Ref. Ares(2023)7600658 - 09/11/2023

ConsenCUS

Planning on demonstration cycles

Date	Version	Status	Initials	Changes Marked
21-08/2023	0.1	Draft	UFBI	No
07/09/2023	0.2	Adding model in section 6	FS & MVS	No
20/10/2023	1.0	Restructured	UFBI	No
9/11/2023	1.1	Added Table 5 and EU disclaimer	UFBI	No

This project has received funding from the European Union's Horizon 2020 research and Innovation programme under grant agreement N° 101022484.

Version Control Sheet

WP	WP5 Demonstrations
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Due Date:	2023-10-31
Date:	
Version:	1.1
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Dissemination Level:	X PU: Public □CO: Confidential, only for members of the consortium (including the Commission)

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1 Introduction

1.1 Executive summary

Within the H2020 ConsenCUS project, a demonstration plant will be developed built and tested on 3 industrial sites across Europe. This deliverable outlines the experiments which will be conducted at each site and documents the underlying assumptions and reasons for the choices made. The plant will initially be used with a conservative configuration, offering redundancy if the experimental hardware should fail. Later, when the level of experience with the plant is higher, the limits of the technology will be demonstrated using the full capacity of the plant.

2 Background

Capture and utilization of CO_2 will happen at three sites; Aalborg Portland, OMV Petrom and Grecian Magnesite, in that order. At each site, the stay is limited to 5 months. Taking into account that siting and commissioning of a containerized demonstration plant (Figure 1) can take up to two months, the time for experiments is scarce.

Figure 1. The containerized demonstration plant.

In this deliverable, the experimental plan for each CO_2 capture campaign or *demonstration cycle* is described for each site. The objectives of the campaigns and relevant parameters are described, as well as the circumstances which decide the sequence. The content of this deliverable was initiated at the general assembly held at Heriot-Watt University in Edinburgh April 2023, and finalized in a project group consisting of WP2, WP3 and WP5.

2.1 D5.3 task description from the grant agreement

To further frame this deliverable, an excerpt from the grant agreement describing task 5.1 is included here:

The definition of the demonstration cycles will be based on input from all WP participants and input from other WPs. The input will mainly come from the technology development in WPs 2 and 3. However, WPs 6,7,8 will also provide input (LCA and economics) in *regards to what should be tested and what is expected from the demonstration. The definition of the validation cycles will include visits to the different test sites by all technology providers (COVAL, WETSUS, DTU).*

3 Reaching the campaign objectives

Referring to the grant agreement Table 1.1 on page 5, the Key Objectives 1-3 define the technical goals for the campaigns. From the experiments documented by WP2, it is clear that some of these objectives, e.g. energy consumption and high CO2 production, cannot be demonstrated simultaneously. Likewise, some constraints from the sites are known up front, e.g. at Aalborg Portland only 400 A will be available, limiting the regeneration module to one stack operation only. This aligns well with the fact that only one stack will be used at Aalborg Portland anyway, to keep one in reserve at the crucial first period of the campaign. Similar considerations were taken into account to maximize the likelihood of reaching each of the key objectives (Table 1).

Table 1. Key Objectives relevant to the CO2 capture campaigns.

KO	Description	Strategical considerations and choices
KO#1	Energy consumption of 1.4 GJ/ton CO_2	OMV Petrom and Grecian Magnesite. Given the experience the group will have gained with the plant when reaching these sites, it makes sense to do this there. In practice a minimum consumption will be found and demonstrated for a limited time for the given site.
	CO2 capture efficiency: (>90%)	Aalborg Portland. This can be demonstrated with just one electrochemical stack.
	CO2 purity of >96%	Aalborg Portland. This can be demonstrated with just one electrochemical stack.
KO#2	-30% of overall energy requirements compared to conventional formate production	OMV Petrom and Grecian Magnesite. First, all reactor configurations will be tested along the campaign. The energy requirement run will be made after testig all reactor configuration
	Conversion rate 300 g/kW/h	OMV Petrom and Grecian Magnesite. First, all reactor configurations will be tested along the campaign. The energy requirement run will be made after testig all reactor configuration
	FA production using CO2, H2O and RES-based electricity	Test will be done off-site in Coval Energy facilities. Formate solution produced from the pilot will be shipped in the Netherlands and upgraded to FA in Coval facilities.
	Product yield > 90%	OMV Petrom and Grecian Magnesite. First, all reactor configurations will be tested along the campaign. The

