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# CONFERENCE ON AVIATION AND ALTERNATIVE FUELS

**Mexico City, Mexico, 11 to 13 October 2017**

**Agenda Item 1: Developments in research and certification of aviation alternative fuels**
**Agenda Item 2: Financing and assistance programmes for aviation alternative fuels**

## SABR-TCR: A STAND ALONE BIOREFINERY SOLUTION FOR ICAO´S "NO COUNTRY LEFT BEHIND"

(Presented by Brazil)

**SUMMARY**

The Brazilian Biojetfuel and Renewables Platform has been promoting the concept of "from research to fly" since its launch on Aviation Day during the RIO+20 (2012) to promote highly integrated, logistically optimized regional value chains to support the global effort towards a low-carbon economy. The SABR-TCR is a sustainable biorefinery concept to enable price competitive sustainable aviation fuels (SAF) production using waste, sludge, agricultural residues and/or biodiesel using UCO and crude vegetable oils in remote sites and islands. The pilot proof of concept value chain is planned for deployment by the Plataforma Mineira de Bioquerosene e Renováveis in Juiz de Fora, MG in the 2018-2020 timeframe.

## 1. INTRODUCTION

1.1 The ICAO's Carbon Neutral Growth - CNG 2020 aspirational goal and the temporary implementation of CORSIA will require a gradual increase on the global access to SAF at prices that are cost effective for the airlines, specifically in remote locations for ICAO´s "no country left behind" campaign.

1.2 To meet ICAO´s Vision 2050, the Brazilian Biojetfuel and Renewables Platform is structuring strategic partnerships and highly integrated regional projects for Sustainable Aviation Fuel. The aim is to address efficient new pathways based on innovative high feedstock flexibility technologies consolidated into a "Verbund" concept to promote regional sustained development under Agenda 2100, Paris Agreement, Agenda 2030, and the proposed ICAO Vision 2050.

1.3 To meet these needs, the strategic partnership formed by Curcas Diesel Brasil Ltda. (CURCAS), Green Fuels Research Ltd. (UK), Susteen Technologies GmbH (Germany), and RenewCo Ltda. (Brazil) has established an international consortium of leading research institutions, Fraunhofer

UMSICHT research institute (Germany), Embrapa Agroenergia (Brazil) and University of Birmingham (UK) to support the implementation of the flexible fuel platform SABR-TCR® based on a combination of leading edge thermo-catalytic reforming technology for the conversion of biomass waste (TCR®) and CAPEX efficient HEFA refining technology (SABR) as a solution for island states and airport in remote locations. The integrated platform is designed to utilize a wide range of waste materials to produce a range of sustainable fuels.

1.4 The integration of these class leading technologies TCR and SABR provides a robust low CAPEX and low OPEX distributed biorefinery solution for SAF and Energy. The Susteen, GFR, RenewCo and Curcas partnership aims at establishing regional, highly integrated ("from research to fly"), multifeedstock, multiprocess, logistically optimized value chains to produce green diesel, biodiesel, biojetfuel and renewable chemicals, supported by a continuous international R&D program for further biorefining efficiency.

1.5 The SABR-TCR® platform will enable high feedstock and refined product flexibility at moderate scale for remote locations with excellent carbon offset characteristics:

- SABR-TCR® is suitable to process vegetable oils, waste fats, municipal waste (organic fraction) and solid residual biomass in an integrated process. The partial use of solid organic waste as a feedstock enables access to low or negative cost feedstock with wide global availability. Feedstock flexibility substantially reduces exposure to feedstock supply price risk.
- The platform is suitable to produce a variable range of hydrocarbons including SAF, Renewable Diesel, Gasoline and Bio Naphtha. Product flexibility also reduces investment risks due to output market exposure.
- The platform includes the integrated production of hydrogen from residual biomass in remote villages and islands, resulting in excellent stand-alone distributed processing capability and carbon offset characteristics.
- The platform is suitable to produce biochar for agricultural application from qualified types of feedstock. The resulting long-term sequestration of carbon offers further opportunities for enhanced carbon offset.
- The platform is perfectly suited to island and remote communities, using local waste to produce a local fuel at an appropriate scale.
- Due to the capital, efficient design of the SABR-TCR® technologies, and using municipal waste, agricultural residues, glycerol, UCO, sludge, and etc. it is expected that resulting SAF will be competitive even at small scale (10,000 t fuel production per year).

