TN 3

PRELIMINAY LIFE SUPPORT SYSTEM DESIGN

MELISSA ADAPTATION FOR SPACE, PHASE II

ESTEC/Contract Nº 20104/06/NL/CP

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ACRONYMS LIST

ARES	Air Revitalization System
BLSS	Bioregenerative Life Support System
BVAD	Baseline Values Assumption Document
BWTU	Black Water Treatment Unit
COTS	Commercial Off The Shelf
ECLSS	Environmental Control and Life Support System
EVA	Extra Vehicular Activity
FPU	Food Production Unit
GCR	Galactic Cosmic Rays
GWTU	Grey Water Treatment 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
SMAC	Spacecraft Maximum Allowable Concentration
SPE	Solar Particles Events
UTU	Urine Treatment Unit

0. SCOPE

This document contains defines the preliminary design of an experimental ECLSS for a future Moon base. The ECLSS is composed European technologies currently under development. The design is based in the MELiSSA, ARES, GWTU and UTU technologies and the use of MIDASS as sensor for microbiological contamination, as well, as other technologies for controlling air quality as ANITA.

In this technical note, a preliminary study of the combination of these before mentioned technologies is performed. The recycling capabilities, element flows and total oxygen,water and food production is assessed.

To perform this study the EcosimPro models developed in the frame of this project and detailed in [R5] are used. These models allow a simulation in steady state of the mass flows between the different components.

The objectives of this technical note are summarised in the list below:

- To identify a configuration that combining MELiSSA's related technologies and other LSS technologies meets the first level of performance (i.e. up to 5% food production) and complies with the LSS requirements established in [R6]. For this configuration:
    - To perform a preliminary LSS design and sizing based on the (static) simulation results.
    - To use the ALISSE metrics in support for design choices.
    - Analysis of the different flows (water, CO_2 / O_2, food) and recycling efficiencies of the different key elements (C, H, O, N, S, P) at molecule levels, including peaks, average values, and uncertainties
    - To determine the loop closure degree and identify the type and amount of consumables needed, accordingly
    - To quantify the simulation uncertainty based on the models' accuracy.
- To identify a LSS configuration that meets the second level of performance (i.e. up to 40% food production). For this configuration:
    - To include a Higher Plants Compartment module in the loop
    - To combine this element with other MELiSSA and/or available LSS technologies
    - To use ALISSE metrics in support for design choices
    - Analysis of the different flows (water, CO_2 / O_2, food) and recycling efficiencies of the different key elements (C, H, O, N, S, P) at molecule levels, including peaks, average values, and uncertainties
    - To determine the loop closure degree and identify the type and amount of consumables needed, accordingly
    - To assess the simulation uncertainty based on the models' accuracy.

1. APPLICABLE AND REFERENCE DOCUMENTS

1.1 Applicable Documents

[A 1] 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

[A 2] 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)

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

[A 4] ESA Fax Ref. RES-PTM/CP7cp/2006.226, dated 29/03/06

[A 5] 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] Advanced Life Support Baseline Values and Assumptions Document. Hanford, A.J. et al. (2004). JSC-47804, NASA CTSD-ADV-484A

[R2] MELiSSA Yearly Report for 2004. The MELiSSA Partners. ESA/EWP-2287.

[R3] Eckart, P., Spaceflight Life Support and Biospherics, Microcosm Press & Kluwer Academic Publishers, 1996

[R4] MELiSSA Loop: First Estimate of Flow Rates and Concetrations through the Loop. Poughon L., Gros J.B. and Dussap C. G. ICES 2000.

[R5] Summary of European Life Support System Technologies, NTE-MEL2-TN-009, Issue 1.0, 28 March 2008

[R6] Moon Base Scenario Definition and Life Support System Requirements, NTE-MEL2-TN-007, Issue 1.0, 11 Jan 2008

[R7] Engineering of the Waste Compartment. Design Report. N. Michel, J. Stuyck, F. Vand Vooren. 5/03/2007.

[R8] Preliminary Design of the Water Recycling System. TN 8. J. Mas. Issue 1.2. 22-Feb-2008

[R9] Technical Specifications for the Re-design of the Compartment IVa Pilot Reactor. UAB.

[R10] Nitrfying Compartment Studies. Starting of the Nitrifying reactor. Issue 1.2. Perez, J. , Montesions J.L., Godia F., September 1996

[R11] Set-up of the Photosynthetic Pilot Reactor. TN 37.2. Issue 1.0. Vernerey. A., Albiol J., Godia F. April 1998.

[R12] Potential Designs for a Food Production Unit. E.G.O.N. Janssen, M.H. Stienstra, D. Wierinck , M. De Ridder, R. Kassel, J. Elvira. TN 2. Issue 1.1. 28 Feb 2005.

[R13] Higher Plant Chamber Prototype for the MELiSSA Pilot Plant: Detailed Design and Verification. Geofrey Watters, Alexandra Massot. Issue 1.0. 26 Sept 2006.

[R14] duplicated

[R15] Design Status of the Closed-Loop Air Revitalisation System ARES for Accommodation on the ISS. Kunke H., Raatschen W., Bockstahler K. ICES 2007

[R16] Alptekin G. et Al. An Advanced Carbon Dioxide Removal and Reduction System. ICES 2003.

[R17] L. Poughon, MELiSSA Technical note 83.11 . Memorandum of Understanding 1907105/NL/CP - Analysis of Working Packages for the MPP Integration Strategy . 2008

[R18] International Space Station Bacteria Filter Element - Post-flight Testing and Service Life Prediction, J. L. Perry, R. G. von Jouanne, E. H. Turner, ICES, 2003

[R19] The Air Quality Monitor ANITA – Going into Operation on the International Space Station, T. Stuffler, H. Mosebach, D. Kampf, A. Honne, H. Odegard, H. Schumann-Olsen, G. Tan, ICES, 2007

[R20] ARES baseline design report, ARES-DOR-RP-001, Issue 5

[R21] System Requirements Document, MiDASS, bioMerieux, Revision 1 Version 1.15/01/2007

[R22] A History of Spacecraft Environmental Control and Life Support Systems. K. Daues, NASA Johnston Space Center. January 6, 2006.

[R23] NTE-MEL2-MN-013. Preliminary Design Review Minutes of Meeting. 4 July 2008

2. INTRODUCTION

In previous technical notes, the requirements for an European Life Support module for a Moon base have been set [R6] and an EcosimPro library with the models of the MELiSSA loop, ARES, UTU and GWTU components has been created and described in [R5].

The current study analyses the different European ECLSS technologies with respect to the ALISSE criteria. However, a tailoring of the ALISSE criteria evaluation is proposed due to some criteria still need further development which is out of the scope of this project.

A preliminary analysis of the different systems is performed taking the information from the current implementations at laboratory scale or from literature. After that, two configurations (5% and 40% of food production) are proposed and evaluated, discussing possible alternatives.

Also in this TN it is reported the flows and recycling capabilities for each component individually. This information has been used to perform the trade-off.

3. SYSTEM SIZING REQUIREMENTS

According to [R6] the main requirements that will drive the system sizing are outlined below:

- Mission duration is continuous stay.
- Crew size is 4 crewmembers.
- Air recycled to close 100%

- Water recycled to >90%
- Up to 5% of diet coverage without Higher Plants Compartment.
- Up to 40% of diet coverage with Higher Plants Compartment.
- Power consumption up to 40 KW.

Therefore, two main configurations have been defined, one to cover 5% of the crew diet only through the MELiSSA CIVa compartment and a second one to cover the 40% including the Higher Plants Compartment.

4. ALISSE CRITERIA

ALISSE criteria as per [RD7] are the following:

- Efficiency:
    - Need Coverage Ratio
    - Efficiency as transformation yield
- Mass:
    - Initial mass
    - Time dependant mass
- Energy: Total energy as a sum of electrical energy, chemical energy, thermal energy.
- Reliability: Probability of failure of a system for a given time.
- Risk to human: Formal risk analysis of each subsystem.
- Crew Time: Crew time is defined as the time required by the crew to perform planned maintenance tasks, non-nominal maintenance tasks, control and operation of the system. The estimation can use historical data or be based on real exercises with the system.

In addition to that criteria, volume will be also estimated. As the designed system has a lot of tanks and buffers, volume is also an important measure in order to provide a preliminary distribution of these components into a potential European Lunar Module.

4.1 Efficiency as Need Coverage Ratio

Efficiency as Need Coverage Ratio is calculated as follows:

$$NCR_i = \frac{COFR_i - CIFR_i}{CNFR_i} \qquad (1)$$

where:
NCR: Need Coverage Ratio
COFR: Compound Output Flow Rate
COIFR: Compound Input Flow Rate
CNFR: Compound Need Flow Rate
and sub-index i can be any compound target of interest (oxygen, water, food)

This calculation will be performed at input and output of the Crew Compartment for the components which are the target of interest, i.e., oxygen, potable water, hygienic water, food.

4.2 Efficiency as transformation yield

Transformation yield is in general calculated as:

$$\eta_i = \frac{P(Z_2)}{I(Z_1)} \quad (2)$$

where:
$P(Z_2)$ is the production rate of the component Z_2 in g/h
$I(Z_1)$ is the input flow rate of the component Z_1 in g/h

This metric defines transformation with respect the total amount in the input. This is a system evaluation parameter but for component evaluation it would be more indicative to calculate the recycling capacity of the component, that is:

$$\eta_i = \frac{P(Z_2)}{O(Z_1) - I(Z_1)}$$

4.3 Mass

Mass will be defined as the initial mass (hardware, connections, tanks, etc.) and the working mass expected for this component (f.i. initial water content). Time dependant mass will not be taken into account since it requires detailed identification of consumables, preventive maintenance issues, expendable parts, etc. and therefore a detailed system design which is out of the scope of the project. However, time dependant mass is considered an important factor, since the systems under study have many parts which need replacement as preventive maintenance.

4.4 Energy

Although ALISSE defines energy criteria as the complete energy balance (electrical, chemical and enthalpy) for this study only average power consumption per hour, that is electrical energy, will be considered. Chemical energy and enthalpy requires a detailed study of the reactions and thermal interactions between of all components which is out of the scope of this project.

4.5 Risk to humans

A preliminary analysis on the main risks that are specific derived from the use of MELiSSA and related technologies

4.6 Reliability

As this parameter depends on the topology of the system, at this time only a qualitative evaluation will be performed. A preliminary analysis will be performed identifying design constraints that can help to improve reliability.

4.7 Crew time

A preliminary evaluation of the principal crew time demanding tasks will be performed.

5. SYSTEM CHARACTERISATION

5.1 MELiSSA

The library components used for the MELiSSA technologies are shown in Figure 5-1. The basic elements are Compartment I (CI), Compartment II (CII), Compartment III (CIII), Compartment Iva (CIVa), Higher Plants Chamber (HPC), Food Treatment Unit (FTU) and the Crew Compartment (CC).

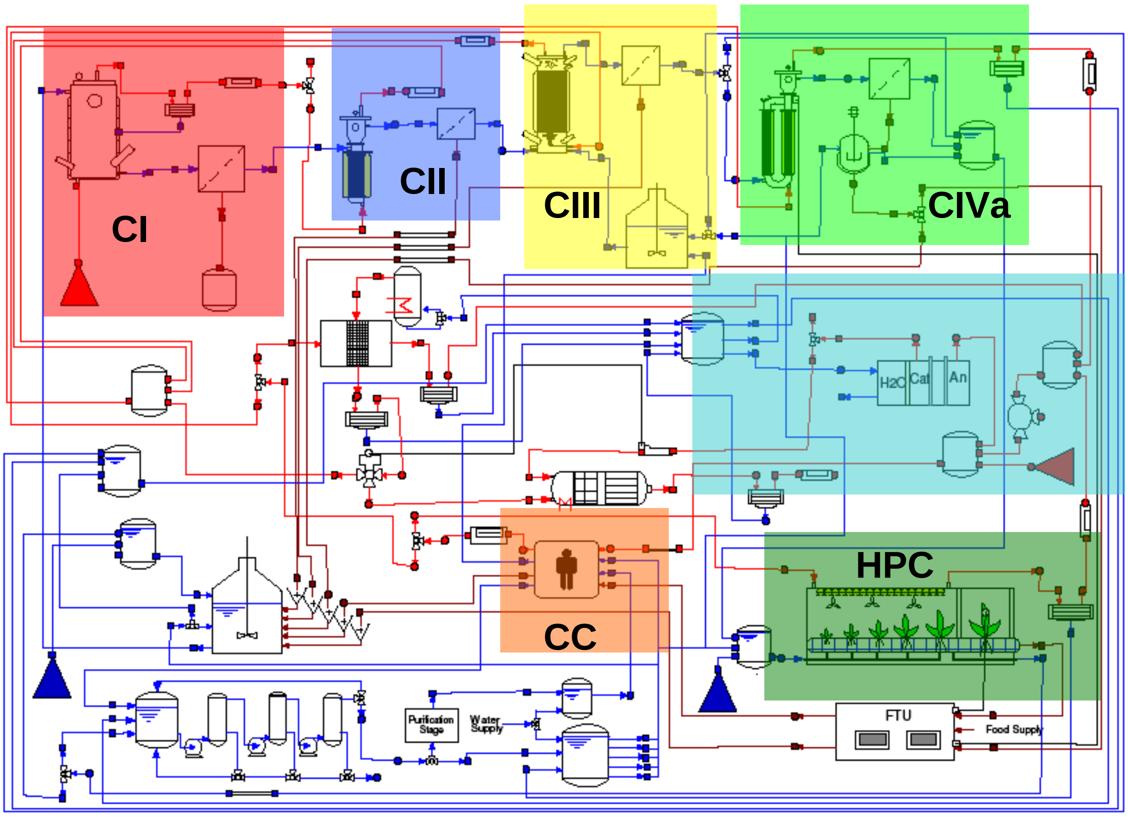


Figure 5-1 MELiSSA Technologies

Compartment I is the liquefying compartment, which contains a Biomass Pre-treatment Unit (BPU), which grinds the wastes from CC and HPC and mixes them with water. The resulting solution is going to the liquefying reactor (CI_BR), where thermophylic anaerobic fermentation takes place. The gas is going to a condenser to recirculate the water to CI_BR and the liquid is going to a solid liquid separator (SLS).

Compartment II is the photoheterotrophic compartment, which contains a bioreactor, in which the micro-organism *Rhodobacter rubrum* is cultured under a photoheterotrophic process, transforming volatile fatty acids (VFA) to Ammonia. The liquid is then passing through another SLS.

Compartment III is the nitrifying compartment, which contains a bioreactor, in which the ammonia is transformed into Nitrates by a co-culture of *Nitrosomonas europaea* and *Nitrobacter winogradskyi*. The liquid is then passing through another SLS.

Compartment IVa is the Photosynthetic compartment, which contains the phototrophic microscopic algae *Arthrospira platensis* to convert nitrates and O_2 to edible biomass and

O_2. The liquid stream is passing through a SLS from where the solid biomass of *Arthrospira* is cleaned from the solute to make it eatable.

The Higher Plants Chamber is the food production unit, which contains of the Higher Plants Chamber itself, where 8 different crops are produced and a condenser to regain the high water contents in the air for the water loop.

The Food Treatment Unit is a single component for gathering the output of Compartment IVa and the Higher Plants Chamber for separating the eatable form the waster material of the produced plant mass.

The Crew Compartment is a single component representing the needs to sustain human life. The daily input needs of air, water and food per person are baseline requirements that drive and set demands for the other compartments.

5.1.1 General Assumptions

In general to assess the power, mass and volume the existing laboratory designs will have to be used. Elements for Compartment I will be obtained from [R7] and power estimations will be obtained from equivalent systems as f.i. from [R8] or directly by the COTS equipment specifications. Elements for Compartment II, III and IVa will be obtained from [R9], [R10] and [R11].

A margin will be calculated to estimate the optimisation of flight hardware according to a comparison of existing ground equipment and the corresponding flight hardware. Values for flight hardware will be taken from [R1], where figures for ISS, Columbus and Space-Lab are presented.

5.2 ARES

The main components of the Air REvitalisation System (ARES) are the Carbon dioxide Concentration Assembly (CCA), the (Carbon dioxide Reduction Assembly (CRA) and the Oxygen Generation Assembly (OGA).

The CCA contains an Adsorber-Desorber component, which separates the CO_2 from the atmosphere. The evaporator (E_CAA) is producing water vapor for the desorption process and two condensers after each of the components recuperates water from the gas streams.

The CRA contains a Sabatier reactor, which receives the CO_2 directly from the CCA. Upstream of the reactors it is mixed with the hydrogen from the OGA convert carbon dioxide and hydrogen to methane and water vapour, through the reaction:

$$CO_2 + 4\,H_2 \leftrightarrow CH_4 + 2H_2O$$

Downstream of the Sabatier reactors is another condenser.

The OGA contains a Water Management Unit, which recovered water from the CCA and CRA. The output is part of the feed of the electrolyser and part of the steam needed in the adsorber. The Electrolyser component has been created to model the electrolysis process which separates Hydrogen and Oxygen.

