Characterization and Integration of Compartments at the MELiSSA Pilot Plant

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Main requirements for Human Space Exploration and life support systems.

Human Space Eploration main challenges

- Safety and protection for the crew. Radiation
- Advanced Propulsion. Reduction of mission time
- Life support. Make the mission posssible
  - Air revitalization
  - Water reutilization
  - Waste management
  - Food production and preparation

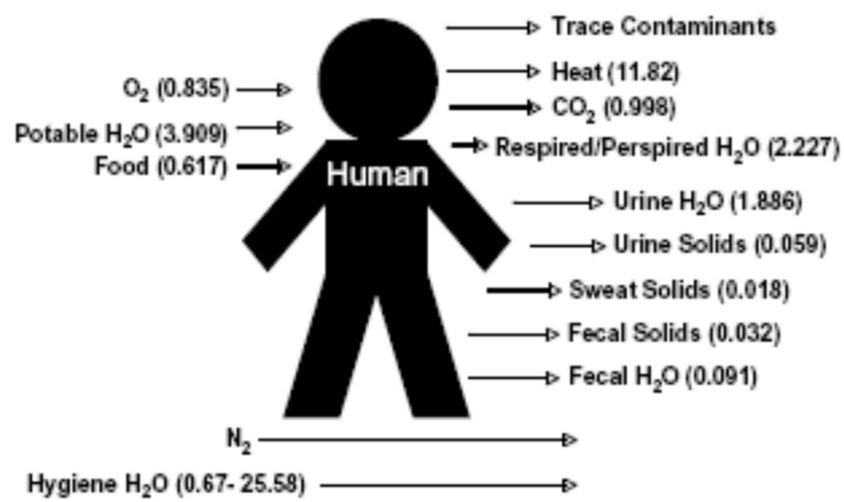


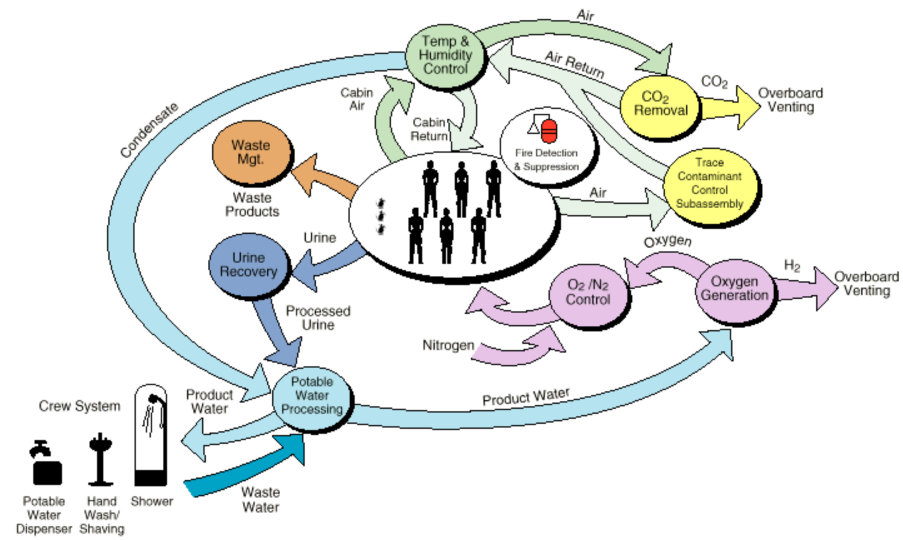
Figure 1. Human Consumable and Throughput Values in kg (or MJ)/crewmember/day

Environmental Control and Life support in ISS and beyond

ISS current life support and environmental control

Open system. No food generation or waste treatment. Supply from Earth

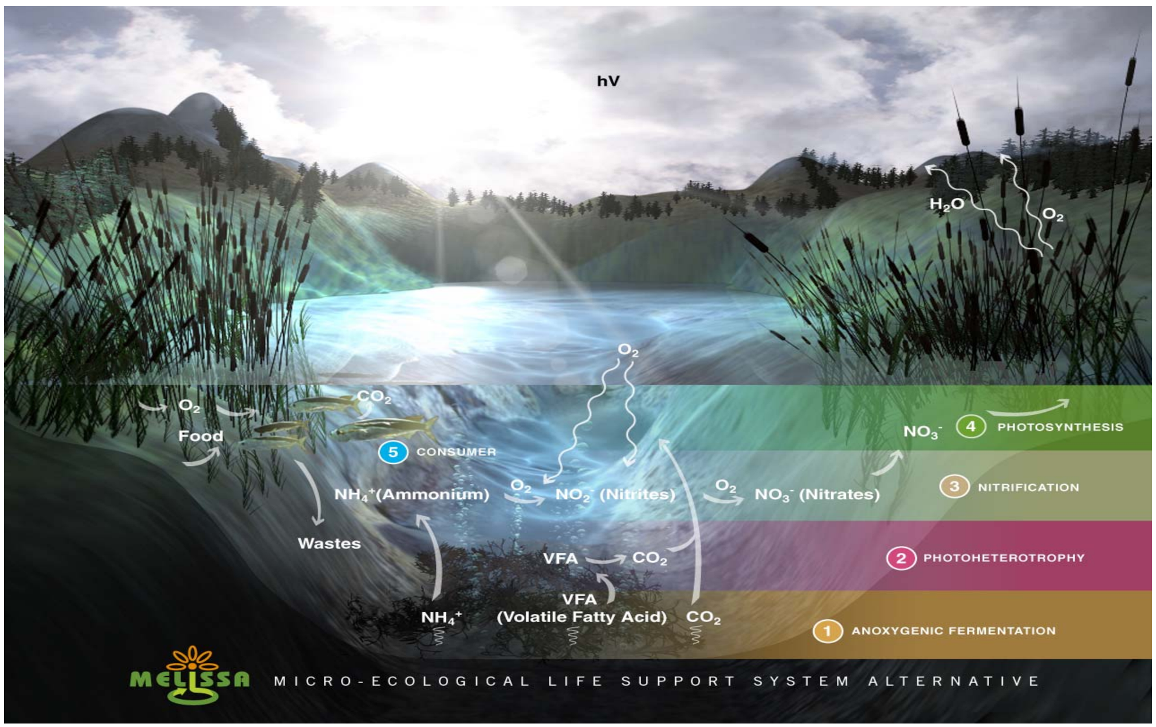
- O_2 generation
- CO_2 capture
- Water reclamation
- Trace contaminants control

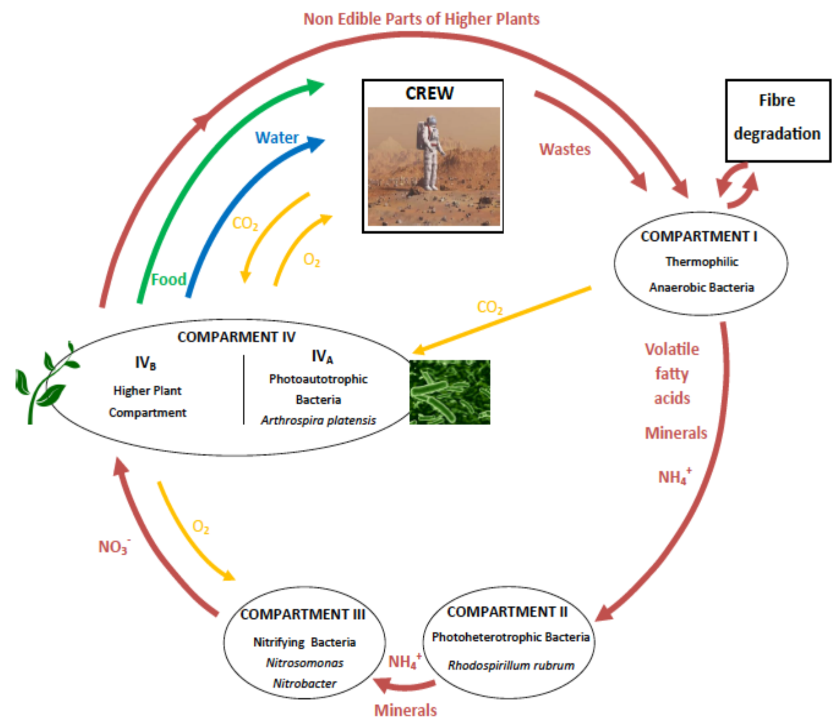


Metabolic consumables: 5 kg/day/person, 6 crew members, 1000 days (Mars mission): 30.000 kg
Including hygiene issues (20 kg/day/person): 132.000 kg
This is a too high mass for a mission … **long-term missions need regenerative LSS**

The MELiSSA Concept: engineering a closed ecosystem

MELiSSA approach is to perform the most relevant biological functions of an ecosystem in individual compartments (bioreactors and higher plant chambers), in continuous and controlled operation



