1 Project description

Name organisation	TNO
Name program	Sourcing of Skids
Tender	European public sourcing program

Project name	Absorber and desorber setup for Direct Air Capture and CO2 capture from fluegas
Project Number	177
Division	NETLAB

2 Project Introduction

Within the NET Lab venture, TNO intends to realise experimental test stations for the testing of different negative emission technologies, focusing specifically on direct air capture. One of the activities is based on CO_2 absorption.

In classical CO_2 Capture plants, a CO_2-containing gas stream enters an absorber column, in which it gets absorbed by a CO_2 capture solvent. Then, the mixture of solvent and CO_2 enters a stripper, in which the CO_2 is released, and the CO_2 capture solvent can be reused in the absorption part.

The aim of the present project is to develop and realise a novel process to capture CO_2 from air by absorption using a known solvent. Since the process is not yet fully developed and widely applied this is an important step on the research for the optimal operation conditions to improve the efficiency and make this process more feasible and competitive in the market.

Two absorption units will be constructed in order to evaluate the differences between direct air capture and CO_2 capture from flue gas.

3 Project Background

The goal of TNO with the NET Lab is to demonstrate the feasibility of several negative emission technologies by constructing several experimental skids in which these processes will be tested. These test installations can be combined with CCU projects and can also be used to try different prototypes in industrially relevant conditions by different parties. The idea is that this installation becomes part of the open innovation facilities in which negative emission technologies can get accelerated towards higher technology readiness level for a final industrial implementation to realise the climate goal of not surpassing the 1.5° C warming.

The three different technologies to be tested in the NET Lab are the following:

- Activity 1: Absorption;
- Activity 2: Adsorption test street;
- Activity 3: Carbon Capture and Utilisation; CHARLIE & SERENA processes, that are integrated CO_2 capture & conversion processes.

The present tender deals with Activity 1, '*Absorption'* which will be divided in two cases: direct air capture and CO_2 capture from flue gas.

4 Scope and deliverables

The scope of the present project is to engineer, manufacture, transport and install a demonstration unit for direct air capture (DAC) capable of processing a gas inlet containing 400 ppm of CO_2 and another unit for flue gas capture containing 4-12%vol. of CO_2. The demonstration unit shall consist of:

- 2 absorption columns (one for DAC and the other one for flue gas),
- 1 stripper column (for both DAC and flue gas cases),
- setup and instrumentation around it,
- all the necessary interconnected and self-contained skid units with individual connections to the site supplied utilities.

4.1 Exclusions

The packing design is out of scope of the tender. The packing materials should be commercially available.

4.2 Scope, and content of the contract

The Contract (absorption columns + setup + instrumentation) relates to the provision of supplies, services or works as specified in the Programme of Requirements as applicable.

The key points of this Contract are:

DESIGN:
- Basic engineering package of the demonstration unit;
- Detailed engineering for the demonstration unit PROCUREMENT & MANUFACTURE
- Procurement and manufacture of equipment as per detailed design

INSTALLATION
- Installation of the components together (e.g. hardware, piping, electricity, , control unit, software, utilities) in a functional system – demonstration unit

INSPECTION and TESTING
- Factory Acceptance Test (FAT) of the unit at the supplier site (e.g. leak test, mechanical integrity, test for performance and so forth)

TRANSPORTATION to TNO given address

INSTALLATION at TNO given address
- Installation of the unit at the TNO given address.
- Site Acceptance Test (SAT) at the TNO given location
- Simple training of the operators (equipment and software)

4.3 End result/deliverable

The result of the project is the commissioned demonstration unit. Next to the demonstration unit, the supplier will need to deliver the following documentation:

As part of the basic engineering package:
- Piping and Instrumentation diagrams;
- Layout drawings;

- Equipment specification sheets;
- Instruments specification sheets;
- Analysers specification sheets;
- Control narrative.

All above described documents will be send to TNO for approval. After the approval of TNO, the detailed engineering and procurement can start.

As part of safety assessment:

- HAZOP report (the HAZOP will be organized and facilitated by the chosen supplier and TNO will be part of the HAZOP sessions).

As part of detailed engineering, procurement and construction:

- P&ID, layout drawing, equipment drawings
- Instruments data sheets
- Analysers data sheets
- Factory Acceptance Test – PLAN
- Operational manual
- Maintenance manual
- Source code of all developed software
- All above described documents will be send to TNO for approval

5 Functional description

5.1 Absorption units

The absorption units are to be used for **CO_2 DAC** and **CO_2 capture from flue gas**. The working principle of both units is the same and the equipment around it as well, however, the absorber columns need to be resized for each case due to the significant difference in CO_2 content in the gas inlet. For this reason, two absorber columns are presented, however, the system should be modular and adjustable in order to facilitate the exchange of columns in a simple way. The desorption side should be operated together with the absorption side of the setup. In order to do so, a desorber column is also part of the design. Along with that, TNO is developing an electrochemical cell (CODEC) that must receive the CO_2-rich solvent after one of the absorption columns, although this cell does not fall in the scope of this project, a connection should be available to couple both systems. Along with that, a desorber column will also be designed as part of this tender.