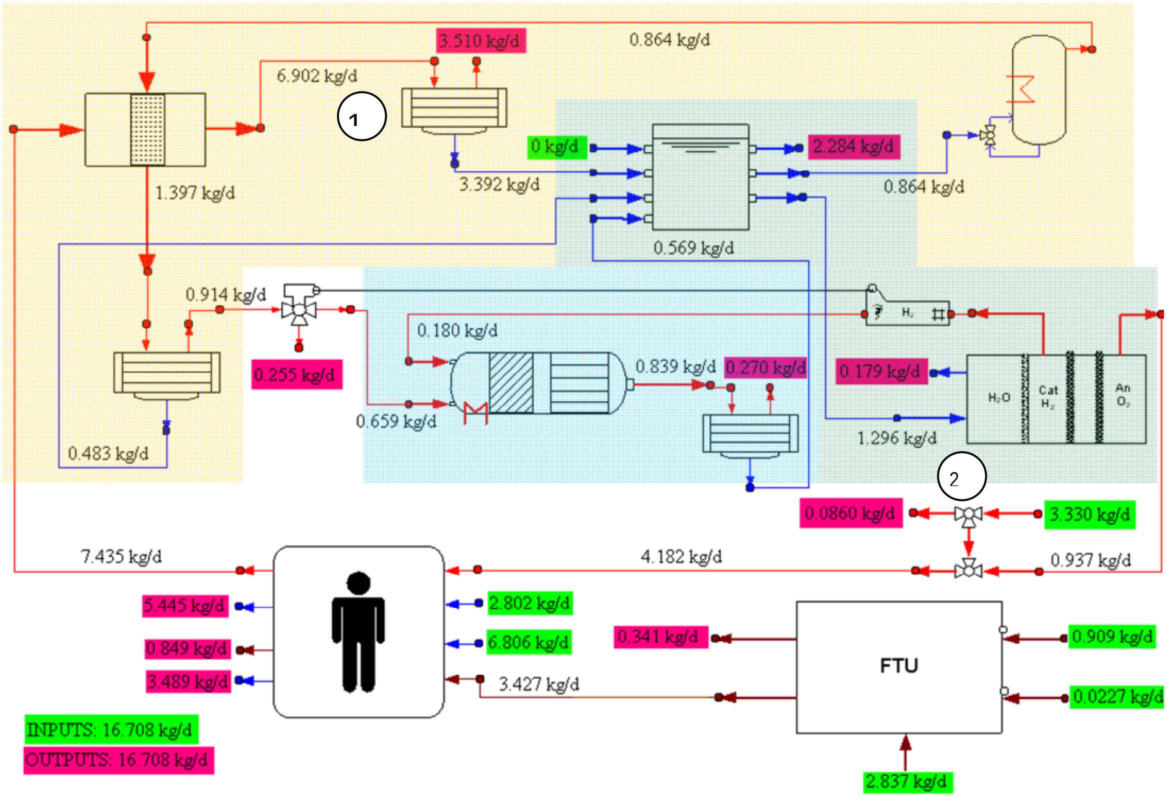


Figure 5-2 ARES technologies

ARES requires around 2.2-3.3kW and weights around 750 Kg for three crew members [R20]. Also it has a high efficiency in recovering oxygen from CO_2 since only with ARES it is possible to practically achieve 100% atmosphere generation. If ARES is used in conjunction with MELiSSA it is possible to even reduce ARES power consumption since it will not be necessary to process all CO_2 generated as the Compartment IVa and the HPC will be also CO_2 consumers.

5.3 UTU

The Urine Treatment Unit represents only the addition of a dissolution phase of the urine before input to the MELiSSA Compartment III. Only some piping equipment is added and the dissolution tank.

5.4 GWTU

The water treatment Unit collects all used water and treats it to potable and hygiene water quality.

The Grey Water Treatment Unit (GWTU) collects yellow water (urine), grey water (from showers, laundry, sinks, etc) and humidity condensate to change it to hygiene water quality. Parts of it is sent in a purification stage to gain potable water. Via a Liquid Collector and Distributor the gained waters of the different purification stage are distributed to their needs.

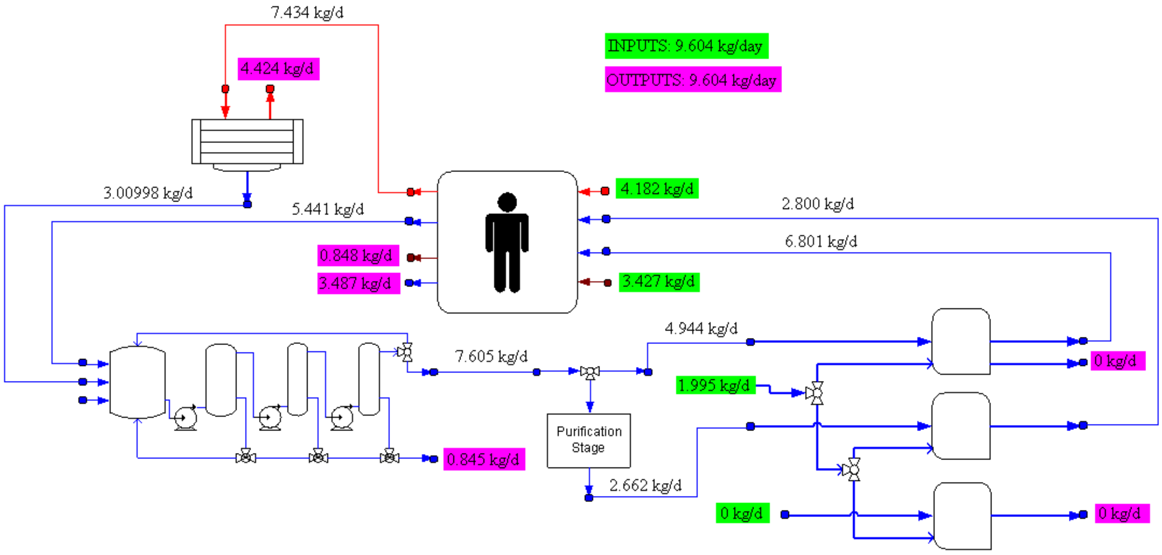


Figure 5-3 GWTU technologies

Mass, power and volume for the Water Recovery System is obtained from [R8] for a system with an input flow of ca. 80 litters/day and reproduced in the tables below:

	Mass Kg	Volume (l)	Power consumption (W)
Membranes	16,80	14,46	0,00
Pumps	162,30	40,90	5.311,00
Valves	40,11	TBD	249,00
Sensors, actuators & Hx	58,92	105,23	1.040,92
Tanks & filters	250,02	688,78	0,00
Piping	79,22	127,40	0,00
Control System	5,50	15,00	190,00
Total	612,87	991,76	6.790,92

Table 1 Mass, Power and Volume of Water Treatment Unit [R8]

This budged included the Nitrification reactor equivalent to the MELiSSA CIII reactor. From the estimation performed in section 5.1 there is only a difference of 10 Kg in mass without tanks and of 400 W in power because in this budget calculation most of the valves are operated manually.

The GWTU is quite efficient in recovering water from the grey water generated by the crew. The high power demand of the pumps is because of the high pressure pumps used in the reverse osmosis filtration unit. However, only with the GWTU it is possible to recover the 90% of water if the UTU is used along with the filtration and potabilisation unit. Furthermore, if it is used in conjunction with MELiSSA other sources of water can come from the condensation units of the different compartments, reaching a near 90% water loop closure [R8].

5.5 ANITA

The Analyzing Interferometer for Ambient Air (ANITA) is the first air quality sensor within the International Space Station (ISS). ANITA monitors optically the air for 30 potentially gaseous contaminants [R19]. The technology consists on a trace gas optical monitoring system based on Fourier Transform Infrared (FTIR).

The FTIR is calibrated to detect low parts per million levels in the cabin atmosphere—everything from formaldehyde to ammonia and carbon monoxide – and additionally to the rapid detection of air quality it also allows to the ECLSS the immediate initiation of countermeasures to mitigate the air contamination.

ANITA is currently installed in the ISS and under operation.

ANITA - I mass	48 Kg
ANITA - I power	70 W / 110 W depending if gas cell pump is operating or not.

Figure 5-4 ANITA Flight Hardware locker 1 [R19]

Figure 5-5 ANITA Flight Hardware locker 2 [R19]

ANITA is under further improvement as a complex air monitoring system to be included in future crew exploration missions to the Moon or Mars.

5.6 MIDASS

MIDASS is an instrument for monitoring environment quality allowing the ECLSS rapid identification of microbial risks. MIDASS technology is based on molecular diagnostic methods. The instrument can be used for monitoring of air and surface samples and detection of microbial contamination of liquid and food samples. The instrument will be placed in principle in the ISS, but it is envisaged to use MIDASS in general for long term crew manned exploration vehicles and permanent planetary bases as an efficient way of detecting and controlling microbial contamination.

Expected power consumption by MIDASS is around 200 W and with a permanent mass of 35 Kg, with a fungible mass of 2 Kg to be replaced every 6 month.

The instrument is currently under development, a bread board could be available in the time frame 2009-2010 [R21].

5.7 Risk to Human

5.7.1 System Malfunctions

As a Life Support system, the major risk to human is a malfunction of the system, eventually stopping any of the critical functions or providing the wrong result such as contaminated air or water. Reliability is briefly analysed in section 5.6.

5.7.2 Microbial Contamination

The risk of microbial contamination is not only coming from the biological system, but also from the crew itself. The microbes in the bioreactor are contained and not exposed to the crew, but in failure of the containment the risk is increased. Therefore, the species used in MELiSSA, have been selected to minimise the risk to humans.
Furthermore, several considerations can be taken into the design to minimise this risk:

- Provide decontamination at several stages and by different methods (UV, sterilisation, pasteurisation, etc.)
- Provide detection of microbial contamination at the different phases (liquid, solid, gas).
- Design protections in case of microbial contamination to avoid delivering the contaminated product to the crew.
- Provide isolation mechanisms to enclose contamination whenever possible, minimising the propagation.

For example the ISS [R18] uses high efficiency particulate air (HEPA) filters to remove particulate matter from the cabin atmosphere. Known as Bacteria Filter Elements (BFEs), there are 13 elements deployed on board the ISS's U.S. Segment.
The filter media is rated at 99.97% efficiency for 0.3-μm diameter particles and is pleated to maximize cross sectional area. A 20-mesh pre-screen on the filter's face serves to capture lint and large debris that may excessively load the HEPA media.
A BFE is designed to have no more than 82.2 Pa pressure drop at 113 m^3/h flow rate. Before the end-of-life pressure drop of 124 Pa is reached, each filter must be able to load with 32 grams of particulate matter.

Figure 5-6 Typical Bacteria Filter Element [R18]

5.7.3 Toxic Gases

It has to be considered that toxic gases will be likely generated by the system. In the case of methanogenesys in the MELiSSA Compartment I for example or in the case of ARES where methane is nominally generated.

To minimise the risk of toxic gases propagation, the container must be pressurized at a higher pressure than the nominal working pressure of the compartments. This will complicate pressure control, which must be communicated with external parts of the container to provide gasses evacuation.

Other gases, in less quantity such as sulphuric can also be generated by the compartment I or even in high concentration CO_2 can also be toxic. The oldest and therefore most mature method of regenerative CO2 removal and used also on board of the ISS are the Molecular Sieve Systems.
Molecular sieve Systems make use of the ability and synthetic zeolite or aluminio-silicate compounds to absorb CO2. The CO2 is removed from the cabin air by pumping the air through adsorption beds containing the zeolite material. Once the adsorption bed is saturated, the carbondioxide can be desorbed with the help of heat and vacuum. Two adsorption bed are mounted, operation alternately in either adsorption or desorption mode to ensure continuous operation.

To early detect toxic gas contamination, sensors such as ANITA can be used. See section 5.5.

5.7.4 Other general risks

Other general risk that must be taken into account are standard to space equipment or human interface design such as electrical safety, rotating equipment, hot spots, fast depressurisation or sharp edges and standard methods have been designed to minimise these types of risks.

5.8 Reliability

The system sizing performed in this study is not accounting for the redundancy required in high reliability systems. In principle, as stated in [R6], the European Life Support Module is expected to operate in parallel with the conventional ECLSS of the Moon base. This relaxes in some measure the reliability requirements. However, as the system has a high dependency between the different components (for instance, oxygen is required by compartment II to operate or Compartment I is basic for the rest of MELiSSA compartments) failure tolerance has to be taken into account from the beginning of the design phase.

In general, several design considerations can be identified to increase system reliability:

- Failure Detection and Isolation (FDI) will be of major importance. Allowing the crew the fast identification of the faulty system. This should include system failure, that is, a pump not working, and function failure, that is, a problem in the quality of the water delivered.
- Failure Tolerance in the sense of providing a smooth degradation of the system functions to give enough time to repair the malfunction before the total system stops.
- Analytical Redundancy as a help to minimise hardware redundancy can also be applied.
- System reconfiguration, that is, the ability of the system to reconfigure itself in order to minimise a system malfunction avoiding the total system stop.

5.9 Crew Time

After the system is assembled, the most demanding crew time activity will be maintenance tasks as nominally a ECLSS does not need operational time. In principle, all measurements is expected that are performed on-line by the proper sensors and analysers.

Maintenance can be classified in preventive maintenance and corrective maintenance, identification of major time consuming tasks is performed in the sections below.

5.9.1 Preventive Maintenance

Preventive maintenance tasks:
- Periodic system sterilisation to maintain anexenic conditions.
- Calibration of instruments
- Change of consumable elements such as membranes or analyser reactant.
- Periodic replacement of lamps

The most time demanding task can be identified as the calibration of instruments since it is expected to have around 60 different sensors and with an average time of calibration of 10 minutes is around 600 minutes every 6 months [R8].

5.9.2 Corrective Maintenance

The most demanding task for corrective maintenance can be identified as the start-up of a compartment in case of biological malfunction. The tasks to clean, sterilise, refill and inoculate the bioreactor can take approximately 24 hours [R8].

5.9.3 Higher Plants Compartment

In [R12] the crew time needed to maintain a greenhouse is estimated as 4 hours per week. This value is assuming that most of the crop handling is performed automatically by a robotic arm that performs at least the following tasks:

- Planting germinated seeds in support tray
- Pollination if needed (depends on plant species and forced convection could be used when required)

- Plant health monitoring
- Plant sanitation (e.g. fungus removal by picking leaves or spraying chemicals)
- Harvesting of plants, including the separation of edible mass from waste

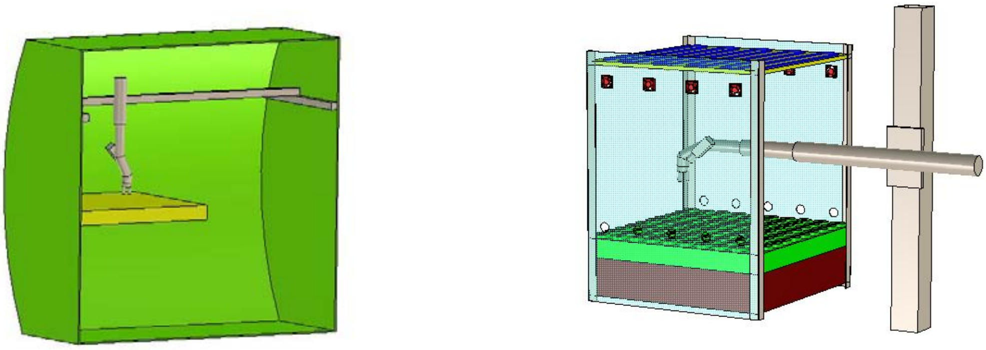


Figure 5-7: concepts for a robotic arm in a growth chamber [R12]

6. BASE LINE VALUES

Following tables define the baseline values used in the simulations.

Parameter	Value	Reference
Food consumed (Kg/ 🧍 /d) dry mass	0.617	[R1]
Potable water consumed (Kg/ 🧍 /d) 2.0 (Kg/ 🧍 /d) of drink water 1.8 (Kg/ 🧍 /d) of food water	3.85	[R1] (rounded from 2.06 to 2.0 litres of drinkable water)
Hygienic Water (Kg/ 🧍 /d)	6.68	[R1] value in range for mission below 30 days (table 4.6.1). This value can be increased up to 25 Kg/ 🧍 /d depending on the comfort required.

Table 2 Crew Consumables

For the crew metabolism a model has been created and is described in [R5]. Oxygen consumed and carbon dioxide produced are related to the food quantity and composition, as well as faeces mass. According to this model following values are obtained:

Parameter	Value	Reference
O_2 consumed (Kg/ 🧍 /d)	0.919	[R5]
CO_2 produced (Kg/ 🧍 /d)	1.083	[R5]
Fecal solid waste (Kg/ 🧍 /d)	0.035	[R5]
Fecal water (Kg/ 🧍 /d)	0.098	[R5]
Respiration and perspiration water (Kg/ 🧍 /d)	2.199	[R5]
Urine Water (Kg/ 🧍 /d)	1.957	[R5]

Table 3 Human Metabolism

Therefore the respiration quotient (O_2 / CO_2) provided by the crew metabolism model is 0.857. In [R1] the respiration quotient is 0.869 (less than 2% different).