		energy requirement run will be made after testig all reactor configuration
KO#3	>1000 operating hours of CCU demonstration plant in cement, magnesia, and refinery flue gases at a scale of 100 kg CO2/h and 14 tonnes FA/y for the capture and the utilization part respectively.	Each site. Note that the production at Aalborg Portland will be reduced to minimize risks. A maximum of CO2 production will be found and demonstrated for a limited time, and a more moderate tradeoff set-point will be then be used for the 1000 hour demonstration to minimize risks of hardware breakdown.

Another way to represent Table 1 is to summarize the campaign strategies on a site basis (Table 2).

Table 2. Campaign objectives and Key Objectives per site.

Campaign site	**Campaign objective**	**Key objectives to pursue**
Aalborg Portland	- Install and commission plant - Capture and desorb CO2 - Produce formate - Make sure at least one electrochemical stack is ready for OMV Petrom campaign	- CO2 capture efficiency: (>90%) - CO2 purity of >96% - >1000 operating hours of CCU demonstration plant
OMV Petrom	- Install and commission plant - Capture and desorb CO2 - Produce formate - Make sure at least one electrochemical stack is ready for Grecian Magnesite campaign	- Energy consumption of 1.4 GJ/ton CO_2 - 30% of overall energy requirements compared to conventional formate production - Conversion rate 300 g/kW/h - Product yield > 90% - >1000 operating hours of CCU demonstration plant
Grecian Magnesite	- Install and commission plant - Capture and desorb CO2 - Produce formate	As above

4 Definition of experimental plan

The demonstration plant is a completely new process plant, placed repeatedly in new settings. The campaigns at each site will have distinct phases (Table 3).

Table 3. Generic campaign phases at each industrial site.

Phase	**Expected duration**	**Main activities**
Installation	1 week	Trucks and cranes lift the modules into position. The modules are connected to utilities and to each other.
Commissioning	1 month	Verification that basic system functionality is intact after the move. Several engineers on site, frequent ad hoc meetings.
Instrument validation	1 week	Verification of the data quality of specific sensors in the plant.
Base case experiments	1 week	Regular experiments. Project group has online meetings twice a week to discuss results.
Key Objectives	As long as possible	Pursuing Key Objectives depending on what site the demo plant is at, building on the results of the base case.
Decommissioning	2 weeks	Plant is cleaned inside and outside and prepared for transport.
De-installation	1 week	Plant is decoupled from utilities, interconnections are removed and everything is stored for transport.

To build an internal reference database and verify the basic functionality of the system, a base case is required. A base case is a well-defined set of experiments which are the first to be done after commissioning. They explore the boundaries of the system within reason, and allows for easy comparison to earlier states of the system. The base case results should define a large envelope, which allows for later targeted experiments.

For the regeneration module and capture module, the project group (consisting of participants from WP2, WP3 and WP5) used an iterative process to define the base case experiments. This was done referring to the simulated results from an Aspen model (Appendix A) prepared in WP2. It was clear that while a base case could be defined a priori, the set points for reaching e.g. a minimum energy consumption state necessarily must rely on actual experimental results. As such, the base case experiments defines the absolute minimum of that needs to be done at each site (Table 4).

Table 4. Base case experiment considerations for the regeneration and capture modules.

