TN 5

LIFE SUPPORT SYSTEM RECOMMENDED DESIGN FOR A DEMONSTRATION IN A MOON BASE

MELISSA ADAPTATION FOR SPACE, PHASE II

ESTEC/Contract Nº 20104/06/NL/CP

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CHANGE RECORD

AUTHOR	ISSUE	DATE	CHANGE
J. Duatis D. Moreno	Draft A	31 July 2009	Preliminary version
J. Duatis	1.0	03 Nov 2009	Updated Section 3 to indicate that design is based on human transitable modules (not habitable). Also added instrumentation for quality control. Changed dark water for black-water. Drawings updated according to actual tank sizes. Updated section 3.7 to indicate the inflatable structure as a selected design for the EELM-HPC. Updated section 4.3 to recalculate EELM-HPC structure mass based on inflatable structures. Added a trade-off about rigid vs. inflatable structure options. Expanded 5.1 to detail currently envisaged lunar cargo possibilities by NASA and ESA. Updated section 6, reviewed TRL. Equipments without adapted design for space considered TRL4 even a ground or commercial equipment already exists. Added functions for quality control (ANITA, MIDASS).

CONTENTS

TABLES

FIGURES

ACRONYMS LIST

ARES	Air Revitalization System
BLSS	Bioregenerative Life Support System
BPU	Biomass Pre-treatment Unit
BVAD	Baseline Values Assumption Document
BWTU	Black Water Treatment Unit
CCA	Carbon dioxide Concentration Assembly
CI	MELiSSA Compartment I
CII	MELiSSA Compartment II
CIII	MELiSSA Compartment III
CIVa	MELiSSA Compartment IVa
COTS	Commercial Off The Shelf
CRA	Carbon Reduction Assembly
ECLSS	Environmental Control and Life Support System
EELM	European ECLSS Lunar Module
EVA	Extra Vehicular Activity
FPU	Food Production Unit
GCR	Galactic Cosmic Rays
GWRU	Grey Water Recovery Unit
HPC	Higher Plants Compartment
ISPR	International Standard Payload Rack
ISRU	In Situ Resources Utilisation
LSS	Life Support System
MELiSSA	Micro Ecological Life Support System Alternative
OGA	Oxygen Generation Assembly
P&ID	Process and Instrumentation Diagram
SMAC	Spacecraft Maximum Allowable Concentration
SPE	Solar Particles Events
TRL	Technology Readiness Level
UTU	Urine Treatment Unit

0. SCOPE

This document defines the recommended overall system design of an European ECLSS Module based on bio-regenerative and physicochemical technologies to provide up to 100% air recycling, 90% water recycling and 40% of the diet for 4 astronauts in a potential Moon Base. The design is based on MELiSSA plus several European technologies developed for Life Support.

For the configurations defined in TN3 [R3] and according to the design decisions taken in the previous TN 4 [R4] a design of the European Life Support Lunar Module will be presented.

This technical note includes the design of each subsystem, showing a preliminary accommodation into standard ISPR racks as well as the design of the internal and external interfaces according to the configuration defined in the TN 3 and TN 4.

Also, this document includes a preliminary analysis of technology readiness level of the technologies applied.

1. APPLICABLE AND REFERENCE DOCUMENTS

1.1 Applicable Documents

[A1] Request for Quotation RFQ/3-11481/05/NL/CP – MELISSA Adaptation for Space - Phase 2, ref.: RES-PTM/CP/cp/2005.915, dated 16/11/05

[A2] Statement of Work MELiSSA Adaptation for Space – Phase 2, Ref. TEC/MCT/2005/3467/In.CL dated November 4th, 2005, Version 1 (Appendix 1 to RFQ/3-11481/05/NL/CP)

[A3] Special Conditions of Tender, Appendix 3 to RFQ/3-11481/05/NL/CP

[A4] ESA Fax Ref. RES-PTM/CP7cp/2006.226, dated 29/03/06

[A5] Minutes of Meeting ESA-NTE Clarification meeting on MELiSSA Adaptation for Space – Phase 2; no reference, dated 20/04/06

1.2 Reference Documents

[R1] Moon Base Scenario Definition and Life Support System Requirements, NTE-MEL2-TN-007, Issue 1.0, 11 Jan 2008. TN 1.

[R2] Summary of European Life Support System Technologies, NTE-MEL2-TN-009, Issue 1.0, 28 March 2008. TN 2.

[R3] Preliminary Life Support System Design, NTE-MEL2-TN-012, Issue 1.0, 05 Dec 2008. TN 3.

[R4] Life Support System Sizing, NTE-MEL2-TN-014, Issue 1.0, July 2009. TN 4.

[R5] WRS Engineering Model - Preliminary Development Plan. Issue 1.2. 28/02/08. TN 4.

[R6] NASA's Exploration Systems Architecture Study (ESAS). Final Report. November 2005.

[R7] Design of a Thermal and Micrometeorite Protection System for Unmanned Lunar Cargo Lander. Hernandez, Carlos A. et Al. The University of Texas, Austin, 1989.

[R8] Radiation effects and shielding requirements in Human Missions to the Moon and Mars. Donald Rapp. Mars 2, 46-71, 2006; doi:10.1555/mars.2006.0004.

[R9] Human Spaceflight Vision. Eurpoean Man-Tended Moon Base. S. Hovland, Editor. ESA. CDF-23(A) Report, January 2004.

[R10] Design & Manufacturing of subscale inflatable Module (IMOD) for Manned Space Applications. M. Nebiolo, 4th European Workshop on Inflatable space structures. 16-18 June 2008 ESA/ESTEC. Noordwijk, The Netherlands.

[R11] Inflatable materials for exploration in a space environment. M Lamantea, R. Destefenis. 3rd European workshop on inflatable Space structures. 10-12 October 2006 ESA/ESTEC. Noordwijk, The Netherlands.

2. INTRODUCTION

In previous technical notes, the requirements for an European Life Support Lunar Module for a Moon base have been set [R1]. An EcosimPro library with the models of the MELiSSA loop, ARES, UTU and GWTU components has been created and described in [R2]. A preliminary design of a Life Support System has been defined in [R3], and a preliminary system sizing has been performed in [R4].

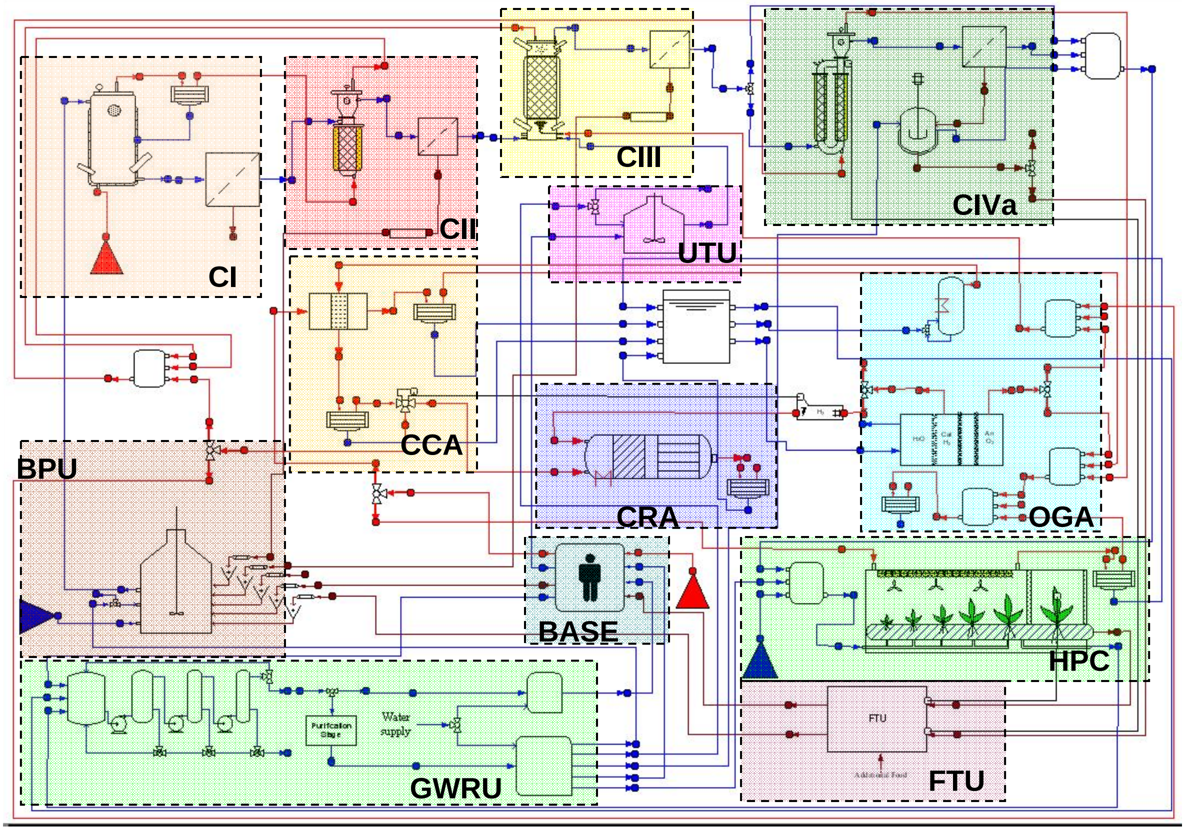


Figure 1 Ecosimpro model of the European Life Support System Design

As a result of this process, a global system design has been step by step specified. The system design is based on the application of several European technologies, both biological and physicochemical to cover the requirements of providing 100% air closure, near 90% of water closure and 40% of the diet, for a crew of 4 astronauts. The simulations allowed obtain recycling efficiencies and adjust the flow rates for the different phases (gas, solid and liquid) of the design, eventually arriving to a final configuration where the interfaces between the different subsystems have been fixed. With this information it has been possible to define the size of the different subsystems and calculate the mass, volume and power of the principal components.

From the P&ID of the MELiSSA compartments as designed for the MELiSSA Pilot Plant, it has been possible to elaborate a list of the components that build up every compartment. From this list of devices, mass, power and volume has been also calculated. These figures, jointly with the reactor, allowed to approximate the mass, volume and power of every subsystem.

Finally, the distribution of the different subsystems into a well known structure as the ISPR rack, let to obtain a configuration of the system into a space module, similar to the Destiny in the ISS. The dimensions of the current launcher design, which is currently being performed by NASA as part of the Constellation program, have been taken into account for the allocation. Therefore, the characteristics of the ARES V rocket and the Altair Moon Lander have been used although other possibilities exist if ESA eventually develops their own Lunar Lander.

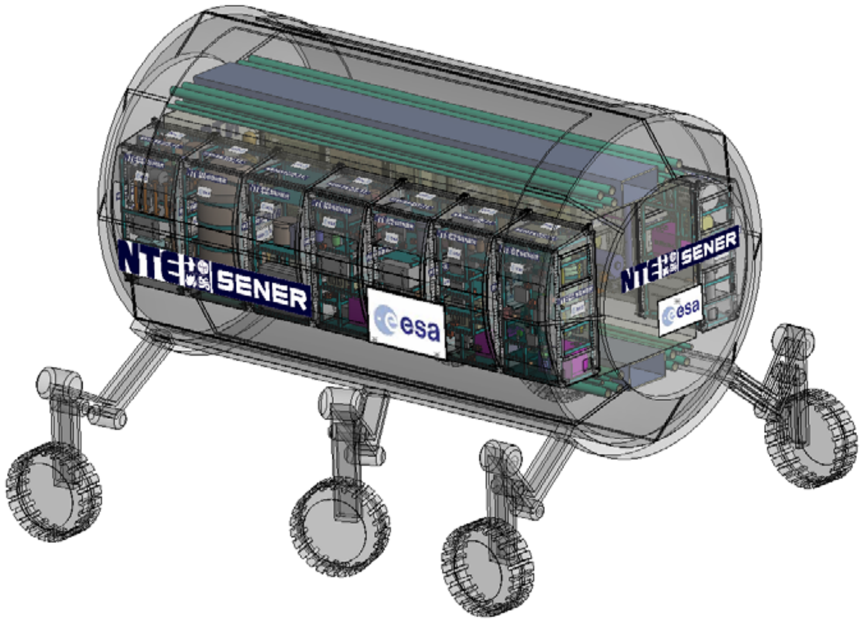


Figure 2 European ECLSS Lunar Module (EELM)

3. SYSTEM DESIGN

The System Design presented hereafter, develops the preliminary design resulted from the simulations and presented in [R3]. The final system includes the MELiSSA Loop with a Higher Plants compartment equivalent to 140 m^2 of cultivable surface, ARES, GWRU a Food Treatment Unit and a Biomass Pre-Treatment Unit. As defined in [R1] the EELM is designed to interface with a main ECLSS already existing in the Moon Base, accordingly the System Design includes the external interfaces with the primary ECLSS as well as the intermediate buffer tanks.

Modules will be transitable by the crew but not habitable. Contamination issues due to permanent habitation of the crew in the modules have not been considered in the design.

3.1 Main System/Subsystem interfaces

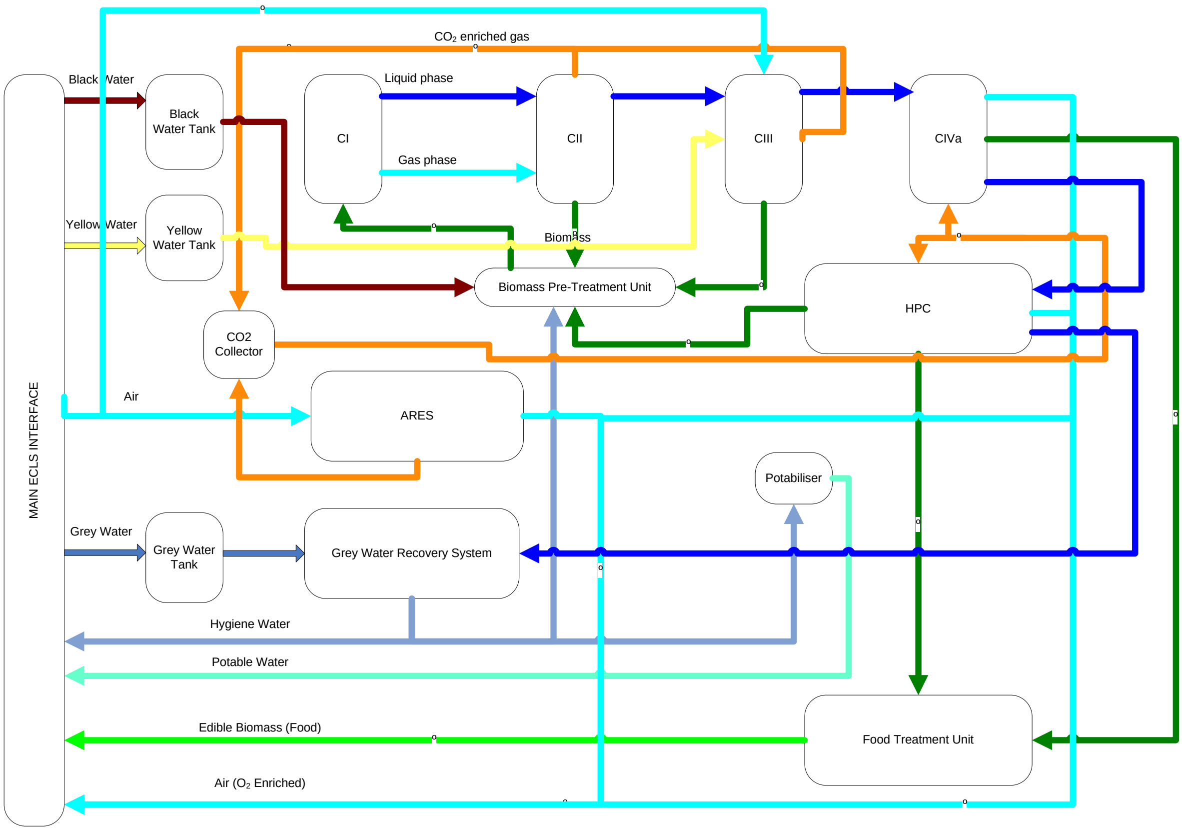


Figure 3 European ECLSS Module System/Subsystem interfaces

In Figure 3 are specified the main connections between the European ECLSS Lunar Module (EELM) and the Main Base and between the different subsystems. Also, it can be noted that some subsystems not considered up to now are indicated. These subsystems are:

- Biomass pre-treatment unit
- Food Treatment Unit
- CO2 collector

Another subsystem that needs to be incorporated at this stage is the Seed Germination Unit.

