Sustainable Jet Fuel from Flexible Waste Biomass

Deliverable D6.3:
Map and quantification of all inputs and outputs for integrated SABR-TCR plant

for:
European Commission
Konstantinos KALOGIANNIS
European Climate, Infrastructure and Environment Executive Agency (CINEA)
Chaussée de Wavre 910
W910 03/30
B-1049 Brussels/Belgium

presented by GreenFlexJET project consortium

Short	Beneficiary	Role
UOB	THE UNIVERSITY OF BIRMINGHAM	CO
FRA	FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.	BEN
UNIBO	ALMA MATER STUDIORUM - UNIVERSITA DI BOLOGNA	BEN
STR	STERLING POWER LTD	BEN
WRG	WRG EUROPE LTD	BEN
GF	GREEN FUELS RESEARCH LTD	BEN
HYG	HYGEAR BV	BEN
ETA	ETA - ENERGIA, TRANSPORTI, AGRICOLTURA SRL	BEN
SKYNRG	SKYENERGY BV	BEN
LEITAT	ACONDICIONAMIENTO TARRASENSE ASSOCIACION	BEN
USFD	THE UNIVERSITY OF SHEFFIELD	BEN
SOM	SORMEC SRL	BEN

CO: Coordinator, BEN: Beneficiary

Version 1.1 re-submission
Ravenna -IT, 30 November 2021

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 792216.

General Information

Call identifier: H2020-LCE-2017-RES-IA
GA Number: 792216
Topic: LCE-20-2016-2017
Start date of project: 01/04/2018
Duration: 72 months
Work Package: WP6 – Environmental sustainability
Type: Deliverable
Number: D6.3
Title: Map and quantification of all inputs and outputs for integrated SABR-TCR plant
Due Date: 30/06/2019 (Month 15)
Submission date: 30/09/2019
New submission date: 30/11/2021
Reference Period: 01/01/2019 – 30/11/2021

Prepared by: Alma Mater Studiorum - Università di Bologna (Lead)
Responsible Person: Serena Righi
Dissemination Level: Public

Document Type		
PRO	Technical/economic progress report (internal work package reports indicating work status)	
DEL	Technical reports identified as deliverables in the Description of Work	**X**
MoM	Minutes of Meeting	
MAN	Procedures and user manuals	
WOR	Working document, issued as preparatory documents to a Technical report	
INF	Information and Notes	

Dissemination Level		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	
CON	Confidential, only for members of the Consortium	

TABLE OF CONTENTS

1 EXECUTIVE SUMMARY

Life Cycle Assessment (LCA) is a method for analysing and evaluating the environmental performance of processes, products or services throughout their entire life cycle and it is a crucial tool to direct new products and innovative processes towards sustainability. The 'Life Cycle Inventory' (LCI) phase aims at realizing an inventory of input/output data with regard to the system being studied. It involves the collection of the necessary data to meet the goals of the defined study. The process of conducting an inventory analysis is iterative. As data are collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the data collection procedures so that the goal of the study will still be met.

1.1 Description of the deliverable content and purpose

Deliverable D6.3 aims to quantify relevant energy and material inputs and outputs of the integrated SABR-TCR demo plant designed within the GreenFlexJET project and to create an inventory referred to the functional units chosen during the "goal and scope definition" phase. The collected data used to map the main input and output flows of energy and materials for each process will also be used for the LCA modelling. The report is divided into five main chapters: the first chapter is this executive summary, the second one is an introduction to the deliverable where aims and methods of the report are briefly described; the third one is the main part of the report where the performed inventory analysis of the SABR-TCR system is described; in the fourth chapter, the LCI is summarised in a table; in the fifth one, the main conclusions from the task are reported.

As mentioned above, the third chapter is the main part of this deliverable. It includes both a detailed description and the collected data for each process included in the system boundaries. Also, the cut-off rules, the assumptions concerning the processes to be included within the system boundaries, and the allocation procedures for both the co-products and the by-products of the system are described in this chapter.

