# MELiSSA Pilot Plant Status and Perspective


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# Main requirements for Human Space Exploration and life support systems.

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## Human Space Exploration: main challenges

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

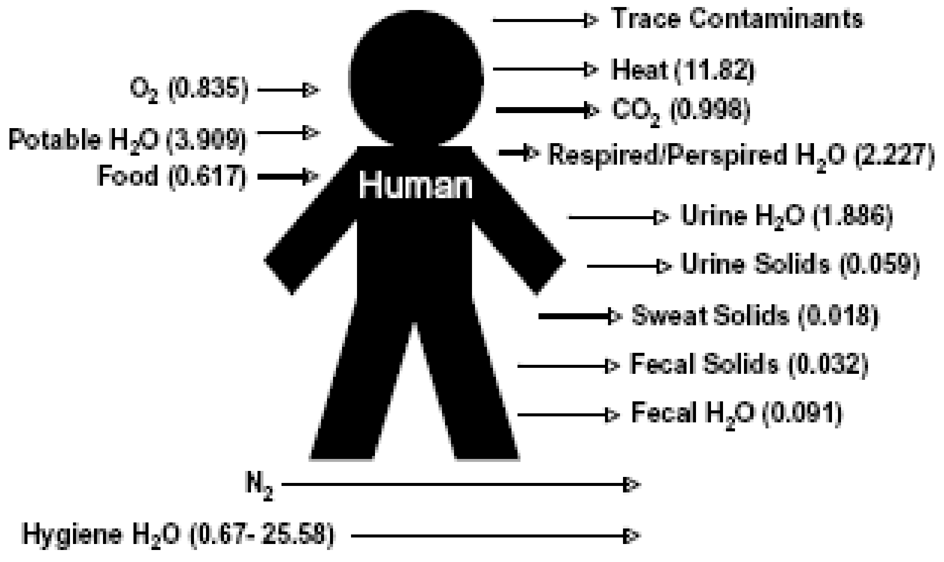
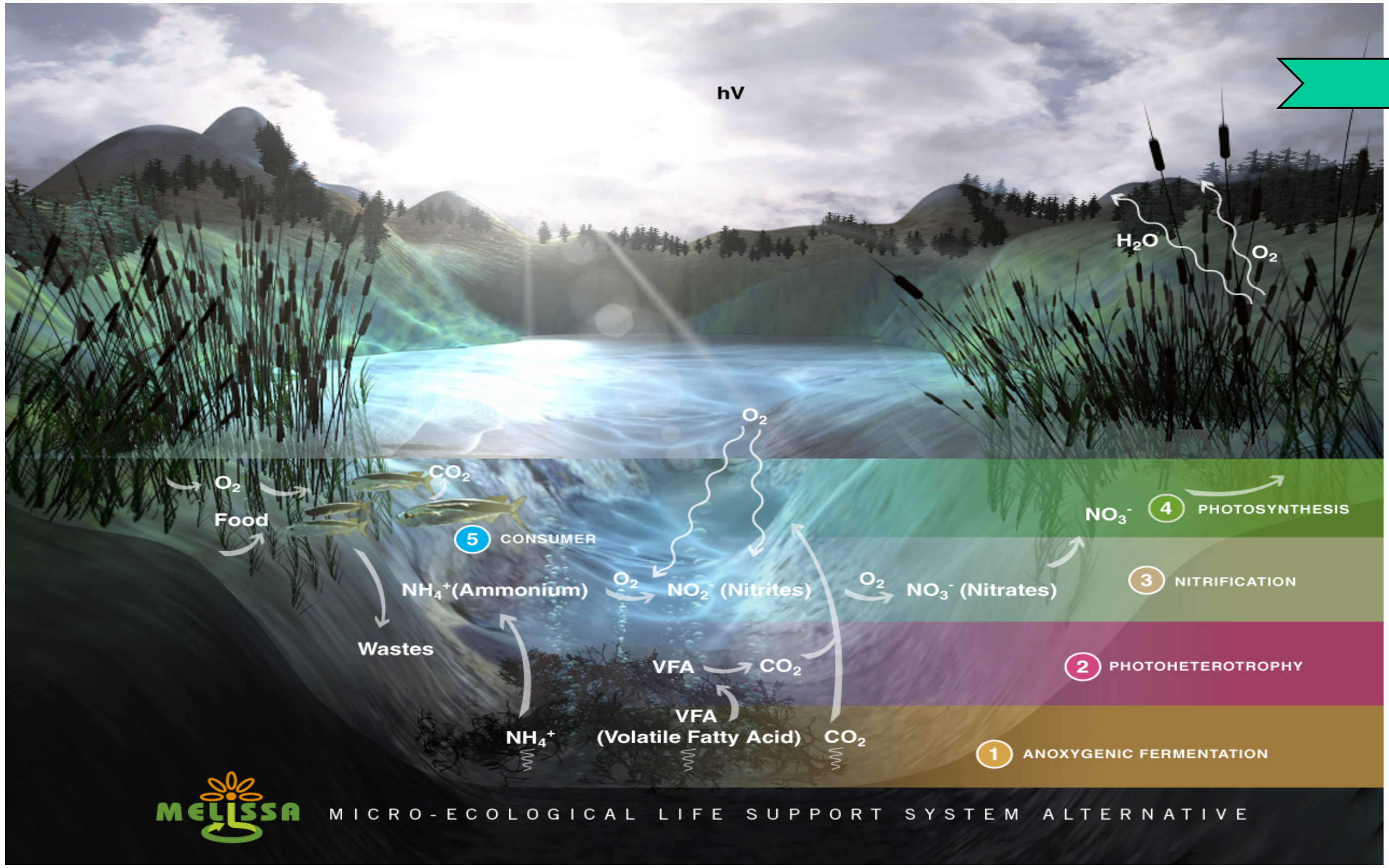


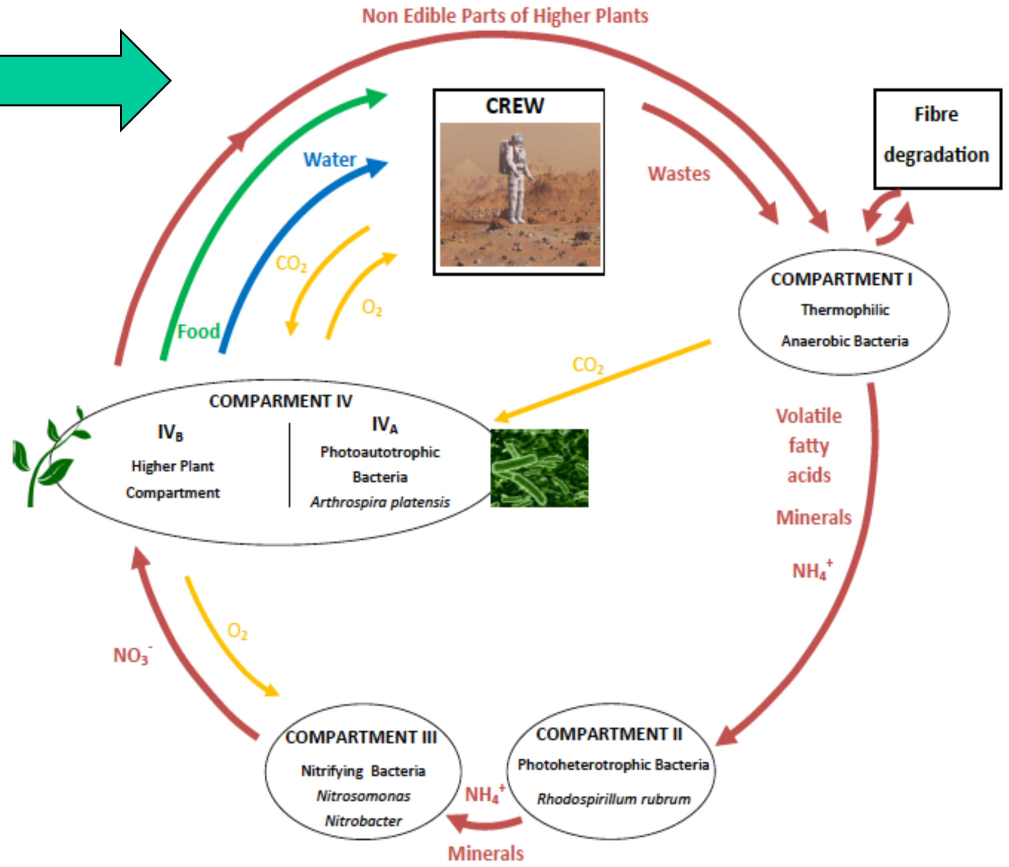

Figure 1. Human Consumable and Throughput Values in kg (or MJ)/crewmember/day

Metabolic consumables: 5 kg/day/person, 6 crew members, 1000 days: 30.000 kg (without hygiene water)
Best launchers could only drop 9 tones … **long-term missions need regenerative LSS**

# The MELiSSA Concept

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

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## Main objectives

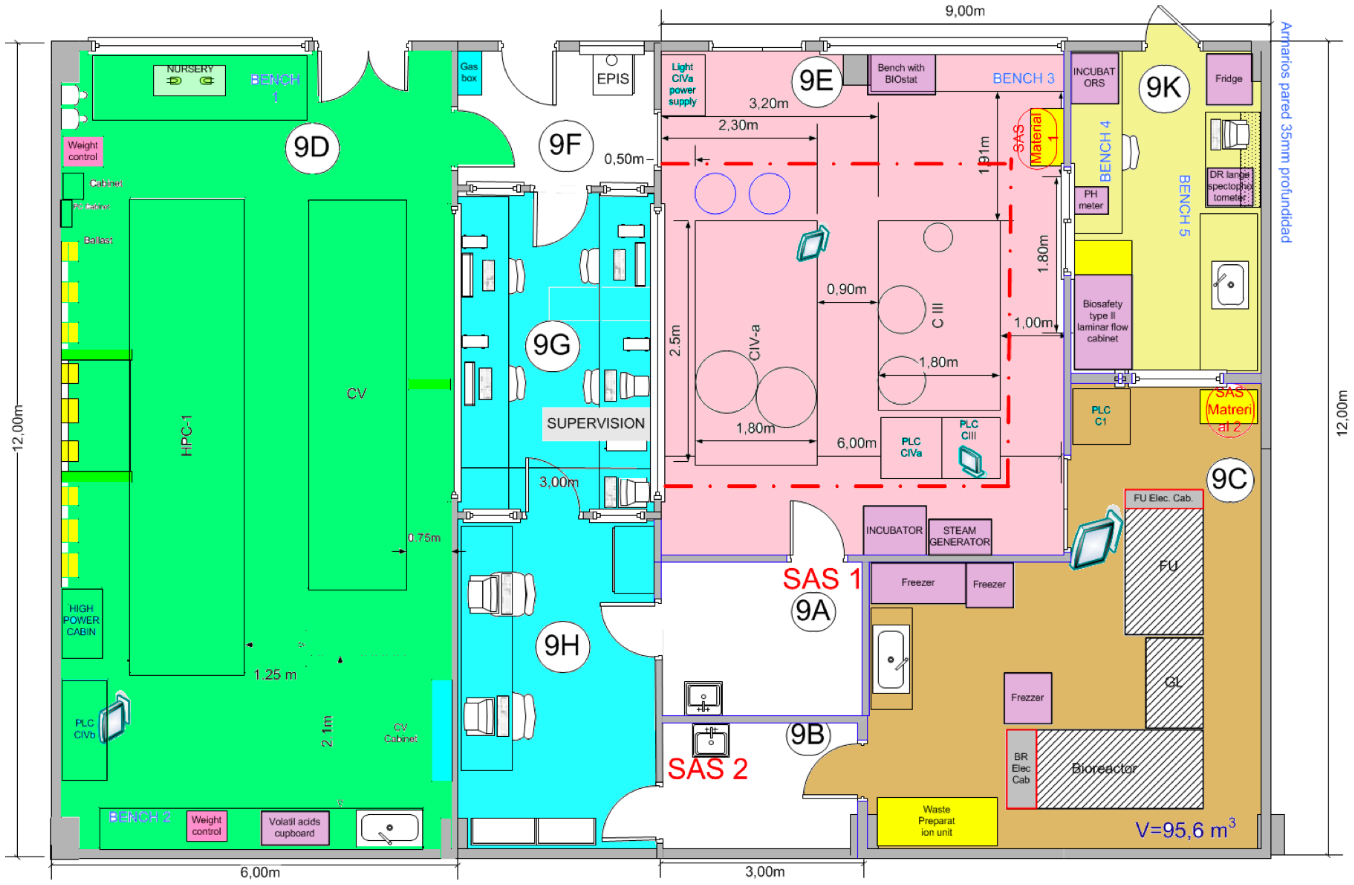
Integration and demonstration of the MELiSSA concept at pilot scale

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

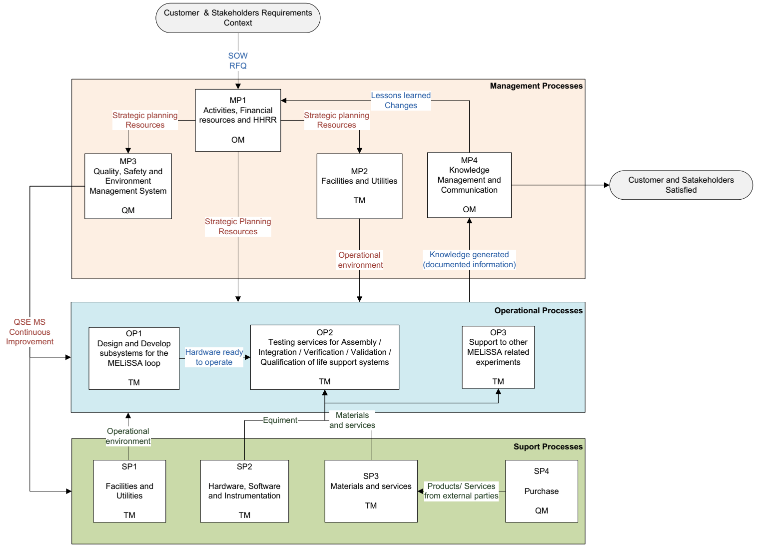
## Layout (214 m$^2$)

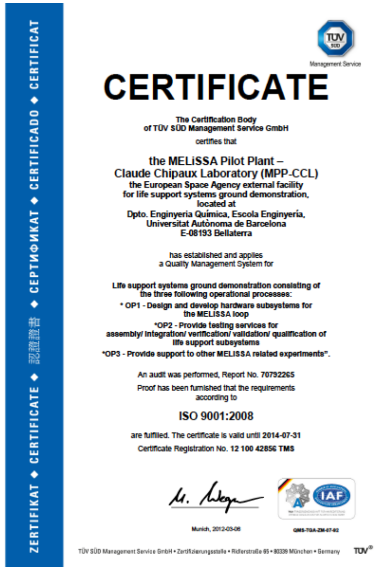



| Comp. IVb and CV | Comp. III and IVa | Control and supervision | Comp I | Analysis Laboratory |
|---|---|---|---|---|

# The MELiSSA Pilot Plant: Clean room up-grade

# Quality and Systems Engineering approach as working framework





CERTIFICATE

The Certification Body
of TÜV SÜD Management Service GmbH
certifies that

the MELiSSA Pilot Plant –
Claude Chipaux Laboratory (MPP-CCL)
the European Space Agency external facility
for life support systems ground demonstration,
located at
Dpto. Enginyeria Química, Escola Enginyeria,
Universitat Autònoma de Barcelona
E-08193 Bellaterra

has established and applies
a Quality Management System for

Life support systems ground demonstration consisting of the three following operational processes:
* OP1 - Design and develop hardware subsystems for the MELiSSA loop
*OP2 - Provide testing services for assembly/ integration/ verification/ validation/ qualification of life support subsystems
*OP3 - Provide support to other MELiSSA related experiments".