Quality control is required for water, air and food. This control is supposed to be performed at subsystem level using devices such as ANITA or MIDASS adaptations. A MIDASS adapted device would allow the detection and quantification of microbial flora in the water, air and even in the food and ANITA would allow to detect an increase of gas trace contaminants in the air.

3.1.1 Interface types

To the EELM following inlet and outlet flows are expected:
- Black water: The waste collector will dilute the faeces and conduct the resulting product to the EELM.
- Yellow water: The waste collector will as well recover the urine, dilute it and conduct the resulting product to the EELM.
- Grey water: The water resulting from personal hygiene, washing, food processing, etc. will be recovered and conducted to the EELM.
- Air: The air will be re-circulated to the EELM in order to remove excess of CO_2 and recover the water.

3.1.2 Interface flow rates

It will be mandatory to have a set of tanks to guarantee a continuous flow to the reactors. The size and volume of the tanks will depend on the input flow rates from the primary ECLSS. We assume that the size will be dimensioned to support one day of continuous flow of a crew of 4 plus a 100% of margin and finally rounded. Tank mass is calculated assuming that the tanks are made of stainless steel with nominal pressure conditions (cabin pressure).

Flow type	Flow rate (l/d)	Interface Tank Volume (litres)	Interface Tank Mass (Kg)
Black water	3.2	10	6.5 (thickness 3 mm)
Yellow water	10.5	25	12 (thickness 3 mm)
Grey water	21.3	50	36.5 (thickness 6 mm)

Table 1 Interface tanks volume and mass

In the simulations performed with the model (see [R3]) the hygienic water is divided in a 10% to dilute faeces, 10% to dilute urine and a 80% for personal hygiene (including shower). The total hygienic water is 26.7 l/d.

3.1.3 Air flow

The air is not expected to be stored in an interface tank but directly pumped inside the system. The estimated flow (used in the calculations) is around 0.0397 m^3/s (140 m^3/h). This is supposing a pressurised volume for crewmembers of 60 m^3 and a resident time of 0.4 hours approximately. The flow is quite high, therefore air inlet to the EELM can be directly connected to the rest of the pressurised volume. ARES is equipped with its own system for air collection. It is supposed that all the air in the base is recirculated through the EELM.

The air collection will generate an air circulation through the entire base. The idea would be to have a conduction for regenerated air and a direct collection of contaminated air. The conduction has to be considered well in advance as part of the overall base design.

The Higher Plants modules will circulate the air in a similar way. The contaminated air will be re-circulated using conduction fans and captured at the end of the circuit when it has been regenerated by the plants. Concentration of CO_2 will be controlled through all the compartments and regulate the air circulation between them.

3.1.4 Internal Interfaces

A preliminary design of the internal interfaces shared among the compartments in the EELM has been performed. These interfaces will supply to the different compartments the services needed and will communicate the different compartments through the liquid, solid and gas phase. The solid phase should be understood as a dilution with a high concentration of solids.

- Cool water: used for heat exchangers to remove heat.
- Steam: used for cleaning and sterilisation purposes.
- Liquid phase: liquid interchange between compartments.
- Gas phase: gas interchange between compartments.
- Solid phase: solid interchange between compartments.

The common equipment will contain a cooling water system and a steam generator that will provide cooling water and steam to the module. The steam will be used for sterilisation of the components and could be used as a heat provider. However, it is assumed that heat will be generated electrically in every compartment.

In this design it is considered that harvesting of the CIVa and the HPC is performed manually. That is, the *Arthrospira Platensis* solid resulting from the solid liquid separation will be treated in the FTU to generate an edible product either in powder or in any other form. The same process will apply to the higher plants. They will be in principle harvested manually and processed in the FTU. The residues of the treatment will be manually inserted in the BPU for further processing in the ECLSS loop.

Electrical interfaces are not detailed as it should be designed applying the common standards for space hardware.

3.2 Biomass Pre-Treatment Unit

The black water will be conducted to the Biomass pre-treatment unit which will be the preliminary treatment before going to the fermentation compartment (CI). To this unit it will come also from other EELM compartments the following products:

1. Biomass from Compartment II
2. Biomass from Compartment III
3. Biomass from Compartment IVa
4. Faeces (from outside the EELM)
5. Residual Part of the Higher Plants from HPC
6. Water added for dilution with additional mineral sales.

The pre-treatment is basically a dilution process with stirring. Higher plant residues should be grinded before going into the dilution tank. Also, some mineral sales will need to be added to re-supply the quantities lost in the purges. The resulting mixture will be conducted to the Compartment I. The Biomass Pre-Treatment unit has an output flow rate of around 70 l/d, thus the tank should be dimensioned as 140 l (with 100% margin).

Bioreactor	Volumetric flow (l/d)
CI	70

CII	60
CIII	88
CIVa	88

Table 2. Volumetric flows between compartments.

The BPU will include a steam and cool water input for temperature control of the tank.

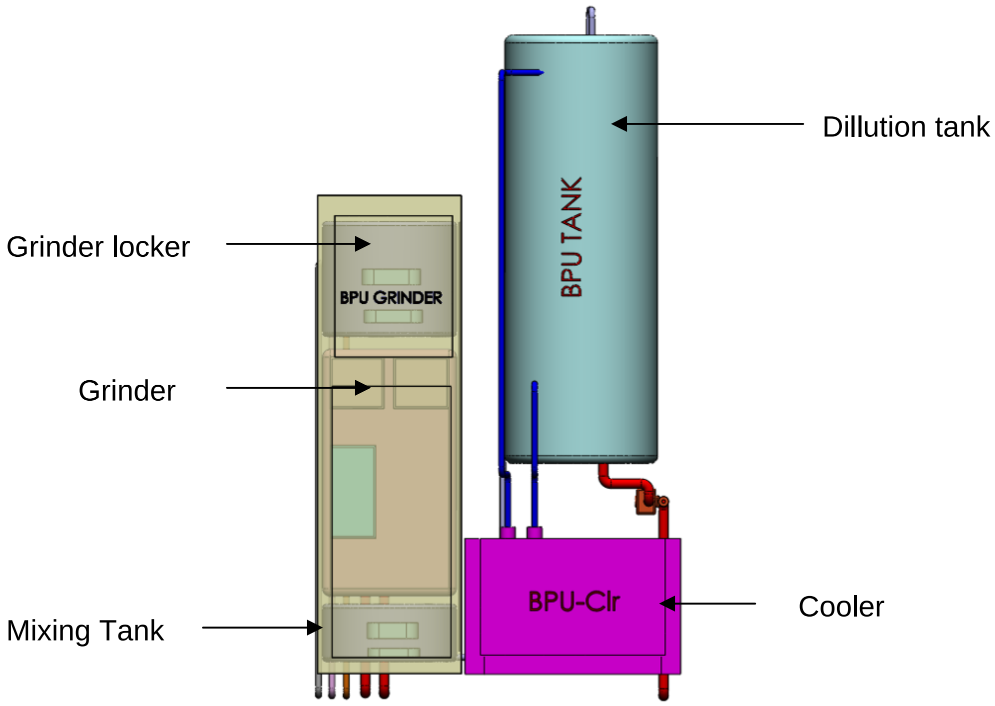


Figure 4 BPU accommodation details

The biomass from the HPC will be stored in bags. This biomass will be produced when harvesting or while processing the food coming from the HPC in the Food Treatment Unit. When the bags are filled it will be introduced in the grinder locker where will be ground and mixed with the biomass coming from other compartments. The mixture will be diluted in a tank at the levels required by the Compartment I. The BPU will feature also a cooler to maintain the temperature of the dilution tank controlled.

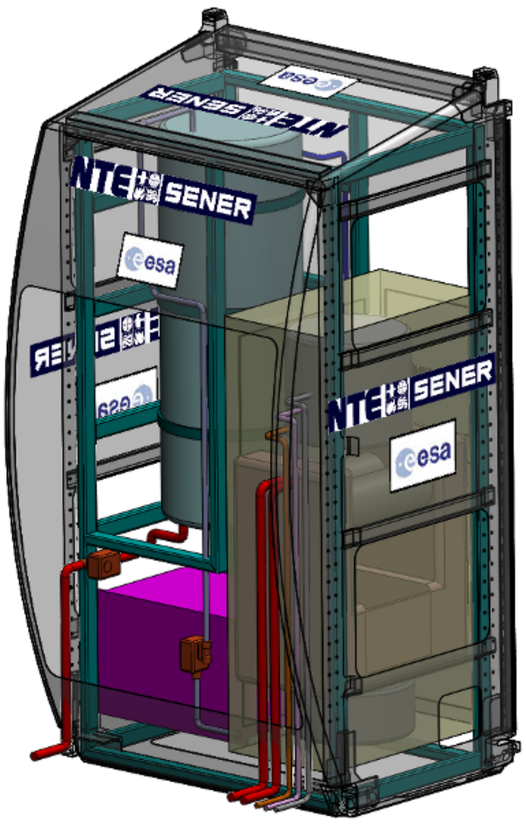


Figure 5 BPU accommodation- racks rear view

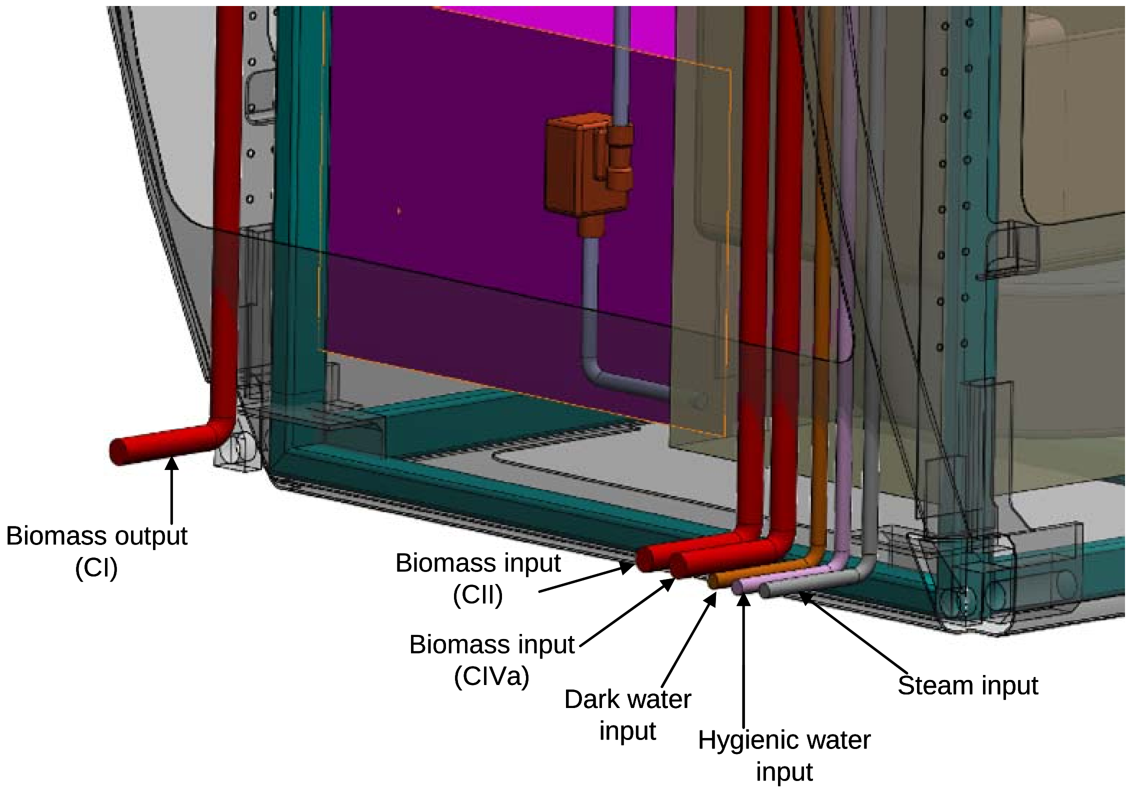


Figure 6 BPU interface details

3.3 Compartment I

The Compartment I will consist mainly of the reactor, a solid-liquid separation (Filtration Unit), and a gas condenser to recover the water in the gas phase. The biomass coming from the Biomass Pre-treatment Unit will be degraded in order to recover the basic compounds. The liquid resulting from the degradation will be passed through a solid-liquid separation system. The solids extracted from the separation will be purged from the system. This purge is the principal loss of compounds in the system and needs to be optimised as much as possible. The resulting liquid phase will be redirected to the Compartment II. The condenser will recover the water (with mineral salts) from the gas phase and redirect it to the CI again. Only the gas phase with low water content will go to the CII. It is understood that before going to the next compartment either the gas and the liquid phases need to be sterilised to maintain the axenic conditions. Therefore, between the compartments a sterilisation process based on micro-filtration and UV sterilisation is included.

It has been obtained also from the simulations that the CI requires an addition of Nitrogen in gaseous state. This Nitrogen, calculated as 0.06 Kg/day needs to be supplied to the system. The CI will include an influent tank and an effluent tank to provide some buffering between the Biomass Pre-Treatment unit plus the black water inputs and the CII compartment respectively. The CI reactor volume is sized to 840 litres.

In addition, the CI includes a cleaning and sterilisation in-process loops, and the respective tanks and conductions have been added to the design.

