D2.1 – Feedstocks for Alternative Aviation Fuels

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Abstract

The present document corresponds to the deliverable D2.1 of the ALTERNATE project, Feedstocks for Alternative Aviation Fuels. It provides information on the selected feedstocks by the EU and the Chinese partners for further examination under ALTERNATE WP2 and WP3.

Keywords

Sustainable aviation fuels, biomass, biofuels, feedstocks

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Acronyms and Terminology

Term	Definition
ATJ	Alcohol-to-jet
CAEP	Committee on Aviation and Environmental Protection
CEF	CORSIA Eligible Fuel
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
FT	Fischer-Tropsch
GHG	Greenhouse Gas Emissions
HEFA	Hydroprocessed Esters and Fatty Acids
ICAO	International Civil Aviation Organization
LCA	Life Cycle Assessment
LUC	Land Use Change
SAF	Sustainable Aviation Fuels

1. Introduction

Recent estimates indicate that aviation accounts for approximately 3 % of total anthropogenic CO_2 (main greenhouse gas (GHG) produced by human activities) emissions.[1] A 2017 study predicted the sector would continue to grow at an annual rate of 3% by 2050, and most rescue policies for the aviation sector in COVID-19 pandemic time attempt to put the sector back on its initial trajectory.[2] Adding up other flight emissions, like different nitrogen oxides (NOx), particles and water vapor, the total effect reaches approximately 5% of total anthropogenic radiative forcing (RF).[3] While this contribution is relatively small compared with other industry sectors, such as energy production and ground transport, these industries have several low-carbon alternative energy sources currently available. In the case of aviation, while solar and electric aircrafts are being researched, they are still a long way from commercial versions due to aviation need for high power-to-weight ratio and globally compatible infrastructure, in particular for long-haul flights. Thus, the aviation sector will still be largely dependent on liquid hydrocarbons by 2050.

In order to decrease the environmental impact of international aviation a number of policies has been instituted by different organizations over the years.[4] In 2013, the International Civil Aviation Organization (ICAO) declared their decarbonization goal, requiring the aviation sector to offset carbon dioxide emissions in excess of the 2020 levels.[5] In order to achieve this, the Committee on Aviation Environmental Protection (CAEP) within ICAO has agreed on developing the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).[6] One of the measures to reduce the emissions from aviation under CORSIA is the deployment of drop-in, sustainable aviation fuels (SAF) from biomass feedstocks.[7] SAF is a blend of fossil-based kerosene with renewable jet fuel, and this mixture can be used without any modifications to the aircraft or to the infrastructure (hence the term “drop-in”). Fuel production pathways, along with blending ratios for these drop-in fuels, are certified by ASTM International that defines international standards for aviation fuels. As of June 2020, 8 drop-in fuel pathways had been authorized (Table 1).[8]

In an effort to specify the fuels with potential environmental benefits certain criteria was set under CORSIA. A CORSIA eligible fuel (CEF) was defined as, SAF that provides at least 10% greenhouse gas (GHG) emissions reduction compared to conventional aviation fuel. Another prerequisite is that the biomass used for a CEF should not be obtained from a land with high carbon stock, causing high emissions from land use change (LUC). For the selection of biomass feedstocks, and jet fuel production pathways with lower GHG emissions, CAEP has developed specific methodologies for the calculation of life cycle emission values (LSf) for SAF.[9] Currently there are 16 different feedstocks included for various pathways as shown in Table 1, and research is on-going for the addition of others.

2. General Outlook

With its commercial-size biofuel plants currently in operation, Europe is one of the main players in the global biofuel production sector. However, the region has limited land for cultivation, and it is not clear yet what share of the future aviation jet fuels will be provided by domestic feedstocks, or imported from other regions. In addition, the aviation sector has to compete for limited biofuel resources with road transport fuels such as biodiesel (i.e. fatty acid methyl esters) and bioethanol.[10]

Table 1.List of ASTM approved pathways with potential feedstocks.[8,11]