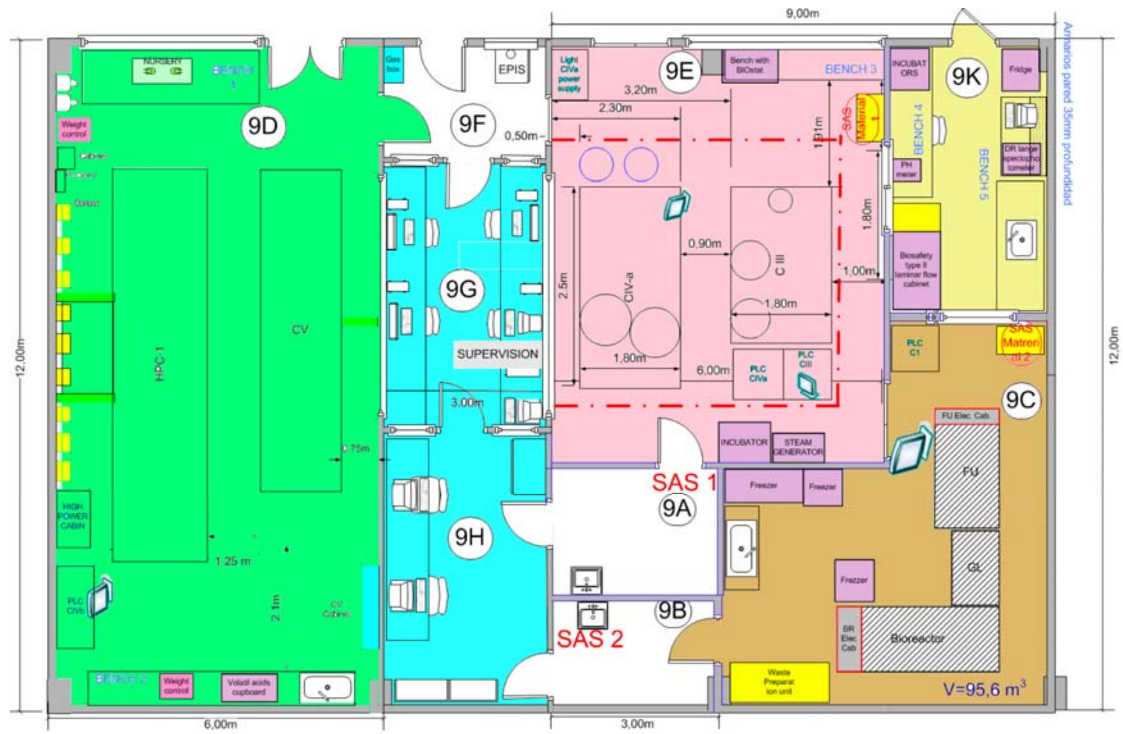


The MELiSSA Pilot Plant: technology demonstration and integration

Main objectives

- Integration and demonstration of the MELiSSA concept at pilot scale
- Technology demonstration:
  - In ground conditions
  - With an animal crew
  - With industry standards
  - Long-term continuous operation
  - Modelling and Control
- Production of Oxygen: equivalent to a one person respiration
  Production of food: at least 20% of a person requirements

Layout (214 m²)



Comp. IVb and CV

Comp. III and IVa

Control and supervision

Comp I

Analysis Laboratory

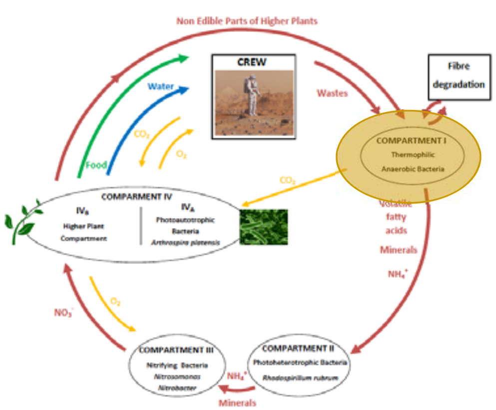
MELiSSA Pilot Plant: a team effort

The MELiSSA Pilot Plant (MPP)

COMPARTMENT	I	II	III	IVa	IVb	V

Function in the loop

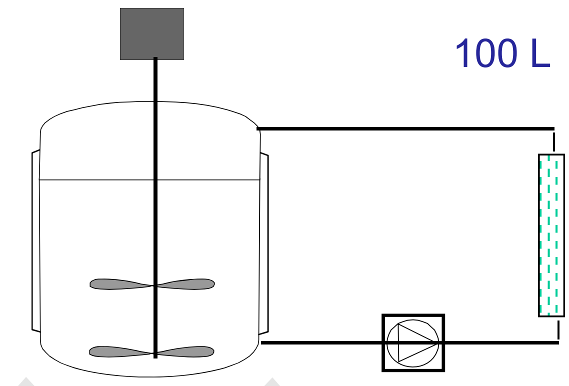
Wastes → **C. I** → **Volatile Fatty Acids (VFA) CO_2**



Biological component

Mixed culture of thermophilic anaerobic bacteria

Technology



Waste Preparation Unit (WPU). Raw materials

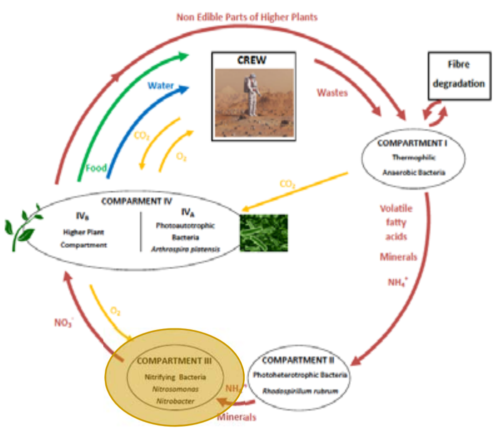
- Plant material (lettuce, wheat straw, beet)
- Toilet paper
- Human faeces

The MELiSSA Pilot Plant (MPP)

COMPARTMENT	I	II	III	IVa	IVb	V

Function in the loop

NH_4^+, O_2 → **C. III** → NO_3^-



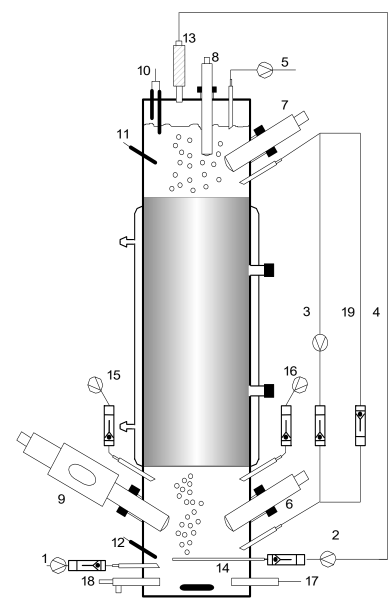
Poster from Justyna Barys

Biological component

Nitrosomonas europaea
Nitrobacter winogradskyi
(Axenic co-culture, aerobic)

Technology

7 L

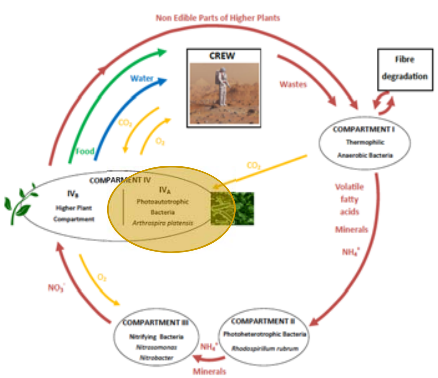


The MELiSSA Pilot Plant (MPP)

COMPARTMENT	I	II	III	IVa	IVb	V

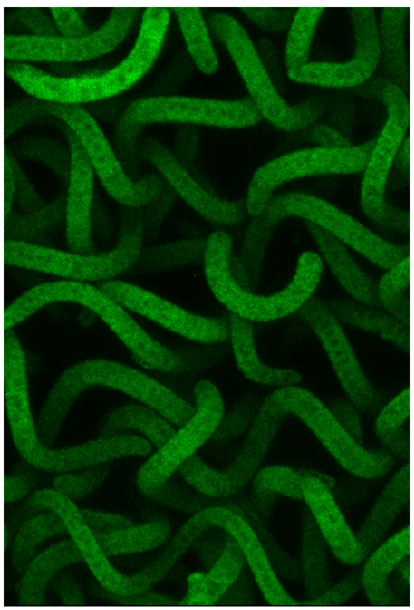
Function in the loop

Light
CO_2 → **C. IVa** → **Biomass**
O_2



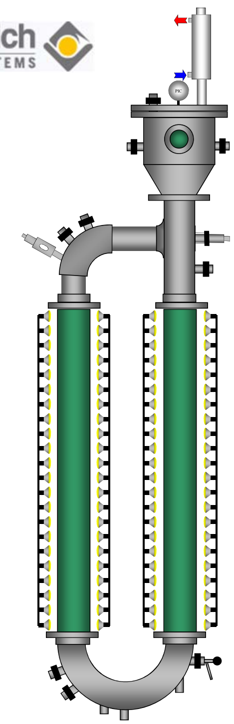
Biological component

Arthrospira platensis
(axenic culture)