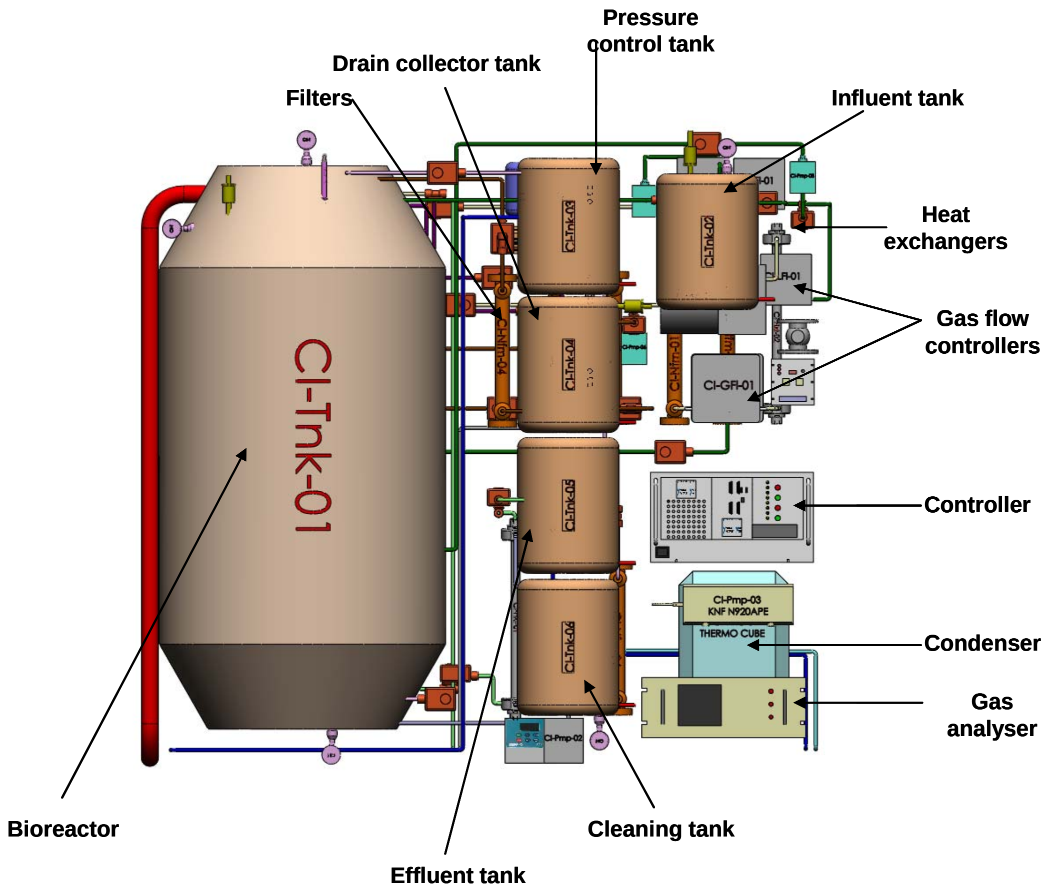


Figure 7 Compartment I accommodation details

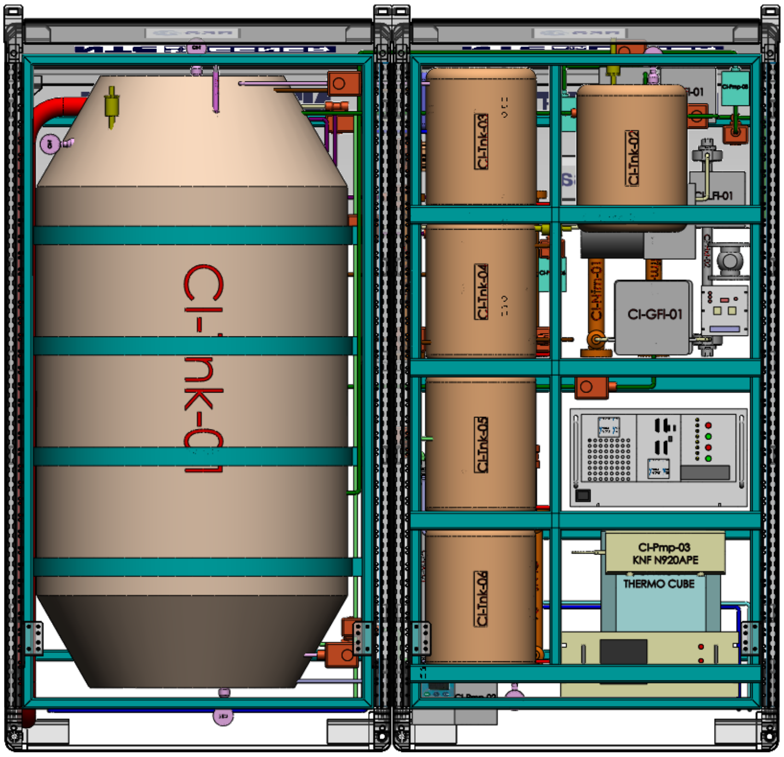


Figure 8 Compartment I accommodation- racks front view

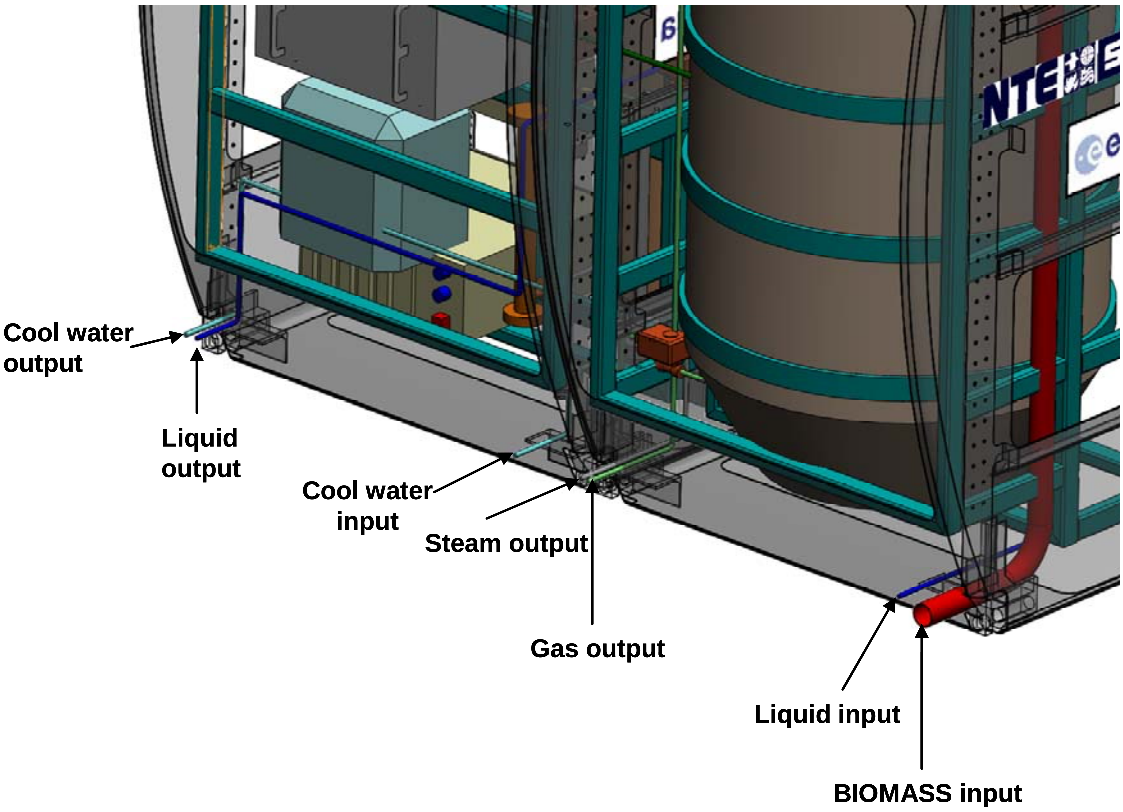


Figure 9 Compartment I interface details

3.4 Compartment CII

The Compartment II will receive the gas and liquid output flows from the Compartment I. This compartment is mainly responsible of the recovering of the carbon by means of oxidation and generation of biomass and CO_2. The output of the gas phase of the reactor is redirected then to a CO_2 enriched gas mixer (CO_2 gas collector). The liquid phase goes to a liquid-solid separation phase. The resulting solid is processed in the Biomass Pre-Treatment Unit and the liquid goes to the next compartment.
The liquid phase needs to pass also through a micro-filtration and sterilisation phase through UV to maintain axenic conditions.
In that case a buffer tank of 70 litres will be added to the input flow in order to retain the flow corresponding to a complete day. As the residence time is short, the volume of the reactor can be sized to 60 litres.
Current lighting system implemented with commercial halogen lamps generates a lot of heat. This heat can not be ventilated to the cabin atmosphere since jointly with the heat generated by the other compartments, the electronics and the rest of the devices it would be probably exceeding the standards for cabin ventilation. Therefore, a specific heating removal system should be included for the lighting system, using the cool water input facility.

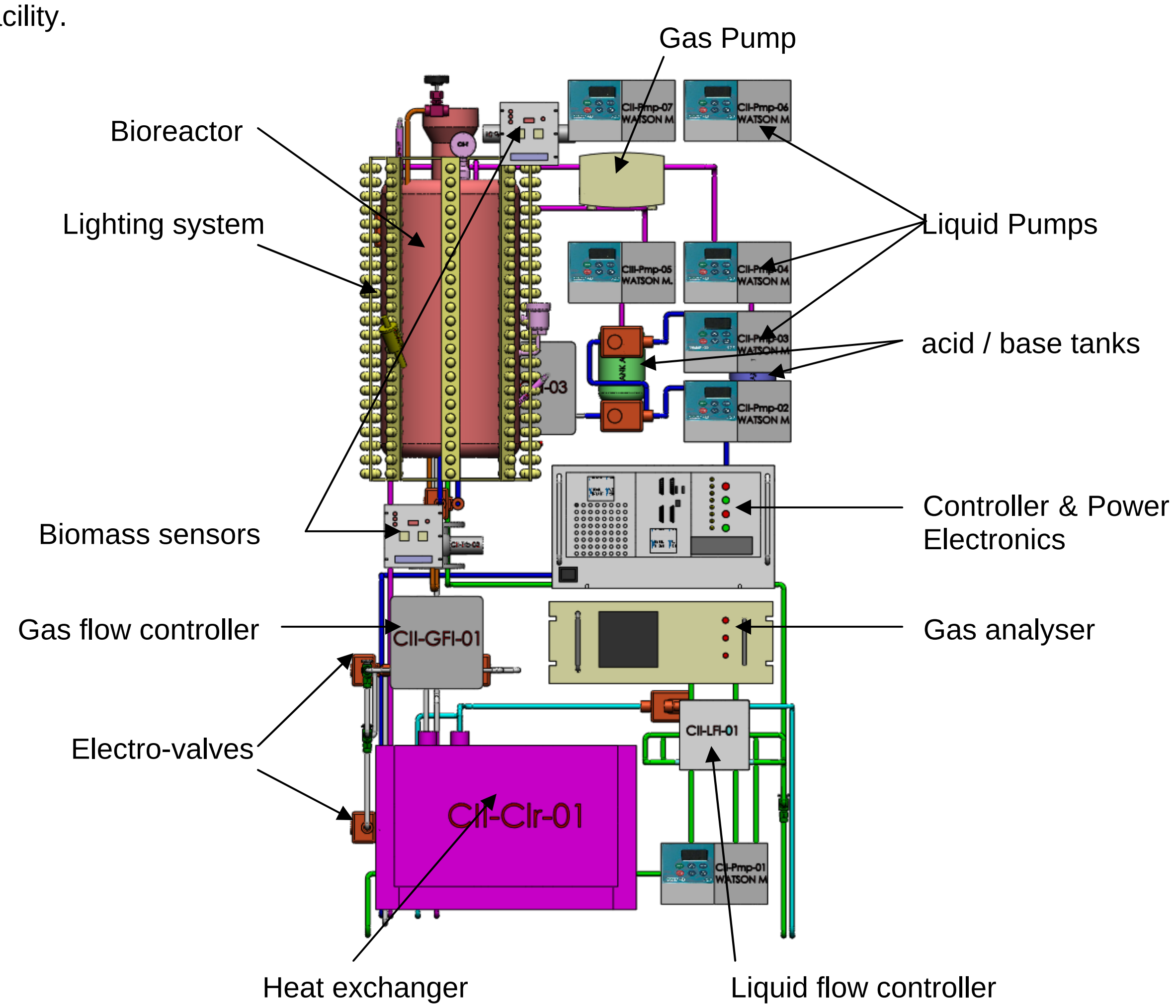


Figure 10 Compartment II accommodation details

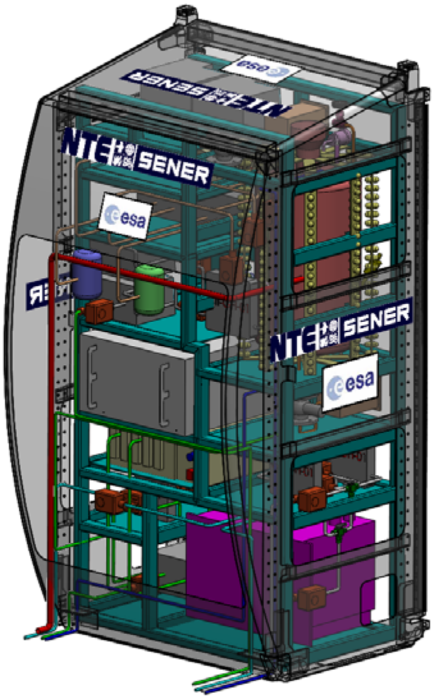


Figure 11 Compartment II accommodation- rack rear view

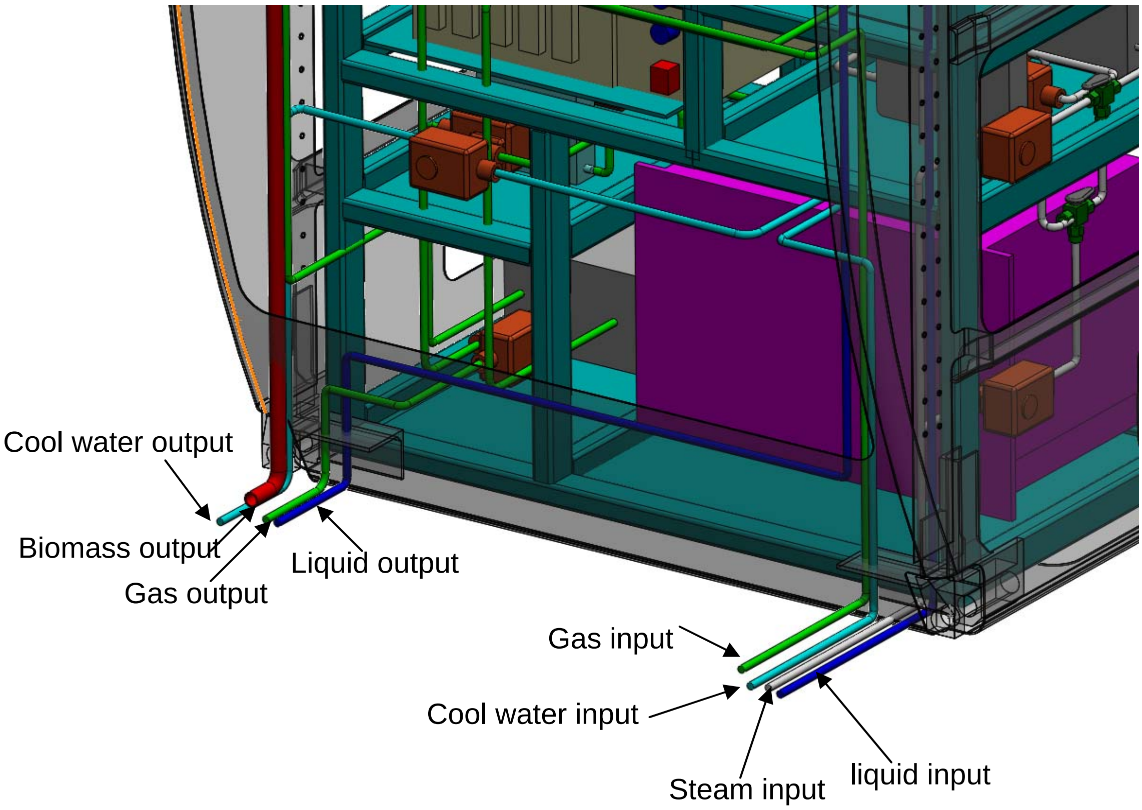


Figure 12 Compartment II Interface details

3.5 Compartment CIII

The compartment CIII contains the Urine Treatment Unit, a 40 litres tank which is designed to process the incoming urine before entering to the CIII. The process will include a micro-filtration and sterilisation phase to remove hormones and other organic compounds. The urine is diluted using water coming from the hygienic water source. The input gas flow is a small portion of the gas that comes from the air input to the EELM since the reactor consumes oxygen. The function in that case is to oxidise the Ammonia into Nitrates, thus in that process, oxygen is consumed. The output gas will go to the CO_2 gas collector where will be mixed with other CO_2 enriched gas sources. Solids are separated in the liquid phase with a solid-liquid separator and directed to the Biomass Treatment Unit. The rest of liquid goes to the nutrients tank of the HPC and to the CIVa. The volume of the reactor has been sized to 50 litres.
The CIII will include an inlet and an outlet buffer tanks to equilibrate the different flow rates.

