MELiSSA

The European Project of Closed Life Support System

Ch. Lasseur, JAXA, January 17th, 2017
• founded in 1975
• executes European space policies
• 22 member states
• cooperation with NASA, Russia, Japan et cetera
• yearly budget > 4.4 miljard EURO
• ESTEC/ESA: largest research facility (Noordwijk, The Netherlands)
• approx. 2700 highly educated scientists
INTRODUCTION

ESTEC/ESA NOORDWIJK
ESA astronauts
Life Support Functions

- For the last 30 years ESA studied:
  - Air Recycling,
  - Water Recycling,
  - Waste Management,
  - Food Production and Preparation,
  - Quality control (chemical and microbiological),
  - Reliability & Safety Issues,
  - Modelling & System tools,
  - Ergonomics & Habitability

For all these functions, physical/chemical/biological processes are considered.
Today ➔ Tomorrow

«Juvenile» system

- Unlimited Resources
- Unlimited Waste

«Mature» system

- Low consumption of resources
- Quasi-cyclical flows of materials
ALiSSE Criteria

• Metric to evaluate and compare ECLSS:
  – Multi-parameters,
    • Efficiency,
    • Mass,
    • Energy, **ENRUM study,**
    • Safety,
    • Crew time.
The Concept
A Community
The Scientific Challenges

• Demonstration of the efficiency of each sub-process,
• Compatibility between processes (static and dynamic),
• Modelling and control of biological processes,
• Limitation/poisoning via traces elements,
• Very long term drift,
• Biosafety,
• Crew Acceptance of recycled products,
• …..
The Technological Challenges

• Robust modelling of all sub-systems,
• Modelling and control of A Closed loop system,
• Control of microbial consortium (axenicity),
• Detection (and modelling) of changes of nature of the sub-processes,
• To stay abreast of technological progress,
• Effects of Space Environment (reduced gravity, radiation,..)
• ....
The Management Challenges

- To Convince the investors for the 40 years (or more) of the project development,
- To identify and convince Customers,
- To manage a very large, multicultural, and multidisciplinary group,
- To structure the project and to allow an historical and comprehensive control of all the database
  - Raw data, models, reports, software, manpower, budget, ….
Roadmap

Technology demonstrators
- Generic life support platform
- Generic bioreactor
- Solid-liquid mixing
- Solid-liquid separator
- Gas-liquid mixing
- Gas-liquid separator
- MiDASS air

Precursors
- Air revitalisation (BIORAT 1)
- Urine treatment (BIORAT 2/UNICUM)
- Food complement (PFPU)
- Closed loop demonstrator (MPP)

Cis-Lunar mission
- Water re-use
- Waste collection
- MiDASS water

Various integration steps
Basic R&D
The Modelling Approach

• As mechanistic as possible.

• Requirements implies:
  – Mass balances to be considered: all elements and all phases
  – Energy balances to be considered
  – Rate limiting processes to be characterized
  – Prediction at nominal point
  – Usable for control purposes
  – Prediction at degraded modes.

• Even if very challenging, “we can... because we must”
The approach Inputs / Outputs

- Solid 1,
- Liquid 1,
- Gas 1

- Process
  - Bioreactor
  - FiltrationUnit

Energy

Solid 2, Liquide2
Gas 2

Waste
(liquid, solids, gas)

This document is provided by JAXA.
Nitrogen Transformation

\[ \text{NH}_4^+ \rightarrow \text{COMPARTMENT III} \rightarrow \text{NO}_3^- \]

Nitrosoconomonas europaea

\[ \text{NH}_4^+ \rightarrow \text{NO}_2^- \rightarrow \text{NO}_3^- \]

Nitrobacter winogradskyi

- Packed-bed reactors
- Immobilized cells
- Pilot scale reactors
- Several reactors
- Biofilm control

This document is provided by JAXA.
Model calibration/validation

### Biological parameters:
- Pures cultures (batch reactors)
- Coculture (fixed-bed reactor and bioreactors)

### Physical parameters:
- DTS: characterisation of the hydrodynamic model
- kLa: characterisation of the gas/liquid transfer rate
High Level of Prediction

