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MPP integration strategy : 2008 recommendations

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Table of Content

1. Scope

The present technical note is summarizing the recommendations made by a group of three experts entrusted to give their opinion on the steps to follow in order to bring the demonstration of the efficiency and robustness of the MELiSSA Pilot Plant complete loop. These steps will constitute the reference for the integration strategy to be followed by the MELiSSA Pilot Plant in its endeavour to demonstrate that the MELiSSA concept is efficient for its purpose of life support system.

The consultancy study was carried out on a one year period, from May 2008 until June 2009

The experts are :

- Mark Kliss, Ph.D, Chief of Bioengineering Branch (SCB), NASA Ames Research Center
- Pr Alexander Tikhomirov, Institute of BioPhysics, Krasnoyarsk Russia
- Dr Christian Guizard, Directeur, Laboratoire de Synthèse et Fonctionnalisation des Céramiques, UMR 3080 CNRS/SAINT-GOBAIN, Saint-Gobain C.R.E.E.

2. Rationale for the consultancy study

The logic followed for this consultancy study was the following.

As a first version of the sequence of steps needed to bring the full demonstration of the integrated MELISSA Pilot Plant loop had been drafted by ESA and the MELiSSA partners, it was submitted to the experts, as an input to the consultancy. This first version is recalled in appendix 1.

Then several meetings were organized in order to answer the experts questions about the different compartments and their possible interconnections. The minutes of the three meetings are also appended for information in Appendix 2.

As a conclusion, the experts provided their own remarks and recommendations on the existing integration strategy for the MELiSSA Pilot Plant, each of them in their fields of expertise.

3. Experts report

3.1. Objectives of the definition of an Integration Strategy for the MELiSSA Pilot Plant

Studies of closed regenerative life support system provide the technology to guarantee the autonomy of the crew during long duration space missions (i.e. Moon or Mars base). So far, after 20 years of activities, MELiSSA project has accumulated the scientific and engineering experience to demonstrate recycling processes at pilot scale. For this purpose, the MELiSSA Pilot Plant (MPP), located at the Universitat Autonoma de Barcelona (UAB), has been created in 1995, and considerably enlarged in 2007 and 2008 (official opening in June 2009).

To reach the level of demonstration expected, a stepwise approach has been chosen for the MELiSSA Pilot Plant. Starting from the definition of a demonstration scenario, a sizing exercise of the MELiSSA compartments has been performed. Hardware has been then developed accordingly. The various compartments built are then extensively characterized during stand-alone operation campaigns. To reach the gas, liquid and solid loops closure, as defined in the demonstration scenario, a progressive integration of these compartments has to be anticipated. This is the aim of the Integration Strategy, as proposed by the MELiSSA Pilot Plant.

This Integration Strategy shall be used:

- to establish a roadmap and workplan for the coming years in the MELiSSA Pilot Plant;
- to anticipate any need for proper performance of the progressive integration of the MELiSSA loop, e.g.:
    - Specific hardware (interface…)
    - Model, control
    - Knowledge
    - Expertise
- To define a dynamic planning as a tool for proper management

3.2. Objectives of the present assessment by external experts

A first attempt to define the MPP Integration Strategy ended by the definition of 18 integration work packages (WPs) (see the annexes). The guideline for this definition was to start from and progressively enrich/consolidate the MELiSSA knowledge.

This first draft Integration Strategy has been screened, internally to the MELiSSA Consortium, through different criteria:

its feasibility versus time has been assessed, the dead line being to get the loop integrated and demonstrated over 3 years at the latest by 2015. This first check led to hardware/knowledge availability issues.

Its technical feasibility has been assessed through static simulation, aiming at answering the following questions: do we have consistent flows, do we have consistent hardware, what is the interest of each integration step versus the final full scenario.

The first objective of the present assessment was to gather around the table several experts' profiles and expertise to get comprehensive recommendations on the MPP integration strategy.

Recommendations were expected at multiple levels:

- On the demonstration scenario itself;
- On the overall MPP work logic (approach, objectives);
- On detailed steps of the progressive integration proposed.

Recommendations were expected to be multidisciplinary:

- On processes;
- On technologies;
- On more fundamental scientific aspects;
- On multiple fields of expertise

4. Recommendations of M. Kliss

4.1. The demonstration scenario itself

The overall concept of reducing the amount of metabolic consumables required for long duration manned space missions by developing regenerative life support systems with a high degree of closure has been widely endorsed by the space community, and research and technology development has been conducted on various aspects of these systems by space agencies, universities and institutions during the past few decades. The complexity of regenerative life support systems are such, however, that very few demonstrations at an integrated systems level have been undertaken.

The approach taken by the MELiSSA team in developing a pilot scale system representative of a full scale manned mission is both original and highly promising. Emphasis on achieving the highest degree of closure in the liquid loop (in comparison to the gas and solid phase loops) is well placed and will add substantial new knowledge toward the development of regenerative systems. Even partial achievement of the stated goals (producing 100% of the daily O_2 needed and 20 % of the daily diet of 1 person; removing 100% of the CO_2 produced by 1 person; degradation of faeces, inedible higher plant material and other organic waste products via biological processors) would represent a significant advancement in regenerative life support system development.

4.2. The overall MPP work logic (objectives and approach)

The stated objective is to demonstrate recovery and production of food, water and oxygen from wastes based upon duplicating the primary consumption, degradation and production functions of an aquatic ecosystem (freshwater lake). The approach is very logical and follows a sound engineering strategy. The key functional elements that comprise such an ecosystem were separated into five compartments, and a detailed knowledge base (hydrodynamic characterization, stoichiometry studies, static and dynamic modelling, etc.) for each compartment has been largely acquired. This knowledge base has allowed the MELiSSA team to derive key complex transfer functions (relationship between inputs and outputs) associated with each individual compartment. Subsequently, these compartments are being integrated at the pilot plant scale in order to demonstrate long-term, stable performance on the ground prior to application to space missions.

4.3. The detailed steps of the progressive integration proposed

In reviewing the Work Packages developed for integration, it was understood that the proposed sequence was primarily focused on obtaining the necessary test data and knowledge required prior to final assembly and integrated operation, and was not intended as an optimized assembly sequence. Changes to various components or subsystems may be made based upon knowledge obtained during the progressive integration sequence. It was also assumed that the duration identified for each Work Package was adequate unless specifically mentioned by one of the consultants.

4.3.1. WP1.

Demonstration of the O2/CO2 control law between compartments CIVa and CV is a logical starting point in gas loop closure because it can draw on the knowledge of the BIORAT experiment and represents the same closure issue. Since the exchange rates of gas for animals are different than what is needed for flow rates in bioreactors, it represents an early opportunity to address hydrodynamic issues as well. Characterization of undesirable gas phase compounds that should not be exchanged between CIVa and CV should be conducted at this stage.

4.3.2. WP2.

Validation of the control loop between CII and CIII is an important early step for subsequent liquid loop closure. Demonstrating that organic compounds/VFAs are prevented from entering CIII from CII is viewed as even more critical for eventual liquid loop closure, however, since failure in CIII is catastrophic to the entire system. Since one must expect that some VFAs may never-the-less enter CIII, early testing should include detection/measurement instrumentation and mitigation/prevention protocols. Additional time may be required to determine how best to transfer material from CII into CIII. Operational knowledge from this workpackage should help refine axenicity protection procedures that will be required more broadly later.

4.3.3. WP3.

This work package provides additional knowledge of liquid and gas control laws between CIII and CIVa, and should be fairly straightforward, as this has been performed at a smaller scale already. One issue to consider during WP3 demonstration is that if carbonate is added in the liquid phase to CIII, it will likely become the dominant pH control for CVIa. If this is not desirable, additional time may be required in this workpackage to address pH control.

4.3.4. WP4.

This work package is a combination of WP1 and the liquid portion of WP2 and WP3, and should also be fairly straightforward. This may be the first opportunity to characterize the different processing rates/dynamics of these three compartments, and will serve as a key test phase for the liquid loop. If time permits, one may wish to consider closing the gas loop from CIVa back to CIII as an additional test during this phase.

4.3.5. WP5.

Closure of the gas loop between CIVb and CV should allow for measurement of actual O2 production during WP5. A gas metering system for CO2 and O2 will likely be required between CIVb and CV, and VOC removal/scrubbing capability may also be required. In addition, any potential gas toxicity issues from CV back to CIVb should be considered during WP5.

4.3.6. WP6.

This appears to represent the first major test of the gas loop and controls associated with CIII, CIVa, CIVb, and CV compartments. Successful demonstration of the oxygen loop closure is viewed as one of the most important, if not the most important near-term milestones. When determining the limit behaviours of the system, characterization of the types and amounts of gaseous contaminants produced by the various compartments will likely be important for overall long-term stability. An additional study on degradation of the solid material (by the fibre degradation/wet oxidation system) removed from CIVa, CIVb and CV may also be useful at this point. This may also be a good time to provide an initial assessment if sufficient nitrogen can be produced by CIII for the CIV compartments.

4.3.7. WP7.

In this workpackage solid waste (inedible and perhaps also edible biomass) from CIVb will be introduced into CI. During discussions it was mentioned that initial integrated tests of the MELiSSA pilot plant will not utilize wastes from CIVb or CV. Since the feed into CI plays a key role in the stability of the whole system, thorough characterization of similarities and/or any significant differences in composition of the waste being introduced into CI during this workpackage would be very valuable.

4.3.8. WPs 8,9 & 10.

Along with WP7, these workpackages involve validating CI and CIV (a & b) working together for the first time, a key loop test. During these validation tests, VFAs present in the gas phase should be characterized and a decision made if they should be utilized or removed. At this point, data from the CI control loop should also give a good indication of the dynamic stability of this loop. These data may help guide decisions (and subsequent workpackage efforts) on the relative priority of achieving initial system stability (reliability) vs. initial system closure (mass balance). If the models for harvesting Rhodospirillum Rubrum and Spirulina platensis assume complete separation of liquids from solids, data should be taken to support a sensitivity analysis of the initial assumptions.

4.3.9. Other WPs

Although the sequence and logic for validation of the liquid control loop for CI – CIV (WPs 11-14), and subsequent validation and demonstration of maximum gas, liquid and fully integrated system closure (WPs 15-18) seems to be very appropriate and reasonable, it is probably premature to provide much comment on these workpackages at this time. Knowledge and experience gained during execution of workpackages 1-10 will likely require additional attention or modification to the control of specific compartments and interactions between compartments, and may also require changes to specific subsystem hardware as well. Accordingly, these final integration workpackages may need to be modified or have new workpackages introduced. Revisiting initial control law assumptions and revising control loop parameters based upon the data obtained will be particularly important during workpackages 13,14 & 15.

4.4. Multidisciplinary Recommendations on:

4.4.1. More fundamental scientific aspects

The MELiSSA team has done a very thorough job of identifying the key scientific challenges associated with the project. Perhaps the most significant challenges to long-term stability of the MELiSSA pilot plant will be minimizing toxicity/poisoning via trace elements or undesirable contaminants (including materials off-gassing), managing the accumulation of recalcitrant organic compounds, and addressing the accumulation and depletion of specific minerals. Few research teams have had the opportunity to address these issues in the comprehensive manner possible with the MELiSSA pilot plant, and it is anticipated that improved contaminant detection and characterization techniques, instrumentation, and remediation methods may be developed. These advances would be of significant benefit to the field of regenerative life support and associated environmental areas.

The control of the microbial consortium in the MELiSSA pilot plant, specifically the need to maintain axenicity in CII and CIVa, represents an additional challenge. This approach is necessary to provide consistent and predictable behaviour in these compartments, but sequential processing systems are heavily dependent upon each processor maintaining its desired functionality. As biological processes are by nature subject to genetic evolution, restarts or re-seeding of these compartments may become necessary. Accordingly, procedures to address the need for sterility of all components associated with these compartments, as well as protocols for long term axenic culturing will likely need to be developed. Both of these fundamental scientific challenges contribute to the issues of stability/reliability and very long term drift in highly closed systems.

4.4.2. Processes/ Technologies

The knowledge base for independent operation of the three bioconversion compartments (CI anaerobic thermophilic bioreactor, CII Rhodospirillum Rubrum photobioreactor, and CIII Nitrosomonas and Nitrobacter fixed-bed bioreactor), the two production compartments (CIVa Spirulina platensis culturing and CIVb higher plant culturing) and crew compartment has been established to a rather high level by the MELiSSA team. Characterization and static modelling is sufficiently developed that more complex dynamic modelling and predictive control for several compartments is well underway. Long-term compatibility between processes, particularly dynamic interactions, remains the control challenge for closed loop operation of the interconnected compartments. The proposed approach of regarding simulation and modelling as an iterative process such that initial mass balance and steady state/dynamic models will be refined based upon new experimental data is excellent. Clear documentation of all key initial assumptions regarding control logic, and frequent revisiting of these assumptions during start-up of continuous operations has proven extremely beneficial for other closed loop life support research efforts.

One processor that has not been discussed much or included in the work package integration strategy is the fibre degradation unit. This processor must degrade the fibrous solid waste residue (~30%) that is not processed by the CI waste liquefaction compartment. In order to compliment the mesophilic degradation of wastes in CI, the fibre degradation unit/wet oxidation system must produce primarily CO2 instead of VFAs. This should be fairly straightforward to accomplish, but during initial operation the material being introduced into the fibre degradation unit will not originate from MELiSSA compartments (CIVb, CV, etc.). As mentioned in WP7, thorough characterization of similarities and/or any significant differences in composition of the initial waste materials (biomass not grown in MELiSSA and animal wastes) vs. those ultimately generated by the integrated MELiSSA pilot plant compartments should be conducted.

5. Recommendations of A. Tikhomirov

5.1. SCENARIOS

5.1.1. WP 1.

On the first stage the gas closure of the CIVa – CV is suggested for an evaluation. From the point of terminology, it would be better to use the term 'gas loop' instead of 'closure'. This scenario should be considered as a preliminary one. Though oxygen and carbon dioxide exchange between the CIVa and CV is marked in «Knowledge»; however, it is supposed to give only a part of oxygen necessary to rats (another part will be delivered from the CIVb). Therefore, in case the full supply of oxygen to rats is planned then most likely, the part of oxygen should be taken from the atmosphere or the number of rats should be less than it has been planned for the experiment. Taking into consideration that, it would be expedient to insert some addition in WP 1 scheme or mention an additional oxygen supply from outside.

5.1.2. WP 2.

The connection of L phase of the CII-CIII is supposed which also will have a general test character. Here it is incomprehensible from the logical point of view what initial components will be assigned in the CII, as the CI, supplying by these components, has not been connected and is not working. From the scheme for the WP2, it is obvious, that L, probably, will be taken from the store. Besides, in the issue 'Constraint (**Content Part b)' the** VFA are mentioned. That means that they will be produced in the CI (?). Or by another way? In case they will be produced in the CI, that means it has already been working. If not, then what kind of products they are, and how they have been prepared? This aspect demands to be cleared up. From here, logically the question arises, what way will the work of the CIII be provided which depends on quantity and quality of the L flow from the CII. In the issue 'Set-point', it has been indicated that the successful criteria of the work performed, the NO2 and NO3 concentrations in the CIII will be considered. Probably that will be the concentrations not corresponding to a steady state (?). Or close to them? It is ill-defined, in case the L phase will be formed taking into consideration the inclusion of human liquid and solid wastes. When including them then in the issue 'Follow-up' the potentiality of amide nitrogen forms should be reserved.