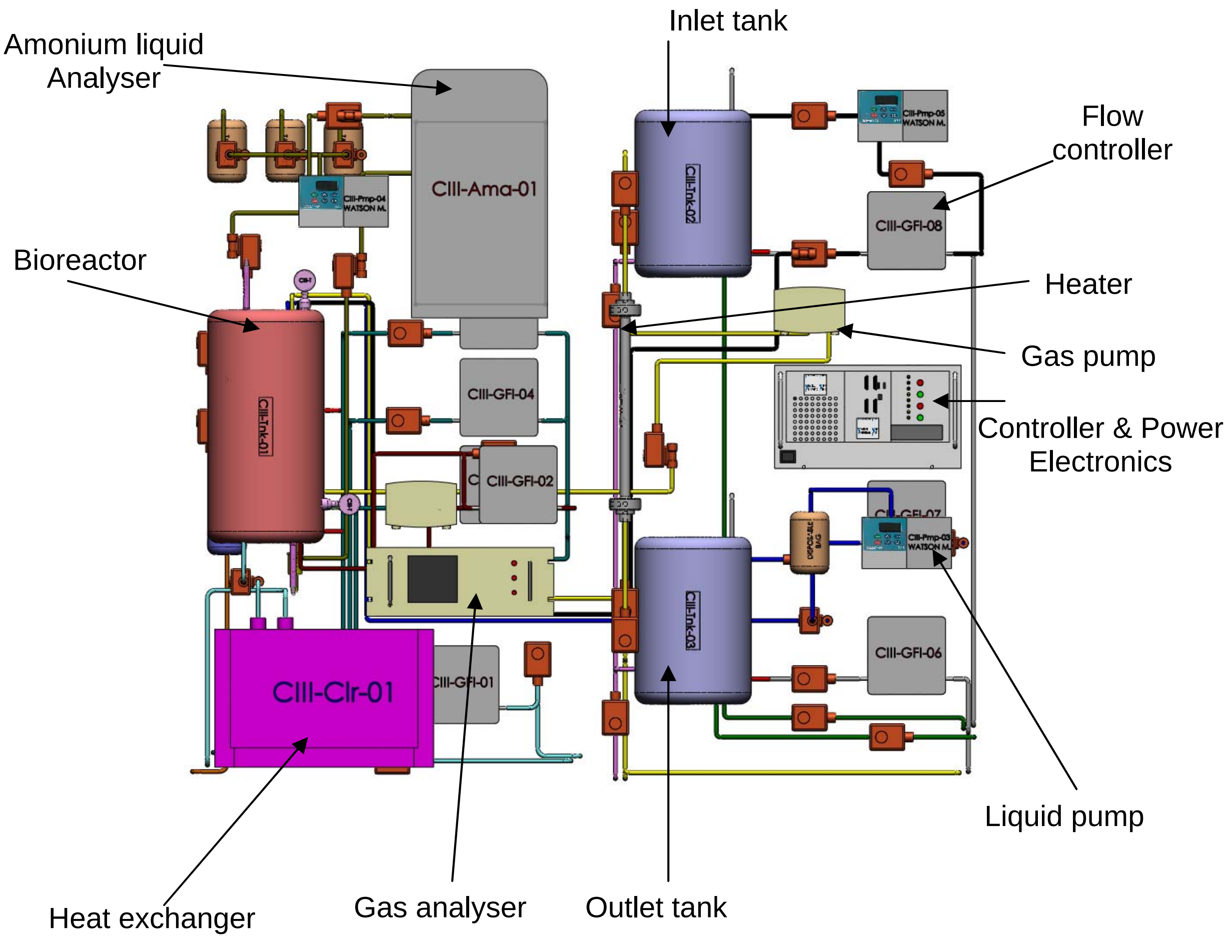


Figure 13 Compartment III accommodation details

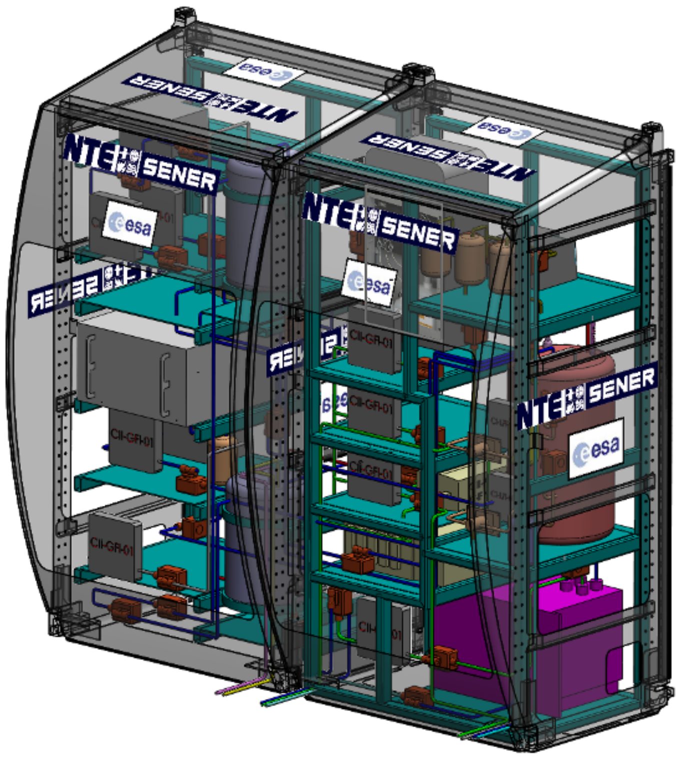


Figure 14 Compartment III accommodation- rack rear view

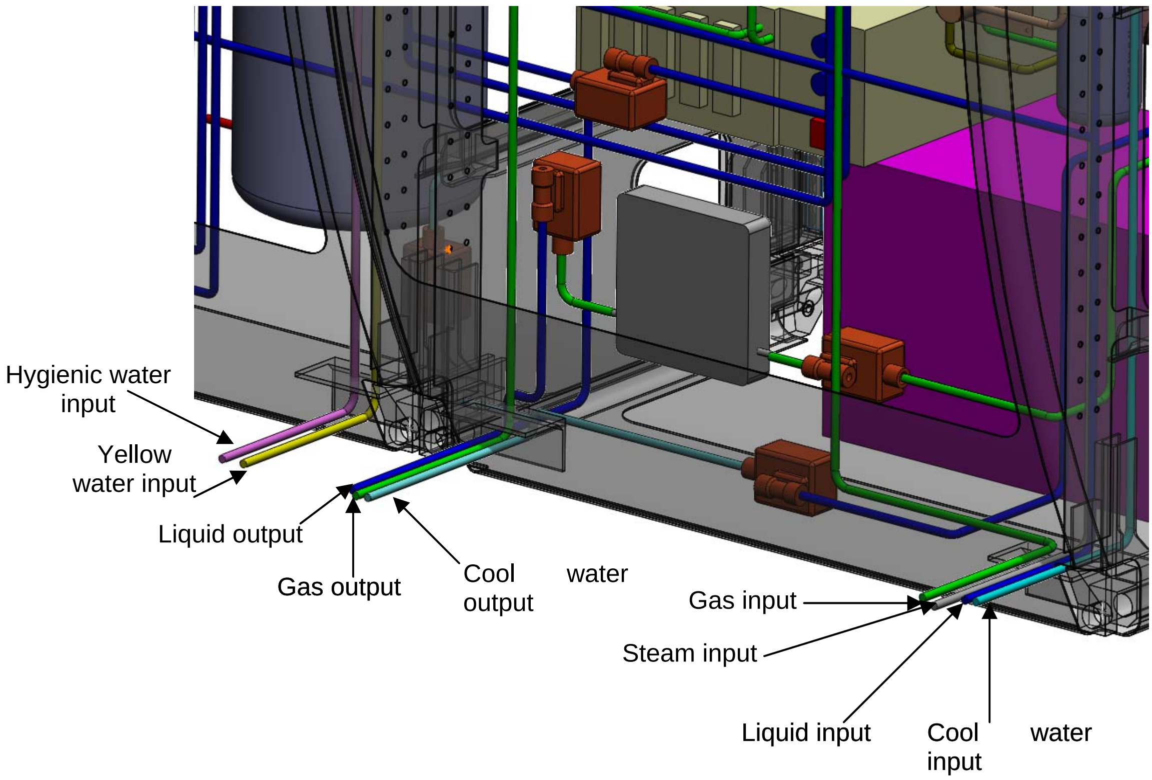


Figure 15 Compartment III Interface details

3.6 Compartment CIVa.

The compartment CIVa receives the gas phase from the CO_2 gas collector, a device which delivers a mixture of gas with a high concentration of CO_2. The gas output will go to the clean air gas collector responsible of mixing the different gas sources with low concentration of CO_2 and high concentration of O_2. The CIVa compartment will be able to provide almost the 6% of total oxygen demand for a crew of 4.

The liquid phase comes from the CIII. The flow rates are very similar, thus no big interface buffer tanks are needed between the reactors. The volume of the reactor is defined as 260 litres.

The solid phase, that is, the cake resulting from the solid-liquid separation would need to be preliminary treated before going to the Foot Treatment Unit. This treatment will consist of a washing phase to remove the excess of mineral salts resulting from the filtration. The resulting mass of this process could be directly processed in FTU. It is possible that all the biomass obtained could not be ingested; some part of the biomass can be separated as waste and directed to the Biomass Treatment Unit.