Cabin atmosphere composition is considered as follows:

Parameter	Value
Temperature (ºC)	23
Pressure (atm)	1
Nitrogen (%)	79.259
Oxygen (%)	20.220
Hydrogen (%)	0.352
Carbon Dioxide (%)	0.128
Ammonia (%)	0.041
Volatile Fatty Accids (%)	6.94×10^{-13}
Humidity (%)	41.398
Air density	1.18
Residence time for the air in the cabin (h)	0.421

Table 4 Atmospheric Conditions of Crew Cabin

Cabin atmosphere composition is a result of the design. The generation and purge of gases in each compartment is balanced to have an approximate 80% Nitrogen / 20%

Oxygen. In [R22] atmosphere composition for the ISS is defined as 78.5% Nitrogen / 21.5% Oxygen. The rest of gases are expected to be transferred to the atmosphere by the different MELiSSA compartments (Hydrogen, VFA and ammonia) in very low quantity. Carbon dioxide concentration is maintained below the 0.2%.

7. CONFIGURATION A. 5% FOOD PRODUCTION

According to the previous section, it can be seen that to recycle 100% air and more than 90% water we need in addition to MELiSSA loop compartments the ARES and the Water recovery system. ARES will provide this 100% air closure since MELiSSA is only able to provide 5% of the total oxygen demand providing the 5% of the diet. Furthermore, to be able to recycle more of the 90% of water we will need the UTU plus the GWTU. With the UTU it is possible to recover the 2 litres of water coming from urine and also the ammonia which will be treated by the CIII.
This configuration assumes that food production of the 5% is achieved by using biomass generated by the CVIa compartment, using *Arthrospira* with the proper treatment (separation, drying, etc.). Although *Arthrospira* is reach in aminoacids and there are concerns about the limit of aminoacids that a human can consume per day, 5% diet represents 123 grams of *Arthrospira*.

Therefore proposed configuration relies on the MELiSSA loop plus ARES, the GWTU and the UTU.

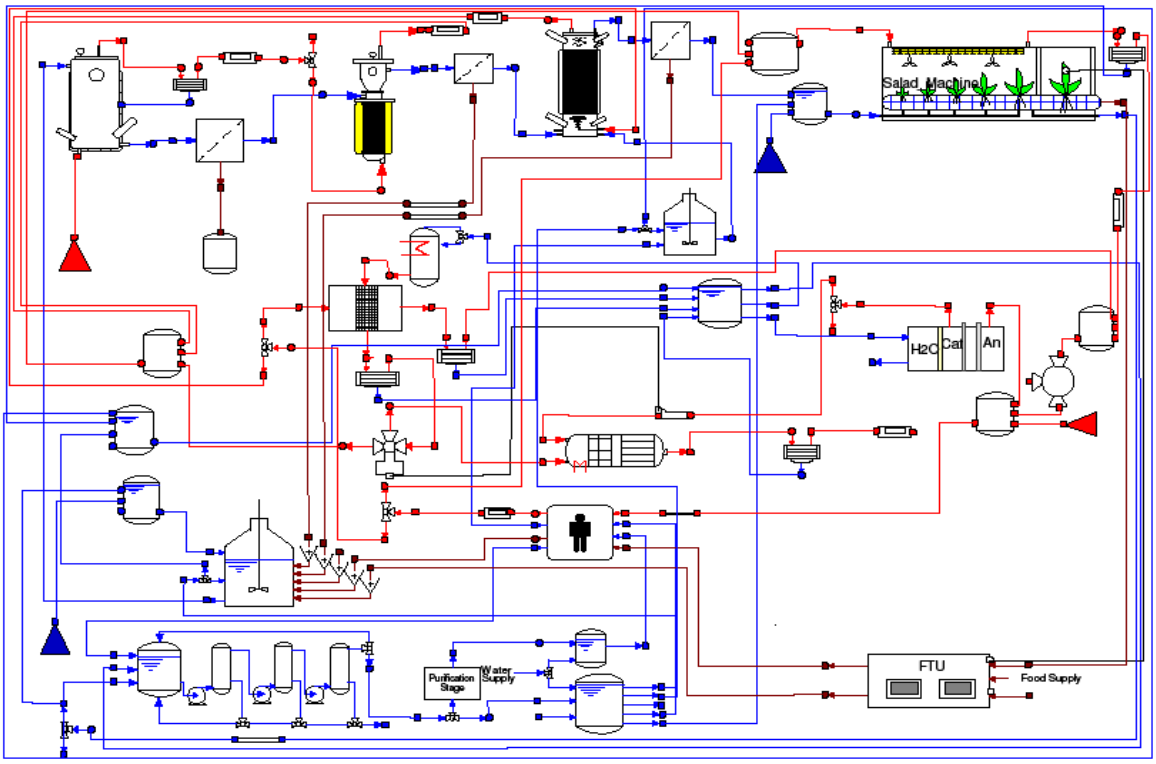


Figure 7-1 ECLSS configuration with 5% food production

The set up in Figure 7-1 used condensed water for the electrolyser. The model is working with the assumption of only H_2O being condensed and therefore no purification is indicated. A real system would need to use purified water.

CIVa produces approximately a 10% of the required oxygen for the 5% diet production. It could be possible to augment Oxygen production by increasing biomass production but this biomass could not be totally consumed by the limit in recommended amino acids ingestion.

The system needs an external supply of circa 5 litres/day. Total water recirculated through the system is around 60 litres/day. This is taking into account also recirculation of the condensate water.

7.1 Oxygen Production

7.1.1 ARES

Oxygen recycling efficiency for ARES is calculated below:

Element	**Variable**	**Quantity (Kg/day)**
CO_2 input	Adsorber_Desorber_1.w_air_in[CO2]	7.735
CO_2 output (towards other subsystems)	CO2_Management_ARES_1.w_gas_left[CO2]	4.927
CO_2 output (vented, not used)	Condenser_CRA.w_gas_out[CO2]	0.1164
Oxygen output	Electrolyser_1.w_out_An[O2]	3.832

Table 5 Oxygen Recycling ARES

Recycling Efficiency	
Need Coverage Ration (O_2)	$ARES - NCR_O = \frac{3.832}{4.049} \approx 95\%$
Transformation Yield (CO_2, O_2)	$ARES - \eta_C = \frac{P(O_2)}{I(CO_2) - O(CO_2)} = \frac{3.832}{7.735 - (4.927 + 0.1164)} \approx 142\%$

Table 6 Recycling efficiency for ARES

As can be seen, oxygen production is a 42% over the carbon dioxide input. This is due to the fact that oxygen is obtained electrolysing water, so first CO_2 is transformed into water + methane and then the water is electrolysed obtaining hydrogen and oxygen. Therefore, the ARES is also a water consumer. In the design water to ARES is redirected from air condensers. The water needed to produce the 3.832 Kg/d of oxygen is 4.621 Kg/day from which 2.121 Kg/day are obtained from the CRA with the CO_2 reduction and the resting 2.5 Kg/day are obtained from other sources. Note that using this configuration an additional treatment must be performed to the condensate water before being used in the electrolyser.

7.1.2 CIVa - *Arthrospira* Compartment

Oxygen recycling efficiency for CIVa MELiSSA compartment is calculated below:

Element	Variable	Quantity (Kg/day)
CO_2 liquid input	CIVa_Bioreactor_1.w_liq_in[CO2]	0.00572

Oxygen liquid input	CIVa_Bioreactor_1.w_liq_in[O2]	0.0002097
CO_2 gas input	CIVa_Bioreactor_1.w_gas_in[CO2]	5.1771
Oxygen gas input	CIVa_Bioreactor_1.w_gas_in[O2]	15.4019
CO_2 liquid output	CIVa_Bioreactor_1.w_liq_out[CO2]	1.7992
Oxygen liquid output	CIVa_Bioreactor_1.w_liq_out[O2]	0.0002097
CO_2 gas output	CIVa_Bioreactor_1.w_gas_out[CO2]	3.1534
Oxygen gas output	CIVa_Bioreactor_1.w_gas_out[O2]	15.6304

Table 7 Oxygen Recycling AW

Recycling Efficiency	
Need Coverage Ration (O_2)	$CIVa - NCR_O = \frac{(15.6304 - 15.4019)}{4.049} \approx 5\%$
Transformation Yield (CO_2, O_2)	$ARES - \eta_C = \frac{P(O_2)}{I(CO_2) - O(CO_2)} = \frac{(15.6304 - 15.4019)}{(5.1771 + 0.00572) - (1.7992 + 3.1534)} \approx 99\%$

Table 8 Oxygen Recycling Efficiency

Note that CIVa is a very good CO_2 processor, so practically all CO_2 is transformed into O_2.

Of course productions are not accounting for purge of air, it has to be taken into account that when some purge in air is performed not only one element is vented but a mixing depending on the concentrations of the different compounds present in the air. This will lead to a loss of oxygen and other compounds.

7.2 Water Production

Liquid input flow into the GWTU is 58.76 l/day and the factor of recycling of 90%.

7.2.1 Water required

Element	Variable	Quantity (Kg/day)
Hygienic water for crew	Liquid_Collector_Ditributor_1.q_hyg_crew	26.72
Potable water for crew	Liquid_Collector_Ditributor_1.q_pot_crew	10
Hygienic water for the Arthrospira Washing	Liquid_Collector_Ditributor_1.q_water_Ap	5
Hygienic water for the CI	Liquid_Collector_Ditributor_1.q_water_CI	3.02
Hygienic water for the UTU	Liquid_Collector_Ditributor_1.q_water_UTU	15.12
Total		59.86

Table 9 Water Requirements

7.2.2 Water produced

Element	Variable	Quantity

		(Kg/day)
GWTU Hygienic water	Grey_Water_Treatment_Unit_1.w_hyg_out	57.049
GWTU waste water	Grey_Water_Treatment_Unit_1.w_waste_out[H2O]	6.339

Table 10 Water Production

Recycling Efficiency hygienic water	
Need Coverage Ration (Hw)	$CIVa - NCR_{H2O\_hyg} = \frac{(57.049)}{(26.72 + 5 + 3.02 + 15.12)} \approx 115\%$

Table 11 Hygiene Water Recycling Efficiency

7.2.3 External water supply

Element	Variable	Quantity (Kg/day)
Nutrients for MELiSSA start-up	Nutrients_Generator_1.Liters_Day	2
Water supply	Liquid_Collector_Ditributor_1.w_sup	1.051

Table 12 Water Supply

Note that water is also recovered from human transpiration, so water supplied through food is also recovered by the system through the condensers. This is because the waste water (5.88 l/d) is higher than the supplied water (4.39 l/d).
An additional water input is required to supply some compounds that could lack on the overall system. In the configuration, an additional input of 2 litres/day to supply phosphates and ammonia to the system has been defined.
Furthermore, it has to be considered that loses are also caused by venting and other purges, although quantities are very small.

The GWTU could contain an electro-dialysis phase to remove creatinine, and nitrates coming from the MELiSSA compartments. This phase would had the purpose of reduce the osmotic pressure of the system. However, power accounted in section TBD is taking into account the full pump pressure.

7.3 Edible Biomass production

In this configuration, only the MELiSSA CIVa is used for biomass production. The total requirement of food for the crew is 2.47 kg/day (dry weight) and then a 5% is determined as 0.123 Kg/day (dry weight).

Recommended Diet requirements of food composition:

Element	Variable	Percentage (%)
Mass fraction of water in damp food.	Food_Treatment_Unit_1.f_H2O_food	75.0
Mass fraction of proteins in dry food.	Food_Treatment_Unit_1.f_prot_food	23.0
Mass fraction of lipids in dry food	Food_Treatment_Unit_1.f_lip_food	17.5
Mass fraction of carbohydrates in dry food	Food_Treatment_Unit_1.f_ch_food	54.5
Mass fraction of fibres in dry food.	Food_Treatment_Unit_1.f_fib_food	5.0

Table 13 Recommended Diet in mass fraction.

FAO/OMS recommended diet values are around 15-30% of lipids, 55-75% of Carbohydrates and 10-15% of proteins[1] of total energy. Note that fractions provided in table 13 are in mass so a conversion needs to be performed to compare values directly.

Food supplied by the CIVa compartment of 5% total mass fraction as defined in the requirements.

Element	Variable	Percentage (%)
Mass fraction of water in damp algae food.	Food_Treatment_Unit_1.algae_in.f_H2O[Ap]	75
Mass fraction of proteins in dry algae food.	Food_Treatment_Unit_1.alga_in.f_prot[Ap]	53.78
Mass fraction of lipids in dry algae food	Food_Treatment_Unit_1.alga_in.f_lip[Ap]	9.6
Mass fraction of carbohydrates in dry algae food	Food_Treatment_Unit_1.alga_in.f_ch[Ap]	35.93

Table 14 Food Supply by CVIa

Therefore, calculated additional food composition is:

Element	Variable	Percentage (%)
Mass fraction of water in damp additional food.	Food_Treatment_Unit_1.f_H2O_adF	73.65
Mass fraction of proteins in dry additional food.	Food_Treatment_Unit_1.f_prot_adF	21.41
Mass fraction of lipids in dry additional food	Food_Treatment_Unit_1.f_lip_adF	17.94
Mass fraction of carbohydrates in dry additional food	Food_Treatment_Unit_1.f_ch_adF	55.55

Table 15 Additional Food for 5% Production Rate

Total edible biomass produced by the CIVa is 0.123 Kg/day, which corresponds to the 5% of the diet in mass. Note that biomass obtained from the CIVa includes the dissolute compounds that have not been possible to separate, that is a 0.49 Kg/day of water in which 0.004 Kg/day correspond to the solute (sulphates, nitrates, ammonia, etc.). Therefore the dry additional food is 2.34 Kg/day (94.7% of total).

Need coverage ratio of food provided by the CIVa

$$CIVa - NCR_{food} = \frac{0.123}{2.46} \approx 5\%$$

[1] http://www.fao.org/spanish/newsroom/news/2003/16851-es.html

7.4 CHONSP Balance

7.4.1 Compartment I

Streams	Elements Molar Flows (mol/day)					
	C	H	O	N	S	P
Gas input	0	0	0	4.284	0	0
Liquid input	7.163	998.358	497.252	1.060	0.0512	0.0864
Liquid output (Effluent)	1.610	750.419	374.291	0.643	0.0366	0.0628
Solid output (Wastes)	5.317	246.786	122.488	0.420	0.0145	0.0235
Gas output to the other Compartments	0.00219	0.0113	0.00462	0.0428	0	0
Gas purged (vented)	0.217	1.116	0.458	4.236	0	0

Table 16 CI CHONSP Composition

For the Compartment I the most important factors will be the capacity to recover the CHONSP elements from the inputs.

Carbon recycling efficiency:

$$C1\eta_C = \frac{P(Z_2)}{I(Z_1)} = \frac{1.610 + 0.00219}{7.163} \approx 23\%$$

Hydrogen recycling efficiency:

$$C1\eta_H = \frac{P(Z_2)}{I(Z_1)} = \frac{750.419 + 0.0113}{998.358} \approx 75\%$$

Oxygen recycling efficiency

$$C1\eta_O = \frac{P(Z_2)}{I(Z_1)} = \frac{374.291 + 0.00462}{497.252} \approx 75\%$$

Nitrogen recycling efficiency

$$C1\eta_N = \frac{P(Z_2)}{I(Z_1)} = \frac{0.643 + 0.0428}{4.284 + 1.060} \approx 12\%$$

Sulphur recycling efficiency

$$C1\eta_S = \frac{P(Z_2)}{I(Z_1)} = \frac{0.0366}{0.0512} \approx 71\%$$

Phosphor recycling efficiency

$$C1\eta_p = \frac{P(Z_2)}{I(Z_1)} = \frac{0.0628}{0.0864} \approx 72\%$$

7.4.2 Compartment II

Streams	Elements Molar Flows (mol/day)					
	C	**H**	**O**	**N**	**S**	**P**
Gas input	0.00219	0.0113	0.00462	0.0428	0	0
Liquid input	1.610	750.419	374.291	0.643	0.0366	0.0628
Liquid output (Effluent)	0.0811	678.245	338.979	0.367	0.0284	0.0339
Solid output to the BPU of Compartment I	1.529	72.172	35.311	0.278	0.00817	0.0289
Gas output to the other Compartments	0.00245	0.0130	0.00612	0.0414	0	0

Table 17 CII CHONSP Composition

For the Compartment II the most important factors will be the capacity to recover the CHONSP elements from the inputs.