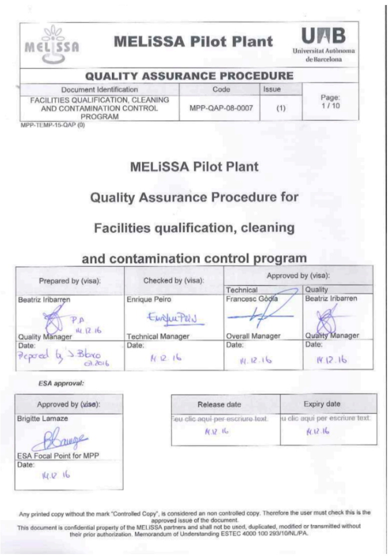
An audit was performed, Report No. 70792265
Proof has been furnished that the requirements according to

ISO 9001:2008

are fulfilled. The certificate is valid until 2014-07-31
Certificate Registration No. 12 100 42856 TMS

Munich, 2012-03-06

TÜV SÜD Management Service GmbH • Zertifizierungsstelle • Ridlerstraße 65 • 80339 München • Germany


MELiSSA Pilot Plant

QUALITY ASSURANCE PROCEDURE

| Document Identification | Code | Issue | Page: |
|---|---|---|---|
| FACILITIES QUALIFICATION, CLEANING AND CONTAMINATION CONTROL PROGRAM | MPP-QAP-08-0007 | (1) | 1 / 10 |

MELiSSA Pilot Plant

Quality Assurance Procedure for

Facilities qualification, cleaning

and contamination control program

| Prepared by (visa): | Checked by (visa): | Approved by (visa): | |
|---|---|---|---|
| Beatriz Iribarren<br>Quality Manager<br>Date: | Enrique Peiro<br>Technical Manager<br>Date: | Technical Francesc Gòdia<br>Overall Manager<br>Date: | Quality Beatriz Iribarren<br>Quality Manager<br>Date: |

ESA approval:

| Approved by (visa): |
|---|
| Brigitte Lamaze<br>ESA Focal Point for MPP<br>Date: |

| Release date | Expiry date |
|---|---|
| | |

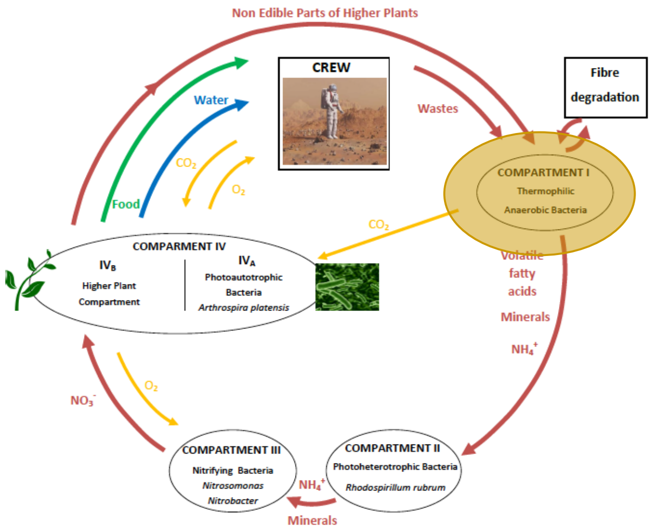
# Compartment I

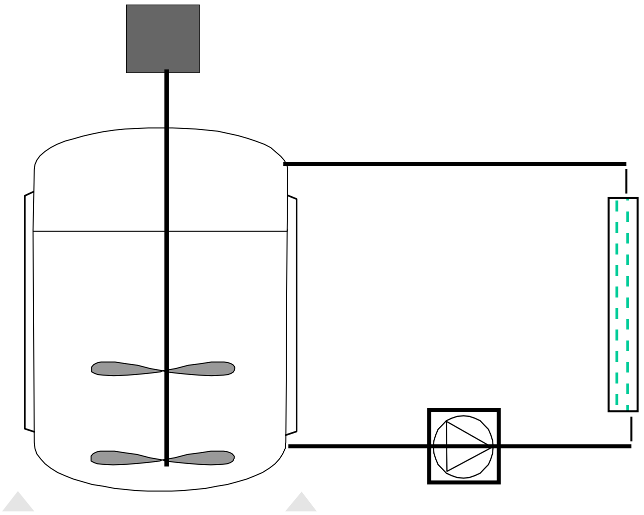
## Waste recovery

## Mixed thermophilic anaerobic bacteria

## Stirred tank

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

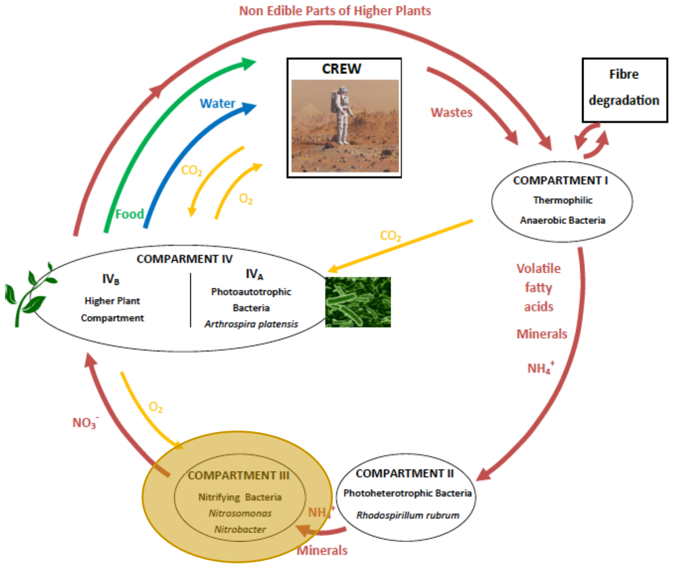


# Compartment III

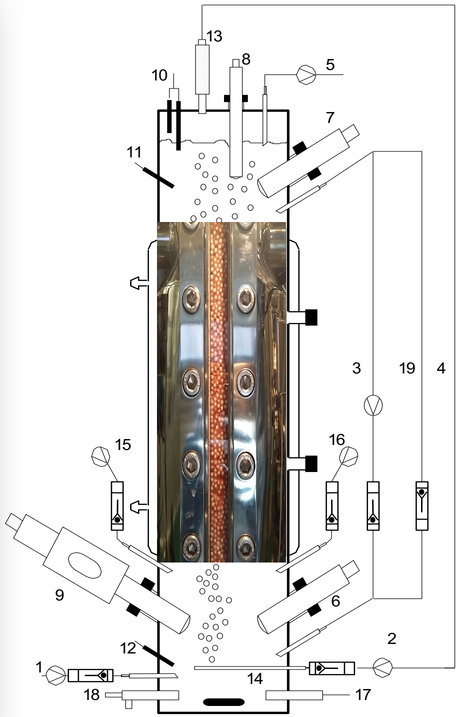
## Nitrification

$NH_4^+$
$O_2$ → **C. III** → $NO_3^-$

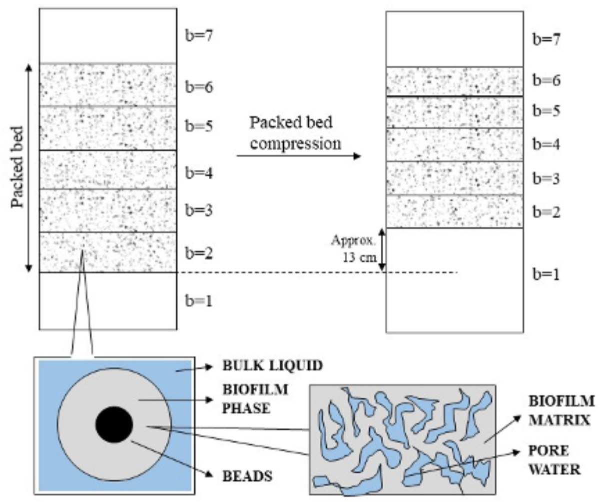


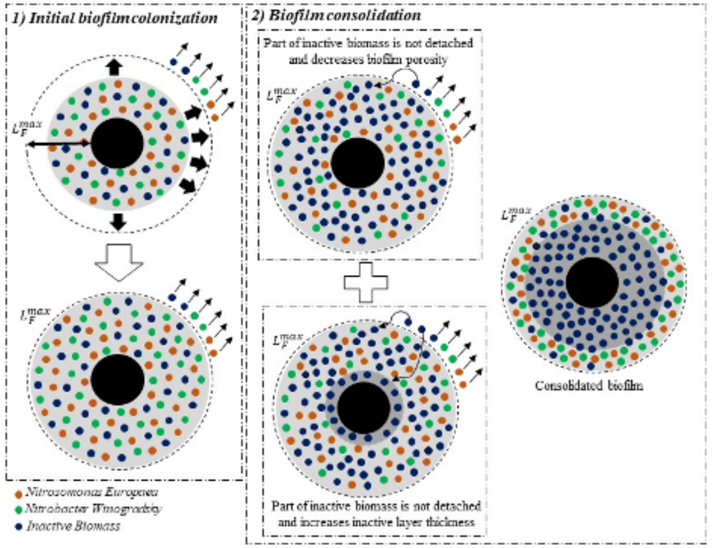

## *Nitrosomonas europaea and Nitrobacter winogradsky* (axenic co-culture, aerobic)

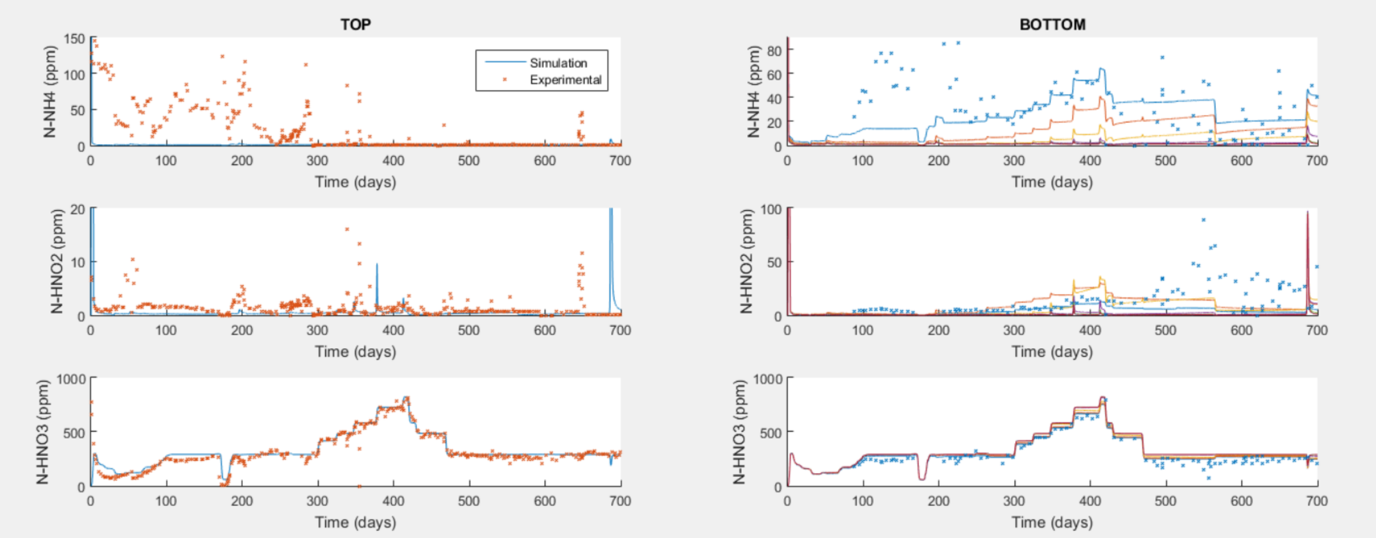
## Packed-bed bioreactor



# Compartment III: modelling
## (L. Alemany, modelling session)




$$\dot{C}_{\ell,j}^{[b]} = \frac{1}{V_\ell^{[b]}}\left(\dot{M}_{\ell,C_{\ell,j}}^{in[b]} - \dot{M}_{\ell,C_{\ell,j}}^{out[b]} + \sum_{i=1}^{n_x}\left(Y_{j/i} + Y_{j/i}^{m}\frac{m_i}{\mu_{max,i}}\right)\left(R_{\ell,X_i}^{[b]} + R_{F,X_i}^{[b]}\right)\right)$$

$$\dot{X}_{\ell,i}^{[b]} = \frac{1}{V_\ell^{[b]}}\left(\dot{M}_{\ell,X_{\ell,i}}^{in[b]} - \dot{M}_{\ell,X_{\ell,i}}^{out[b]} + R_{\ell,X_i}^{[b]} + u_{det}^{[b]}A_F^{[b]}\tilde{X}_{F,i}^{[b]}\right) - b_i^{lethal}X_{\ell,i}^{[b]}$$