5.1.1 CO_2 capture process description

The absorption process for the CO_2 capture from air or flue gas is part of Activity 1 of the NET Lab project, i.e. ‘Absorption’. The function of the absorption process as part of Activity 1, ‘Absorption’ is to serve as the CO_2 capture side of the setup by absorbing the gas in a liquid alkaline solvent that will be constantly circulating in the setup. The CO_2 is absorbed in the liquid via a chemical reaction with the solvent, and it is circulated to the desorber column for the CO_2 to be released and the liquid regenerated to be able to capture more CO_2 in a continuous way. Figure 1 shows a simple diagram of the absorption column and the vessels around it. Controlling, measurements devices and analytical equipment will be further described.

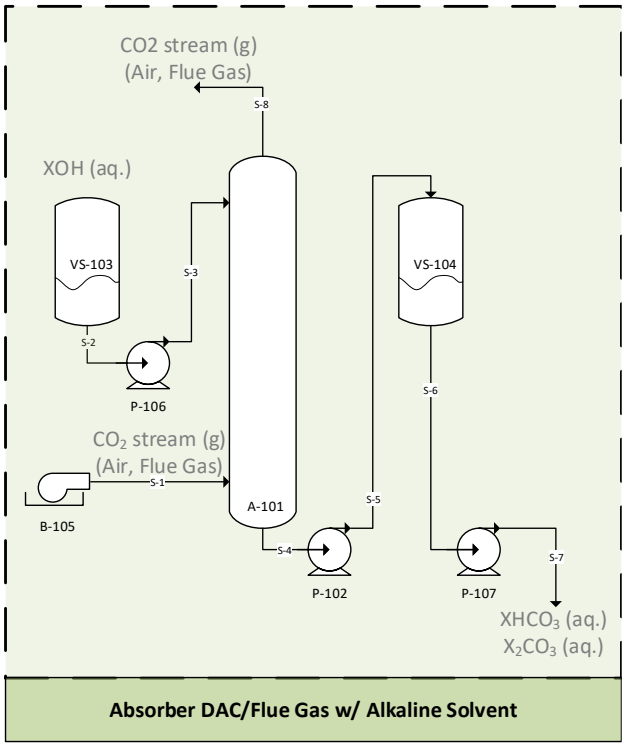

Figure 1 – Schematic representation of the absorption section

It must be stressed that the absorption process & setup is a completely standalone skid, independent of any of the desorption units that will be later coupled to it and are also part of Line 1 of the NET Lab project. Its design shall be modular and must be completely autonomous, regardless the possible interconnections with other parts and units of other processes. The intention with this setup is that, beyond the NET Lab project, it shall be functional and adaptable to other processes and systems and that different configurations could be used for other applications.

5.1.2 Principle of CO_2 Absorption in a solvent

The CO_2 content in different gas streams varies significantly. Considering DAC cases, the quantities are around 400 ppmv, while for flue gas cases it can be between 8-12 vol%. Although this requires a change in the sizing of the equipment and solvent concentration, the principle of the absorption remains the same for both cases. An alkaline aqueous solvent (KOH solution) in this case will be used for this process.

The inlet gases enter the absorber column and there the CO_2 contacts the solvent and it is directly absorbed by the reaction with the solvent as shown in equation 1. This process happens at 40°C.

$$2KOH + CO_2 \rightarrow K_2CO_3 + H_2O \quad (1)$$

The solvent which is now rich in CO_2 leaves the sump of the absorber and passes a heat exchanger that will increase the temperature to 80°C to facilitate the regeneration process. The solvent is then regenerated and the CO_2 leaves the process in the gas form at the desorber stage. The liquid, which is now lean in CO_2, is pumped back to the top of the absorber and flows down to the bottom of the column in counter current to the gas flow. The solvent capacity is determined by the

difference in loading between the rich and the lean and determines the amount of CO_2 that can be captured in the process.

Equipment's material SHALL be in SS316 and connections should be imperial and not metric. All equipment SHALL withstand a large pH range (range 6-14).

5.1.3 Absorber setup configuration

5.1.3.1 Direct air capture case

The challenge of capturing CO_2 from air relates to the high air flows needed in comparison to the liquid flows used in the setups. The conditions used and the equipment needed for both gas inlet and outlet of the absorber are shown in Tables 1 and 2. Regarding the liquid, the conditions and equipment needed are presented in Tables 3 and 4.