1.6 **The Technology**

1.6.1 The SABR-TCR® platform is built on the innovative SABR refining technology from Green Fuels Research Ltd. (UK) and TCR® biomass conversion technology from Susteen Technologies GmbH and Fraunhofer UMSICHT (Germany).

1.6.2 **SABR – "Sustainable Aviation Through Biofuel Refining".** Green Fuels is the global leading and longest established manufacturer of decentralised biodiesel production equipment, with over 30 major bio-refineries already commissioned around the world, along with thousands of decentralised biodiesel processors producing over 1 million litres of biodiesel every day.

1.6.3 Green Fuels Research (GFR), the innovation branch of the company, has developed and patented SABR, a new process for obtaining renewable aviation fuel from **waste cooking oil, animal fat**

**residues or other waste bio-oils**, which is ideal to meet the market request of the **aviation industry** (end users) and **biodiesel manufacturers** (clients) for the following key purchasing factors:

- **Scalable and low capital intensity plant**: the SABR process is highly scalable, less complex and capital-intensive to operate than existing large centralised HEFA biorefineries, and is designed to produce fuel **with a price point competitive to fossil jet fuel**. The capital cost of the SABR plant will be around **0.075 €/litre/year**, which is **85% less capital intensive** than a new HEFA biorefinery.
- **Integration to existing biodiesel plants**: the key innovation of the SABR technology is that it can be **retrofitted to existing biodiesel production facilities**, obtaining a fuel with the necessary properties to be certified as renewable jet fuel within the ASTM standard D7566. In this way, our existing customers' base (biodiesel manufacturers) can add value to their biodiesel facilities and recover competitiveness in a sector characterised by a strong overcapacity and reduced operating margins. In fact, in Europe nearly 250 biodiesel plants are operational with a total installed capacity of around 24 Mtons, while the production reaches only 12 Mtons [Eubia], with a 50% unexploited overcapacity. The same is happening in US with 3.5 Mtons production over 7 Mtons production capacity. Besides, the use of existing biodiesel facilities allows a simplified permitting process.
- **Flexible production**: The SABR process allows for customers to flexibly produce either biodiesel or renewable jet fuel following the market demand and price fluctuations.
- **Flexible feedstock**: **SABR's renewable jet fuel can be produced from biodiesel coming from any source, without this affecting the final fuel composition**. By interfacing with the existing biodiesel industry, the SABR process capitalises on existing ecosystems for collection and management of waste feedstock, including Used Cooking Oils (UCO) and vegetable oils (macauba, camelina, rapeseed, sunflower and more), and once the economic viability is proven, from other sources including algal species and novel non-food feedstocks. Hence the process does not rely on a specific feedstock supply, but on the use of existing supply chains, with no need to re-invent the feedstock ecosystem.