Carbon recycling efficiency:

$$C1\eta_C = \frac{P(Z_2)}{I(Z_1)} = \frac{0.0811 + 0.00245 + 1.529}{0.00219 + 1.610} \approx 100\%$$

Hydrogen recycling efficiency:

$$C1\eta_H = \frac{P(Z_2)}{I(Z_1)} = \frac{678.245 + 0.013 + 72.172}{0.0113 + 750.419} \approx 100\%$$

Oxygen recycling efficiency

$$C1\eta_O = \frac{P(Z_2)}{I(Z_1)} = \frac{338.979 + 0.00612 + 35.311}{0.00462 + 374.291} \approx 100\%$$

Nitrogen recycling efficiency

$$C1\eta_N = \frac{P(Z_2)}{I(Z_1)} = \frac{0.367 + 0.414 + 0.278}{0.0428 + 0.643} \approx 154\%$$

Sulphur recycling efficiency

$$C1\eta_S = \frac{P(Z_2)}{I(Z_1)} = \frac{0.0284 + 0.00817}{0.0366} \approx 100\%$$

Phosphor recycling efficiency

$$C1\eta_p = \frac{P(Z_2)}{I(Z_1)} = \frac{0.0339 + 0.0289}{0.0628} \approx 100\%$$

7.4.3 Compartment III

Streams	Elements Molar Flows (mol/day)					
	C	**H**	**O**	**N**	**S**	**P**
Gas input	3.130	76.712	1020.51	3865.75	0	0
Liquid input	0.0811	678.245	338.979	0.367	0.0284	0.0339
Urine input	3.500	2859.346	1429.519	6.197	0.414	0.699
Liquid output (Effluent)	0.641	3388.01	1711.45	6.852	0.439	0.726
Solid output to the BPU of Compartment I	0.400	19.741	9.788	0.112	0.00347	0.00697
Gas output to the other Compartments	5.66993	206.552	1067.77	3865.35	0	0

Table 18 CIII CHONSP Composition

For the Compartment III the most important factors will be the capacity to recover the CHONSP elements from the inputs.

Carbon recycling efficiency:

$$C1\eta_C = \frac{P(Z_2)}{I(Z_1)} = \frac{0.641 + 5.66993 + 0.4}{3.130 + 0.0811 + 3.5} \approx 100\%$$

Hydrogen recycling efficiency:

$$C1\eta_H = \frac{P(Z_2)}{I(Z_1)} = \frac{3388.01 + 206.552 + 19.741}{76.712 + 678.245 + 2859.346} \approx 100\%$$

Oxygen recycling efficiency

$$C1\eta_O = \frac{P(Z_2)}{I(Z_1)} = \frac{1067.77 + 1711.45 + 9.788}{1020.51 + 338.979 + 1429.519} \approx 100\%$$

Nitrogen recycling efficiency

$$C1\eta_N = \frac{P(Z_2)}{I(Z_1)} = \frac{6.852 + 0.112 + 3865.35}{3865.75 + 0.367 + 6.197} \approx 100\%$$

Sulphur recycling efficiency

$$C1\eta_S = \frac{P(Z_2)}{I(Z_1)} = \frac{0.439 + 0.00347}{0.0284 + 0.414} \approx 100\%$$

Phosphor recycling efficiency

$$C1\eta_p = \frac{P(Z_2)}{I(Z_1)} = \frac{0.726 + 0.00697}{0.0339 + 0.699} \approx 100\%$$

7.4.4 Compartment IVa

Streams	Elements Molar Flows (mol/day)					
	C	H	O	N	S	P
Gas input	117.634	208.376	1292.6	3865.39	0	0
Liquid input	0.641	3388.01	1711.45	6.852	0.439	0.726
Liquid output (Effluent)	40.742	3192.04	1691.91	5.590	0.413	0.699
Solid output to the Arthrospira Washing	5.881	100.536	50.066	0.884	0.0259	0.027
Gas output towards a condenser before being sent to the Crew	71.652	303.813	1262.07	3865.77	0	0

Table 19 CIVa CHONSP Composition

For the Compartment IVa the most important factors will be the capacity to recover the CHONSP elements from the inputs.

Carbon recycling efficiency:

$$C1\eta_C = \frac{P(Z_2)}{I(Z_1)} = \frac{40.742 + 5.881 + 71.652}{117.634 + 0.641} \approx 100\%$$

Hydrogen recycling efficiency:

$$C1\eta_H = \frac{P(Z_2)}{I(Z_1)} = \frac{3192.04 + 100.536 + 303.813}{208.376 + 3388.01} \approx 100\%$$

Oxygen recycling efficiency

$$C1\eta_O = \frac{P(Z_2)}{I(Z_1)} = \frac{1691.91 + 50.066 + 1262.07}{1292.6 + 1711.45} \approx 100\%$$

Nitrogen recycling efficiency

$$C1\eta_N = \frac{P(Z_2)}{I(Z_1)} = \frac{5.59 + 0.884 + 3865.77}{3865.39 + 6.852} \approx 100\%$$

Sulphur recycling efficiency

$$C1\eta_S = \frac{P(Z_2)}{I(Z_1)} = \frac{0.413 + 0.0259}{0.439} \approx 100\%$$

Phosphor recycling efficiency

$$C1\eta_p = \frac{P(Z_2)}{I(Z_1)} = \frac{0.699 + 0.027}{0.726} \approx 100\%$$

7.4.5 ARES

7.4.5.1 Carbon dioxide Collection Assembly

Streams	Elements Molar Flows (mol/day)			
	C	**H**	**O**	**N**
Steam input	0	388.56	194.28	0
Air input (from Crew)	175.754	4306.84	57294.3	217034
Air output (dry)	8.788	3341.42	56477.7	217034
CO2 gas output (dry)	166.966	2.701	335.28	0
Water output 1 (from the condenser 1)	0	1299.35	649.67	0
Water output 2 (from the condenser 2)	0	51.93	25.96	0

Table 20 CCA CHON Composition

For the CCA the most important factors will be the capacity to recover the CHON elements from the inputs.

Carbon recycling efficiency:

$$C1\eta_C = \frac{P(Z_2)}{I(Z_1)} = \frac{8.788 + 166.966}{175.754} \approx 100\%$$

Hydrogen recycling efficiency:

$$C1\eta_H = \frac{P(Z_2)}{I(Z_1)} = \frac{3341.42 + 2.701 + 1299.35 + 51.93}{388.56 + 4306.84} \approx 100\%$$

Oxygen recycling efficiency

$$C1\eta_O = \frac{P(Z_2)}{I(Z_1)} = \frac{56477.7 + 335.28 + 649.67 + 25.96}{194.28 + 57294.3} \approx 100\%$$

Nitrogen recycling efficiency

$$C1\eta_N = \frac{P(Z_2)}{I(Z_1)} = \frac{217034}{217034} \approx 100\%$$

7.4.5.2 Carbon Reduction Assembly

Streams	Elements Molar Flows (mol/day)			
	C	**H**	**O**	**N**
Gas input 1 (CO2)	55.0046	0.8897	110.454	0
Gas input 2 (H2)	0	457.277	13.065	0
Gas output vented (dry)	55.0046	222.693	5.782	0
Liquid output (from the condenser)	0	235.474	117.737	0

Table 21 CRA CHON Composition

For the CRA the most important factors will be the capacity to recover the CHON elements from the inputs.

Carbon recycling efficiency:

$$C1\eta_C = \frac{P(Z_2)}{I(Z_1)} = \frac{55.0046}{55.0046} \approx 100\%$$

Hydrogen recycling efficiency:

$$C1\eta_H = \frac{P(Z_2)}{I(Z_1)} = \frac{222.693 + 235.474}{0.8897 + 457.277} \approx 100\%$$

Oxygen recycling efficiency

$$C1\eta_O = \frac{P(Z_2)}{I(Z_1)} = \frac{5.782 + 117.737}{110.454 + 13.065} \approx 100\%$$

7.4.5.3 Oxygen Generation Assembly

Streams	Elements Molar Flows (mol/day)			
	C	**H**	**O**	**N**
Water input	0	513.02	256.51	0
H2 gas vented	0	50.809	1.452	0
H2 gas towards Sabatier Reactor	0	457.277	13.065	0
O2 gas towards the Crew	0	4.899	241.976	0

Table 22 OGA CHON Composition

For the OGA the most important factors will be the capacity to recover the CHON elements from the inputs.

Hydrogen recycling efficiency:

$$C1\eta_H = \frac{P(Z_2)}{I(Z_1)} = \frac{457.277 + 4.899}{513.02} \approx 90\%$$

Oxygen recycling efficiency

$$C1\eta_O = \frac{P(Z_2)}{I(Z_1)} = \frac{13.065 + 241.976}{256.51} \approx 99\%$$

7.5 Alternative 5% food production with a Salad Machine

The “Salad Machine” was one of the first attempts to grow plants in a sufficiently large scale as to meet a fraction of nutritional requirements for a Space crew. The “Salad Machine” project was carried out at NASA’s Ames Research Centre in the early 1990s. It was based on growing garden-variety plants (lettuce, radish, onion ..) on a volume equivalent to that of an ISS rack using hydroponics growing techniques. Figure 7-2 shows a “Salad Machine” mock-up.

Figure 7-2 “Salad Machine" Rack Space Station prototype mock-up, 1991 (source: NASA).

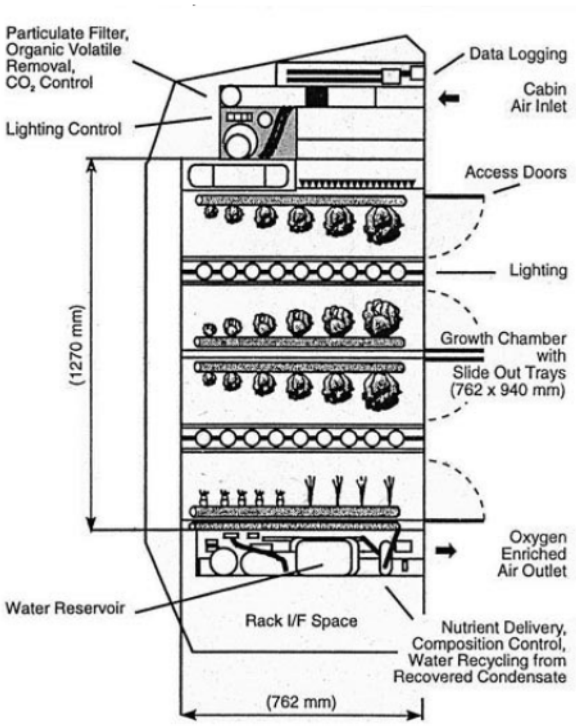


Figure 7-3 Salad Machine Schematic [R18]

The option of using a Salad Machine instead of compartment IVa is a potential alternative to be studied here. This configuration is similar to the previous one, it only assumes that food production of 5% is achieved by using biomass generated by a Salad Machine.

Therefore the proposed alternative configuration relies on the MELiSSA loop with a Salad Machine plus ARES and the GWTU plus the UTU.

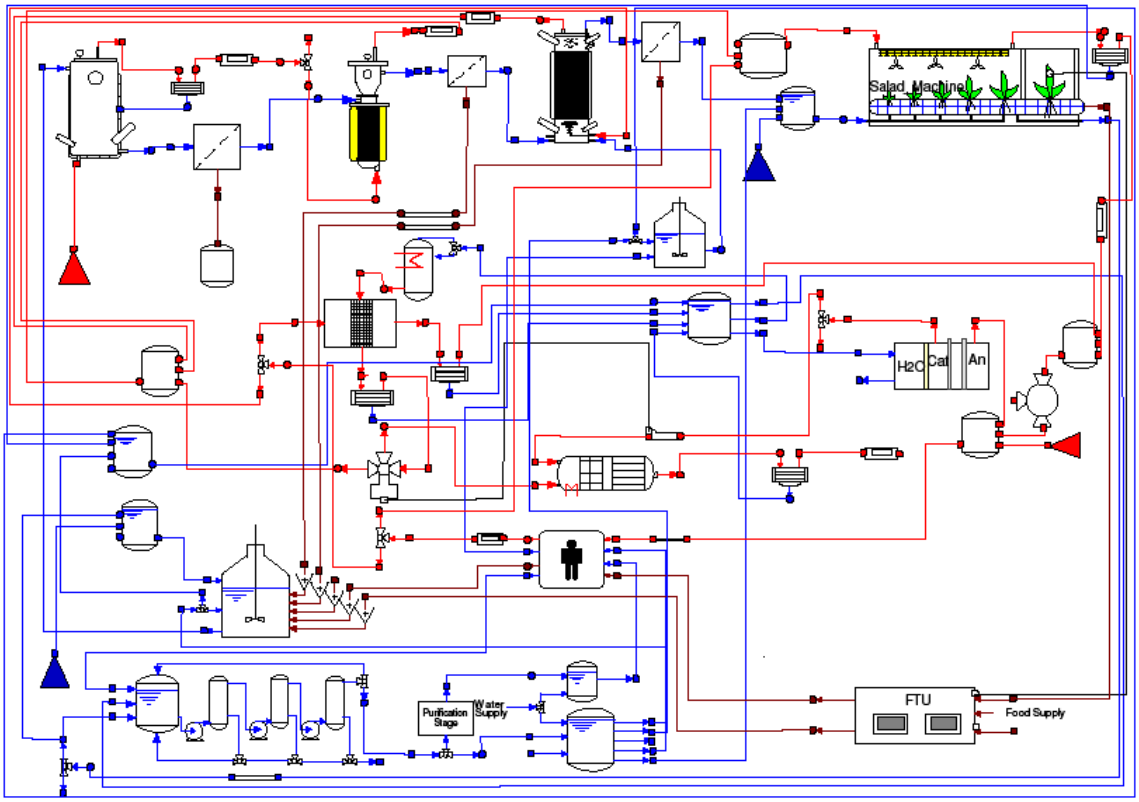


Figure 7-4 ECLSS configuration with 5% food production with Salad Machine

The surface required to cultivate the needed amount of vegetables, that is 0.229 kg/dry mass (0.125 Kg/day edible and 0.104 Kg/day non-edible) is 20.65 m^2.

7.5.1 Oxygen Production

In that case ARES oxygen production would be as follows:

Element	Variable	Quantity (Kg/day)
CO_2 input	Adsorber_Desorber_1.w_air_in[CO2]	4.90984
CO_2 output (towards other subsystems)	CO2_Management_ARES_1.w_gas_left[CO2]	2.12981
CO_2 output (vented, not used)	Condenser_CRA.w_gas_out[CO2]	0.121825
Oxygen output	Electrolyser_1.w_out_An[O2]	3.68488

Table 23 Oxygen Production ARES

And the Salad Machine oxygen production would be as follows:

Element	Variable	Quantity (Kg/day)
CO_2 gas input	Higher_Plants_Chamber1.w_gas_in[CO2]	0.790926
Oxygen gas input	Higher_Plants_Chamber1.w_gas_in[O2]	6.85357
CO_2 gas output	Higher_Plants_Chamber1.w_gas_out[CO2]	0.371389

Oxygen gas output	Higher_Plants_Chamber1.w_gas_out[O2]	7.19619

Table 24 Oxygen Production Salad Machine

Recycling Efficiency	
Need Coverage Ration (O_2)	$Salad - NCR_O = \frac{7.19619 - 6.85357}{4.049} \approx 8\%$
Transformation Yield (CO_2, O_2)	$Salad - \eta_C = \frac{P(O_2)}{I(CO_2) - O(CO_2)} = \frac{7.19619 - 6.85357}{0.790926 - 0.371389} \approx 80\%$

Table 25 Oxygen Recycling Efficiency

7.5.2 Water Production

Water required

Element	Variable	Quantity (Kg/day)
Hygienic water for crew	Liquid_Collector_Ditributor_1.q_hyg_crew	26.72
Potable water for crew	Liquid_Collector_Ditributor_1.q_pot_crew	8.24
Hygienic water for the CI	Liquid_Collector_Ditributor_1.q_water_CI	8.5
Hygiene water for the Salad Machine	Liquid_Collector_Distributor1.q_water_HPC	1
Hygienic water for the UTU	Liquid_Collector_Ditributor_1.q_water_UTU	15.12
Total		64.58

Table 26 Water Requirements

In that case, the CI needs more water for dillution, so total ammount of water required is increased.

Water produced by the GWTU

Element	Variable	Quantity (Kg/day)
GWTU Hygienic water	Grey_Water_Treatment_Unit_1.w_hyg_out	32.3841
GWTU waste water	Grey_Water_Treatment_Unit_1.w_waste_out[H2O]	3.59823

Table 27 GWTU Water Production

Recycling Efficiency	
Need Coverage Ration (HW)	$Salad - NCR_{H2O\_hyg} = \frac{32.3841}{26.72 + 8.5 + 1 + 15.12} \approx 63\%$

Table 28 Hygiene Water Recycling Efficiency

7.5.3 Food Production

Food supplied by the Salad Machine of 5% total mass fraction as defined in the requirements.

Element	Variable	Percentage (%)
Mass fraction of water in damp salad food.	Food_Treatment_Unit_1.plant_in.f_H2O_com	95.27
Mass fraction of proteins in dry salad food.	Food_Treatment_Unit_1.plant_in.f_prot_com	30.56
Mass fraction of lipids in dry salad food	Food_Treatment_Unit_1.plant_in.f_lip_com	5.38
Mass fraction of carbohydrates in dry salad food	Food_Treatment_Unit_1.plant_in.f_ch_com	26.89

Table 29 Food Production

7.5.4 Trade-off

The following table provides the main differences between the two designs, producing the 5% of edible biomass with the MELiSSA CIVa or the Salad Machine:

Parameter	CIVa	Salad Machine
O_2 need coverage ratio	5%	8%
CO_2 / O_2 Transformation yield	99%	80%

Table 30 Comparison of 5% food production with either CIVa or Salad Machine

From the perspective of oxygen production it is difficult to be definitive choosing a technology as one produces a little bit more oxygen but the other fixes more CO_2. Other factors that need to be considered are that with the current MELiSSA Pilot Plant design, the energy consumed by the CIVa is high, although many improvements can be performed. On the other hand, to provide the 5% diet with a salad machine following the same design than the Higher Plants compartment 25 m2 of surface is needed. Also crew time to maintain crops cultivation can be estimated as quite higher than just performing the maintenance of a bioreactor.