ASTM reference	Conversion pathway	Feedstock type	Feedstocks evaluated for CORSIA eligible fuels	Blend ratio by volume
D7566 Annex 1	*FT-SPK*: Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene	Coal, natural gas, biomass	Agricultural residues, Forestry residues, MSW, Poplar, Miscanthus, Switchgrass	50 %
D7566 Annex 2	*HEFA-SPK*: Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids	Fats, oils and greases	Tallow, UCO, PFAD, Corn oil, Soybean oil, Rapeseed oil, Palm oil	50 %
D7566 Annex 3	*SIP*: Synthesized iso-paraffins from hydroprocessed fermented sugars	Sugars	Sugarcane, Sugar beet	10 %
D7566 Annex 4	*FT-SKA*: Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources	Coal, natural gas, biomass		50 %
D7566 Annex 5	*ATJ-SPK*: Alcohol to jet synthetic paraffinic kerosene	Sugar/starch producing feedstocks and cellulosic biomass	Agricultural residues, Forestry residues, Sugarcane, Switchgrass, Miscanthus, Corn grain	50 %
D1655 Annex 1	Co-processing			5 %
D7566 Annex 6	*CHJ*: Catalytic hydrothermolysis jet	Fats, oils and greases		50 %
D7566 Annex 7	*HC-HEFA-SPK*: synthesized paraffinic kerosene from hydroprocessed hydrocarbons, esters and fatty acids	Bio-derived hydrocarbons and lipids		10 %

Finally, due to its higher prices, mostly driven by the biomass feedstock market value, SAF are currently not competitive with kerosene and investments in production capacities remained so far limited. Under these circumstances, establishing a new sustainable fuel supply chain requires setting up strong policies promoting the use of most promising sustainable feedstocks and efficient refining processes. As a result, the dependency of the aviation industry on fossil fuels may be reduced, along with the GHG emissions from aviation. China set a quantitative target for energy conservation and emission reduction. The total energy consumption of civil aviation will be reduced by 22% in 2020 compared with in 2005. From 2010 to 2015, the fuel consumption and carbon dioxide emissions has been achieved 4.2% reduction per ton.km, which will be further reduced more than 3% from 2015 to 2020. As many new energy sources, such as electric energy, solar energy, hydrogen energy cannot be used at large scale for commercial aviation in the near-term, in order to achieve this emission reduction target, bio-jet fuel has become the target alternative energy to the aviation industry in China.

Recent analyses[3,12] indicate that the availability of feedstock for the production of SAF at the European, and global scale will to a large extent depend on the policy incentives encouraging the use of these feedstocks for SAF production. For example, Staples et al.[3] find that in order for SAF to significantly reduce aviation's lifecycle emissions, policies will not only have to significantly incentivize the production of biomass, but SAF production would also need to be prioritized over other potential uses of these resources. A reduction of GHG emissions by 15% by 2050 would require the construction of approximately 60 new biorefineries annually, which would be similar to the growth in global ethanol and biodiesel production capacity in the early 2000s, and a capital investment of approximately 12 billion USD, which is approximately one fifth of the current global capital investment into petroleum refining.

3. Objectives

ALTERNATE aims to enlarge the aviation sustainable fuel framework, in both technical and economic areas, starting with the possible use of more feedstocks and sustainable production pathways than the existing ones. The feedstock and life cycle inventory values gathered, and land use change estimates computed in WP2 will be the basis for the development of the LCA in WP3. For this deliverable we have conducted a resource assessment that evaluates the potential feedstocks for the production of SAFs within the near future, in the EU and in China. Feedstocks that have been already approved as CEF (Table 1), and the ones that are currently under consideration for approval will also be reviewed where needed for sake of completeness. In addition, selected feedstocks that currently receive academic and commercial interest will be evaluated in detail as part of the overarching LCA conducted in WP2 and WP3 (Table 2).

4. Feedstocks

For ease of presentation we have categorized the feedstocks into the following groups: oilseed crops, lignocellulosic biomass, carbohydrate crops, wastes, fossil fuels. In each section, we have included the feedstocks that are of interest for the project with brief explanations.