5.1.3. WP 3.

The connection of L и G phases for the CIII and CIVa is considered. It is supposed that definite values of gases (O2, NO3 or NO2) will be achieved due to manipulation of the CIVa light, CO2 addition CIVa. Probably, the main purpose of this scenario is to test the CIVa operation.

5.1.4. WP 4.

This scenario may be considered as the propagation of WP 1, when the contribution of 'Connection L phase CII-CIII-CIVa' is added. However, here as well as in WP 1, we cannot speak about 'Closure G phase CIVa-CV', as the steady-state of the entire system has not been achieved yet. In the issue 'Knowledge', the 'Output of WP1+WP2+WP3' is indicated. It is not exactly since in WP 4, according to the scheme 'G phase CIVa-CIII' is missing which was present in WP3. The problem regarding insufficient supply of rats by oxygen, first appeared in WP1, has remained unsettled.

5.1.5. WP 5.

For the first time the estimation of the CIVb work is supposed, which, meanwhile, one should consider as a testing one. The important peculiarity of this stage lies in the absence of the interruption of the anew connected CIVb work until the last WP 18. It is advisable not only from the point of the further formation of matter turnover processes but for saving time and efforts, which will be wasted in the case of the break of this compartment's work. In the issue 'Set-point', the concentrations of O_2 and CO_2 in the CV gas phase are mentioned. It may be understood as the potentiality to supply the CV according to these gases in a full-scale volume, which is impossible, as this supply should be implemented at the expense of both the CIVb and the CIVa, which is not connected in this scenario. The same situation has already been considered when discussing WP1. Therefore, this situation should also be specified. It is important to take into consideration that the rats' microflora can reach the higher plants via gas flow and may interact with them. This interaction may differ in comparison with that of the human microflora. This problem should be paid special attention to during the investigations.

5.1.6. WP 6.

Here the tasks that have separately been implemented in WP 1, WP 3 and partially in WP 4 are intergraded on a higher level. The tasks set by already allow preliminary estimation of closure of matter turnover including vegetative and animal objects. In the issue '**WP title'** the 'Closure G phase CIVb-CV' has not been mentioned though it is indicated on the scheme of WP6, and the CIVb is mentioned in the item 'Quality control' and other items. It is early to speak about the preliminary calculations for a gas phase management between the compartments meaning all the compartments as the CI and CII have not been connected up to the entire system.

5.1.7. WP 7.

The characteristic property of this scenario consists in the beginning of a new work cycle on the S inclusion in the closing process. The CI and CIVb options seems to be well grounded as in the CI the primary processing of S is carried out, and the CIVb is one of the basic suppliers of S in the form of a vegetative biomass. Besides, for the first time the attempt of at least partial connection of the CI to a mass exchange has been made. In the scheme, the outward flow L is representing the CI input terminal. It is difficult to understand how it is developing and what it is containing. In the final version of the scenario, that aspect should be made clear.

5.1.8. WP 8.

This scenario practically appears to be the continuation and development of WP 7. Here the 'Connection G phase CI-CIVb' has been added. The gas loop between these two compartments has not been closed and only the flow from the CI to the CIVb is estimated... The return flow is thrown in atmosphere. Thereby the 'Manipulable inputs', that first of all refer to the CIVb are of a highly preliminary character. That also applies to the G loop closure demonstration, which is mentioned in '**Remarks'.**

5.1.9. WP 9.

This scenario is characterized by the further development of the CI connection and is tightly associated with WP 8. In contrast to WP 8, the loop for S between the CI and CIVb is fully closed. The statement that the CI is fully characterized, meanwhile, is open to question, as here the CI and CI1 has not been connected, and their interference on the process of the entire system work has not been investigated yet.

5.1.10. WP 10.

Here the novelty is represented by the CII addition to the system connection, started for S in WP 7 for the several compartments' group. In the issue '**Remarks'** it is mentioned that **'**MILESTONE' is the Solid loop closure demonstration, it is significant that this demonstration is only testing as the flow rate and possibly its composition may substantially have changed after the launch of the entire system (WP 18). Therefore, this phrase should be worded more precisely. At the creation of an interaction of the compartments' group starting from WP 7, all L flows are present but look like artificially created outside the system (incoming) and thrown out (outgoing). It would be advisable to explain the way the L flows have been developed outside the system for CI, CII, CIVa, CIVb. That explanation would give the possibility to understand better the correctness of the works conducted in WP 7 – WP10.

5.1.11. WP11.

Here logically the work on CI connection to system has been continued. In the given case, that means the connection to CII and CIVb for L, S and G phases. The process of 'Connection S phase CIVb-CI' is investigated during the WP7 –PW10, and 'Connection G phase CI-CIVb' during the WP8 –PW10, therefore in the issue 'Knowledge' it would be more logical to mention not only WP8, but the WP7 –WP10 as well. The novelty appears to be the beginning of the L stepwise introduction into the intersystem mass exchange due to 'Connection L phase CI-CII'. In '**Remarks'** it is said **'**Can be performed after WP8, or 9 depending if opportunity is taken to have CIVa biomass sent to CI as well', that presumes the potentiality of an alternative flows' way. However, that is not depicted in the scheme to WP11. It might be indicated by a dotted line as, for example, in the scheme to WP6. It is very important to decide the CIVa biomass fate as it is inedible on 95% by a human, and its introduction into intersystem mass exchange would be a very significant new achievement.

5.1.12. WP12.

This scenario is a logical continuation of WP11. Here in addition to the loop for L the CIII is connected, however the L outflow is not closed any longer. Therefore, this scenario is actually devoted to the estimation of this compartment work at the L introduction in it and the nitrification analysis according to the outgoing flows. The comment to the '**Remarks'** are the same as that of to WP11.

5.1.13. WP13.

To develop WP12 according to L the CIVa is added to the loop. However, the loop for the CIVa is not closed on outgoing flows. Therefore, this scenario is practically devoted to the adjustment of the CIVa work taking into consideration an incoming flow according to L. That process has been tested in WP4 but then the CI input into the flows has not been considered. In the given scenario, that aspect is taken into account, and therefore the rate characteristics and composition of the L flow incoming the CIVa is closer to the real values of the entire system's work. In the result of this scenario's work, four of five compartments (except CV) are involved in a general loop of mass exchange though it is not complete for G, S, L.

5.1.14. WP14.

Being connected in the previous scenario the CIVa is partially closed on a gas loop with the CIII taking into consideration the CI and CII influence that was missing in the prior implemented similar closure of WP3. However, that closure is not complete in view of potentiality of outcome of the part of gas flows from the CIVa and CIII (for analysis and corrections?).

5.1.15. WP15.

The novelty of the given scenario is the creation of a gas loop between the CV – CIVa and the CV – CIVb. The significance of this scenario consists, in the first place, of all compartments participation in the system's operation; in the second place, the closed gas loop is created for the abovementioned CIVa, CIVb, CV compartments taking into consideration the effect of all system compartments (in contrast to WP6 when the CI and CII were not connected). Here it is necessary once more to pay attention to possibility of the rats' microflora influence on higher plants that has been mentioned in WP5. Provided in WP5 that aspect is of a pure scientific interest and may be analyzed, then on the final stages of the system's development such as the WP15 appears to be, one should take into consideration the results of those researches of WP5 and, when it is necessary, to exclude that microflora with the help of airflows purification (?). In '**Rationale',** it has been written about 'Combination of L phase and G phase loop closure'. Strictly speaking, it is impossible to agree with that statement on the stage of this scenario implementation. One can speak only about a closed gas loop for the CIVa and CV and CIVb whereas for L even partial closure has not been achieved.

5.1.16. WP16.

The novelty of this scenario consists in the following:

1) At the expense of introduction of a 'feedback' of the CIVa – CI, the closed loop for L has been created, connecting for gas the CI-CII-CIII-CIVa. However, in the '**WP title'** it is written 'Connection L phase CI-CII-CIII-CIVa ', as in the WP13 – 15, where the complete closure are missing but only the successive connections of these compartments for L phase are present without 'feedback' of the CIVa – CI. To underline the presence of a closed loop it would be advisable to write **'**Closure L phase loop CI-CII-CIII-CIVa' in the '**WP title**';

2) The testing 'Connection L phase CIVb-CV' has been implemented to estimate the effect of this flow on the CV. Taking into consideration these new connections the operation of the prior executed (WP10) 'Connection S phase CIVb-CI, CIVa-CI'will and also earlier fulfilled (WP14) 'Connection G phase CIVa – CIII' will be tested. Taking into consideration these

remarks in 'Knowledge' instead of 'Output WP 16 (?) it would be advisable to include those abovementioned WP.

5.1.17. WP17.

This scenario is concluding the development of the compartments' connection to create the final variant of mass exchange processes of the entire system. In addition to the WP16 scenario with the closed gas loop the connection of the CIVa - CV– CIVb (like in WP15) has been added. However, unlike all previous WP the closure for gas is provided containing all system compartments. Against those connections, the 'Connection S phase CIVb-CI, CIVa-CI, CII-CI; Connection G phase CIVa – CIII' (prior evaluated in WP 14 and 16) are once again estimated and corrected. However, only WP10 and WP15 are mentioned in the issue 'Knowledge'. Most likely it would be logical also to indicate WP 14 and WP16, which data might be useful for the WP17 analysis. In the scheme related to WP17 the wording corresponding to 'Closure G phase CV-CIVb and CV-CIVa' are missing. Since CV is connected in this scenario, why is CIVb O2 production missing in 'Set-point'?

5.1.18. WP18.

Assembled on the base of the WP1 –WP17 researches' system should be put in the steady-state operation, and then to work in a stationary regime during 24 months. It has been not explained what 1 month + 9 months to reach the steady-state is meaning. Why 1+9? From the WP18 scheme it is obvious that the part of L and S flows will irreversibly withdrawn through CV from the system. Besides, (that has not been shown in the scheme) the human wastes will be introduced in the system. How will these flows be balanced? In what way will that affect the expected closure coefficients for G, S, L? Is it possible to increase the closure for S, making use of the part of the vegetative biomass for the rats feeding?

5.2. LOGIC OF WORK

The work logic accepted may be evaluated according to the consequence of the scenarios testing from the point of time and man-hour economy.

Considering that the technological breaks between the implementation of separate WP are not foreseen, and they will be realized one after it is possible to carry out the time costs of the work with different system's compartments. For that task, the time data of different MPP compartments integration in the frames of separate WP implementation is used. WP18 is not included in these calculations as in the frames of this scenario all MPP compartments should be integrated. The number of breaks in work of different compartments has also been taken into consideration. The data obtained are represented in the table.

Table. The time spent on integration of separate compartments of MPP.

Compartment	WP in the frame of which the work of a separate compartment will be performed	The number of interruptions in work in the compartment work at its	Total time costs spent on the compartment integration in	The time of continuous compartment operation at integration in

		integration to MPP	MPP, months	months
CI	7 - 17	0	78	78
CII	2;4;10-17	2	80	60
CIII	2-4;6;12-17	2	78	45
CIVa	1;3-4;6;9-10;13-17	4	84	41
CIVb	5-17	0	93	93
CV	1;4-6;15-17	2	63	63

From the given table it is seen, that the CIVb will work in a continuous long-term functioning longer than other compartments. The CIVa is the next long-duration working compartment; however, its continuous work will be about a half of total operation time. The CII occupies the third position with 75% of continuous operation time. On the fourth place according to this parameter the CI and the CIII can be placed, though the CI is working all operation time in a continuous regime whereas the CIII only 58% of total time. The CV is situated on the last place with its part of continuous work about 50% of total time.
The data analysis of this table may be useful when considering the important role in efficiency of the scenarios realization in terms of time and man-hour during integration of every system compartment. Let us analyze these data on two examples. The CIVb may be mentioned in this regard. This compartment with higher plants appears to be one of the most labour-consuming and responsive to a set-up and demands much time for its imbedding in an operation for testing. It would be logical to accept the succession of the scenarios launching when the operation of the CIVb will actually not be interrupted starting from WP5. Thus according to the table data the CIVb will longer other compartments be operated in a continuous regime from scenario to a scenario that is quite justified. The CV may be taken as another example. The analysis has shown the least time costs for this compartment. That also can be justified, as the interruption in its work and its launching in operation are not labour-consuming and do not demand long time for a set-up. Besides one can suppose that the double interruption of this compartment functioning also will cause difficulties as this compartment technically is not complex and relatively fast goes out in a working regime. From the examples given one can conclude that, on the whole, the consecutive sequence of the scenarios realization, their duration and the continuity level of the compartments functioning has been chosen quite logical.

5.3. SOME DETAILED STEPS FOR PROGRESSION.

In the final scenarios description it would be better not to only indicate the experimentally simulated S, L, G flows when the compartments are not in operation but to give a determination what is entering them on different stages of the scenarios development. At the compartments' launching, the gas flows will enter the CIVb from outside for a long time. For example, the plants productivity will strongly depend on O2 concentration that will affect the rates and values of connected to it the L and S flows via which the manipulation is being carried out until gas closure. What source of CO2 inflow will be used in the CIVb: from atmosphere? From cylinders? How will its concentration be chosen? It is necessary to coordinate its inputs into the system from outside (for example, the human exometabolites) and outputs from the system (animal solid wastes, etc.), to determine the closure levels for S, L, G, expected for the system.

5.3.1. PROCESSES.

In the scenarios, the possibility of direct gas circulation between the CIVa and the CIVb has not been foreseen. Is it possible to reserve that potentiality for more flexible regulation of O2 and CO2 in the system? It would be necessary to foresee the control of possible gas pollutants of construction materials. It would be advisable to include that aspect in the final scenarios description.

5.3.2. TECHNOLOGIES.

It has not been marked whether there will be differences in processing technologies of edible and inedible biomass of higher plants and their inclusion in matter turnover. That is connected to the question whether the consumption by a virtual human of a vegetative edible biomass will be simulated in the system; and how it will be considered in the matter turnover process. Do the CII technologies not include a gas phase?

5.3.3. QUALITATIVE ASPECTS OF DEVELOPMENT OF CLOSURE PROCESSES FOR G, L, S.

It is a pity it is impossible to give the quantitative estimation of dynamic changes of closure coefficients for the parameters investigated as the flow rates and their interaction character is not given. However, one can qualitatively examine how the closure processes for G, L, S are formed in the process of the system development. The construction of mass exchange starts from the formation of G, L, S flows in WP1. However, until WP5 the compartments inclusion in mass exchange processes has episodic character and the compartments are periodically connected and disconnected. Starting from WP5 the CIVb is constantly present in mass exchange processes. Starting from WP7 the construction of closure loops for S (WP7,9,10,16), G (WP8,14,15), L (WP11,12,13,16,17) is carried out. Firstly, the closure for S is planned to be implemented, then for G and at the end of the entire system development- for L. The process of gas closure may increase (until WP15), then lessen and again increase to the end of the system development; that does not result in technical difficulties and is carried out to solve some technological tasks. At the same time the closure for S, which is planned to be implemented in the frames of WP10, remain fixed. That may be logically justified in case the manipulation with its closedness is connected to significant technical inconveniences. The longest in terms of time appears to be the fulfillment of the closure for L, which is supposed to be finished to the end of the system development (WP17).