Through an iterative, resource-intensive and time-consuming process, it was possible to map the main input and output flows of most of the system. Unfortunately, it was not possible to complete the inventory with the quantification of all input and output flows, since the further investigation and additional information from project partners is needed to complete it. Missing data will be collected over the coming months as soon as partners will make them available.

2 INTRODUCTION

The introduction reports the goal of the deliverable and a brief introduction to LCA methodology. This second part aims at contextualizing the collection of the data necessary to meet the goals of the WP6, so a focus on the "Life Cycle Inventory" phase is reported, since it is the LCA phase to which this deliverable refers.

2.1 Goal of this deliverable

The goal of task 6.2 is twofold. The first goal is to collect data from the integrated SABR-TCR plant design (WP2) to quantify all relevant energy and material inputs and outputs of the system and create an inventory referring to the functional unit. A second goal is to create scenarios of alternative uses of the feedstocks. As a consequence, this task foresees two deliverables:

- **D6.3 – the present document, which is dedicated to the SABR-TCR system;**
- D6.4 – which is dedicated to the alternative uses of the feedstocks and to the production of jet fuel from fossil raw materials.

2.2 Introductory overview of Life Cycle Assessment

Life Cycle Assessment (LCA) methodology is standardized by EN ISO 14040:2006 (ISO, 2006a; ISO 2006b). There are four phases in the LCA study (Figure 1):

a. goal and scope definition;
b. inventory analysis;
c. impact assessment;
d. interpretation.

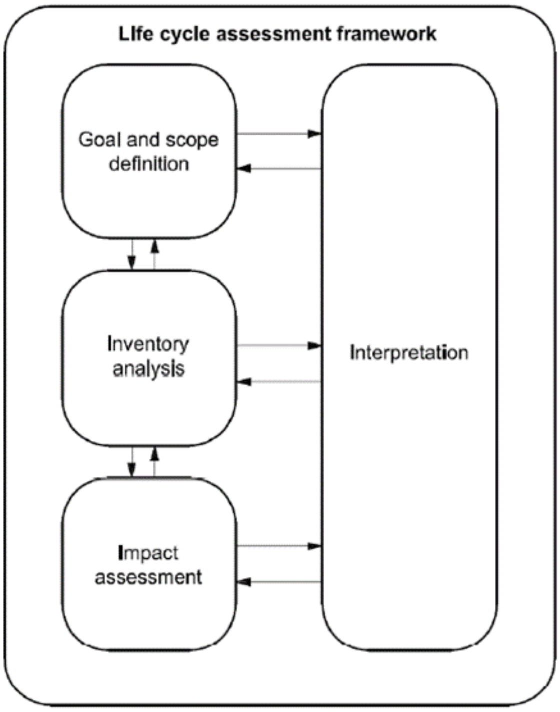

Figure 1 – Stages of an LCA

Goal definition identifies the specific purpose of the LCA analysis. The scope of an LCA analysis, including system boundaries and level of detail, depends on the subject and the intended use of the study. The depth and the breadth of an LCA analysis can differ considerably depending on the goal.
The Life Cycle Inventory analysis (LCI) phase is an inventory of input and output data with regard to the system being studied. It involves the collection of the necessary data to meet the goals of the defined study.

The Life Cycle Impact Assessment phase (LCIA) is the third phase of the LCA. It is aimed at evaluating the significance of potential environmental impacts using the LCI results.
Life cycle interpretation is the final phase of the LCA procedure, in which the results of an LCI or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition.

2.2.1 Life Cycle Inventory analysis

Life Cycle Inventory analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system.
The process of conducting an inventory analysis is iterative. As data are collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the data collection procedures so that the goal of the study will still be met. Data for each unit process within the system's boundary can be classified under major headings, including:

- energy inputs, raw material inputs, other physical ancillary inputs;
- products, by-products and waste;
- emissions to air, discharges to water and soil;
- other environmental aspects.

