MELiSSA: an approach to using Biological Systems for Life Support in Space

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Outline

- Background
- The MELiSSA concept and approach
- The MELiSSA Pilot Plant. Laboratory Calude Chipeaux
- MELiSSA Compartments Development
- MELiSSA Pilot Plant hardware

The metabolic consumables for Life Support in Space

- **Metabolic consumables: for 5 kg/day/person, 6 crew members, 1000 Days (Mars mission): 30.000 kg**
- **Including hygiene water (20 kg/day/person): 132.000 kg**
- **Best launchers could only drop 9 tones …**

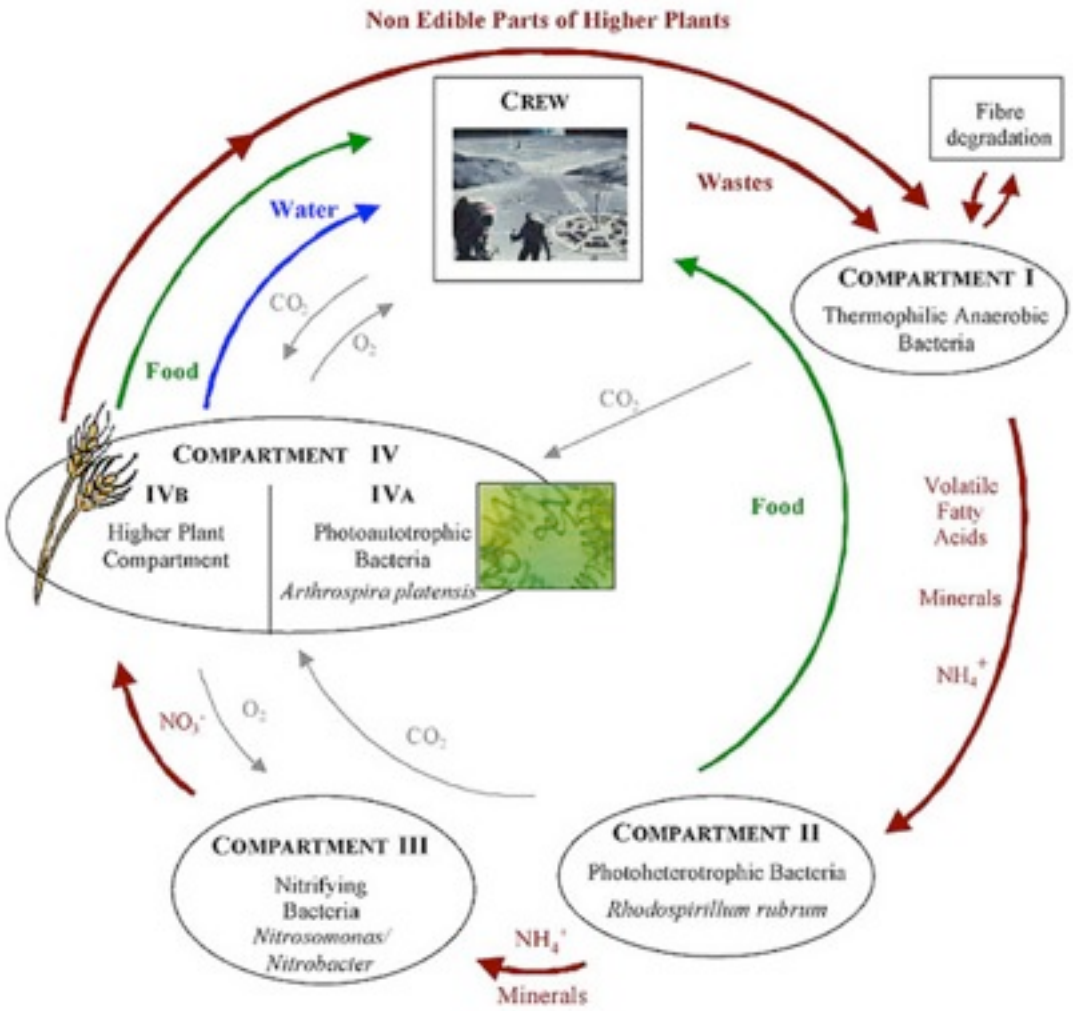
Life Support Functions

For the last 20 years ESA studied :

- **Air Recycling**
- **Water Recycling**
- **Waste Management**
- **Food Production and Preparation**
- **Quality control (chemical and microbiological)**
- **Reliability and Safety Issues**
- **Modelling and System tools**
- **Ergonomics and Habitability**

The MELiSSA Concept

The MELiSSA Concept



- MELiSSA is conceived as a Closed Life Support system, based on the assembly of biological and physico-chemical processes
- It is based on different biological compartments, each one performing a specific task within the loop
- Goals are the recovery of Food, Water and Oxygen from Waste and CO_2
- Global approach of the Life Support requirements
- Overall Engineering approach

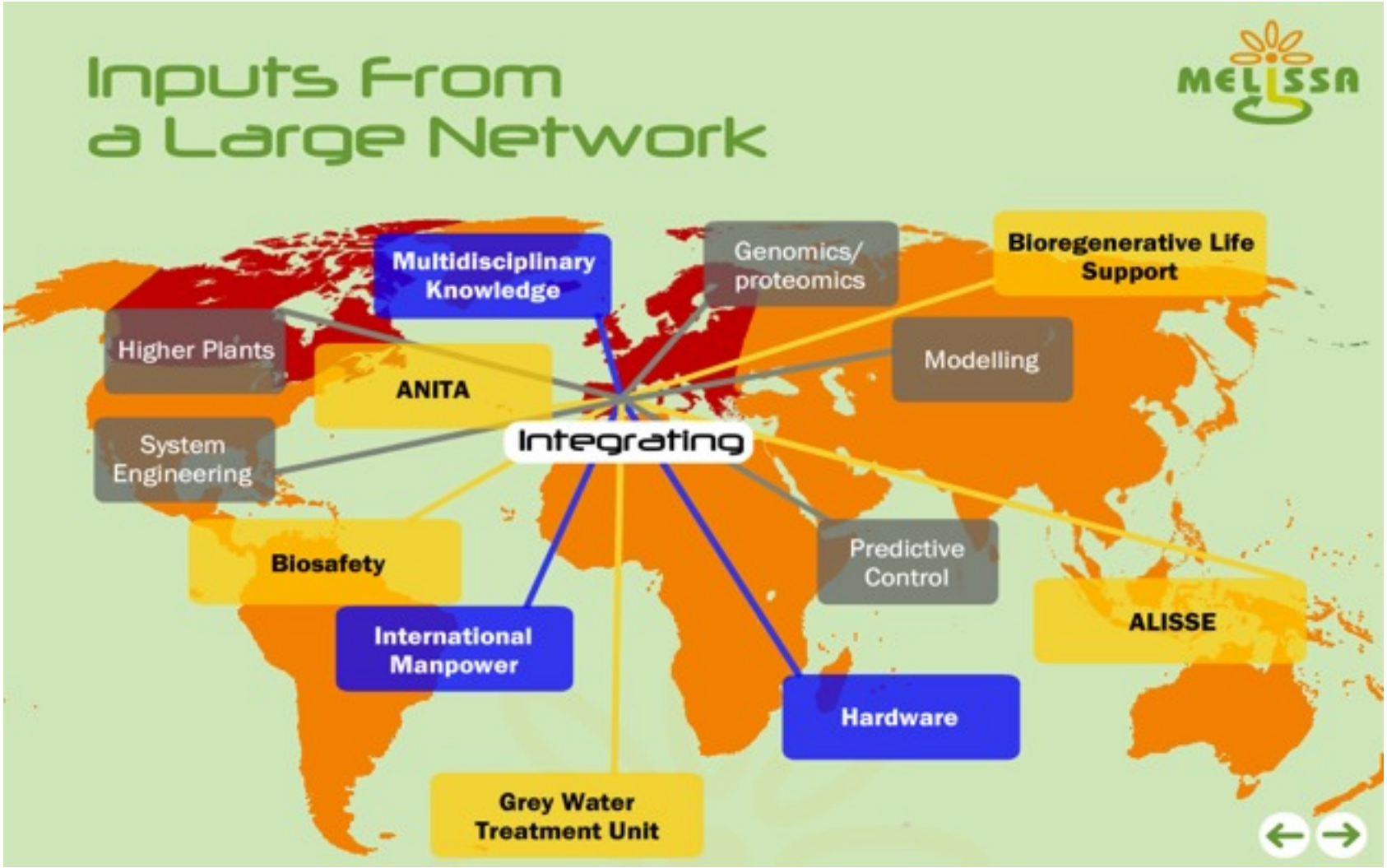
MELiSSA Consortium: and International Collaborative Effort

