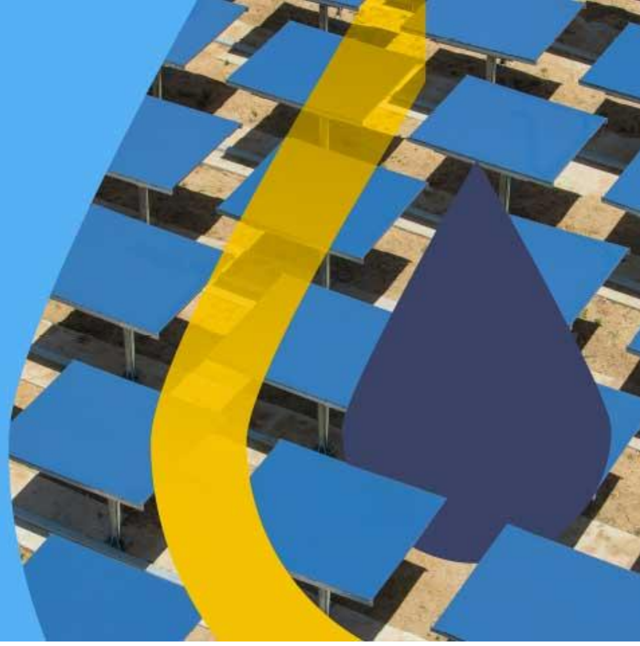
SUNtoLIQUID II
FUELS FROM CONCENTRATED SUNLIGHT



D6.1: Adapted GtL system

Lead beneficiary: HyGear
Due date: 31/01/2025
Actual submission date: 30/04/2025

Grant Agreement number	GA 101122206
Project acronym	SUN-to-LIQUID II
Project title	SUNlight-to-LIQUID: Efficient solar thermochemical synthesis of liquid hydrocarbon fuels using tailored porous-structured materials and heat recuperation
Type of action	Research and Innovation (RIA)
Start date of the project	01/11/2023
Duration	48 months
Project coordinator (organisation)	Dr Andreas Sizmann (Bauhaus Luftfahrt)
Phone	+49-171-3373210
E-mail	contact@sun-to-liquid-2.eu
Website	sun-to-liquid-2.eu

Funded by
the European Union

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs,
Education and Research EAER
State Secretariat for Education,
Research and Innovation SERI

Funded by the European Union under GA 101122206. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Document information

Document Name	D6.1: Adapted GtL system
Version	VF
Version Date	28/04/2025
Author	Simon Haanschoten
Dissemination level	Public

Approvals

	Full Name	Organisation	Date
Coordinator	Andreas Sizmann	Bauhaus Luftfahrt	26/04/2025
WP Leader	Dick Lieftink	HyGear	24/04/2025
Task Leader	Simon Haanschoten	HyGear	24/04/2025
Other (Quality)	Julie Chupin	LUP	28/04/2025

Documents history

Version	Date	Modification	Name (Organisation)
V1	24/04/2025	First version	HyGear
V2	27/04/2025	Coordinator review	BHL
VF	28/04/2025	Quality check	LUP

Distribution list

Name	Organisation
SUN-to-LIQUID II Consortium	N/A
Project Officer Luca Bondi	EC / CINEA
AB members	

Executive summary

The SUN-to-LIQUID II (StL-II) project advances the European Green Deal's objective of reducing transport emissions by 90% by 2050 through the production of sustainable solar-based synthetic fuels. Building on the success of the previous H2020 SUN-to-LIQUID (StL) project, StL-II aims to significantly scale up solar fuel production by enhancing the energy efficiency of the solar reactor from 4.1% to at least 15%. This efficiency gain results in a substantial increase (up to 200%) in the volume of syngas directed to the Gas-to-Liquid (GtL) system, necessitating major system upgrades.

This report, developed under Task 6.1, outlines the redesign, optimization, and implementation of the adapted GtL facility. Key modifications include an upgraded syngas intake system, integration of a new low-pressure buffer to manage peak production flows, and expansion of the high-pressure buffer capacity to improve system flexibility and reactor operation. These changes ensure that the system can accommodate the increased throughput while maintaining stability and performance. Additionally, the Fischer-Tropsch (FT) reactor has been enhanced with a bluff body to mitigate thermal runaways during high flow conditions and improve heat management at the reactor inlet. Other upgrades include catalyst replacement, improved cooling systems, and updated instrumentation for better control and monitoring.

A comprehensive inspection and refurbishment of the system was carried out due to its inactivity since 2019. Potential wax discoloration issues were investigated, with initial findings suggesting oxidation-related causes, pending further analysis during the operational phase.