Table 1 - Absorber inlet (air) conditions and necessary equipment

Air inlet		
Equipment	**Range**	**Unit**
Blower	150-400	Nm^3/h
	up to 150	mbar
Evaporator/Humidifier	20-40	°C
	50-100	RH
CO_2 analyzer	0-500	ppmv
Thermocouple	0-60	°C
Pressure sensor	0-2	bara
Mass flow meter	150-400	Nm^3/h

Table 2 - Absorber outlet (air) conditions and necessary equipment

Air outlet		
Equipment	**Range**	**Unit**
CO_2 analyzer	0-500	ppmv
Thermocouple	0-60	°C
Pressure sensor	0-2	bara

Table 3 - Absorber inlet (liquid) conditions and necessary equipment

Liquid inlet		
Equipment	**Range**	**Unit**
Vessel	80	L
Pump	3-20	kg/h
Cori flow	2-20	L/h
Heat exchanger	-	-
Water bath	500 (cooling) 2000 (heating)	W
Thermocouple	0-100	°C
Pressure sensor	0-5	bara
Three way valve	-	-
Sample point	-	-

Table 4 - Absorber outlet (liquid) conditions and necessary equipment

Liquid outlet		
Equipment	**Range**	**Unit**
Pump	3-20	kg/h
Cori flow	2-20	L/h
Thermocouple	0-100	°C
Pressure sensor	0-5	bara
pH sensor	6-14	-
Vessel	80	L

The column should be designed wide enough to be able to handle the large streams of air while maintaining the liquid in the installation. Along with that, the pressure difference in the packing should be low (e.g. cooling tower packing). The dimensions of the column are shown in Table 5.

Table 5 - Absorber column dimension for direct air capture case

Column 1 – Absorber for direct air capture			
Parameter	**Dimension**	**Unit**	**Comment**
Diameter	0,44	m	-
Packing height	2	m	2 sections of 1 m each, possibility to remove 1 section
Packing type			Mellapack CC or cooling tower packing
Packing specific area	100-200	m^2/m^3	
Pressure drop	max 50	Pa/m	Pressure drop through the packing (max F factor within the set experimental range)

Sump volume	1- 4	L	Minimun 1 to maximum 4 L

The desorption in this scenario will be done with the desorber column. Together with this, a connection to the CODEC setup is also needed.

5.1.3.2 Flue gas case

The concentration of CO_2 present in the flue gas is significantly higher than in air which allows for operation with lower gas inlet flow and narrower but higher columns. Although as observed in Tables 6 and 7 the gas flows are different than for the other scenario, the liquid conditions and instrumentation are the same as presented in Tables 3 and 4.

Table 6 - Absorber inlet (gas) conditions and necessary equipment

Gas inlet		
Equipment	**Range**	**Unit**
Mass flow controller CO_2	0.1-0.5	Nm^3/h
Mass flow controller Air	0.5-3.0	Nm^3/h
Evaporator	20-40	°C
	50-100	RH
CO_2 analyzer	1-50	vol%
Thermocouple	20-80	°C
Pressure sensor	1-5	bara
Mass flow meter	0-5	Nm^3/h

Table 7 - Absorber outlet (gas) conditions and necessary equipment

Gas outlet		
Equipment	**Range**	**Unit**
CO_2 analyzer	1-50	vol%
Thermocouple	20-80	°C
Pressure sensor	0-2	bara

As stated before, the column in this case has a smaller diameter and different packing since somewhat higher pressure drop is acceptable in this case. The dimensions of the column are shown in Table 7.

Table 8 - Absorber column dimension for CO_2 capture from flue gas

Column 2 - Absorber for flue gas			
Parameter	**Dimension**	**Unit**	**Comment**
Diameter	0.045	m	-
Packing height	2	m	2 sections of 1 m each, possibility to remove 1 section
Packing type			Structured packing with specific surface area of 250 m2/m3 or higher

Pressure drop	max 1000	Pa/m	Pressure drop through the packing (max F factor within the set experimental range)
Sump volume	1- 4	L	Minimun 1 to maximum 4 L

The absorber will be connected to a desorber column with the same dimensions shown in Table 8. The equipment needed for the outlet of the desorber are presented in Table 9. The pressure inside the column is regulated by a pressure sensor in combination with a pneumatic valve on top of the column.

Table 9 - Desorber outlet (gas) conditions and necessary equipment

Gas outlet		
Equipment	**Range**	**Unit**
CO_2 analyzer	1-50	vol%
Thermocouple	50-150	°C
Pressure sensor	0-5	bara
Pneumatic valve	0-5	bara

5.2 Absorption Setup

5.2.1 Process Description

The PFD for the Absorption setup for both scenarios (direct air capture and flue gas) can be found in File 1 of the Appendix, '*Absorber setup.pdf*'.

The operation of the absorber setup for DAC has a blower in the inlet to be able to reach high flows of gas needed for the process. For the flue gas, on the other hand, the gases come from gas cylinders and are controlled with the help of mass flow controllers.

After the blower/mass flow controllers the gas passes through an evaporator to be saturated with water. The gas enters the absorber column and the CO_2 is reacted when in contact with the solvent. In the gas inlet line, temperature, pressure, flow and CO_2 content are measured.

The rich liquid is pumped to a heat exchanger to increase the temperature before going to the desorber process. A vessel should be designed to act as a buffer in case the desorber is not in operation.