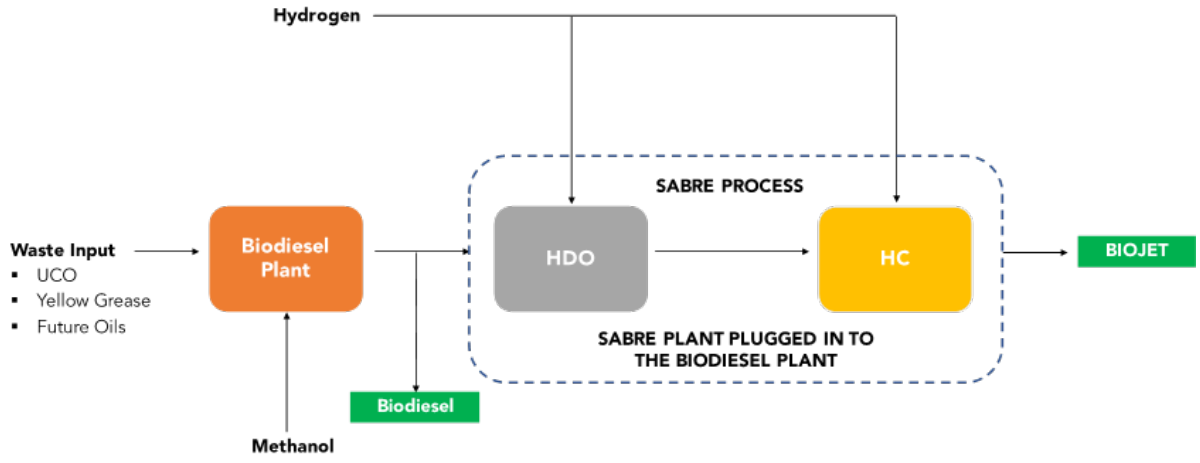


*Figure 1: SABR process layout*

1.6.4 **TCR® - "Thermo-Catalytic Reforming".** Thermo-catalytic reforming is a three-stage thermo-chemical process combining catalytic pyrolysis, cracking and reforming to decompose organic materials into gas, oil and char while upgrading these products throughout the process. Carbon-based, organic solid material enters the TCR® reactor through an injection system which is designed to keep oxygen out of the process, avoiding the combustion of the feedstock. The feedstock is heated up in an auger pipe reactor stage to temperatures ranging 400-500°C. First water contained in the feedstock is evaporated. At higher temperatures, complex organic molecules such as cellulose or lignin are decomposed into carbon, carbon-monoxide, carbon-dioxide, hydrocarbons and water. Carbon and minerals contained in the feedstock form a solid char while other products form a vapour phase. A second stage fixed bed reactor filled with char from the first stage is used to upgrade the process products to unprecedented quality. TCR® gas is enriched with hydrogen while sticky tars are removed. TCR® oil is reduced in acidity and oxygen content resulting in the first primary conversion oil that is directly suitable for engine applications and standard oil refining technology.

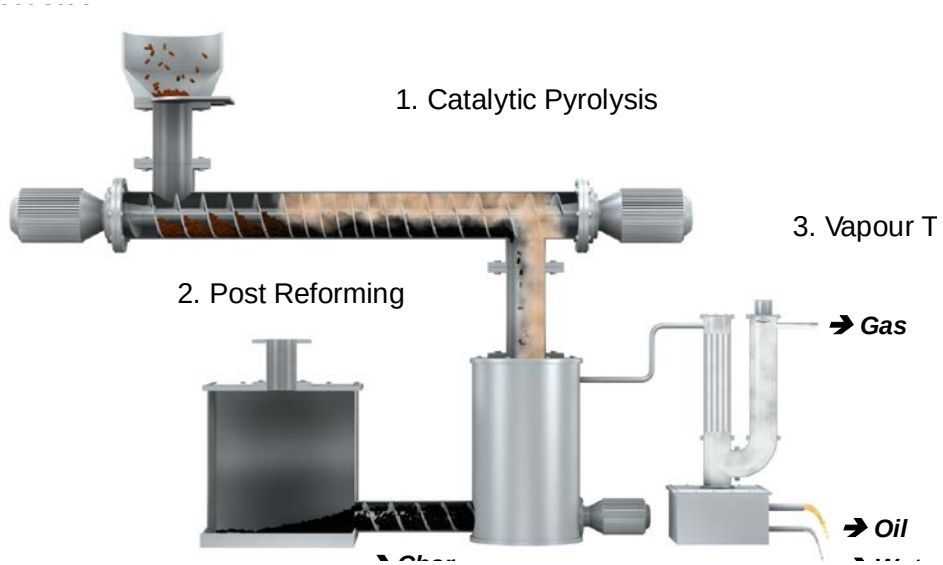


*Figure 2: Thermo-Catalytic Reforming process layout*

1.6.5 The process is characterized by:

- High feedstock flexibility with over 50 waste biomass feedstocks successfully tested by Fraunhofer UMSICHT. Feedstock options include organic waste fractions, sewage sludge, animal manure, and harvesting/biomass processing by-products. Mixed feedstock, plastics content, variable water content and particle size are all tolerated making the technology suitable for many waste applications.
- Products reach unprecedented quality including up to 50% hydrogen content in gas, oil acidity and energy content comparable to used cooking oil, and high quality non-toxic biochar for agricultural and energy applications.
- Major industrial process robustness as the formation of tar is avoided at the root and expensive product cleaning technologies are not required.
- Capital cost for TCR® is estimated at less than 40% of a comparably sized waste incineration plant as solid waste combustion and related emissions are entirely avoided.