Overall, the adapted GtL system in StL-II is now capable of supporting the intensified operational demands of high-efficiency solar fuel production and represents a critical step toward the scalable deployment of renewable fuels in the transport sector.

Table of contents

List of figures

List of tables

Glossary

Acronym	Signification
CO_2	Carbon dioxide
Deoxo	Deoxygenation
FT	Fischer-Tropsch
GtL	Gas-to-Liquid
H_2	Hydrogen
H_2O	Water
HP	High-pressure
LP	Low-pressure
NoBo	Notified body
PFD	Process flow diagram
StL	SUN-to-LIQUID
StL-II	SUN-to-LIQUID II
slm	standard liters per minute

1. Introduction

The European Green Deal aims at a 90% reduction in transport emissions to achieve climate neutrality by 2050. The main leverage of aviation and waterborne transport is increasing the share of renewable fuels. SUN-to-LIQUID II (StL-II) addresses this challenge with an integrated solar-thermochemical pathway that has the potential to produce sustainable and cost-effective fuels at the scale of future demand directly from sunlight, water and CO_2. This thermochemical production chain from H_2O and CO_2 to kerosene has already been demonstrated on a pilot-scale level in the preceding H2020 SUN-to-LIQUID (StL) project. Figure 1 illustrates the process flow diagram of this solar-to-fuel plant consisting out of a solar field with heliostats, the solar reactor at the top of the tower and the gas-to-liquid (GtL) unit.

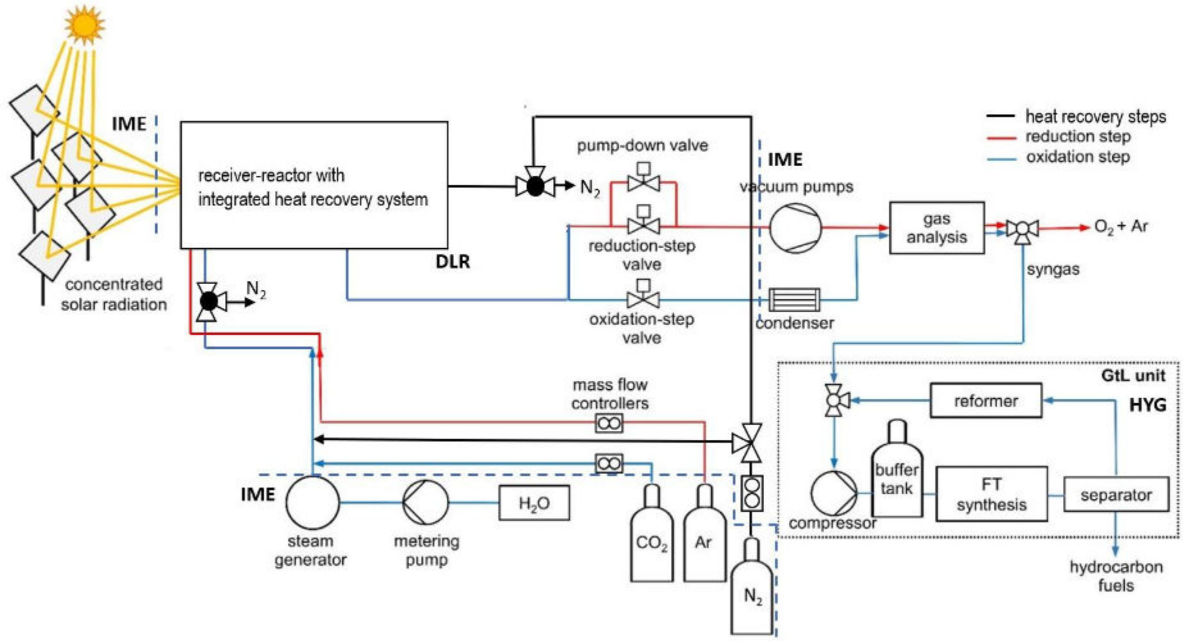


Figure 1: Process flow diagram (PFD) of the StL II plant adapted from the preceding StL design as presented by [1]. The PFD includes an integrated heat recovery system as part of the goal of the StL-II project.

With the ambitious goal to increase the solar reactor energy efficiency up to 15% or higher (compared with 4.1% in the preceding project), the operating conditions and in particular the expected in- and output volume streams of the various modules significantly change. This incorporates an substantial increase in the syngas feed to the GtL system. Therefore, to make sure that the GtL system can process the increased flows from the solar reactor, the existing system has to be adapted.