- 20 years of research on closed recycling system
- A community of around 30 European organisations from universities, SME, world leaders,...(11 organisations in a MOU)
- Roughly 70 persons actively working
- Multiple challenges:
  - Scientific: understanding complex biological systems
  - Engineering: systems engineering, phase separation, modelling, control, bioreactor design and operation, etc.
  - Management: large community, many years, many contracts

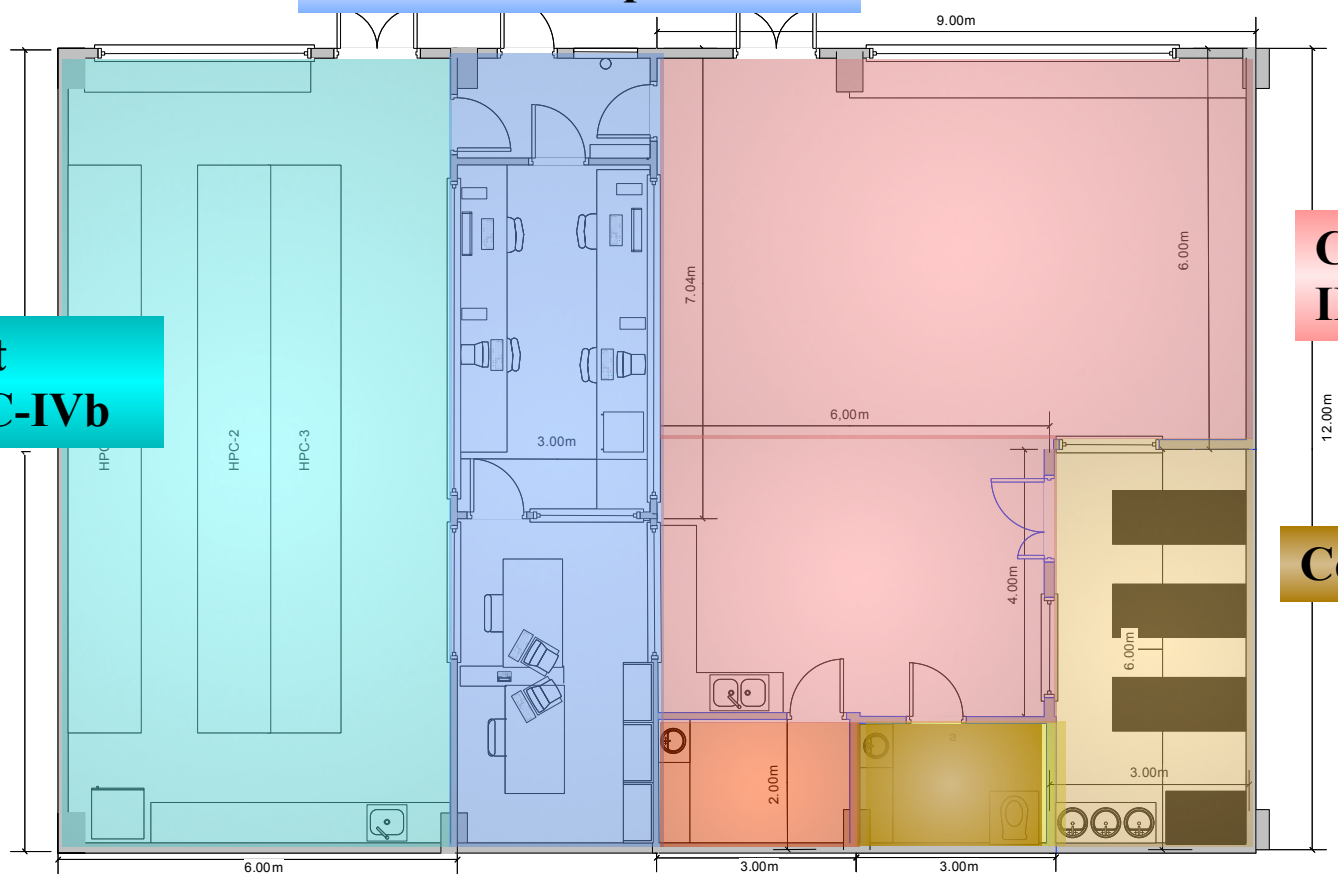
MELiSSA Pilot Plant. Laboratory Claude Chipeaux

- Today, based on all additional MELiSSA knowledge, developed as a second generation laboratory (new hardware, additional team skills), closer to industrial standards.
- The MELiSSA Pilot Plant is now the primary European Facility for Life-Support ground demonstration attracting interests, collaborations and supports from all over the world

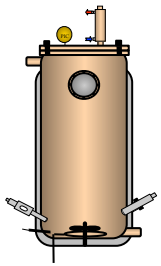
MELiSSA PILOT PLANT: A collaboration effort within and outside the MELiSSA Consortium



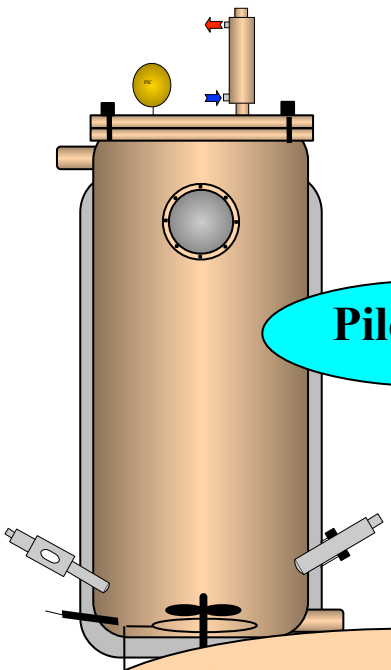
The MELiSSA Pilot Plant at UAB: General lay-out



Development of individual compartments



Bench scale



Pilot scale

- Cell growth
- Light distribution
- Gas-liquid mass transfer
- Reactor hydrodynamics
- Design equations
- Quality control

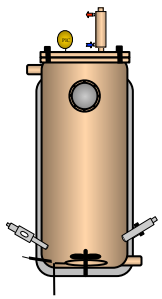
Basic design and characterization

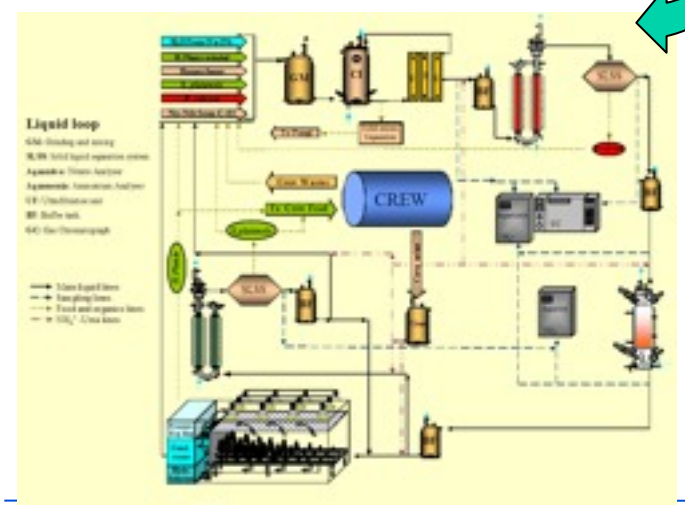
- On-line monitoring
- Development of mathematical models
- Development of control laws
- Continuous operation: steady-state and perturbations

Operation, monitoring and control

Collaboration of various MELiSSA partners

Integration of the MELiSSA loop: main guidelines





- Individual compartments at pilot scale
- Associated control laws
- Interfaces, such as holding tanks, biomass harvesting systems, feed preparation unit, …
- Associated sensors, sampling protocols, quality control procedures

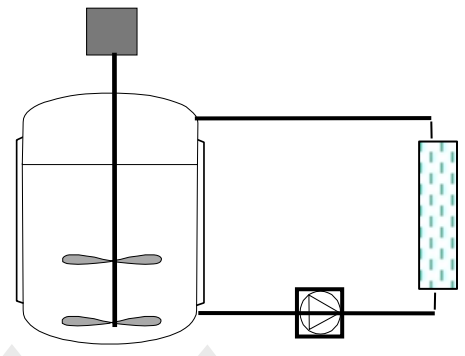
Progressive integration when inputs available

- Step by step approach
- Three main loops: gas-liquid-solid
- Closure of elemental mass balances (C,N, O, H, …)
- Progressive development of control laws