1.6.6 TCR® oil is suitable for industry standard refining. Hydro-treatment of TCR® oil results in clean hydrocarbons (Hydrated Bio Oil HBO) with chemical properties very close to crude oil products. Combined refining with crude oil and FAME (bio diesel) is possible and will be contemplated in the R&D program of the Consortium. The fractionated distillation of HBO allows the production of Renewable Diesel, Sustainable Aviation Fuel and Gasoline fractions as illustrated by the following boiling curve for TCR® oil from sewage sludge. The produced fuels meet European fuel norms for Diesel and Gasoline.

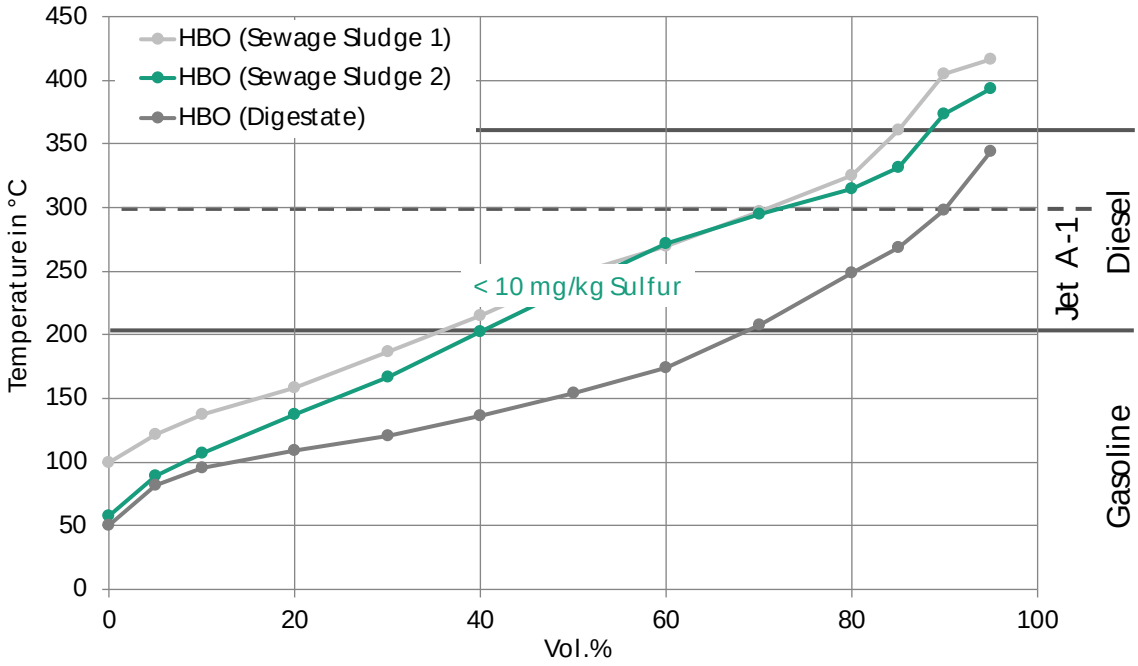


*Figure 3: Boiling curve for refined TCR® biocrude oil from sewage sludge and fermentation digestate*

## 1.7 Description of the development process

1.7.1 **SABR-TCR® Flexible Fuel Refining Platform.** The SABR-TCR® flexible fuel refining platform can process vegetable oils and waste fats such as used cooking oil along with organic solid waste, sludge from sewage treatment and residual biomass feedstocks. Based on these inputs, the platform can produce a variable slate of Sustainable Aviation Fuel, Renewable Diesel, Gasoline (or Bio Naphtha) along with renewable power and optional biochar. The platform uses standard transesterification technology to convert vegetable oils and waste fats into bio diesel (FAME). It is also possible to retrofit existing bio diesel production facilities into a SABR-TCR® solution and take advantage of the idle capacity of the biodiesel plants in Brazil.

1.7.2 The SABR technology uses a combination of hydrodeoxygenation, hydro cracking & isomerization and fractionated distillation to produce sustainable aviation fuel from FAME which is compliant to ASTM D7566 -11 standards and hence suitable for commercial application at up to 50% blending ratio with fossil aviation fuel.

1.7.3 In parallel a TCR® reactor processes organic waste fractions or other biomass residue to produce TCR® biocrude oil, hydrogen-rich synthesis gas and biochar. The system can also process glycerol from the transesterification as a co-feedstock thereby closing the loop on that side-product while increasing fuel yields.