5.4. CONCLUSION

The given analysis has shown that the scenario variants suggested allow the development of different compartments in detail for their further integration in MPP. The time scheduled for this work seems to be sufficient to thoroughly estimate the compartments operation and to make necessary corrections at their inclusion in mass exchange processes. The first 12 months of WP18 are the reserve time for the system adjustment for a stationary regime. The rest 24

months meant for the demonstration of the MPP operation will allow exhaustive estimation of the stability of the system operation.
It is clear that during the preparation works unforeseen consequence are possible demanding to produce necessary changes that is quite admissible under implementation of this great and complex task.
The fulfillment of the work program designated will give high-grade scientific and practical material on the construction principles of matter turnover processes in LSS. The data obtained will be a unique technological basis for creation of advanced for planetary bases beyond Biosphere and for practical terrestrial applications (out-of-the-way regions-mountains, deserts, Artic Zone, Antarctica, etc.).

6. Recommendations of C. Guizard

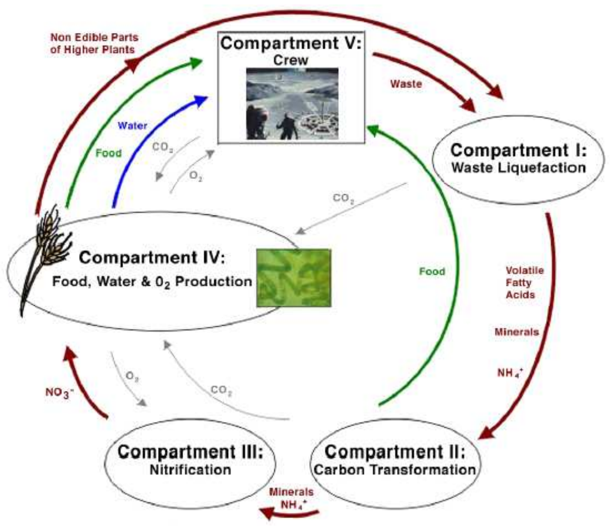
As the MPP Integration Strategy is less advanced on gas phase than on liquid phase, recommendations were oriented on how to reach a well defined gas phase management strategy.

Christian Guizard

Gas (and vapor) management in the MELiSSA advanced loop concept

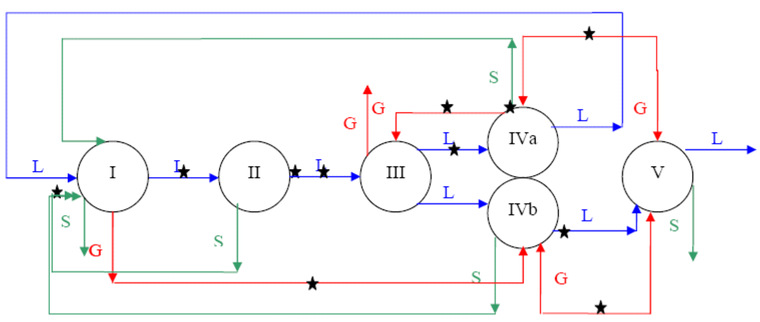
Hurdles and Challenges

The MELiSSA advanced loop concept



16/07/2008 Christian Guizard 2

Main objective: implementation of a fully connected gas distribution network



⇨ **methodology**

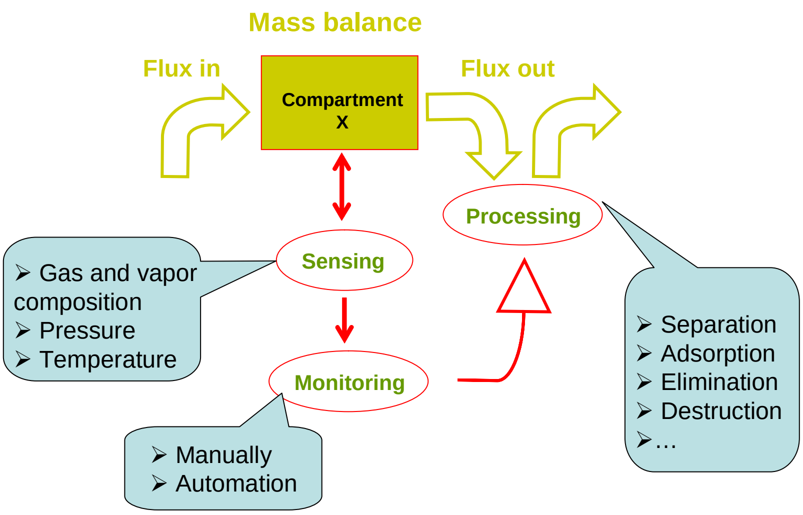
16/07/2008 Christian Guizard 1

Basic data to be collected on gas and vapors implemented in the MELiSSA loop

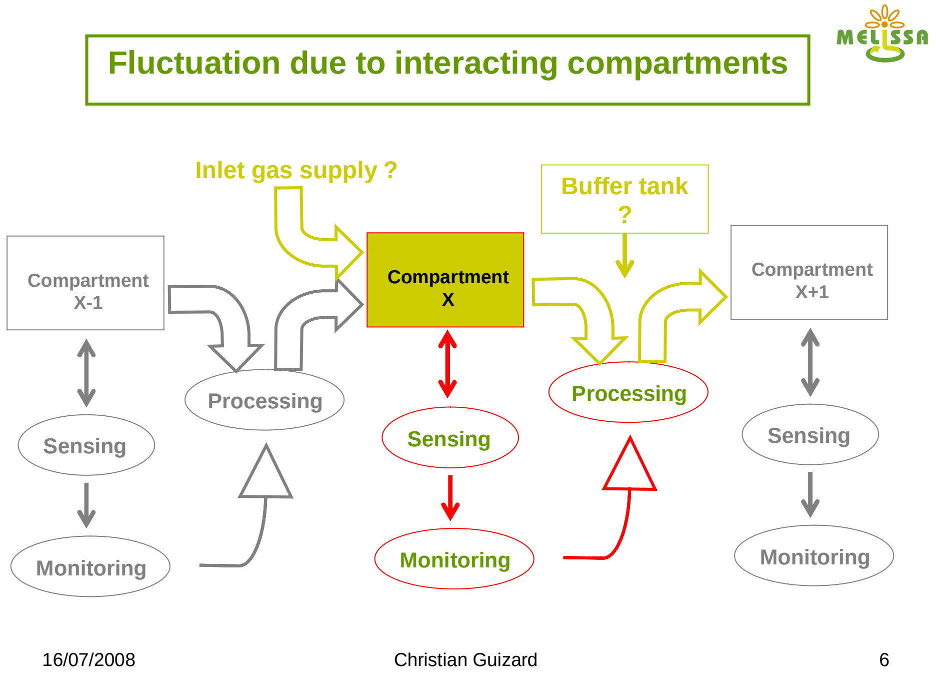
- Produced and consumed gases and vapors
  - O_2
  - CO_2
  - H_2O (vapor)
  - VOC
  - …
- Supplied gases
  - N_2
  - He
  - …
- Gas and vapor composition in each compartment
  - Upper and lower limits
  - Partial pressure, temperature, RH
  - …

16/07/2008 Christian Guizard 4

Basic steps for gas management in a compartment



16/07/2008 Christian Guizard 5


Fluctuation due to interacting compartments
Inlet gas supply ?
Buffer tank ?
Compartment X-1
Compartment X
Compartment X+1
Processing
Processing
Sensing
Sensing
Sensing
Monitoring
Monitoring
Monitoring
16/07/2008
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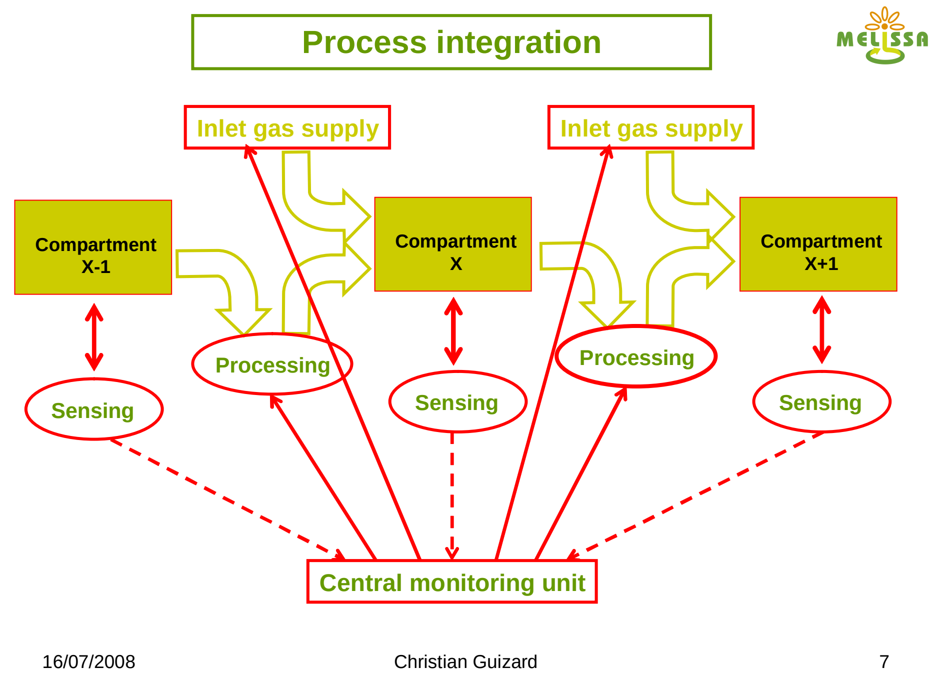
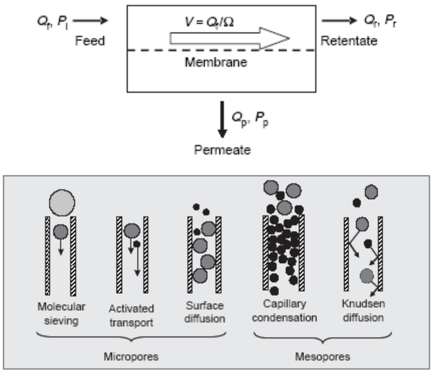
6

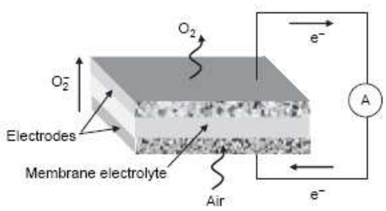

Process integration
Inlet gas supply
Inlet gas supply
Compartment X-1
Compartment X
Compartment X+1
Processing
Processing
Sensing
Sensing
Sensing
Central monitoring unit
16/07/2008
Christian Guizard
7

Gas and vapor separation

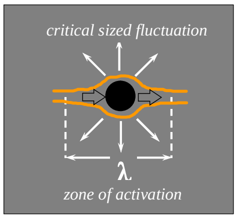
- Porous membrane separation



- Electro-pumping



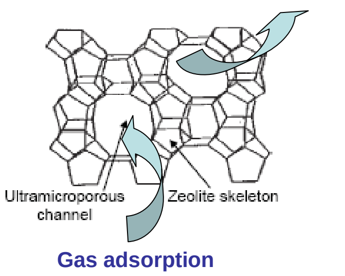
- Solution diffusion



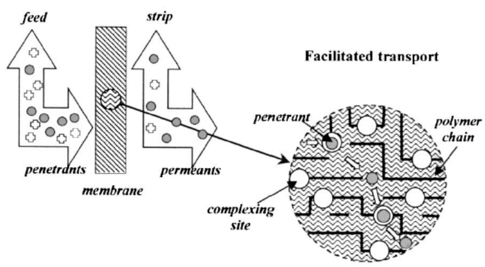
16/07/2008 Christian Guizard 8

Adsorption/Complexation

- Pressure swing adsorption

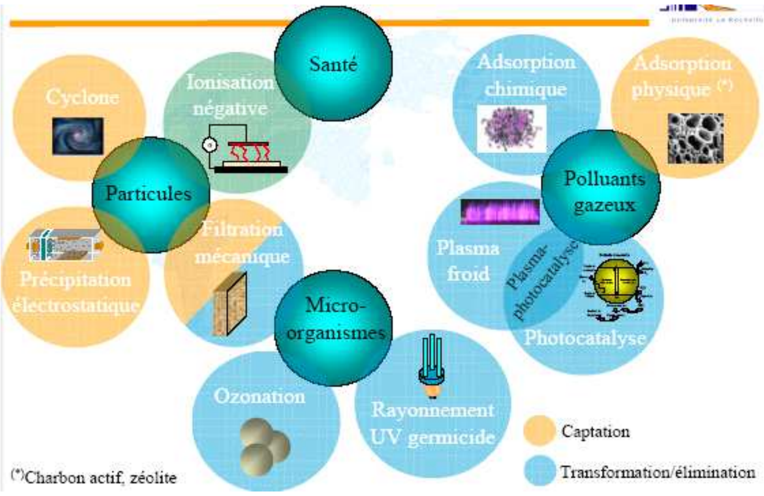


- Facilitated transport using selective complexants



16/07/2008 Christian Guizard 9

Pollutants elimination in the gas phase



16/07/2008 Christian Guizard 10

7. Conclusion and perspectives

The output of this consultancy study has been very valuable to the MELiSSA project, mainly for the liquid and gas loops of the system.

The recommendations provided by the experts will be the basis of the continuation of the work in the MELiSSA Pilot Plant in order to update the integration strategy and start defining the first work packages to be implemented on the MPP compartments and their interfaces.

Appendix 1 – Draft version of the MPP integration strategy

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08193 Bellaterra Spain

DRAFT version

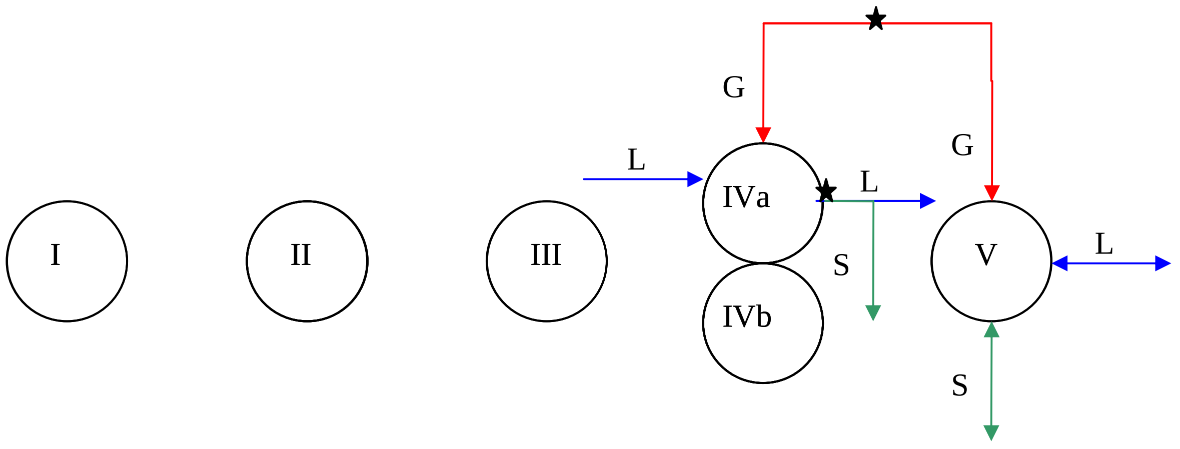
MELiSSA Pilot Plant

Integration Workpackages

Version: 2.0
Prepared: 04/07/2008

WP number	1.	WP title	Closure G phase CIVa - CV	
duration	4 months			
inputs	Hardware	CIVa refurbished and validated CV delivered and validated Ar. Platensis harvesting system Interface G phase CV-CIVa(CV G phase purification?)		X X TBD TBD
	Software	Control laws implemented in MPP PLCs Cpts connected to the MPP supervision system, level 2 control preliminary architecture		TBD TBD
	Knowledge	Control law CIVa (C) Kla CIVa Control law O_2/CO_2 Sizing validation		X TBD X X
content	Constraint	animal		
	Manipulable inputs	CIVa light, CIVa dilution rate, pH CIVa		
	Set-point	concentrations in O_2 and CO_2 in CV gas phase		
	Culture conditions	Ar.Platensis culture on nitrate		
	Follow-up	O_2, CO_2, CV gas phase composition, CIVa liquid phase composition (SO4, PO4, C, N)		
	Quality control	axeny CIVa and CV		
	Duration	1 month preparation + 1 month continuous operation +2 month additional study		
Objectives/ outputs	1-Demonstration of Biorat O_2/CO_2 control law (with pH control and no equilibrium of respiratory coefficient) 2-Validation of AP harvesting system 3- management of contaminants of CV gas phase			
Rationale	Demonstration of the O2/CO2 control law on new hardware Communication impact Good training for the new MPP team			
Remarks	Purification of CV G phase to be foreseen, thermal control as well			

