Sustainable Jet Fuel from Flexible Waste Biomass

Deliverable D2.3:
Design of flue gas infrastructure from defined syngas treatment requirements

for:
European Comission
Agata Przadka
Innovation and Networks Executive Agency (INEA)
Chaussée de Wavre 910
W910 03/30
B-1049 Brussels

presented by GreenFlexJET project consortium

Short	Beneficiary	Role
UoB	THE UNIVERSITY OF BIRMINGHAM	CO
Fraunhofer	FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.	BEN
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SUSTEEN GMBH	SUSTEEN TECHNOLOGIES GMBH	BEN
USFD	THE UNIVERSITY OF SHEFFIELD	BEN

CO: Coordinator, BEN: Beneficiary

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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	

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1 EXECUTIVE SUMMARY

The objective of the GreenFlexJET project is to demonstrate a new integrated process combining transesterification of waste vegetable oil with thermo-catalytic reforming (SABR-TCR). A Pressure Swing Adsorption (PSA) system is installed to separate the green hydrogen followed by subsequent hydrotreating to refine the produced TCR biocrude. The targeted product is jetfuel.

In this report the flue gas emissions from the GreenFlexJET installation are identified and analysed for NO_x, SO_x, heavy metals and particulate matter.

The analysis show that the emission are kept below the threshold values from EU legislation by installing at planned desulphurization reactor in the TCR product gas train, use of state of the art combustion technologies for flare applications and common mercury capture technology.

1.1 Description of the deliverable content and purpose

The GreenFlexJET D2.3 is a public report describing the flue gas emission sources of the GreenFlexJET plant. Its due date is M3 and it applies to the Task 2.3. It has been updated to match the new plant as it will be built in Berkeley, UK

2 INTRODUCTION

This deliverable deals with the flue gas emission part of the integrated SABR-TCR®-PSA-HDO plant constructed and operated in the GreenFlexJET project. Feedstocks like UCO and "food & market waste", which may contain some residual packaging, are converted into biocrudes and by refining using the produced hydrogen these biocrude is converted into jet fuel. In the process there are some streams which will be combusted and thus produce flue gasses. The schematic set up of the various technology blocks is provided in the diagram on the next page (Figure 1). We anticipate the following emission points:

1. Combustion system processes clean syngas after hydrogen separation. The syngas is cleaned in the TCR product gas train to remove particles (through cyclone and electro-static precipitator), aerosols (ESP), ammonia (acidic scrubber), and H_2S (iodized activated carbon filter – also removes residual aerosols)
2. The flue gas from syngas combustion is expected to comply with EU emission specifications without further treatment (to be confirmed). The clean flue gas would be diluted with pre-heated air to supply process heat to dryer.
3. Drying process will enrich dryer air with ammonia and organic smell. Dryer air would pass through an acidic scrubber (sulphuric acid) for ammonia removal and biofilter through smell mitigation
4. Flare temporarily processing off-spec syngas from TCR during start-up, shut-down and in exceptional operating scenarios. The duration of such scenarios is limited. The flare will continuously run a pilot flame on natural gas, which would comply with TA Luft. Due to the safety requirements in exceptional scenarios flue gas cleaning is not an option.

In this report the compositions of the stream leading to flue gasses are described and the potential emissions are discussed.