Technology

83 L De Dietrich PROCESS SYSTEMS

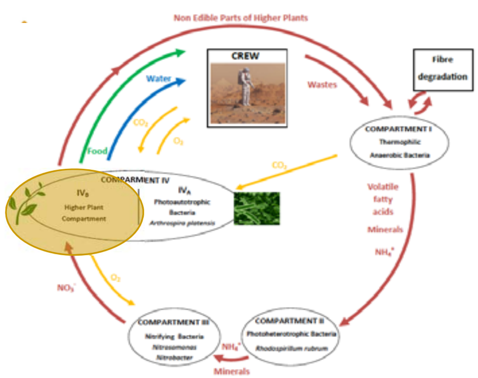


The MELiSSA Pilot Plant (MPP)

COMPARTMENT	I	II	III	IVa	IVb	V

Function in the loop

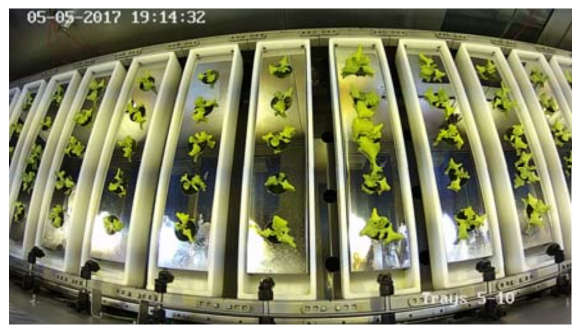
Light
CO_2 → **C. IVa** → **Biomass**
O_2



Presentation from UNapoli + Enginsoft

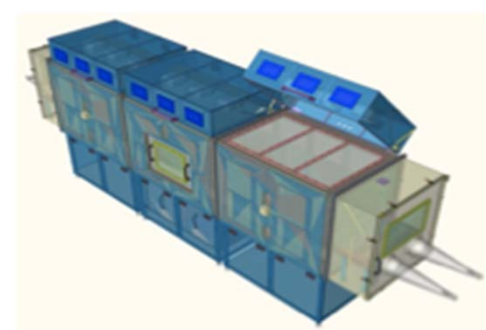
Biological component

Higher plants
(letuce, beat,wheat)



Technology

UNIVERSITY of GUELPH Amstrong Engineering



The MELiSSA Pilot Plant (MPP)

COMPARTMENT	I	II	III	IVa	IVb	V

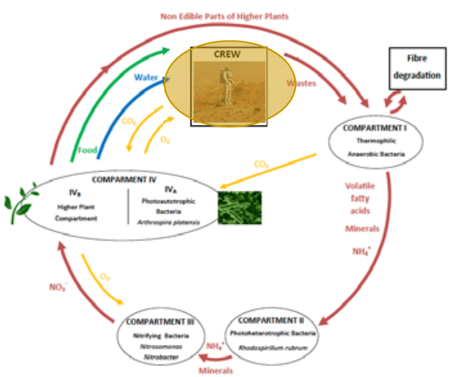
Function in the loop

O_2
Feed → **C. V** → Wastes
CO_2

Biological component

Laboratory Wistar rats

Technology



Presentation from Hosokawa Micron Ltd.

Integration Strategy: C. III / C. IVa / C. V

Top requirements for the MELiSSA Pilot Plant

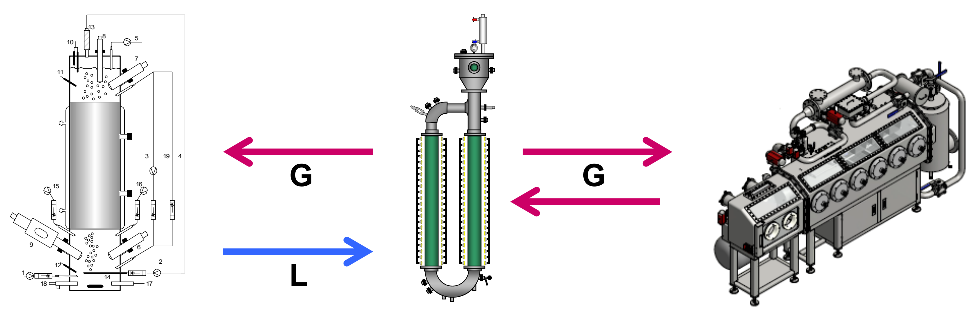
1/ Progressive demonstration of MELiSSA concept

2/ Stepwise integration

3/ Capitalization of knowledge

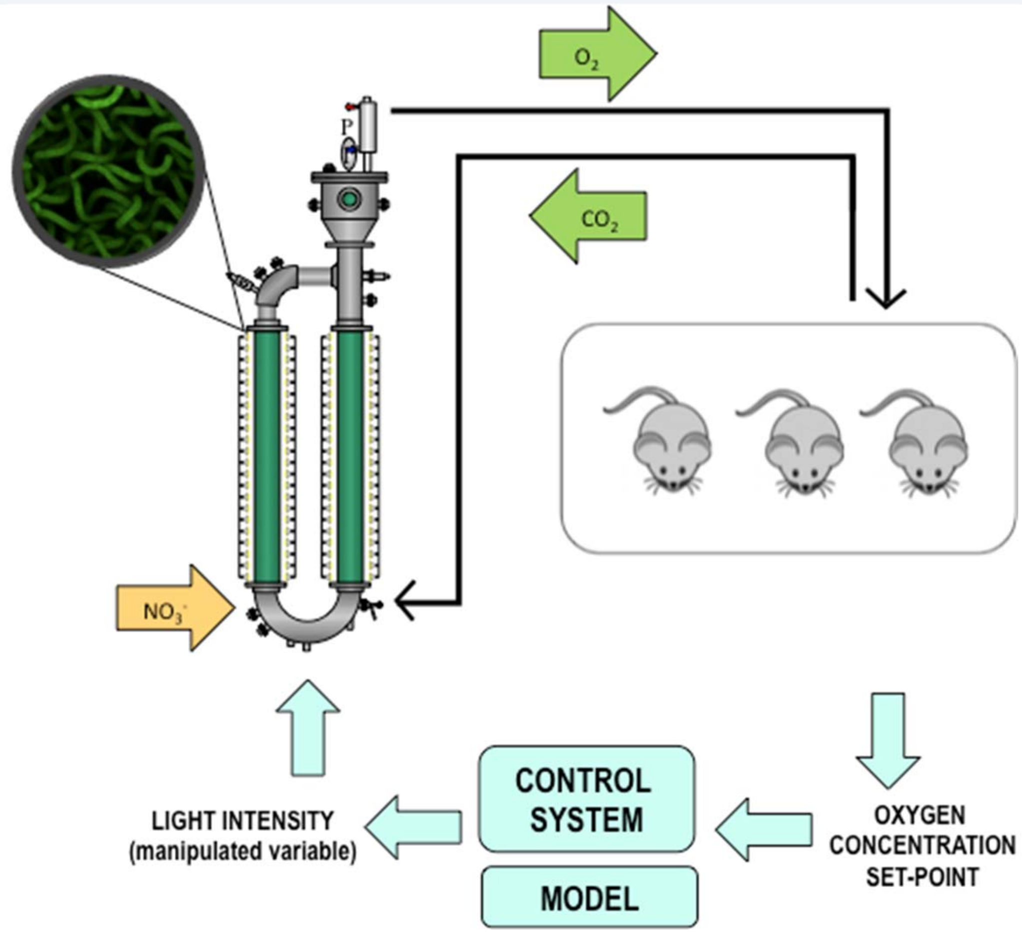
First integration steps based on the most advanced compartments in terms of knowledge, model and control

Integration WP1 | **Integration WP3** | **Integration WP4** | **Integration WP6**