Variation of the Dissolved Oxygen
The Producer

• Food, oxygen and water productions are organised via two processes:
  – An Algae compartment (IV a)
  – An Higher plant compartment (IV b)
Higher Plants Research
Modelling

- Light interception
- Photosynthesis
- Gas exchange
- Sap conduction: Xylem, Phloem
- Respiration
- Root absorption
- Storage
- Growth
- Temperature, photoperiod
- Development, Architecture & Morphology
- Water + minerals
- Atmosphere
Plant Characterisation
Unit preliminary design

- Objectives:
  - Characterize plant growth (gas exchanges, nutrient uptake, water uptake) under varying environmental conditions including root microbiology
  - Characterize plant composition (chemical and nutritional quality) under varying environmental conditions including root microbiology
  - Develop first principle mathematical model of plant growth
  - Develop predictive control algorithm for optimization and control of the MELiSSA Higher Plants Chamber
Crop cultivar test

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<th>Nutrient</th>
<th>Annabelle</th>
<th>Bintje</th>
<th>Desiree</th>
<th>Innovator</th>
<th>Annabelle</th>
<th>Bintje</th>
<th>Desiree</th>
<th>Innovator</th>
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<td>1.58</td>
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<td>0.07</td>
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Participation in Bedrest

✓ 24 subjects (women).
✓ 3 groups: Controls – Exercise – Nutrition.
✓ Duration: 106 days for each successive period
Preliminary Space Experiments
Regularly in Space

- MESSAGE 1: October 2002
- MESSAGE 2: October 2003
- BASE: September 2006/October 2009
- NITRIMEL: August 2014
- DEMES & BISTRO: September 2015
ARTEMISS- In ISS September 2017
Oxygen/CO₂

CO₂

Micro-Algues

Nutriments

Oxygen

Proteines
Oxygen/CO$_2$
Integration for Ground Demonstration
Concordia Station

Altitude: 3233 m
Thickness ice layer: 3300 m
Distance from sea: > 1000km
Summer $T^\circ$: -30°C
Winter $T^\circ$: -60°C
Minimum $T^\circ$: -80°C
Atmospheric pressure: 645 hPa
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
Space Design

– Preliminary sizing
– System studies
PS selected concepts for further analysis

1 - INFLATABLE DOME – ONE MEMBRANE
   - Axonometry
   - SICSA MarsLab Concept [2004]

2 - INFLATABLE CYLINDER W. INT. STRUCTURE
   - LGH Arizona University [on-going]
   - NASA/ILC Lunar Habitat [1996]
   - TASI/Aero Sekur STEPS2 [on-going]

3 - INFLATABLE CYLINDER W. INT. RIGID CORE
   - NASA/ILC Dover/TASI TransHab [2000]
   - NASA/Bigelow Genesis I, II and BEAM [on-going]
   - ESA/TASI/Aero Sekur IMOD [2006]
Terrestrial Interest
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<tr>
<th>SITE</th>
<th>PAYS</th>
<th>Année</th>
<th>Q.té (m³)</th>
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<td>FRIELAS</td>
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Water Recycling
Microbial Safety: MiDASS

- Fast Microbial Identification and quantification <3 hours
- Pan fungi, pan bacteria,
- Fully automated,
- Unique technology,
- Large terrestrial market: from hospital to pharmaceutical industry
- 50/50% investment with private industry
ALGOSOLIS
Green Building
XTU Initiative
Industrial Ecology

Diagram showing the interconnection of various industrial processes:
- Lake Tisso
- Tisso pipeline
- Statoil refinery
- Asnaesvaerket power station
- Novo Nordisk biotechnology facility
- Gyproc plaster board manufacturer
- District heating
- Future green houses
- Fish pond

Connections include:
- Water
- Sulfur
- Steam
- Cooling water
- Waste water
- Gas
- Waste heat
- Fly ash
- Biosludge fertilizer for farming
- Other

Products and flows:
- Sulfuric acid for sale
- Fly ash sold to cement manufacturers
- Steam, Cooling water, Waste water, Gas, Waste heat, Fly ash, Biosludge fertilizer for farming, Other
- Other
- Other
- Other
Conclusion

• Very high level of challenges,

• An existing community and 27 years of research,

• Objectives in line with Terrestrial and Space R&D and evolution, (e.g. Circular Economy),

• Very much open for collaboration.