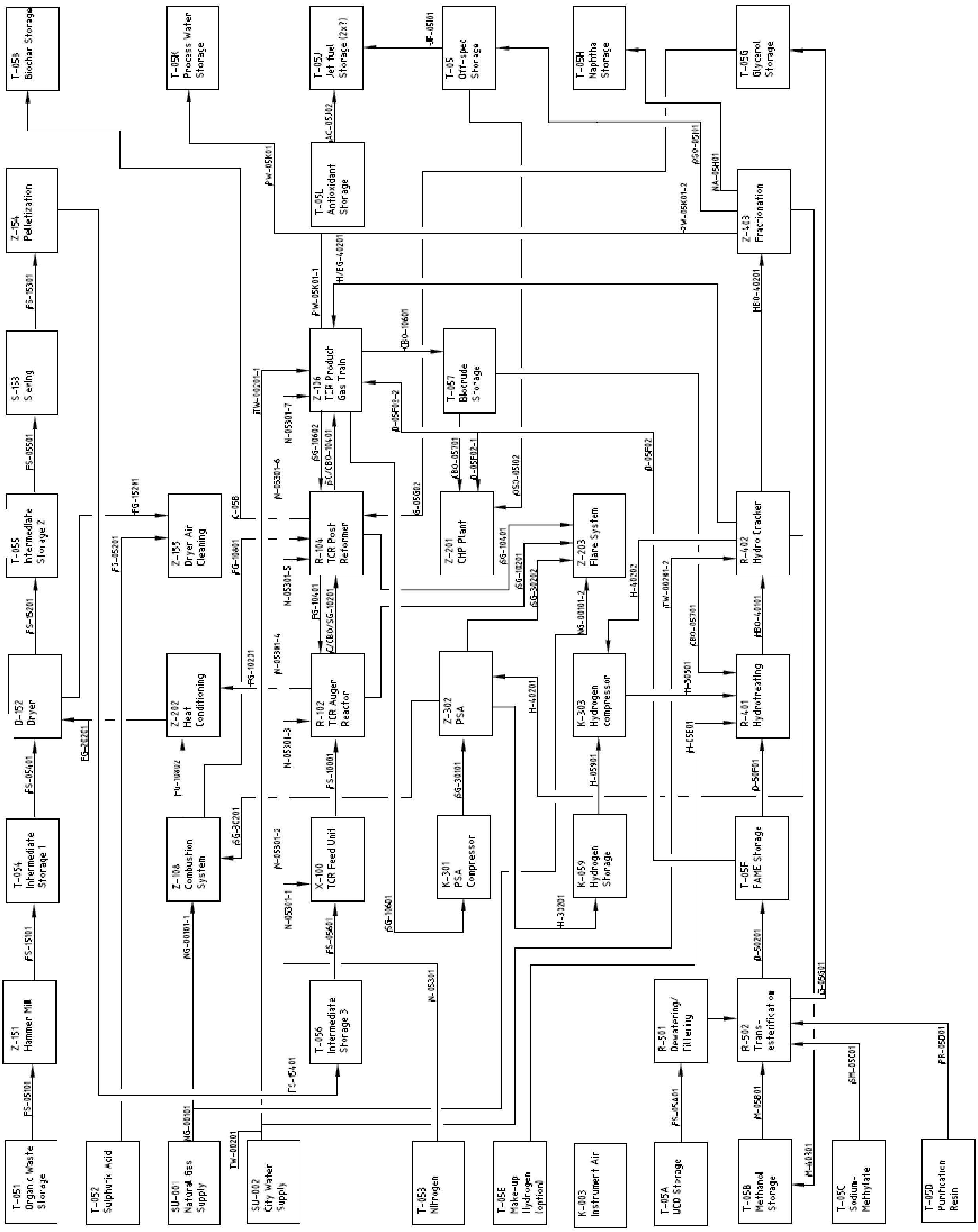

Figure 1: Block diagram from the entire GreenFlexJET system

DESCRIPTION OF FLUE GAS STREAMS

In the GreenFlexJET plant, there will be 3 flue gas stream which will be vented to the atmosphere. In this chapter these stream are described in composition and the potential emissions. The composition of the flue gasses is of interest, the quantity is less important as the entire operation strategy of the plant and thus the amount of flue gas cannot be determined this early in the project (M3).

2.1 Compositions

Some of the composition of the gases are fixed like the natural gas, others can vary because they are depending on the operation of the GreenFlexJET plant.

2.1.1 Combustion system (Z-108)

In the combustion system natural gas and PSA off gas (= the non hydrogen components of the PSA feed) are combusted to provide heat for the TCR post-reformer and the feed stock dryer.

