MELiSSA Pilot Plant: Developing Life Support Technology for Human Space Exploration

MELiSSA Pilot Plant – Claude Chipaux Laboratory
Universitat Autònoma de Barcelona - European Space Agency

First Lego League 2018.
Escola Politècnica Superior. Universitat de Lleida. 27.11.18
Current International Planning

Using the International Space Station
Missions: 6-12 months
Return: Hours
≈400 km/250 miles

Operating in the Lunar Vicinity
Missions: 1-12 months
Return: Days
≈380,000 km/240,000 miles

Leaving the Earth-Moon System
Missions: 2-3 years
Return: Months
≈220 million km/140 million miles

Reaching the Mars Surface
One year stay
Limited return opportunities
Autonomy required
Utilize local resources
Mobility for Science

A step-wise journey from the safety of Earth’s orbit, to the vicinity of the Moon and then into the Solar System
Main requirements for Human Space Exploration and life support systems.

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)
STATE-OF-THE-ART TECHNOLOGY INTERNATIONAL SPACE STATION

- water recovery and management system
- urine, condensate and Sabatier water
- physical-chemical processes (VCD, filtration)
- potable water
URINE, AN IMPORTANT WATER RECOVERY TARGET IN A RLSS

URINE IS RICH IN NUTRIENTS

COD
other

6-9 g N/L

water

COD
other

N

salts

Cl

Na

Mg

SO₄

Ca

PO₄

K

1 g P/L

2 g K/L

The International Space Station toilet. NASA (www.nasa.gov)
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.
- \( \text{O}_2 \) generation
- \( \text{CO}_2 \) 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
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 one person respiration
Production of food: 20-40 % of a person requirements

Layout (214 m²)
### The MELiSSA Pilot Plant (MPP)

**Function in the loop**

Wastes → C. I → Volatile Fatty Acids (VFA) → CO₂

**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

### COMPARTMENT

<table>
<thead>
<tr>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IVa</th>
<th>IVb</th>
<th>V</th>
</tr>
</thead>
</table>

**Notes:**
- The MELiSSA Pilot Plant (MPP) involves the processing of wastes through a series of compartments.
- The biological component includes a mixed culture of thermophilic anaerobic bacteria.
- The waste preparation unit contains raw materials such as plant material, toilet paper, and human faeces.

**Images:**
- Diagram showing the flow of materials through the plant,
- Photograph of the equipment in the plant.
The MELiSSA Pilot Plant (MPP)

Function in the loop

\[
\begin{align*}
&\text{NH}_4^+ \quad \rightarrow \quad \text{C. III} \quad \rightarrow \quad \text{NO}_3^- \\
&\text{O}_2
\end{align*}
\]

Biological component

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

Technology

7 L
The MELiSSA Pilot Plant (MPP)

Function in the loop
- Light
- CO₂
- C. IVa
- Biomass
- O₂

Biological component
- Arthospira platensis (axenic culture)

Technology
- 83 L
The MELiSSA Pilot Plant (MPP)

Function in the loop

Light $\text{CO}_2$ \rightarrow C. IVb \rightarrow Biomass $\text{O}_2$

Biological component

Higher plants *(lettuce, beet, wheat)*

Technology

Armstrong Engineering
The MELiSSA Pilot Plant (MPP)

Function in the loop

- **O₂ Feed** →  C. V →  **CO₂**

Biological component

- **Wastes** →  **Laboratory Wistar rats**

Technology

- **COMPARTMENT I**  
  - III  
  - IVa  
  - IVb  
  - V

- **Biodegradation**
- **N₂**: Nitrogen Fixation
- **H₂**: Hydrogen involvement
- **Organic Components**: Decomposition
- **Water**: Water management

- **Non-Odorous Fats of Higher Plants**
- **ChEAT**
- **Organic Components**: Decomposition
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. CIVa + CV connection by gas phase

- Continuous gas phase connection CIVa-CV at different conditions in CV (set points of % O₂)

- CIVa illumination adjusted by the control system to produce the oxygen necessary to maintain set-point of O₂ in CV, according to the knowledge model linking O₂ production and illumination
WP1 integration. Experimental results. CIVa + CV sequential test

Oxygen – Light control system

- C.V Oxygen concentration
  - Control System I
    - C.IVa Oxygen production
      - Control System II
        - C.IVa Light

Light and Oxygen evolution in CIVa and CV compartments

The system response to CV oxygen set point changes is consistent in the range tested.
WP4 integration. CIII + ClVa connection by liquid phase and ClVa + CV by gas phase.
WP4 integration. CIII + ClVa connection by liquid phase and ClVa + CV by gas phase

- All compartments operating in continuous mode and connected for several months
- Dynamic and static operation under control system fully demonstrated
MELiSSA Pilot Plant: a team effort
Acknowledgements

**MELiSSA Partners**

ESA (EU), SCK/CEN (B), University of Ghent (B), 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)

**Funding**

ESA (several programs), several national delegations (Spain, Belgium, Canada, Italy, France, Norway)

UAB

SEIDI, CDTI, GdC

**MELiSSA Pilot Plant Team**

Enrique Peiro
Beatriz Iribarren
Carolina Arnau
Vanessa García
Cynthia Munganga
Raúl Moyano
David García
Daniela Emiliani
Cristian Eslava

Laura Alemany
Justyna Barys
Jolien de Paeppe
Carles Ciurans

**MELiSSA ESA-ESTEC**

Christophe Lasserre
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’au 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

The lake, a model ecosystem

The future MELiSSA loop...