$$\dot{X}_{\ell,0}^{[b]} = \frac{1}{V_\ell^{[b]}}\left(\dot{M}_{\ell,X_{\ell,0}}^{in[b]} - \dot{M}_{\ell,X_{\ell,0}}^{out[b]} + u_{det,0}^{[b]}A_F^{[b]}\rho_{bio}\left(1-\varepsilon_{F,\ell}^{[b]}\right)\varphi_{F,0}^{[b]}\right) + \sum_{i=1}^{n_x} b_i^{lethal}X_{\ell,i}^{[b]}$$

$$\dot{C}_{g,j}^{[b]} = \frac{1}{V_g^{[b]}}\left(\dot{M}_{C_{g,j}}^{in[b]} - \dot{M}_{C_{g,j}}^{out[b]} + k_{LA,j}\left(C_{\ell,j}^{[b]} - C_{\ell,j}^{*[b]}\right)V_\ell^{[b]}\right)$$

$$\dot{\bar{X}}_{F,i}^{[b]} = \frac{R_{F,X_i}^{[b]}}{V_F^{[b]}} - \frac{u_{det}^{[b]}A_F^{[b]}}{V_F^{[b]}}\tilde{X}_{F,i}^{[b]} - b_i^{lethal}\bar{X}_{F,i}^{[b]} - \bar{X}_{F,i}^{[b]}\frac{\dot{V}_F^{[b]}}{V_F^{[b]}}$$

$$\dot{\bar{X}}_{F,0}^{[b]} = -\frac{u_{det,0}^{[b]}A_F^{[b]}}{V_F^{[b]}}\tilde{X}_{F,0}^{[b]}\times\frac{1000\ L}{1\ m^3} + \sum_{i=1}^{n_x} b_i^{lethal}\bar{X}_{F,i}^{[b]} - \bar{X}_{F,0}^{[b]}\frac{\dot{V}_F^{[b]}}{V_F^{[b]}}$$

$$\dot{L}_F^{[b]} = u_F^{[b]} - u_{det}^{[b]}$$

$$\dot{L}_{F,0}^{[b]} = \left(u_{att,0}^{[b]} - \phi_{F,0}^{[b]}\frac{A_F^{[b]}}{A_{F,0}^{[b]}}\left(u_{det}^{[b]} - u_{det,0}^{[b]}\right)\right)\frac{\tilde{X}_{F,0}^{[b]}}{\rho_{bio}\left(1-\varepsilon_{F,\ell}^{[b]}\right)} - \left(\frac{A_{F,0}^{[b]} - A_b^{[b]} - \phi_{F,0}^{[b]}\left(A_F^{[b]} - A_b^{[b]}\right)}{A_{F,0}^{[b]}}\right)\frac{\dot{d}^{[b]}}{2}$$

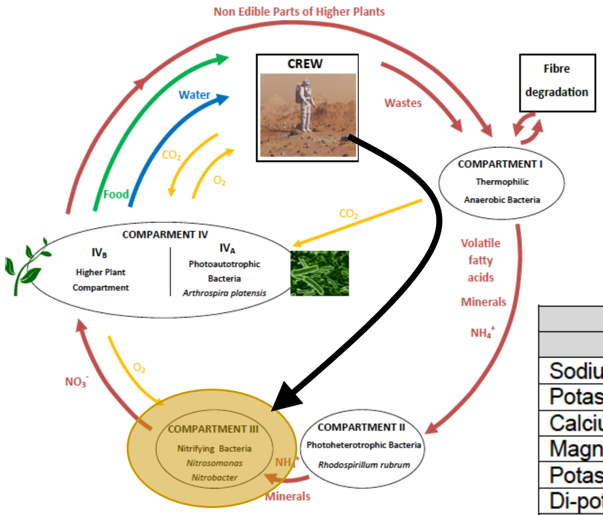
$$\dot{\varepsilon}_{F,\ell}^{[b]} = -\frac{1-\varepsilon_{F,\ell}^{[b]}}{V_F^{[b]}}\left[A_F^{[b]}\left(u_{det}^{[b]} - u_{det,0}^{[b]}\right)\varphi_{F,0}^{[b]} - \left(A_F^{[b]} - A_b^{[b]}\right)\frac{\dot{d}^{[b]}}{2}\right]$$

$$\dot{\eta}_\ell^{[b]} = -\frac{\dot{V}_b^{[b]} + \dot{V}_F^{[b]}}{V_T^{[b]}} + \left(1-\eta_\ell^{[b]}\right)\frac{\dot{V}_T^{[b]}}{V_T^{[b]}}$$

$$\Delta\left\{\dot{h}^{[b]} = \delta^{[b]}K\left(\eta_\ell^{[b]} - \eta_\ell^{min}\right)^2\frac{Q_{\ell,in} + Q_{\ell,recy}}{\frac{\pi}{4}D^2}\quad b = 2\dots n-1\right\}$$

# Compartment III: preparing transition to urine

(M. Vilaplana, poster session)




***Nitrosomonas europaea***
***Nitrobacter winogradskyi***

***Synthetic urine***

***Pseudomonas fluorescens***
***Comamonas testosteroni***
***Acidovorax delafieldii***
***Cupriavidus necator***

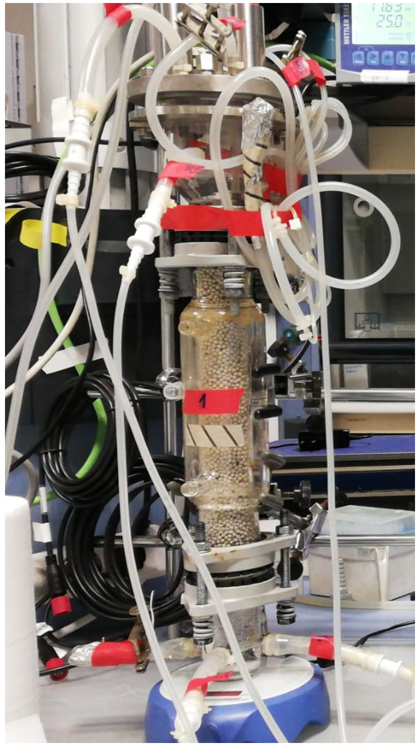
*Urea hydrolysis Heterotrophs* — *Ammonium oxidation AOB* — *Nitrite oxidation NOB*

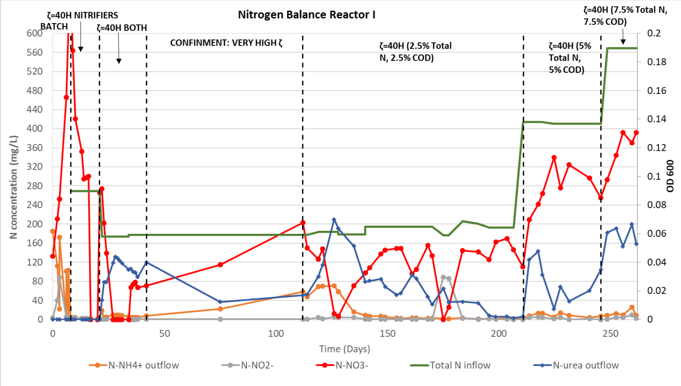
urea → $NH_4^+$ → $NO_2^-$ → $NO_3^-$

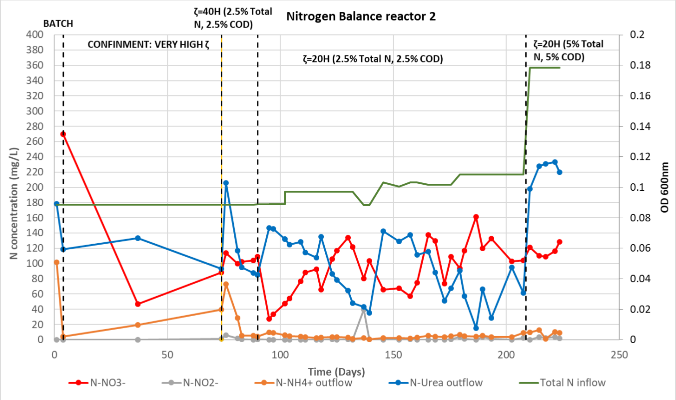
*COD removal Heterotrophs*

COD → $CO_2$

| Component | Concentration [g/L] |
|---|---|
| **Salts** | |
| Sodium chloride | 0.500 |
| Potassium chloride | 0.100 |
| Calcium chloride dihydrate | 0.069 |
| Magnesium sulphate heptahydrate | 0.105 |
| Potassium dihydrogen phosphate | 0.190 |
| Di-potassium hydrogen phosphate | 0.240 |
| **Nitrogen compounds** | |
| Ammonium sulphate | 0.217 |
| Urea | 1.400 |
| **Organics** | |
| Creatinine | 0.469 |
| Citric acid | 0.162 |
| Hippuric acid | 0.170 |
| **Amino acids** | |
| RMPI 1640 amino acid solution (50*) | 2.5 ml/L |
| Glycine | 0.032 |
| L-cysteine | 0.033 |
| L-histidine | 0.026 |
| L-glutamine | 0.023 |
| ***Trace elements*** | ***Concentration [µg/L]*** |
| Iron (II) sulphate heptahydrate | 50 |
| Zinc sulphate heptahydrate | 31 |
| Copper (II) chloride dihydrate | 27 |
| Ammonium heptamolybdate tetrahydrate | 77 |
| Nickel (II) sulphate hexahydrate | 22 |
| Aluminium potassium sulphate | 70 |





# Compartment IVa

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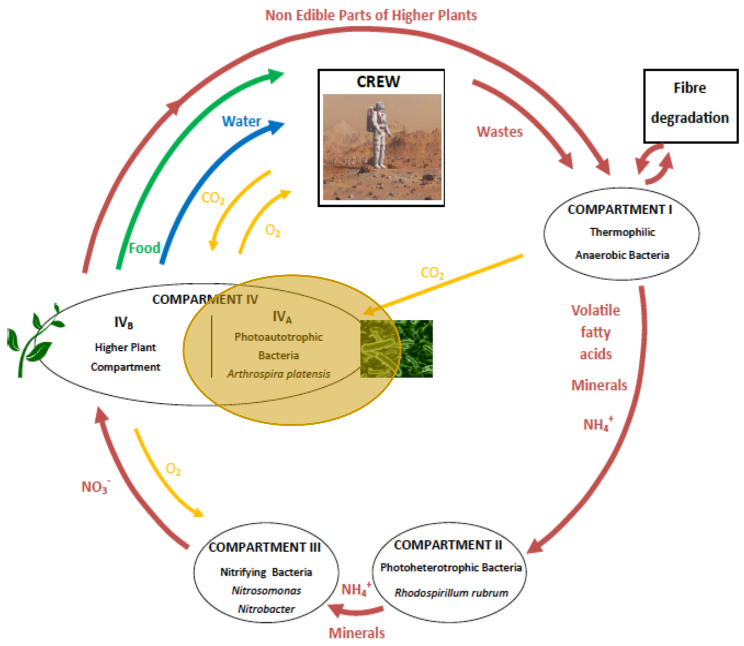
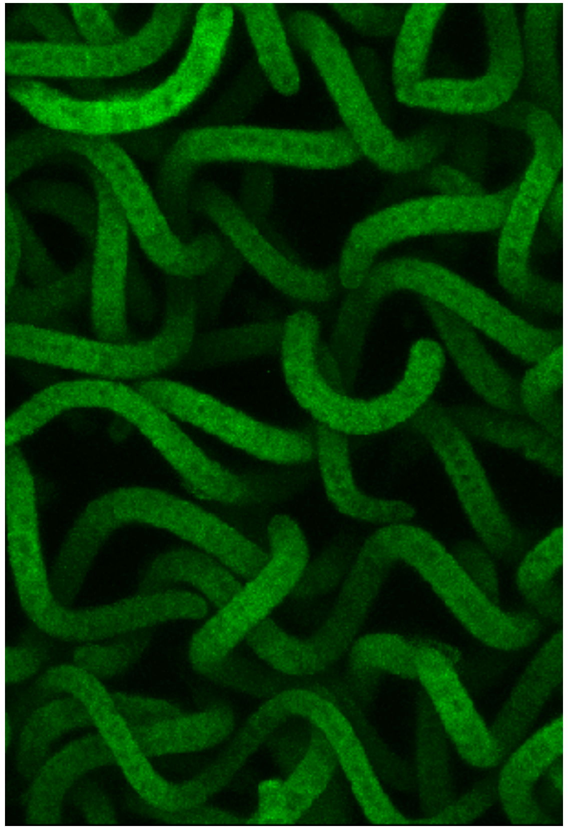
## Oxygen and Food production