Integration and demonstration of the complete MELiSSA loop in the Pilot Plant

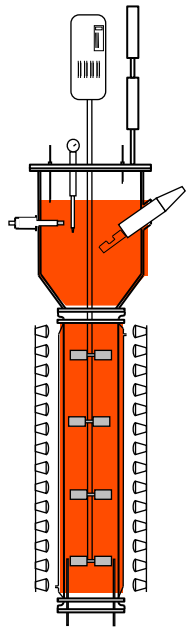
MELiSSA Compartments Development: C-I

Wastes → COMPARTMENT I → VFA



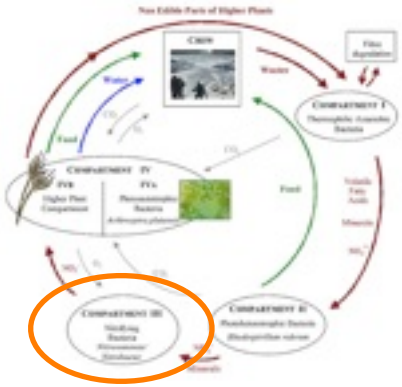
- Thermophilic anaerobic digestion.
- Optimization of the microbial consortium
- Optimization of VFA yields and operation conditions
- Bioreactor: continuous stirred tank with cell and suspension solids retention by external membrane filtration

MELiSSA Compartments Development: C-II

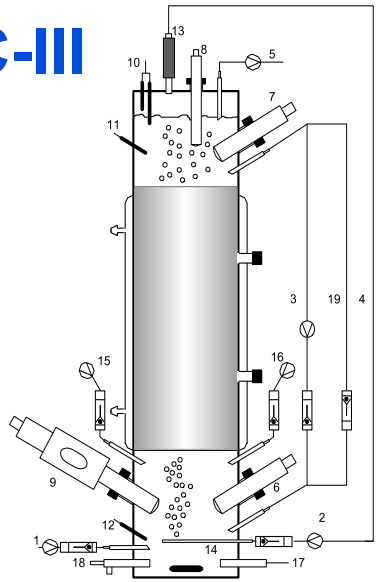


- Axenic culture of *Rhodospirilum rubrum* in anaerobic photoheterotrophic conditions.
- Optimization of the culture conditions, strains, media, etc.
- Development of the mathematical model and control system
- Bioreactor: continuous stirred tank with external illumination

MELiSSA Compartments Development: C-III



NH_4^+ → COMPARTMENT III → NO_3^-



- Axenic co-culture of *Nitrosomonas europaea* and *Nitrobacter winogradsky*.
- Optimization of the culture conditions, strains, media, etc.
- Development of the mathematical model and control system
- Bioreactor: continuous packed-bed with immobilized cells, biofilm generation on polystyrene support

Compartment III redesign: characterization of Biofilm: A cooperative research with L. Hendrickx team at SCK (Belgium)

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Distribution of *Nitrosomonas europaea* and *Nitrobacter winogradskyi* in an autotrophic nitrifying biofilm reactor as depicted by molecular analyses and mathematical modelling

Anna Montràs[a,1], *Benny Pycke*[b,c,1], *Nico Boon*[c], *Francesc Gòdia*[a], *Max Mergeay*[b], *Larissa Hendrickx*[b,†], *Julio Pérez*[a,*]

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Compartment III redesign: characterization of Biofilm: A cooperative research with L. Hendrickx team at SCK (Belgium)

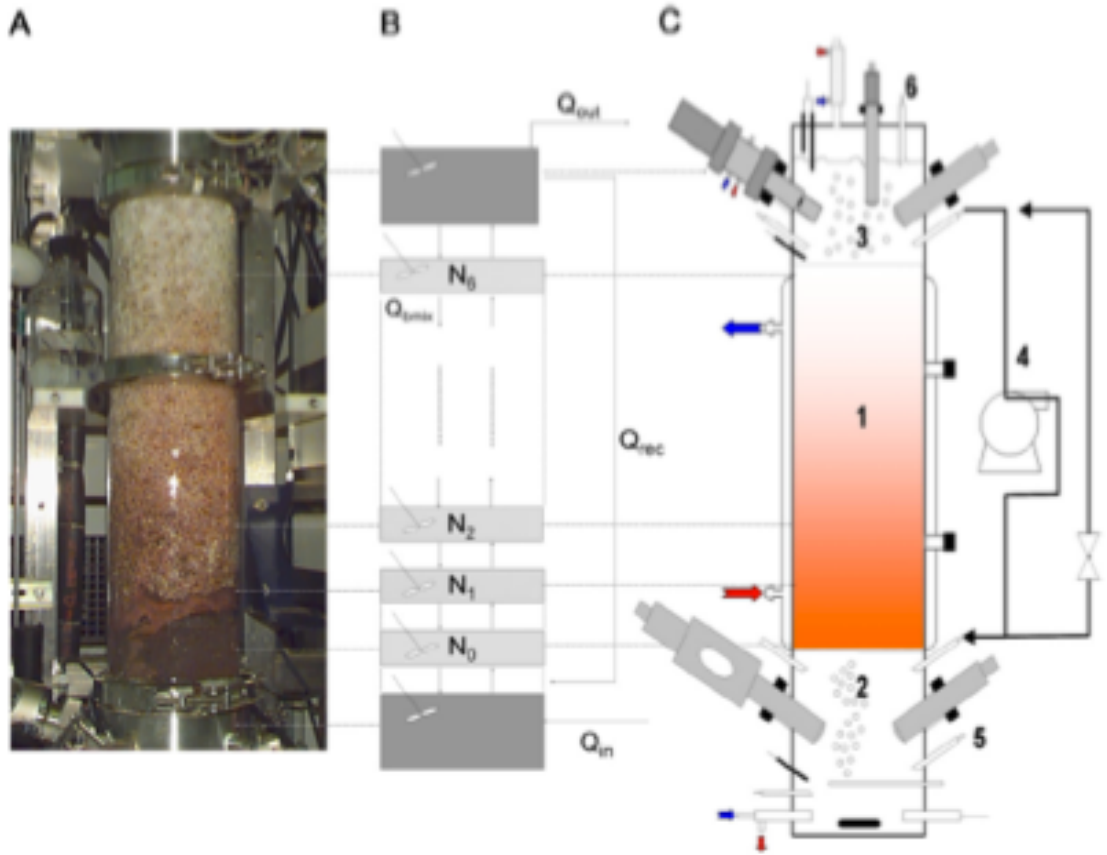
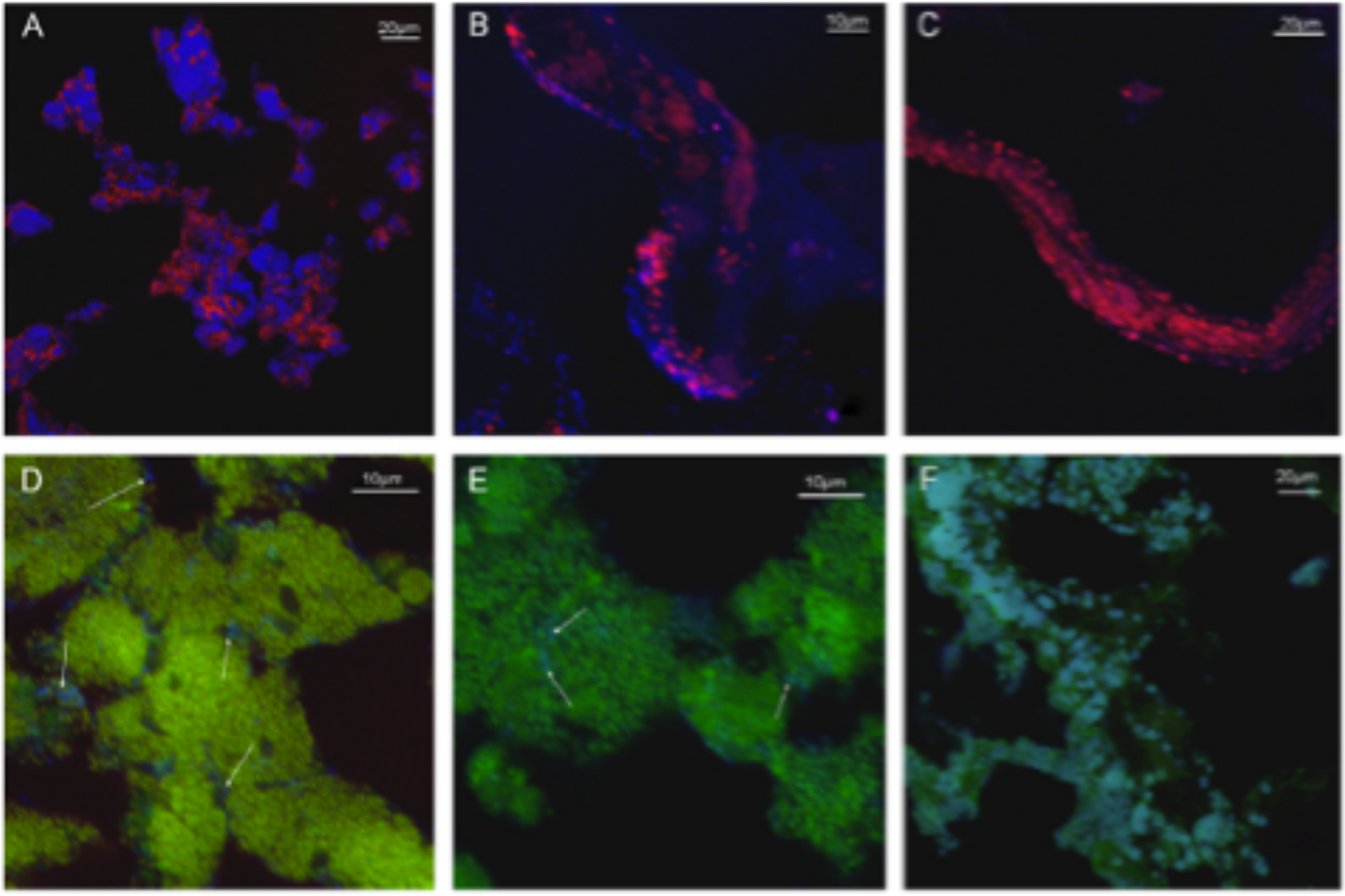
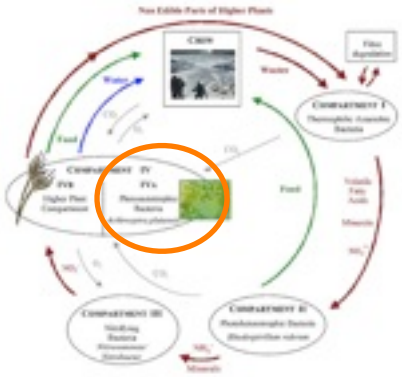
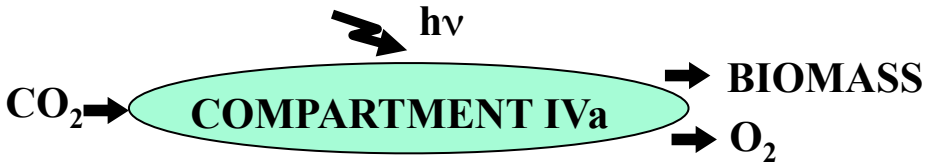