Data collection can be a resource-intensive process. Practical constraints on data collection should be considered in the scope and documented in the study report.

3 INVENTORY ANALYSIS OF LCA APPLIED TO GreenFlexJET PROJECT

This chapter describes the following issues: the assumptions made during the Life Cycle Inventory analysis of the SABR-TCR system; the allocation methods adopted to address the multifunctionality of the system, i.e. the production of multiple co-products; the processes and their related data collected. As hereinafter explained, it was not possible to complete the inventory with the quantification of all the input and output flows, and consequently with the calculation of their quantities referred to the different functional units chosen during the “goal and scope definition” phase.

As already discussed in Deliverable 6.2, the goal of the GreenFlexJET project, that is to produce Sustainable Aviation Fuel (SAF) potentially able to replace the conventional jet fuels using waste biomass as feedstock, has positive effects from an environmental point of view also because it allows managing organic waste effectively, providing a sustainable alternative for their disposal. Therefore, we decided to put a dual purpose in our LCA analysis and to adopt both the process- and the product-oriented approach:

- the first purpose is to assess the environmental benefits of the SABR-TCR technology as a new alternative for “end-of-life” treatment of both used cooking oils (UCO), digestate waste (DW) and waste wood (WW), following the so-called “process-oriented” approach;
- the second one is to assess the environmental performance of the SABR-TCR technology as a new alternative potentially replacing current jet fuel production technology; this is the so-called “product-oriented” approach.

The adoption of both approaches will allow us to quantify the environmental sustainability of the integrated SABR-TCR technology, and to compare the results with those of alternative jet fuel production technologies and those of alternative feedstock valorisation routes in support of future commercialisation, in compliance with the requirements set by the EU revised Renewable Energy Directive.
The intended audience to which the LCA analysis is addressed consists of a wide variety of subjects:

- internal members of the project (GreenFlexJET partners);
- external members involved in the project (the European Commission and the stakeholders);
- a more general public, including the scientific community.

The results are intended to be used in comparative assertions which will be disclosed to the general public.

3.1 Assumptions

In collecting data from the SABR-TCR plant design phase and in modelling the scenarios, the following cut-off rules and assumptions were adopted:

1) start-up, shut-down, hot idle and combined refining operating modes, together with maintenance operations, were omitted; only HEFA jet fuel production, that is the main operating mode, was considered;
2) emergency flows and fugitive emissions were omitted; they will be added when data from the operating demo plant will be available;
3) capital goods (e.g. construction of factory buildings, vehicles, machines and auxiliary equipment) were not included; this is a relatively usual practice in LCA studies, as in literature is found that for technical systems with long life, the environmental impact deriving from construction is often small in relation to impact caused by operations (Geisler et al., 2004; Hischier at al., 2005);
4) material transport, waste production and waste disposal were included in the system boundaries for each scenario;
5) the operating time of the plant was set at over 7,000 h/y, consistently with the Amendment request AMD-792216-7.

3.2 Allocation

Concerning the feedstocks, following the state of the art analysis performed in Task 6.1, both the used cooking oils and the biomass waste were considered as a waste and they were assumed to have a ”zero burden”, which means that it was considered that these waste residues carry none of the upstream environmental burdens into the waste management system (Clift et al., 2000). This approach is debated in literature but is still widely adopted (Laurent et al., 2014), as we highlighted in Deliverable 6.1. Consistently, also the feedstock introduced by AMD-792216-7 - the digestate waste and waste wood - are considered "zero burden".