Light
$CO_2$ → C. IVa → Biomass
$O_2$

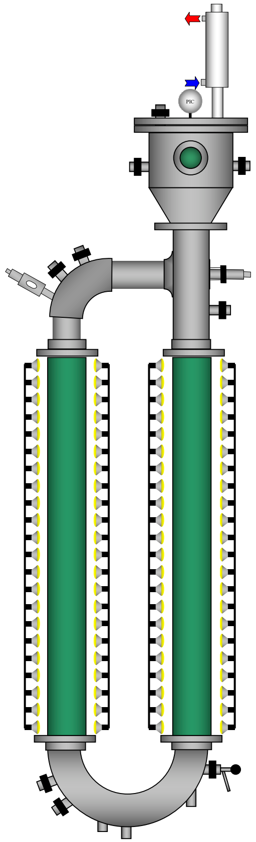



## *Limnospira indica, also known as Arthrospira platensis* (axenic culture)

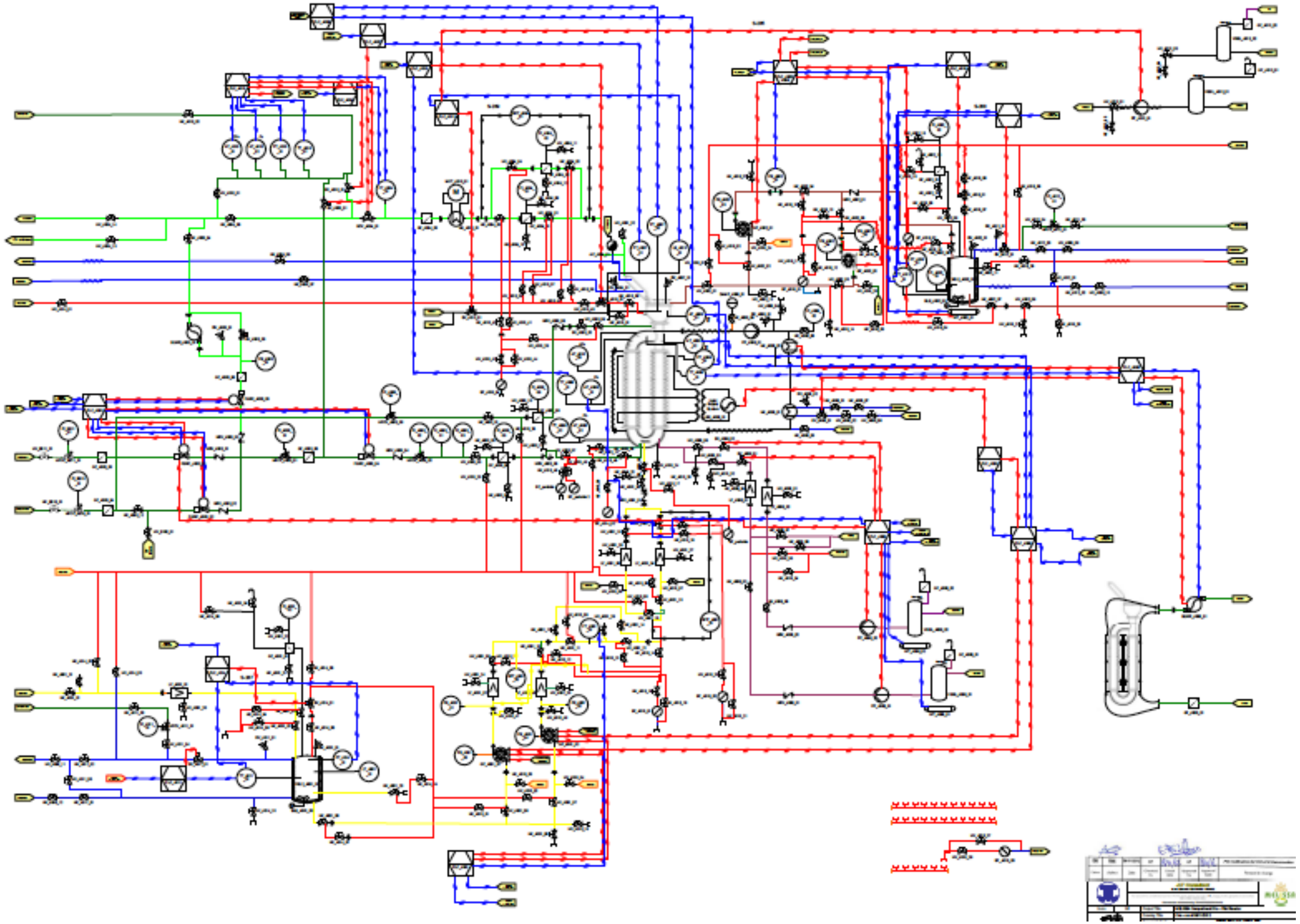


## Photobioreactor

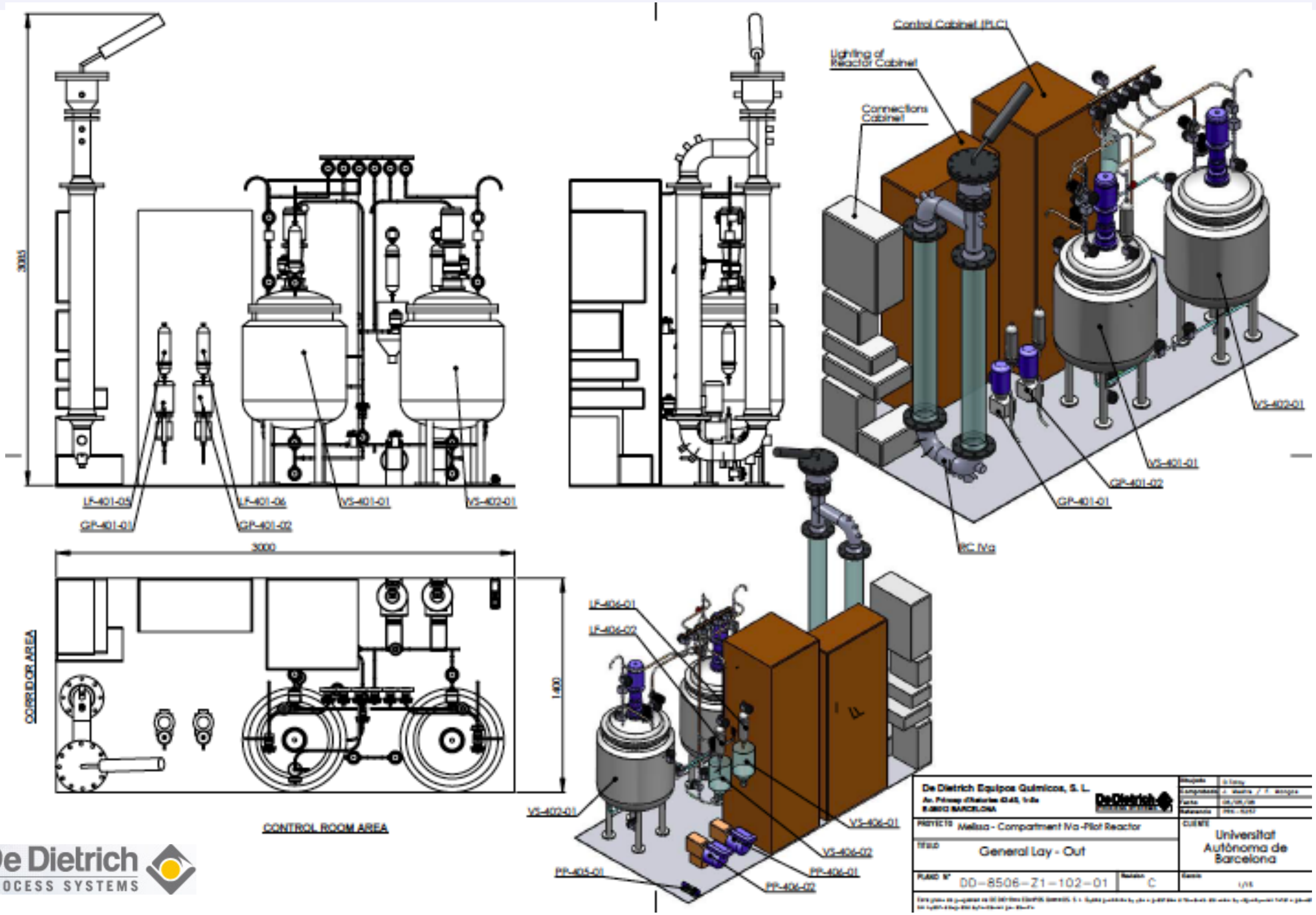
INTRAVISION
De Dietrich PROCESS SYSTEMS



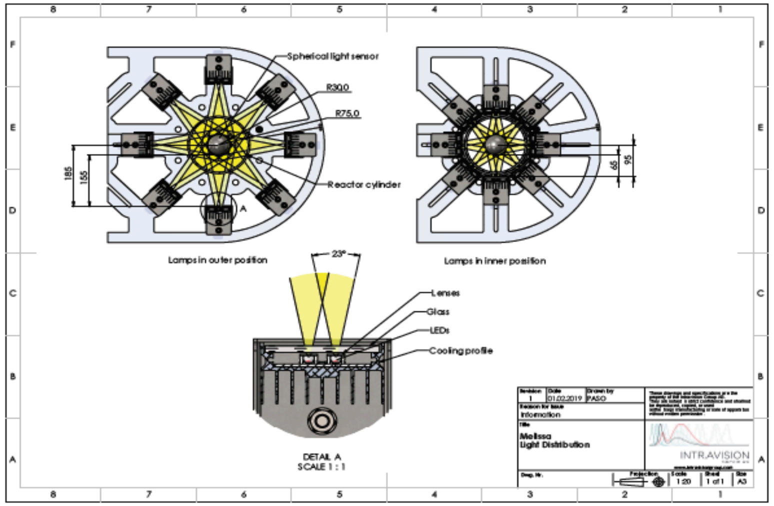
# Compartment IVa

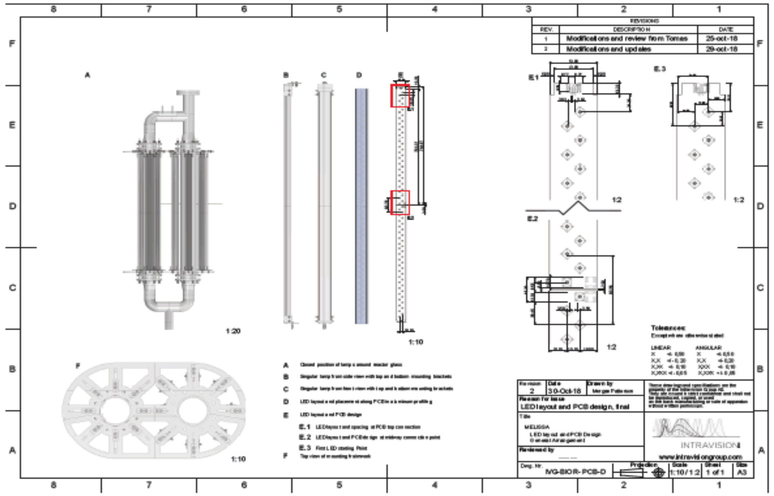


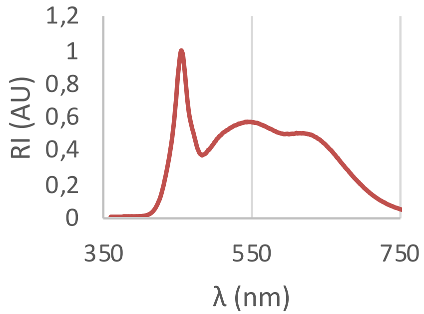
# Compartment IVa

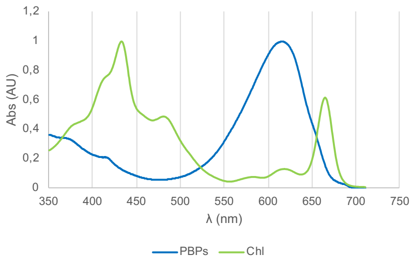



# Compartment IVa: new illumination system



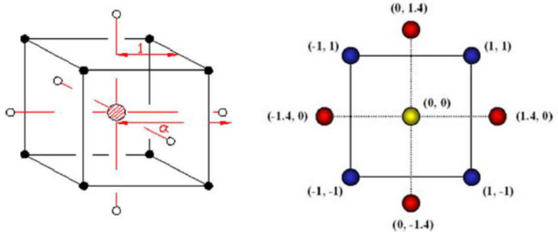



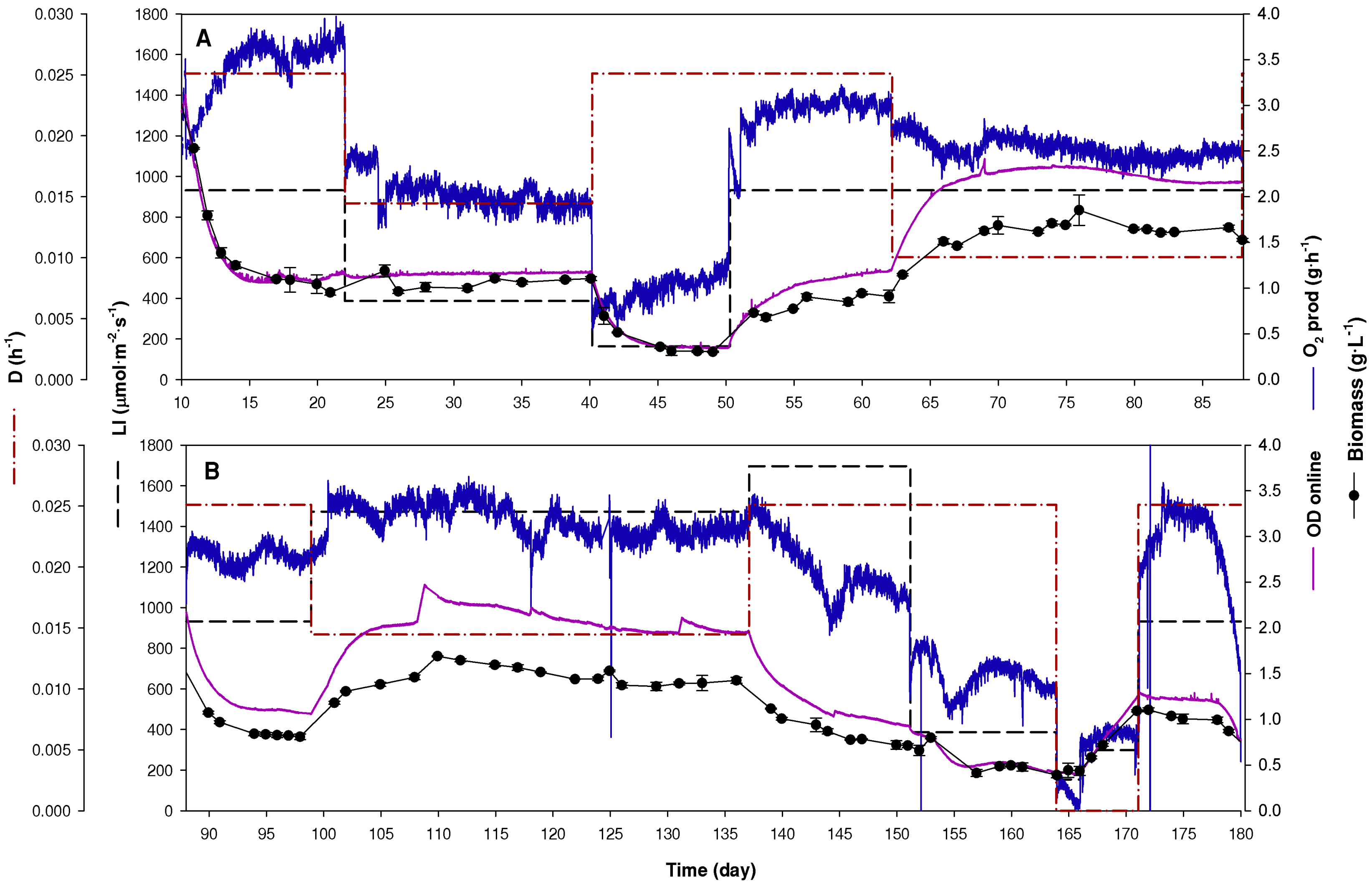
# Compartment IVb: new illumination system