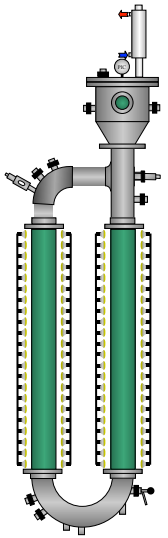
Fig. 1 – (A) Picture of the reactor at t = 1750 days. (B) Flow model of the fixed-bed reactor as defined for AQUASIM modelling. (C) Scheme of the hardware of the packed bed bioreactor used in this study (Pérez et al., 2004). (1) Packed bed section, (2) bottom section for air and liquid supply, (3) top section for liquid–gas separation, (4) liquid recirculation and back-washing loop, (5) reactor liquid feeding and (6) reactor liquid exhaust.


A
20μm
B
10μm
C
20μm
D
10μm
E
10μm
F
20μm

MELiSSA Compartments Development: C-IVa

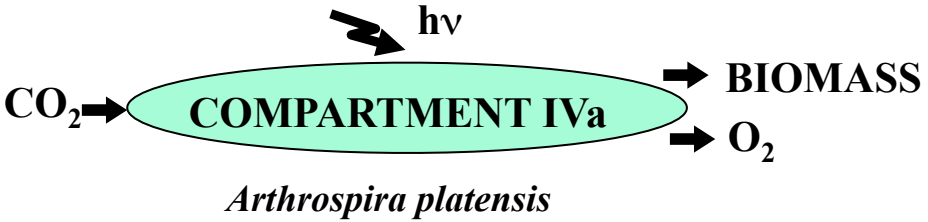




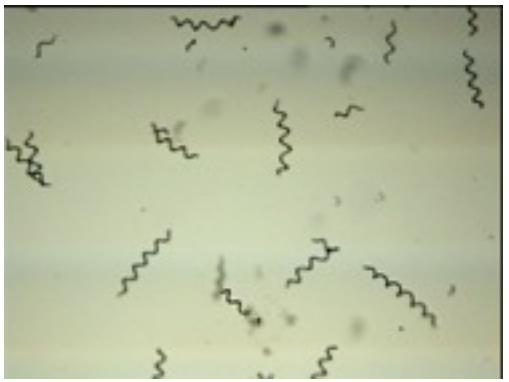


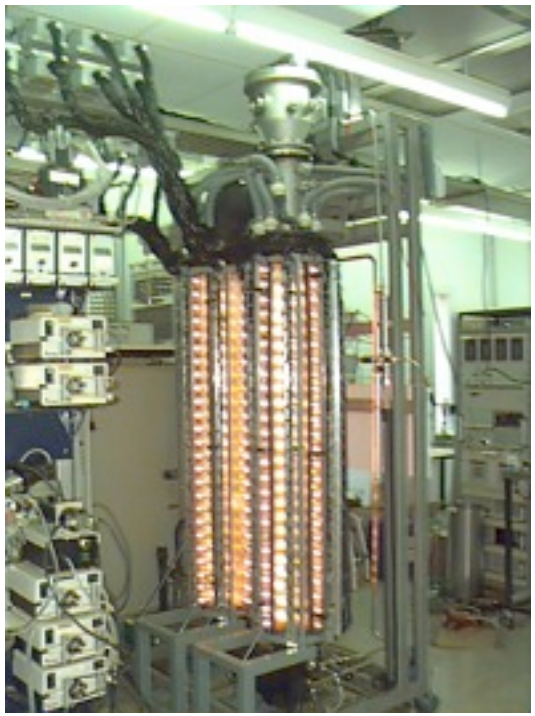
- Axenic co-culture of *Arthrospira platensis*.
- Optimization of the culture conditions, strains, media, etc.
- Development of the mathematical model and control system
- Bioreactor: continuous gas-lift reactor with external loop, and external illumination