4.1. Oilseed crops

Drop-in SAFs can be produced from different types of feedstocks, and some of these feedstocks are suitable for more than one type of fuel production pathway (Table 1). However, a large share of commercial SAFs produced today comes from the hydroprocessing of triglyceride fatty acids from fats, oils and greases (FOGs). Oils from crops like rapeseed/canola, soybean, palm and sunflower constitutes more than 80% of the global production[13] and can be utilized as feedstocks for these hydroprocessed esters and fatty acid (HEFA) fuels.[14] However, first-generation feedstocks like these are widely used for biodiesel production, creating competition for feedstocks. In addition, the utilization of food resources for biofuels raises concerns over global food security due to land use change. Waste oils (e.g. used cooking oil, tallow), that have been associated with lower life cycle GHG emissions, are another sustainable option as feedstocks.[15] Currently within the EU, rapeseed oil is the main feedstock for biofuels accounting for 39% of the total biodiesel produced in 2018.[10] It is followed by used cooking oil (22%), palm (19%), soybean, animal fats, sunflower and others (pine/tall oil, fatty acids).

In light of the above information, there is growing interest for non-food oilseed crops with high oil yields that can grow on marginal lands. These include crops like camelina and Ethiopian mustard (brassica carinata) that are currently being evaluated for inclusion under CORSIA.[9] As such, for ALTERNATE we will mostly be concentrating on non-food crops as potential feedstocks for SAF. While jatropha, pennycress, energy tobacco, salicornia and castor will be investigated by the EU consortium, the Chinese consortium will focus on jatropha, xanthoceras and microalgae.

4.1.1. Jatropha (Jatropha curcas)

The prospect of high oil yield (1.2 t/ha-yr) from jatropha seeds, along with the capability of the plant to grow on marginal lands with low input, made jatropha appealing as a biodiesel feedstock in the early 2000s.[16] It was planted widely in India, followed by China and other Asian and African countries. Jatropha-based HEFA fuel was one of the first SAFs that was used for flight tests[17] and since then, there has been growing interest in jatropha within the international

Table 2. General overview of feedstocks for ALTERNATE.

Feedstock Type	Feedstock Name	CORSIA	New Feedstocks
Oilseed crops	Camelina	■	
	Carinata	■	
	Castor bean		●
	Corn oil (from DDGS)	■	
	Jatropha		●○
	Microalgae		○
	Palm	■	
	Palm fatty acid distillate	■	
	Pennycress		●
	Rapeseed	■	
	Salicornia		●
	Soybean	■	
	Tobacco		●
	Xanthoceras		○
Lignocellulosic biomass	Agricultural residues	■	○
	Forest residues	■	
	Giantreed		●
	Miscanthus	■	
	Reed canary grass		●
	Short rotation woody crops	■	
	Switchgrass	■	
Carbohydrate crops	Sweet sorghum		●
	Sugar beet	■	
	Sugar cane	■	
	Wheat		●
Wastes	Municipal Solid Waste (MSW)	■	
	Used cooking oil	■	○
	Tallow	■	
Fossil fuels	Crude oil		○
	Natural gas		○

■ Feedstocks that have values under CORSIA
● Feedstocks that will be evaluated by the EU consortium of ALTERNATE
○ Feedstocks that will be evaluated by the Chinese consortium of ALTERNATE

aviation community. However, the actual oil yield obtained from the field trials was lower than expected[16,18,19], and attempts to domesticate this wild plant for optimum yields still continue.[20]

4.1.2. Pennycress (Thlaspi arvense)

Pennycress has the potential to serve as a winter crop in rotation with conventional summer crops (i.e. corn, soybean, etc.), and be used as feedstock for biofuels without impacting the food supply or land use[21]. The oil content of the seeds is high (up to 36 wt %), and its meal is rich in protein content so it could be used as animal feed. A genetically-improved variety of pennycress with oil and protein content similar to canola is currently being commercialized.[22]

4.1.3. Tobacco (Nicotiana tabacum)

Tobacco is a widely cultivated plant throughout the world with its leaves used for the production of smoking products. Asian countries, especially China, account for more than half of its worldwide production, while in the EU Greece is a big producer exporting most of its production.[13] Tobacco seeds are considered a by-product of the tobacco leaf production and they are mostly left in the field unused.[23] These seeds have a moderate oil yield, which can be used for biofuel production.[24] Recently a nicotine-free version of the tobacco plant was developed to be used as biomass feedstock, and it was investigated within the EU project SOLARIS for cultivation trials in Italy.[25] Now, in collaboration with Boeing and South African Airways a new project is underway to obtain renewable diesel and jet fuel from tobacco seed oil.[26]