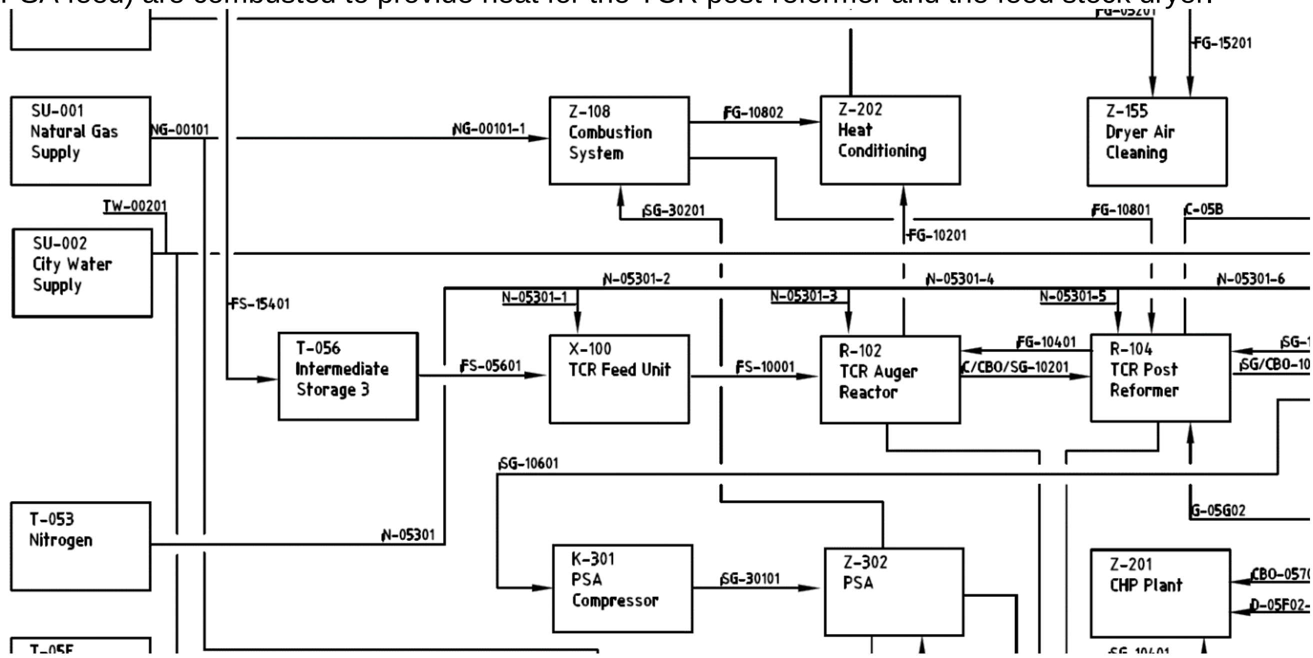

Figure 2: Block diagram with streams around the combustion system (Z108)

The natural gas comes from the grid and has a composition provided in table 1. The PSA off gas is less well defined as its composition is dependent on the PSA operation and the PSA feed. In table 1 a typical off gas composition is provided based on known TCR performance by project partners Fraunhofer UMSICHT. This off gas can change to higher hydrogen concentrations at the expense of the other species when a certain amount of the spent hydrogen from the hydrotreating is recycled to the TCR product gas train. In this TCR product gas train the hydrogen is cleaned from ammonia and hydrogen sulphide and fed back to the PSA to remove CO, H_2O and other present impurities.

Table 1: gas compositions of natural gas in Europe[1] and of PSA offgas based on TCR syngas composition

Component	Russian H gas (vol%)	North Sea H gas (vol%)
CH4	96,96	88,71
CO2	0,18	1,94
N2	0,86	0,82
C2H6	1,37	6,93
C3H8	0,45	1,25

Component	Concentration in off gas (vol%)
Hydrogen	4%
Methane	14%
Carbon monoxide	11%
Carbon dioxide	42%
Nitrogen	20%
Ethane	3%
Propane	3%
ethene	1%
water	0%

In natural gas a sulphur containing substance (THT, mercaptanes) is added as odorant. Usually the concentration is about 5-10 ppm. Through combustion, this will add a small fraction of SO_x in the flue gas. The PSA off gas does not contain sulphur as it is removed from the TCR gas by a scrubber upstream of the TCR gas compressor. NO_x can be created at high operating temperatures and long residence times in the burner. We are currently exploring flameless oxidation or low temperature oxidation burners to achieve low NO_x emissions.

Table 2: heavy metal in the TCR feed and its products (measured by Fraunhofer institute). Al values in ppm.

Species	TCR feed	solid	oil	water
Cu	520	810	2	0
Zn	1300	2260	2	1
As	16	24	16	2
Pb	50	93	0	0
Cd	1	2	0	0
Cr	51	120	0	0
Ni	48	87	0	0
Hg	0	0	0	0

Table 2 shows the presence of heavy metal in the TCR feed and the distribution in the products from TCR as measured by Fraunhofer Umsicht. It shows that most of the heavy metal will be concentrated in the solid fraction. A very small fraction of arsenic and zinc are measured in the biocrude. Only mercury is not collected in the solid or liquid fraction and is thus assumed present in the gas phase. This leads to the assumption that per hour of TCR500 operation 150 mg of mercury is released in the gas phase. The mercury can be captured in the TCR product gas train, but it is also possible it remains in the gas phase entering the PSA. Here it will be collected in the off gas and move onwards to the combustion system. The off gas stream is expected to be about 250 Nm^3/h, which means a mercury concentration of 0.6 mg/Nm^3 of off gas. In the combustion system this will be further diluted with air. The combustion system has not been design in detail so the amount of air needed which dilutes the mercury is not known yet. The 0.6 mg/Nm^3 is the maximum value.