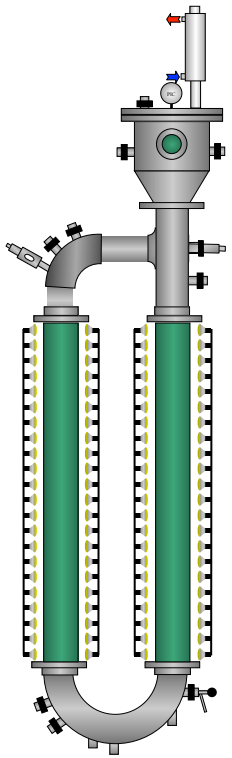
Compartment C-IVa operation

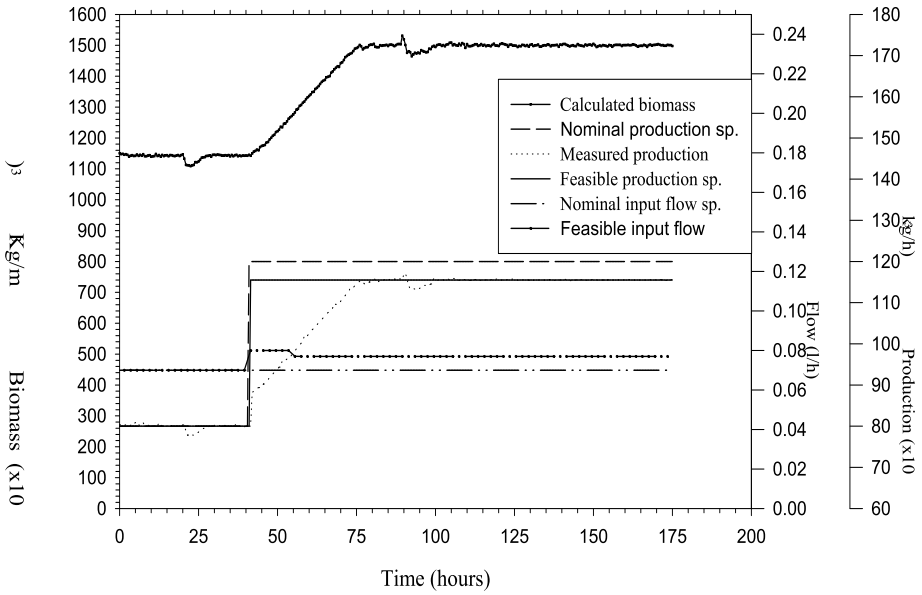


Arthrospira platensis





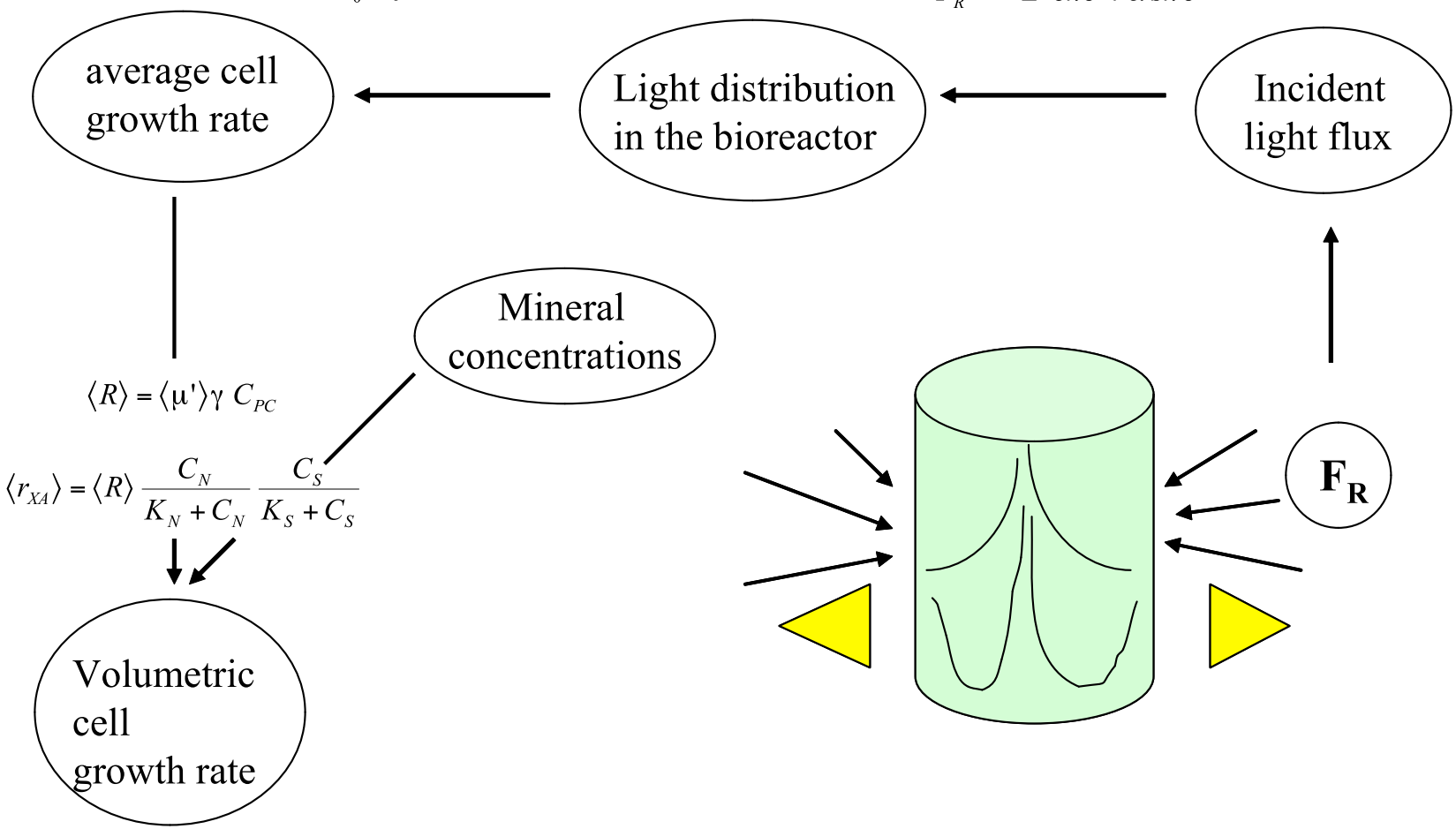




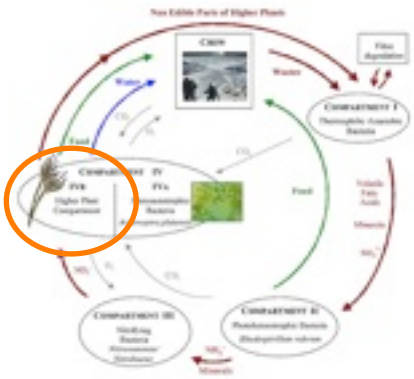
Mathematical model: Growth-light interaction (LGCB, UBP)

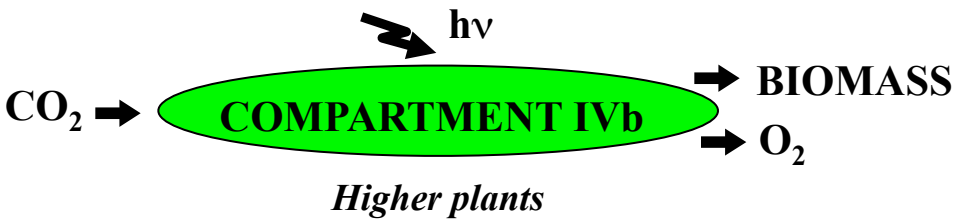
$$\langle \mu' \rangle = 2\mu'_m \int_0^1 \frac{4\pi\, Jr}{K_J + 4\pi\, Jr}\, r\left(4\pi\, Jr \rangle 1W/m^2\right) dr$$

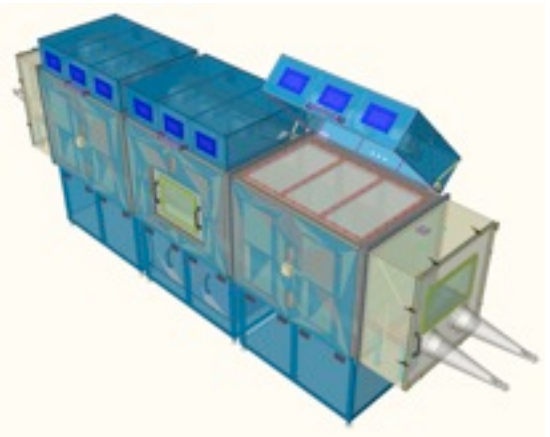
$$\frac{4\pi\, Jr}{F_R} = \frac{1}{Z}\,\frac{2ch\delta\, Z}{ch\delta + \alpha\, sh\delta}$$



MELiSSA Compartments Development: C-IVb

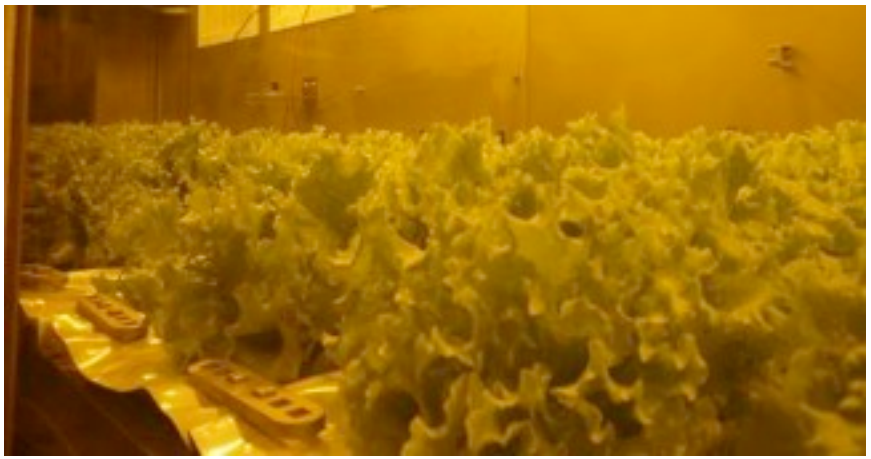






- Plant culture in hydroponic systems.
- Crop characterization: beet, lettuce, wheat, durum wheat, soybean, potato
- Development of the mathematical model and control system: effect of light, medium composition, basic stoichiometries
- Plant culture chambers based on staggered culture and maximum gas phase tightness.