NOTA : the highlighting in yellow identifies the points to be confirmed/discussed with the experts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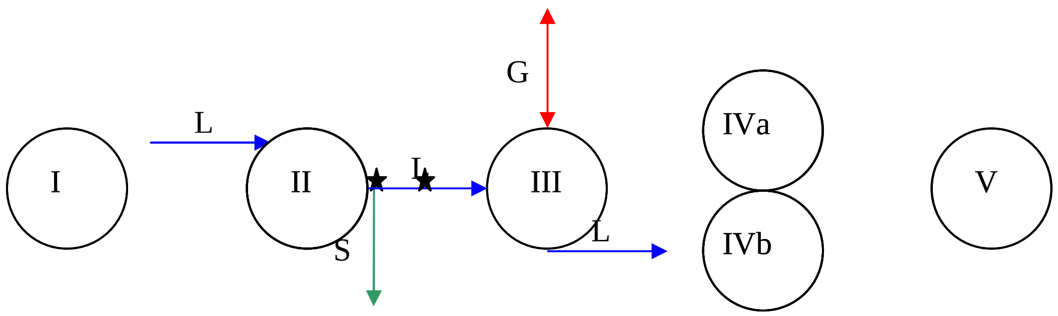
WP number	2.	WP title	Connection L phase CII-CIII	
duration	7 months			
inputs	Hardware	CIII validated , operational steady state CII validated Rubrum harvesting system Additional interface to remove potential residual VFA in CII output		X X X TBD
	Software	Control laws implemented in MPP PLCs Cpts connected to the MPP supervision system, level 2 control preliminary architecture		TBD TBD
	Knowledge	Part a: control law CIII (N), Kla CIII Part b: Control law CIII(N), Kla CIII, control law CII (C, N)		TBD TBD
Content Part a	Constraint	CII dilution rate and CII light		
	Manipulable inputs	CIII dilution rate (hydraulic residence time CII), O2 input (TBC)		
	Set-point	NO2 and NO3 concentrations CIII		
	Culture conditions	Segers&Verstraete CII		
	Follow-up	pH CIII, pO2 CIII, NH4+, NO2, NO3 CIII, VFA, NH4+ CII liquid phase, SO4, PO4 CII and CIII		
	Quality control	axeny		
	Duration	1 month preparation + 3 months continuous operation		
Content Part b	Constraint	C sources (VFA composition and concentration) CII liquid input		
	Manipulable inputs	CII light, CII dilution rate, CIII dilution rate (hydraulic residence time in CII), O2 input (TBC)		
	Set-point	NH4 and VFA concentrations CII, NO2 and NO3 concentrations CIII		
	Culture conditions	Segers&Verstraete modified (various VFA sources) CII		
	Follow-up	CII: VFA, NH4+ , SO4, PO4 CIII: pH, pO2 , NH4+, NO2, NO3, SO4, PO4		
	Quality control	axeny		
	Duration	3 months continuous operation		
Objectives/ outputs	Control law validated: CIII(N) , CII (C, N)			

Rationale	After CIVa, CIII is the most advanced (know-how, knowledge). 1st step in the closure of the liquid phase.
Remarks	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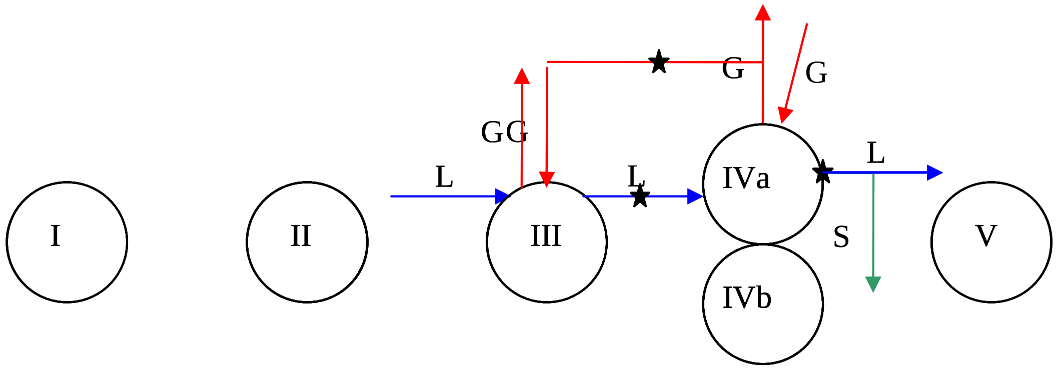
WP number	3.	WP title	Connection L phase CIII-CIVa Connection G phase CIVa-CIII	
duration	3 months			
inputs	Hardware	CIII validated, operational steady state CIVa refurbished, validated Interface L phase CIII-CIVa Interface G phase CIVa – CIII Spiru harvest. system		X X X TBD TBD
	Software	Control laws implemented in MPP PLCs Cpts connected to the MPP supervision system, level 2 control preliminary architecture		TBD
	Knowledge	Preferably performed after WP 2.a, however feasible if control law CIII, Kla CIII, control law CIVa (including O2/CO2 dynamic equilibrium in the produced gas phase jointly with pH control) and Kla CIVa known and validated		TBD
content	Constraint	CIII dilution rate		
	Manipulable inputs	CIVa light, CO2 addition CIVa		
	Set-point	CIVa O2 production, CIII [NO3 or NO2 , depending on control law design] output		
	Culture conditions	Winogradsky CIII		
	Follow-up	CIII: pH, pO2, NH4+, NO2, NO3, SO4, PO4, O2 CO2 gas phase CIVa: pO2, NO3, SO4, PO4		
	Quality control	axeny		
	Duration	1 month preparation + 2 months continuous operation.		
Objectives/ outputs	Control laws validated: CIII-N+ dynamic gas phase C,O and CIVa-C,N +gas/liquid dynamic			
Rationale	Continuation of the study of the liquid phase closure Opportunity to initiate additional study of gas phase closure			
Remarks	Equilibrium G-L phases CIII – CIVa to be studied Validation of O2 toxicity in case of excess from CIVa to CIII			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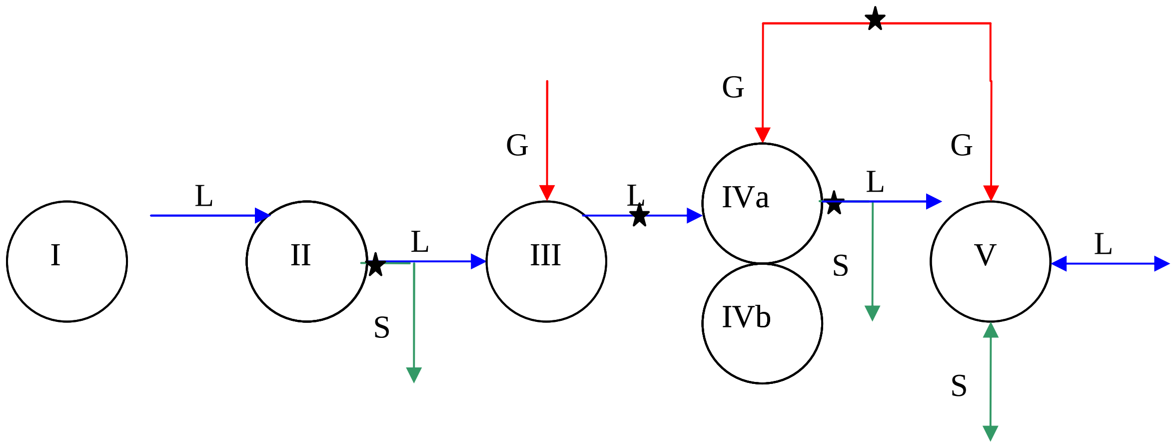
WP number	4.	WP title	Closure G phase CIVa-CV Connection L phase CII-CIII-CIVa	
duration	13 months			
inputs	Hardware	CII validated CIII validated, operational steady state CIVa refurbished, validated CV validated Interface L phase CIII-CIVa Interface G phase CV-CIVa Spiru Harvest. System Rubrum harvest. system		X X X X TBD TBD X
	Software	Control laws implemented in MPP PLCs Cpts connected to the MPP supervision system, level 2 control preliminary architecture		TBD
	Knowledge	Output of WP1+WP2+WP3		
content	Constraint	animal		
	Manipulable inputs	dilution rate, light, CII, dilution rate CIII (hydraulic residence time CII), CIVa light		
	Set-point	O2/CO2 CV		
	Culture conditions	Segers&Verstraete CII		
	Follow-up	CII: NH4+, VFA, SO4, PO4 CIII: pH , pO2 , NH4+, NO2, NO3 , SO4, PO4 CIVa: pO2, NO3, SO4, PO4 , O2, CO2 CV: O2, CO2, contaminants gas phase		
	Quality control	axeny (CIII,CIVa), CV		
	Duration	2 month preparation + 12 months continuous operation/study. (Validation of two control 1 loops (CIII –N and CIVa-C+N) on CIII synthetic media→ 6 months Determination of limit behaviors → 6 months)		
Objectives/ outputs	Control loops validated: CIII(N) and CIVa (C+N)			
Rationale	Logic step after WP1, 2 and 3, progressive closure of the liquid loop, including the dynamic brought by the animals on the gas phase Validation of the results obtained in the past, on new generation hardware			
Remarks	Performance with or without Spiru harvesting This scenario for L phase connection has been performed in the past however with “manually “connected compartments FIRST MILESTONE for L phase connection demonstration			

NOTA : the highlighting in yellow identifies the points to be confirmed/discussed with the experts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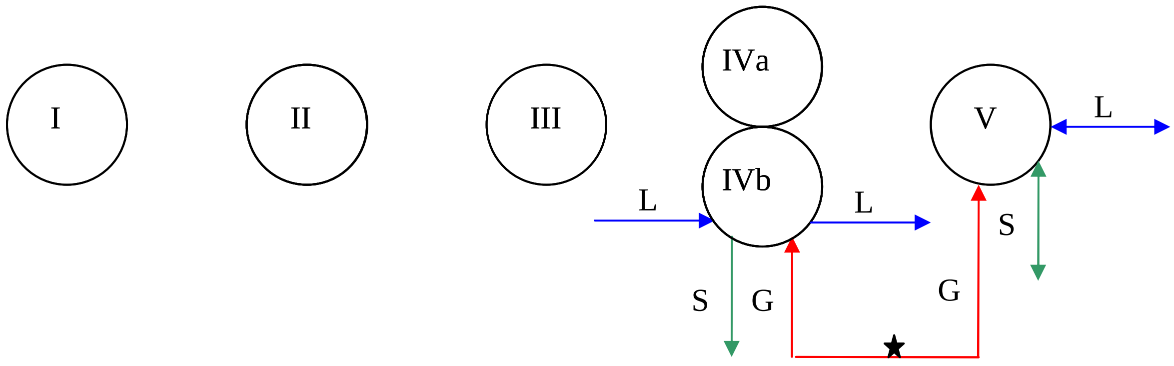
WP number	5.	WP title	Closure G phase CIVb-CV
duration	5 months		

inputs	Hardware	CIVb validated, operational steady state CV validated Interface G phase CIVb-CV	X X TBD
	Software	Control laws implemented in MPP PLCs Cpts connected to the MPP supervision system, level 2 control preliminary architecture	X
	Knowledge	Control law CIVb Preliminary sizing validation (O2 production)	TBD

content	Constraint	animal
	Manipulable inputs	CIVb light, composition and residence time of CIVb liquid phase , CIVb light
	Set-point	concentrations in O_2 and CO_2 in CV gas phase
	Culture conditions	Hoagland for CIVb
	Follow-up	CIVb gas phase composition (including hormones if possible) , O_2, CO_2, CV gas phase composition, CIVb liquid phase composition (TBD)
	Quality control	CV microbiological control CIVb (HPC surfaces, liquid phase, roots),
	Duration	1 month preparation + 4 month study
Objectives/ outputs	Validated control law CIVb (light, gas phase, NH4+/NO3 ratio)	
Rationale	Need to progress on CIVb knowledge and know-how	
Remarks	Necessity of preliminary calculations for gas phase management between the compartments	

NOTA : the highlighting in yellow identifies the points to be confirmed/discussed with the experts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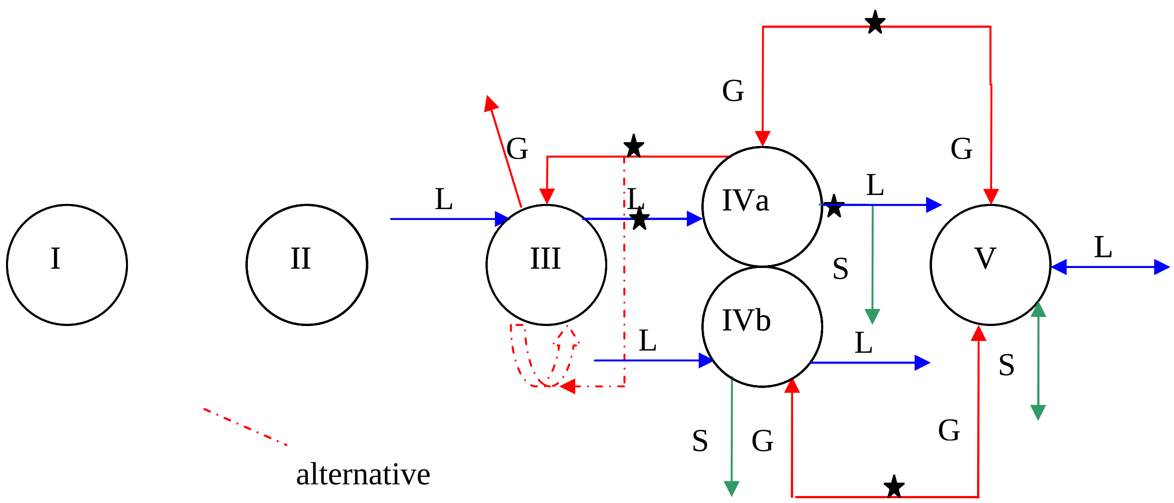
WP number	6.	WP title	Connection L phase CIII-CIVa Connections G phase CIVa-CIII Closure G phase CIVa-CV	
duration	10 months			
inputs	Hardware	CIII validated, operational steady state CIVa refurbished, validated CIVb validated, operational steady state CV validated Interface G phase CIVb-CV Interface G phase CIVa-CV Interface L phase CIII-CIVa Interface G phase CIVa – CIII Spiru harvest. system		X
	Software	Control laws implemented in MPP PLCs Cpts connected to the MPP supervision system, level 2 control preliminary architecture		X
	Knowledge	Output of WP1+WP3+WP5 Preliminary sizing validation (O2, CO2)		
content	Constraint	animal		
	Manipulable inputs	CIII dilution rate, O2 in CIII CIVb liquid phase composition and residence time CIVa light, CIVb light pH CIVa		
	Set-point	concentrations in O_2 and CO_2 in CV gas phase		
	Culture conditions	Winogradsky CIII Hoagland CIVb		
	Follow-up	CIII: pH, pO2 , NH4+, NO2, NO3, SO4, PO4,O2 CO2 gas phase CIII CIVa: liquid phase composition (SO4, PO4, C, N), pO2, NO3, SO4, PO4 CIVb: CIVb gas phase composition (including hormones if possible) CV: O_2, CO_2, CV gas phase O_2, CO_2, CV gas phase composition, CIVb liquid phase composition (TBD)		
	Quality control	Axeny: CII, CIII, CIVa CV microbiological control CIVb (HPC surfaces, liquid phase, roots),		
	Duration	1 month preparation and then 6 months 3 months		
Objectives/	1-Validation of two control 1 loops (CIII –N and CIVa- C+N) on CIII			

outputs	synthetic media 2- Determination of limit behaviors Gaining expertise on process operation, especially on gas phase management
Rationale	Continuation of the study on gas loop closure
Remarks	To avoid loosing O2 in CIII output gas phase, recirculation of CIII gas phase could be foreseen Necessity of preliminary calculations for gas phase management between the compartments FIRST MILESTONE For gas loop closure demonstration