Operational variable	**Values**	**Considerations**
No of stacks	A, B, A+B	A at Aalborg Portland, A+B at OMV Petrom and Grecian Magnesite.
Operation mode	Parallel, Serial, Sequential, Island mode	At the time of this deliverable, the Aspen model cannot provide results for other than the parallel modes. The primary exploration of different modes will be done at OMV Petrom.
Current density (A/m^2)	100 – 1,200	250 A/m2 chosen as the "very low" set point due to this being a reference in earlier WP2 lab experiments (see D2.2). The base case does not go beyond 500 A/m2, but in order to fulfil the KPI of maximum production, the experiments will go beyond that limit. This will be done at OMV Petrom, and with a single stack to begin with.
Flue gas flow rate (Nm^3/h)	0 – 500	Generally set so that the regeneration module can keep up with the amount of CO2 absorbed at a given site.
CO2 content (%)	3 - 20%	While the plant allows for manipulation of the CO2 content by recycling captured CO2, this feature will not be used.
Solvent flow rate from regeneration module to capture module (kg/h)	0 – 6,000	The current set points (300, 700, 1200) are chosen to allow for an exploration in both directions from an initial simulated indication of an optimum at 700 kg/hr.
Solvent flow rate internally in capture module (kg/hr)	0 – 10,000	This set so that a highly loaded CO2 rich solvent can be provided for the regeneration module.
Lean solvent K+ content (mol/l)	0.5 – 3.0	1.1 (given by prior experimentation, see D2.2)
Sulphate concentration (mol/l)	0.05 – 1.0	0.1 (given by prior experimentation, see D2.2)
Temperature (C)	20 – 40	The solvent temperature will not be allowed to exceed 40C, otherwise no experiments will be done with this as a factor.

In addition to these experiments it's likely that the group will decide on clarifying experiments to be done in order to pinpoint the best parameter set to fulfil the Key Objectives. The experimental plan allows for this (Appendix B), thereby being a live document, that defines the mandatory base case experiments and allows for setting and recording basic experimental values for subsequent experiments as chosen by the project group.

For the utilization module, a similar approach was taken, with the exception that no full model exists for the module (Table 5). The expected values are instead based on prior experiments in the lab and a priori calculations. The base case experiments for the utilization module are shown in Appendix C.

Table 5. Base case experiment considerations for the utilization module.

Operational variable	**Values**	**Considerations**
No of stacks	A, B, C or combinations	Reactors are not identical. Some design details and electrode and catalyst materials vary. This is described in more detail in D3.4. Consequently, separate reactors will be tested at each site. A at Aalborg Portland, B at OMVPET, C at GM to focus on performance.
Current density (A/m^2)	150 – 1200	150 is for reactor A, which has a robust design but is limited in current density. The higher current density is expected to be applied for the other reactors.
Recirculation flowrate catholyte (L/h)	650-2000	Depends on the number of reactors. This defines flow velocity inside the reactors. The value is chosen best to compare scaled up performance with laboratory results.
Recirculation flowrate anolyte (L/h)	650-2000	As above.
Concentration KOH (M)	0.5-1.0	The lower the concentration of KOH, the higher expected product purity. Higher concentration of KOH on the other hand leads to higher production rate. Recent tests in lab indicate that 0.5 M could be feasible.
Pressure (bar)	10-40	The higher the pressure, the higher the production rate. But it lowers the product yield, defining a trade-off situation. The best trade-off is expected at 20 bar.
Product flowrate (L/h)	3.0-8.2	When the purification is running, the product volume will decrease as the concentration increases and water is removed. More reactors in operation will create more product. Mass balance calculations show that 8.2 l/hr from one reactor, un-purified should produce 1 M of product.
Duration (hours)	-	This set to 8 hrs x 3 for the base case for a total of 24 hrs for each base case experiment.
Concentration/purification of product on or off	On or off	The purification step is separate from the rest of the process and is expected to work.

Besides the values recorded directly in the excel sheets, the demonstration plant logs all flows, temperatures and other values in an online cloud solution so that researchers can mine the data extensively, referring to the experimental plans for a basic overview.

5 Conclusion

The demonstration plant built and used in this project is one of a kind. To make sure that the Key Objectives of the project are pursued in the best way, an experimental plan has been defined, comprising both mandatory elements which build a sound foundation as well has leaving room for decisions during the campaigns. This deliverable outlines the experiments which will be conducted at each site and documents the underlying assumptions and reasons for the choices made. The regeneration module in the plant will initially be tested with a single electrochemical stack, offering redundancy if the experimental hardware should fail. Later, when the level of experience with the plant is higher, the limits of the technology will be demonstrated using the full capacity of the plant.