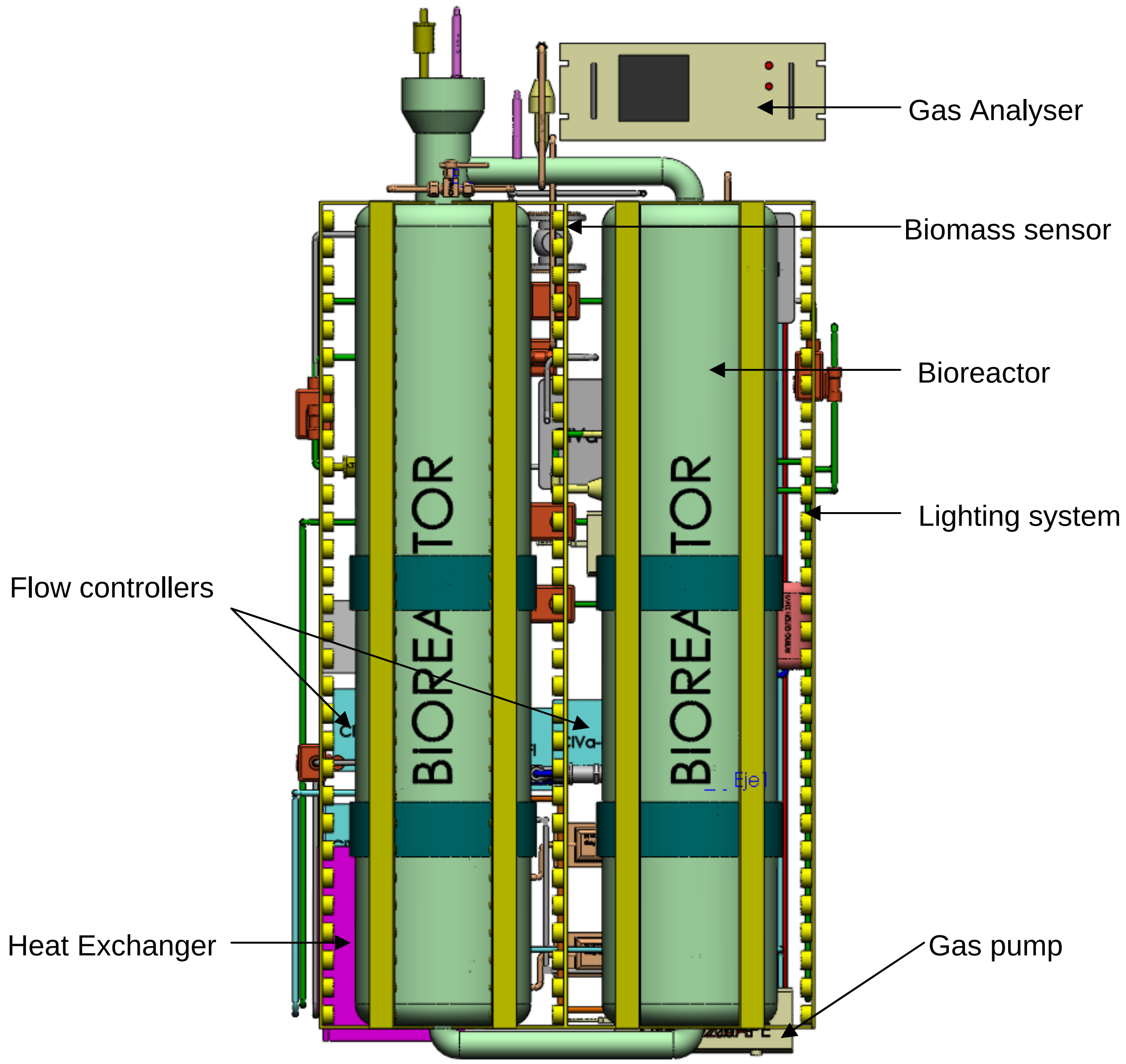


Figure 16 Compartment VIa accommodation details

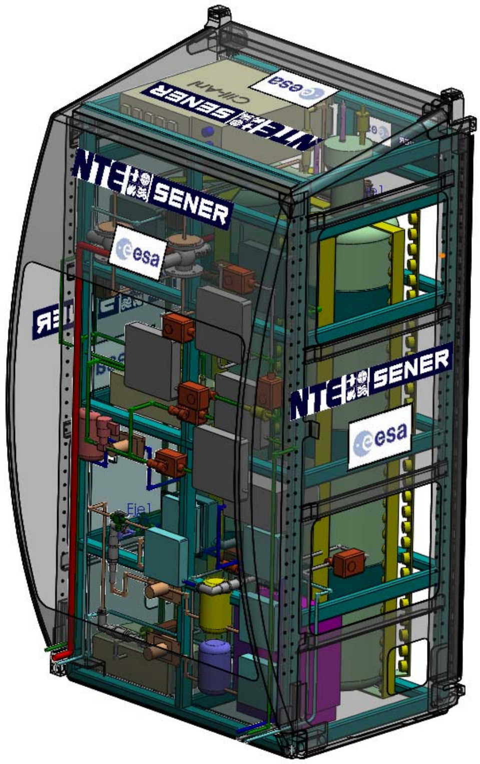


Figure 17 Compartment IVa accommodation- rack rear view

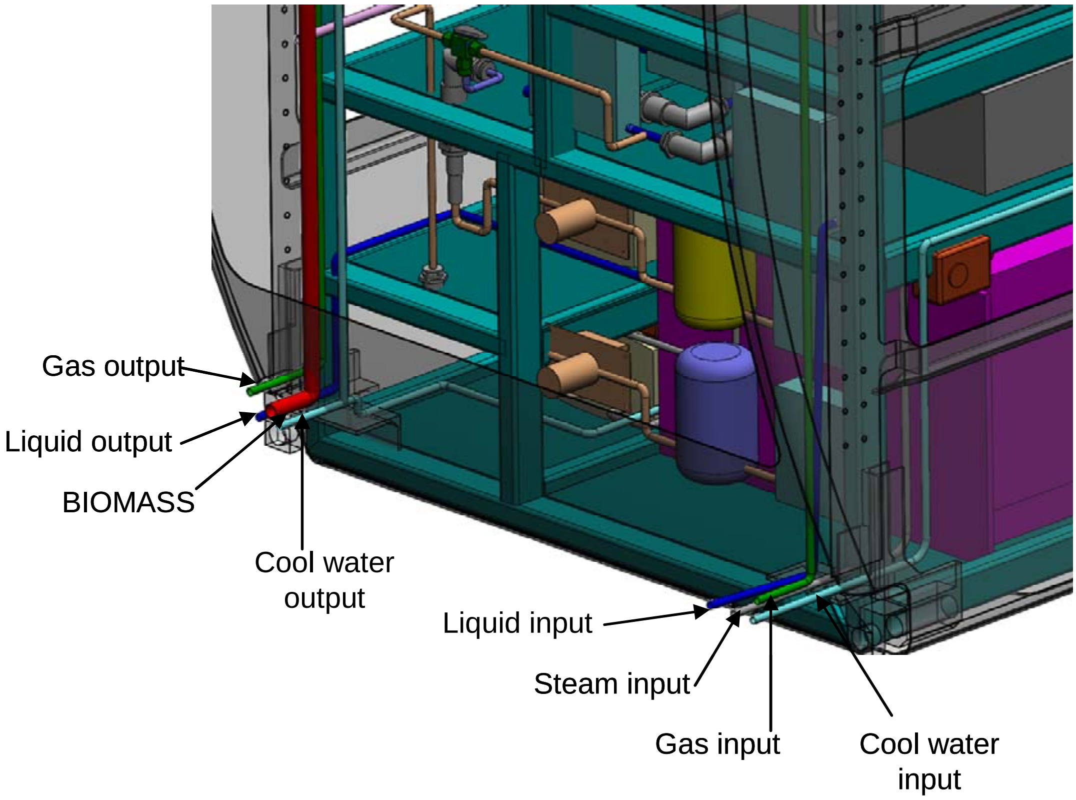


Figure 18 Compartment IVa interface details

3.7 Higher Plants Compartment

Although in the TN3 [R3] it was proposed a module like Destiny for the HPC, other possibility is to use an inflatable structure. In this section, the structure of the EELM-HPC is based on this second alternative, mass and configuration for the first is given in [R4].

In the case of an inflatable structure, the Higher Plants Compartment will consist on one single module to provide the total 140 m^2 of cultivation surface. This surface is the necessary to provide the 40% of the diet requirements for a crew of 4 according to the simulation results obtained in [R3]. In this way, the EELM equipped with the MELiSSA and related technologies and the EELM-HPC can be assembled in two phases. During the first phase the EELM will be able to recycle 100% air, 90% water and provide 5% food, while in the second phase, with the EELM-HPC attached, the system will be able to provide the aforementioned 40% of the diet for the given crew.

The HPC will receive from the CIVa and the CIII the liquid phase enriched with nitrates and other nutrients. This phase will go to the nutrients tank. In the HPC, the nutrient tanks are interconnected, allowing recirculation through the compartment. The HPC will feature also a condenser to recover the water from the air. This water will be also accumulated in the nutrient tanks.

The cultivation is supposed to be based on hydroponics technology, that is, the plants will be placed in trays and nutrients will circulate in a liquid solution in contact with the roots. This is the current configuration in the MEliSSA Pilot Plant.

Water is recirculated in the compartment according to the mineral salts concentration, maintaining the level of the concentration according to the plant requirements. Therefore, the design should provide recirculation of the water output and only a portion should be renewed.

The nutrients tank is divided into several distributed through the compartment. Each tank could be calculated as the total volume for one day divided by the number of tanks, that is, around 150 l. Other auxiliary equipment needed to run the HPC is the Seed Germination Unit. This Unit will be where seeds are initially germinated in order to be transplanted to the HPC (see section 3.12).

In the case of the gas phase, the flow rate is around 125 m^3/h. Although it is a high flow, a conduction of around 250 mm of section would be enough for the air inlets and outlets. The HPC is processing around 3800 Kg/d of air, generating near to 3 Kg of O_2, that is almost the 65% of the total oxygen demand. The air in the output will be directed to the interface of the EELM, to be added to the main pressurised volume where the crew members develop their activity. In principle, the EELM is designed to be transitable but not habitable.

The air coming from the base (crew cabin pressurised volume) will be re-circulated through the HPC compartment using big conduction fans located near the ceiling of the compartment. By using these fans it will be possible to control the CO_2 concentration in the compartment volume. The regenerated air will be collected and conducted by a gas pipe located in the ceiling of the compartment. This conduction will connect to the main base and distribute the regenerated air through all the pressurised volume of the base.

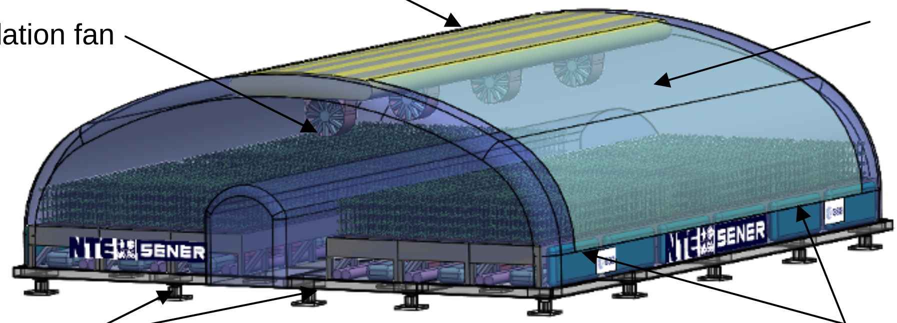


Figure 19 Higher Plants Compartment module

3.8 CO_2 gas collector

The CO_2 gas collector will be a device where different gas streams rich in CO_2 will be mixed. The gas will come from the CII, CIII and the CO_2 that cannot be processed in ARES.

Compartment	Flow(m3/h)
ARES	13.6
CIII	0.27
HPC	125
Total to EELM	140

Table 1. Gas flows between compartments

3.9 Air Recovery System

ARES in this design will be connected to the hygiene water circuit. Therefore, in case that ARES needs additional water to produce the required oxygen, it will be able to obtain water from the system, thus it will be connected to the output water from the GWRU. However, since water to be used by ARES needs to be purified, a purification stage will be required. It is assumed that ARES has its internal water management system, since it has a water tank were condensation and water generated by the Sabatier Reactor is also recovered and reused. ARES processes approximately the 5% of the input air in this configuration (around 7 Kg/d) although produces around the 30% of the total oxygen required (ca. 1Kg of O_2).

3.10 Grey Water Recovery System

The GWRS will be only connected to the liquid phase. Receiving directly the grey water from the interface tank, the unit will remove the contaminants through micro-filtration and reverse osmosis. In a first phase, the resulting water will be only usable for hygiene purposes, a second stage will mineralise the water to produce water with the quality levels required to provide drinking water for the crew. The hygiene water will be used for several purposes inside the system, it will be conducted to a buffer tank and from there redirected to the following subsystems:

Subsystem	Flow (l/d)
Biomass Treatment Unit	60
Urine Treatment Unit	17
Arthrospira washing	5
Crew hygiene water (EEM interface)	28
Nutrients tank of the HPC	520*

Table 3. Flow rates of hygiene water

**This 520 l/d directed to the HPC could be reduced if the option of high percentage of water recirculation is considered.*

The water potabiliser will generate around 10 l/d of potable water directly redirected to the EELM interface to be serviced in the base pressurised volume.