## (D. García, microalgae and photobioreactors session)




$$Y_n = b_0 + \underbrace{\sum_{i=1}^{k} b_i X_i}_{Lineal} + \underbrace{\sum_{i=1}^{k} b_{ii} X_i^2}_{Curvature} + \underbrace{\sum_{i=1<}^{k} \sum_{j=1}^{k} b_{ij} X_i X_j}_{Interaction}$$

| Exp | x1 | x2 | Q (L/h) | LI (%) |
|---|---|---|---|---|
| 1 | -1 | -1 | 28.79 | 19.17 |
| 2 | 1 | -1 | 71.21 | 19.17 |
| 3 | -1 | 1 | 28.79 | 86.13 |
| 4 | 1 | 1 | 71.21 | 86.13 |
| 5 | 1.41 | 0 | 80.00 | 52.65 |
| 6 | -1.41 | 0 | 20.00 | 52.65 |
| 7 | 0 | 1.41 | 50.00 | 100.00 |
| 8 | 0 | -1.41 | 50.00 | 5.30 |
| 9 | 0 | 0 | 50.00 | 52.65 |
| 10 | 0 | 0 | 50.00 | 52.65 |
| 11 | 0 | 0 | 50.00 | 52.65 |
| 12 | 0 | 0 | 50.00 | 52.65 |
| 13 | 0 | 0 | 50.00 | 52.65 |



# Compartment IVb

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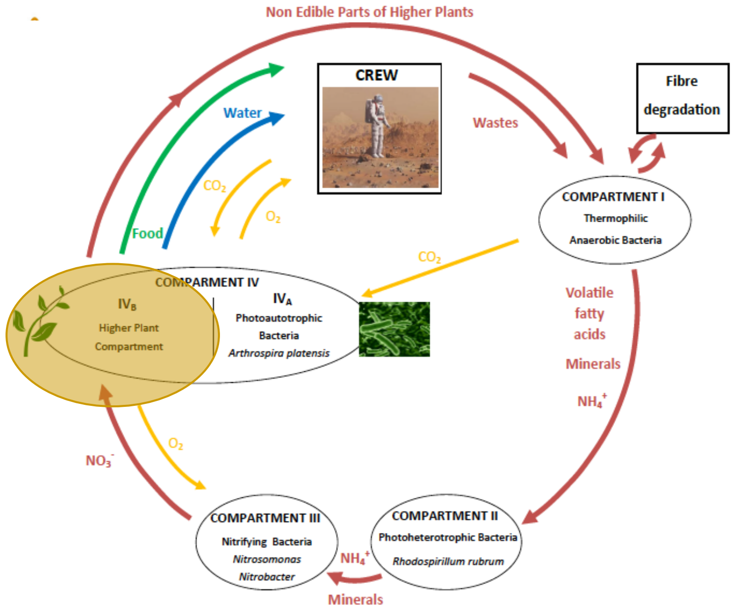
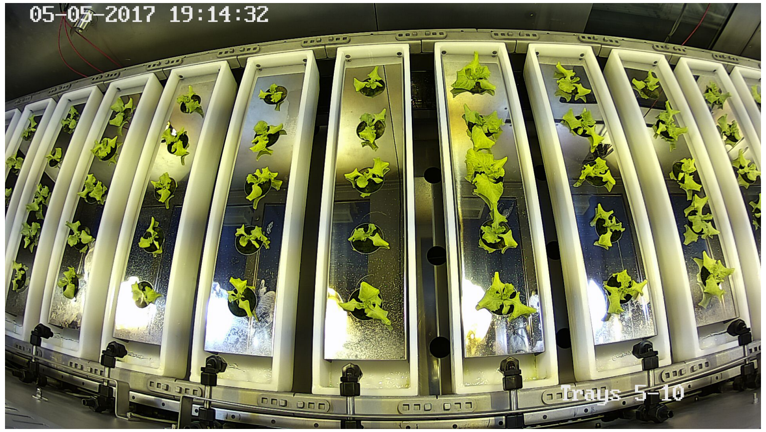
## Oxygen and Food production

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




## Higher plants: lettuce, beet, wheat





## Plant Chamber

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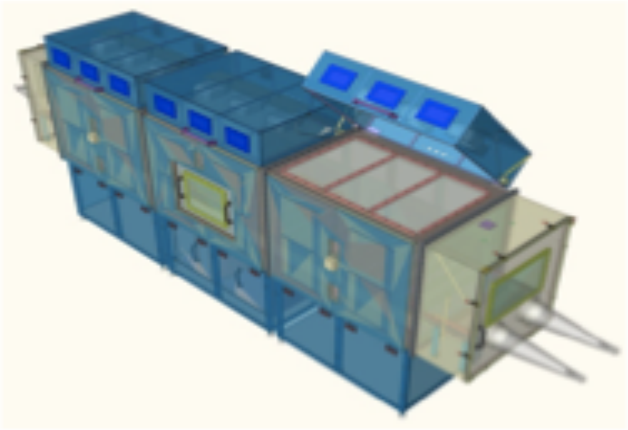
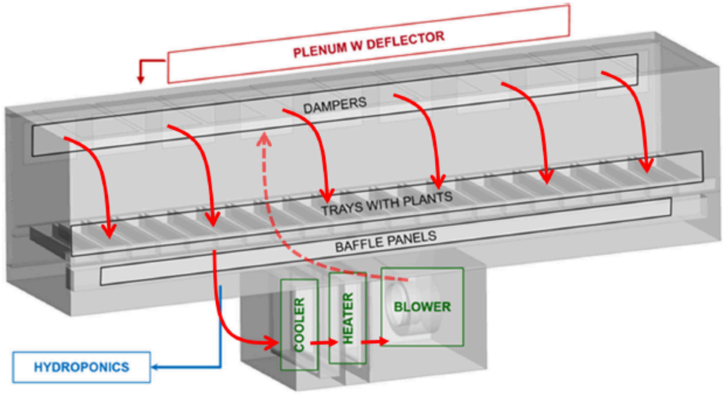
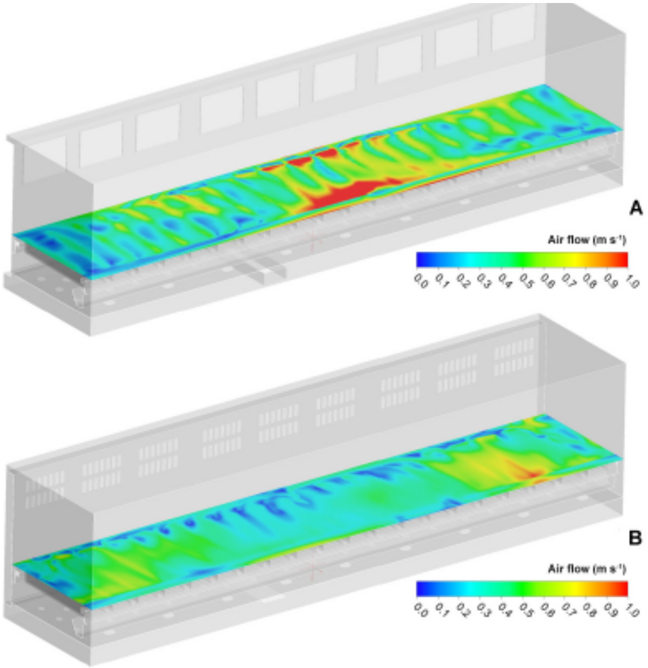
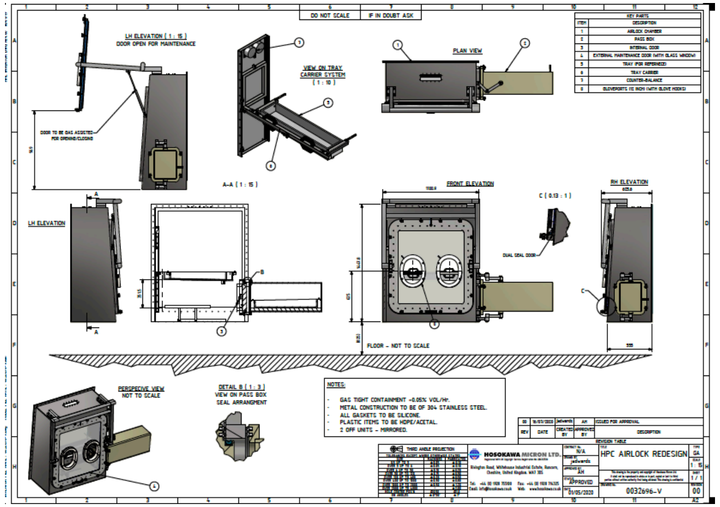
Università degli Studi di Napoli Federico II

