs in related industries.

When assessing in detail the camelina-based value chain, ITAKA has evidenced the potential impact of camelina production on rural development (mainly in southern Europe semiarid regions) and, consequently, for the creation of direct and indirect employment. This is strongly linked to the main value proposition offered to the farmer for adopting camelina, which is based on the advantages of its cultivation on a rotation scheme in semi-arid regions. The reason for its competitive advantage resides in the typical low productivities registered in these areas, normally compromising the feasibility of almost any crop (including barley). Therefore, introducing energy crops such as camelina in a rotation scheme increases the yearly income and, consequently, the profit of a certain agronomic exploitation per hectare.

On the other hand, the mentioned camelina crop scheme represents an additional revenue to the farmer, without the need of replacing other crops and, therefore, adding a significant net income to the regions adopting it.
Feedstock production within ITAKA's value chain does have further socio-economic impacts with regards to the valorisation of camelina cultivation co-products. Camelina oil meal, the co-product of camelina oil extraction, is a protein-rich and often oil-rich feed with potential in livestock feeding. Camelina meal is an excellent source of Omega-3 in livestock and poultry feeds. The exploitation of such co-products will decrease the EU's dependency on soya bean import for the animal feed industry.

The dependency of the EU's livestock farming sector can also be illustrated by the amount of soya bean meal used per unit of meat produced: 232, 648 and 967 g/kg for beef, pork and poultry, respectively. The EU's low self-sufficiency in protein-rich feed materials led to an EU Parliament motion that called for putting more effort in breeding, research and development, and extension to increase the EU's own production of these materials. This low self-sufficiency exposes the EU to possible trade distortions, sustainability problems, scarcity and price volatility of soya bean on the global market. Thus, counting on an additional protein-rich crop with high potential in Europe will significantly reduce EU's dependency problem.

The adoption of alternative fuels for aviation will contribute to increase the demand for advanced biofuels in the international market. The amounts of biofuels required for the transition to sustainable transport will accelerate the production of sustainable biomass and the development of key infrastructures, but also the construction of bio-refineries and the development of new conversion technologies. As a result, the production of advanced biofuels will deliver not only significant environmental benefits through the reduction of GHG emissions, but also contribute to rural development and a better management of natural resources.

In addition, shifting to a greener aviation industry will strengthen energy security and independence in Europe, which net imports accounted for 53.5% in 2014. These societal transformations will definitely pave the way towards the bio-economy, which is expected to play an important role in creating a more sustainable future.

A good metric for socio economic impact assessment is the Gross Value Added (GVA). This is normally calculated as revenues minus cost of goods sold (CoGS), normally direct costs as grain, chemicals, water, materials, excluding labour. It is a frequent measure of the wealth created by an action across a sector or region.

Taking into account the assumptions used in previous calculations, and considering that direct costs account for an 80%, the following calculation can provide the GVA for every 100kt of camelina oil produced.

100kt of camelina-based biojet would require 184.6kt of camelina oil (at 0.65% yield efficiency); considering an average cost of the oil of 600 €/t, the total GVA would account for 88.6 M€ per every 100k tonnes of biojet fuel produced.

POLITICAL IMPACT

There are currently several political challenges for biojet fuels. A full implementation of value chains like the one deployed in ITAKA will make a meaningful contribution in the short term. These are listed below:

- Broader acceptance of opt-ins across European Member States. These measures will significantly contribute to the achievement of the Renewable Energy Directive.

Since December 2012, aviation in the Netherlands can opt-in towards this obligation. There is interest in some other Member States, although not all MS are currently on track to meet European targets. A broader acceptance of opt-in mechanisms across Europe would help to increase the number of biojet fuel suppliers and, therefore, will drive down the price gap and contribute to achieve the expected renewable energy targets.

- Indirect land-use change (ILUC) remains a challenge. ILUC has been largely discussed in the EU and USA since 2008, although no global agreement has yet been achieved. Various studies have shown a large variability in the size of potential ILUC of different crops and in different settings and results still remain uncertain. However, results of all economic models are above zero and, therefore, ILUC must be addressed. The main problem is that ILUC effect is not measurable, and can only be modelled.

The Renewable Energy Directive (RED), agreed to establish a cap on biofuels from "food crops" to 7% of final energy consumption in transport, and is expected to be reduced in the future due to ILUC effects. EU legislation on ILUC mitigation should consider including more ways to mitigate ILUC than just capping all first-generation biofuels. ILUC can be mitigated or even prevented when taking a sustainable approach to all crop production (whether for food, feed, fiber or fuel purposes).

For this, a sustainable approach to all crop production for food, feed, fiber and fuel purposes is essential. EU legislation on ILUC mitigation should then consider allowing **certified low-ILUC-risk biofuel production** to contribute to the renewable energy target out of that food crops cap. Implementing the sustainability approach offered by camelina cultivation within the ITAKA project is a key option to mitigate ILUC resulting from crop-based biofuel production.

Supportive carbon price through emissions trading (ICAO's CORSIA scheme). As recently agreed by the UN's aviation agency ICAO, the Carbon Offset and Reduction Scheme for International Aviation (CORSIA), aims to deliver carbon-neutral emissions growth for the international aviation industry from 2020. The scheme is designed to supplement an agreement made earlier this year by ICAO to deliver emissions standards for new aircrafts, and plans by the sector to further curb emissions via operational efficiencies and technological advances such as the increased use of biofuels. As a result, the implementation of biojet value chains such as the one represented by ITAKA will directly impact on the quantities to be accounted towards the CORSIA scheme.

- Need for a strong 2030 EU energy and climate framework. On 23 October 2014, the European Council agreed on a new 2030 Framework for climate and energy, including EU-wide targets and policy objectives for the period between 2020 and 2030. These included the binding targets at least 40% GHG reduction compared to 1990 and 27% RES in final energy. In addition, it included an indicative target of at least 27% energy efficiency improvement compared to baseline; this target is expected to be reviewed in 2020.

The implementation of ITAKA's value chain will also help to achieve these targets, since the potential calculated for camelina oil is sufficiently relevant so as to be a significant contributor towards the mentioned targets.

Participants of the ITAKA Final Workshop

COLLABORATORS

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