4.1.4. Salicornia (Salicornia bigelovii)

Salicornia is a member of the halophyte family, which are known for their ability to grow in brackish water on marginal lands.[27] As a result, their agriculture is beneficial in terms of land and water resources. In a joint project between the Masdar Institute, Etihad Airways, Boeing, Safran and other entities, locally produced salicornia-based fuel blend has been used for commercial flights in 2019.

4.1.5. Castor (Ricinus communis)

Castor is originally a tropical season crop that can also grow in temperate climates as an annual crop.[28] The seeds have high oil content (50 wt %), more than twice as much as soybean, and the oil yield from castor can be as high as 2 t/ha-yr.[29] Castor oil is the only commercial source of ricinoleic acid, which is a hydroxylated 18-carbon fatty acid used for various chemical products such as lubricants, paints, cosmetics and shampoo. Ricinoleic acid also allows castor oil to be miscible with ethanol and methanol without applying extra heat, giving it an advantage during the trans-esterification to FAME-biodiesel.[30] India is the biggest exporter of castor oil followed by Brazil and China.[13]

4.1.6. Yellow horn (Xanthoceras sorbifolia)

Yellow horn is a plant endemic to northern China suitable for both warm and temperate climates. Its drought tolerant and it can grow well in different types of soil. It is considered as a promising feedstock for biofuels in China with a high seed oil content (55-65 wt %).[31] However, research continues in order to genetically improve the seed yield of this plant.[32] Chinese partners of the ALTERNATE consortium will be focusing on this feedstock.

4.1.7. Microalgae

Algae are fast-growing, aquatic microorganisms that are capable of producing lipids, carbohydrates and lignin through photosynthetic reactions. They can grow in saline water, and also on marginal lands that are unfit for agriculture. Microalgae with their high lipid content has been studied extensively for the production of biofuels[33] however, the cost of production is currently high limiting its usage.[34] Chinese partners of the ALTERNATE already have extensive experience with algae research[35], and as such they will be focusing on this feedstock.

4.2. Wastes

Chinese partners of ALTERNATE will evaluate the potential of used cooking oil as a feedstock for SAF in China.

4.2.1. Used cooking oil (UCO)

UCO is a promising alternative to vegetable oils as biofuel feedstock with its worldwide availability, especially in the developed countries, and its lower prices. UCO is already used for biofuels in the EU accounting for 22% of the biodiesel produced.[10] According to estimates the amount of waste cooking oil collected in the EU is about 0.4 Mt/yr, while the potential amount available is estimated to be as high as 1 Mt/yr.[36] In China this number is found to be much higher, around 5 MMt.[37]

4.3. Lignocellulosic biomass

Lignocellulosic biomass such as agricultural residues (e.g. corn stover, wheat straw, etc.), forest residues, and perennial energy crops (e.g. switchgrass and miscanthus) are being explored extensively as feedstocks for biofuels.[34] These have great potential for the future since they are abundant, non-food feedstocks, that are cheaply available. They are considered by some to be more environmentally friendly for ethanol production, than corn-based ethanol.[38] SAF production from these biomass sources is through conversion pathways such as Fischer-Tropsch (FT), alcohol-to-jet (ATJ) and pyrolysis. These technologies are not fully commercial yet, although pilot and demonstrative plants exist with low production capacities. The EU consortium of ALTERNATE will examine the two lignocellulosic feedstocks with high feasibility for the EU, reed canary grass and giant reed. The Chinese partners will evaluate the agricultural residues, more specifically: corn stover and wheat straw.