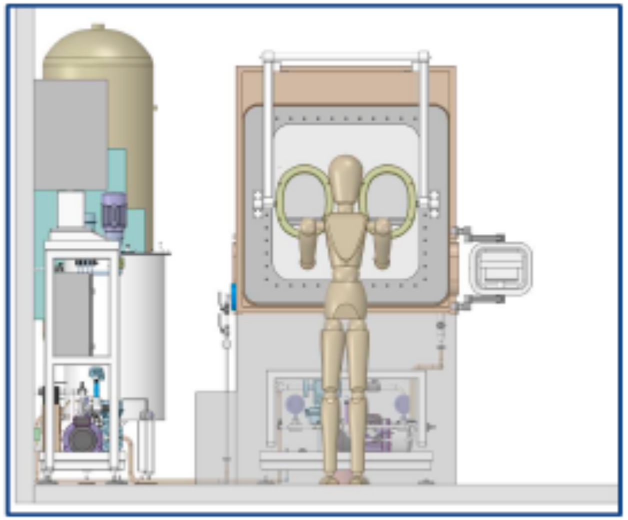


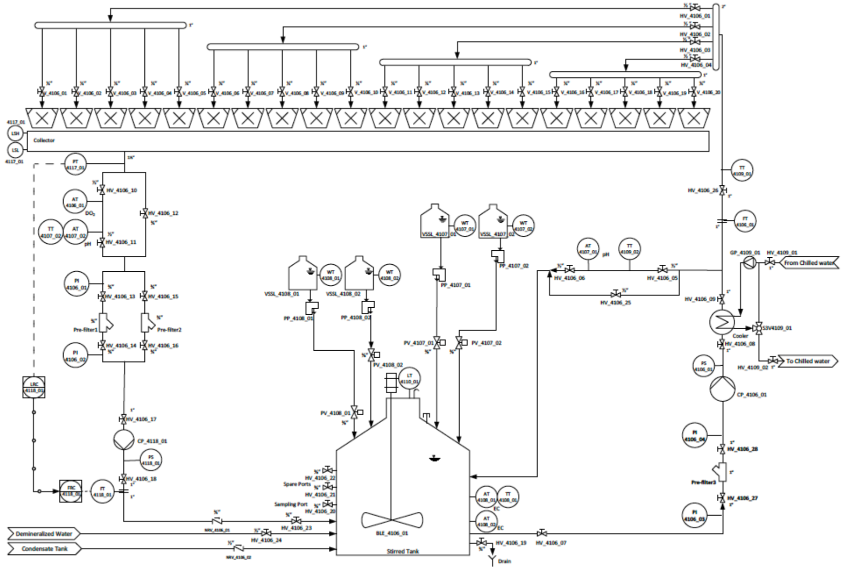
# Compartment IVb up-grade

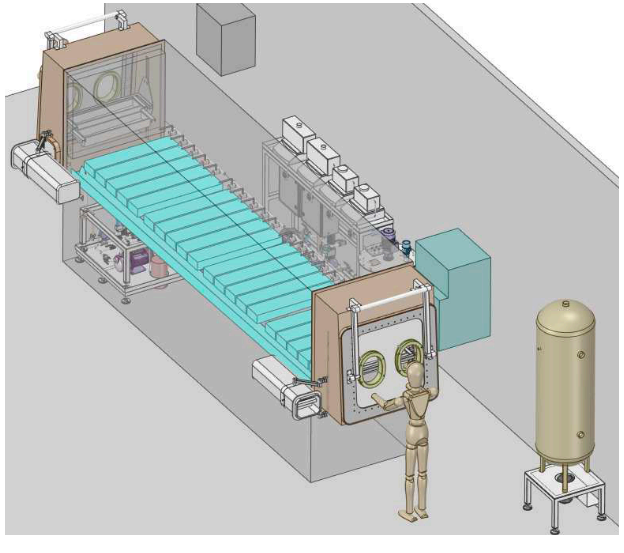


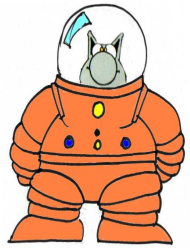







# Compartment V

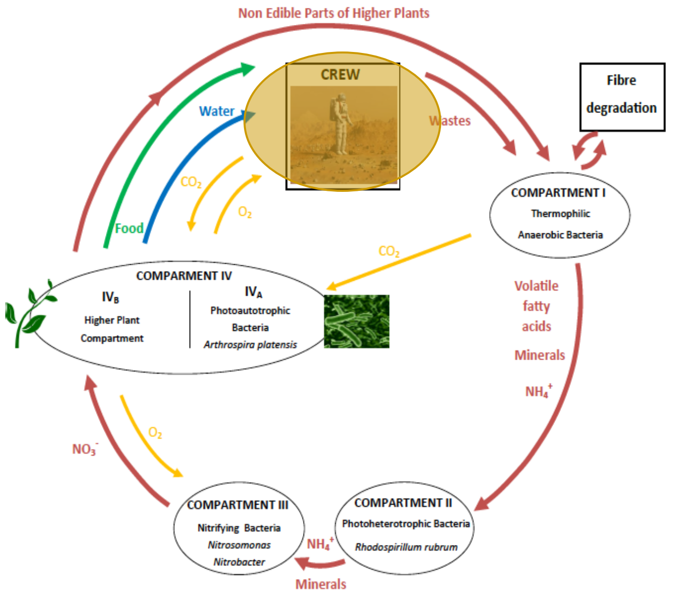


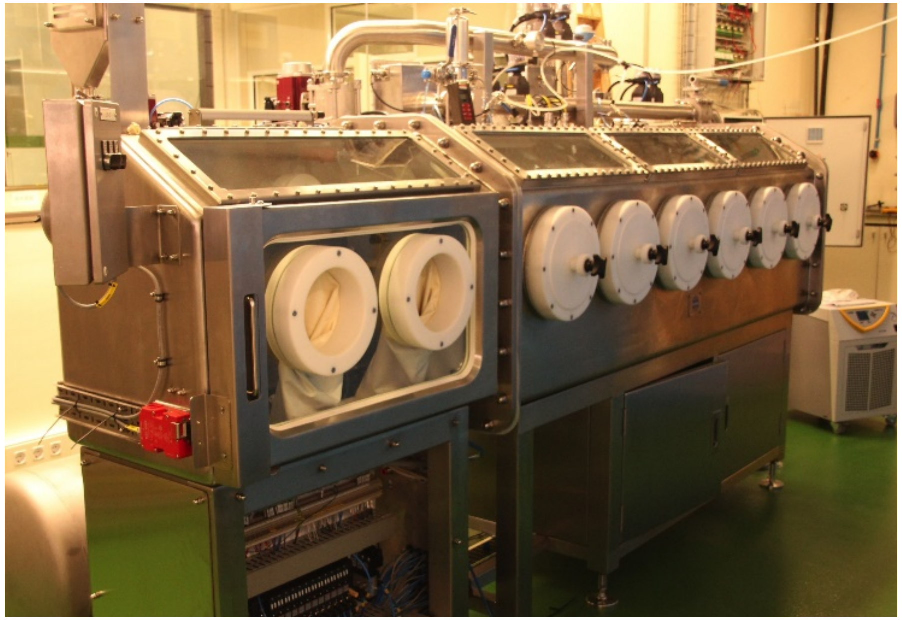
**Crew mock-up**

**Laboratory *Wistar* rats**

**Animal Isolator**

$O_2$
Feed → **C. V** → Wastes
$CO_2$



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

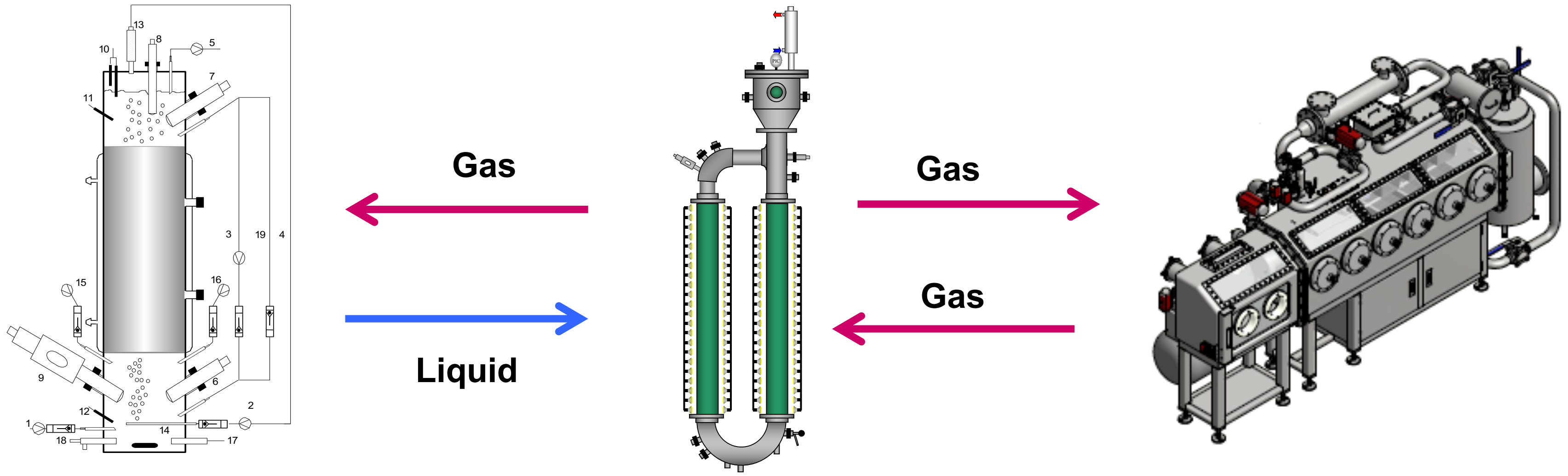
**Top requirements for the MELiSSA Pilot Plant**

1/ Progressive demonstration of MELiSSA concept

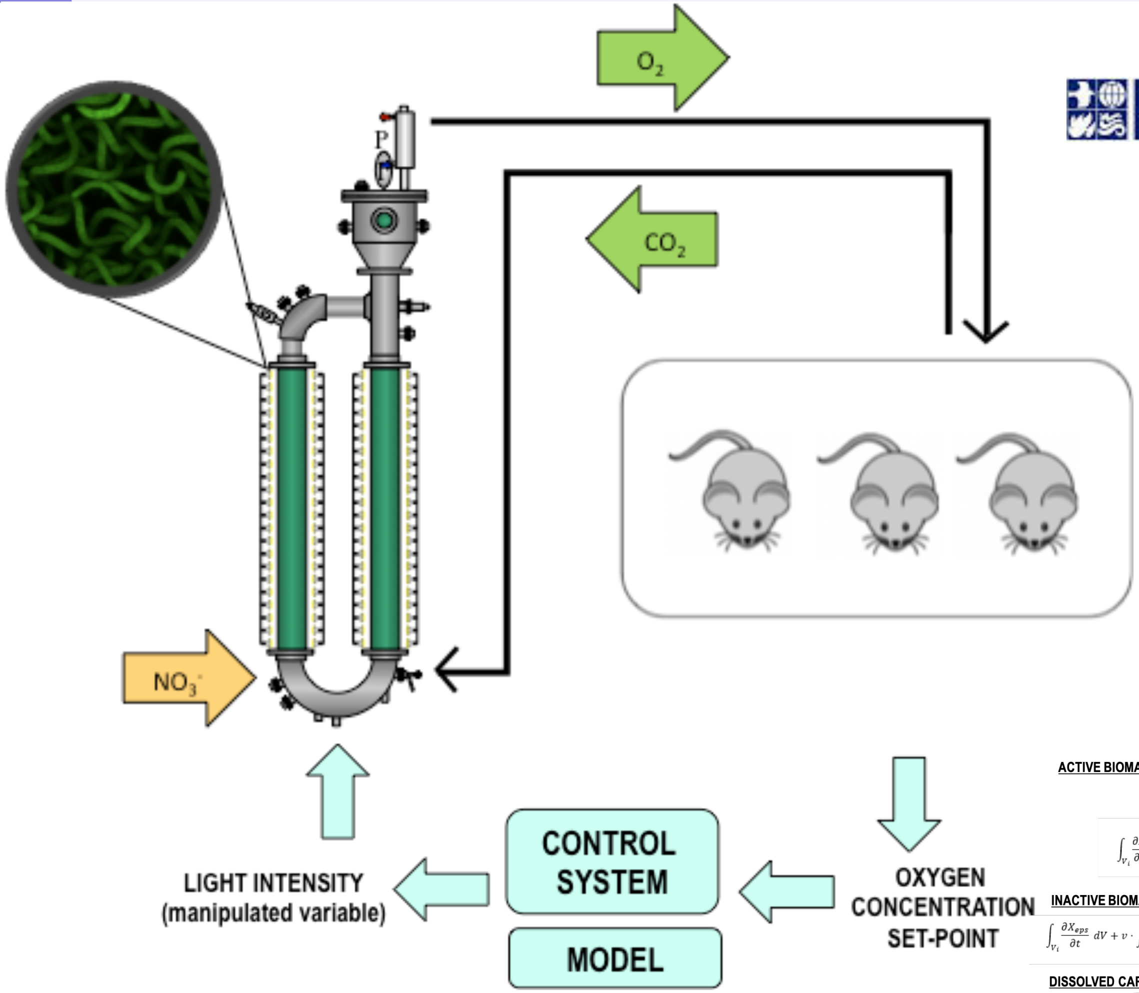
2/ Stepwise integration

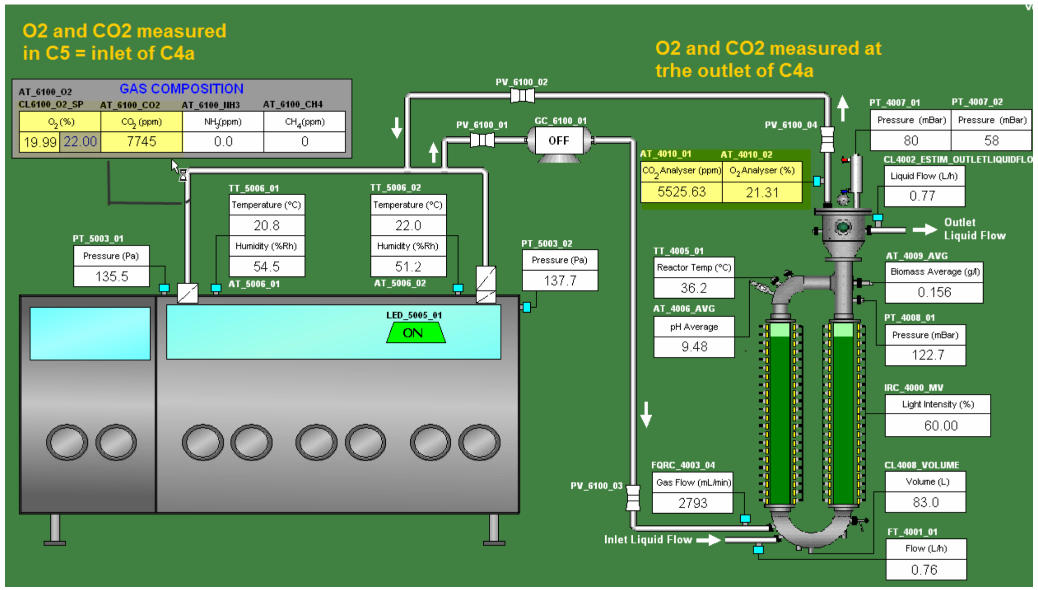
3/ Capitalization of knowledge

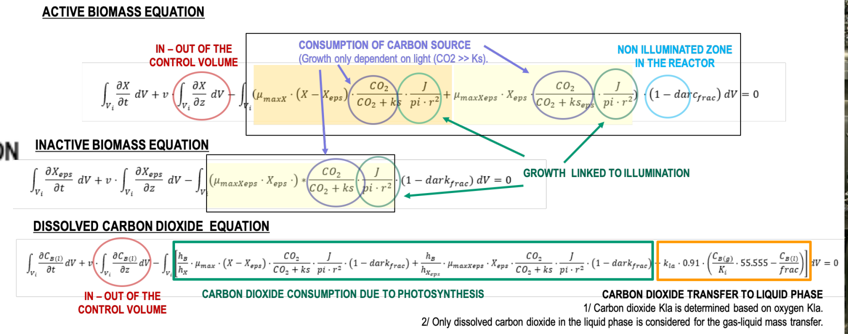
Integration logic based on the most advanced compartments in terms of knowledge, model and control