Since the system generates multiple co-products (jet fuel, bio-naphtha, glycerol, power and heat), allocation methods have to be defined to address the multifunctionality of the system and to distribute the generated environmental impacts among them.
Table 1 shows the allocation methods chosen for both approaches. In the 'process-oriented' analysis the system expansion was adopted, i.e. the co-products generated by the system substitute the same (or similar) products produced in the "business as usual" way. On the other hand, in the 'product-oriented' analysis the energy allocation was adopted between jet fuel and bio-naphtha produced (and system expansion for possible credit from glycerol, electricity and thermal energy production), based on their higher heating value.

Table 1 – System function, functional unit and allocation method adopted for each alternative scenario

Approach	Function	Functional unit	Allocation	Alternative scenarios
Process-oriented	UCOs, DW and WW management	1 tonne of UCOs/DW/WW ready to be treated	System expansion	UCO / biodiesel production UCO / bio-lubricants production DW / agricultural amendment WW / gasification WW / incineration WW / activated carbon production
Product-oriented	Jet fuel production	1 MJ of HHV in the produced fuel	Energy allocation for jet fuel and bio-naphtha System expansion for possible credit of glycerol, electricity and thermal energy	fossil-based jet fuel production

3.3 Data collection

As reported in the Grant Agreement, this Deliverable 6.3 was planned to collect data from the integrated SABR-TCR plant design (WP2, Task 2.5) to quantify all the relevant energy and material inputs and outputs of the SABR-TCR system and to create an inventory referred to the functional unit. A detailed process description and all available characteristics of the products and co-products have to be included. In view of this, we focused on the basic of the SABR-TCR integrated plant, which foresees Berkeley (UK) as the plant site for TCR, PSA and the SABR hydrotreatment (transesterification, hydrodeoxygenation, hydrocracking and fractionation).
Since Deliverable 2.5 and all the information contained therein are confidential, it is not possible to show and quote them in this public deliverable. Therefore, only the inventory of input and output flows will be shown, without any quantification.

4 LIFE CYCLE INVENTORY

Due to the many gaps in the quantification of material and energy flows for many parts of the system, it was not possible to create a complete inventory related to the functional units as defined for the different scenarios identified in Deliverable 6.2. However, a comprehensive mapping of the processes and the main input and output flows was performed and is shown in the following Table 2. Further information and data exchanges with project partners are necessary to quantify the flows and complete the inventory referred to the selected functional units.

Table 2 – Comprehensive inventory of the main input and output flows of GreenFlexJET integrated SABR-TCR system