4.3.1. Reed canary grass (Phalaris arundinacea)

Reed canary grass (RCG) is a perennial grass suitable for cool temperate climates. In the past, some field trials were performed in Sweden and Finland.[39] More recently, RCG was shown to give better yields than miscanthus and switchgrass in the challenging soil conditions of North East England with a lower cost.[40]

4.3.2. Giant reed (Arundo donax)

Giant reed is a perennial herbaceous plant that originates from Asia, but it is suitable for cultivation in a wide variety of climates. Its cultivation has been studied in the Southern Europe, and depending on site conditions it was shown to give high biomass yields similar miscanthus (3-37t DM/ha-yr). [41–43] It is resistant to drought, and it requires low irrigation and nitrogen input.

4.3.3. Agricultural residues

Agricultural residues (stovers, straws, husks, shells, leaves, etc.) are among the most abundant biomass feedstocks available, since they are leftovers from the harvesting and processing of common crops like corn, wheat and rice.[44] These are mostly burned for energy, causing environmental problems and, in some cases, left in the field and utilized as fertilizers. A small portion of these residues are used as feed for animals by farmers. Consequently, utilization of these residues as feedstocks for biofuels production could be highly beneficial since they incur no food or land competition.

4.4. Carbohydrate crops

This category not only includes crops such as sugar cane and sugar beet, rich in simple sugars, but also those that contain more complex forms of sugars like starch containing corn, wheat, cassava.[45] Sugars that are extracted from these crops can be fermented into alcohols, which are then upgraded into aviation fuel.[46] However, for crops with polysaccharides, there lies a problem. The amount of starch only represents a small percentage of the total plant biomass in these crops, and the rest is cellulose and hemicellulose. These polymeric sugars can also be converted into simple sugars, although the process is more difficult, and the conversion technologies have to be improved for more efficient production.[47] We will evaluate the following carbohydrate feedstocks that are drawing attention in the EU for ALTERNATE.

4.4.1. Sweet sorghum

Sweet sorghum is a promising energy crop for ethanol production with its high sugar content. Moreover, the bagasse left after the juice extraction could also be used as lignocellulosic feedstock. Sorghum is highly resistant to abiotic stress caused by drought and it has a high rate of carbon sequestration.[48] Cultivation of sweet sorghum is investigated under multiple EU-funded projects, and found to be highly promising, with its higher efficiency than cereals and sugar beet for bioethanol production in the EU.[49,50]

4.4.2. Wheat

Wheat is one of the common crops that is available in most parts of the world. It is also an important crop for biofuels production in the EU, since along with corn it is widely used for bioethanol production.[49] In 2016 about 25% of the bioethanol consumed in the EU was obtained from wheat, followed by corn (22%) and sugar beet (17%).[51] The wheat varieties with high starch and low protein content, and high yields are the most desired ones for ethanol production. Although it is a food resource, it is important to explore the potential for wheat considering it is not currently investigated under CORSIA.

4.5. Fossil fuels

The Chinese partners of ALTERNATE will explore inferior crude oil and natural gas to establish baseline values for these feedstocks within China.

References

(1) European Union Aviation Safety Agency. *European Aviation Environmental Report 2019*; 2019. https://doi.org/10.2822/309946.

(2) Air Transport Action Group. *Beginner's Guide to Sustainable Aviation Fuel*; 2017.

(3) Staples, M. D.; Malina, R.; Suresh, P.; Hileman, J. I.; Barrett, S. R. H. Aviation CO2 Emissions Reductions from the Use of Alternative Jet Fuels. *Energy Policy* **2018**, *114* (July 2017), 342–354. https://doi.org/10.1016/j.enpol.2017.12.007.

(4) European Commision (EC). *Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources*; 2018.

(5) International Civil Aviation Organization. *Resolutions Adopted by the Assembly-38th Session-Provisional Edition*; 2013.

(6) International Civil Aviation Organization. *Annex 16 to the Convention of International Civil Aviation. Environmental Protection, Volume IV, Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)*; 2018.

(7) International Civil Aviation Organization. ICAO Environmental Report 2019, Chapter 6: An Overview of CORSIA Eligible Fuels (CEF). **2019**, 228–231.

(8) ASTM International: ASTM D7566-Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons. Accessed June 2020. https://www.astm.org/Standards/D7566.htm.