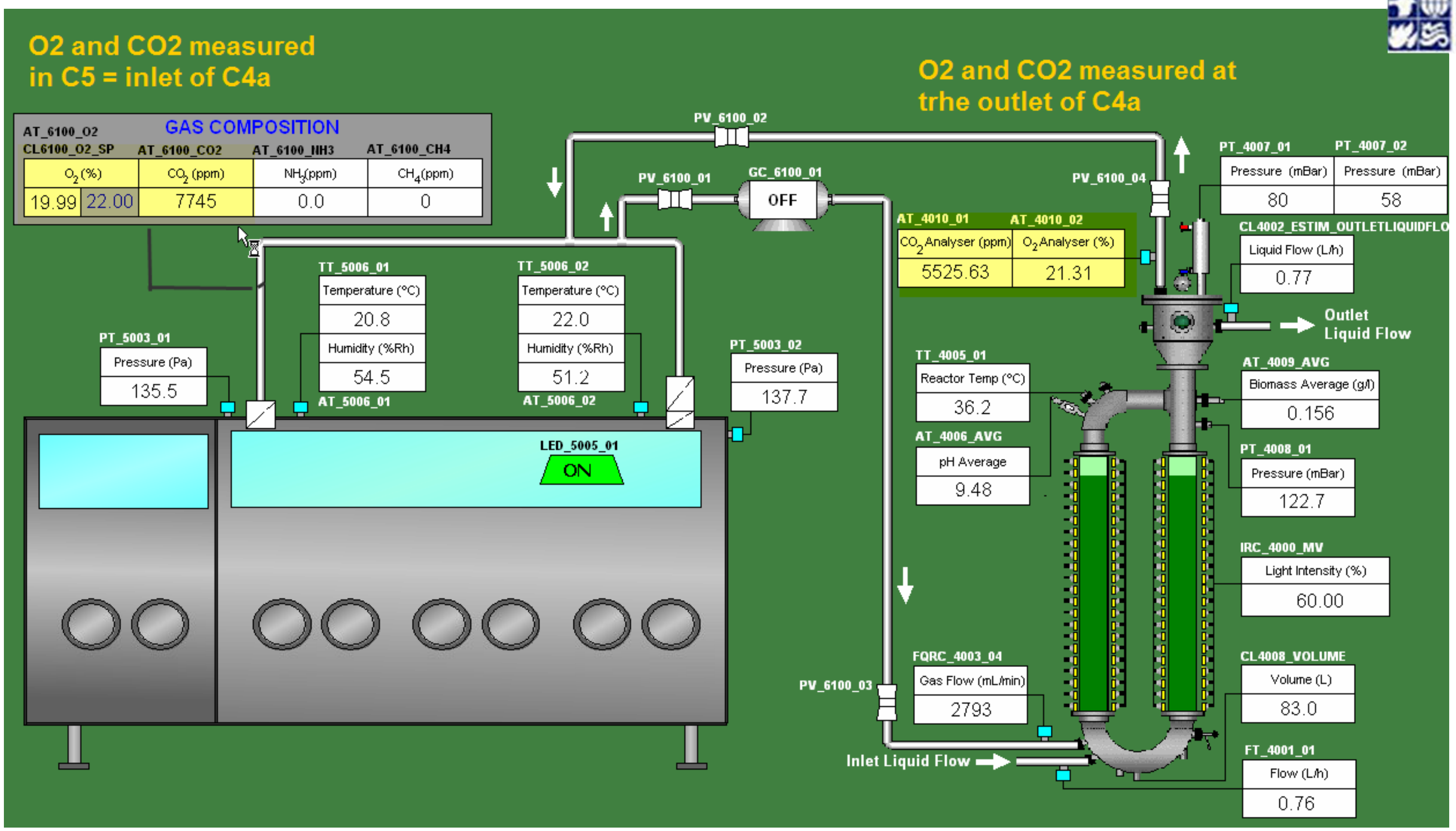


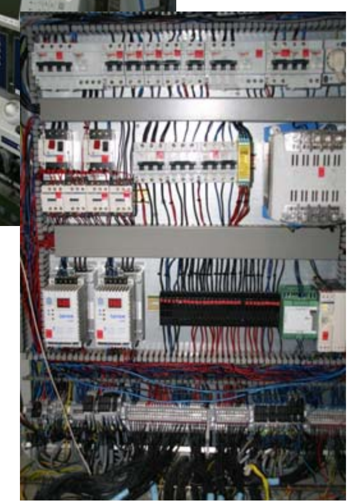
WP1 integration. ClVa + CV connection by gas phase

- Continuous gas phase connection ClVa-CV at different conditions in CV (set points of % O_2)
- ClVa illumination adjusted by the control system to produce the oxygen necessary to maintain set-point of O_2 in CV, according to the knowledge model linking O_2 production and illumination



Instrumentation, supervision and control at MPP: Integration WP1





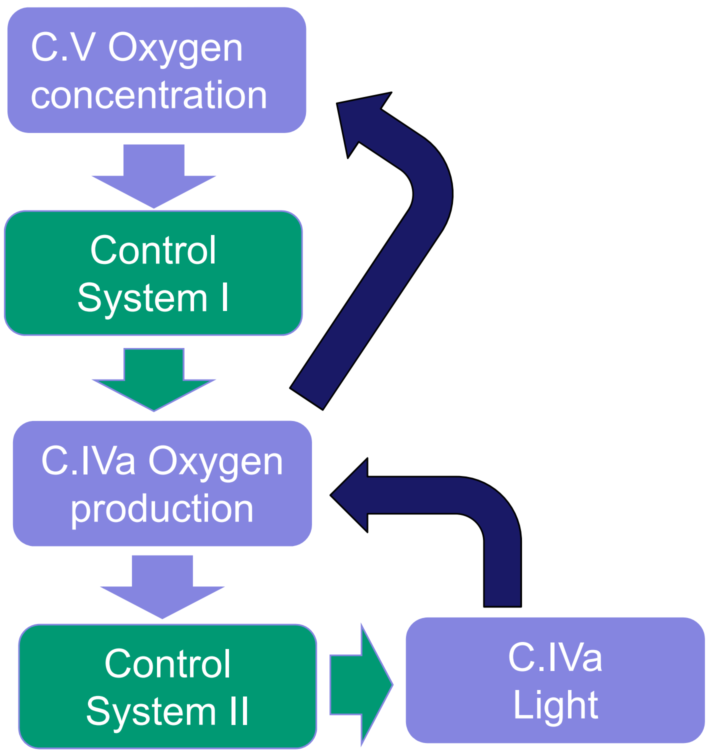
WP1 Integration. Experimental Results. Compartment conditions

COMPARTMENT V SUBSYSTEM	
Volume	1600 L
Temperature	22 ºC
Pressure	1.002 bar
Number of rats	3

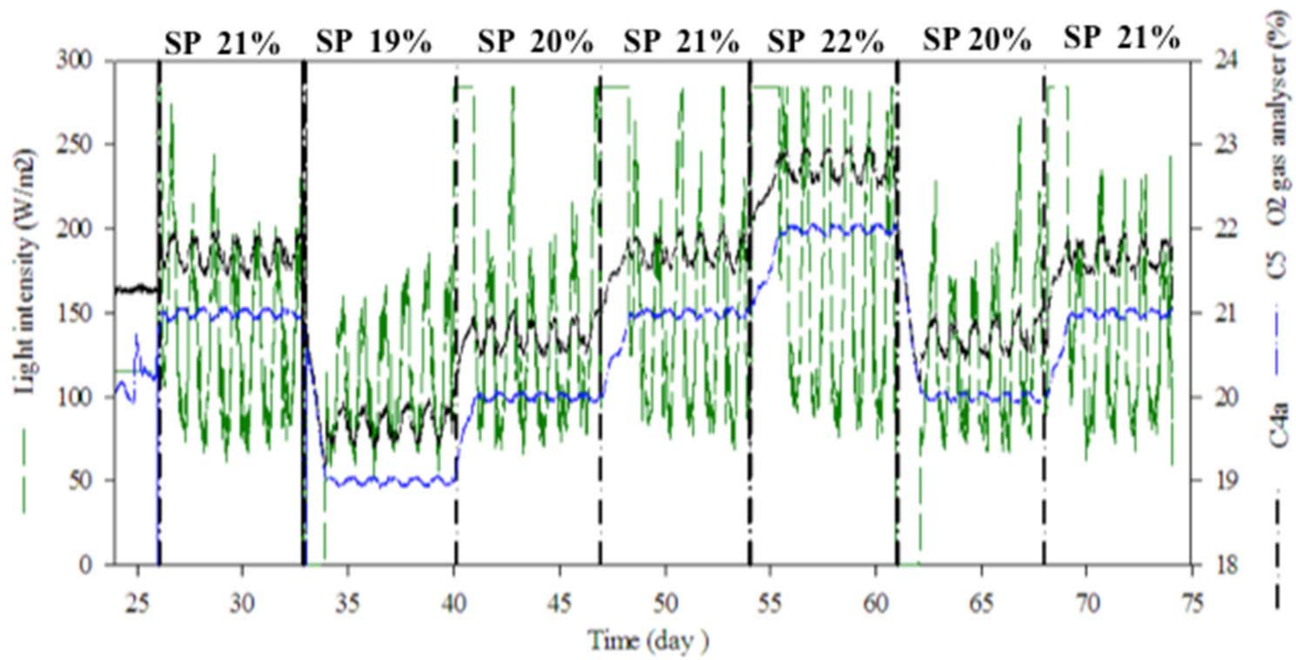
COMPARTMENT IV SUBSYSTEM	
Temperature	36ºC
Pressure	1.08 atm
pH	9.4
k_La	11 h^{-1}
Reactor characteristic length	0,076 m
Reactor volume	83 L
Reactor gas volume fraction	1%
Liquid flow rate	0.75 L/h
Gas flow rate	168 L/h