After the desorption process, the liquid is cooled down via the heat exchanger and is pumped back to the top of the absorber. Both rich and lean lines contain temperature, pressure, flow, density, pH and conductivity sensors. Every section of the absorber column also has temperature sensors (beginning, middle and end of the packing section). In the gas outlet line, temperature, pressure, flow and CO_2 content are measured.

The mentioned equipment in the above paragraphs or arrangement of the various equipment units from the appended PFD are just a suggestion for the tenderer to do the design of the absorption setup. The list of requirements that the absorption setup design shall comply with can be found in Section 6.2 Absorber setup technical design.

6 Programme of requirements

The Programme of Requirements is divided into the following sections:

- Delivered goods and regulations
- Organizational aspects: Procedure, Planning, Risk and Risk Mitigations (section Project plan and implementation).
- Technical functional aspects for the Absorber setup (section Absorber setup technical design **Error! Reference source not found.**).

The delivered goods need to comply with the following regulations:

Nr.	General regulations requirements
6.1.1	The unit SHALL comply with all applicable Dutch laws, regulations, rules, standards and guidelines. Furthermore it shall also comply with European standards and requirements, in particular risk management and safety regulations.
6.1.2	The delivered goods SHALL have CE conformity.
6.1.3	The design of the unit SHALL be in line with international engineering standards.
6.1.4	The unit SHALL comply with the HAZOP that will be performed by the parties involved
6.1.5	Any Party (i.e. entity, governmental body or individuals) that responds to this tender, WILL be screened according to the TNO Sanctions & Export Control Policy. In case of conflicts arising from this, TNO has the right to decline the response of the Party upon its own discretion, with no further liabilities towards Party.

Nr	General safety requirements
6.2.1	Piping, flanges and vessels with its accessories with a design pressure higher than 0.5 bar(g) SHALL be designed, fabricated and installed according to the requirements set out in the Dutch pressure vessel regulations.
6.2.2	All vessels, piping and safety accessories SHALL have a CE marking as stated within the regulations.
6.2.3	Piping, flanges and vessels with its accessories less than or equal to 0.5 bar(g) SHALL conform to the additional requirements as stipulated in the Dutch regulations and SHALL also be CE marked.

6.1 Project plan and implementation

The object of the present tender can be seen as two main stages:

- The design phase;
    - In the design stage, it is envisaged that it will involve a team of engineers from both TNO as well as the tenderer.
- The building and commissioning phase.

Nr.	Planning & implementation requirements

6.1.1.1	Language for all documentation and correspondence SHALL be in English.
6.1.1.2	The official language within the TNO team SHALL be English. The team members are expected to be sufficiently proficient in both written and verbal language.
6.1.1.3	With the team members, on a personal level, a Non Disclose Agreement SHALL be signed.
6.1.1.4	The complete installation (Absorber setup + instrumentation) SHALL be ready BEFORE September 1st 2021
6.1.1.5	The overall plan for the manufacturing and delivery of the Absorber setup (columns + setup + instrumentation) SHALL consist of the design phase, and the building and commissioning phase
6.1.1.6	The design phase will consist of the following tasks: - T1. *Requirement specification* - T2. Absorber setup *conceptual design* - T3. Absorber setup *engineering design* - T4. Absorber setup *components specification* - T5. Safety study Tenderer SHALL accept that TNO will review all documents and deliverables out of the design phase, so it should be possible to make recommendations and changes during the design phase.
6.1.1.7	The building and commissioning phase will consist of the following tasks: - T6. *Choice of suppliers and ordering of components* - T7. *Mechanical and electrical assembling, construction and column manufacturing* - T8. *Automation system* - T9. *FAT and SAT* - T10. *Final documentation* The building and commissioning phase will start only if all documents, outputs and deliverables from the design phase produced by the tenderer have been approved by TNO. Tenderer SHALL accept that TNO will review all documents and deliverables out of the building and commissioning phase, so it should be possible to make recommendations and changes during the design phase.
6.1.1.8	Task 1, '*Requirement specification'*, is owned by TNO and the requirements SHALL be formulated together with the tenderer company
6.1.1.9	Task 2, ' Absorber setup conceptual ***design'***, is carried out by the tenderer and will be the design of the setup for operation. All possible IP generated with the design of the Absorption setup column will become property of TNO
6.1.1.10	Task 2, ' Absorber setup *conceptual design'*, is owned by the tenderer and it results into a conceptual design which can be a process flow diagram. TNO should be consulted and it should approve this diagram before the next stage begins. The completion of this task should take into account the requirements defined at Task 1 and the one agreed upon at the signing of the contract.
6.1.1.11	Task 3 ' Absorber setup *engineering design*', is owned by tenderer company and it should have as output the engineering design for the pilot based on input from Task 1 and Task 3 and it should be approved by the TNO engineering team. This task has two outputs: - Output 4.1 is the P&ID of the Absorption setup - Output 4.2 is the Design document