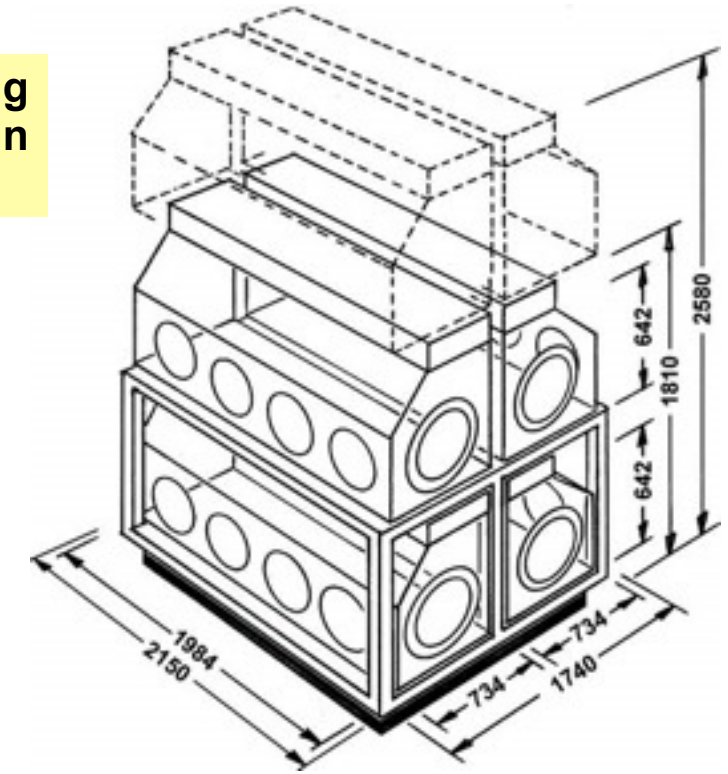
Compartment C-IVb operation



MELiSSA Compartments Development: C-V

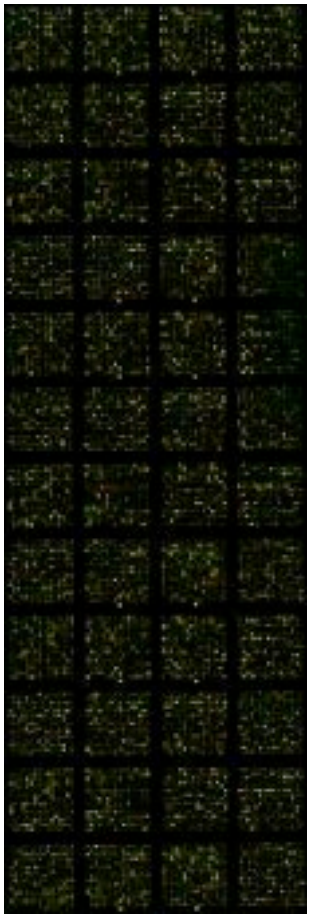
Laboratory Wistar rats

The number of animals simulating the breathing of one person is about 40 rats, to be kept in isolators



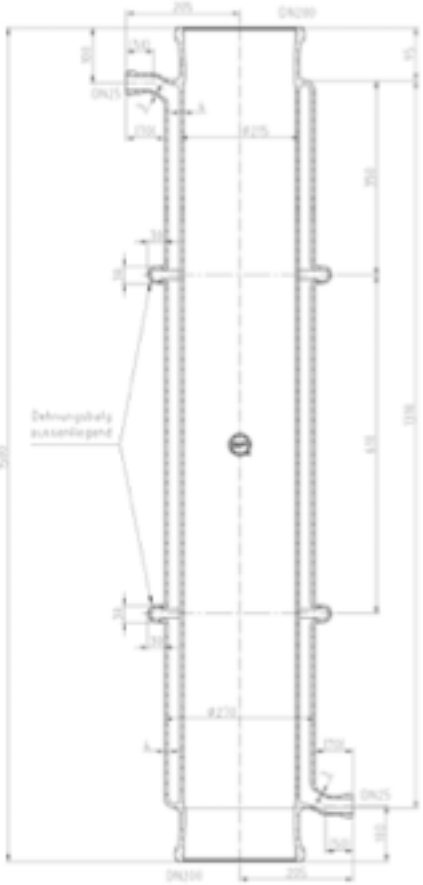
Additional important factors to be considered, related to the use of biological compartments, under axenicity conditions

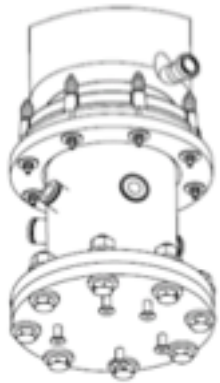
- Clean room operation. Monitoring and control of microorganisms in the atmosphere of the MPP
- Maintenance of culture axenicity over long operation periods
- Genetic stability (genomes of *A. platensis* and *R. rubrum* completed)
- Influence of Space conditions on cellular behaviour