WP1 integration. Experimental results.
CIVa + CV sequential test

Oxygen – Light control system



Light and Oxygen evolution in CIVa and CV compartments

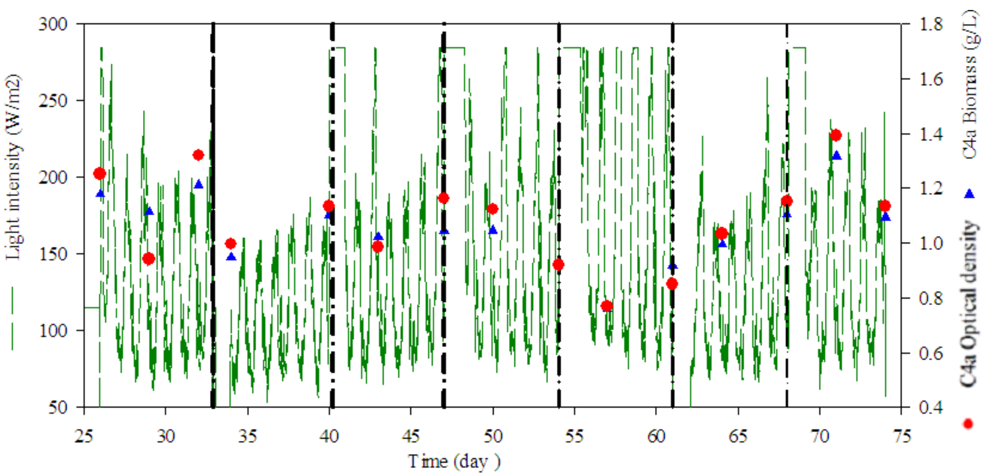


The system response to CV oxygen set point changes is consistent in the range tested.

WP1 integration. Experimental results.
CIVa + CV sequential test

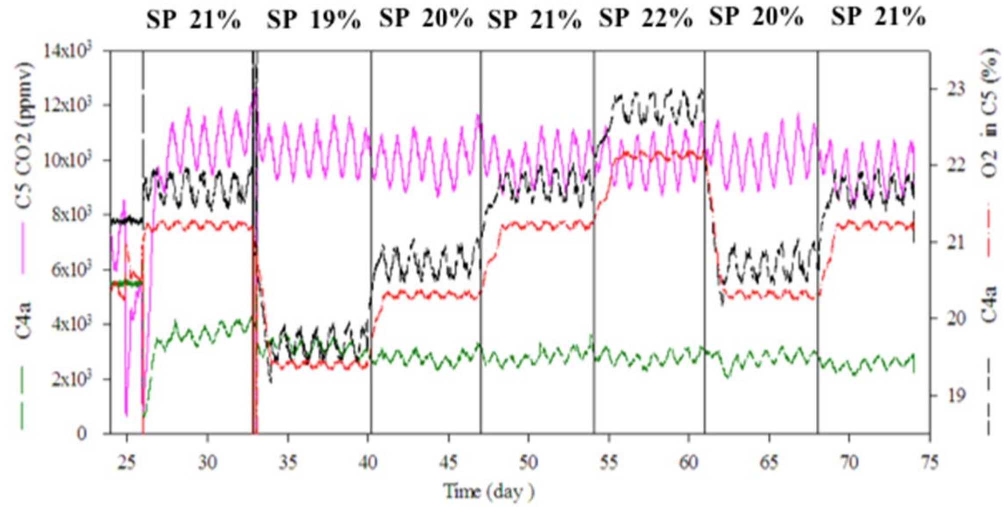
Light and biomass evolution (dry weight and optical density)

Biomass concentration during the test was maintained in the same range.



Oxygen and carbon dioxide evolution (gas composition)

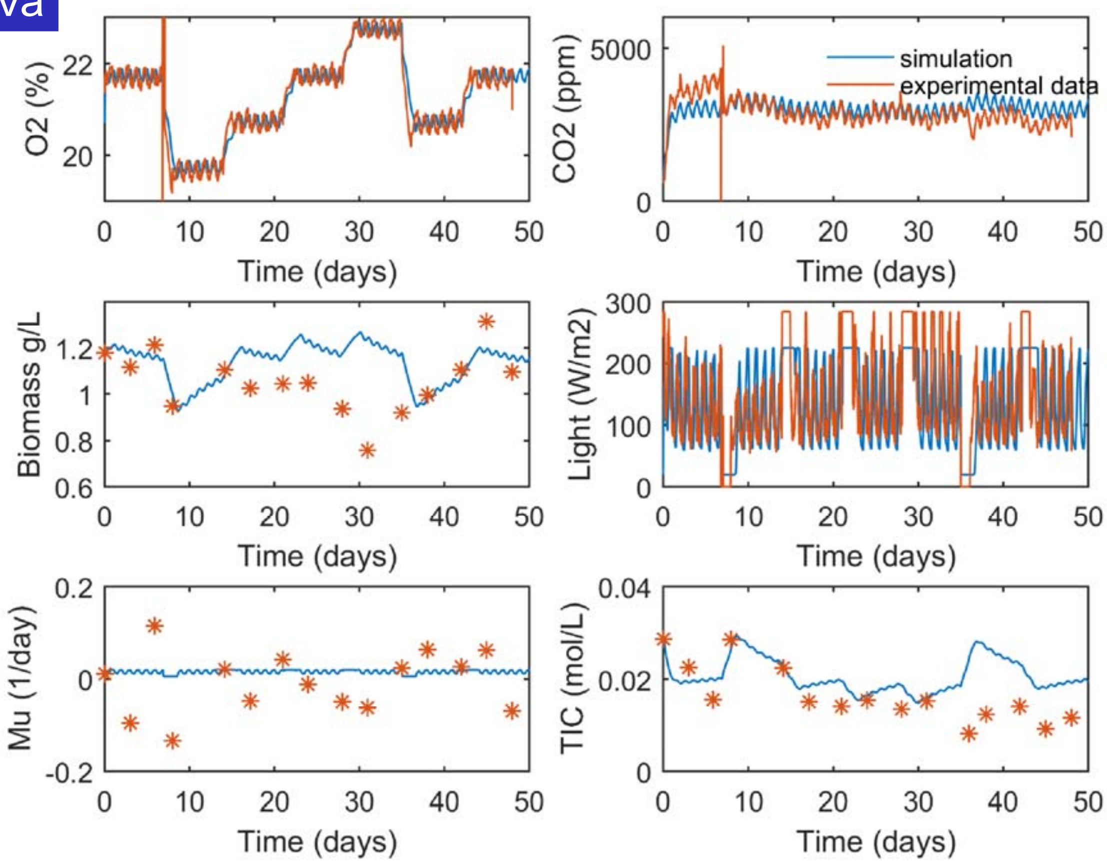
Carbon dioxide concentration in C.V compartment is lower than the toxic limit ($20 \cdot 10^3$ ppm).



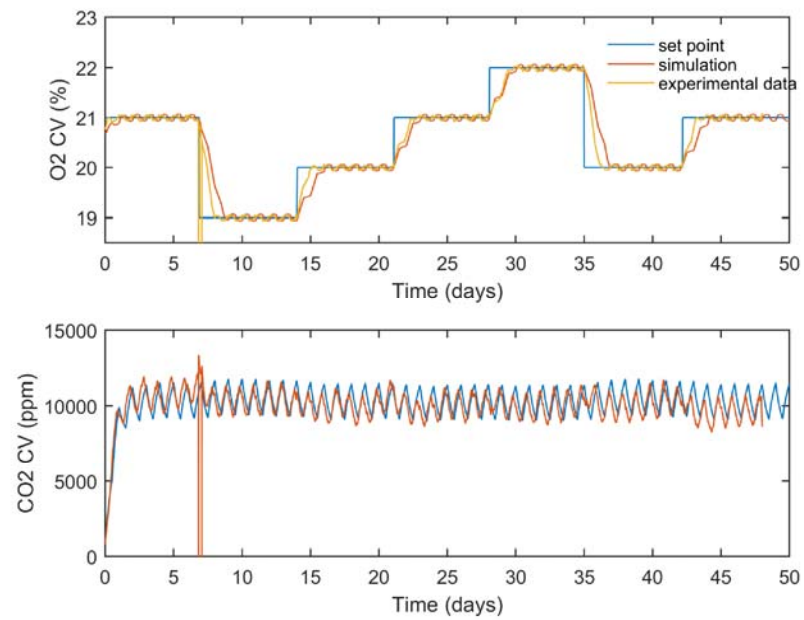
WP1 integration. Modelling and simulation.
CIVa + CV sequential test