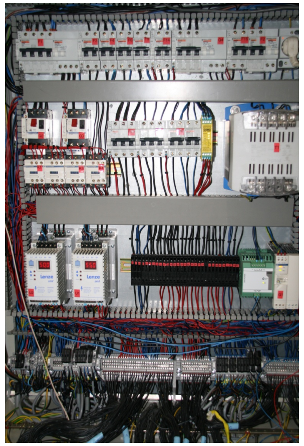


# Integration of compartments: CIVa + CV connection by gas phase



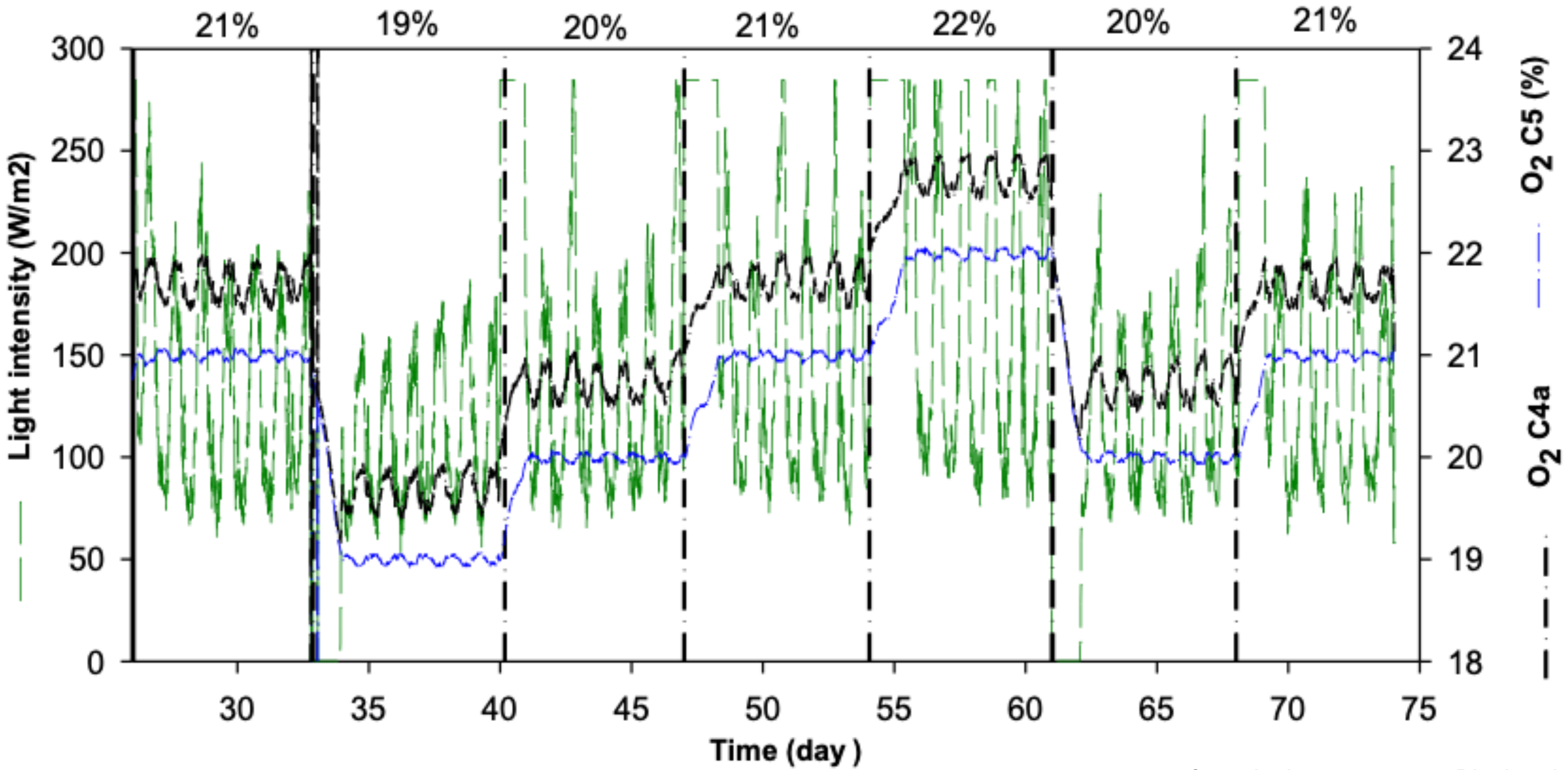



# Integration of compartments: CIVa + CV connection by gas phase

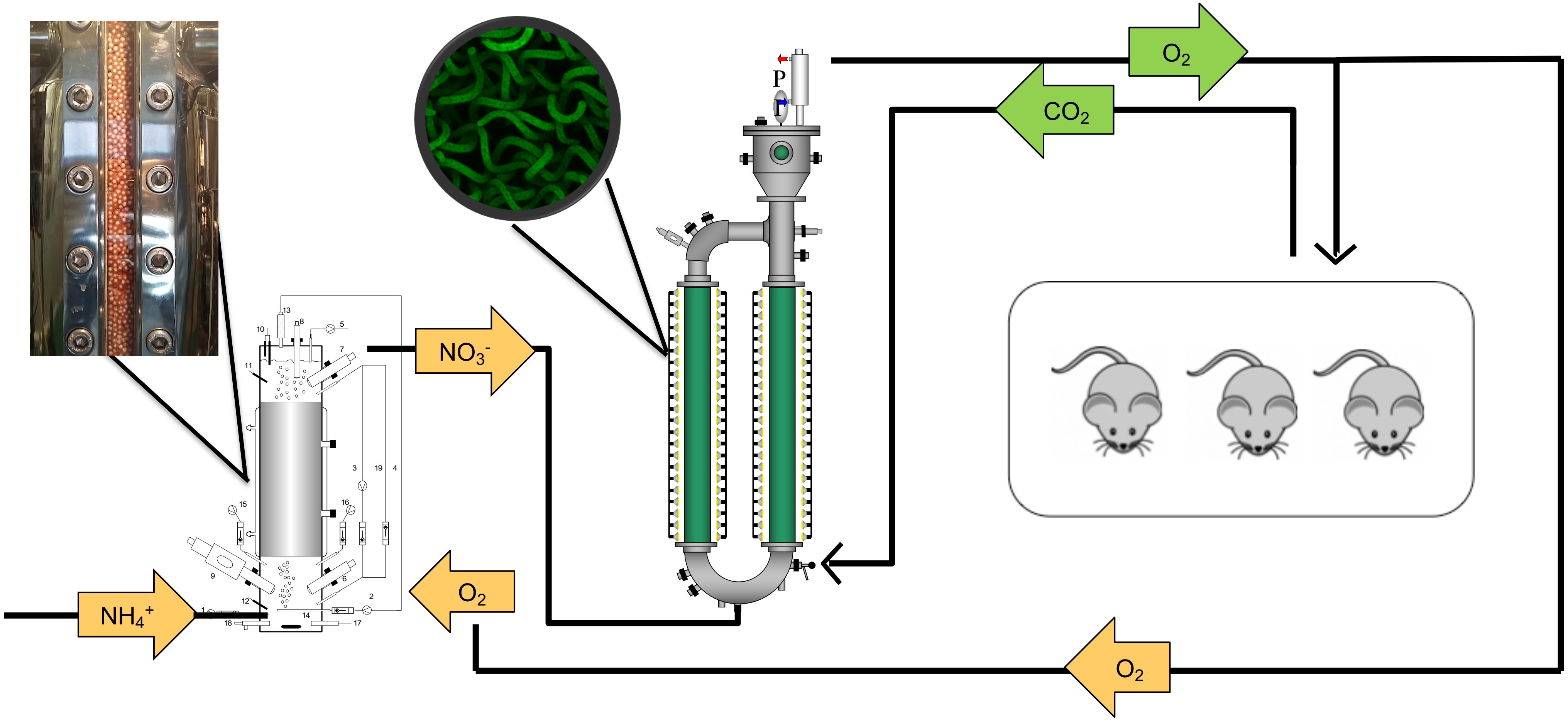
## Light and Oxygen evolution in CIVa and CV compartments



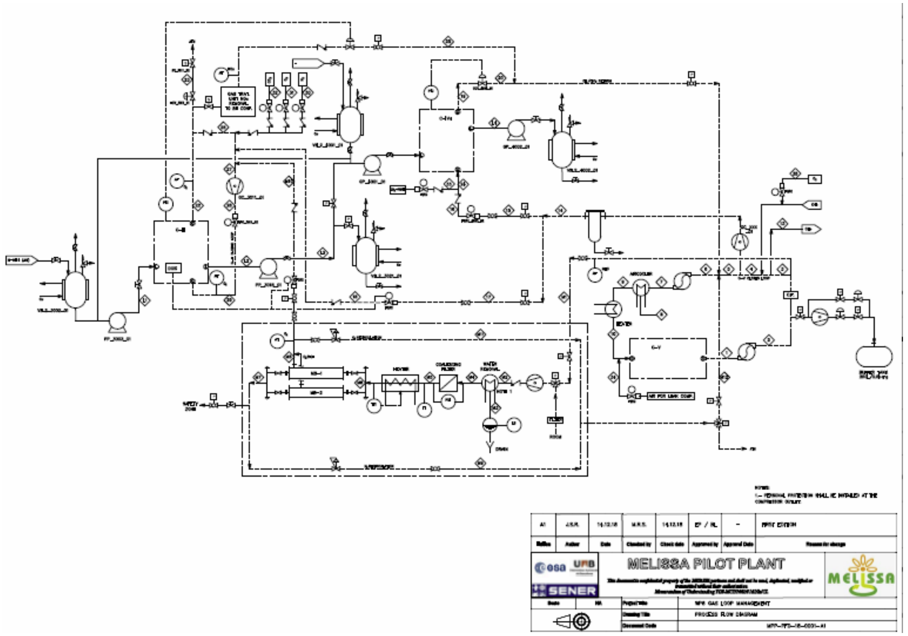


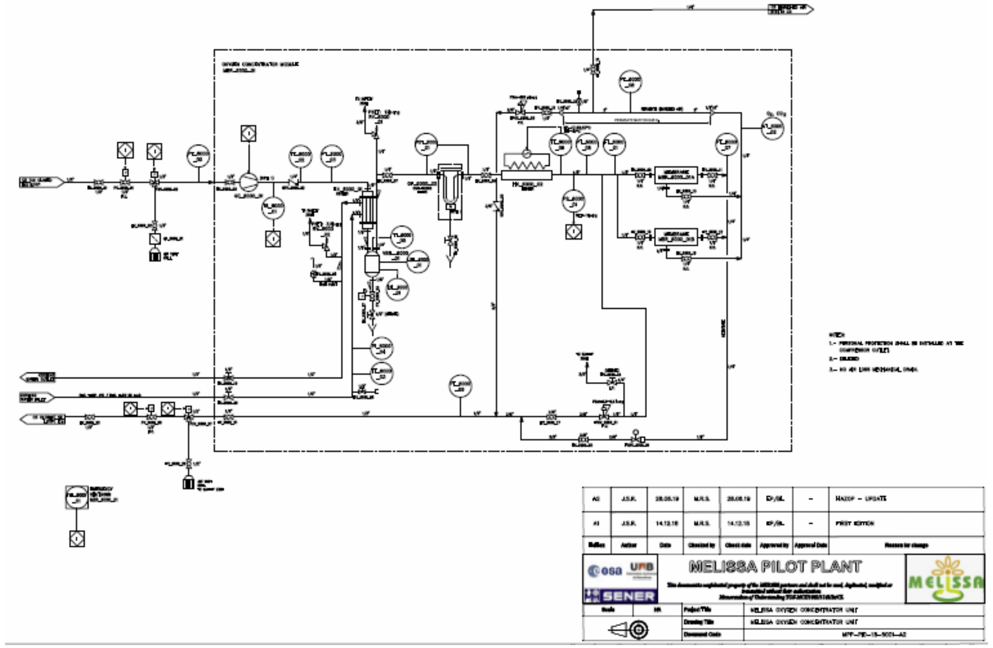
from L. Alemany et al,. *Biochemical Engineering Journal,* 151:107323 (2019)

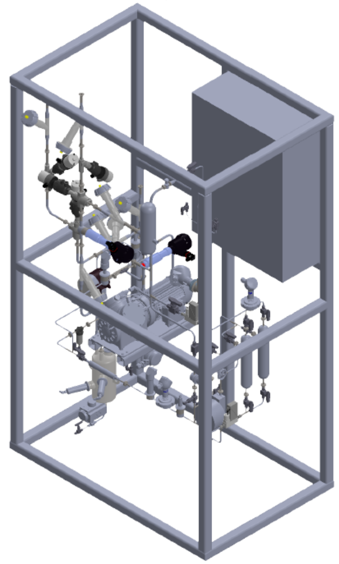
# WP6: integration of compartments: CIII + CIVa + CV, gas+liquid.

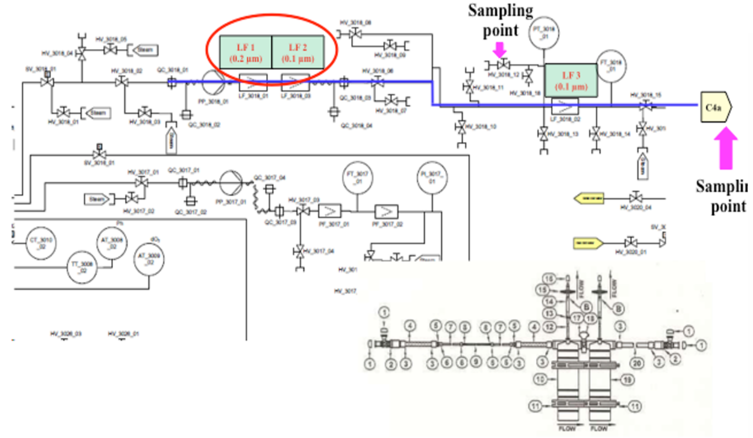


# WP6: integration of compartments: CIII + CIVa + CV, gas+liquid. (E. Peiro, Ground demonstration session)



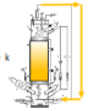






**INPUTS**

| | |
|---|---|
| C3 Volume (L) | 7 |
| C3 Temperature (°C) | 30 |
| C3 Pressure (mbarg) | 80 |
| $C^*_{DOL}$ (AIR, 30°C) (g/L) | 0.00757 |
| Weight kLa TOP Section (%) | 85 |