6.1.1.12	Task 4, ' Absorber setup *components specification*', is owned by the tenderer and it results into a component specification and a list of components. For the completion of this task, the input from previous tasks should be taken into account. This list should be as concrete as possible and supplying companies already need to be indicated here.
6.1.1.13	Task 5 '*Safety study*', is owned by the tenderer but TNO will be part of the safety discussions. The tenderer is responsible to compile and deliver the safety documentation of the installation and process (HAZOP methodology to be used here).
6.1.1.14	The design phase SHALL not take more than 6 months from beginning of Task 1 till the completion of Task 5.
6.1.1.15	Task 6, '*Choice of suppliers and ordering of components'*, is owned by the tenderer, and consists of the ordering of the components. A list of all the components and the technical documentation of the main components will be prepared by the tenderer to be delivered to TNO.
6.1.1.16	Task 7, '*Mechanical and electrical assembling, construction and column manufacturing*', is owned by the tenderer, and consists of the assembling and building of the Absorber setup , as well as the manufacturing of the Absorber setup . A setup layout diagram and a detailed drawing of the Absorber setup will be provided to TNO by the tenderer.
6.1.1.17	Task 8 '*Automation system*', is owned by the tenderer, and consists of the creation of the automation system for the Absorber setup , as well as its implementation in the constructed skid, incl. alarms, wiring, cabinet installation, etc.. A manual of control system will be provided together with the software. Source code of the software will also be provided.
6.1.1.18	Task 9, '*FAT and SAT*', is owned by the tenderer, and consists of the Factory Acceptance Test (FAT), at the tenderer premises, and the Site Acceptance Test (SAT), at the chosen TNO premises. During the SAT at TNO location, the tenderer SHALL provide a simple training to the operators so that they can have enough knowledge of the equipment, software and how to operate it. The three deliverables of this task are the report for the FAT, the report for the SAT and the basic training of TNO personnel.
6.1.1.19	The FAT and SAT SHALL comply with a list of requirements, stated in a validation plan, proposed by the supplier, and agreed by TNO. This validation plan SHALL be finalised two months before the start of the FAT
6.1.1.20	Task 10 '*Final documentation*', is owned by the tenderer, and consists of the preparation of all necessary documentation: technical operation manual, declaration of conformity.
6.1.1.21	The building and commissioning phase SHALL not take more than 9 months from beginning of task T6 till the completion of task T10
6.1.1.22	After the completion of Task 10 the delivered installation SHALL have a test period of 2 months, in which the delivered installation must comply with the agreed specifications and without faults or malfunctions.

The requirements related to the FAT and SAT can be found in the following tables:

Nr.	Factory Acceptance Test (FAT) and Site Acceptance Test (SAT)
6.1.2.1	A Factory Acceptance Test (FAT) which is performed at the factory before delivery to TNO;
6.1.2.2	A Site Acceptance Test (SAT) SHALL be performed at TNO after delivery. During this test, the setup SHALL be able to run independently overnight.

6.1.2.3	The requirements shall be validated according a validation plan proposed by the supplier and agreed by TNO.
6.1.2.4	A first draft of this validation plan shall be supplied to TNO before the delivery of the design phase.
6.1.2.5	The validation plan shall be finalized two months before the start of the FAT, and SHALL be approved by TNO.
6.1.2.6	The validation plan will be used in both the FAT and the SAT.

Nr.	The SAT contains the following checkpoints:
6.1.3.1	The system will be checked for damages;
6.1.3.2	The proper functioning of the equipment will be checked; • Mechanical functions; • Electrical safety- and switching functions; • User interface(s), including software.
6.1.3.3	All requirements and possible Preferences will be checked; The presence and quality of the documentation will be checked
6.1.3.4	A full acceptance test on-site must be performed by the Tenderer in cooperation with TNO. The Tenderer shall put forward a FAT and SAT proposal. The details of the FAT and SAT shall be agreed between TNO and the Tenderer. Following the approved SAT, the delivered equipment shall be at the unrestricted disposal of TNO for two months. If the system works according to the agreed specifications and without faults or malfunctions during this period, the test period is approved. If not, the faults or malfunctions shall be amended and another test period of two months should successfully be completed and approved.

Nr.	Validation plan for FAT & SAT
6.1.4.1	The connection of the components that might trigger a warning and/or alarm to the central control system will be checked for errors and connectivity issues.
6.1.4.2	The safety components, (e.g.: pressure relief valves, flammable gas sensor, etc.) will be set up and inspected.
6.1.4.3	The different components of the setup will be inspected to check whether the lay-out of the as-built setup is in correspondence with the delivered documentation & P&ID.
6.1.4.4	The setup will be checked for leakages in a control experiment with water and also to test the functionality of pumps, heat exchangers, valves and mass flow meters and controllers.
6.1.4.5	The setup will be checked in a simulated experiment at relevant process conditions to test all safety and instrumentation equipment, as well as the correct functionality of all sub-systems and the capability of capturing CO_2 for both DAC and fluegas operation.
6.1.4.6	The response of the setup will be checked in a simulated crash of the control system.
6.1.4.7	The emergency shutdown and power cut procedures will be tested to check whether they trigger the actions reported in the safety documentation.
6.1.4.8	The emergency shutdown button will be tested.