PROCESS		FLOW	I/O	U.M.	1 tonne of UCO ready to be treated	1 tonne of DW ready to be treated	1 tonne of WW ready to be treated	1 MJ of HHV in the produced jet fuel
Feedstock collection		Digestate waste transport	I	km/kg	[redacted]	[redacted]	[redacted]	[redacted]
		Used cooking oil transport	I	km/kg	[redacted]	[redacted]	[redacted]	[redacted]
		Waste wood transport	I	km/kg	[redacted]	[redacted]	[redacted]	[redacted]
		Digestate waste collected	O	kg	[redacted]	[redacted]	[redacted]	[redacted]
		Used cooking oil collected	O	kg	[redacted]	[redacted]	[redacted]	[redacted]
		Waste wood collected	O	kg	[redacted]	[redacted]	[redacted]	[redacted]
TCR package	Feed unit	Electricity	I	MJ	[redacted]	[redacted]	[redacted]	[redacted]
		Feedstock pellets	I	kg	[redacted]	[redacted]	[redacted]	[redacted]
		Nitrogen	I	kg	[redacted]	[redacted]	[redacted]	[redacted]
		Feedstock pellets	O	kg	[redacted]	[redacted]	[redacted]	[redacted]
	Auger Reactor	Feedstock pellets	I	kg	[redacted]	[redacted]	[redacted]	[redacted]
		Nitrogen	I	kg	[redacted]	[redacted]	[redacted]	[redacted]
		Lubricating oil	I	kg	[redacted]	[redacted]	[redacted]	[redacted]
		Char, vapours and gases	O	kg	[redacted]	[redacted]	[redacted]	[redacted]
	Post reformer	Char, vapours and gases	I	kg	[redacted]	[redacted]	[redacted]	[redacted]
		Gases and vapours	O	kg	[redacted]	[redacted]	[redacted]	[redacted]
		Char	O	kg	[redacted]	[redacted]	[redacted]	[redacted]
	Gas product conditioning	Gases and vapours	I	kg	[redacted]	[redacted]	[redacted]	[redacted]
		FAME	I	kg	[redacted]	[redacted]	[redacted]	[redacted]
		Nitrogen	I	kg	[redacted]	[redacted]	[redacted]	[redacted]
		Softened water	I	kg	[redacted]	[redacted]	[redacted]	[redacted]
		Cooling water	I	kg	[redacted]	[redacted]	[redacted]	[redacted]
		TCR oil	O	kg	[redacted]	[redacted]	[redacted]	[redacted]
		TCR syngas	O	kg	[redacted]	[redacted]	[redacted]	[redacted]
		Process water	O	kg	[redacted]	[redacted]	[redacted]	[redacted]
		Water vapour	O	kg	[redacted]	[redacted]	[redacted]	[redacted]
	Combustion chamber	Natural gas	I	kg	[redacted]	[redacted]	[redacted]	[redacted]
		Thermal energy	O	MJ	[redacted]	[redacted]	[redacted]	[redacted]
PSA package	Syngas compression	Syngas (purified)	I	kg	[redacted]	[redacted]	[redacted]	[redacted]
		Instrumental air (7 bar)	I	Nm^3	[redacted]	[redacted]	[redacted]	[redacted]
		Heat transfer liquid	I	kg	[redacted]	[redacted]	[redacted]	[redacted]
		Electricity	I	MJ	[redacted]	[redacted]	[redacted]	[redacted]

		Syngas (compressed)	O	kg	[redacted]
		Heat transfer liquid	O	kg	[redacted]
	Syngas and recycled hydrotreating gas mixing	Syngas (compressed)	I	kg	[redacted]
		HDO recycle gas	I	kg	[redacted]
		Electricity	I	MJ	[redacted]
		Syngas + HDO gas	O	kg	[redacted]
	PSA unit	Syngas + HDO gas	I	kg	[redacted]
		Nitrogen	I	kg	[redacted]
		Instrumental air	I	Nm^3	[redacted]
		Active coal	I	kg	[redacted]
		Electricity	I	MJ	[redacted]
		Hydrogen	O	kg	[redacted]
		Off gas	O	kg	[redacted]
		Active coal (waste)	O	kg	[redacted]
	Hydrogen compression	Hydrogen	I	kg	[redacted]
		Instrumental air (7 bar)	I	Nm^3	[redacted]
		Heat transfer liquid	I	kg	[redacted]
		Electricity	I	MJ	[redacted]
		Hydrogen (compressed)	O	kg	[redacted]
		Heat transfer liquid	O	kg	[redacted]
Trans esterification	UCO processing	Preheated UCO	I	kg	[redacted]
		Methanol	I	kg	[redacted]
		Methanol recovered	I	kg	[redacted]
		Sodium methylate	I	kg	[redacted]
		Electricity	I	MJ	[redacted]
		Thermal energy	I	MJ	[redacted]
		FAME	O	kg	[redacted]
		Glycerol	O	kg	[redacted]
	FAME purification	FAME	I	kg	[redacted]
		Resins	I	kg	[redacted]
		Electricity	I	MJ	[redacted]
		FAME purified	O	kg	[redacted]
		Resins to regeneration system	O	kg	[redacted]
	Methanol recovery	FAME purified	I	kg	[redacted]
		Cooling water	I	kg	[redacted]
		Electricity	I	MJ	[redacted]
		FAME finished	O	kg	[redacted]
		Methanol recovered	O	kg	[redacted]
		Cooling water	O	kg	[redacted]
SABR hydro treatment	Reactor modules	FAME	I	kg	[redacted]
		Hydrogen	I	kg	[redacted]
		Nitrogen	I	kg	[redacted]
		Jet fuel to reprocessing	I	kg	[redacted]
		Heavy organics to reprocessing	I	kg	[redacted]