(9) International Civil Aviation Organization. *CORSIA SUPPORTING DOCUMENT, CORSIA Eligible Fuels – Life Cycle Assessment Methodology*; 2020.

(10) Flach, B.; Lieberz, S.; Bolla, S. *USDA Foreign Agricultural Service, Gain Report NL 9022, EU-28 Biofuels Annual 2019*; 2019.

(11) International Civil Aviation Organization. Conversion Processes. Accessed June 2020. https://www.icao.int/environmental-protection/GFAAF/Pages/Conversion-processes.aspx.

(12) de Jong, S.; van Stralen, J.; Londo, M.; Hoefnagels, R.; Faaij, A.; Junginger, M. Renewable Jet Fuel Supply Scenarios in the European Union in 2021–2030 in the Context of Proposed Biofuel Policy and Competing Biomass Demand. *GCB Bioenergy* **2018**, *10* (9), 661–682. https://doi.org/10.1111/gcbb.12525.

(13) Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT). Accessed June 2020. http://www.fao.org/faostat/en/#home.

(14) Kalnes, T. N.; McCall, M. M.; Shonnard, D. R. Renewable Diesel and Jet-Fuel Production from Fats and Oils. In *Thermochemical Conversion of Biomass to Liquid Fuels and Chemicals*; Crocker, M., Ed.; RSC Publishing: Cambridge UK, 2010; pp 468–495.

(15) Seber, G.; Malina, R.; Pearlson, M. N.; Olcay, H.; Hileman, J. I.; Barrett, S. R. H. Environmental and Economic Assessment of Producing Hydroprocessed Jet and Diesel Fuel from Waste Oils and Tallow. *Biomass and Bioenergy* **2014**, *67*, 108–118. https://doi.org/10.1016/j.biombioe.2014.04.024.

(16) Singh, K.; Singh, B.; Verma, S. K.; Patra, D. D. Jatropha Curcas: A Ten Year Story from Hope to Despair. *Renew. Sustain. Energy Rev.* **2014**, *35* (2014), 356–360. https://doi.org/10.1016/j.rser.2014.04.033.

(17) International Air Transport Association. *IATA Sustainable Aviation Fuel Roadmap*; 2015.

(18) Kant, P.; Wu, S. The Extraordinary Collapse of Jatropha as a Global Biofuel. *Environ. Sci. Technol.* **2011**, *45* (17), 7114–7115. https://doi.org/10.1021/es201943v.

(19) Edrisi, S. A.; Dubey, R. K.; Tripathi, V.; Bakshi, M.; Srivastava, P.; Jamil, S.; Singh, H. B.; Singh, N.; Abhilash, P. C. Jatropha Curcas L.: A Crucified Plant Waiting for Resurgence. *Renew. Sustain. Energy Rev.* **2015**, *41*, 855–862. https://doi.org/10.1016/j.rser.2014.08.082.

(20) Brittaine, R.; Lutaladio, N. *Jatropha: A Smallholder Bioenergy Crop The Potential for Pro-Poor Development; Food and Agriculture Organization of the United Nations*; 2010.

(21) Fan, J.; Shonnard, D. R.; Kalnes, T. N.; Johnsen, P. B.; Rao, S. A Life Cycle Assessment of Pennycress (Thlaspi Arvense L.) -Derived Jet Fuel and Diesel. *Biomass and Bioenergy* **2013**, *55*, 87–100. https://doi.org/10.1016/j.biombioe.2012.12.040.

(22) Covercress-Producing a low carbon intensity crop on unused land over winter www.covercress.com.

(23) Barla, F. G.; Kumar, S. Tobacco Biomass as a Source of Advanced Biofuels. *Biofuels* **2019**, *10* (3), 335–346. https://doi.org/10.1080/17597269.2016.1242684.

(24) Poltronieri, P. Chapter 6 - Tobacco Seed Oil for Biofuels; Poltronieri, P., D'Urso, O. F. B. T.-B. of A. W. and B.-P., Eds.; Elsevier, 2016; pp 161–187. https://doi.org/https://doi.org/10.1016/B978-0-12-803622-8.00006-9.