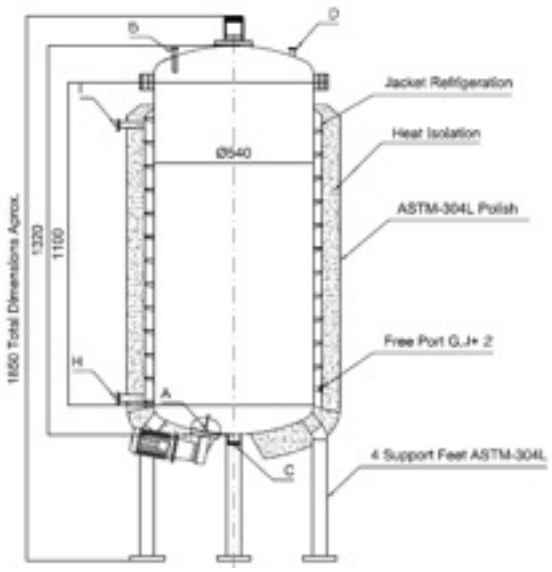


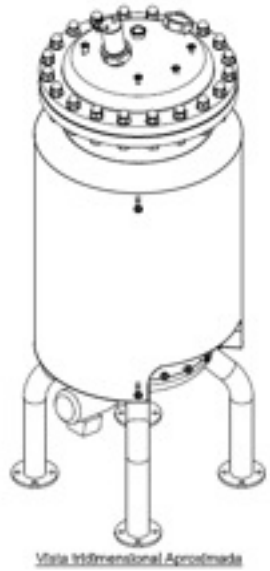
Compartment I

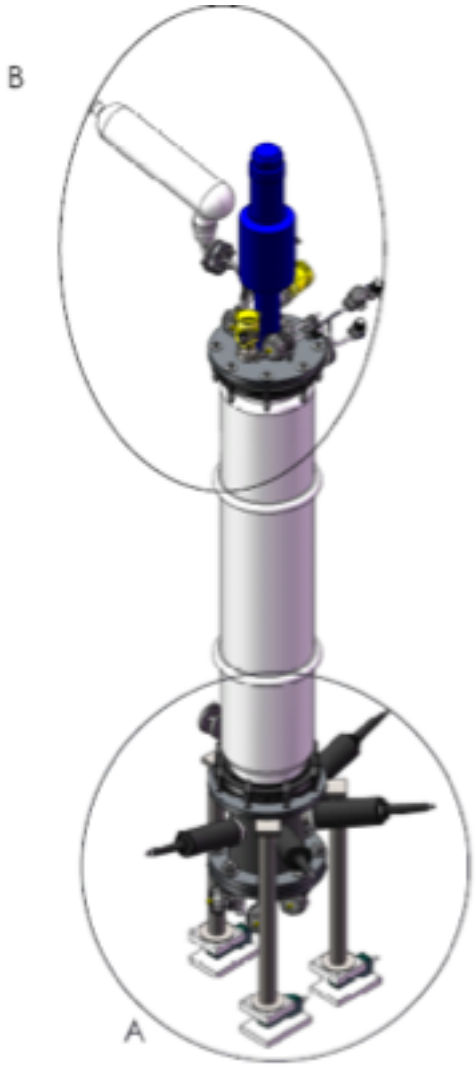
Compartment II: Final design



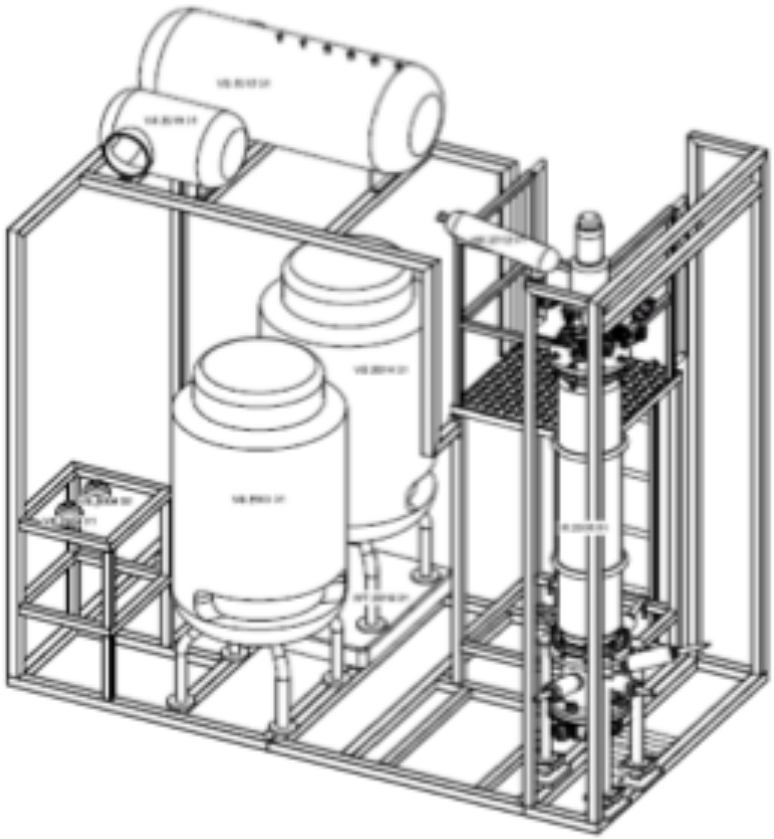


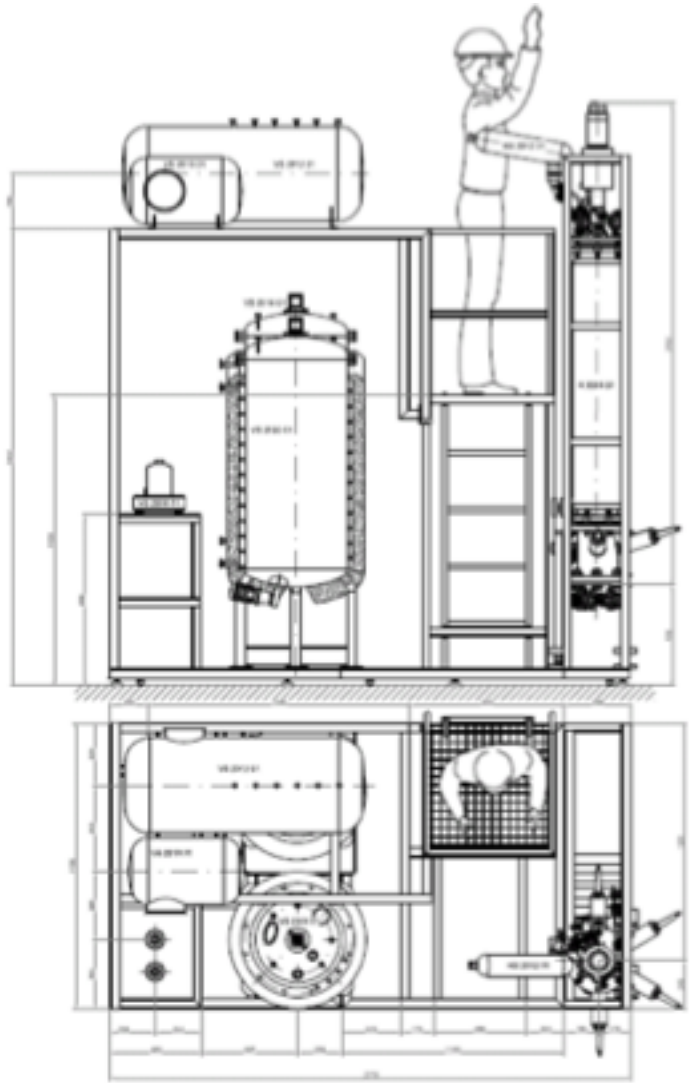




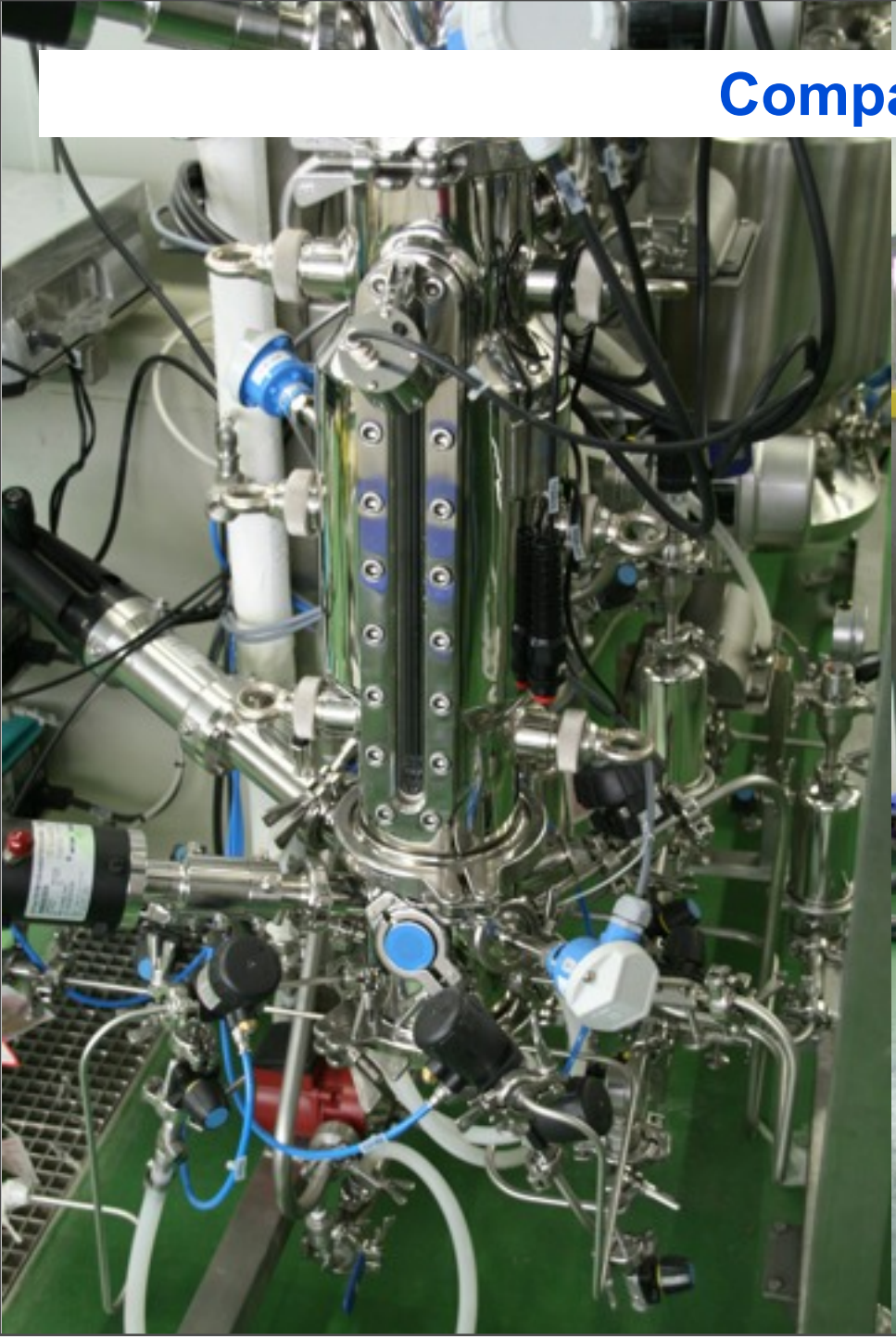


Compartment II: Final layout





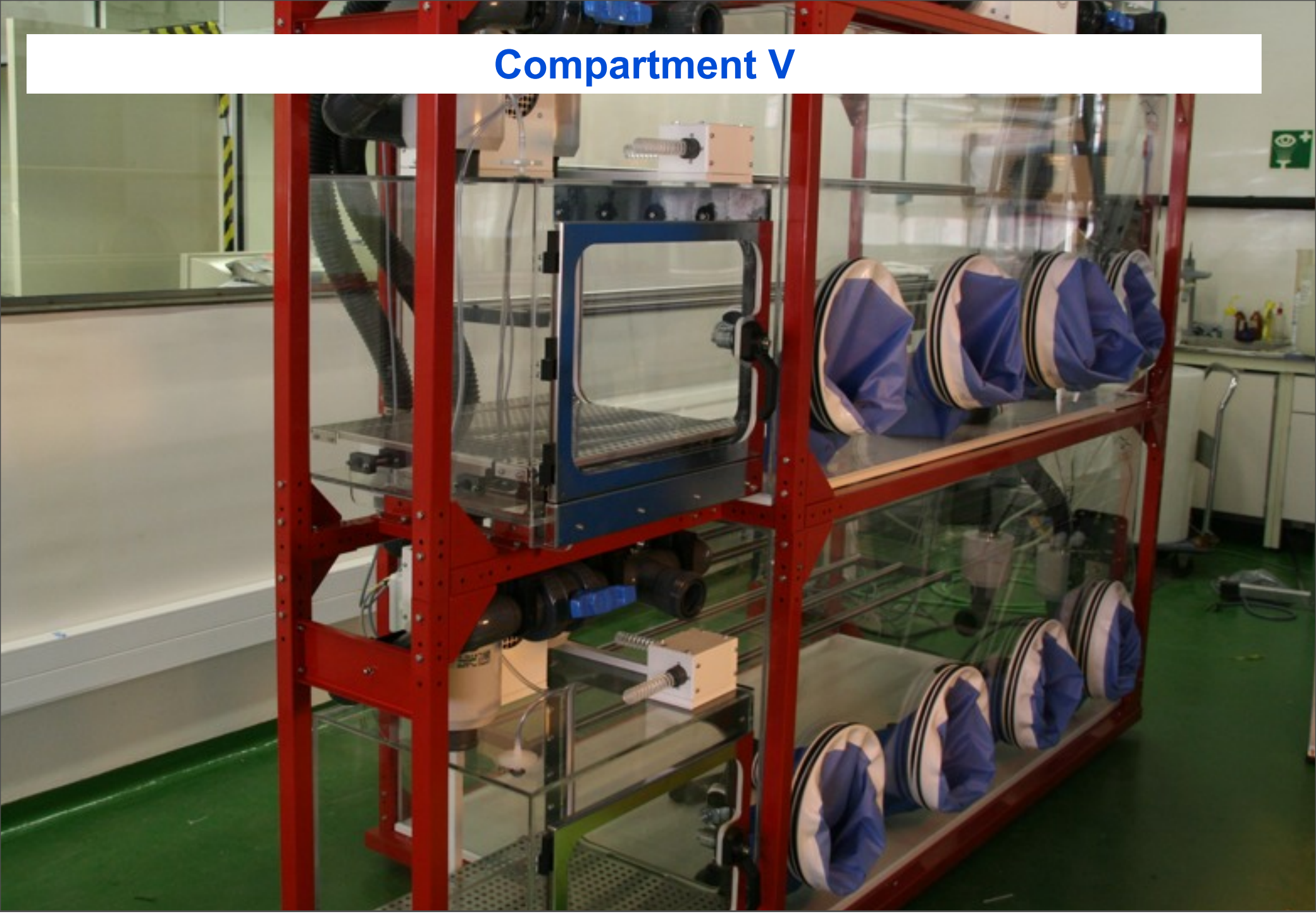
Compartment III



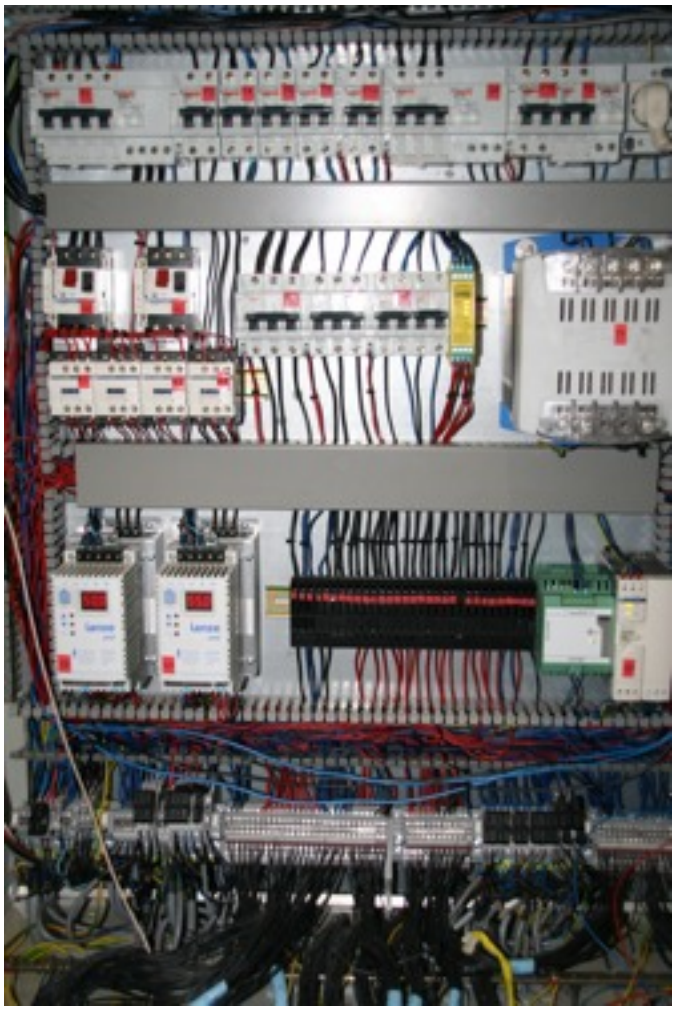
Compartment IVa

Compartment IVb