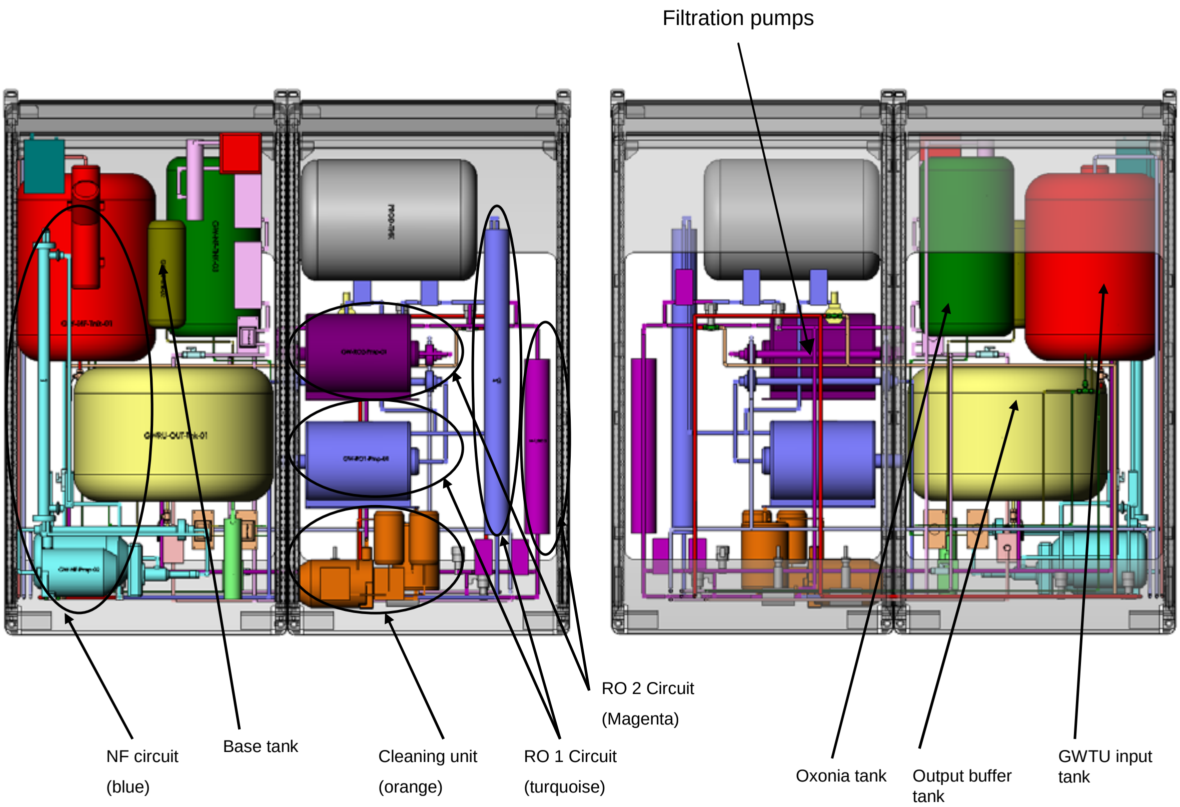


Figure 20 GWRU accommodation details

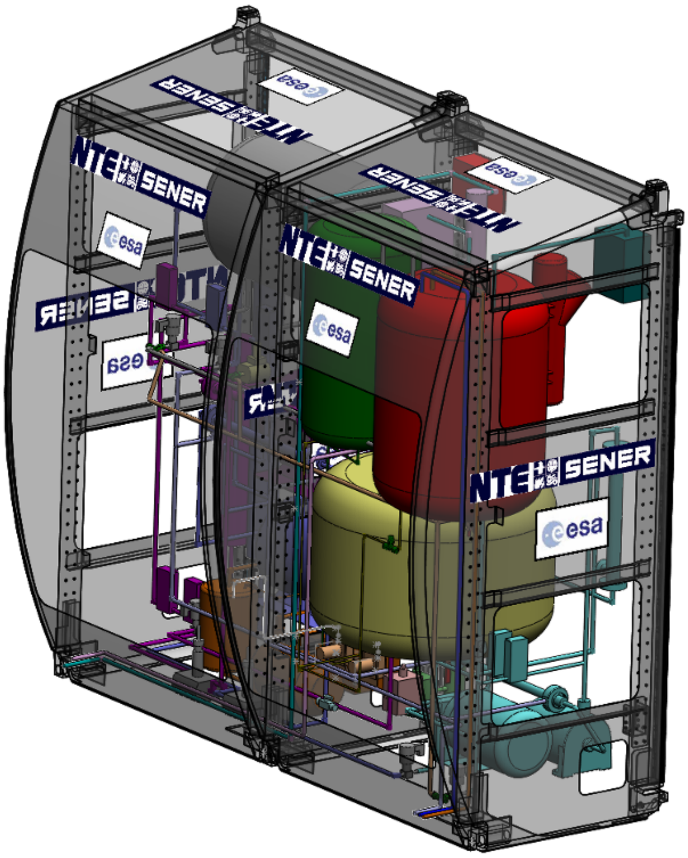


Figure 21 GWRU accommodation- rack rear view

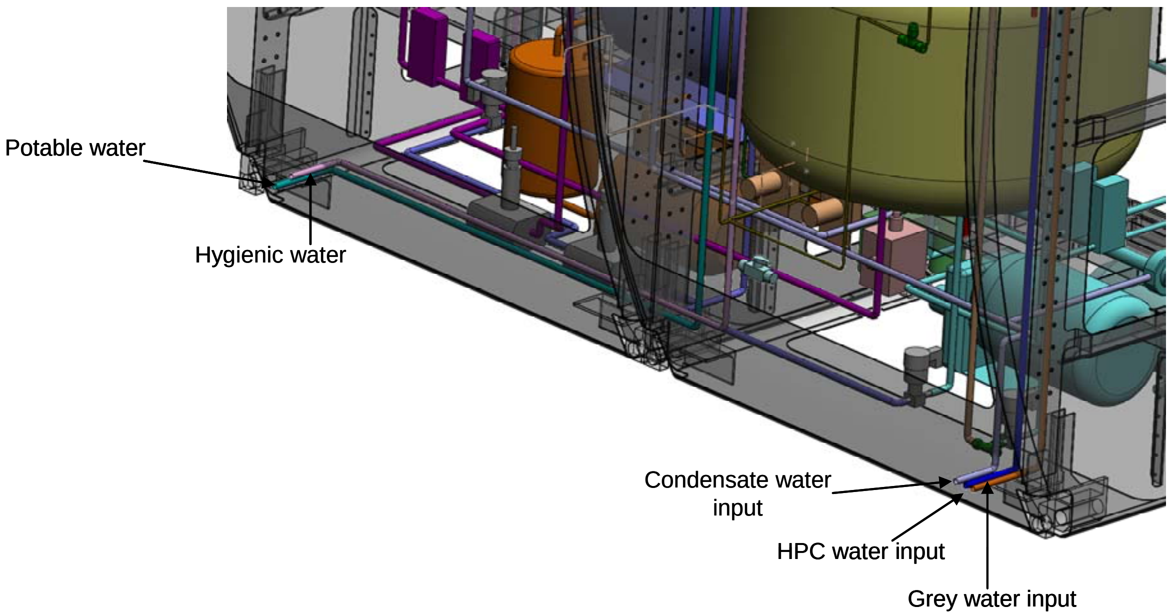


Figure 22 GWRU interface details

3.11 Food Treatment Unit

The Food Treatment Unit should include several devices to perform basic treatments of the edible biomass generated in the system. Some of these devices could be partially automated. For instance, to separate the wheat or rice seeds a grinding mill could be used. To process the Spirulina, a dryer could recover the water and generate a powder to be used in the meals. Other vegetables such as lettuce, tomatoes or potatoes do not need special processing, only a washing unit and centrifugation. The Foot Treatment Unit should also considered to be equipped it with a fridge and a vacuum sealer, and therefore food can be stored and consumed in good conditions when needed.

3.12 Seed Germination Unit

The Seed Germination Unit will consist of a ISPR rack equipped with several lockers containing trays were seeds will be germinated before being translated to the HPC modules. The unit will comprise the following subsystems:

- Lighting subsystem
- Temperature control
- Humidity control
- O_2/CO_2 concentration control
- Pressure control
- Irrigation / nutrients control

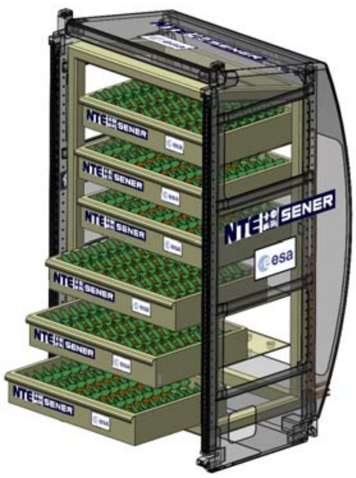


Figure 23 Seed Germination Unit accommodation.

In brief, it will be a small higher plants compartment with similar control requirements. In order to fix properly the seeds into a growing substrate, non-edible parts of the plants could be used after some pre-treatment (drying, compacting, etc.), or a expendable material specially designed with some nutrients, which would be already prepared on earth (seed pads). First option is obviously preferred in order to decrease the re-supply mass.

The Seed Germination Unit would be connected to the gas phase and liquid phase in order to benefit from CO_2 absorption and the O_2 generation during the germination process. Also nutrients in liquid phase should be re-circulated through the trays.

The lighting system could be based on LED in the proper wavelength band to maximise the photosynthesis active radiation (PAR).

3.13 Common Equipment Rack

The interface buffers and common equipment rack (IB&CE) will contain the interface buffer tanks and the common equipment shared by several compartments. The common equipment was defined in [R4] as a cooling element, which will regulate the temperature of the cooling water that will go to the different compartments, a condensing element and the steam generator.

In addition, in this rack will be allocated the interface buffers as defined in Table 1.

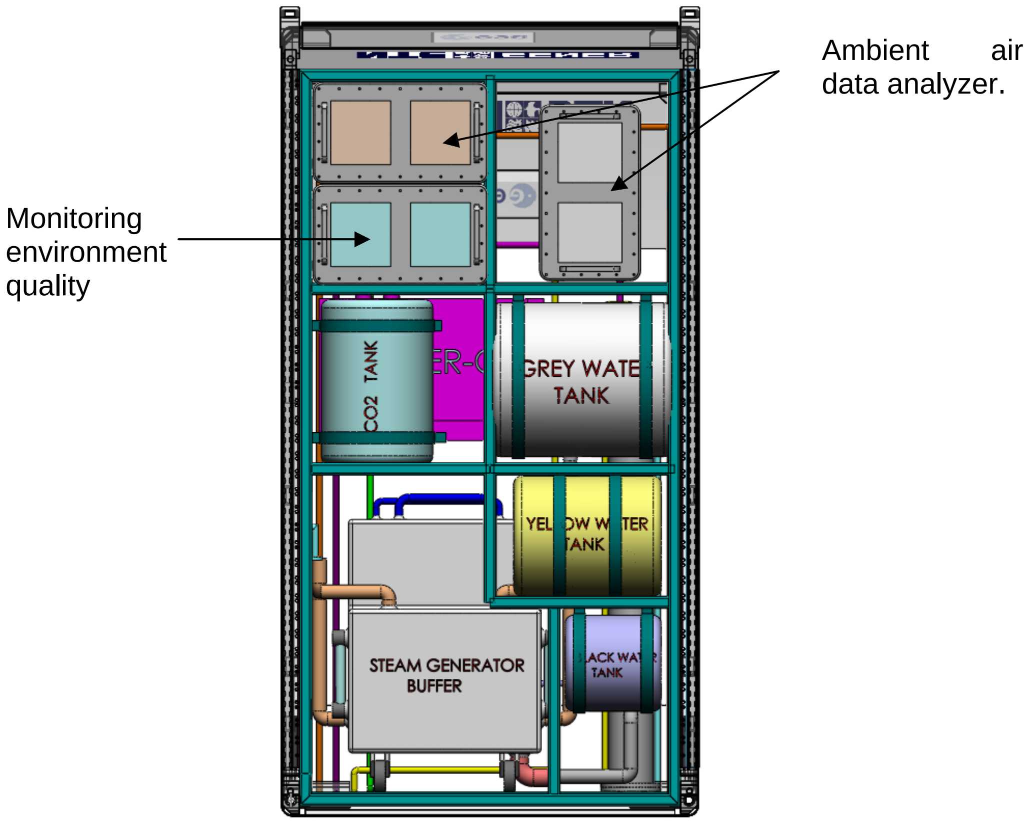


Figure 24 IB&CE rack accommodation details

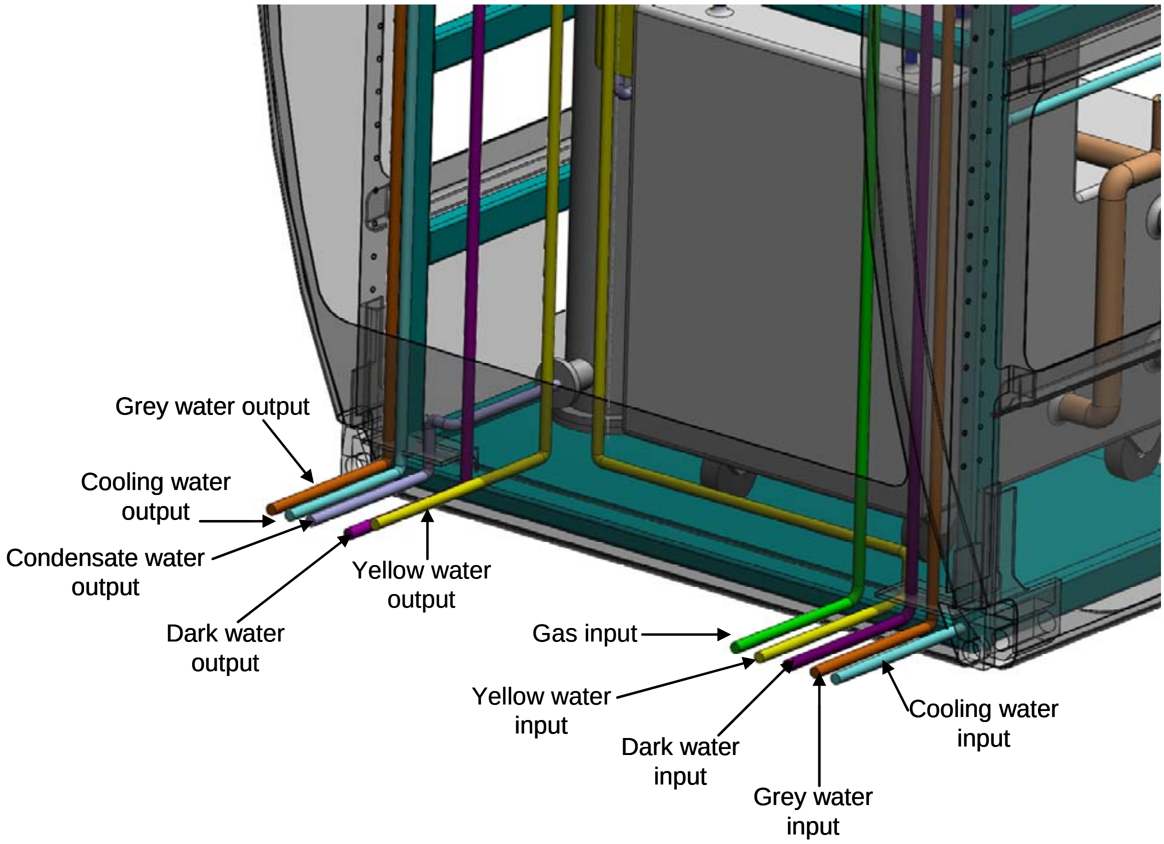


Figure 25 IB&CE interface details

4. SIZING OF THE RECOMMENDED DESIGN

4.1 ISPR Mass

Each ISPR provides 1.571 m³ (55.5 ft³) of internal volume being about 2 m (79.3 in) high, 1.05 m (41.3 in) wide, and 85.9 cm (33.8 in) deep. The rack is 104 kg (230 lbm) and can accommodate an additional 700 kg (1540 lbm) of payload equipment.

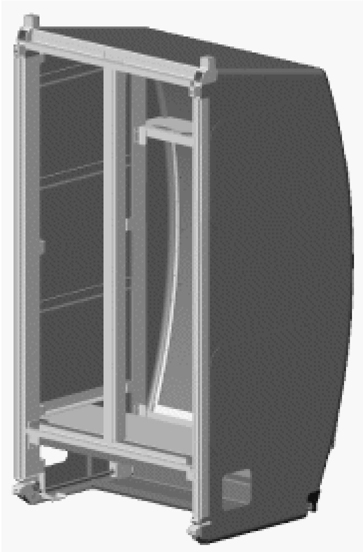


Figure 26 ISPR Rack

4.2 EELM Mass

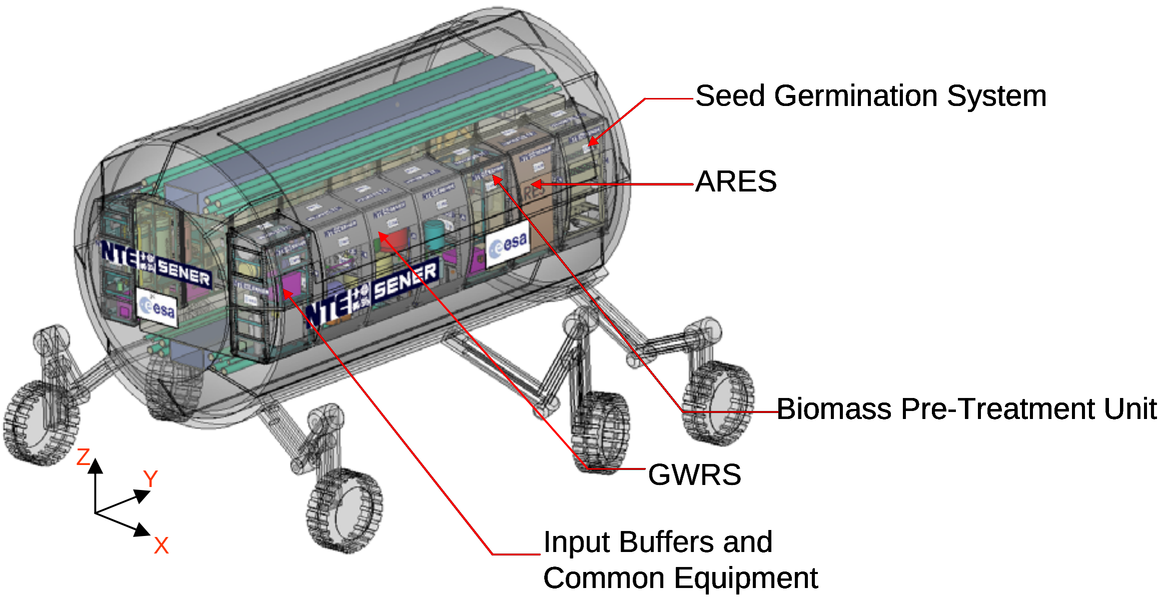


Figure 27 EELM Racks distribution - right side

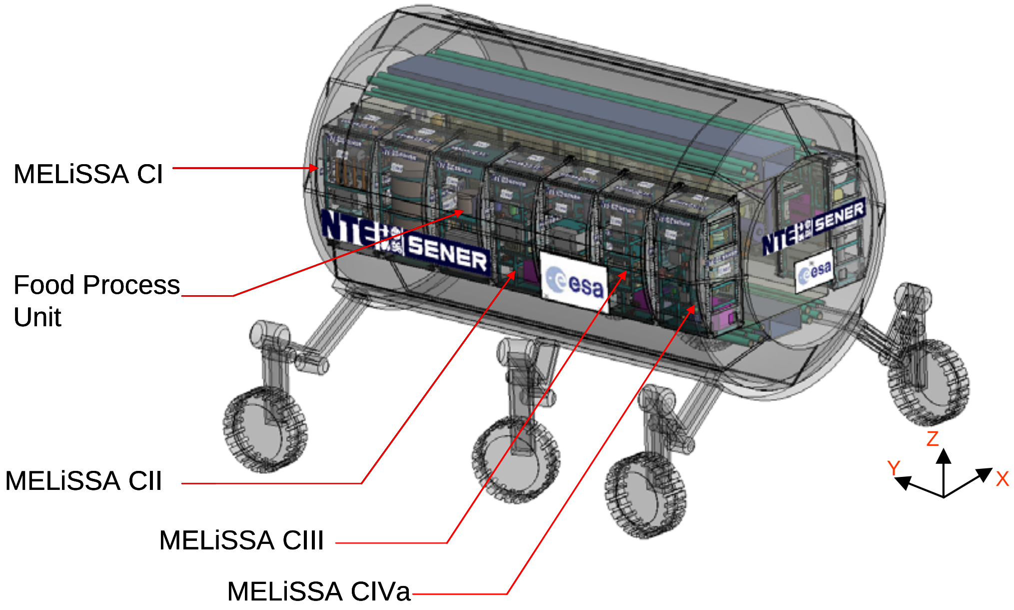


Figure 28 EELM Racks distribution - left side

Distribution of the EELM is as follows:

Right side[1]:

Rack R1	IB&CE	Input Buffers and Common Equipment
Rack R2	GWRS	Grey Water Recovery System
Rack R3		
Rack R4	BPU	Biomass Pre-treatment Unit
Rack R5	ARES	Air Recovery System (ARES)
Rack R6	SGU	Seed Germination Unit

Table 4 EELM racks distribution - right side

Left Side:

Rack R1	CI	MELiSSA CI
Rack R2		
Rack R3	FPU	Food Process Unit
Rack R4	CII	MELiSSA CII
Rack R5	CIII	MELiSSA CIII
Rack R6	CIVa	MELiSSA CIVa

Table 5 EELM racks distribution - left side

Weight for EELM is calculated as the aggregation of the weight of the different subsystems (compartments) distributed in the corresponding ISPR racks.