Nr.	Failure in FAT / SAT
6.1.5.1	In the event that the Deliverables fail to meet the Acceptance Criteria for the FAT and the SAT, as the case may be, the parties shall jointly set out such failures in a written statement, to be signed by both parties.

6.1.5.2	On TNO-side this will be done by TNO-management and TNO Procurement. Tenderer shall provide Purchaser with a corrective action plan for such failures within fifteen (15) business days (or different period agreed to by the Parties) of the date of signing of such statement and, upon approval of such corrective action plan, Tenderer shall correct such failures at no additional charge within the timeframe laid down in the corrective action plan

The requirements related to the Engineering Change Notice (ECN) can be found in the following table:

Nr.	**Engineering Change Notice (ECN) after contract award:**
6.1.6.1	All Engineering Change Notice and acceptance or rejection of such orders shall be in writing and made pursuant to the ECN procedure set forth below. All changes are subject to mutual agreement of the parties. When the change affects pricing about the delivered skid, the written approval must be in the form of a purchase order issued by TNO. When the change affects specifications about the delivered skid, the written approval must be issued by TNO.
6.1.6.2	Upon TNO's submission of an ECN, Supplier will as soon as reasonably possible advice TNO of the resulting impact on cost and Time Schedule and will provide such information as TNO may reasonably request to determine the reasonableness of the cost and delivery schedule impact. The parties will negotiate the ECN request in good faith, including reasonable adjustment of cost, schedule and/or other Project and Agreement terms. After reaching agreement on such cost, schedule and other terms, Supplier will proceed with the ECN.
6.1.6.3	Supplier may request an ECN, provided cost and delivery impact are properly detailed with such information as will permit TNO to determine the reasonableness thereof. The parties will negotiate the ECN request in good faith, including reasonable adjustment of cost, schedule and/or other Project and Agreement terms. After reaching agreement on such cost, schedule and other terms, Supplier will proceed with the change notice.

The tenderer is required to provide an answer for the following requirement:

Nr.	**KW1 Project plan and implementation**
KW1	TNO seeks a proposal for a project plan, including a planning, risks (on the side of the tenderer) and necessary mitigation actions for the implementation. The project plan should describe, how this is best achieved, and how the needed delivery time is met. The proposed tasks by TNO in the design and building and commissioning phases shall be present in the proposed plan by the tenderer. The tenderer is free to suggest modifications and/or additions to the proposed tasks by TNO. If tenderer wishes to suggest changes to the workflow, TNO expects the clear reasoning. Please include the following items in the project plan: • Planning; • Risks and Risk mitigation actions, describing the 5 most important risks for realisation of the project by the tenderer in terms of cost and time, together with mitigation measures proposed; • Milestones;

	• Meetings (when and where), minutes & change notifications; • Deliverables & documents, etc.; • Listing of estimates in total hours and/or budget of TNO/Tenderer per stage: • Design, procurement (purchase of components), project management, building & commissioning • Brief description of the team that will work on the project, with the title and the function they will perform (3 lines per person); Preliminary plan for a maintenance service of the delivered goods (e.g.: for non-Dutch tenderers, maintenance tasks can be outsourced to a local company to avoid long waiting periods for the tenderer to travel to the TNO premises)
	The entire answer should be straight to the point, concise and easily readable. The entire answer should be no more than 20 (twenty) A4 pages. If the answer exceeds twenty A4 pages, the additional pages will be disregarded.

6.2 Absorber setup technical design

In the following tables, the requirements and preferences for the Absorber setup are presented.

Nr.	Absorber setup Requirements
6.2.1.1	The Absorber setup SHALL consist of: 1. Gas inlet section to be shifted between DAC and flue gas modes 2. Absorber column for DAC 3. Absorber column for operation with flue gas 4. Rich line section with instrumentation and equipment needed 5. Desorber column 6. Lean line section with instrumentation and equipment needed
6.2.1.2	The Absorber column for direct air capture SHALL be able to operate with gas flow rates up to 400Nm^3/h and liquid flows of maximum 20 NL/h.
6.2.1.3	The Absorber column for the CO_2 capture from flue gas SHALL be able to handle up to 3.5 m^3/h of gas and 20 L/h of liquid.
6.2.1.4	All lines (liquid and gas) SHALL be equipped with sensors and analysers that can be instantly and easily checked in the software to make sure the operation is under control (as shown in the P&ID)
6.2.1.5	The CO_2 concentration in the gas inlet and outlet SHALL be able to be accurately measured inline
6.2.1.6	The setup SHALL be designed for a 24/7 operation without the constant need of an operator
6.2.1.7	The setup SHALL be equipped with safety measures such as emergency shut down that will stop the plant completely in a controlled way in case of: low-low level in the columns, high-high levels in the columns, electrical failure, or other hazardous situations.
6.2.1.8	Regardless the chosen column configuration (DAC or Flue Gas columns), the setup components SHALL be able to run and ensure a safe operation at the stated operating conditions in Section 5.1.3.1 for DAC, and 5.1.3.2 for Flue Gas. The tenderer SHALL have tested the setup to check whether the abovementioned operating conditions can be reached safely and a demonstration will be done during the SAT at TNO location.