This work is written in context of Task 6.1: *Gas-to-Liquid system* and acts as supplement on the demonstrator Deliverable D6.1: *Adapted GtL system*. The aim of the work is to briefly describe the redesign, on-site adaptations and optimization of the already existing GtL facility from the preceding H2020 SUN-to-LIQUID project. Among others, this includes the adapted mass balances, solar gas intake adaptations, addition of high and low-pressure (LP) buffer, reactor redesign and updated controls.

2. Adaptation of the GtL system

In this chapter, the reader is first given an impression of the magnitude of the required scale-up of the GtL system. Subsequently, the key modifications are described that have been implemented to cope with the new input flowrates.

2.1. Syngas production

The solar-to-syngas efficiency is an important parameter used in the calculations of the in- and output flowrates. The solar-to-syngas energy conversion efficiency $\eta_{solar\text{-}to\text{-}syngas}$ is defined as the ratio of the higher heating value of the syngas produced over the cycle to the sum of solar radiative power input Q_{solar} and other energy inputs (e.g. energy inputs associated with vacuum pumping).

$$\eta_{\text{solar-to-syngas}} = \frac{Q_{\text{syngas}}}{Q_{\text{input}}}$$

With the integration of the heat recovery system, advanced redox structures and a heat recovery shield in StL-II, the goal has been set to reach a solar-to-syngas efficiency of 15% (Table 1). This results in significant different in- and output flowrates for which the GtL plant needs to be adapted. Due to confidentiality considerations, the exact new flowrate values have been excluded from this report. However, for a rough indication, it can be assumed that the average input flowrates of H_2, CO and CO_2 to the GtL system need to be increased to approximately 300% with respect to the StL system. For peak syngas production values during the oxidation cycle, the same peak ratios have been assumed as presented by Zoller et al [1].

	Operating case	
	Reference SoA RPC [1]	*With 3D printed structures + heat recovery + active aperture shutter*
Solar-to-Syngas efficiency (%)	*5*	*15*
Input flowrates GtL system	*100%*	*300%*

Table 1: Solar-to-syngas efficiency projection

Once produced, the syngas needs to undergo several steps before entering the Fischer-Tropsch reactor. First, oxygen and water need to be removed and the pressure is elevated to inject the syngas into the compressor section. Here, the gas is compressed and stored in a high-pressure (HP) buffer. The Fischer-Tropsch reactor consequently uses the gas from this buffer as feed. The gaseous (by)products from the FT-reactor are recycled back to the compressor and buffer section. Figure 2 gives a schematic representation of this system as it has been designed in the preceding StL project.

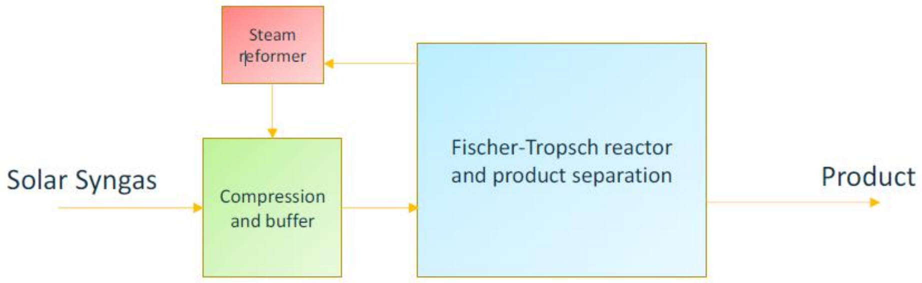


Figure 2: Schematic overview of GtL plant in preceding StL project.

2.2. Syngas intake

The main adaptations that have been done to handle the increased intake of solar syngas are:

- The Deoxygenation (Deoxo) reactor catalyst has been replaced and it has been verified that the Deoxo reactor can still handle the increased peak flows regarding pressure drop and oxygen conversion.
- The gas intake pump has been tuned to run at higher frequencies to cope with the increased solar syngas production and peak flows (See Figure 4). The syngas pump can now process up to 60 standard liters per minute (slm) of syngas.
- The high-pressure compressor that was used in StL has a maximum capacity of 20 slm. This implies that the syngas flow during the peak production of StL-II would be too large to handle. Therefore, an intermediate low-pressure buffer of 800 L is introduced upfront of the HP-compressor. During the oxidation cycle, the gas intake pump will store excessive syngas in the LP-buffer up to maximally 385 mbar(g). During the reduction cycle the HP-compressor has enough time to empty out the LP-buffer again and so restarts the cycle. Figure 5 shows the low-pressure buffer vessel that has now been installed with the GtL system.
- The capacity of the high-pressure buffer has also been increased to gain more flexibility in standalone operation of the FT-reactor module and the compression and buffer module. Additionally, this will improve start-up and shutdown frequency which is desirable for the FT-reactor. The capacity has been increased by adding a second 50L HP syngas cylinder (max 200 bar(g)) to the storage system as illustrated in Figure 6.