(25) Solaris energy tobacco for the creation of a European sustainable biojet fuel value chain. Accessed June 2020. https://cordis.europa.eu/project/id/778030/it.

(26) Solaris oil to pave the way for scaling up RSB-certified sustainable local fuel supply in South Africa. Accessed June 2020. https://rsb.org/2019/11/29/solaris-oil-to-pave-the-way-for-scaling-up-rsb-certified-sustainable-local-fuel-supply-in-south-africa/.

(27) Sharma, R.; Wungrampha, S.; Singh, V.; Pareek, A.; Sharma, M. K. Halophytes as Bioenergy Crops. *Front. Plant Sci.* **2016**, *7* (September), 1–8. https://doi.org/10.3389/fpls.2016.01372.

(28) Barnes, D. J.; Baldwin, B. S.; Braasch, D. A. Degradation of Ricin in Castor Seed Meal by Temperature and Chemical Treatment. *Ind. Crops Prod.* **2009**, *29* (2–3), 509–515. https://doi.org/10.1016/j.indcrop.2008.09.006.

(29) Scholz, V.; da Silva, J. N. Prospects and Risks of the Use of Castor Oil as a Fuel. *Biomass and Bioenergy* **2008**, *32* (2), 95–100. https://doi.org/10.1016/j.biombioe.2007.08.004.

(30) Cavalcante, K. S. B.; Penha, M. N. C.; Mendonça, K. K. M.; Louzeiro, H. C.; Vasconcelos, A. C. S.; Maciel, A. P.; de Souza, A. G.; Silva, F. C. Optimization of Transesterification of Castor Oil with Ethanol Using a Central Composite Rotatable Design (CCRD). *Fuel* **2010**, *89* (5), 1172–1176. https://doi.org/10.1016/j.fuel.2009.10.029.

(31) Li, J.; Fu, Y. J.; Qu, X. J.; Wang, W.; Luo, M.; Zhao, C. J.; Zu, Y. G. Biodiesel Production from Yellow Horn (Xanthoceras Sorbifolia Bunge.) Seed Oil Using Ion Exchange Resin as Heterogeneous Catalyst. *Bioresour. Technol.* **2012**, *108*, 112–118. https://doi.org/10.1016/j.biortech.2011.12.129.

(32) Yao, Z. Y.; Qi, J. H.; Yin, L. M. Biodiesel Production from Xanthoceras Sorbifolia in China: Opportunities and Challenges. *Renew. Sustain. Energy Rev.* **2013**, *24*, 57–65. https://doi.org/10.1016/j.rser.2013.03.047.

(33) Costa, J. A. V.; de Morais, M. G. The Role of Biochemical Engineering in the Production of Biofuels from Microalgae. *Bioresour. Technol.* **2011**, *102* (1), 2–9. https://doi.org/10.1016/j.biortech.2010.06.014.

(34) Huber, G. W.; Iborra, S.; Corma, A. Synthesis of Transportation Fuels from Biomass: Chemistry, Catalysts, and Engineering. *Chem. Rev.* **2006**, *106* (9), 4044–4098. https://doi.org/10.1021/cr068360d.

(35) Guo, F.; Zhao, J.; A, L.; Yang, X. Life Cycle Assessment of Microalgae-Based Aviation Fuel: Influence of Lipid Content with Specific Productivity and Nitrogen Nutrient Effects. *Bioresour. Technol.* **2016**, *221*, 350–357. https://doi.org/10.1016/j.biortech.2016.09.044.

(36) Supple, B.; Howard-Hildige, R.; Gonzalez-Gomez, E.; Leahy, J. J. The Effect of Steam Treating Waste Cooking Oil on the Yield of Methyl Ester. *JAOCS, J. Am. Oil Chem. Soc.* **2002**, *79* (2), 175–178. https://doi.org/10.1007/s11746-002-0454-1.

(37) Zhang, H.; Aytun Ozturk, U.; Wang, Q.; Zhao, Z. Biodiesel Produced by Waste Cooking Oil: Review of Recycling Modes in China, the US and Japan. *Renew. Sustain. Energy Rev.* **2014**, *38*, 677–685. https://doi.org/10.1016/j.rser.2014.07.042.