2.1.2 Flare system (Z203)

The flare is a module in which a wide range of gases should be combusted. In case of start-up or shutdown the flare will burn product gases from the TCR Auger reactor and from the TCR post reformer product gas to prevent hydro-carbons to be emitted to the atmosphere during those periods. This is a standard during stabilization of the plant (max. 1-2 hours during start-up) and for residual syngas generation during plant shut-down. Also the PSA off gas is flared

[1] http://dev-gasinfocus.lateos.com/en/indicator/composition-of-natural-gas-consumed-in-europe/

when it cannot be dispatched to the combustion system. During the start up the composition of the gases going to the flare will vary. The flare also operates with natural gas from the grid to be able to combust low caloric gases form the modules in startup or shutdown phase. The flare is operated with 200% excess air to assure complete combustion of the flammable and poisonous species.

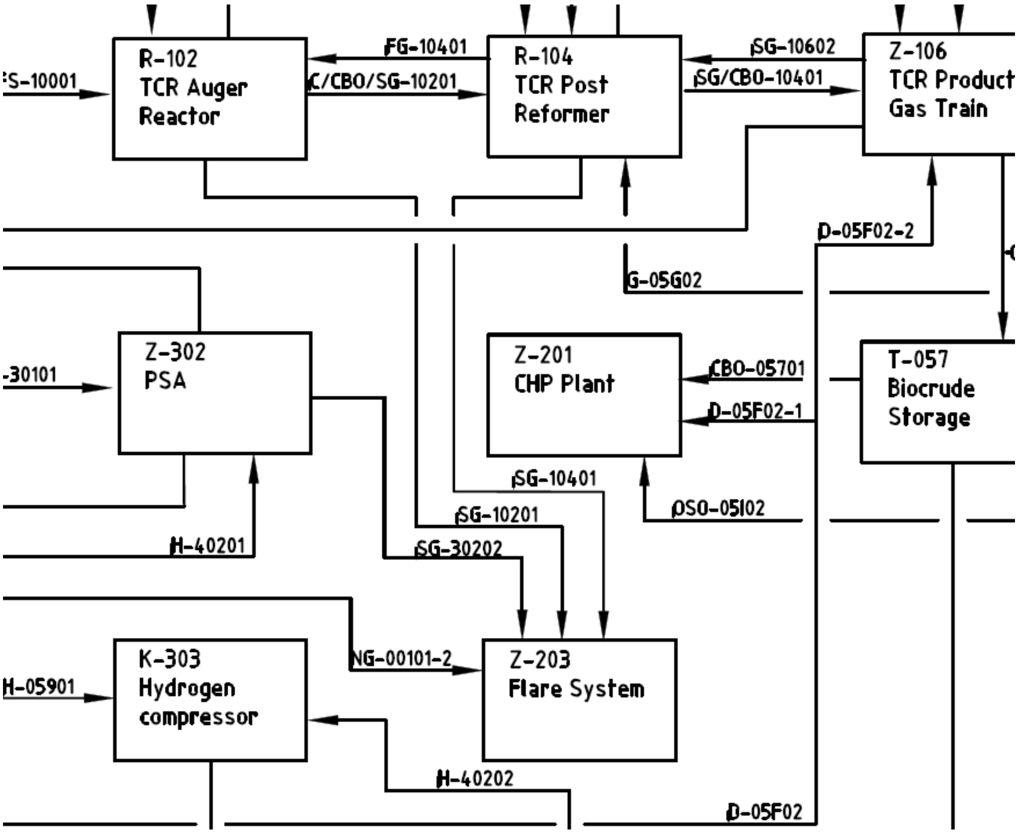

Figure 3: Block diagram with streams around the flare (Z-203). (Stream NG-00101-2 is natural gas to ignite and sustain the flare.

Another reason for a continuous flow of natural gas to the flare is because it should also be able to combust gas stream coming from safety relief valves from the GreenFlexJET plant. This only in a hazardous operating scenario when the plant runs into over-pressure and a pressure relief in the reactor is required. Those streams are only vented in emergencies and are not expected to contribute to the emissions during normal operation. The amount of gas emitted this way depends on the size and content of the reactors, designed in the project.