		Electricity	I	MJ	[redacted]
		Thermal energy	I	MJ	[redacted]
		Products	O	kg	[redacted]
	Downstream separation	Products	I	kg	[redacted]
		Electricity	I	MJ	[redacted]
		Thermal energy	I	MJ	[redacted]
		Catalysts	O	kg	[redacted]
		Gas fraction	O	kg	[redacted]
		Aqueous phase drainage	O	kg	[redacted]
		Light organics	O	kg	[redacted]
		Naphtha	O	kg	[redacted]
Process energy generation package	CHP unit	TCR oil	I	kg	[redacted]
		FAME	I	kg	[redacted]
		Lubricating oil	I	kg	[redacted]
		Electricity	O	MJ	[redacted]
		Thermal Energy	O	MJ	[redacted]
	Gas flare	TCR off-gas	I	kg	[redacted]
		PSA off-gas	I	kg	[redacted]
		SABR off-gas	I	kg	[redacted]
		NO_x	O	kg	[redacted]
		N_2O	O	kg	[redacted]
		SO_2	O	kg	[redacted]
Char management (gasification + CHP)		Char	I	kg	[redacted]
		Electricity	O	MJ	[redacted]
		Thermal energy	O	MJ	[redacted]
		Ash	O	kg	[redacted]

5 CONCLUSIONS

The Life Cycle Inventory analysis for the integrated SABR-TCR plant of GreenFlexJET project involved at first relevant scientific literature review, and documents and deliverables study concerning the designed processes; subsequently, data collection from relevant project partners and calculation procedures to quantify relevant inputs and outputs of the system. During this latter iterative, resource-intensive and time-consuming process it was possible to complete the mapping of the main input and output flows concerning most of the SABR-TCR process steps, but unfortunately, because of lack of quantitative data, it was not possible to complete the inventory with the quantification of the flows, and consequently with the calculation of their quantities referred to the different functional units chosen during the “goal and scope definition” phase. Further investigation and additional information from project partners are needed to complete the inventory, and they will be collected over the coming months as soon as they will be made available by partners. However, it was possible to establish the cut-off rules, make the assumptions concerning the processes to be included within the system boundaries, and finally establish the allocation procedures for both the co-products and the by-products of the system.

6 REFERENCES

European Commission (EC) 2010. Commission Staff Working Document accompanying the Communication from the Commission to the Council and the European Parliament on Future Steps in Bio-waste Management in the European Union. SEC(2010) 577 Final

European Commission (EC) 2017. PEFCR Guidance document – Guidance for the development of Product Environmental Footprint Category Rules (PEFCRs), version 6.3.

Geisler, G., Hofstetter, T.B., Hungerbühler, C. K. 2004. Production of fine and speciality chemicals: procedure for the estimation of LCIs. International Journal of Life Cycle Assessment. 9(2), pp. 101–113

Hischier, R., Hellweg, S., Capello, C., Primas, A. 2005. Establishing Life Cycle Inventories of chemicals based on differing data availability. International Journal of Life Cycle Assessment. 10(1), pp. 59–67

ISO 2006a. Environmental Management-life Cycle Assessment-principles and Framework, second ed. ISO 14040; 2006e07-01; ISO, Geneva, Switzerland.

ISO 2006b. Environmental Management-life Cycle Assessment-requirements and Guidelines, first ed. ISO 14040; 2006e07-01; ISO, Geneva, Switzerland.

Sphera 2021. Available at: http://www.gabi-software.com/databases/gabidatabases/professional/ (visited on November 2021).

7 ACKNOWLEDGEMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 792216.