NOTA : the highlighting in yellow identifies the points to be confirmed/discussed with the experts



<table>
<tr><td>WP number</td><td>7.</td><td rowspan="2">WP title</td><td colspan="3" rowspan="2">Connection S phase CIVb-CI</td></tr>
<tr><td>duration</td><td>7 months</td></tr>
<tr><td rowspan="3">inputs</td><td>Hardware</td><td colspan="3">CI fully characterized
CIVb validated, operational steady state
Interface S phase CIVb-CI</td><td>X
X

TBD</td></tr>
<tr><td>Software</td><td colspan="3">Control laws implemented in MPP PLCs
Cpts connected to the MPP supervision system, level 2 control preliminary architecture</td><td>TBD</td></tr>
<tr><td>Knowledge</td><td colspan="3">Control 1 loop CI (C+N)
Control law CIVb or output WP5</td><td>TBD</td></tr>
<tr><td rowspan="7">content</td><td colspan="2">Constraint</td><td colspan="3">Plants metabolism/composition</td></tr>
<tr><td colspan="2">Manipulable inputs</td><td colspan="3">CI residence time
CIVb light
CIVb liquid solution composition and residence time</td></tr>
<tr><td colspan="2">Set-point</td><td colspan="3">CI [VFA] L output</td></tr>
<tr><td colspan="2">Culture conditions</td><td colspan="3">Hoagland CIVb</td></tr>
<tr><td colspan="2">Follow-up</td><td colspan="3">CI: L input composition, L output composition, G composition
CIVb: composition of plants, G phase composition</td></tr>
<tr><td colspan="2">Quality control</td><td colspan="3">microbiological control CIVb (HPC surfaces, liquid phase, roots),</td></tr>
<tr><td colspan="2">Duration</td><td colspan="3">1 month + 6 months study</td></tr>
<tr><td>Objectives/ outputs</td><td colspan="5">Knowledge on CI outputs
Further validation of CI control 1 loop</td></tr>
<tr><td>Rationale</td><td colspan="5">Initiate study of solid phase in MELiSSA with MELiSSA crops cultivated in controlled conditions</td></tr>
<tr><td>Remarks</td><td colspan="5">Depending on the availability of HPCs (1, 2 or 3), the amount of plants might be different</td></tr>
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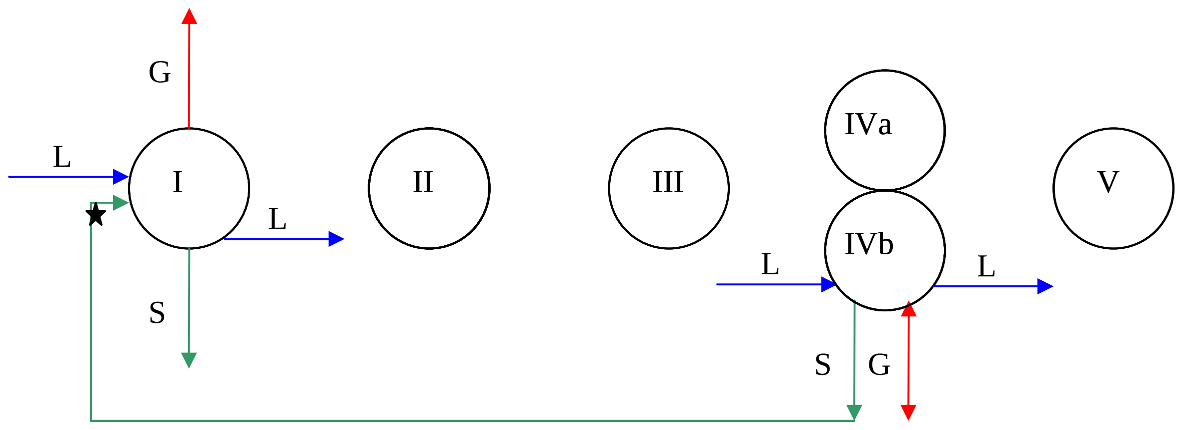
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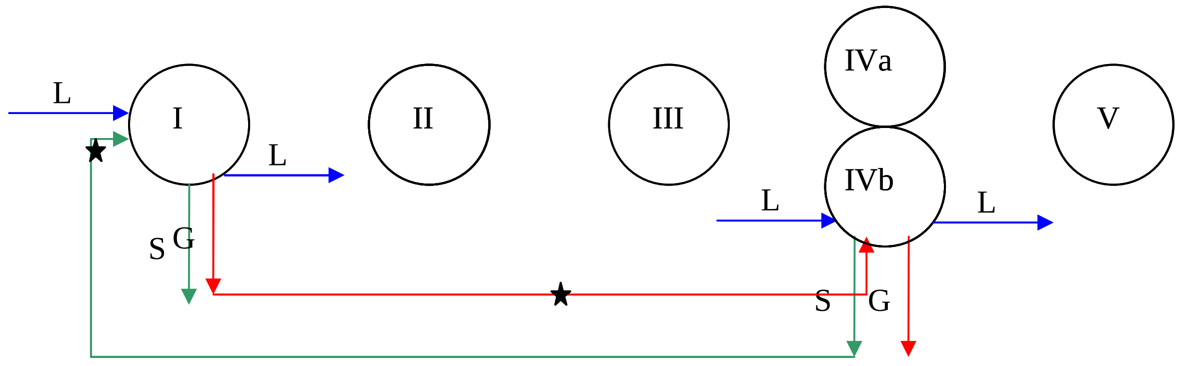
WP number	8.	WP title	Connection S phase CIVb-CI Connection G phase CI-CIVb	
duration	7 months			
inputs	Hardware	CI fully characterized CIVb validated, operational steady state Interface S phase CIVb-CI Interface G phase CIVb-CI		X X TBD TBD
	Software	Control laws implemented in MPP PLCs Cpts connected to the MPP supervision system, level 2 control preliminary architecture		TBD
	Knowledge	Output WP 7 Preliminary sizing validation on gas phase and solid phase		TBD
content	Constraint	Plants metabolism/composition		
	Manipulable inputs	CI residence time CIVb light CIVb liquid solution composition and residence time		
	Set-point	CI [VFA] L output		
	Culture conditions	Hoagland CIVb		
	Follow-up	CI: L input composition, L output composition, G composition CIVb: composition of plants, G phase composition		
	Quality control	microbiological control CIVb (HPC surfaces, liquid phase, roots),		
	Duration	1 month + 6 months study		
Objectives/ outputs	Knowledge on CI outputs Further validation of CI control 1 loop New step in the study of gas phase and solid phase			
Rationale	Logic continuation of WP 7 to gain knowledge and know-how on gas phase management			
Remarks	Depending on the availability of HPCs (1, 2 or 3), the amount of plants might be different SECOND Milestone for G loop closure demonstration			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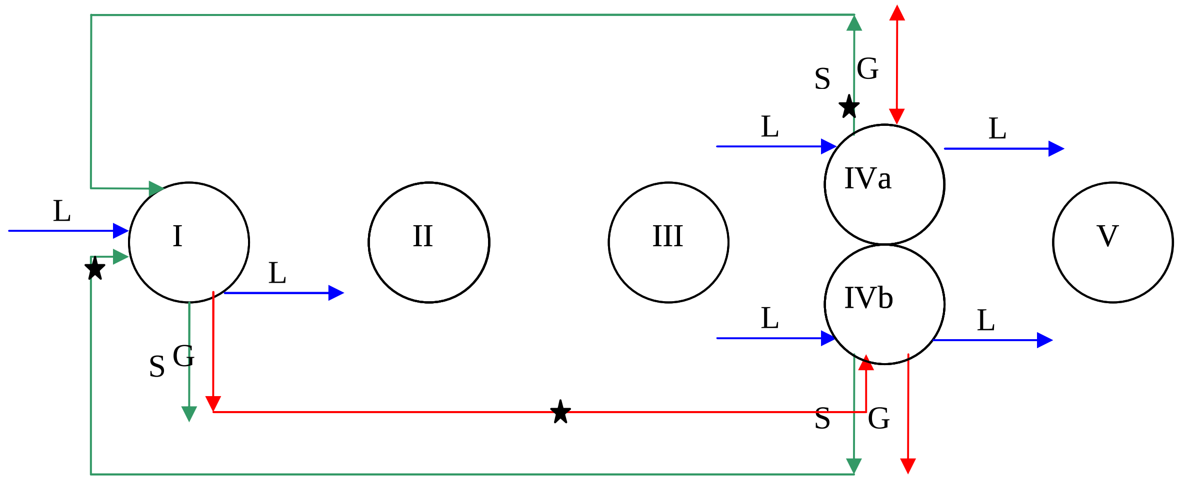
WP number	9.	WP title	Connection S phase CIVb-CI and CIVa – CI Connection G phase CI-CIVb	
duration	4 months			
inputs	Hardware	CI fully characterized CIVb validated, operational steady state CIVa in operational steady state Interface S phase CIVb-CI Interface G phase CIVb-CI Spiru. Harvesting system		X X TBD TBD
	Software	Control laws implemented in MPP PLCs Cpts connected to the MPP supervision system, level 2 control preliminary architecture		TBD
	Knowledge	Output WP 8 Preliminary sizing validation on Solid phase		TBD
content	Constraint	Plants and algae metabolism/composition		
	Manipulable inputs	CI residence time CIVa light and dilution rate, pH CIVb light		
	Set-point	CI [VFA] L output		
	Culture conditions	Zarrouk for CIVa Hoagland CIVb		
	Follow-up	CI: L input composition, L output composition, G composition CIVa :liquid phase composition, biomass composition CIVb: composition of plants, G phase composition		
	Quality control	microbiological control CIVb (HPC surfaces, liquid phase, roots), axeny CIVa		
	Duration	1 month + 3 months study		
Objectives/ outputs	Knowledge on CI outputs Further validation of CI control 1 loop New step in the study of gas phase and solid phase (composition of the gas phase versus waste composition)			
Rationale	Logic continuation of WP 8 to gain knowledge and know-how on CI			
Remarks	Depending on the availability of HPCs (1, 2 or 3), the amount of plants might be different It is mandatory to make some preliminary sizing validation to define the quantities of plants/ algae to be used			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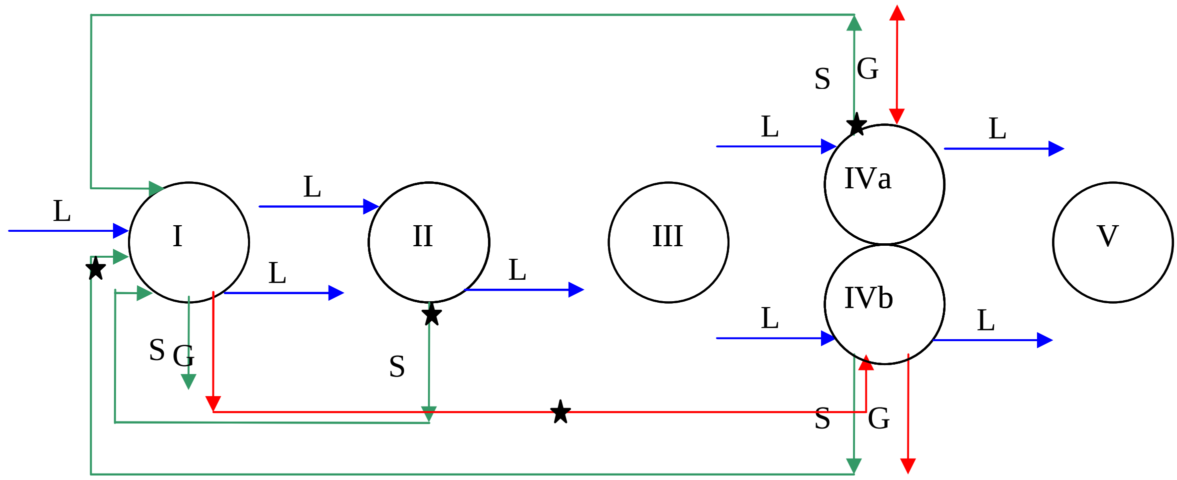
WP number	10.	WP title	Connection S phase CIVb-CI, CIVa – CI and CII-CI Connection G phase CI-CIVb	
duration	6 months			
inputs	Hardware	CI fully characterized CII in operational steady state CIVb validated, operational steady state CIVa in operational steady state Interface S phase CIVb-CI Interface G phase CIVb-CI Spiru. Harvesting system R. Rubrum harvesting system		X X TBD TBD
	Software	Control laws implemented in MPP PLCs Cpts connected to the MPP supervision system, level 2 control preliminary architecture		TBD
	Knowledge	Output WP 9 Preliminary sizing validation on Solid phase		TBD
content	Constraint	Plants and algae metabolism/composition		
	Manipulable inputs	CI residence time CII dilution rate and light CIVa light and dilution rate, pH CIVb light, composition and residence time of liquid solution		
	Set-point	CI [VFA] L output		
	Culture conditions	Segers and Verstraete CII Zarrouk for CIVa Hoagland CIVb		
	Follow-up	CI: L input composition, L output composition, G composition, S composition CII : liquid phase composition, biomass composition CIVa: liquid phase composition, biomass composition CIVb: composition of plants, G phase composition		
	Quality control	microbiological control CIVb (HPC surfaces, liquid phase, roots), axeny CII and CIVa		
	Duration	1 month + 5 months study (TBC, why 5 here and 3 in WP9)		
Objectives/ outputs	Knowledge on CI outputs Further validation of CI control 1 loop New step in the study of gas phase and solid phase (composition of the gas phase versus waste composition)			
Rationale	Logic continuation of WP 9 to gain knowledge and know-how on CI			
Remarks	Depending on the availability of HPCs (1, 2 or 3), the amount of plants might be different It is mandatory to make some preliminary sizing validation to define the			

	quantities of plants/ algae to be used and to validate that CI can reach a steady state MILESTONE on Solid loop closure demonstration