Presentation by Enrique Peiro

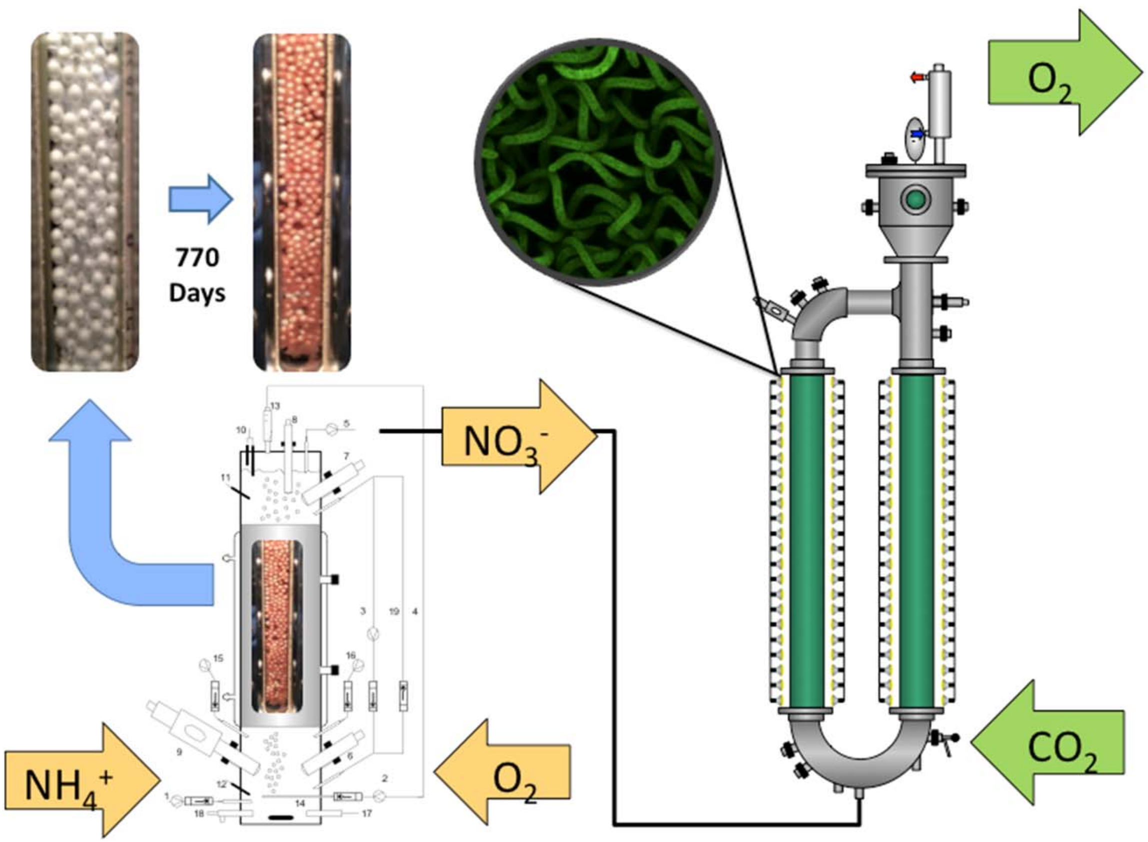
C. IVa



C. V

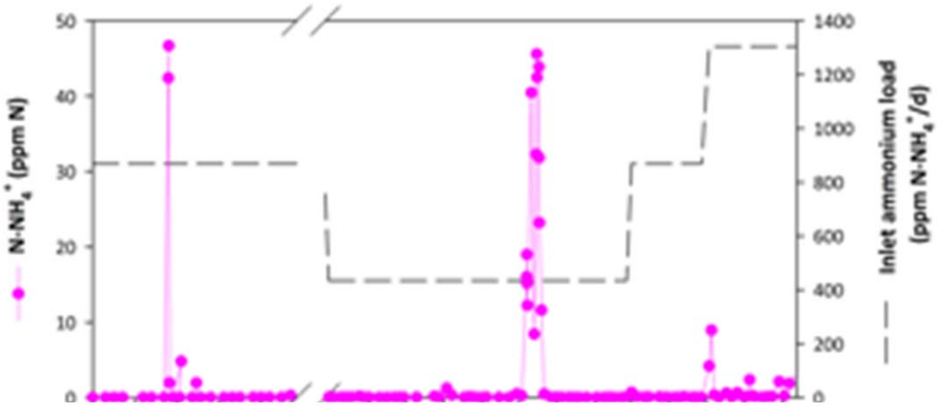


WP3 integration. CIII + CIVa connection by liquid phase



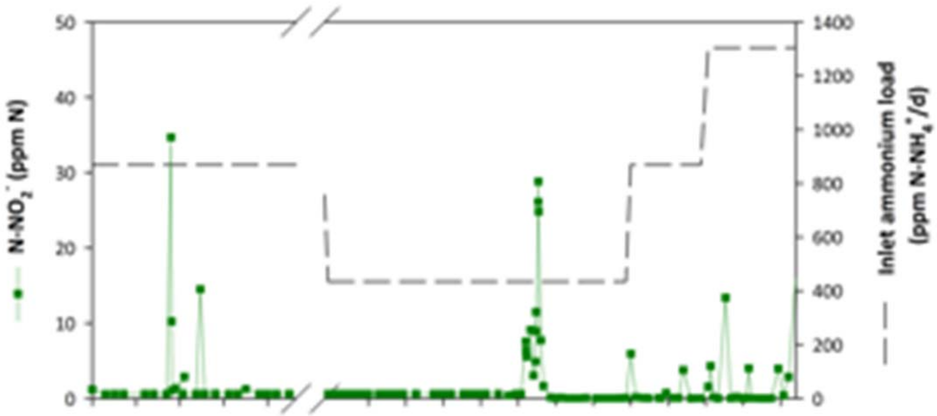
- C3 bioreactor is fed with media containing different nitrogen loads: **434, 869** and **1304** N-NH_4^+ ppm·d^{-1}
- C4a bioreactor *Arthrospira platensis* culture is illuminated at two different light intensities: **120 W·m^{-2} and 285 W·m^{-2}**
- Different inlet flows are used (**10L·d^{-1}, 20L·d^{-1} and 30 L·d^{-1}**) in order to modify the ammonium load and obtaining different *A.platensis* cell concentrations in C4a

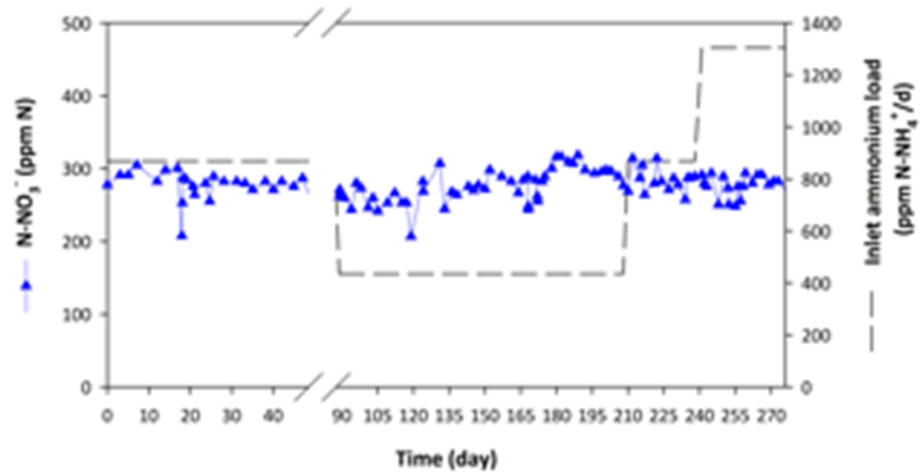
WP3 integration. CIII + CIVa connection by liquid phase: CIII operation



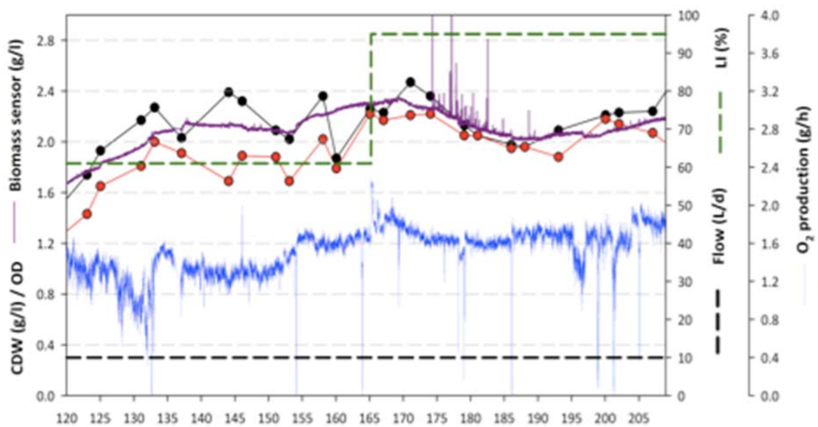
Compartment III operation

- ❑ Complete ammonium elimination
- ❑ Complete nitrification
- ❑ Continuous robust operation. Nitrification is recovered very fast after occasional NH_4^+/NO_2^- due to operational changes
- ❑ Nitrogen balance fully closed: no N loses