Factor	CIVa	Salad Machine
O_2 need coverage ratio	negative	positive
CO_2 / O_2 Transformation yield	positive	negative
Energy	negative	positive
Volume / surface	positive	negative
Crew time	positive	negative

Although is still early to perform a firm selection, for this study the compartment CIVa will be selected. Objectively has more positive aspects and in addition has the capability of adapting faster to changes in oxygen requirement.

8. CONFIGURATION B. 40% FOOD PRODUCTION

For this second configuration the only difference is that food demand is set to 40% to be provided by the ECLSS module. In order to provide this amount of food it is considered the use of the MELiSSA Higher Plants Compartment. Using the HPC affect air recycling, it is possible to reduce de ARES capabilities and then their power consumption and mass. This will also affect water balance as more water will be needed and produced by transpiration of the plants.

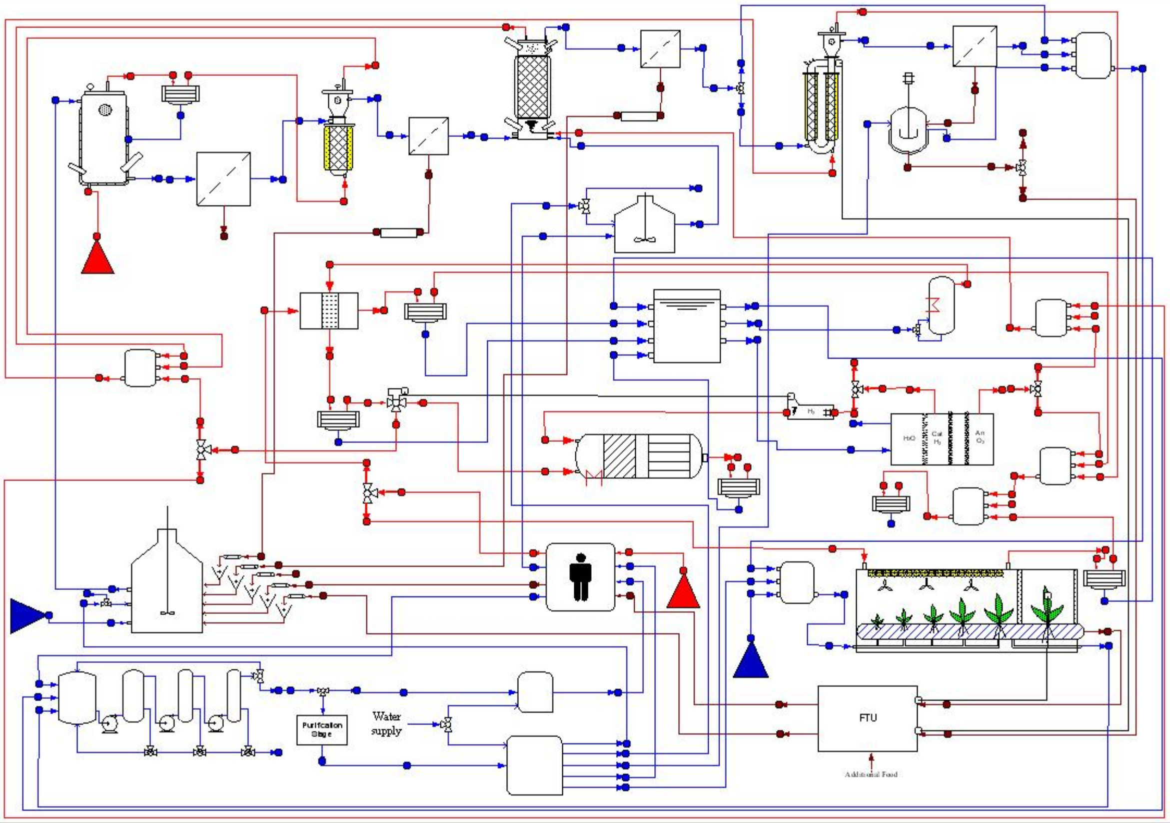


Figure 8-1 ECLSS configuration with 40% food production

The set up in Figure 7-1 used condensed water for the electrolyser. The model is working with the assumption of only H_2O being condensed and therefore no purification is indicated. A real system would need to use purified water.

8.1 Oxygen production

8.1.1 ARES

Oxygen recycling efficiency for ARES is calculated below:

Element	Variable	Quantity (Kg/day)
CO2 input	Adsorber_Desorber_1.w_air_in[CO2]	0.96
Oxygen output	Electrolyser_1.w_out_An[O2]	1.19
Total oxygen production		1.19

Table 31 Oxygen Recycling ARES

8.1.2 CIVa - *Arthrospira* Compartment

Oxygen recycling efficiency for CIVa MELiSSA compartment is calculated below:

Element	Variable	Quantity (Kg/day)
CO2 input	CIVa_Bioreactor_1.w_gas_in[CO2]	0.29
Oxygen input	CIVa_Bioreactor_1.w_gas_in[O2]	1.47
Oxygen output	CIVa_Bioreactor_1.w_gas_out[O2]	1.70
Total oxygen production		0.23

Table 32 Oxygen Recycling AW

Recycling Efficiency	
Need Coverage Ration (O_2)	$CIVa - NCR_O = \frac{1.7 - 1.47}{4.049} \approx 5\%$ (idem previous configuration)

8.1.3 CIVb – Higher Plants Chamber

Oxygen recycling efficiency for CIVb MELiSSA compartment is calculated below:

Element	Variable	Quantity (Kg/day)
CO2 input	Higher_Plants_Chamber_1.w_gas_in[CO2]	24.28
Oxygen output	Higher_Plants_Chamber_1.w_gas_out[O2]	867.61
Oxygen Input	Higher_Plants_Chamber_1.w_gas_in[O2]	865.00
Total oxygen production		2.61

Table 33 Oxygen Recycling HPC

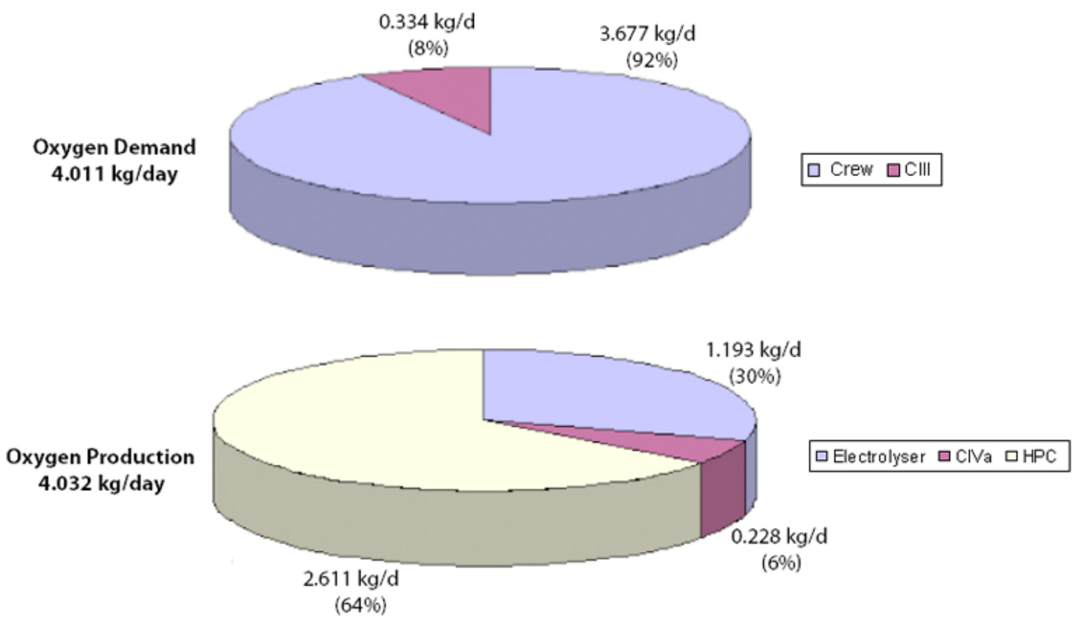


Figure 8-2 Oxygen Production

Recycling Efficiency	
Need Coverage Ration (O_2)	$HPC-NCR_O = \frac{867.61-865}{4.049} \approx 63\%$

8.2 Water Production

Liquid input flow into the GWRU is 9.942 L/day and the factor of recycling of 90%.

Water required

Element	Variable	Quantity (L/day)
Hygienic water for crew	Liquid_Collector_Ditributor1.q_hyg_crew	6.68
Potable water for crew	Liquid_Collector_Ditributor1.q_pot_crew	2.50
Hygienic water for the Arthrospira Washing	Liquid_Collector_Ditributor1.q_water_Ap	5.00
Hygienic water for the CI	Liquid_Collector_Ditributor1.q_water_CI	57.85
Hygienic water for the UTU	Liquid_Collector_Ditributor1.q_water_UTU	16.26
Hygienic water for the HPC	Liquid_Collector_Ditributor1.q_water_HPC	500.00
Total		588.29

Table 34 Water Requirement

Water produced

Element	Variable	Quantity (L/day)
GWTU Hygienic water	Grey_Water_Treatment_Unit_1.w_hyg_out	27.89
Water from HPC condenser	Condenser_HPC.w_liq_out[H2O]	583.32

Table 35 Water Production

External water supply

Element	Variable	Quantity (Kg/day)
Water with Nutrients for HPC start-up	Nutrients_Generator_HPC.Liters_Day	2.00
Water with Nutrients for MELiSSA start-up	Nutrients_Generator_CI.Liters_Day	2.00
Water supply	Liquid_Collector_Ditributor1.w_sup	4.62

Table 36 Additional Water Supply

CI needs the more water the more wastes you have in order to maintain the dilution rate of 1/10.

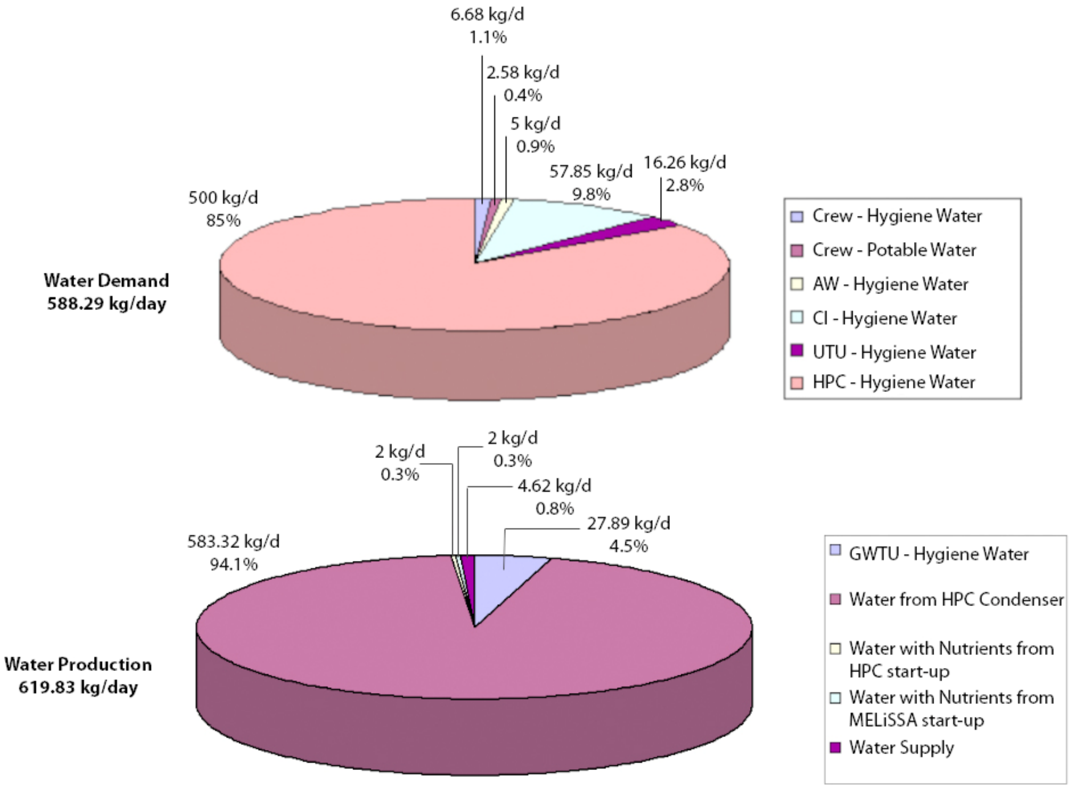


Figure 8-3 Water Production

8.3 Edible Biomass Production

In this configuration, the MELiSSA CIVa and HPC are used for biomass production. The total requirement of food for the crew is 2.47 kg/day (dry weight) and then a 40% is determined as 0.123 Kg/day (dry weight) from algae and as 0.864 kg/day (dray weight) from Higher Plants.

Recommended Diet requirements of food composition:

Element	**Variable**	**Percentage (%)**
Mass fraction of water in damp food.	Food_Treatment_Unit_1.f_H2O_food	75.0
Mass fraction of proteins in dry food.	Food_Treatment_Unit_1.f_prot_food	23.0
Mass fraction of lipids in dry food	Food_Treatment_Unit_1.f_lip_food	17.5
Mass fraction of carbohydrates in dry food	Food_Treatment_Unit_1.f_ch_food	54.5
Mass fraction of fibres in dry food.	Food_Treatment_Unit_1.f_fib_food	5.0

Table 37 Dietary Requirements

Food supplied by the CIVa compartment of 5% total mass fraction as defined in the requirements.

Element	**Variable**	**Percentage (%)**
Mass fraction of water in damp algae food.	Food_Treatment_Unit_1.algae_in.f_H2O[Ap]	75.0
Mass fraction of proteins in dry algae food.	Food_Treatment_Unit_1.alga_in.f_prot[Ap]	53.78
Mass fraction of lipids in dry algae food	Food_Treatment_Unit_1.alga_in.f_lip[Ap]	9.6
Mass fraction of carbohydrates in dry algae food	Food_Treatment_Unit_1.alga_in.f_ch[Ap]	35.93

Table 38 Food Supply by CVIa

Food supplied by the HPC of 35% total mass fraction as defined in the requirements.

Element	Variable	Percentage (%)
Mass fraction of water in damp edible HP food.	Food_Treatment_Unit_1.plant_in.f_H2O_com	65.23
Mass fraction of proteins in dry edible HP food.	Food_Treatment_Unit_1.plant_in.f_prot_com	12.99
Mass fraction of lipids in dry edible HP food	Food_Treatment_Unit_1.plant _in.f_lip_com	2.29
Mass fraction of carbohydrates in dry edible HP food	Food_Treatment_Unit_1.plant_in.f_ch_com	72.88

Table 39 Food Supply by HPC

The production of 0.864 kg/day of edible plants produces 1.051 kg/day of residual biomass

Therefore, calculated additional food composition is:

Element	Variable	Percentage (%)
Mass fraction of water in damp additional food.	Food_Treatment_Unit_1.f_H2O_adF	76.87
Mass fraction of proteins in dry additional food.	Food_Treatment_Unit_1.f_prot_adF	26.28
Mass fraction of lipids in dry additional food	Food_Treatment_Unit_1.f_lip_adF	27.04
Mass fraction of carbohydrates in dry additional food	Food_Treatment_Unit_1.f_ch_adF	45.34

Table 40 Additional Food Supply

Note that biomass obtained from the CIVa includes the dissolute compounds that have not been possible to separate, that is 0.49 Kg/day of water in which 0.00034 Kg/day correspond to the solute (sulphates, nitrates, ammonia, etc.). Therefore the dry additional food is 1.48 Kg/day (59% of total).