These improvements enable it to store and process the higher expected syngas flows in StL-II. Figure 3 shows the proposed GtL plant setup.

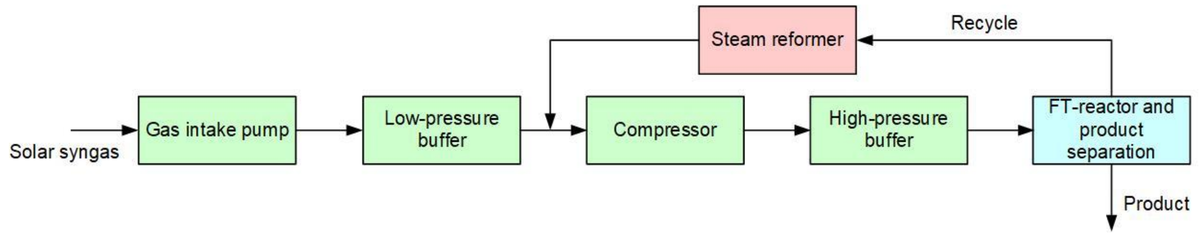


Figure 3: Schematic overview of GtL plant in StL-II.

Figure 4: Syngas pump for solar gas intake.

Figure 5: Low-pressure syngas buffer vessel of 800 L. The vessel is to be installed adjacent to the GtL system at the IMDEA site.

Figure 6: New high-pressure buffer setup with additional HP syngas buffer cylinder of 50L.

2.3. Fischer-Tropsch reactor

Also, the Fischer-Tropsch reactor has been adapted to be able to process higher feed flowrates. A bluff body has been introduced at the gas inlet of the catalyst chamber of the reactor. Here, the reaction rates are the highest and therefore the most heat is generated. In StL, thermal runaways have been experienced with high temperature peaks at the reactor inlet leading to system shutdown. Specifically, when higher gas flowrates were fed to the reactor, the reactor cooling could not keep up with the heat production in the inlet section. This can probably be related to a runaway methanization reaction due to insufficient heat transfer at the reactor inlet. Accordingly, the goal of the bluff body is to reduce the catalyst radial thickness and thereby reducing heat transfer limitations at gas inlet. It is expected that this will enable higher feed flowrates to the FT-reactor. To maintain confidentiality, detailed design images of the bluff body have been omitted from this work.

Next to the introduction of the bluff body, some small adjustments have been done like exchanging the spend catalyst for fresh catalyst, replacing the thermal oil and thermocouples.

2.4. General equipment inspection and replacement

Since the StL system has last been operational in 2019, all equipment has been subject to aging, corrosion or any other degradation. Rigorous inspection and cleaning of all equipment and piping has been performed to investigate the state of the system. When necessary, parts have been replaced.

Special attention has been paid to find any source of contamination that could have caused brown colouring of the wax product. During inspection, it has been found that any wax that was still present in the reactor or reactor outlet piping was white. Wax in the gas liquid separator downstream of the reactor was more brownish. However, no clear source of the discolouration could be identified. Since the gas-liquid separator has been open to air for the last few years, this implies that the discolouration can possibly be related to oxidation of the oil. Also, free radical formation due to repetitive heating could have an effect on the colour of the oil [2]. Since no clear cause for the discolouration has been identified, this phenomenon will be further analysed in the testing phase of the StL-II system.

Figure 7: Pictures illustrating the white color of the was found in the tubing at the outlet of the Fischer-Tropsch reactor (left) and brown color of the wax in the gas-liquid separator (right)..

Some equipment has also been replaced to accommodate the higher production capacity. This includes, replacement of mass flow controllers, relief valves, adsorbents and the chiller. Also, the sampling system has been updated to better suit the measurement range of CH_4, CO and CO_2 based on the findings from StL.

Figure 8: Example of new back pressure regulator and pressure relief valve used in StL-II

Figure 9: Chiller system with expansion vessel.

3. Assembly

This chapter shows some images of the final assembly of the StL-II system:

Figure 10: Front view of (cleaned) GtL container. Rework of paint to be done before shipment to IMDEA.