1.7.4 While TCR® biocrude is co-refined with FAME on the SABR reactor the hydrogen for oil refining is supplied from the TCR® syngas through industry standard pressure swing adsorption technology. The fuel components produced from TCR® biocrude are chemically comparable with fossil aviation and road fuels. Road fuel components comply with relevant norms, while the aviation fuel component is expected to meet the chemical parameters of fossil aviation fuel as well. Nevertheless, TCR® aviation fuel components will still require adequate certification as the fossil aviation fuel norm ASTM D1655 is strictly limited to fossil feedstock at the current stage. During the certification process the alternative sale of TCR® fuel fractions into road fuel markets is viable. The proposed generic ASTM approval of the final product irrespective of the source feedstock will help bring this alternative route faster to the market.

1.7.5 Additional TCR® biocrude oil could be supplied from satellite TCR® units processing locally available biomass residue without major transportation overhead, while supplying renewable power and biochar for agricultural use at such satellite locations. Using tail gases from the main processes the SABR-TCR® platform will produce sufficient renewable power and heat to cover its entire process energy demand from renewable sources. Excess power & heat (or cooling) generation could be exported for external use.

1.7.6 The overall process design is displayed in the subsequent chart. The input shares of vegetable or used cooking oil versus solid biomass residue feedstock can be varied in wide ranges. Such a facility would also process approx. 70,000 t/year of organic waste, while the capital cost of the entire plant unit is 25-50% below a waste incineration plant of the same scale.

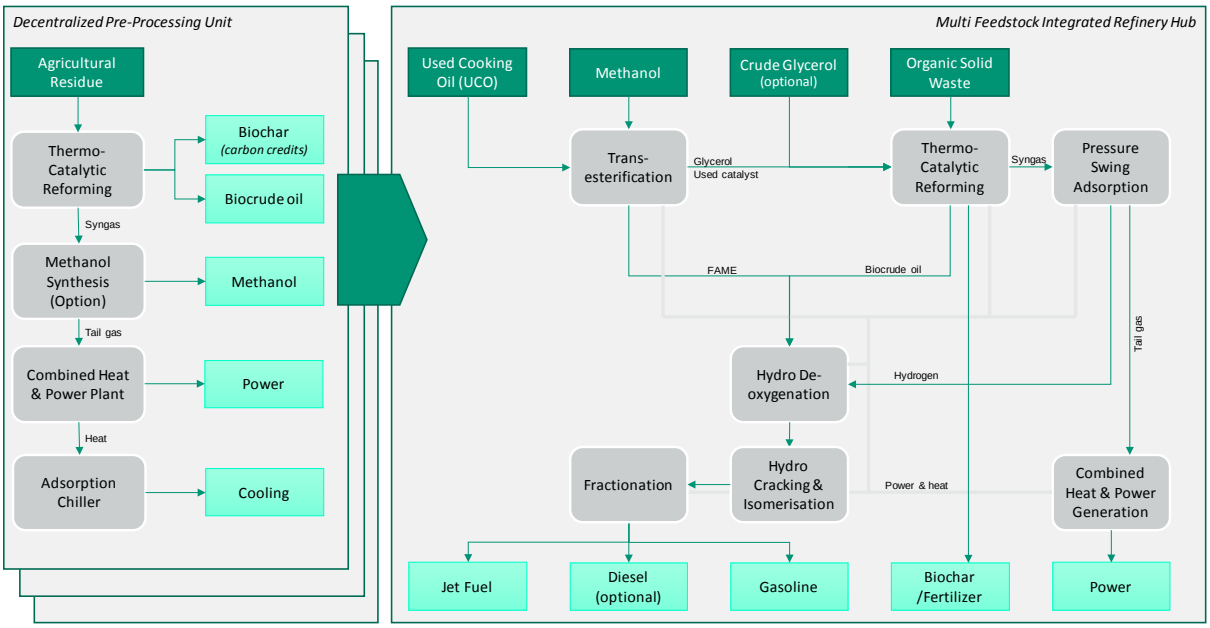


*Figure 4: SABR-TCR® platform process layout*

## 2. TECHNOLOGY DEMONSTRATION IN MINAS GERAIS

2.1 SABR technology for SAF has been successfully tested at pilot scale since 2015 and is currently being scaled up to approx. 1000 t/year of fuel output. TCR® technology has also been piloted

successfully since 2015 and is currently being scaled to facility for processing up to 2300 tons/year of dried sewage sludge in Germany.