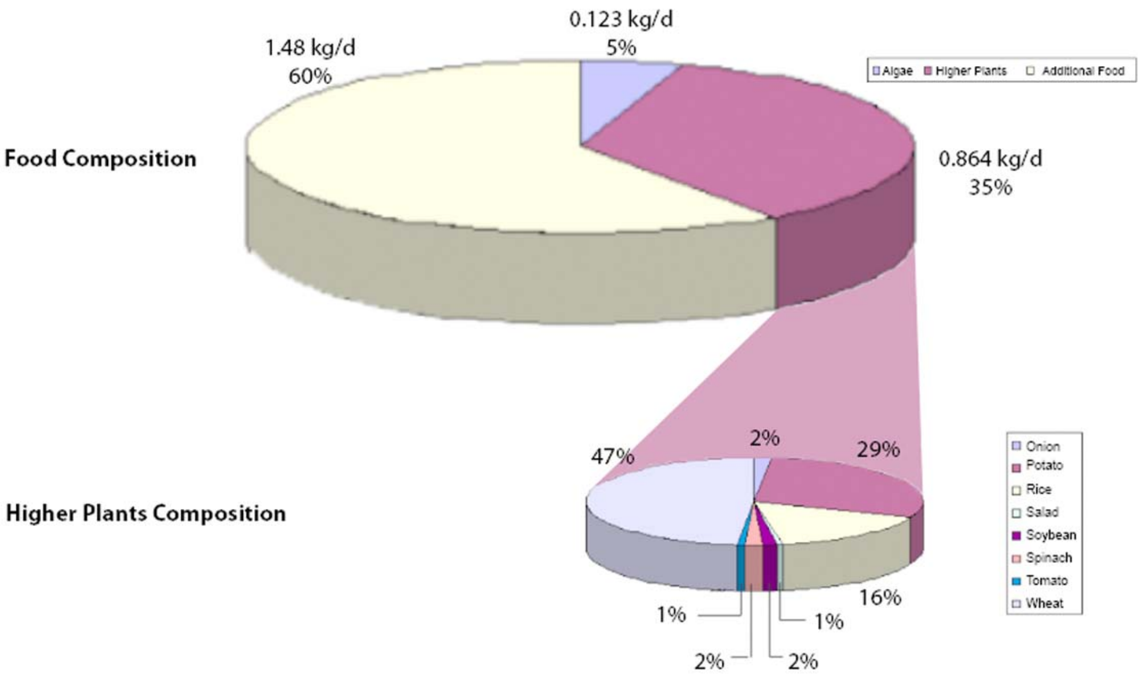


Figure 8-4 Food Production

8.4 Volumes Estimation

Volumes have been calculated as for the 5% food production configuration. The difference comes from the fact that volumetric flows are different.

Bioreactor	Volumetric flow (l/d)	Residence time (days)	Volume (liters)
CI	71.65	10	716.5
CII	60.55	0.33 – 1.25	19.98 – 75.69
CIII	83.81	0.42*	35.20
CIVa	41.76	2 – 10	83.52-417.60
UTU (dissolver tank)	27.86	1	27.86

(*) CIII residence time is without accounting for the urine treatment TBC.

Table 41 Volume Estimation

Flow to the CIVa can be also reduced depending on the nutrients demand to produce the 5% of food. This will lead to a reduction of the total volume.

Volumes have to be increased in a approximately a 10% to take into account the gas.

9. CONCLUSIONS

Two configurations have been presented of a complete ECLSS based on MELiSSA, GWTU, UTU and ARES. In the first configuration, to provide the 5% of the diet the CIVa is considered the best choice at this stage for engineering reasons. Other facts could have been considered as psychological impact or diet preferences that could change this decision.

To provide the 40% diet a Higher Plants compartment is added which increases the total water of the system even this not affect dramatically to the external water supply as the water can be recirculated through the same HPC compartment, minimising the loses. The fact of adding a HPC implies also to increase the structural complexity and mass, and therefore will imply a notable increment of the overall system mass.

In both cases it can be seen that a critical element is the Compartment I, where are the main loses of CHONSP elements. Any improvement in this compartment will have a high impact on the overall recycling capacity.

With respect the air recycling, ARES is a key technology since is able to provide the 100% of the need coverage ratio. However, attention must be given to the power consumption, as more air to be recycled, more energy is required. In any case, with the HPC only a small ARES will be needed since depending on the crop selection and total biomass produced it is possible to reach the 80% of the oxygen demand.

Water recycling is achieved through the Grey Water Recovery Unit, although water is also recovered using air condensers and from the HPC it is possible to obtain potable water with low effort.

In the following TN a detailed study of mass, energy and volume of each design will be performed and total mass for each configuration will be estimated.

Results given in this TN must be considered preliminary until a validation against real experimental data can be performed. Data has been obtained from models based on the physical representation of the system and have been validated one by using the mass balance equations, so in principle the results are as good as are the models. Furthermore the results are highly influenced by the input data (diet composition, water consumption, human metabolic rate, etc.). Values have been continuously compared with the work performed in [R4] from the *Université Blaise Pascal* and models are also based on this work.

10. FLOWS AND RECYCLING CAPABILITIES FOR INDIVIDUAL COMPONENTS

For the verification of the individual library components each compartment is tested individually. Therefore either existing baseline input values from literature or from experiments will be used and the outputs compared.

The values in this program are given in international SI units. The reason for this is justified by the calculation on atomic level inside the compartments. Therefore the input values need to be given in the SI units; whereas an easy output calculation can be set to give outputs in kg/d to compare with literature values.

A change in the set up to compensate this is not foreseen, as the program is usually not checked on component level for running simulations of MELiSSA loop configurations.

10.1 MELiSSA

10.1.1 Compartment I – Flows and Recycling Capabilities

Compartment I consists of four library components, which are the Biomass Pre-treatment Unit (BPU), the Compartment I Bioreactor (CI_BR), a Condenser and a Solid Liquid Separator (SLS).

10.1.1.1 Important Data

Some operational values have been modified from the ones given in technical note 2 [R5]. For the mass balance operational conditions have been defined as given in Table 42.

Symbol	*Value*	*Comment*
Bioreactor		
Pr	101325 Pa	At 1 atm
T	328 K (55ºC)	
pH	6	Methanogenesis inhibited: Acetic and CO2 conversions zero
L	1001.640 kg/m3	Density of the liquid within the bioreactor
Gout	0.942 kg/m3	Density of the gas that leaves the bioreactor
Xch	60%	Conversion carbohydrates
Xlip	60%	Conversion lipids
Xprot	60%	Conversion proteins
Xfib	35%	Conversion fibres
XVFA	0%	Conversion Volatile Fatty Acids
Condenser		
Pr	101325 Pa	At 1 atm
T	298 K (25ºC)	

Table 42 Operational Data for Compartment I

The input data for the BPU to run the compartment are gained from the Crew Compartment outputs, as the human metabolism is defining the output values of that compartment, which provides good values for the simulation.

The element-composition of the biomass is strongly influencing the outcome of all bioreactors and needs to be considered when comparing data with other studies or experiments. The ones used in Compartment one are the following:

Faeces: $C\ H_{1.6409}O_{0.5584}N_{0.05306}S_{0.003402}P_{0.005141}$

Residual part of Higher Plants : $C\ H_{1.43}O_{0.62}N_{0.017}S_{0.007}$

Residual Biomass (RB) at the Bioreactor inlet: $C\ H_{1.4542}O_{0.6129}N_{0.02113}S_{0.006587}P_{0.0005894}$

Biomass produced in the Bioreactor: $C_5H_7O_2N$

Residual Biomass (RB) at the Bioreactor outlet with the biomass produced included: $C\ H_{1.2675}O_{0.4925}N_{0.01344}S_{0.0009428}P_{0.00008435}$

10.1.1.2 Mass Balance

An overview of the in- and outflows in the compartment result to the values given in Table 43. The variation between the in- and outflow values is based on rounding of values.
The data input for this compartment are derived from the outflow streams of the crew compartment and higher plants chamber.

Inflow				Outflow		
W_{Gin_CI}	Inflow of nitrogen to CI_BR	0.06 kg/d		W_{Gout_CI}	Outflow of gas from Condenser	0.138 kg/d
W_{Lin_CI}	Inflow of liquid to BPU	62.345kg/d		W_{Lout_CI}	Outflow of liquid from SLSI and BPU	60.792 kg/d
W_{Sin_CI}	Inflow of solid to BPU	9.623 kg/d		W_{Sout_CI}	Outflow of solid from SLSI	11.096 kg/d
$\mathbf{W_{total\_in}}$	**Total Inflow**	**72.028kg/d**		$\mathbf{W_{total\_out}}$	**Total Outflow**	**72.026kg/d**

Table 43 Flows for Compartment I

An overview of the mass flows of the compartment are shown in Figure 10-1 with the major components of the individual flows. In the Ecosim data output the volatile fatty acids (VTA) are listed individually as acetic, butyric, caproic, proprionic and valeric. For this overview they have been summarized in one value.

In Figure 10-1 the in- and outflow rates are shown with the liquids in blue, solids in brown and gases in red.

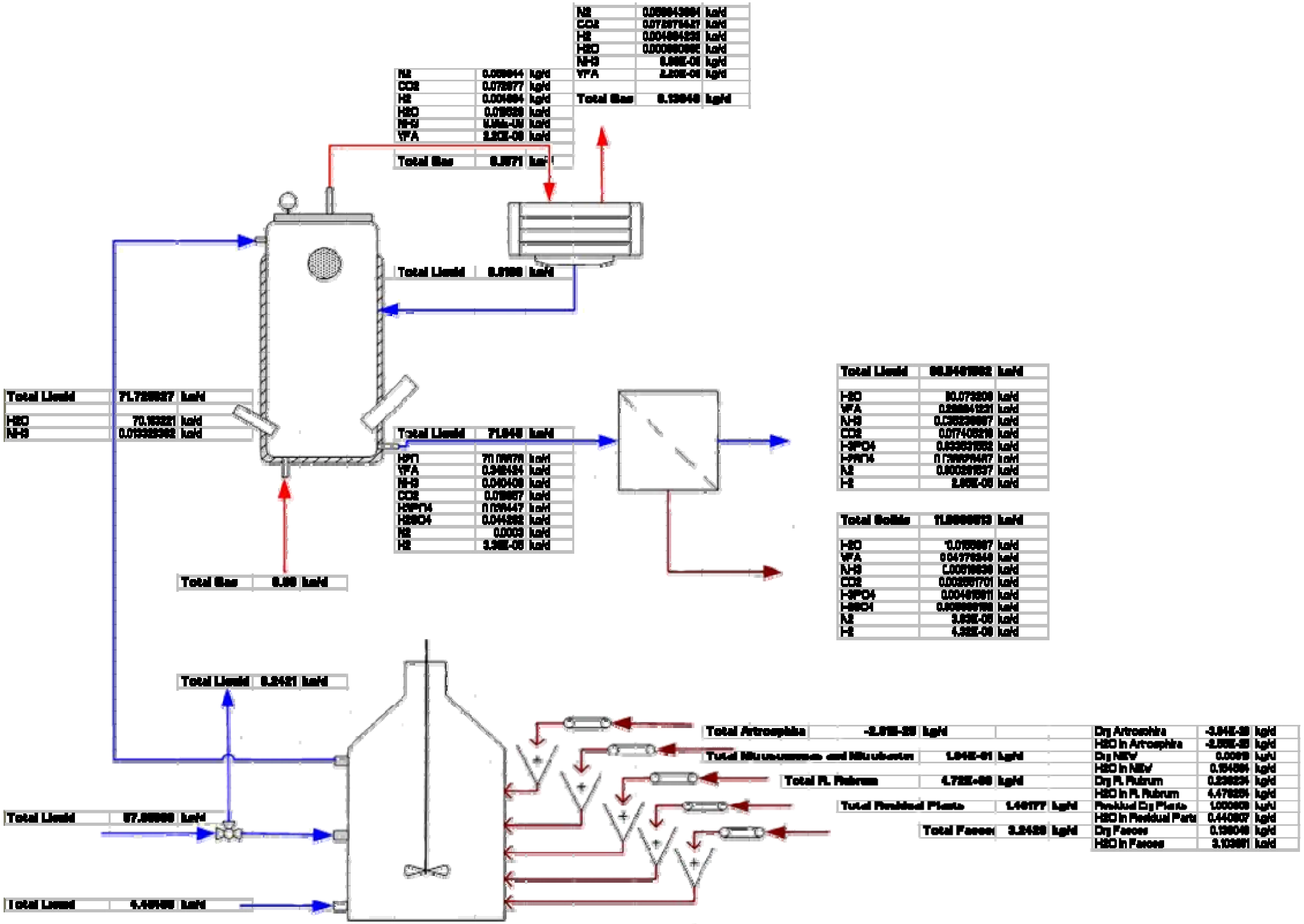


Figure 10-1 Compartment I Elements and Flows

10.1.2 Compartment II – Flows and Recycling Capabilities

Compartment II consists of two library components, which are the Compartment II Bioreactor (CII_BR) and a Solid Liquid Separator (SLS).

10.1.2.1 Important Data

The input data for this compartment are the output data from Compartment I. The biomass of *R. rubrum* consists of the following element-distribution:

$$C\ H_{1.6446}O_{0.3210}N_{0.1618}S_{0.003755}P_{0.01704}$$

10.1.2.2 Mass Balance

An overview of the in- and outflows in the compartment result to the values given in Table 44. The variation between the in- and outflow values is based on rounding of values.

Inflow				***Outflow***		
w_{Gin_CII}	Inflow of gas to CII_BR	0.001 kg/d		w_{Gout_CII}	Outflow of gas from CII_BR	0.001 kg/d
w_{Lin_CII}	Inflow of liquid to CII_BR	60.549 kg/d		w_{Lout_CII}	Outflow of liquid from SLSII	55.825 kg/d
				w_{Sout_CII}	Outflow of solid from SLSII	4.725 kg/d
$\mathbf{w_{total\_in}}$	**Total Inflow**	**60.550 kg/d**		$\mathbf{w_{total\_out}}$	**Total Outflow**	**60.551 kg/d**

Table 44 Flows of compartment II

In

Figure 10-2 the in- and outflow rates are shown with the liquids in blue, solids in brown and gases in red.

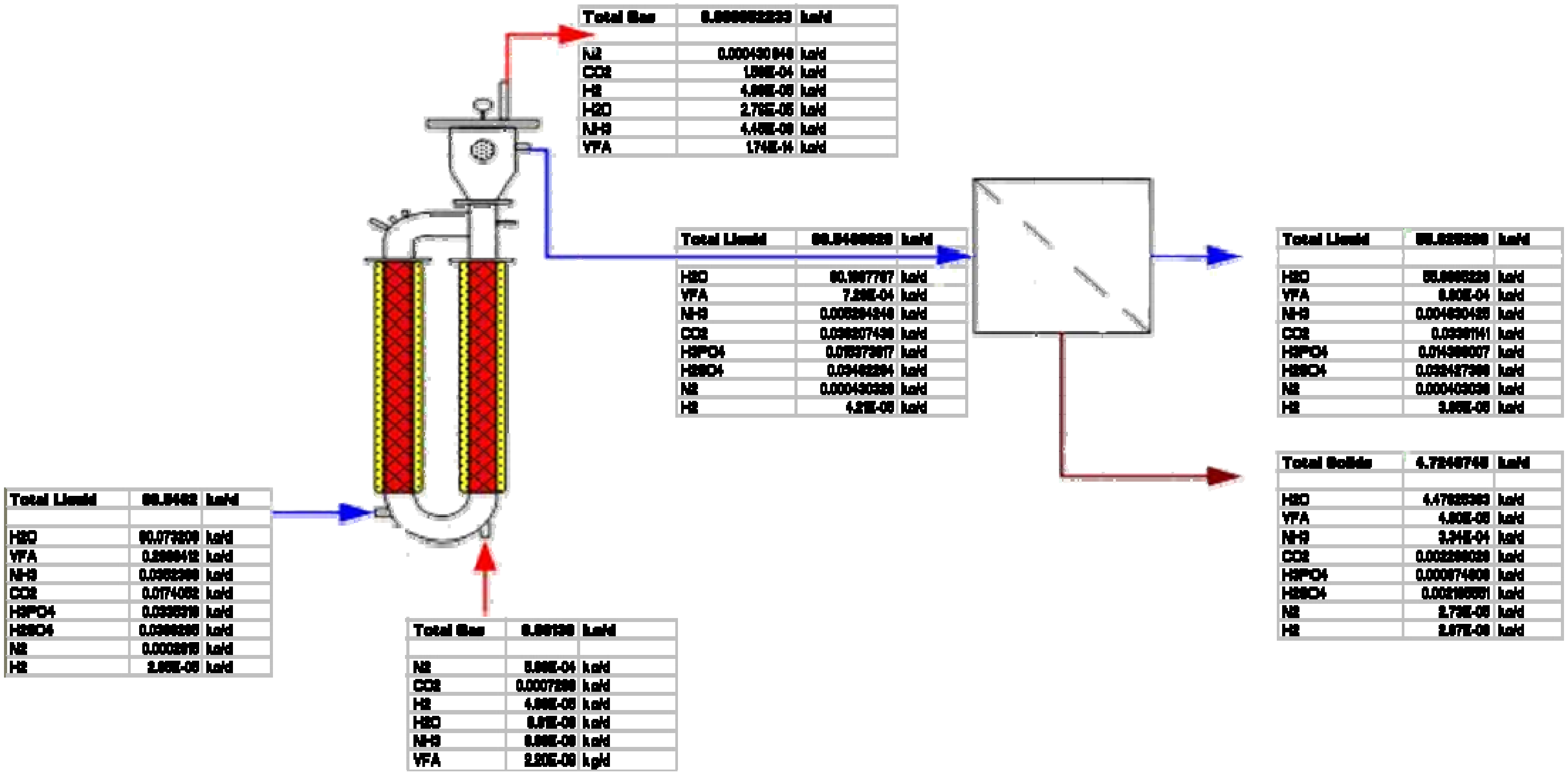


Figure 10-2 Compartment II Elements and Flows

10.1.3 Compartment III – Flows and Recycling Capabilities

Compartment III consists of two library components, which are the Compartment III Bioreactor (CII_BR) and a Solid Liquid Separator (SLS).