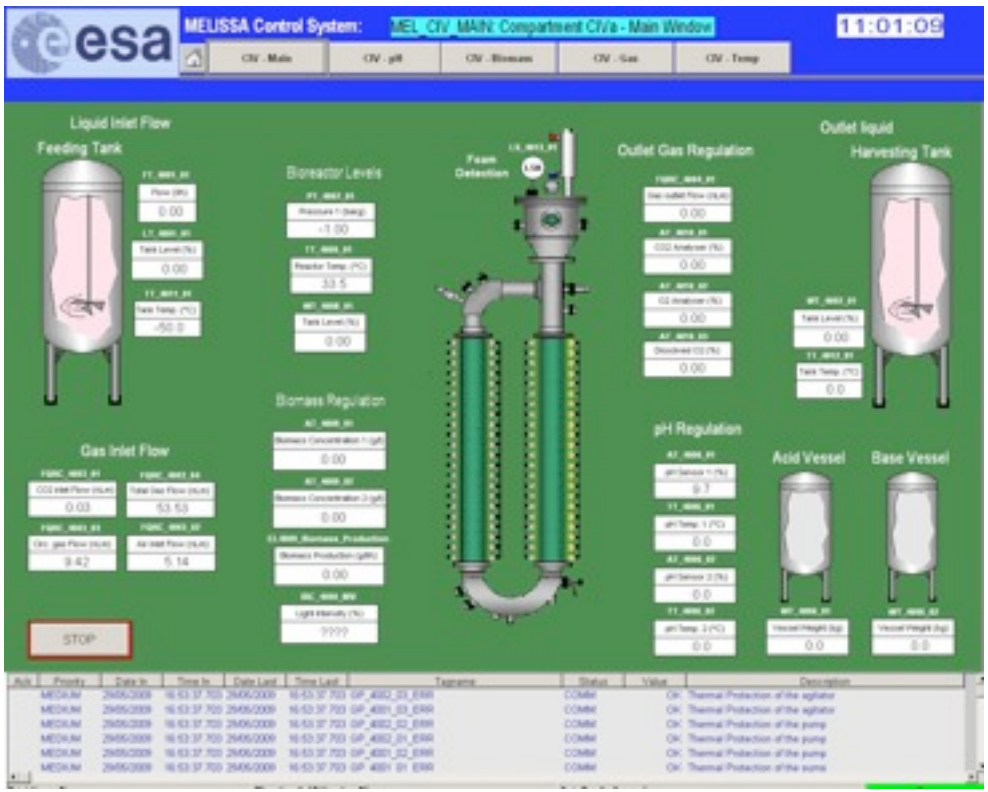
Compartment V

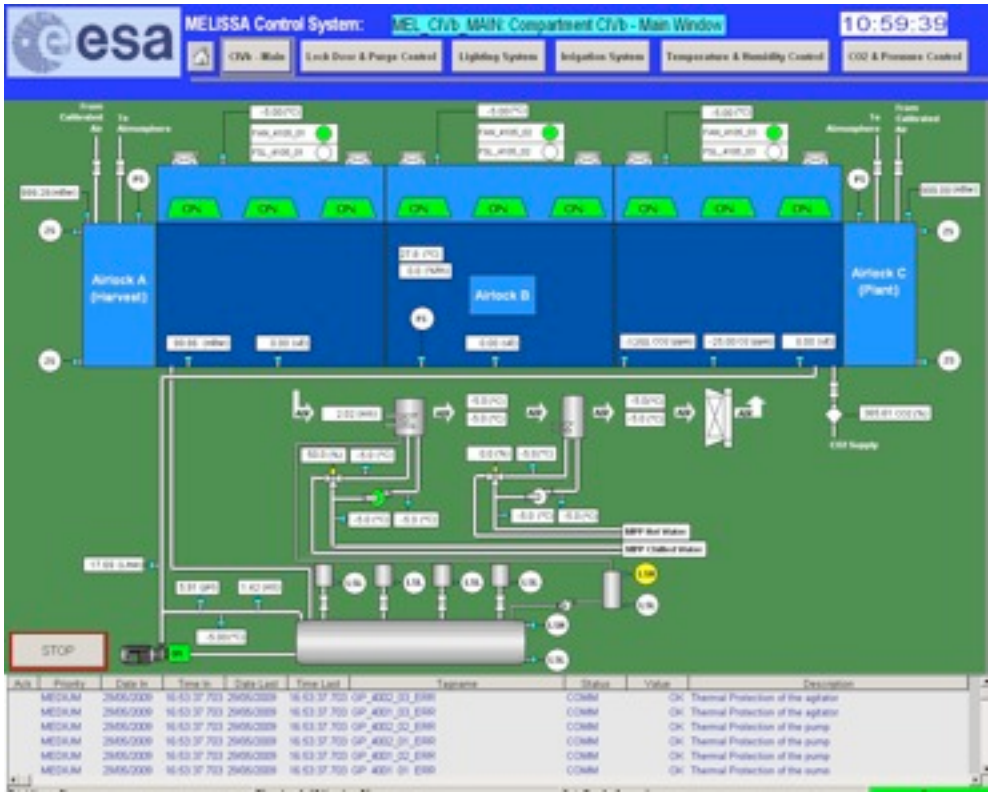


Instrumentation and Control aspects associated to the MPP



Instrumentation and Control aspects associated to the MPP





Acknowledgements

MELiSSA Partners

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MELiSSA Pilot Plant

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Stephanie Raffestin
Ines Antunes
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Christel Paillé