Subsystem	**Mass (Kg)**	**Rack (Kg)**	**Add. Mass (Kg)**	**Total (Kg)**
CI	343	208	55	606
CII	242	104	35	380
CIII	216	104	32	352
CIVa	242	104	35	381

[1] Right and Left sides are indicated looking at the module from the front part which is connected to the Base.

Subsystem	Mass (Kg)	Rack (Kg)	Add. Mass (Kg)	Total (Kg)
IB&CE	214	104	32	350
SGU	592	104	70	766
FPU	150	104	25	279
BPU	150	104	25	279
ARES	750			750
GWRU	386	208	59	653
Tanks mass	530			530
Initial mass	1250			1250
Total EELM				6547

Table 6 EELM payload mass.

A 10% of additional mass has been taken into account for support structures in the racks.

4.3 EELM Structure Mass

The module structure is designed according to the requirements of pressure, gravity, micro-meteorites impact and radiation shielding. As explained in [R3], the cylinder shape with a transportation system (like NASA Athlete) is selected and for the HPC system an inflatable system is proposed as per trade-off indicated below.

The EELM module structure will be made of aluminium honey-comb. For radiation protection and according to [R3]; High Density Polyethilene can be used with optimal results. A density of 5 gr/cm2 of HDPE provides a high level of protection while 2 gr/cm^2 provides an acceptable protection level, thus the second option is selected. In the case of the HPC system, the inflatable structure is equipped with a redundant bladder materials with acceptable performance against radiation and micro-meteorite impacts, besides bladder let an acceptable pressure control inside the system (Bladder is composed of textil shells based on high performance aramid fibres and shells based on low permeability polymeric films). The porosity due the materials can be minimised by 2 or 3 spaced redundant shells and between these spaces place pressure control. The Table 10 shows a generic trade-off between inflatable structures and metallic rigid structures.

There is the possibility to use the direct Sunlight if a semi-permanent illuminated spot is finally selected to place the Moon Base. In that case, the materials used for the inflatable would need to be semi-transparent, with the adequate filtering for UV and other harmful radiation. ESA has recently started a study of the feasibility of transparent surfaces in inflatables. The Inflatable structure is placed over a rigid structure with linear actuators (composite material & aluminium) in order to avoid the lunar surface irregularities (holes, dust, etc).

According to [R11] the following multi layer approach is currently being developed to provide proper radiation protection, micro-meteorite shielding, thermal insulation and air containment:

- An external MLI for thermal insulation, AO erosion and UV degradation.
- A MMOD (Micro-Meteoroids & Orbital-Debris) Shield to protect from MMOD high velocity impacts, composed by successive Bumper and Foam layers.
- A Structural restraint to assure pressure load carrying capability and to provide support for the internal bladder and the external layers.
- A redundant bladder for perform the air containment function.
- An internal barrier to protect the outer layers from fire and damages (scratches, tears and punctures) accidentally induced by crew activity.

Kevlar and Nextel materials are currently being characterised according to radiation protection protocols. Results with Kevlar are promising, the better protection is achieved using High Density Polyethylene.

ESA has developed a prototype and a sample wall mass manufactured was 6 Kg/m^2 [R10].

The current designs allow a working pressure of 1027 kPa, compatible with humans (or plants) presence.

The design is equipped with 3 redundant layers to minimise leaks. Measurements performed in the scale model with respect air resulted in a total of 8 g/ m^2 /day.

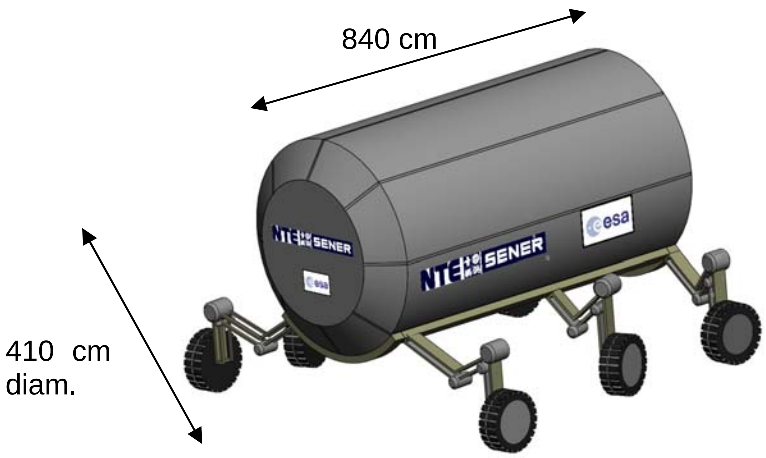
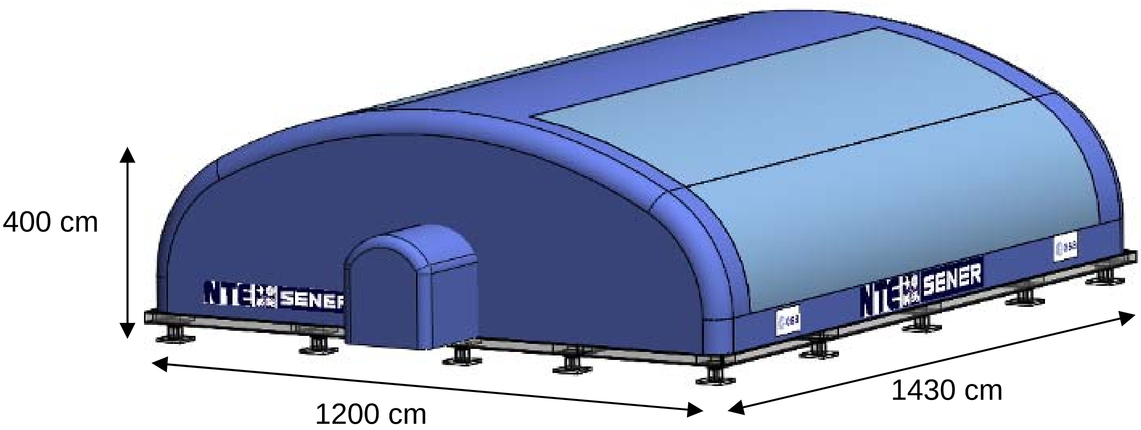


Figure 29 EELM dimmensions



EELM size	

Diameter (m)	4.1
Length (m)	8.4
Surface (m^2)	134

HPC size	
Wide (m)	12
Length (m)	14.3
Base surface (m^2)	171.6
Upper surface (m^2)	221
Total surface (m^2)	392.6

Table 7 EELM and EELM HPC size

Material		**Reference**
Aluminium density (Kg/m^2)	20.3	RD3
Sctructure mass (Kg)	2719.3	
HDPE Shielding density (Kg/m^2)	20.0	RD3
Shielding mass (Kg)	2679.2	
MLI Density (Kg/m^2)	0.5	RD7
MLI mass (Kg)	67.0	
Total EELM structure mass (Kg)	5465.5	

Table 8 EELM module mass.

HPC Material		**Reference**
Bladder or shells density (Kg/m^2)	6	RD10
Bladder or shells mass (Kg)	1326	
Base structure mass (Kg)	2000	
Tanks & plants container mass (Kg)	500	
Total HPC mass (Kg)	3892	

Table 9 EELM-HPC module mass.

According to Table 9 and Table 6 it is possible to approximate the mass of the EELM and the EELM-HPC modules with the subsystems installed. As can be seen, the total mass of the EELM is around 12 mT which in principle fits inside the estimations performed by NASA in [R3] about the cargo possibilities (see section 5.1). This mass can be reduced by different ways; one possibility is to study more effective composite materials that provide better shielding/mass ratio. Other possibility is to consider increased shielding only in the more exposed geometry while decreased shielding can be used in the part of the module near the ground which is less exposed [R8]. Besides, further analysis of equipment mass is required to quantify the possible reduction of mass if space hardware is used instead of the ground hardware estimated in this study, or the use of lightweight materials for some of the tanks.

About the transportation system, the Inflatable structure proposed in the HPC lets reduce considerably the total mass respect the metallic structure modules; using metallic structures the shape is determined by the launcher capacities (volume for storage and weight to load). In this case, 4 modules should be used instead of one inflatable structure in order to have the same cultivation area. The weight of each metallic module structure is

estimated around 5.5 mT, that means 22 mT for a complete HPC required for the same cultivation area, while the weight of an inflatable structure is around 4 mT for the complete HPC cultivation area. On the other hand, the inflatable structure has a major leakage than a rigid structure. Taking in consideration the measures at scale model, if a total of 8 g/ m^2 /day of air is lost due to porosity, a EELM-HPC of 221 m^2 of cover surface will result in 1,8 Kg / day of air mass loss.
Mass of equipments and internal structures is around 12 mT, which results of a total mass of 16 mT for the complete EELM-HPC. Again, optimisation of the equipments can be performed to try to reduce the mass, but the system is not far from currently envisaged launch possibilities.

Condition/structure	Inflatable structure	Metallic structure
Displacement	Fixed	Displacement available
Construction	Assembly process required	Already assembled
Transportation Weight	Low	High
Transportation Volume	Low	High
Air Leakage	High (porosity)	Low
Shape	w/o restrictions	Constrained by transportation
Rigid	No consistently	Consistently

Table 10 Trade-off between rigid and inflatable structure

The Figure 30 shows a complete EELM Module & EELM HPC assembly proposed. The EELM module is assembled by a rear door with the EELM HPC. A bellow is proposed as interface between both structures (done by composite materials), in this way the level deference of the floors could be compensated.

The installation procedure suggested consist as first step the installation of Inflatable structure base on the lunar surface, level the upper surface with the actuators, install the EELM HPC structure, approach the EELM module to the HPC dock and joint them by the bellows (see Figure 30 below).

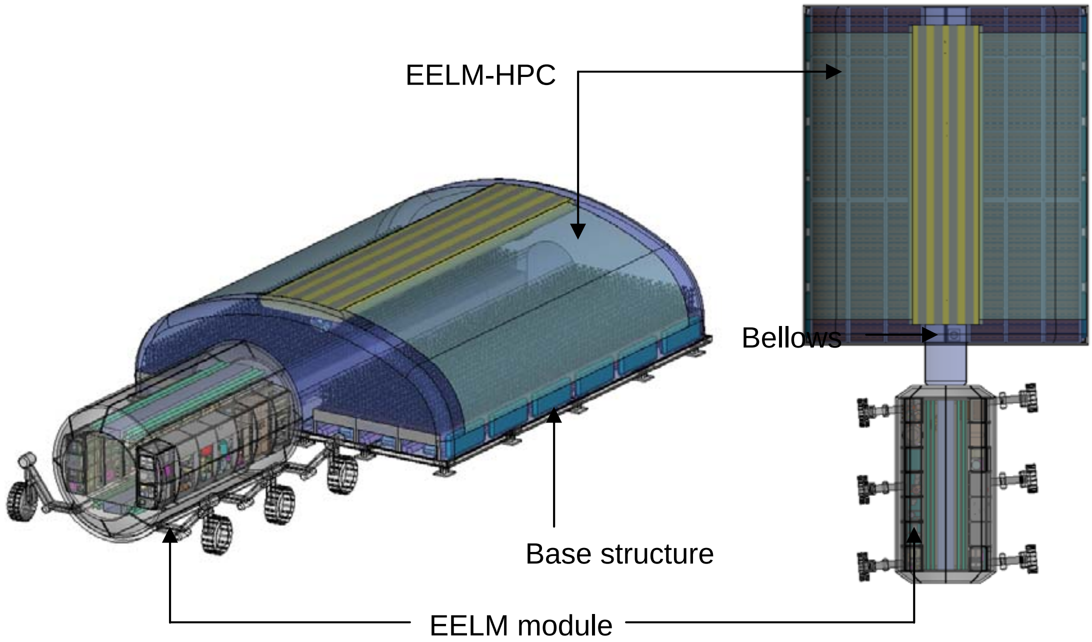


Figure 30 EELM plus EELM-HPC deployed.

5. EELM LUNAR BASE DEPLOYMENT

5.1 NASA Lunar cargo capabilities

Initially, NASA plans are to perform crewed sortie missions during 2-4 years, starting around 2020. Although not definitively defined, configurations currently managed imply two launches, one with the EDS (Earth Departure Stage) + LSAM (Lunar Surface Access Module) structure and a second with the EDS + CEV (Crew Exploration Vehicle). In these initial missions, the LSAM will be able to deliver 500 Kg of additional payload mass to the surface of the Moon.

Total ascent stage to LLO	Kg	9,898.0
Mission payload	Kg	500
Descent stage wet mass	Kg	18,010
LSAM mass including ascent stage	Kg	27,908
LSAM mass limit	Kg	29,100

Table 11. LSAM mass break-down (from [R6])

The possibility of a cargo mission with the same launch configuration than for the initial crewed sortie missions, would allow to take the ascent stage LSAM mass for cargo and simplify the LSAM.