10.1.3.1 Important Data

The input values for this compartment are the output values from Compartment II. The biomass composition of *Nitrosomonas* and *Nitrobacter* consists of the following element-distribution:

$C\ H_{1.6147}O_{0.3906}N_{0.1994}S_{0.0035}P_{0.0089}$

10.1.3.2 Mass Balance

An overview of the in- and outflows in the compartment result to the values given in Table 45. The variation between the in- and outflow values is based on rounding of values.

Inflow				***Outflow***		
W_{Gin_CIII}	Inflow of gas to CIII_BR	8.064 kg/d		W_{Gout_CIII}	Outflow of gas from CIII_BR	8.064 kg/d
W_{Lin_CIII}	Inflow of liquid to CIII_BR	83.685 kg/d		W_{Lout_CIII}	Outflow of liquid from SLSIII	83.644 kg/d
				W_{Sout_CIII}	Outflow of solid from SLSIII	0.164 kg/d
$\mathbf{W_{total\_in}}$	**Total Inflow**	**91.749kg/d**		$\mathbf{W_{total\_out}}$	**Total Outflow**	**91.872kg/d**

Table 45 Flows of Compartment III

In Figure 10-3 the in- and outflow rates are shown with the liquids in blue, solids in brown and gases in red.

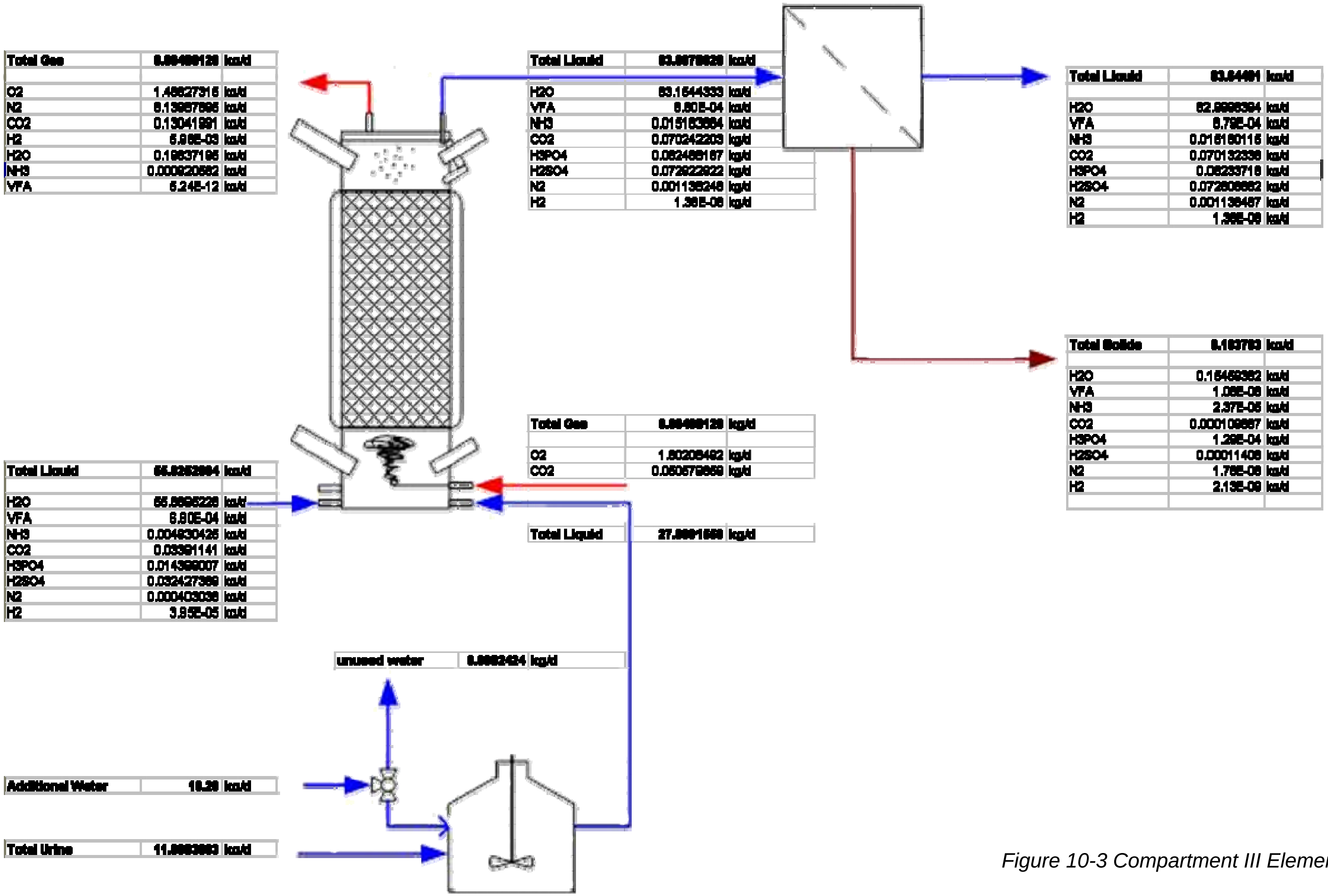


Figure 10-3 Compartment III Elements and Flows

10.1.4 Compartment IVa – Flows and Recycling Capabilities

Compartment IVa consists of three library components, which are the Compartment IVa Bioreactor (CIVa_BR), a Solid Liquid Separator (SLS) and Arthrospira Washing (AW).

10.1.4.1 Important Data

The input values for this compartment are parts of the liquid output from Compartment III and the gas output from Compartment II. The biomass for *Arthrospira platensis* consists of the following element-distribution: $C\ H_{1.5842}O_{0.4725}N_{0.1460}$

10.1.4.2 Mass Balance

An overview of the in- and outflows in the compartment result to the values given in Table 46. The variation between the in- and outflow values is based on rounding of values.

Inflow				***Outflow***		
W_{Gin_CIVa}	Inflow of gas to CIVa_BR	8.102 kg/d		W_{Gout_CIVa}	Outflow of gas from CVIa_BR	8.162 kg/d
W_{Lin_CIVa}	Inflow of liquid to CVIa_BR and water for AW	46.822 kg/d		W_{Lout_CIVa}	Outflow of liquid from SLS III and AW	45.775 kg/d
				W_{Sout_CIVa}	Outflow of solid from AW and SLS III	0.987 kg/d
$\mathbf{W_{total\_in}}$	**Total Inflow**	**54.924 kg/d**		$\mathbf{W_{total\_out}}$	**Total Outflow**	**54.924 kg/d**

Table 46 Flows of Compartment VIa

In Figure 10-4 the in- and outflow rates are shown; liquids in blue, solids in brown and gases in red.

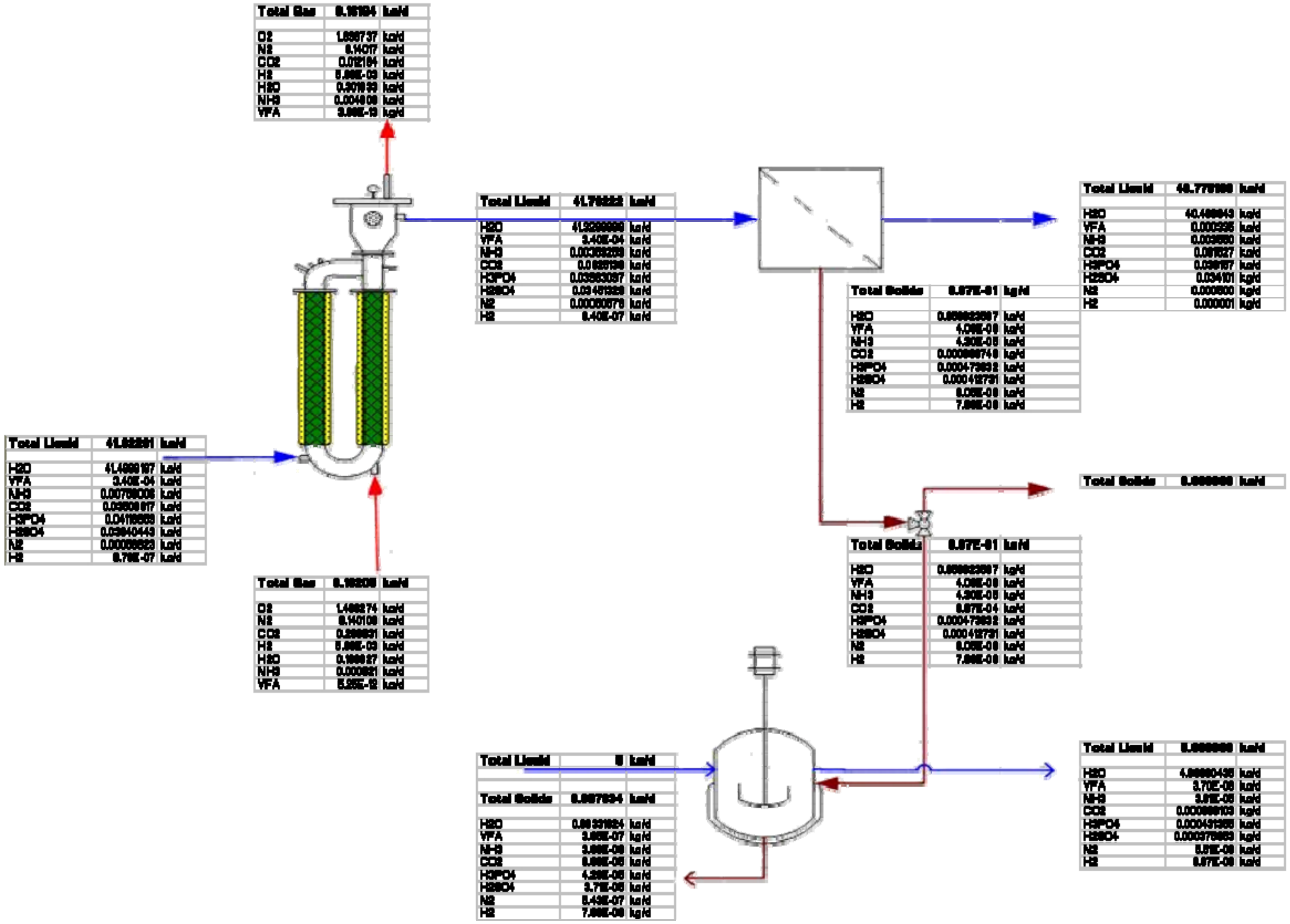


Figure 10-4 Compartment VIa Elements and Flows

10.1.5 Higher Plants Chamber – Flows and Recycling Capabilities

The Higher Plants Chamber consists of two library components, which are the Higher Plants Chamber (HPC) and a Condenser.

10.1.5.1 Important Data

The input values for the gas flow are from the crew compartment and the input of the water is a part from the output of Compartment III
The biomass output of the reactor is dependant on the different crop types and amount of each crop produced. The CHONSP composition of both, the edible and non-edible biomasses vary greatly with it. In Figure 10-5 an overview of the distribution of the different plant species considered is shown and the CHONS of the different plant types is as follows:

Onion	$CH_{1.765}O_{0.774}N_{0.052}S_{0.0007}$
Potato	$CH_{1.649}O_{0.781}N_{0.029}S_{0.0001}$
Rice	$CH_{1.849}O_{0.88}N_{0.027}S_{0.0007}$
Salad	$CH_{1.691}O_{0.573}N_{0.09}S_{0.0013}$
Soybean	$CH_{1.673}O_{0.38}N_{0.11}S_{0.0029}$
Spinach	$CH_{1.642}O_{0.444}N_{0.132}S_{0.0062}$
Tomato	$CH_{1.756}O_{0.813}N_{0.038}S_{0.0001}$
Wheat	$CH_{1.657}O_{0.735}N_{0.038}S_{0.0011}$
Residue	$CH_{1.43}O_{0.62}N_{0.017}S_{0.007}$

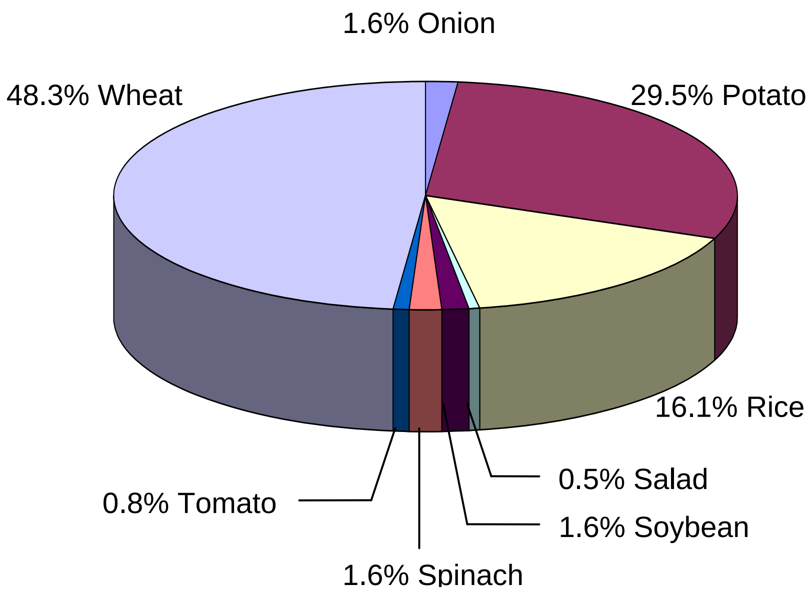


Figure 10-5 Crop Distribution amongst Higher Plants

10.1.5.2 Mass Balance

An overview of the in- and outflows in the compartment result to the values given in Table 47. The high flow rate values are only needed for sufficient gas and water exchange for the production of edible plant mass 1.05 kg/d for 4 people

Inflow				***Outflow***		
W_{Gin_HPC}	Inflow of gas to HPC	3870.75kg/d		W_{Gout_HPC}	Outflow of gas from Condenser	3860.65 kg/d
W_{Lin_HPC}	Inflow of liquid to HPC	589.63 kg/d		W_{Lout_HPC}	Outflow of liquid from SLS III and Condenser	595.75 kg/d
				W_{Sout_HPC}	Outflow of solid from HPC	3.98 kg/d
$\mathbf{W_{total\_in}}$	**Total Inflow**	**4460.38 kg/d**		$\mathbf{W_{total\_out}}$	**Total Outflow**	**4460.38 kg/d**

Table 47 Flows of Higher Plants Camber

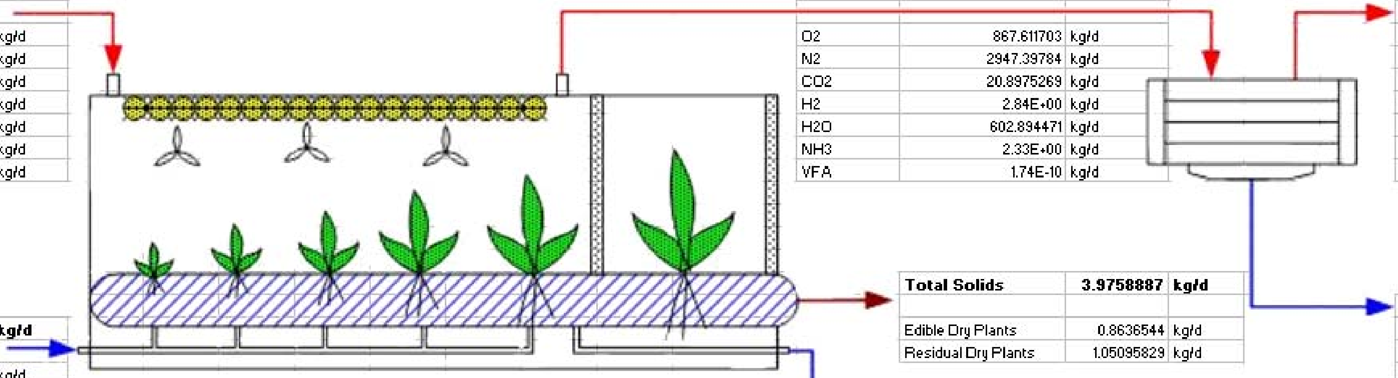
In Figure 10-6 the in- and outflow rates are shown with the liquids in blue, solids in brown and gases in red.

As no reference values are found in literature for the exact values needed here, a first test is made with excess values for plant growth. From this test run the molar flows of CO2, H2SO4, H3PO4, NH3, HNO3 are known and from those the flow rate and the concentration of CO2, N2, O2 can be calculated. The overall liquid flow is the flow of water.

The Molar flows of N_2 and O_2 are from the crew compartment and add to the gas flow rate.