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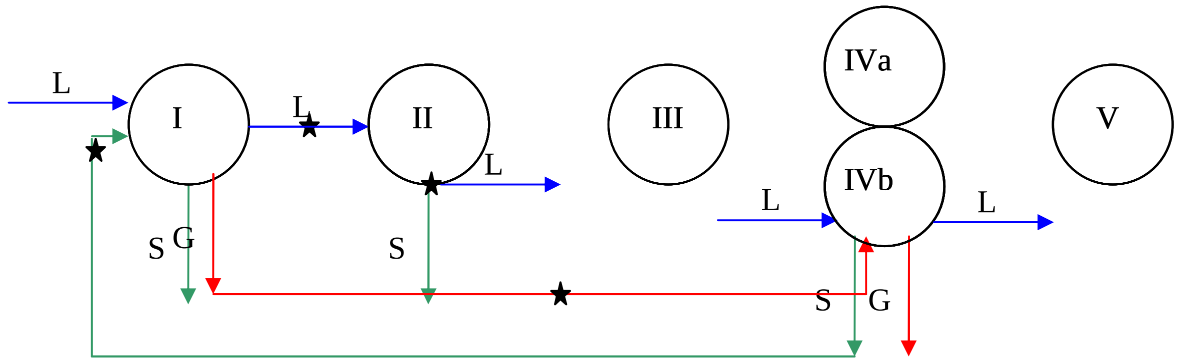
WP number	11.	WP title	Connection L phase CI-CII Connection S phase CIVb-CI Connection G phase CI-CIVb	
duration	9 months			
inputs	Hardware	CI fully characterized CII operational steady state CIVb validated, operational steady state Interface L phase CI-CII (if any) Interface S phase CIVb-CI Interface G phase CIVb-CI R.Rubrum harvesting system		X X TBD TBD
	Software	Control laws implemented in MPP PLCs Cpts connected to the MPP supervision system, level 2 control preliminary architecture		TBD
	Knowledge	Output WP 8 Control law CII Full characterization of CI and CI L output Preliminary sizing validation on gas phase and solid phase		TBD
content	Constraint	Plants metabolism/composition CII liquid input composition		
	Manipulable inputs	CI residence time (as a consequence CII dilution rate) CII light (and agitation?) CIVb liquid solution composition and residence time, CIVb light		
	Set-point	CI : total VFA concentration L output (however difficult to have on-line)or CII biomass production?		
	Culture conditions	Hoagland CIVb		
	Follow-up	CI: L input composition, L output composition, G composition CII: L output composition (including VFA), biomass composition CIVb: composition of plants, G phase composition		
	Quality control	microbiological control CIVb (HPC surfaces, liquid phase, roots), CII axeny		
	Duration	1 to 2 months + 7 months study		
Objectives/ outputs	1- Add. validation of Control 1 loop CII(C+N)→ 1 month 2- Determination of CII limit behaviors→ 6 month New step in the study of L phase connection Further validation of CII control law			
Rationale	Necessity to progress on study of the liquid loop closure (the last step is the connection from CI L phase to the rest of the Cpts)			
Remarks	Depending on the availability of HPCs (1, 2 or 3), the amount of plants might be different			

	Can be performed with or without R. Rubrum harvesting system Can be performed after WP8, or 9 depending if opportunity is taken to have CIVa biomass sent to CI as well.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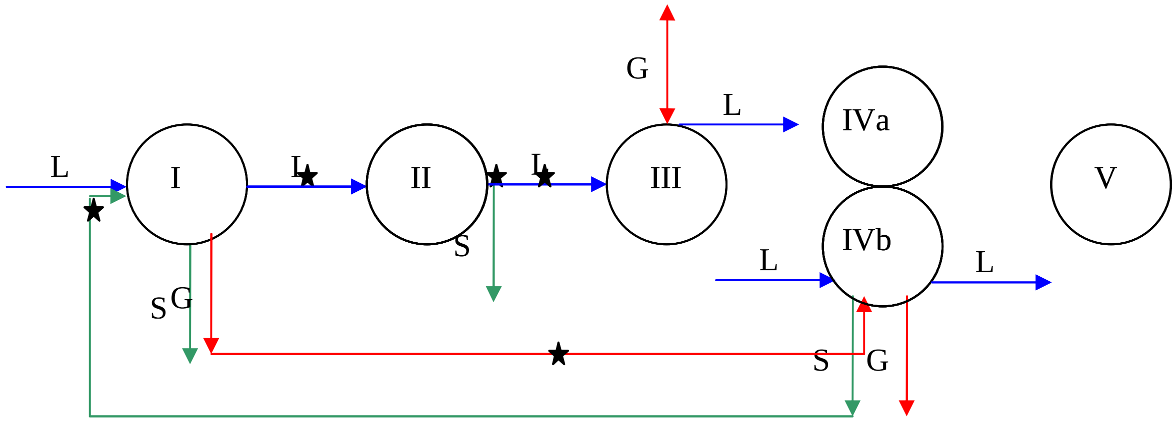
WP number	12.	WP title	Connection L phase CI-CII-CIII Connection S phase CIVb-CI Connection G phase CI-CIVb	
duration	4 months			
inputs	Hardware	CI fully characterized CII operational steady state CIII operational steady state CIVb validated, operational steady state Interface L phase CI-CII (if any) Interface S phase CIVb-CI Interface G phase CIVb-CI R.Rubrum harvesting system		X X TBD TBD
	Software	Control laws implemented in MPP PLCs Cpts connected to the MPP supervision system, level 2 control preliminary architecture		TBD
	Knowledge	Output WP 11 and WP2 Full characterization of CI and CI L output		
content	Constraint	Plants metabolism/composition CII liquid input composition		
	Manipulable inputs	CI residence time (as a consequence CII and CIII dilution rate) CII light (and agitation?) CIII : O2 input (TBC) CIVb liquid solution composition and residence time, CIVb light		
	Set-point	CIII [NO3] output		
	Culture conditions	Hoagland CIVb		
	Follow-up	CI: L input composition, L output composition, G composition CII: L output composition (including VFA, NH4+ , SO4, PO4), biomass composition CIII: pH, pO2 , NH4+, NO2, NO3, SO4, PO4 CIVb: composition of plants, G phase composition		
	Quality control	microbiological control CIVb (HPC surfaces, liquid phase, roots), CII and CIII axeny		
	Duration	1 month + 3 months study		
Objectives/ outputs	1- Add. validation of Control 1 loop CII(C+N)→ 1 month 2- Determination of CII limit behaviors→ 6 month New step in the study of L phase connection Further validation of CII and CIII control law			
Rationale	Necessity to progress on study of the liquid loop closure (the last step is the connection from CI L phase to the rest of the Cpts)			
Remarks	Depending on the availability of HPCs (1, 2 or 3), the amount of plants might be different			

	Can be performed with or without R. Rubrum harvesting system Can be performed after WP8, or 9 depending if opportunity is taken to have CIVa biomass sent to CI as well.



<table>
<tr><td>WP number</td><td>13.</td><td rowspan="2">WP title</td><td colspan="2" rowspan="2">Connection L phase CI-CII-CIII-CIVa
Connection S phase CIVb-CI
Connection G phase CI-CIVb</td></tr>
<tr><td>duration</td><td>4 months</td></tr>
<tr><td rowspan="3">inputs</td><td>Hardware</td><td colspan="2">CI fully characterized
CII operational steady state
CIII operational steady state
CIVa operational steady state
CIVb validated, operational steady state
Interface L phase CI-CII (if any), CII-CIII (if any), CIII-CIVa (if any)
Interface S phase CIVb-CI
Interface G phase CIVb-CI
R.Rubrum harvesting system
Spiru. Harvesting system</td><td>X
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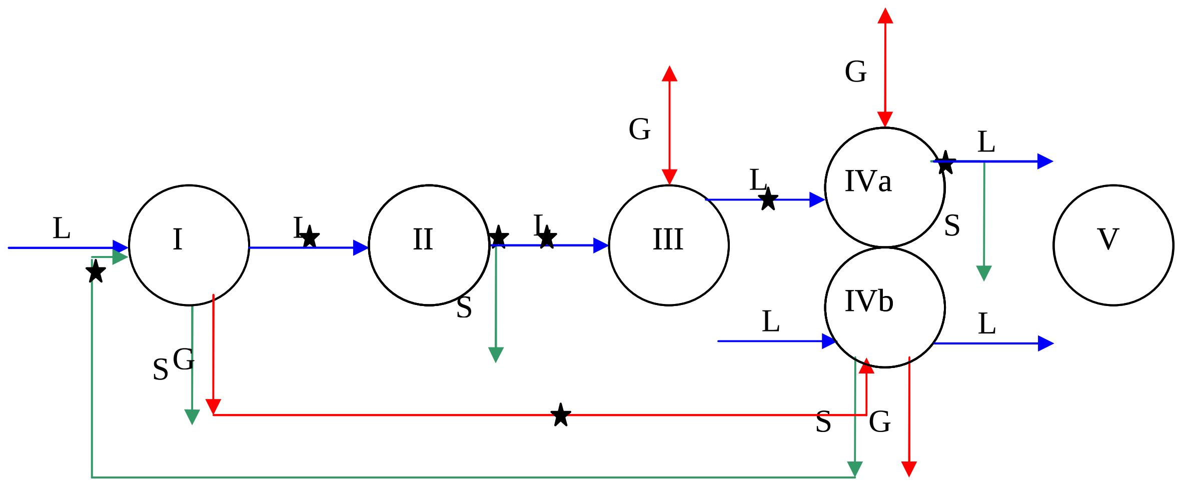
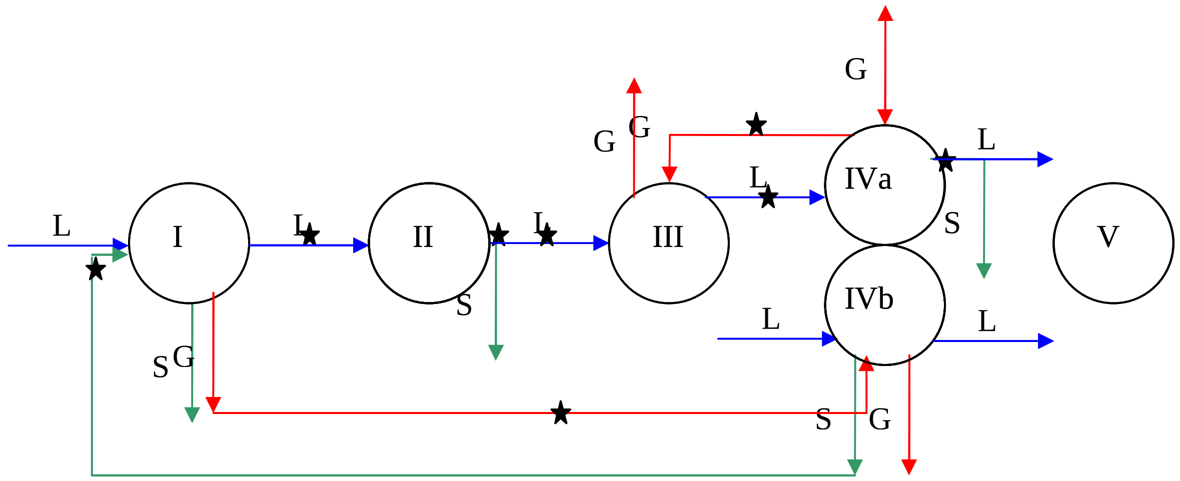
<tr><td>Software</td><td colspan="2">Control laws implemented in MPP PLCs
Cpts connected to the MPP supervision system, level 2 control preliminary architecture</td><td>TBD</td></tr>
<tr><td>Knowledge</td><td colspan="2">Output WP 12 and WP4</td><td></td></tr>
<tr><td rowspan="7">content</td><td>Constraint</td><td colspan="3">Plants metabolism/composition
CII liquid input composition</td></tr>
<tr><td>Manipulable inputs</td><td colspan="3">CI residence time (as a consequence CII and CIII dilution rate)
CII light (and agitation?)
CIII : O2 input (TBC)
CIVa : light
CIVb liquid solution composition and residence time, CIVb light</td></tr>
<tr><td>Set-point</td><td colspan="3">CIVa O2 production</td></tr>
<tr><td>Culture conditions</td><td colspan="3">Hoagland CIVb</td></tr>
<tr><td>Follow-up</td><td colspan="3">CI: L input composition, L output composition, G composition
CII: L output composition (including VFA, NH4+ , SO4, PO4), biomass composition
CIII: pH, pO2 , NH4+, NO2, NO3, SO4, PO4
CIVa: L output composition, biomass composition
CIVb: composition of plants, G phase composition</td></tr>
<tr><td>Quality control</td><td colspan="3">microbiological control CIVb (HPC surfaces, liquid phase, roots), CII, CIII and CIVa axeny</td></tr>
<tr><td>Duration</td><td colspan="3">1 month + 3 months study</td></tr>
<tr><td>Objectives/ outputs</td><td colspan="4">Demonstration of L phase connection over 4 cpts</td></tr>
<tr><td>Rationale</td><td colspan="4">Necessity to progress on study of the liquid loop closure (the last step is the connection from CI L phase to the rest of the Cpts), logic step after</td></tr>
</table>

	WP 12
Remarks	Depending on the availability of HPCs (1, 2 or 3), the amount of plants might be different Can be performed with or without R. Rubrum and Spiru.harvesting system Any interest in: having CIVa biomass sent to CI as well? Connecting CIVb on L phase? SECOND MILESTONE for L phase connection demonstration



WP number	14.	WP title	Connection L phase CI-CII-CIII-CIVa Connection S phase CIVb-CI Connection G phase CI-CIVb and CIVa - CIII	
duration	6 months			
inputs	Hardware	CI fully characterized CII operational steady state CIII operational steady state CIVa operational steady state CIVb validated, operational steady state Interface L phase CI-CII (if any), CII-CIII (if any), CIII-CIVa (if any) Interface S phase CIVb-CI Interface G phase CIVb-CI and CIVa-CIII R.Rubrum harvesting system Spiru. Harvesting system	X X TBD TBD	
	Software	Control laws implemented in MPP PLCs Cpts connected to the MPP supervision system, level 2 control preliminary architecture	TBD	
	Knowledge	Output WP 13 and WP3 Preliminary sizing validation on Gas phase management		
content	Constraint	Plants metabolism/composition CII liquid input composition		
	Manipulable inputs	CI residence time (as a consequence CII and CIII dilution rate) CII light (and agitation?) CIII : O2 input (TBC) CIVa : light CIVb liquid solution composition and residence time, CIVb light		
	Set-point	CIVa O2 production, CIVb biomass production		
	Culture conditions	Hoagland CIVb		
	Follow-up	CI: L input composition, L output composition, G composition CII: L output composition (including VFA, NH4+ , SO4, PO4), biomass composition CIII: pH, pO2 , NH4+, NO2, NO3, SO4, PO4 CIVa: L output composition, biomass composition CIVb: composition of plants, G phase composition		
	Quality control	microbiological control CIVb (HPC surfaces, liquid phase, roots), CII, CIII and CIVa axeny		
	Duration	1 month + 5 months study		
Objectives/	Further validation of CIII control law			

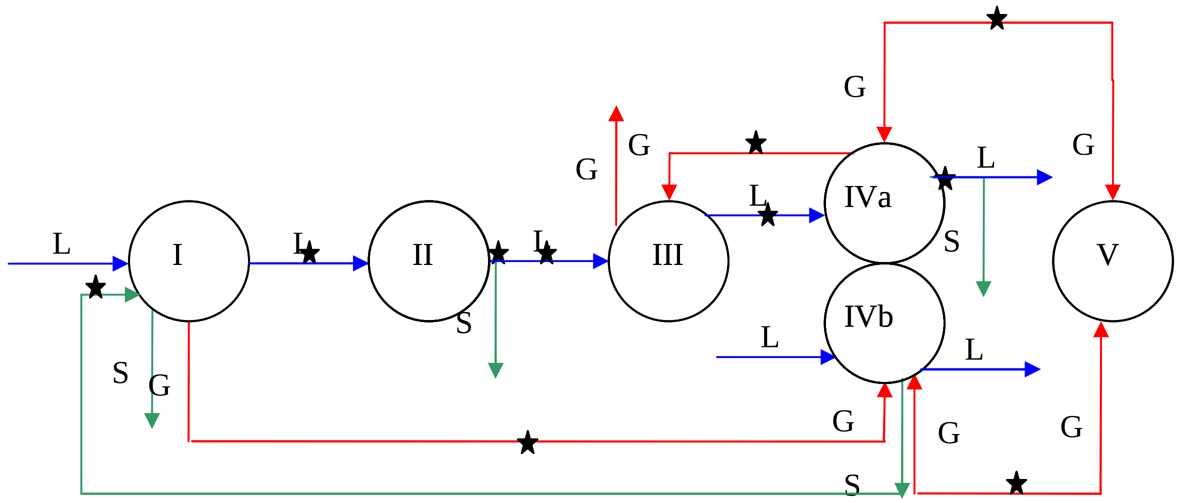
outputs	Progressive demonstration of the loop robustness
Rationale	Several scenarii have been performed to reach key knowledge on L phase connection, closure of solid loop and gas phase management/loop closure. The scenarii studied previously need to be combined progressively up to maximal closure as foreseen in the MELiSSA Pilot Plant. This WP is the first one in this logic.
Remarks	Depending on the availability of HPCs (1, 2 or 3), the amount of plants might be different Can be performed with or without R. Rubrum and Spiru.harvesting system Any interest in: having CIVa biomass sent to CI as well? Connecting CIVb on L phase?