6.2.1.9	The design of the Absorber setup SHALL accommodate the easy and facile transformation between (DAC), Option #2 (flue gas) as well to be coupled to the desorber (desorption column), or be transferred out of the setup.
6.2.1.10	In the Absorber setup, the different equipment and components SHALL be easily exchangeable for the operator and commercially available
6.2.1.11	The Absorber setup SHALL be gas tight and leak free
6.2.1.12	The humidifier should be able to humidify the total direct air to 100%. All the connections to demi water should be available

Nr.	Absorber setup Requirements
6.2.2.1	The absorber column SHALL be dimensioned for the amount of CO_2 that needs to be captured and should be different from each case as described in Table *5* and Table *8*
6.2.2.2	All the equipment SHALL be able to withstand the operation conditions (if plastic installations are available they should comply to the temperature, pressure and pH of the system)
6.2.2.3	The system should be able to handle 20-30 L of solvent
6.2.2.4	The pressure drop through the packing for the DAC process should not exceed 50 Pa/m (max factor within the set experimental range)
6.2.2.5	The pressure drop through the packing for the flue gas process should not exceed 1000 Pa/m (max factor within the set experimental range)

Nr.	Absorber setup General User Requirements
6.2.3.1	The Absorber setup SHALL be able to operate at pH between 5 and 14;
6.2.3.2	The Absorber setup SHALL be able to operate at temperature between 10 – 100° C;
6.2.3.3	The Absorber setup SHALL be able to stand pressures up to 5 bar(a);
6.2.3.4	The Absorber setup SHALL be able to operate at a pressure of 1 – 2 bar(a);
6.2.3.5	The Absorber setup SHALL be able to operate at liquid flowrates 3 – 20 L/h;
6.2.3.6	The materials SHALL be resistant to CO_2, O_2, water, HCO_3^-, CO_3^{2-}, NH_3, aqueous solutions of NaOH (0,2 – 3M), KOH (0,2 – 3M), monoethanolamine (1 – 6M)
6.2.3.7	The Absorber setup SHALL have a lifetime of at least 5 years of 24/7 continuous operation, with respect to corrosion resistance, mechanical stability, etc., and be able to withstand a cyclic operation (e.g.: repeated loading and unloading of the different buffer vessels).
6.2.3.8	The Absorber setup equipment SHALL be robust and functional to allow to be multiple times easily assembled and disassembled by the operator,
6.2.3.9	The columns SHALL be able to accommodate counter current operation
6.2.3.10	The mass flow controllers at both outlets SHALL withstand humidity
6.2.3.11	It SHALL be taken into account that the analysers need protective measures to avoid contact with moisture
6.2.3.12	Sample points SHALL be available at both lean and rich lines
6.2.3.13	The setup SHALL enter alarm mode in case of low-low or high-high flows in the columns
6.2.3.14	The reactor SHALL have spare parts of critical components (e.g.: as automatic valves, filters, etc.)
6.2.3.15	The setup SHALL be equipped with a leaking tray that can fit the entire inventory of the setup in case of a leakage

Nr.	Absorber setup, Material Requirements

6.2.4.1	The construction materials and equipment used SHALL be resistant to KOH and high pH The materials SHALL be resistant to CO_2, O_2, water, HCO_3^-, CO_3^{2-}, NH_3, aqueous solutions of NaOH (0,2 – 3M), KOH (0,2 – 3M), monoethanolamine (1 – 6M)
6.2.4.2	The equipment and analysers for the absorber setup SHALL be commercially available and maintenance should be available
6.2.4.3	All materials, sensors, analysers and valves SHALL be compatible with the test conditions mentioned previously in the technical requirements. All the piping and connections should be SS316 and imperial scale (not metric)