Total Gas	3870.74942	kg/d
O2	865.00076	kg/d
N2	2947.39784	kg/d
CO2	24.27824	kg/d
H2	2.84267	kg/d
H2O	28.90240	kg/d
NH3	2.32752	kg/d
VFA	0.00000	kg/d

Total Liquid	589.62519	kg/d
H2O	588.96347	kg/d
VFA	0.00068	kg/d
NH3	0.03917	kg/d
CO2	0.11749	kg/d
H3PO4	0.08076	kg/d
H2SO4	0.07088	kg/d
N2	0.00107	kg/d
H2	0.00000	kg/d



Total Gas	4443.97172	kg/d
O2	867.611703	kg/d
N2	2947.39784	kg/d
CO2	20.8975269	kg/d
H2	2.84E+00	kg/d
H2O	602.894471	kg/d
NH3	2.33E+00	kg/d
VFA	1.74E-10	kg/d

Total Gas	3860.65147	kg/d
O2	867.61170	kg/d
N2	2947.39784	kg/d
CO2	20.89753	kg/d
H2	2.84267	kg/d
H2O	19.57422	kg/d
NH3	2.32752	kg/d
VFA	0.00000	kg/d

Total Solids	3.9758887	kg/d
Edible Dry Plants	0.8636544	kg/d
Residual Dry Plants	1.05095829	kg/d

Total Liquid	583.32025	kg/d
H2O	583.32025	kg/d
VFA	0.00000	kg/d
NH3	0.00000	kg/d
CO2	0.00000	kg/d
N2	0.00000	kg/d
H2	0.00000	kg/d

Total Liquid	12.427006	kg/d
H2O	11.8841048	kg/d
VFA	6.79E-04	kg/d
NH3	0.024859051	kg/d
CO2	0.117491122	kg/d
H3PO4	0.08075698	kg/d
H2SO4	0.037912861	kg/d
N2	0.001073474	kg/d
H2	1.32E-06	kg/d

Figure 10-6 Higher Plants Chamber Elements and Flows

10.1.6 Crew Compartment – Flows and Recycling Capabilities

10.1.6.1 Important Data

This compartment needs several input values to run a simulation. The values resulting from this compartment will in return be used for the other compartments for their simulation. The values used are given in Table 48. The basic ones are the food composition and the flow rates and concentration of the water and gas flows.

The values for the food components are the same as in the matlab simulation [R17] and the ones for the flow rates and concentrations are taken from [R1]

Name	***Value***	***Units***	***Reference value***	***Source***
food.C_ch_food	1	-	1	[R17]
food.C_food	1	-	1	[R17]
food.C_lip_food	1	-	1	[R17]
food.C_prot_food	1	-	1	[R17]
food.H_ch_food	1.67	-	1.67	[R17]
food.H_food	1.64597506	-	1.6476049	[R17]
food.H_lip_food	1.714	-	1.714	[R17]
food.H_prot_food	1.526	-	1.526	[R17]
food.M_food	0.0229646296	-	0.0230011335	[R17]
food.N_ch_food	0	-	0	Chemical structure
food.N_food	0.0578479236	-	0.0516420643	[R17]
food.N_lip_food	0	-	0	Chemical structure
food.N_prot_food	0.2496	-	0.2496	[R17]
food.O_ch_food	0.711	-	0.711	[R17]
food.O_food	0.510114834	-	0.518080876	[R17]
food.O_lip_food	0.204	-	0.204	[R17]
food.O_prot_food	0.327	-	0.327	[R17]
food.P_ch_food	0.004	-	0.004	Chemical structure
food.P_food	0.00658473922	-	0.00674128181	[R17]
food.P_lip_food	0.02	-	0.02	[R17]
food.P_prot_food	0	-	0	[R17]
food.S_ch_food	0	-	0	Chemical structure
food.S_food	0.00370820023	-	0.00331038873	[R17]
food.S_lip_food	0	-	0	[R17]
food.S_prot_food	0.016	-	0.016	[R17]
food.W_food	7.14e-006	kg/s	Tab. 3.3.6: 0.617kg/ 🧍 /day	[R1]
food.f_H2O_food	0.82	-	Tab. 3.10 and Tab. 3.11: between 13.26% and 97.56% for used vegetables, depends on amount of vegetable and % of additional food	[R5]
food.f_ch_food	0.595	-	Tab. 4.3.10: 0.62	[R1]
food.f_lip_food	0.175	-	Tab. 4.3.10: 0.65	[R1]
food.f_prot_food	0.205	-	Tab. 4.3.10: 0.19	[R1]
gas_in.Con[N2]	33	-		
gas_in.Con[O2]	8.25	-		
gas_in.Q	4.16964637e-005	m^3/s	Tab. 4.1.1: low 0.385 kg/ 🧍 /day, upper 1.852 kg/ 🧍 /day	[R1]
hyg_water.Con[H2O]	55555.56	-	$1000kg_{H2O}/m^3_{H2O}$ / 0.018kg/mol	
hyg_water.Q	7.871025e-008 (Q=Con[H2O] * Q * M_H2O * 86400=6.8kg/d)	m^3/s	Tab. 4.6.2: 7.67kg/ 🧍 /day for early planetary bases and 25.58kg/ 🧍 /day for mature planetary bases	[R1]
potable_water.Con[H2O]	55555.56	-	$1000kg_{H2O}/m^3_{H2O}$ / 0.018kg/mol	
potable_water.Q	3.24075e-008 (Q=Con[H2O] * Q * M_H2O * 86400=2.8kg/d	m^3/s	Tab. 4.3.4: 2kg/ 🧍 /day for drinking, 3.9 kg/ 🧍 /day including food preparation Tab. 4.3.8: maximum of 0.7 for water in food, 1.0 for rehydration water and 1.2 kg/ 🧍 /day for additional drinking	[R1]

) water

Table 48 Input Values of Crew Compartment

10.1.6.2 Mass Balance

The Crew Compartment (CC) is one single component in itself. In Figure 10-7 the in- and outflow rates are shown with the liquids in blue, solids in brown and gases in red.

Inflow				***Outflow***		
w_{Gin_CC}	Inflow of gas to CC	4021.17 kg/d		w_{Gout_CC}	Outflow of gas from CC	4032.03 kg/d
w_{Lin_CC}	Inflow of Potable and Hygiene Water into CC	36.72 kg/d		w_{Lout_CC}	Outflow of urine and residual water from CC	32.98 kg/d
w_{Sin_CC}	Inflow of Food	9.87 kg/d		w_{Sout_CC}	Outflow of solid from CC	3.24 kg/d
$\mathbf{w_{total\_in}}$	**Total Inflow**	**4068.25 kg/d**		$\mathbf{w_{total\_out}}$	**Total Outflow**	**4068.25 kg/d**

Table 49 Flows of Crew Compartment

Parameter	**Value**	**Reference Values**	**Reference**
O2 consumption	0.92 kg/d	0.6 - 1 kg/ 🧍 /d	[R3]
CO2 production	1.087 kg/d	0.7 - 1.2 kg/ 🧍 /d	[R3]
Potable Water	2.802 kg/d	2.27 – 3.63 kg/ 🧍 /d	[R3]
Hygiene Water	6.806 kg/d	1.36 – 9 kg/ 🧍 /d	[R3]
Dry mass food	0.617 kg/d	0.5 - 0.863 kg/ 🧍 /d	[R3]
Solid faeces	0.0315 kg/d	0.03 kg/ 🧍 /d	[R3]
Dry mass urine	0.0737 kg/d	0.06 kg/ 🧍 /d	[R3]

Table 50 Verification of reasonability of values for simulation for one person

Figure 10-7 Crew compartment Flows (4 crew)

10.2 ARES

10.2.1 CCA – Flows and Recycling Capabilities

The Carbon dioxide Concentration Assembly (CCA) contains an Asdorber-Desorber component, an evaporator and two condensers.

10.2.1.1 Mass Balance

Inflow				***Outflow***		
W_{Gin_CCA}	Inflow of gas from CC	7.435 kg/d		W_{Gout_CCA}	Outflow of gas to	4.424 kg/d
W_{Lin_CCA}	Inflow of Water from OGA	0.864 kg/d		W_{Lout_CCA}	Outflow of condensated water to OGA	3.875 kg/d
$\mathbf{W_{total\_in}}$	**Total Inflow**	**8.299 kg/d**		$\mathbf{W_{total\_out}}$	**Total Outflow**	**8.299 kg/d**

Table 51 CCA Flows

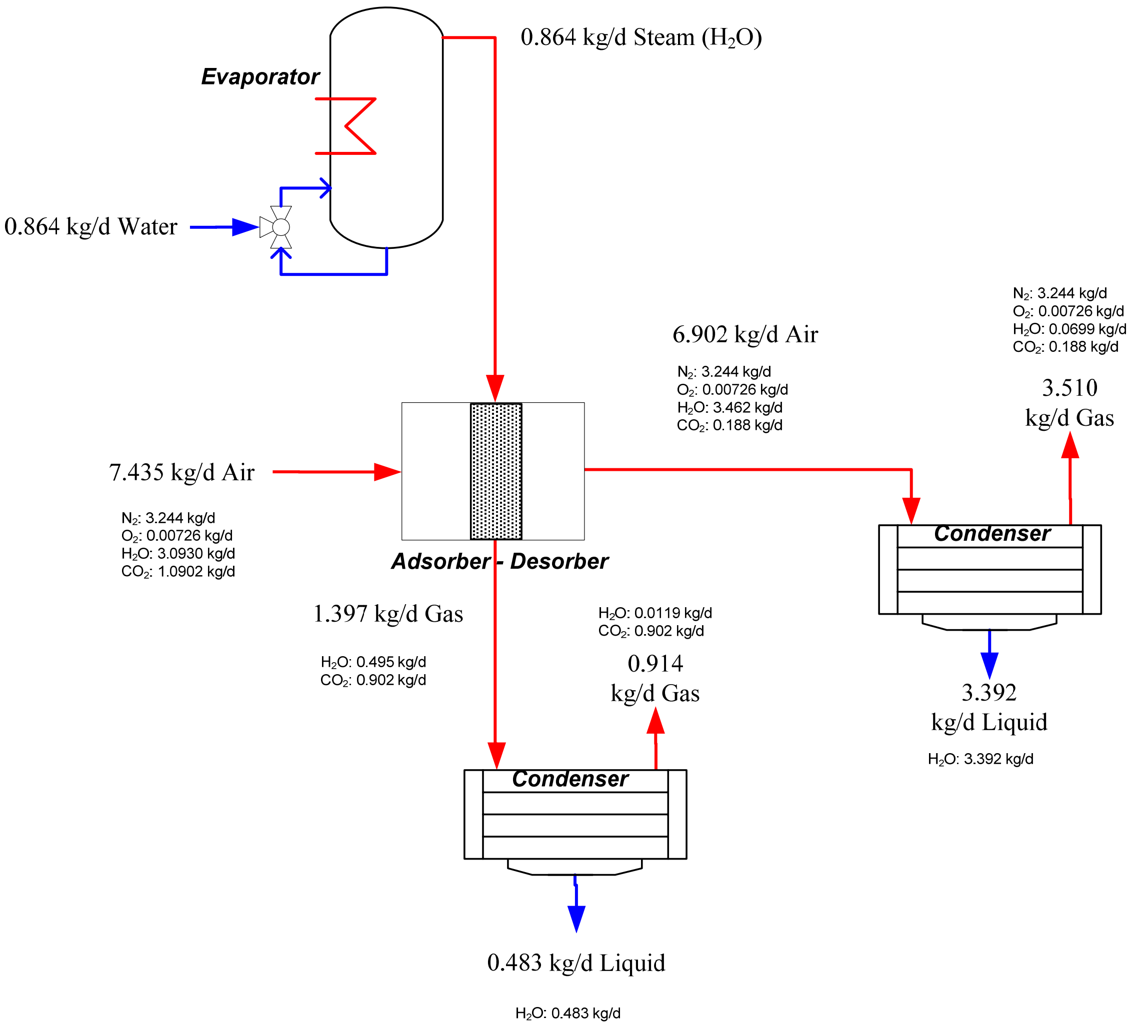


Figure 10-8 CCA Flows

10.2.2 CRA – Flows and Recycling Capabilities

The Carbon dioxide Reduction Assembly (CRA) contains a Sabatier reactor and a condenser.

10.2.2.1 Mass Balance

Inflow				***Outflow***		
W_{Gin_CRA}	Inflow of CO_2 from CCA and H_2 from OGA	0.839 kg/d		W_{Gout_CRA}	Outflow of gas	0.270 kg/d
				W_{Lout_CRA}	Outflow of condensate water to OGA	0.569 kg/d
W_{total_in}	**Total Inflow**	**0.839 kg/d**		**W_{total_out}**	**Total Outflow**	**0.839 kg/d**

Table 52 CRA Flows

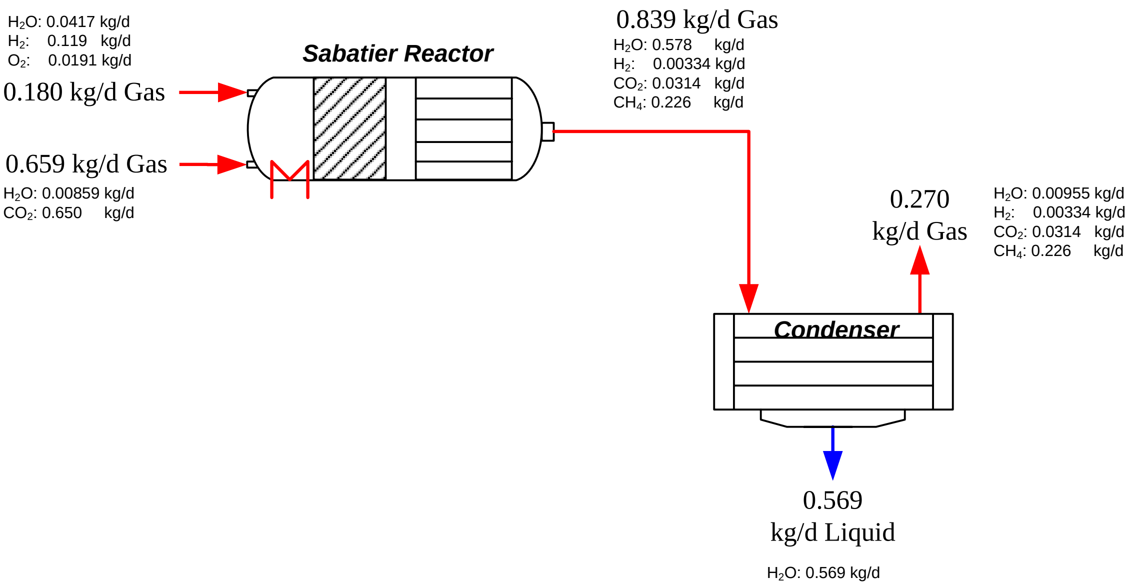


Figure 10-9 CRA Flows

10.2.3 OGA – Flows and Recycling Capabilities

The Oxygen Generation Assembly (OGA) contains a Water Recovery Unit and an Electrolysis Unit.

10.2.3.1 Mass Balance

Inflow				***Outflow***		
				W_{Gout_OGA}	Outflow of gas	1.127 kg/d
W_{Lin_OGA}	Inflow of Water from	4.444 kg/d		W_{Lout_OGA}	Outflow of	3.327 kg/d
W_{total_in}	**Total Inflow**	**4.444 kg/d**		**W_{total_out}**	**Total Outflow**	**4.444 kg/d**

Figure 10-10 OGA Flows

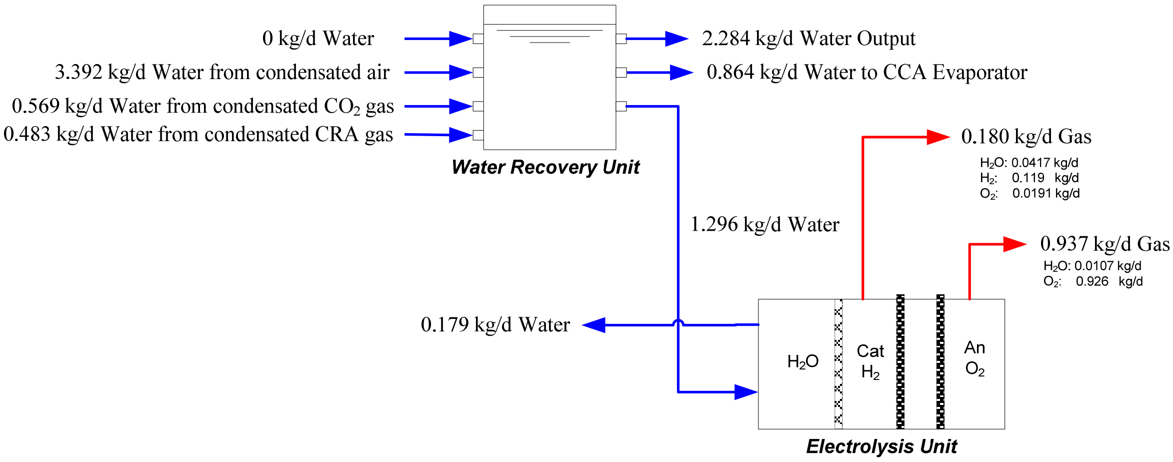


Figure 10-11 OGA Flows