Table 3: Representative elemental analysis of Biocrude from TCR (Susteen data)

Element	Content (wt%)
C [on dry matter]	77,0 - 85,4
H [on dry matter]	7, 0 - 10,8
N [on dry matter]	0,2 - 8,5
S [on dry matter]	0,1 - 1,1
O [on dry matter, calculated by difference]	3,5 - 10,4
Ash [on dry matter}	<0,005
H_2O	0,7 - 2,2

During most of the GreenFlexJET plant operation the hydrocracker will refine pure FAME to comply with ASTM jet fuel norm. The biocrude is the basis for hydrotreating reactions in which the nitrogen, oxygen and sulphur will be removed from the stream. The produced hydrogen sulphide and ammonia are transferred to the TCR product gas train where it will be removed from the gas and taken out of potential flue gas streams. During some test phases the unrefined biocrude is blended with the FAME and the blended feedstock passes through the hydrocracker for refining. Those product hydrocarbons will not comply with ASTM norm but is used for evaluation and future certification. The product will be analysed for suitability as jet fuel. The stream has very low sulphur content < 10 ppm as the FAME is meeting the EN14214 standard and the biocrude has been hydrotreated.

Emission Limits

The plant will be installed in Berkeley, UK.. The emission limits can be found in various documents which are available on the internet. For GreenflexJET the emissions limits for use of new engines and turbines in the EU are given in Table 4

Table 4: Emission limits for medium combustion plants according to DIRECTIVE (EU) 2015/2193[2]

Emission limit values (mg/Nm³) for new engines and gas turbines

Pollutant	Type of medium combustion plant	Gas oil	Liquid fuels other than gas oil	Natural gas	Gaseous fuels other than natural gas
SO_2	Engines and gas turbines	—	120 (1)	—	15 (2)
NO_x	Engines (3) (4)	190 (5)	190 (5) (6)	95 (7)	190
	Gas turbines (8)	75	75 (9)	50	75
Dust	Engines and gas turbines	—	10 (10) (11)	—	—

(1) Until 1 January 2025, 590 mg/Nm³ for diesel engines which are part of SIS or MIS.
(2) 40 mg/Nm³ in the case of biogas.
(3) Engines running between 500 and 1 500 hours per year may be exempted from compliance with those emission limit values if they are applying primary measures to limit NO_x emissions and meet the emission limit values set out in footnote (4).
(4) Until 1 January 2025 in SIS and MIS, 1 850 mg/Nm³ for dual fuel engines in liquid mode and 380 mg/Nm³ in gas mode; 1 300 mg/Nm³ for diesel engines with ≤ 1 200 rpm with a total rated thermal input less than or equal to 20 MW and 1 850 mg/Nm³ for diesel engines with a total rated thermal input greater than 20 MW; 750 mg/Nm³ for diesel engines with > 1 200 rpm.
(5) 225 mg/Nm³ for dual fuel engines in liquid mode.
(6) 225 mg/Nm³ for diesel engines with a total rated thermal input less than or equal to 20 MW with ≤ 1 200 rpm.
(7) 190 mg/Nm³ for dual fuel engines in gas mode.
(8) These emission limit values are only applicable above 70 % load.
(9) Until 1 January 2025, 550 mg/Nm³ for plants which are part of SIS or MIS.
(10) Until 1 January 2025, 75 mg/Nm³ for diesel engines which are part of SIS or MIS.
(11) 20 mg/Nm3 in the case of plants with a total rated thermal input equal to or greater than 1 MW and less than or equal to 5 MW.

The syngas burner will be between 600 and 800kW. The emissions will be met using state of the art combustion and flare technologies which are developed to reduce NO_x by reducing flame temperature and residence time in the burner, hence by adequate burner design. Additional NO_x reduction is not expected to be necessary in the combustion system and the flare.

In the United Kingdom, there is a limit on fine particle emissions of 40µg/ m^3 for PM10 particles. This limit should be discussed with the manufacturer of the flare and the combustion system. Those modules should have emissions according to this limit. If this is not possible, additional filters or cyclones will be applied.

The analysis show that mercury is the most probable heavy metal which can be in the gas phase and in the end in the flue gas. The emission specification of mercury in the EU are provided in 2010/75/EU and have a value of 0.05 mg/Nm^3.

[2] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015L2193&rid=4

As described above in the most negative scenario that all mercury from the TCR feed enters the PSA off gas a dilution of 12 times in the combustion system is needed to meet this specification. When this dilution is not reached in the combustion system, a commercial mercury trap, which is an activated carbon filter can be applied. This is common technology in (natural) gas cleaning business.

3 CONCLUSIONS

The expected emissions from the GreenFlexJET installation concerning the flue gasses have been determined. The emissions in those flue gasses concerning NO_x, SO_x and particulates have been analysed.
The emission goals can be reached the planned installation of desulphurization system for the TCR gas and the recycled hydrotreating gas. NO_x emissions can be reached by using state of the art combustion hardware.
Mercury is of the heavy metals the most likely to appear in the flue gas stream. Mercury capture technology is commonly used in gas cleaning and will be applied if the emission specification is not reached.

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