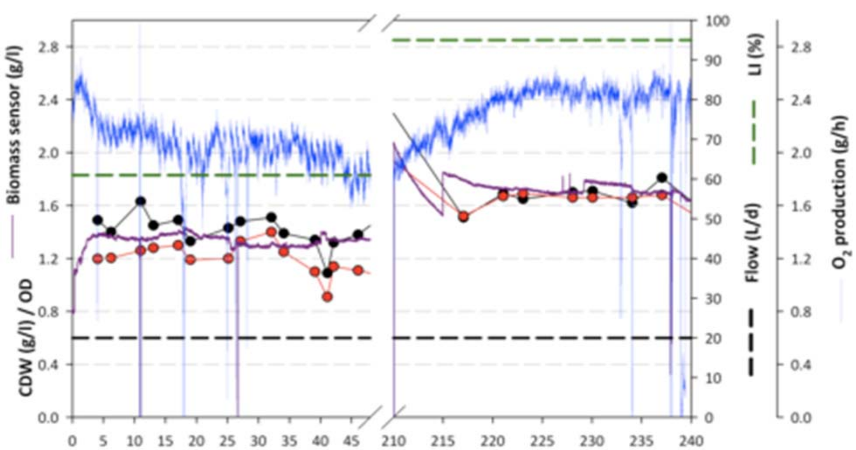


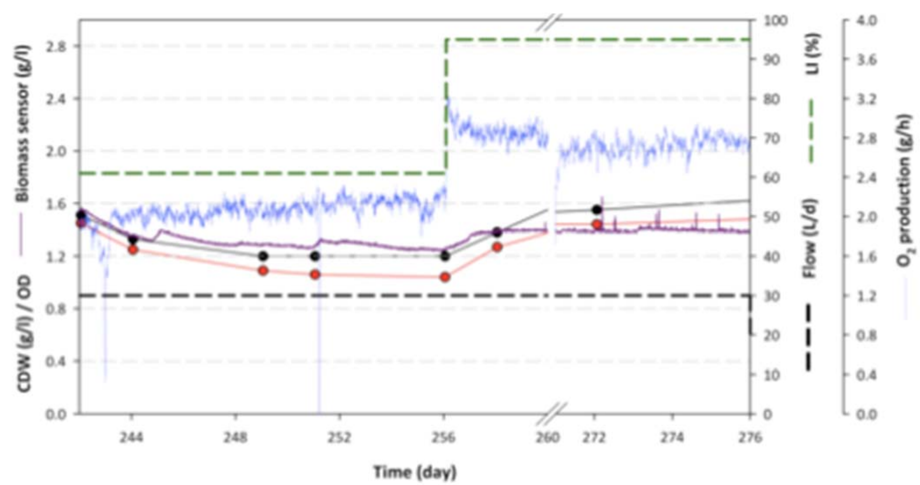
WP3 integration. CIII + CIVa connection by liquid phase: CIVa operation



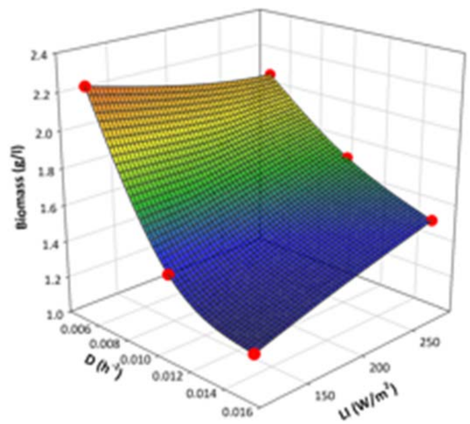
Compartment IVa operation

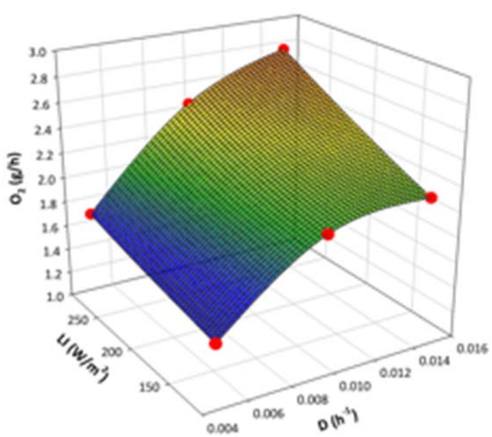
- ❑ Steady-state operation achieved for the three experimental conditions testes (10, 20, 30 L d^{-1})
- ❑ Cell concentration ranging from 1.2-2.2 g l^{-1}
- ❑ Oxygen production ranging from 1.2-2.8 g h^{-1}