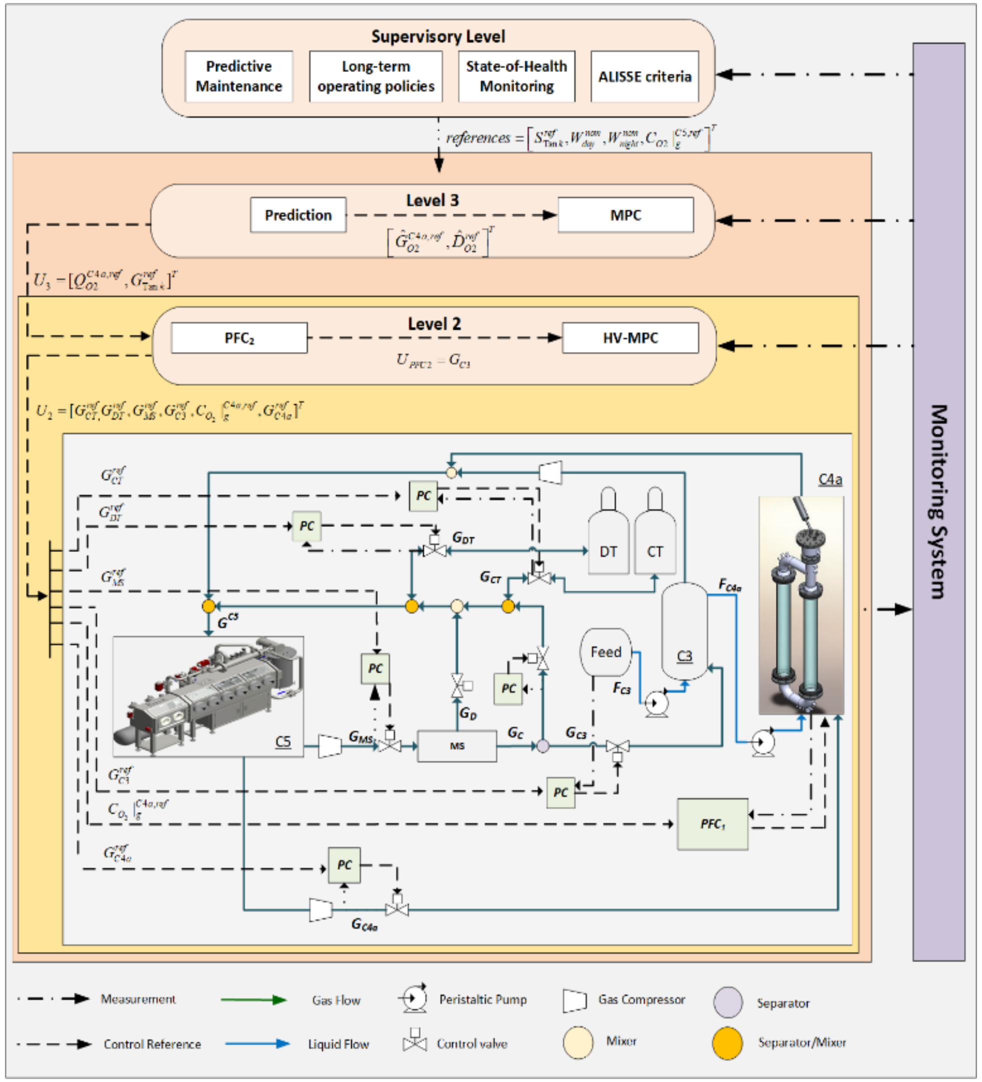



| | N° | MODE * | C3 Feed Load (ppm/d) | C3 Actual Load (ppm/d) Conv.:93.3% | Total Air flowrate (L/min) | $k_La$ TOP (1/h) | $k_La$ LOWER (1/h) | (% mol/mol) $O_2$ C3 Gas Phase | $C^*_{DOL}$ Interface Disolved $O_2$ equilibr. C3 (g/L) | DO % | $C_{DOL}$ Disolved $O_2$ Aqueous Bulk C3 (g/L) | TOP SECTION $R_{O2}$ $O_2$ transfer rate to liquid ($gO_2$/L.h) | TOP SECTION $N_{O2}$ $O_2$ transfer flow gas to liquid (gO2/h) | LOWER SECTION $R_{O2}$ $O_2$ transfer rate to liquid ($gO_2$/L.h) | LOWER SECTION $N_{O2}$ $O_2$ transfer flow gas to liquid ($gO_2$/h) | TOTAL TOTAL $N_{O2}$ TOTAL $O_2$ trans. flow gas to liquid ($gO_2$/h) | MATERIAL BALANCE $O_2$ consumption by Bacteria ($gO_2$/h) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NORMAL OPERATIONAL CONDITIONS | 1 | MODE 1 | 367 | 342 | 3.0 | 31.995 | 52.785 | 19.8 | 0.00800 | 80 | 0.00605 | 0.06245 | 0.37155 | 0.10302 | 0.10817 | 0.4797 | 0.4579 |
| | 2 | MODE 2 | 608 | 567 | 3.0 | 31.995 | 52.785 | 24.0 | 0.00971 | 80 | 0.00605 | 0.11710 | 0.69675 | 0.19319 | 0.20285 | 0.8996 | 0.7593 |
| MODE 1 DESIGN CASE | 3 | MODE 1 | 251 | 235 | 3.0 | 31.995 | 52.785 | 18.5 | 0.00742 | 80 | 0.00605 | 0.04372 | 0.26013 | 0.07213 | 0.07573 | 0.3359 | 0.3140 |
| | 4 | MODE 1 | 486 | 453 | 3.0 | 31.995 | 52.785 | 21.3 | 0.00855 | 80 | 0.00605 | 0.07992 | 0.47554 | 0.13186 | 0.13845 | 0.6140 | 0.6062 |
| | 5 | MODE 2 | 1286 | 1199 | 3.0 | 31.995 | 52.785 | 32.0 | 0.01288 | 80 | 0.00605 | 0.21847 | 1.29992 | 0.36044 | 0.37846 | 1.6784 | 1.6046 |
| MEMBRANE DESIGN CASE | 6 | MODE 2 | 1714 | 1599 | 3.0 | 31.995 | 52.785 | 38.0 | 0.01520 | 80 | 0.00605 | 0.29264 | 1.74119 | 0.48279 | 0.50693 | 2.2481 | 2.1380 |

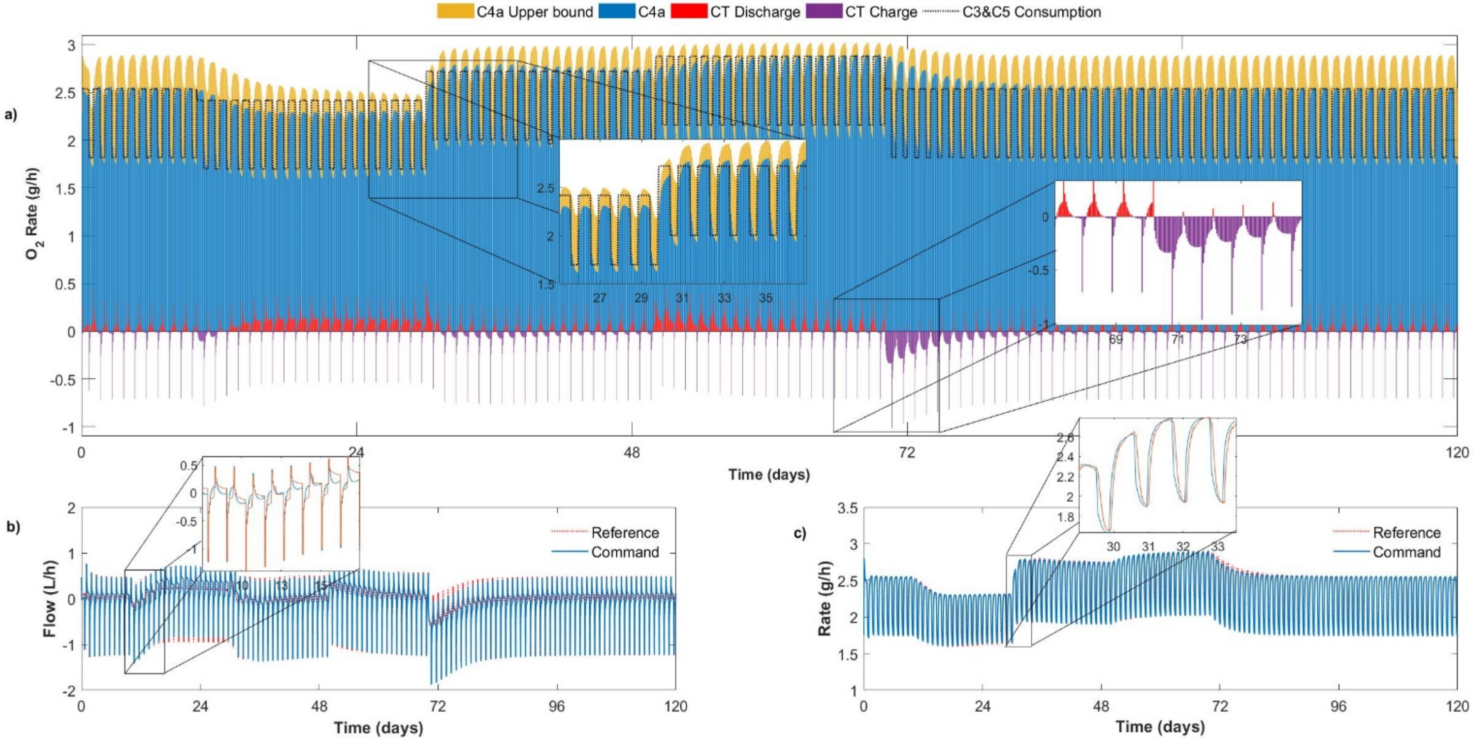
(*) MODE 1: LOW N LOAD MODE ; MODE 2: OXYGEN CONCENTRATION

# Control architecture for the loop

## (C. Ciurans, poster presentation)




**Designing a hierarchical control structure for the MELiSSA Pilot Pant**



# Integration of MPP: future steps

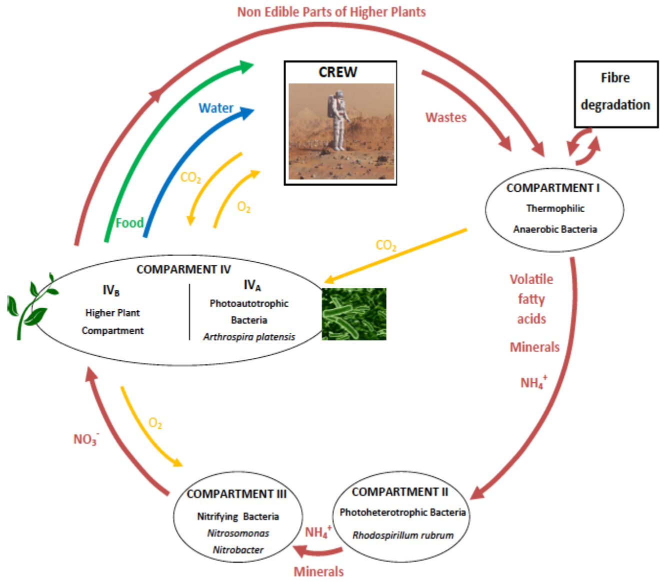
**Integration of Higher Plant Chamber (gas and liquid phase)**

**Operation with urine**

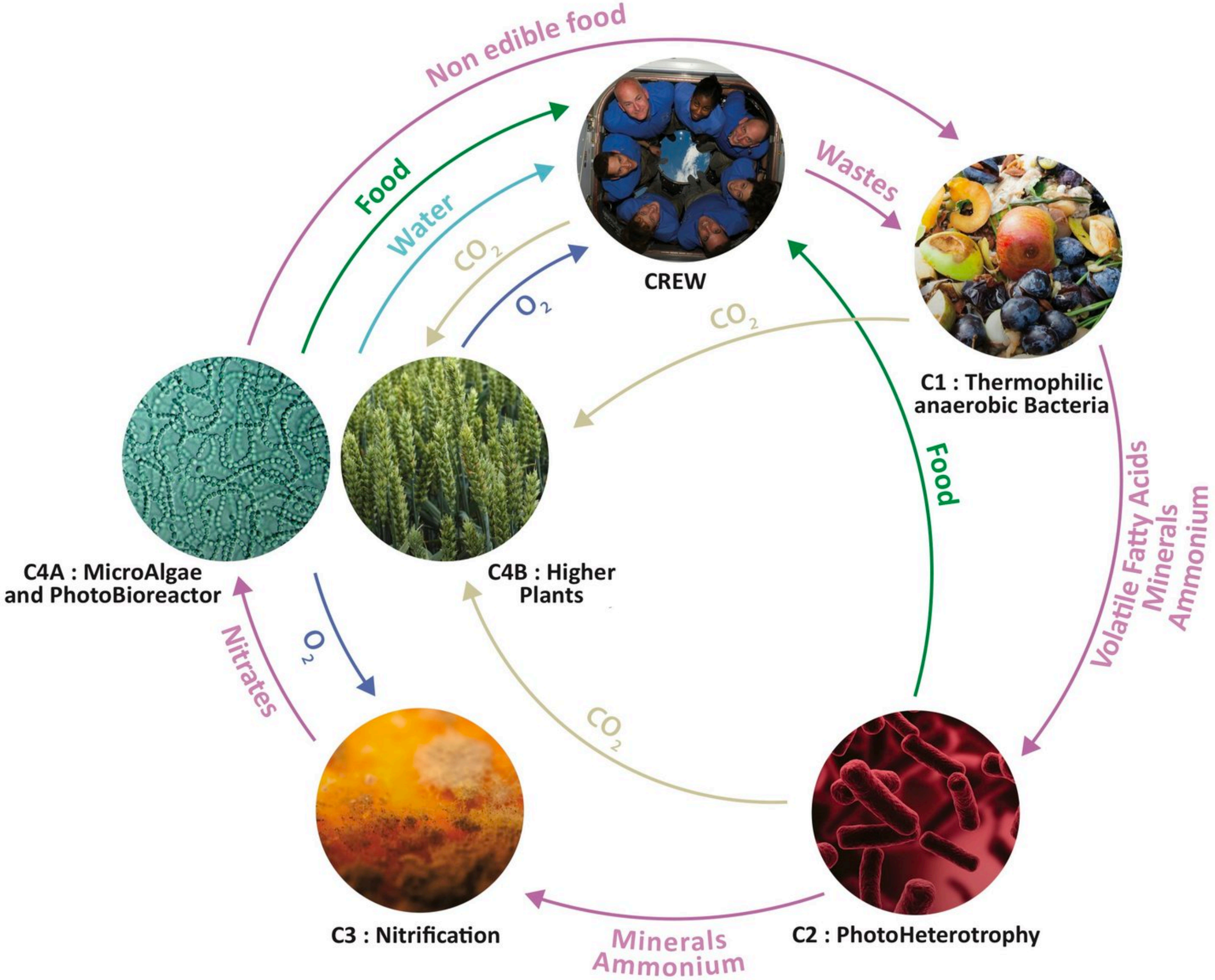
**Harvest system for *Limnospira indica* (solid-liquid separation)**

**Integration of waste degradation technology**

**Final demonstration of the complete loop**



# Integration of MPP: future steps

# Acknowledgements

## MELiSSA Partners

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

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Carles Ciurans

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## MELiSSA ESA-ESTEC

Christophe Lasseur
Brigitte Lamaze
Christel Paillé
Pierre Rebeyre
Marco Volponi

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

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

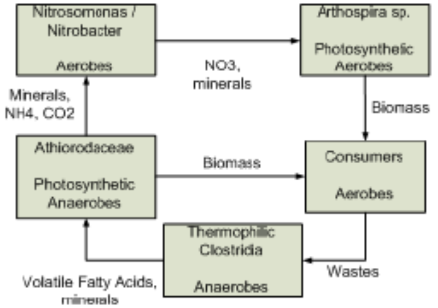
**Claude Chipaux (1935-2010),**

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?"*

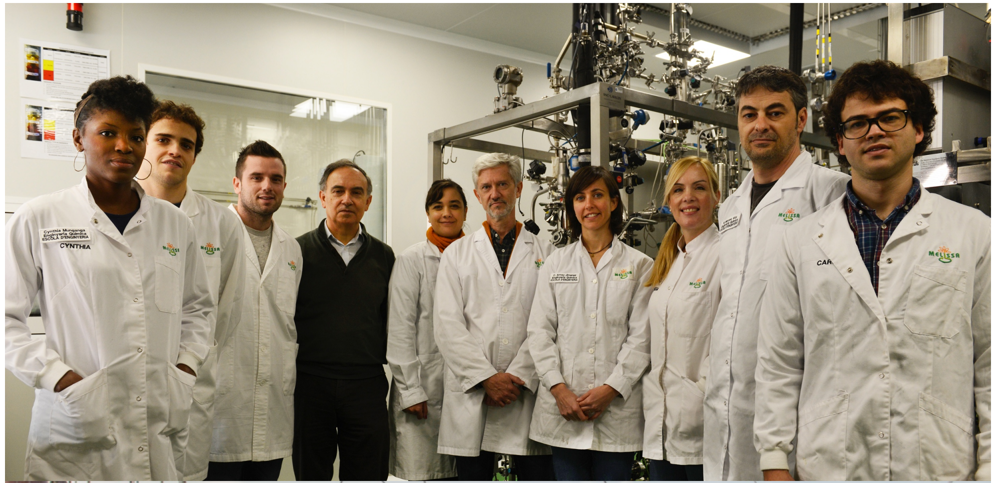
**The first MELiSSA loop concept**




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

**The lake, a model ecosystem**

**The future MELiSSA loop...**



MELiSSA
MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE

# THANK YOU.

**Francesc Gòdia**
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