2.2 The technology consortium proposes to demonstrate the integrated SABR-TCR® platform at pilot scale in Juiz de Fora, MG (Brazil) in the 2017-2021 timeframe. A pilot plant with a capacity of producing 1,000 tons per year of fuels (at least 50% SAF) is anticipated. There are excellent export logistics by rail of TCR crude bio-oil and/or green diesel through the Port of Rio de Janeiro to the global biofuel and renewable chemicals market and/or to Rio de Janeiro airports (SDU, GIG).

2.3 Based on the successful technology demonstration, the consortium would develop four pilot regional projects under the Sustainable Energy for All Americas – SE4ALL Americas and ICAO – "no country left behind" concept:

a) LATAM+Caribbean pilot project:
- Dominican Republic and/or Haiti

b) Northern Brazil – SE4ALL:
- CELPA Energy+SAF

c) Plataforma Mineira de Bioquerosene e Renováveis:
- Juiz de Fora – integrated value chain model – IZA Airport, with reforestation effort using Macauba, a native Brazilian Palm.
- Metropolitan Belo Horizonte - BH Airport, Lagoa Santa and Confins Municipality.

d) Plataforma Pernambucana de Bioquerosene e Renováveis:
- SUAPE – multifeedstock, multiprocess platform to provide SAF to REC Airport.
- Tacaimbó – Waste-to-Energy and use of gray lines from sewage treatment for the reforestation effort with oil bearing species of regional biodiversity.

2.4 **"Waste-to-SAF" Latin America & Caribbean**

2.4.1 The platform partners Curcas, Green Fuels & Green Fuels Research, RenewCo and Susteen propose the use of this breakthrough solution for a low CAPEX distributed processing platform to provide energy, biodiesel and SAF for the Island States of ICAO and remote airports in the Americas.


2.4.2 Integrating the multi feedstock flexibility (Agricultural Residues, Municipal Waste, Glycerol, Sludge, etc.) and co-products (bio-oil, syngas, bio-char) of the TCR® process with the transesterification (Used Cooking Oils, Animal fats, Macauba oil), then HEFA route of the SABR process into a multi process platform (biodiesel, SAF, and Green Diesel integrated stand-alone SABR-TCR® units) will provide a solution for the proposed 2021 target of 1% blend of the ICAO SUSTAF Vision 2050 – " no country left behind".


2.4.3 The Caribbean islands present a very interesting context for the distributed low cost concept of SABR-TCR® that can be replicated around the globe:

- heavy international tourist aviation traffic (CORSIA);
- reduce high fossil oil importation costs;
- resolve critical waste disposal issues;

- autonomous supply of bioenergy;
- tourism based economies prone to support voluntary contributions for bio-based projects of circular economy and low carbon flights.

2.5 **Proposed Timeline**

a) **Q4 2017**

- Structuring of the MG-JDF-001 project group.
- Implementation of Energy+Food UTDs – Technical Demonstration Units, intercropping Macaúba (*Acrocomia aculeata*) with cash crops to introduce advanced sustainable agricultural practices to small holders, including intensive use of Information Technology (IoT, Big Data, predictive analysis, drone technology), soil management with use of bio-char from the TCR process to increase productivity in a 1 hectare template.
- Development of a pilot 10,000 hectare environmental recuperation project using Macaúba (*Acrocomia aculeata*) in the PABE34 and PABD24 watersheds that provide water for *Dr. João Penido* and *Ribeirão do Espírito Santo* dams in an área of approximately 213 sq km. Based on the regional PRA (environmental recovery plan), the project will engage the agricultural properties of Juiz de Fora and 45 additional municipalities (Zona da Mata Platform) to meet environmental recuperation and remediation under the new Brazilian Forestry Code.

    - The Municipality of Juiz de Fora has established an environmental tax to provide funds for the reforestation program with Macaúba to recuperate the Permanent Protection Areas of the key watersheds of the Municipality.