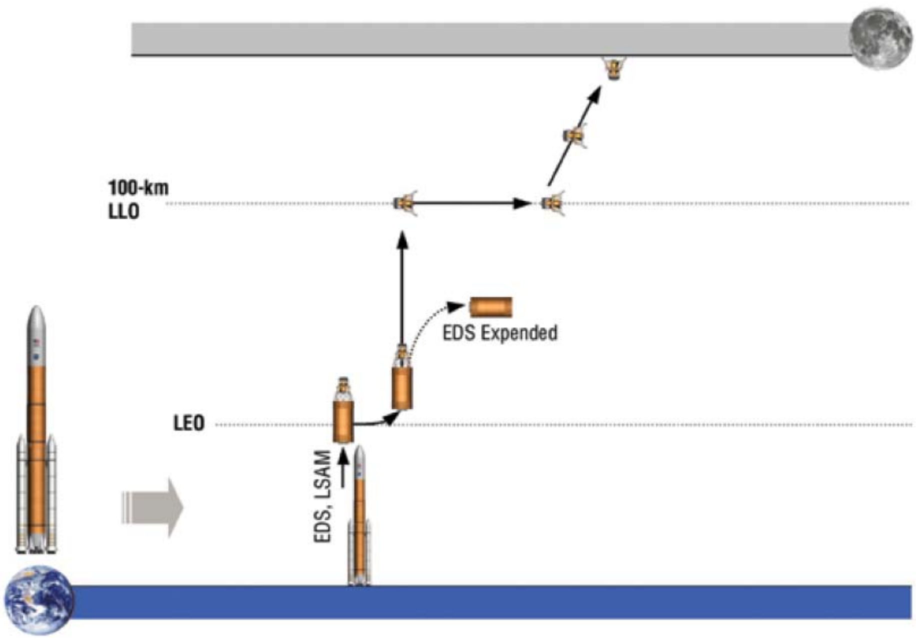


Figure 31 Lunar Surface Cargo Mission (from [R6])

The NASA's Exploration Architecture Study [R6] of 2005 performs a preliminary indication of mass cargo transportation to the Moon using same launcher configurations than for the crewed missions. Depending on the final launcher selected, cargo mass ranges from 18 mT to 20.9 mT. The total LSAM mass is from 27.9 mT to 46.9 depending on the launch configuration. Only one launch is required since EDS and LSAM are launched together.

5.2 ESA Lunar cargo capabilities

ESA study for an European manned outpost on the Moon [R9] is based on two cargo configurations, a 5 mT and a 10 mT class cargo delivery using Ariane 5 ECB with a Vulcain Mk.III as the main engine, able to deliver up to 27 mT to LEO. This Arian variation is called Arian 5-27 and is assumed to be available by 2015. With this configuration it would be needed one Arian 5-27 launch for the 5mT cargo delivery and two Arian 5-27 launches for 10 mT cargo delivery to the surface of the Moon.

Payload Class	Launch configuration	Orbit	Propellant	Payload
10 mT class cargo	Double Ariane 5-27 launch	Direct insertion in LTO and docking in LLO	Cryo Lunar orbit injection and descent.	7.3 mT payload on the Moon
5 mT class cargo	Single Ariane 5-27 launch	Direct insertion in LTO	Cryo Lunar orbit injection and descent.	4.1 mT payload on the Moon

Table 12.Ariane 5-27 Lunar cargo capabilities (from [R9])

5.3 EELM Deployment

The EELM will be formed by one EELM-Subsystems module plus one EELM-HPC module. The modules are designed to be stand-alone and thus operative from the first launch. The first module to be deployed will be the EELM subsystems module, which will be able to provide 100% air, 90% water and 5% diet for a crew of 4. The next module will be the

EELM-HPC, which will increase the diet supply of fresh products up to the 40% and therefore decrease the needs for food re-supply.

According to NASA and ESA current designs for cargo capabilities it is feasible to place the EELM on the Moon in a single launch, either with the CaLV configuration from NASA or using the Ariane 5-27.

The EELM-HPC, that is, the greenhouses, would need further development and special focus on inflatable structures progress.

6. CRITICALITIES AND TECHNOLOGY LEVEL

In order to study the system criticalities and the corresponding readiness level of the associated technology (TRL) a functional break-down of the system will be performed. This break-down will identify the main functions of the system and associates the related hardware. Most of the functions already exist in form of ground prototype in the MELiSSA Pilot Plant, others as ARES have a bread-board already build and for some of them already exist flight hardware.

Technology readiness level table	
TRL1	Basic principles observed and reported
TRL2	Technology concept and/or application formulated
TRL3	Analytical and experimental critical function and/or characteristic proof-of-concept
TRL4	Component and/or breadboard validation in laboratory environment
TRL5	Component and/or breadboard validation in relevant environment
TRL6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
TRL7	System prototype demonstration in space environment
TRL8	Actual system completed and "flight qualified" through test and demonstration (ground or space)
TRL9	Actual system "flight proven" through successful mission operations

Table 2. Technology Readiness Level Table

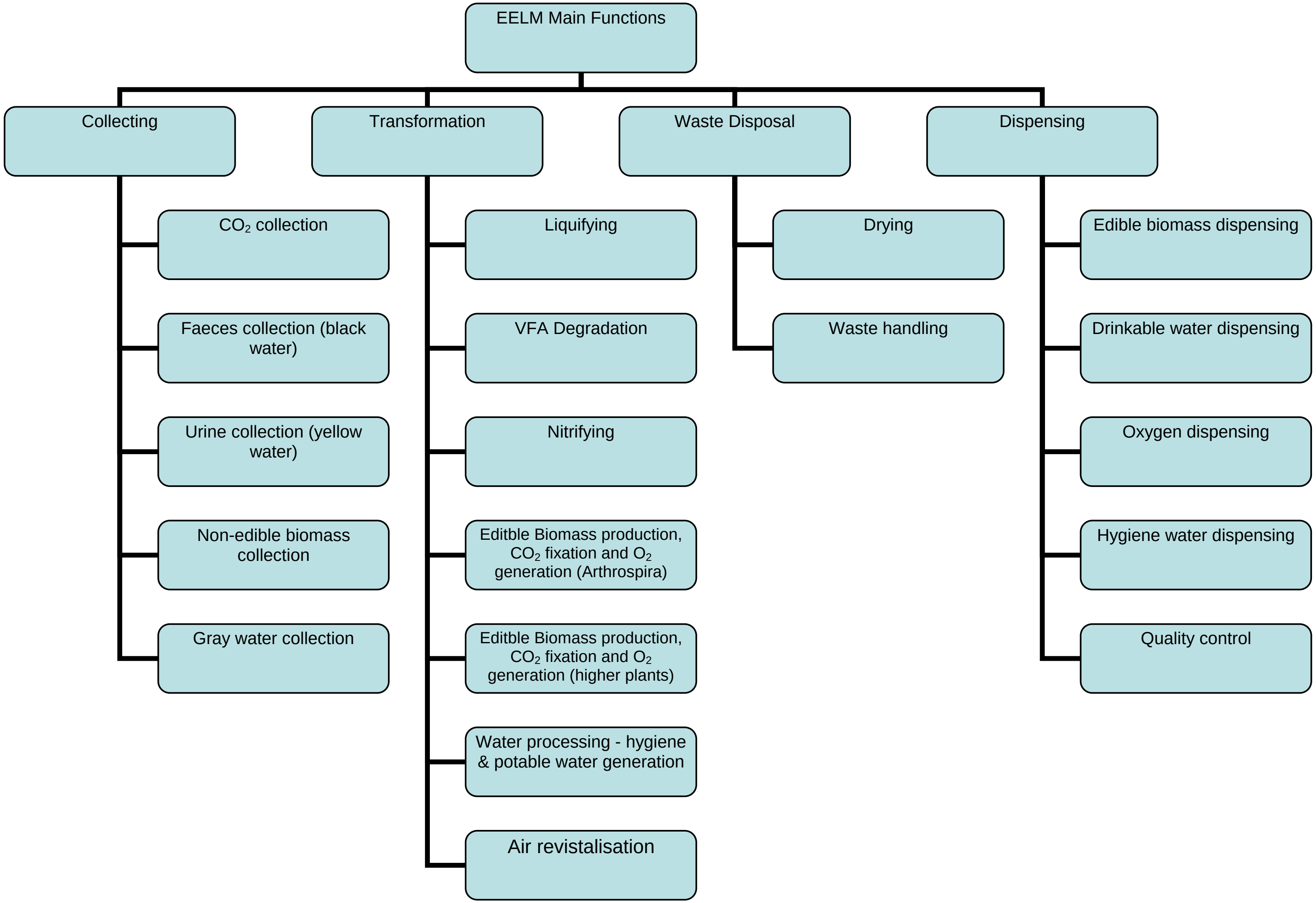


Figure 32 EELM Main Functions

Code	Function Name	Function details	Related Hardware	Status	TRL
1. COLLECTION					
1.1	Collection of air	Moon Base air is circulated through the EEM, CO_2 removed and O_2 added. High flow. Mandatory to be anticipated in the Moon Base design.	Conductions & Fans	Similar HW already exists on ISS	TRL9
1.2	Urine collection	Waste Collector Unit equipped with a urine collector and proper conduction to the EELM.	Conductions and pumping	Similar HW already exists on ISS	TRL9
1.3	Faeces collection	Waste Collector Unit equipped with a faeces collector. Several options possible, dilution with water and conduction through pumping (ground approach) or packing and grinding before use.	Waste Collector Unit	Needs development. System breadboard currently under development.	TRL4
1.4	Non-edible biomass collection	Grinding and dilution of non-edible biomass in order to obtain a homogeneous mixture to be input to the liquefying compartment.	Biomass Treatment Unit	Similar HW already exists on the MPP	TRL5
1.5	Gray water collection	Conduction of grey water to the EELM. Mandatory to be anticipated in the Moon Base design.	Conduction and pumping	Similar HW already exists on ISS	TRL9
2. TRANSFORMATION					
2.1	Liquifying process	Is a critical process. Recycling efficiency is being improved since this process is where more non-recyclable waste is generated.	Compartment I	First version already in the MPP, improvements under design.	TRL3
2.1.1	Biomass measurement	Adaptation to space hardware of on-line sensors for main compounds.	Biomass sensor	Similar HW already exists in the MPP	TRL4
2.2	VFA Degradation	Process validated in MPP	Compartment II	Similar HW already exists in the MPP	TRL4
2.2.1	VFA sensors	Adaptation to space hardware of on-line sensors for main compounds.	VFA sensor	Ground HW already exists	TRL4
2.3	Nitrifying	Process validated in MPP	Compartment III	Similar HW already exists in the MPP	TRL4
2.3.1	Urine treatment	Urine treatment is still to be designed and is only a preliminary concept.	Urine Treatment Unit	Hardware still to be developed	TRL2
2.3.2	Amonia / Nitrite measurement	Adaptation to space hardware of on-line sensors for main compounds.	Amonia sensor	Ground HW already exists	TRL4
2.4	Edible biomass production, CO_2 and O_2 (Arthrospira Platensis)	Process validated in MPP	Compartment CIVa	Similar HW already exists in the MPP	TRL4
2.4.1	Arthrospira Solid - Liquid separation	Process to separate solid/liquid has been designed but hardware is still to be developed.	Compartment CIVa	Hardware still to be developed	TRL3
2.4.2	Arthrospira washing	Process for Arthrospira washing is still to be designed although it does not seem a critical development.	Compartment CIVa	Hardware still to be developed	TRL3
2.5	Edible biomass production, CO_2 and O_2 (Higher Plants)	Process validated in MPP	HPC	Similar HW already exists in the MPP	TRL4
2.6	Water recovery	Hygiene water recovered from Grey water through microfiltration and reverse osmosis.	GWRU	Hardware existing and already working in the Concordia Antartic Base for several years.	TRL4
2.6.1	Potabiliser	A device to process hygiene water to convert it to potable water. The process would consist on adding salts and bactericide to the hygiene water. A WRS that recovers water from cabin air condensate and urine has been recently started on the ISS.	Potabiliser	Similar HW already exists on ISS. Equipment is under test.	TRL8
2.7	Air Revistalisation	Air revitalisation is performed by ARES. A breadboard of ARES already exists and plans to build a space hardware model have been set.	ARES	Breadboard already exists. Electrolyser already exists on ISS.	TRL4

Code	Function Name	Function details	Related Hardware	Status	TRL
2.8	Seed Germination Unit				
3. WASTE DISPOSAL					
3.1	Drying	Residual waste that cannot be processed should be dried. The process could be thermal but still to be defined.	Waste Processing Unit	Design to be adapted/improved although similar hardware already exists on ISS	TRL5
3.2	Waste Handling	Waste would need to be compacted and contained in sealed bags the option of being returned to earth is to be considered.	Waste Handling Unit	Design to be adapted/improved although similar hardware already exists on ISS	TRL5
4. DISPENSING					
4.1	Edible Biomass Dispensing	Edible biomass should be treated and packed for storage. Treatments can include drying, freezing or fresh packing. Also non edible biomass should be separated from the edible biomass. These residues need to be redirected to the Biomass Treatment Unit.	Food Processing Unit	Design to be performed although ground commercial systems can be adapted.	TRL3
4.2	Drinkable Water Dispensing	Conduction, pumping and storage has to be defined to dispense drinkable water. This is mandatory to be anticipated in the Moon Base design.	Conductions and pumping	Similar HW already exists on ISS	TRL9
4.3	Oxygen Dispensing	Conduction and funs to be defined to conduct O_2 enriched air. This is mandatory to be anticipated in the Moon Base design.	Conductions and fans	Similar HW already exists on ISS	TRL9
4.4	Hygiene Water Dispensing	Conduction, pumping and storage has to be defined to dispense hygiene water. This is mandatory to be anticipated in the Moon Base design.	Conductions and pumping	Although not implemented on ISS, hardware to conduct water already exist on ISS	TRL9
4.5	Water Quality Control (Microbial)	Detection and quantification of microbial species on water	Water Microbial Sensor	ESA is developing a microbial sensor for air (MIDASS) that could be adapted for water. Currently in phase A.	TRL3
4.5	Water Quality Control (Chemical)	Detection and quantification of trace chemical compounds on water	Water Chemical Analyser	NASA has developed a chromatograph to analyse cabin air. Could be adapted for water.	TRL3
4.6	Air Quality Control (Microbial)	Detection and quantification of microbial species on air	Air Microbial Sensor	ESA is developing a microbial sensor for air (MIDASS) .	TRL3
4.6	Air Quality Control (Chemical)	Detection and quantification of trace chemical compounds on air	Air Chemical Analyser	NASA (JPL) has developed a gas chromatograph plus a Mass Spectrometer to analyse cabin air (VCAM).	TRL8
4.7	Food Quality Control (Microbial)	Detection and quantification of microbial species on food	Food Microbial Sensor	Devices and methods used for ground analysis could be adapted to space.	TRL2
4.8	Food Quality Control (Chemical)	Detection and quantification of trace chemical compounds on food	Food Chemical Sensor	Devices and methods used for ground analysis could be adapted to space.	TRL2
5. COMMON EQUIPMENT					
5.1	Sterilisation	Sterilisation is now performed using steam. Steam requires high power to be generated, other methods could be studied to be used in a space environment as for instance vacuum or chemical processes.	All compartments	Steam sterilisation used in the MPP.	TRL4
5.2	Artificial illumination	Compartment II and IVa uses artificial light as they are phototrophic compartments. Current designs have a high power demand	Compartment II, CIVa and HPC	Artificial illumination already used in the MPP however needs improvement	TRL5

Code	Function Name	Function details	Related Hardware	Status	TRL
5.3	Water Condensation	Several condensers have been identified in the system to recover water from the gas phase.	Condensers	Similar HW already exists on ISS	TRL9

Table 13 Technology Level Readiness of EELM main functions