WP number	15.	WP title	Connection L phase CI-CII-CIII-CIVa Connection S phase CIVb-CI Connection G phase CI-CIVb and CIVa – CIII Closure G phase CV-CIVb Closure G phase CV-CIVa
duration	6 months		

inputs	Hardware	CI fully characterized CII operational steady state CIII operational steady state CIVa operational steady state CIVb validated, operational steady state CV validated, operational steady state Interface L phase CI-CII (if any), CII-CIII (if any), CIII-CIVa (if any) Interface S phase CIVb-CI Interface G phase CIVb-CI, CIVa-CIII, CV-CIVa, CV-CIVb R.Rubrum harvesting system Spiru. Harvesting system	
	Software	Control laws implemented in MPP PLCs Cpts connected to the MPP supervision system, level 2 control preliminary architecture	TBD
	Knowledge	Output WP 14 and WP6 Preliminary sizing validation on Gas phase management	
content	Constraint	Animal	
	Manipulable inputs	CI residence time (as a consequence CII and CIII dilution rate) CII light (and agitation?) CIII : O2 input (TBC) CIVa : light CIVb light, liquid solution composition and residence time	
	Set-point	CIVa O2 production, CIVb O2 production	
	Culture conditions	Hoagland CIVb	
	Follow-up	CI: L input composition, L output composition, G composition CII: L output composition (including VFA, NH4+ , SO4, PO4), biomass composition CIII: pH, pO2 , NH4+, NO2, NO3, SO4, PO4 CIVa: L output composition, biomass composition CIVb: composition of plants, G phase composition	

	Quality control	microbiological control CIVb (HPC surfaces, liquid phase, roots), CII, CIII and CIVa axeny CV
	Duration	1 month + 5 months study
Objectives/ outputs	Further validation of CIII control law Progressive demonstration of the loop robustness	
Rationale	See WP 14 Combination of L phase and G phase loop closure	
Remarks	Depending on the availability of HPCs (1, 2 or 3), the amount of plants might be different Can be performed with or without R. Rubrum and Spiru.harvesting system Any interest in: having CIVa biomass sent to CI as well? Connecting CIVb on L phase? THIRD MILESTONE for G loop closure demonstration	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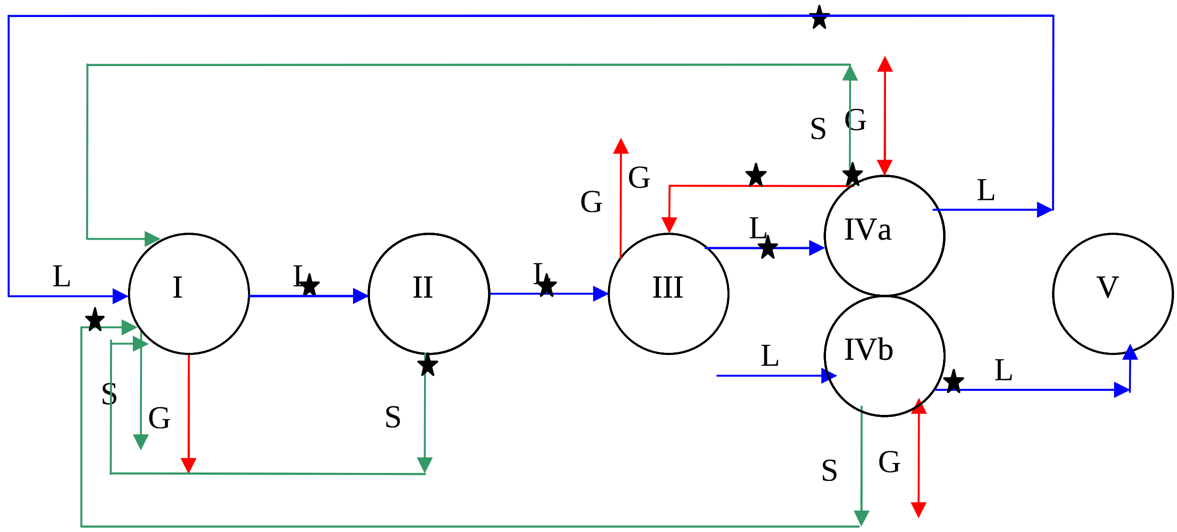
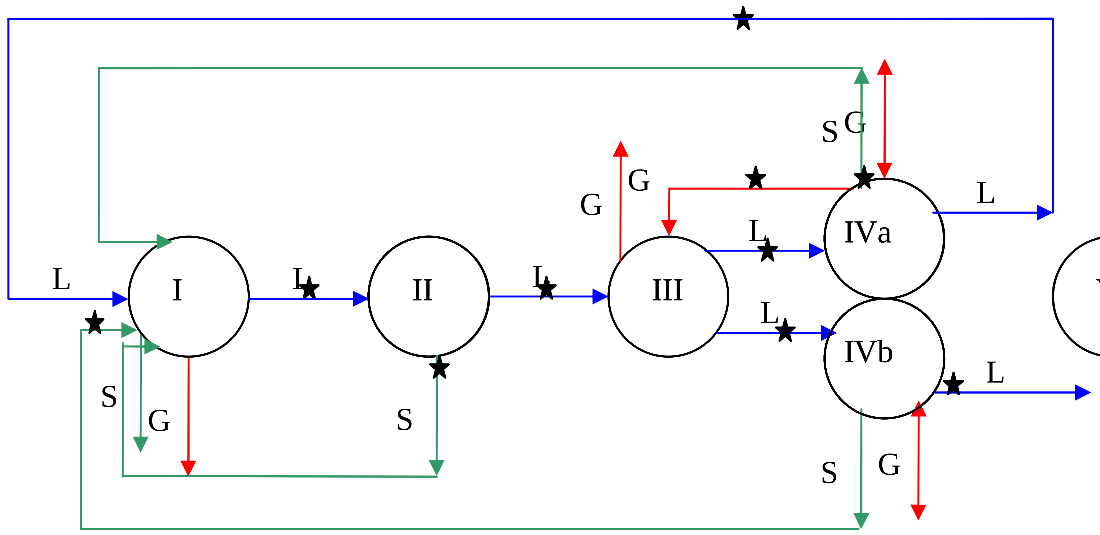
WP number	16.	WP title	Connection L phase CI-CII-CIII-CIVa Connection L phase CIVb-CV Connection S phase CIVb-CI, CIVa-CI, CII-CI Connection G phase CIVa – CIII	
duration	15 months			
inputs	Hardware	CI fully characterized CII operational steady state CIII operational steady state CIVa operational steady state CIVb validated, operational steady state Interface L phase CI-CII (if any), CII-CIII (if any), CIII-CIVa (if any), CIVa-CI (if any), CIII-CIVb(if any) Interface S phase CIVb-CI Interface G phase CIVa-CIII R.Rubrum harvesting system Spiru. Harvesting system		
	Software	Control laws implemented in MPP PLCs Cpts connected to the MPP supervision system, level 2 control preliminary architecture	TBD	
	Knowledge	Output WP 16 Preliminary sizing validation on Liquid phase management		
content	Constraint	CI liquid output		
	Manipulable inputs	CI residence time (as a consequence CII and CIII dilution rate) CII light (and agitation?) CIII : O2 input (TBC) CIVa : light CIVb light		
	Set-point	CIVa O2 production, CIVb L output		
	Culture conditions	Hoagland CIVb		
	Follow-up	CI: L input composition, L output composition, G composition, S composition CII: L output composition (including VFA, NH4+ , SO4, PO4), biomass composition CIII: pH, pO2 , NH4+, NO2, NO3, SO4, PO4 CIVa: L output composition, biomass composition CIVb: composition of plants, G phase composition, L output composition		
	Quality control	microbiological control CIVb (HPC surfaces, liquid phase, roots), CII, CIII and CIVa axeny CV		

	Duration	1 month + 14 months study
Objectives/ outputs	Further validation of CI control law/performances when increasing L loop closure Progressive demonstration of the loop robustness	
Rationale	New step in liquid loop closure	
Remarks	Depending on the availability of HPCs (1, 2 or 3), the amount of plants might be different	

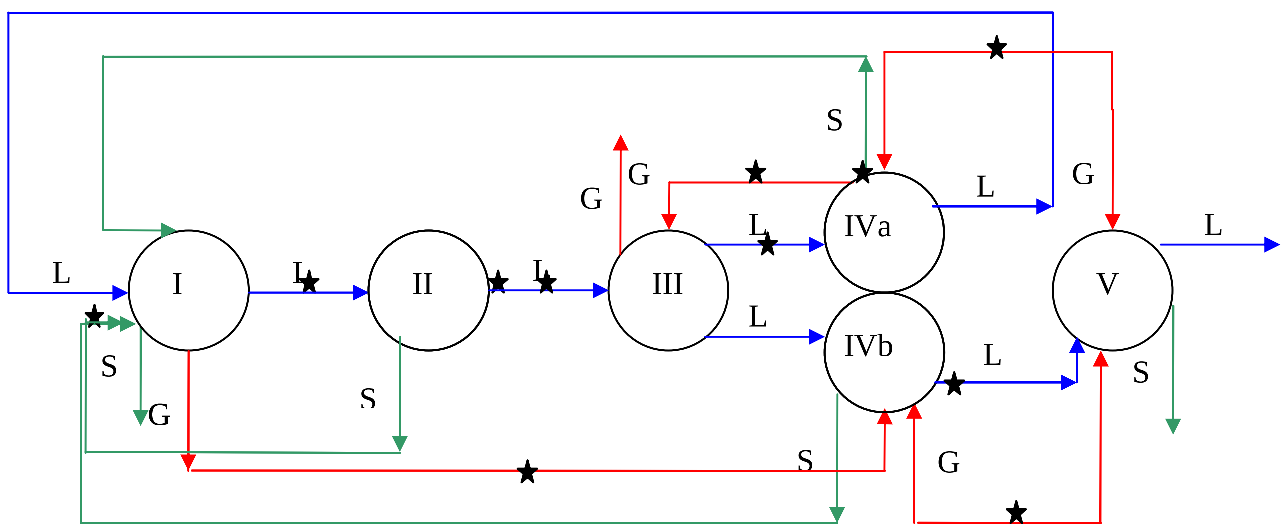


WP number	17.	WP title	Connection L phase CI-CII-CIII-CIVa-CIVb Connection S phase CIVb-CI, CIVa-CI, CII-CI Connection G phase CIVa – CIII Closure G phase CV-CIVb Closure G phase CV-CIVa	
duration	10 months			
inputs	Hardware	CI fully characterized CII operational steady state CIII operational steady state CIVa operational steady state CIVb validated, operational steady state Interface L phase CI-CII (if any), CII-CIII (if any), CIII-CIVa (if any), CIII-CIVb (if any) Interface S phase CIVb-CI Interface G phase CIVb-CI, CIVa-CIII, CV-CIVa, CV-CIVb R.Rubrum harvesting system Spiru. Harvesting system		
	Software	Control laws implemented in MPP PLCs Cpts connected to the MPP supervision system, level 2 control preliminary architecture	TBD	
	Knowledge	Output WP 15 and WP10 Preliminary sizing validation on Liquid phase management		
content	Constraint	TBC		
	Manipulable inputs	CI residence time (as a consequence CII and CIII dilution rate) CII light (and agitation?) CIII : O2 input (TBC) CIVa : light CIVb light CO2 input		
	Set-point	CIVa O2 production, CIVb biomass production		
	Culture conditions			
	Follow-up	CI: L input composition, L output composition, G composition, S composition CII: L output composition (including VFA, NH4+ , SO4, PO4), biomass composition CIII: pH, pO2 , NH4+, NO2, NO3, SO4, PO4 CIVa: L output composition, biomass composition, G phase composition CIVb: composition of plants, G phase composition, L		

		output composition
	Quality control	microbiological control CIVb (HPC surfaces, liquid phase, roots), CII, CIII and CIVa axeny
	Duration	1 month + 9 months study
Objectives/ outputs	Further validation of CI control law/performances when increasing L loop closure Further validation of CIVb control law	
Rationale	See WP 14 Combination of L phase and S phase loop closure	
Remarks	Depending on the availability of HPCs (1, 2 or 3), the amount of plants might be different Any interest ending CIVb L output back to CI?	



WP number	18.	WP title	MELiSSA loop demonstration	
duration	34 months			
inputs	Hardware	All compartments and interfaces operational and in steady-state		
	Software	Control laws implemented in MPP PLCs Cpts connected to the MPP supervision system, level 2 control preliminary architecture		TBD
	Knowledge	Output of all WPs Preliminary sizing validation on all phases management		
content	Constraint	animal		
	Manipulable inputs	CI residence time (as a consequence CII and CIII dilution rate) CII light (and agitation?) CIII : O2 input (TBC) CIVa : light CIVb light		
	Set-point	CV O2 input		
	Culture conditions			
	Follow-up	CI: L input composition, L output composition, G composition, S composition CII: L output composition (including VFA, NH4+ , SO4, PO4), biomass composition CIII: pH, pO2 , NH4+, NO2, NO3, SO4, PO4 CIVa: L output composition, biomass composition, G phase composition CIVb: composition of plants, G phase composition, L output composition CV: G phase		
	Quality control	microbiological control CIVb (HPC surfaces, liquid phase, roots), CII, CIII and CIVa axeny, CV		
	Duration	1 month + 9 months to reach steady-state + 24 months continuous operation		
Objectives/ outputs	Full demonstration			
Rationale	Combination of L phase, G phase and S phase loop closure			
Remarks	Should be performed with the three HPCs Any interest ending CIVb L output back to CI?			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Logic of the integration approach, main guidelines:
we start where we have the max knowledge on control issues
we use as much as possible CIVb biomass to feed CI
we progressively enhance our control knowledge
we deal with the availability of hardware

Rk:
additional knowledge on CI may introduce some changes in the WP (depending on the composition of the gas phase….)
additional investigation in sizing simulation may introduce drastic changes
For CIVb liquid output, we have considered only one liquid stream; however, maybe we could separate the liquid nutrient solution from the evapotranspirated water (foreseen to be used (partly or totally)for preparation of animal “potable”water; then should we envisage to feed-back CI with the rest of the available water?
From the preliminary information we have on sizing (e.g. calculations performed within BELISSIMA), we know that most probably, CI liquid output will have to be diluted before being further processed by CII . This may introduce some changes in the WPs scenario
The potential integration of complementary technologies (e.g. Fiber degradation unit) can introduce major changes as well.
Sizing for gas phase management is clearly an issue as today we still miss basic information, like buffer capacities, strategy of storage (e.g do we reach a given composition for each gas stream, so that they can be mixed and used for buffer capacity,….)