WP3 integration. CIII + CIVa connection by liquid phase: CIVa operation





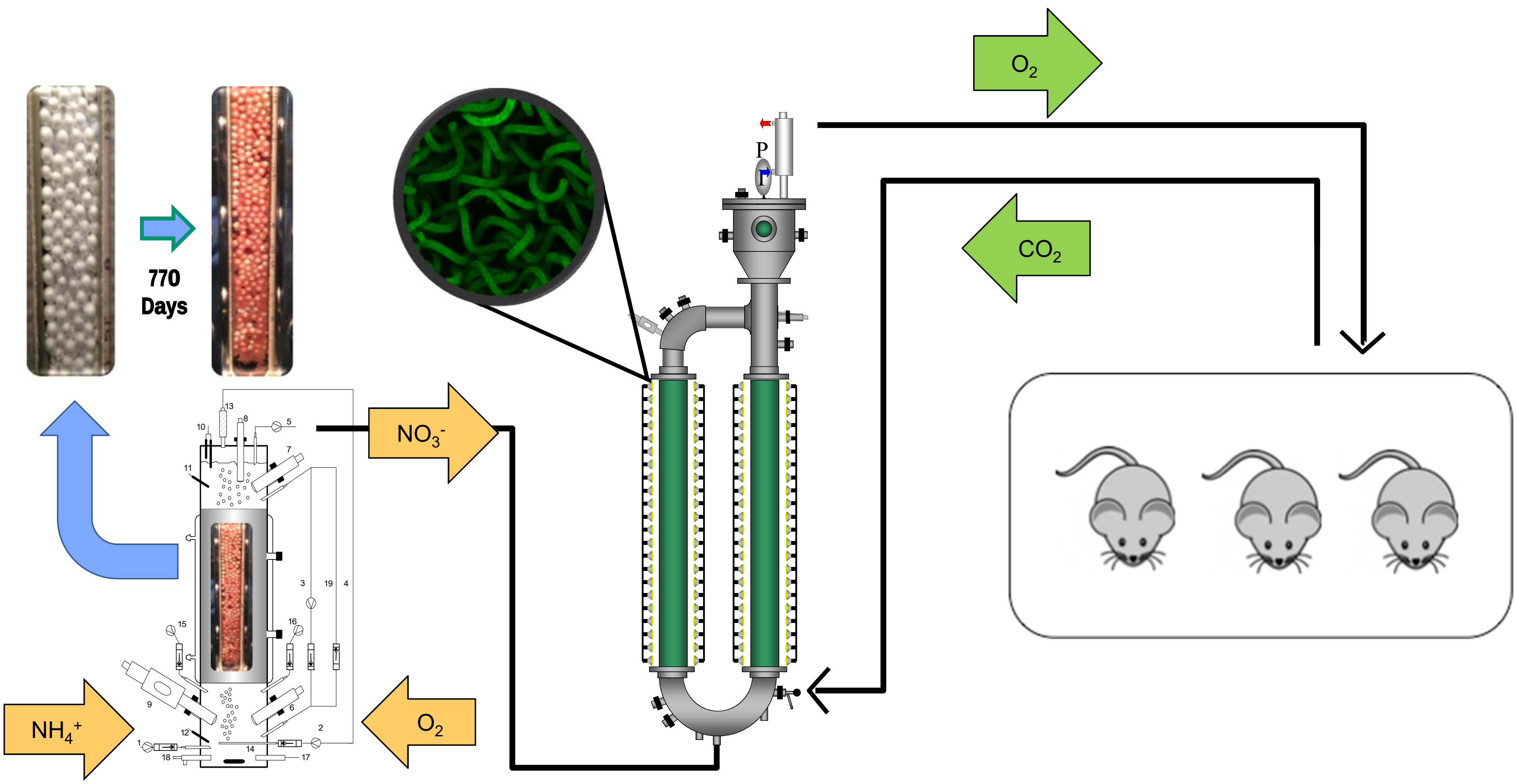
Oxygen production

Poster by David García

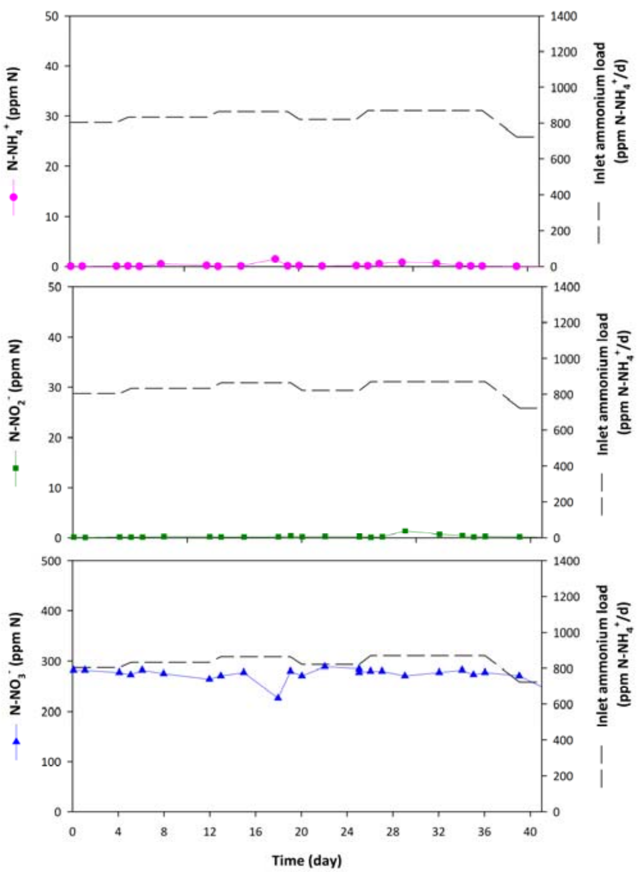
- Cell concentration in C4a is mainly affected by dilution rate
- Oxygen production is more dependent on dilution rate than light intensity due to shadow effect of *A. platensis* at low dilution rate
- Specific oxygen production is directly affected by dilution rate. At higher values, Oxygen productivity is increased

D (h^{-1})	Q ($L \cdot h^{-1}$)	Light (W/m^2)	O_2 Production ($g\ O_2/h$)	Biomass (g/l)	qO_2 (mmol/ g·h)
0.005	10	120	1.43±0.18	2.24±0.15	**0.18**
		285	1.68±0.14	2.05±0.31	**0.24**
0.010	20	120	2.03±0.15	1.41±0.12	0.44
		285	2.44±0.13	1.70±0.07	**0.46**
0.015	30	120	2.11±0.08	1.20±0.00	**0.55**
		285	2.76±0.10	1.50±0.08	**0.60**

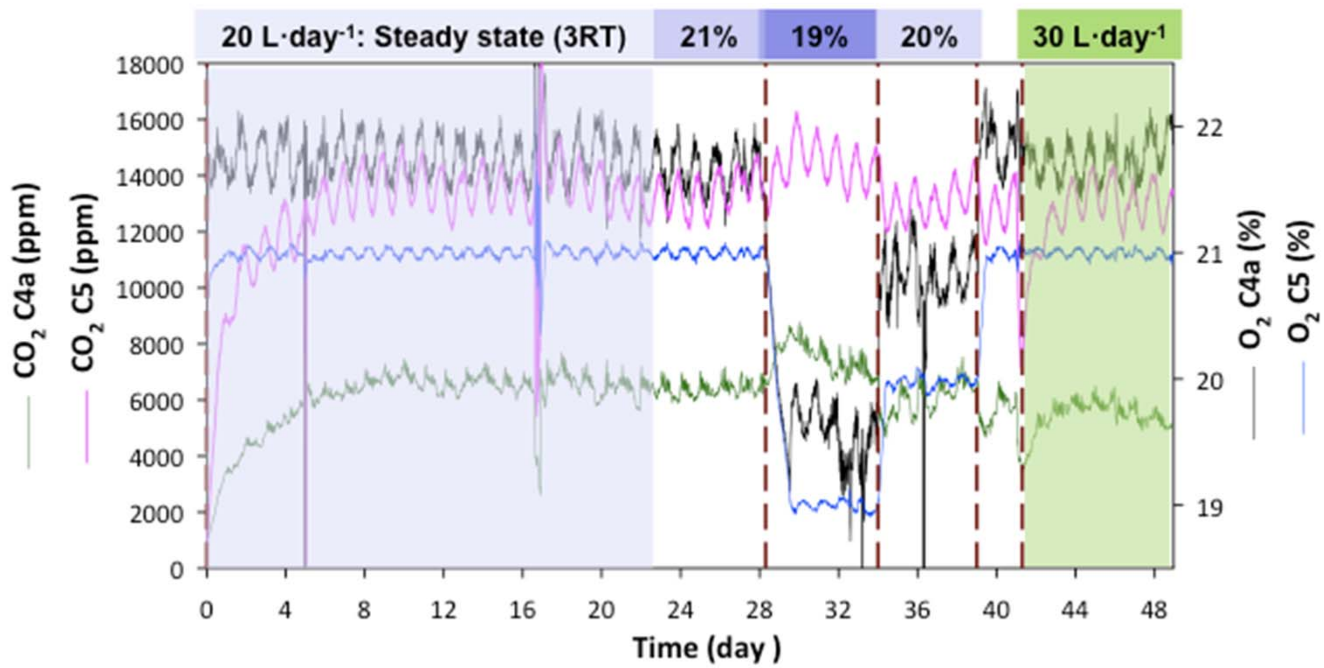
WP4 integration. CIII + CIVa connection by liquid phase and CIVa + CV by gas phase



WP4 integration. CIII + CIVa connection by liquid phase and CIVa + CV by gas phase



- All compartments operating in continuous mode and connected for several months
- Dynamic and static operation under control system fully demonstrated



Conclusions

- The MELiSSA Pilot Plant is a prolonged effort of the complete MELiSSA Consortium and associated parties
- Since its initial steps in 1995, it has been consolidating several steps in pursuing its main goal: the demonstration and integration of the complete MELiSSA loop and its several subsystems
- MELiSSA Pilot Plant has achieved high quality standards of operation
- Continuous long-term operation of pilot scale compartments under well controlled conditions has been achieved and has enabled to accumulate a lot of knowledge on these systems
- Three integration steps have been completed, involving three compartments
- The achieved goals and future activities planned should enable the MPP to generate valuable data and evidence for the design of life support systems for Space Exploration

Acknowledgements

MELiSSA Partners

ESA (EU), SCK/CEN (B),
University of Ghent (B),
VITO (B), Enginsoft (I)
SHERPA Engineering (F) ,
University Clermont Auvergne
University of Guelph (CND),
Université Mons Hainaut (B)
IP Star (NL), Univ. Napoli (I)
Univ. Lausanne (CH)

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Ca

Funding

ESA (several programs), several national delegations (Spain, Belgium, Canada, Italy. France, Norway)
UAB
SEIDI, CDTI, GdC

MELiSSA ESA-ESTEC

Christophe Lasseur
Brigitte Lamaze
Christel Paillé
Pierre Rebeyre

MELiSSA: from the concept to a solid reality through a collaborative effort

The MELiSSA Pilot Plant was dedicated
on April 26th, 2011 to

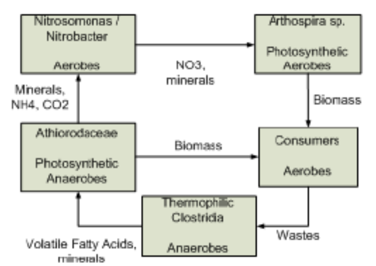
Claude Chipaux (1935-2010),

Founder of the MELiSSA Project,
As a tribute to his visionary and pioneering contribution
in the field of Closed Life Support Systems

"Sur la lune, il y a des enfants
Qui regardent la terre en rêvant.
- Croyez-vous qu'aussi loin
Il y ait des humains?"

"On the Moon are children
Who see the Earth and wonder.
- Could there be some human-kind
Far away, out yonder?"

The first MELiSSA loop concept



Mergeay, Verstraete, Dubertret, Lefort-Tran, Chipaux, Binot (1988)
"MELiSSA – A micro-organisms based model for CELSS development"
Proc. 3rd Eur. Symp. Spac. Therm. Con & LSS, Noordwijk NL, 3-6 Oct 1988

The lake, a model ecosystem

The future MELiSSA loop...