(38) U.S. Department of Energy (DOE/GO-102005-2135) and U.S. Department of Agriculture. *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*; 2005.

(39) Börjesson, P. Environmental Effects of Energy Crop Cultivation in Sweden - I: Identification and Quantification. *Biomass and Bioenergy* **1999**, *16* (2), 137–154. https://doi.org/10.1016/S0961-9534(98)00080-4.

(40) Lord, R. A. Reed Canarygrass (Phalaris Arundinacea) Outperforms Miscanthus or Willow on Marginal Soils, Brownfield and Non-Agricultural Sites for Local, Sustainable Energy Crop Production. *Biomass and Bioenergy* **2015**, *78*, 110–125.

https://doi.org/10.1016/j.biombioe.2015.04.015.

(41) Cosentino, S. L.; Copani, V.; Patanè, C.; Mantineo, M.; D'Agosta, G. M. Agronomic, Energetic and Environmental Aspects of Biomass Energy Crops Suitable for Italian Environments. *Ital. J. Agron.* **2008**, *3* (2), 81–95. https://doi.org/10.4081/ija.2008.81.

(42) Monti, A.; Zanetti, F.; Scordia, D.; Testa, G.; Cosentino, S. L. What to Harvest When? Autumn, Winter, Annual and Biennial Harvesting of Giant Reed, Miscanthus and Switchgrass in Northern and Southern Mediterranean Area. *Ind. Crops Prod.* **2015**, *75*, 129–134. https://doi.org/10.1016/j.indcrop.2015.06.025.

(43) Lewandowski, I.; Scurlock, J. M. O.; Lindvall, E.; Christou, M. The Development and Current Status of Perennial Rhizomatous Grasses as Energy Crops in the US and Europe. *Biomass and Bioenergy* **2003**, *25* (4), 335–361. https://doi.org/10.1016/S0961-9534(03)00030-8.

(44) Zabed, H.; Sahu, J. N.; Boyce, A. N.; Faruq, G. Fuel Ethanol Production from Lignocellulosic Biomass: An Overview on Feedstocks and Technological Approaches. *Renew. Sustain. Energy Rev.* **2016**, *66*, 751–774. https://doi.org/10.1016/j.rser.2016.08.038.

(45) Food and Agriculture Organization of the United Nations. *The State of Food and Agriculture, 2008*; 2008.

(46) Wang, W.-C.; Tao, L.; Markham, J.; Zhang, Y.; Tan, E.; Batan, L.; Warner, E.; Biddy, M. *National Renewable Energy Laboratory Technical Report (NREL/TP-5100-66291), Review of Biojet Fuel Conversion Technologies*; 2016.

(47) Gupta, V. K.; Potumarthi, R.; O'Donovan, A.; Kubicek, C. P.; Sharma, G. D.; Tuohy, M. G. *Bioenergy Research: An Overview on Technological Developments and Bioresources*; Elsevier, 2014. https://doi.org/10.1016/B978-0-444-59561-4.00002-4.

(48) Mathur, S.; Umakanth, A. V.; Tonapi, V. A.; Sharma, R.; Sharma, M. K. Sweet Sorghum as Biofuel Feedstock: Recent Advances and Available Resources. *Biotechnol. Biofuels* **2017**, *10* (1), 1–19. https://doi.org/10.1186/s13068-017-0834-9.

(49) Soldatos, P.; Lychnaras, V.; Panoutsou, C.; Cosentino, S. L. Economic Viability of Energy Crops in the EU: The Farmer's Point of View. *Biofuels, Bioprod. Biorefining* **2010**, *4*, 637–657. https://doi.org/10.1002/bbb.257.

(50) Zegada-Lizarazu, W.; Monti, A. Are We Ready to Cultivate Sweet Sorghum as a Bioenergy Feedstock? A Review on Field Management Practices. *Biomass and Bioenergy* **2012**, *40*, 1–12. https://doi.org/10.1016/j.biombioe.2012.01.048.

(51) Ecofys. *Technical Assistance in Realisation of the 2018 Report on Biofuels Sustainability-Final Report, Project Number:SISNL17791/147631*.