Appendix 2 – Minutes of the meetings held with the experts

Kick-Off meeting (28/05/2008), Progress Meeting (16/07/2008), Final meeting (05/06/2009)

Date : 28-May-08

Meeting place : ESA-ESTEC, room Ef 103

SUBJECT : Kick Off Meeting Consultancy Study for the MPP integration strategy

Attendees :

Company	ESA	MELISSA Pilot Plant	Consultants
Names	C. LASSEUR (CL) B. LAMAZE (BL)	F. GODIA (FG) A. FOSSEN (AF)	Alexander Tikhomirov (AT) Elena Tikhomirova, Mark Kliss (MK) Christian Guizard (CG)

Distribution list : the attendees and the following listed persons

Company	UAB	MELISSA Pilot Plant
Names		Enrique Peiro

Main conclusions :

Approval by all attendees :

Company	ESA	ESA	Consultant	Consultant	Consultant	MPP
Name	C. LASSEUR	B. LAMAZE	M KLISS	A. TIKHOMIROV	C. GUIZARD	F. GODIA A. FOSSEN
Visa						

Item	Action #	Resp	Date
Agenda: 1. Signature of the Non Disclosure Agreements 2. Tour de table 3. Objectives of the study. Final deliverables 4. The MELiSSA project: a general overview 5. The MELiSSA Pilot Plant: current status and future perspectives 6. Integration strategy for the MELiSSA Pilot Plant 7. Contractual aspects and practical details concerning the Consultants **Purpose of the meeting:** KOM of the consultancy study for the definition of the integrations strategy for the MPP **Discussion:** 1. NDA signed by all consultants 2. Done 3. The objectives of the study were reviewed, with specific mention of the meetings to be performed: follow-up in July, Montreal, during COSPAR, final meeting in Paris, prior to the MYM, by 19-11-08. The date for the meeting in Montreal will be fixed in accordance to the schedule of Cospar program. ChL will make a proposal in this respect. The main deliverable from the study is the report on the integration strategy. Individual reports from each consultant will be prepared, with draft in October 15th, and merging the conclusions by November 19 in Paris. This merged document, with “recommendations for MELiSSA Pilot Plant Integration Strategy” will be presented in the ALS WS in Barcelona, in June 2009, by one of the Consultants. 4. Done 5. Done 6. Taking into account their prior review of the document “Basis for the MPP Integration Strategy”, and the previous presentations, the consultants provided some initial remarks:			

- MK. System failure analysis: identification of circumstances in the operation of the reactor that in case of occur would affect severely the operation of the rest of the loop, also in terms of process. By anticipating them, install the measures to prevent them - MK. Need for a systematic activity in terms of maintenance and calibration of instrumentation - AT. Degree of closure. It is interesting always to show how the closure of the system is approached (for example with mass balance for each integration step). To be shown in a specific WP of integration - CG. Gas phase management is today poorly adressed in the document (strategy, loop, specific separation needs..) Following to these initial points, a more detailed discussion was initiated on various steps of the integration proposed in the mentioned document. This discussion was considered very helpful to understand the logic of the complete study, and already provided a number of additional remarks. After the discussion, the following conclusions were reached: - the document on the basis for the integration strategy will be completed by ESA and UAB by providing the overall rationale for the integration. - also, the most important criteria considered when proposing each one of the integration steps will be described - it is also important to define in each WP what are the main aspects to analyze and to record properly, in order to have them completely characterized - the complete gas loop in the MPP should be defined in order to progress in the different gas-phase interactions among compartments. It is also important to define the expected conditions expected in terms of VOC, inert gases, humidity, partial pressure of main compounds, etc. - the last points will provide a better basis for the Consultants to prepare their specific recommendations on the integration strategy - it will also be important to review the general time-line of the integration activity, and define two aspects. One, identify if the timeschedule of the WPs offers some time gaps for the performance of WP preparatory tasks (e.g. ramp-up of compartments…). Two, identify	1	ESA/U	21/6/08

specific milestones along the integration process, enabling to follow-up and report the progressive achievements in the integration path. **Actions:** 1. ESA and UAB will provide the additional information on the rationale used for the proposed integration steps, in three weeks 2. The Consultants will prepare their individual inputs/comments on the integration strategy, to be presented in the second meeting in Montreal 3. ChL will propose and coordinate the date for the next meeting in Montreal 4. FG will prepare and sent to AT and ChG the proposal for the consultancy contracts Enclosed information: 1. presentations from ESA and UAB regarding points 4 and 5 2. list of mails of all the attendees to the meeting	 2 3 4	AB Consul tants ESA FG	 15/7/08 ? ?

Date : 16-July-08

Meeting place : Palais des Congrés, Montreal, Canada

SUBJECT : Second Meeting Consultancy Study for the MPP integration strategy

Attendees :

Company	ESA	MELISSA Pilot Plant	Consultants
Names	C. LASSEUR (CL)	F. GODIA (FG)	Alexander Tikhomirov (AT) Elena Tikhomirova, Mark Kliss (MK) Christian Guizard (CG)

Distribution list : the attendees and the following listed persons

Company	UAB	MELISSA Pilot Plant
Names		Enrique Peiro Arnaud Fossen

Main conclusions : Progress of the Consultancy study for the MPP integration strategy

Approval by all attendees :

Company	ESA	Consultant	Consultant	Consultant	MPP
Name	C. LASSEUR	M KLISS	A. TIKHOMIROV	C. GUIZARD	F. GODIA
Visa					

Item	Action #	Resp	Date
Agenda: 1. Introduction. 2. Feed-back from the Consultants in respect to the previous meeting discussion and the document circulated on "MPP Integration Workpackages" **Purpose of the meeting:** Progress Meeting of the consultancy study for the definition of the integration strategy for the MPP **Discussion:** C. Guizard provided an analysis of the main gas-vapour fluxes in the MPP, also taking into account the presence of VOC. He pointed out the need to establish a methodology to reach the final integration of the gas phase. First, Collection of basic data: produced and consumed gases and vapors, supplied gases, and interaction between the two groups, gas and vapor composition in each compartment (upper and lower limits, partial pressure, humidity, temperature). Second, mass balance in each compartment. For each compartment we should measure gas-vapor composition, P, T, and then at the outlet we should define what is the required processing of the gas: separation, adsorption, elimination, etc. We also will need to define the monitoring (manual or automated). Third, interaction between compartments, and analysis of the need of buffer tanks in the interface. Also, consider at this point the external gases added to a compartment and their interaction with the rest of the gases. Fourth, consider a central monitoring unit. The presentation provided by C. Guizard is enclosed to these minutes. It is also important to consider the type of technologies to be used in the processing part of the gas phase flow between compartments: porous membrane separation, electro dumping, solution diffusion, adsorption-complexation, etc. Another important aspect is the elimination of pollutants in the gas phase, that could be solid particles or gas pollutants. Compartment IV is basic for gas management, and it should be considered to start from these compartments.			

It can be considered in parallel the work to complete the information on the complete process and the analysis of a specific integration step.

At this moment of the discussion, M. Kliss brought the point that it is important to decide if the study considers in one side the main gases (CO2, O2), and the rest of pollutants apart. This can be taken as a starting point. There was a general agreement on this approach. Strict control on the elimination of Ethylene was stressed, although some other compounds could be present (hormones, etc,) but probably less important (M. Kliss will consult R. Wheeler on this point) . A. Tikhomirov added that it is also important to consider potential emissions from the construction materials, like cables, plastic, type of stainless steel (more important in the liquid loop). F Gòdia commented that the presence of particles in the gas phase may not be a big problem, since the gas phase is sterilized by filtration.

The realization of a given integration step will depend also on the knowledge on the data from the compartments and the definition/implementation of the interface technologies.

M. Kliss reported his progress on the analysis up to step 10. Waste preparation, providing the input to C-I is an important element. Urine should also be considered. In principle we will use NH4 in the C-III. In parallel, a study on the degradation of urea is done. M. Kliss made the point that artificial urea is not the same as human, and that the degradation of urea would also provide a number of side products. M Kliss has a number of questions on the dynamics between compartments. Gas metering, O2, CO2, and also water vapor.

A. Tikhomirov provided written comments to the proposed integration strategy, that are enclosed to these minutes. A question is raised on the basis of the integration approach, in the sense that the complete integration of the loop should be considered from the beginning.. The answer to the question, as provided by ESA and UAB, is that before going into the final integration scenario, a number of intermediate partial steps should be tested. However, it is then clear that the conditions tested in one specific test may vary when the final closure scenario will be done. In the wording, it was agreed that the term closure should not be used when working in one particular step. Alternatively, use liquid/gas transfer, etc, but closure only comes at WP18.

It was agreed that the integration steps may be changed during the realization of the work. It was agreed that step CIVa-CV is strong in the issue of gas separation-purification, as the step CI-gas loop is good for elimination of VOC. When preparing the final document, a comprehensive introduction section should be written, where the logics of the integration work is presented, showing the need to progress in the knowledge building on the different steps, in order to reach finally the integration of the complete loop. **<u>Next steps:</u>** - C. Guizard will propose an analysis of the gas phase on the integration taking compartment C-IV as the center of it. - M Kliss will complete his analysis - A. Tikhomirov will do a second analysis - Questions and comments should be posed by mail for the group interaction, and in order to prepare a document that would be understand by the people outside of MELiSSA - Feed-back at the end of September, considering a telephone meeting Enclosed information: 1. presentation from C. Guizard 2. considerations from A. Tikhomirov			

Date : 05-June-2009

Meeting place : MPP

SUBJECT : FINAL Meeting Consultancy Study for the MPP integration strategy

Attendees :

Company	ESA	MELISSA Pilot Plant	Consultants
Names	C. LASSEUR (CL) B.LAMAZE (BL)	F. GODIA (FG) E.PEIRO (EP) A.FOSSEN (AF)	Alexander Tikhomirov (AT) Elena Tikhomirova, Mark Kliss (MK)

Distribution list : the attendees and the following listed persons

Company	UAB	MELISSA Pilot Plant
Names		

Main conclusions : conclusion of the Consultancy study for the MPP integration strategy

Approval by all attendees :

Company	ESA	ESA	Consultant	Consultant	MPP	MPP	MPP
Name	C. LASSEUR	B. LAMAZE	M KLISS	A. TIKHOMIROV	F.GODIA	E.PEIRO	A.FOSSEN
Visa							

Item	Action #	Resp	Date
<u>Agenda:</u> 3. Introduction. 4. Final feed-back from the Consultants in respect to the previous meeting discussion and the document circulated on "MPP Integration Workpackages" **<u>Purpose of the meeting:</u>** Final Meeting of the consultancy study for the definition of the integration strategy for the MPP **<u>Discussion:</u>** **1- Work Packages from the Integration strategy were reviewed one by one, taking into considerations the comments provided by the experts** **WP1** Gas phase composition was raised as a critical issue by MK: how to trace, monitor , control, eliminate undesirable chemicals? CL clarified that the knowledge gained in the frame of the BIORAT study on this aspect is rather limited, as the experiment was of short duration; HEPA filters were used to avoid microbiological contamination. Ep emphasized the possibility to use a specific ammonia probe on top of more standard commercially available sensors. The strategy agreed for this WP is the removal of contaminants, in order to focus on hydrodynamics aspects of O2/CO2 exchanges. Advantage shall be taken from the performance of this WP to collect data on gas phase composition (e.g. use of sampling ceramics…). FG stressed the various steps of the WP.: installation of CV in its room, characterization of gas flows from to CIVa, definition of 3 gas loops (internal to CV, internal to CIVa, exchange loop), contaminants removal most probably in each internal gas loop, using technologies selected from a bibliographic review. **WP2** It was emphasized that residual VFAs from CI (i.e. to avoid wash-out of CII) will be present in CIII. CIII should however be maintained in autotrophy regime. A proper characterization of CIII biomass should be obtained thanks to the analysis of biomass collected from CIII			

backwashing phases. This WP shall take into account as an input, the data available and to be collected on the VFA concentration at CI output. CII shall then be fed with a synthetic media mimicking, as close as possible, CI composition. A direct connection of CI to CII is today considered as too risky for CII operation **WP3** No specific remarks **WP4** Process dynamics was emphasized. The need of R. Rubrum harvesting was stressed **WP5** Experts are considering as critical the issue linked to O2/CO2 buffering/separation. Dynamics of the process are considered more cirtical than with CIVa. Gas flows measurement might be an issue, depending on the flow range. Measurement technologies shall be studied. It was recommended to perform a simulation case with SHERPA on control aspects. **WP6** Due to the numerous dynamics aspects of this WP, a simulation with Sherpa on control aspects was recommended **WP7** The supply origins shall be clarified. It was recommended to perform this WP with a mixture of plants. The availability of Higher Plant Chambers was raised as a critical issue. **WP 8, 9 and 10** The strategy for these three workpackages was stressed as depending on CI gas phase composition, today not know with appropriate accuracy. The loss of water during harvesting phases was emphasized as potentially critical. Depending on the availability of one or several HPCs, it was considered more appropriate to use a mix of plants for these WPs. MK stressed the impact of the knowledge gained along the performance of the various WPs on the definition of demonstration objectives (e.g. reliability/stability of the loop versus loop closure/mass balance). **Other WPs** It was considered by the experts as very difficult and not accurate to assess in detail the following WPs, as their definition/performance is			

strongly dependent on knowledge acquired during previous WPs (i.e 1to 10).

2- additional overall recommendations

To keep the MPP Integration Strategy as a useful MPP management document, it was decided to:

- maintain an updated overall document and an associated planning under Microsoft Project
- create additional individual documents, for each WP, defining in more details the steps of the WP, and corresponding test plans
- defining/anticipating as much as possible the needs of interfaces (hardware, software, knowledge).

In terms of hardware, some interfaces were stressed as critical: R. Rubrum harvesting, A. Platensis harvesting, additional Higher Plants Chambers. Their unavailability could jeopardize the performance of the WPs. The time needed for the integration should be taken into account in the overall integration planning.
Knowledge needs should be even more anticipated, as time to acquire knowledge is usually higher than hardware procurement time.

For the overall integration strategy document, it was strongly recommended, for each WP:

- to identify clearly, the external supplies
- to identify more accurately ancillary equipment (e.g. Waste Preparation Unit…)
- - to use a more accurate wording, e.g. closure, partial closure, connection…

Experts recommended that communication about the MPP integration status shall not be driven by conferences but by major outputs preliminary identified.
Their last recommendation was to organize the MPP integration strategy assessment on a regular basis, e.g. every 2 years.

<u>Next steps:</u>

- Issue the final report of the consultancy study
- Update the overall MPP integration strategy and associated planning according to the recommendations