Nr.	Absorber setup, skid & control system requirements
6.2.5.1	The Absorber setup SHALL be assembled in a frame with lockable wheels that can be movable and hoisted. This means that it can be easily disconnected and reconnected for transport through laboratory doors. In addition, adjustable feet should be placed for stable final placement during operation. Not only shifting the absorbers should be easy but also coupling the absorbers to the desired desorber technology
6.2.5.2	When operating the Absorber setup, it SHALL not exceed a noise limit of 80 dB
6.2.5.3	The Absorber setup SHALL feature a computer, a screen and some keyboard + mouse (or touchscreen) in which the control software is installed and operative. The computer SHALL be integrated in the Absorption setup, and be a functional part of the skid.
6.2.5.4	The operator SHALL be easily able to reach the instruments and sample points in the skid manually for maintenance and modification purposes.
6.2.5.5	Sufficient lighting SHALL be mounted in the skid to facilitate operation.
6.2.5.6	The Absorber setup SHALL include a control system to operate the skid, incl. hardware and software
6.2.5.7	The Absorber setup SHALL be fully automated, i.e., it shall be able to record data from sensors autonomously, and run unattended without the action of an operator (continuous operation).
6.2.5.8	The Absorber setup SHALL be able to be operated remotely through an internet connection.
6.2.5.9	The Absorber setup SHALL have a data-logging system for all the sensors of the setup to record all variables measured during operation
	The CODEC setup SHALL record all available raw data from the installed sensors.
	The CODEC setup SHALL record all data on a hard disk, so that, in case of a power failure, the loss of data shall be of maximum 1 minute.
6.2.5.10	The Absorber setup SHALL have spare parts available for AT LEAST 1 year after delivery and SAT
6.2.5.11	The Absorber setup SHALL be operated by TNO personnel at the chosen premises in which the skid will be delivered and installed
6.2.5.12	The Absorber setup SHALL be operated according to the TNO regulations of the chosen premises
6.2.5.13	The Absorber setup SHALL feature buttons for emergency stop of the operation that are easily reachable by the operators
6.2.5.14	The Absorber setup SHALL feature pressure relief valves or a similar system to prevent a dangerous overpressure in any part of the system
6.2.5.15	The Absorber setup SHALL feature leak trays or drip trays to allow the collection of any possible spilled chemical or substance from the setup
6.2.5.16	All piping and tubing in the Absorber setup SHALL be easily exchangeable. When applicable, for stainless steel piping, it is highly preferred to have Swagelok Imperial tubing in the Absorber setup, as it is the current standard at the TNO premises
6.2.5.17	The Absorber setup SHALL alert the operators in case of an alarm with a sound and lighting system

6.2.5.18	The control system of the Absorber setup SHALL allow the definition of different situations, like Emergency Shutdown, or Power cut, that are triggered by specific alarms, and prompt actions in the system to safely stop the setup operation.
	All error codes, alarm situations and warnings SHALL be recorded and logged into the system.
6.2.5.19	The control software interface SHALL be open source for the TNO personnel to have access and be able to modify it. It is highly preferred to have as control interface environment the software LabVIEW, as it is the current standard at the TNO premises
6.2.5.21	The control hardware SHALL feature control bus connections. It is highly preferred to have as control bus connections the type FLOWBUS, especially for the connections of flowmeters and pumps for the local flowrate control loop.

Nr.	**KW2 Absorption setup technical design**
KW2	The proposed PFD for the Absorption setup (Appendix) is an initial suggestion to start with the design of the installation. Given the programme of requirements for the Absorption setup, it is expected from the tenderer to provide a basic preliminary conceptual design for the Absorption setup, complying with the mentioned list of technical requirements, that comprises the 6 abovementioned sections of the Absorption setup. The tenderer must provide the following: • a basic conceptual design of the Absorption setup; • a basic preliminary PFD for the Absorption setup; • a flow diagram of the control loop to be implemented; • information about components suppliers, type, model and operational range of the equipment; • Accessible replacement and maintenance of parts/equipment • when applicable and available, a preliminary solution to have as much as possible a metal-free setup. The key highlights of the design must be presented, along with the main advantages and characteristics. Address the challenges and solutions in the design, and the motivation to any proposed modifications to the presented PFD for the Absorption setup (Appendix). Provide information about the reasons to choose the selected components. Please be aware that it is not the intention to have a detailed and complete engineering design, but just the main guidelines and the strategy to follow during the design phase to come up with a successful skid.
	The entire answer should be concise, easily readable and not too extensive. Preliminary sketches and diagrams can also be part of the answer.

7 Abbreviations and definitions

Shall : Statements is mandatory and can only be waived with the formal approval of TNO.

Will	:	Statements that should be interpreted as fact.
Hazardous material	:	Hazardous materials are either explosive, flammable or toxic to people and the environment.
ATEX directive	:	Directive for electrical, electronic and mechanical equipment intended for use in Explosive ATmospheres. The European directive which was subsequently included into the Dutch legislation (Warenwet and Arbowet).
EMC directive	:	Directive for electrical and electronic equipment does not generate or is affected by electromagnetic disturbance which was subsequently included in the Dutch legislation (Warenwet and Telecommunicatiewet.
PED directive	:	Pressure Equipment Directive which was subsequently included into the Dutch legislation (Warenwet). European directive intended for the design, fabrication and use of pressure equipment above 0.5 bar.
LVD directive		Directive for electrical and electronic equipment with a voltage rating between 50 – 1000 VAC and 75 – 1500 VDC which was subsequently included into the Dutch legislation (Warenwet).
NET		Negative Emission Technologies
CCU		Carbon Capture & Utilisation
PFD		Process Flow Diagram
FAT		Factory Acceptance Test
SAT		Site Acceptance Test
RH		Relative humidity

8 Appendix

- PFD for the Absorber setup:.

Adobe Acrobat Document