    - Recuperation program for the Legal Reserves of the Agricultural properties using Macaúba up to 50% percent. The technical demonstration units will support the recuperation drive intercropping Macaúba with cash crops.

b) **Q1 2018**

- TCR Demonstration run of TCR300 at Schwandorf, Bavaria.
- Tri-lateral R&D consortium (UK, Germany, and Brazil) formed by Green Fuels Research/University of Birmingham, Susteen/Fraunhofer and RenewCo/Embrapa Agroenergia to test TCR conversion of low end Brazilian feedstocks at the TCR plant at the University of Birmingham (UK) and characterization of the co-products: bio-oil, syngas, and bio-char.
- Proposed feedstocks:
    - Macaúba residues and crude oil from the Entaban plantation in Olaria/Lima Duarte, MG;
    - Sludge from the Juiz de Fora sewage treatment plant;
    - Eucaliptus;
    - Sugarcane bagasse from Minas Gerais;
    - Soy residues from Southern Minas Gerais.

c) **Q2 2018**

- Proof of concept of the symbiotic integration of SABR-TCR flexible platform.

- Planning for the implementation of UTDs in the 45 municipalities of the Zona da Mata Platform.

d) **Q3 2018**
- Stand alone biodiesel unit in Juiz de Fora, MG, to produce biodiesel for the diesel fleet of the Municipality, and establish the basis for the SABR-TCR module.

e) **Q1 2019**
- Stand alone TCR500 unit to process sludge from the new sewage treatment plant of Juiz de Fora, producing bio-oil, bio-char, and syngas from urban waste, agricultural residues, and sludge. Supply of bio-oil for co-processing with crude fossil oil.
- Implementation of UTDs in the 45 municipalities of the Zona da Mata Platform.

f) **Q3 2019**
- Integration of the two systems, Verbund concept, first step production of hydrogen for the SABR hydrotreating process.
- Enable the processing of TCR crude bio-oil by SABR into price competitive SAF.
- Demonstration runs.
- Biomass Processing platform – multifeedstock crushing plant.

g) **Q3 2020**
- Production of biojetfuel and certification.

h) **Q2 2021**
- Inaugural flight from IZA regional airport.

## 3. BACKGROUND TO CONSORTIUM

### 3.1 About Green Fuels

3.1.1 Green Fuels Ltd., headquartered in Gloucestershire, England (UK), is the leading supplier of skid-mounted decentralised biodiesel processors. Green Fuels systems are designed for safety, easy installation and usage, industrial strength and the flexibility that enables them to convert a variety of feedstocks, including used cooking oils, virgin oils, animal fats and tallows. They can be scaled to the quantity of feedstock available locally, and offer immediate payback and long term investment protection. Green Fuels has over equipment operating in 50 countries producing some 400m litres of biodiesel every year. Green Fuels holds a Royal Warrant for its supply of sustainable biofuel to HRH the Prince of Wales.

3.1.2 Green Fuels has changed biodiesel production from a high cost, expensive to run, feedstock-intensive and cumbersome operation to a modular operation that can be deployed to used cooking oil collection points, virgin oil pressing facilities and even to cities, or can be scaled at a central facility as feedstock supplies increase. The flexibility of the system allows for the production of consistent quality even when using variable feedstocks.

3.1.3 Since 2007 Green Fuels and its sister company, Green Fuels Research have been developing the SABR process to upscale biodiesel to SAF and has an operating pilot located in the UK.

### 3.2 About Susteen Technologies

3.2.1 Susteen Technologies is a spin-off company of Fraunhofer UMSICHT based in Bavaria/Germany and holds the global, exclusive license on the TCR® technology for biomass. Several patents for TCR® have been filed.

3.2.2 Susteen Technologies develops applications based on the TCR® technology and designs & delivers TCR reactor equipment for such applications.
Susteen Technologies designs and markets clean technology focusing on the efficient conversion of carbon-based waste into sustainable resources and energy.

3.3 **About RenewCo**

3.3.1 RenewCo is the industrial systems integration company of the Brazilian Biojetfuel and Renewables Platform, bringing together stakeholders and technology partners to deliver sustainable value added biofuels solutions to the global market under the “from research to fly” concept.

3.4 **About Curcas**

3.4.1 Curcas is the integrator of the Brazilian Biojetfuel and Renewables Platform, Plataforma Mineira de Bioquerosene e Renováveis and coordinator of the Consortium MacaubaBR, dedicated to environmental recuperation projects using oil bearing species of the Brazilian biodiversity to meet the Brazilian NDC reforestation targets.

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