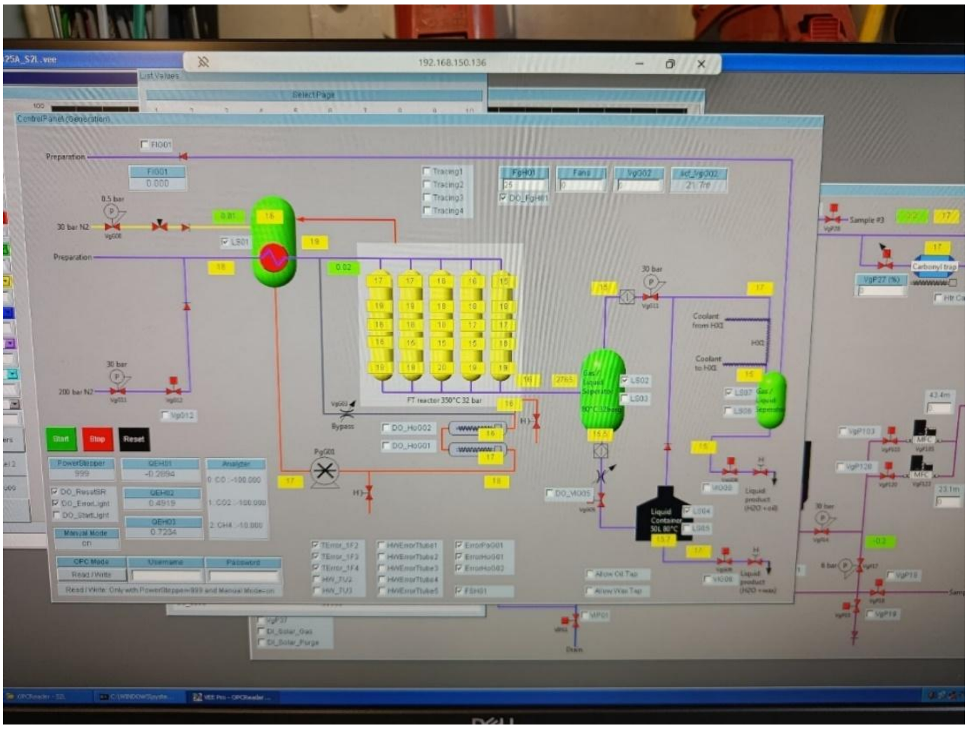


Figure 11: Control panel of the Fischer-Tropsch reactor and separation section.

Figure 12: View of the roof of the GtL container. It contains the rooftop blower for ventilation and multiple process vents.

Figure 13: Gas intake and compression section.

Figure 14: FT-reactor and separation section. Insulation has not been installed since the Notified Body (NoBo) must be able to do visual inspection of the pressure equipment.

Figure 15: Recycle section with reformer, humidifier and heat exchanger.

Figure 16: New mass flow controllers for gas feed to FT-reactor.

4. Conclusions and Outlook

The Gas-to-Liquid system of the H2020 SUN-to-LIQUID project has been successfully adapted to support the efficiency and production goals of StL-II. Key system adaptations include an upgraded syngas intake system, integration of a new low-pressure buffer to manage peak production flows, expansion of the high-pressure buffer capacity to improve system flexibility and reactor operation, mitigation measures for heat transport limitations in the Fischer-Tropsch reactor and extensive inspection a restoration of equipment.

The new GtL system will now be tested at the HyGear facility with synthetic solar gas as part of the work package that comprises the set-up and integration of components for the 50-kW solar fuel plant at IMDEA Energía in Móstoles, Spain. The system will be tested to understand the relation between quality and quantity of the hydrocarbon product, solar feed gas and operational parameters. Issues like unexpected discolouring of the product are studied. The recycle loop operation to increase liquid products yield will be validated and optimised. The produced hydrocarbon products are analysed in a specialized laboratory for hydrocarbon content and if required metals. After testing the GtL plant will be shipped to IMDEA Energía in Móstoles, Spain.

These developments not only reinforce the technical feasibility of solar fuel synthesis but also contribute meaningfully to the European Green Deal's decarbonization targets for the transport sector.

5. Bibliography

[1] S. Zoller, E. Koepf, D. Nizamian, M. Stephan, A. Patané, P. Haueter, M. Romero, J. González-Aguilar, D. Lieftink, E. d. Wit, S. Brendelberger, A. Sizmann and A. Steinfeld, „A solar tower fuel plant for the thermochemical production of kerosene from H2O and CO2," *Joule,* pp. 1606-1616, 20 07 2022.

[2] K. Jaarin and Y. Kamisah, Repeatedly Heated Vegetable Oils and Lipid Peroxidation, vol. 10, InTech Open, 2012, pp. 211-228.