MELiSSA: The European project of Closed Life Support System

EMC 13, October 26th
IPSA, Ivry sur seine
Knowledge Transfer

«Juvenile» system

- Unlimited Resources
- Unlimited Waste

<system components>

«Mature» system

- Low consumption of resources
- Quasi-cyclical flows of materials
The MELiSSA Concept
Who?

- Around 30 European organisations (from CDN, CH, B, D, DK, F, E, I, IRL, N, NL) participate:
  - Universities,
  - Public research centres,
  - SMEs,
  - Industrial World leaders,
  - Space companies,
- 11 of them have signed a M.O.U.,
- Around 70 persons are involved,
- ~50% is academic manpower,
- On request of the partners, ESA is in charge of the coordination.
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,…. 
Organisation

• The project organised in 5 parts (e.g. phases):
  – 1) Basic R&D
  – 2) Preliminary Flight Experiment
  – 3) Ground and Space demonstration
  – 4) Technology Transfer
  – 5) Education & Communication
Basic R&D
The approach Inputs / Outputs

- Solid 1,
- Liquid 1,
- Gas 1

- Process
- Bioreactor
- FiltrationUnit

Energy

Waste
(liquid, solids, gas)

Solid 2, Liquide2
Gas 2
MELiSSA: Compartment III (Nitrogen transformation)

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

* Nitrobacter winogradskyi
  \[ \text{NH}_4^+ \rightarrow \text{NO}_2^- \rightarrow \text{NO}_3^- \]
  * Nitrosomonas europaea

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

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)
MELiSSA: Compartment IV (Food/oxygen producer)

- Basic studies: strain, medium, etc.
- Complete math. modeling
- Design and installation of pilot reactor
- Continuous operation of the pilot reactor. Control.
- Scale-up
- Hydrodynamic characterization

$\text{CO}_2 \rightarrow \text{COMPARTMENT IV} \rightarrow \text{BIOMASS} \rightarrow \text{O}_2$
Production : Variable Contrôlée(-) Consigne(--)
Plant Characterisation Unit

• 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
Modelling: Main plant processes and organisation

- Light
- Atmosphere
- Water + minerals
- Temperature, photoperiod
- Development, Architecture & Morphology
- Storage
- Growth
- Sap conduction: Xylem Phloem
- Respiration
- Root absorption
- Light interception
- Photosynthesis
- Gas exchange
- Atmosphere
Modelling: Comparison with the experimental data

Lettuce carbon exchange rates

CO\textsubscript{2} exchange flux (mol/h/plant)

Experimental: Simulation

Lettuce carbon content

Experimental: Simulation

Lettuce water uptake

Water uptake rate (mol/h/plant)

Experimental: Simulation

Experimental biomass: 306 ± 40 g
Simulated biomass: 338 g
Food Preparation

- Definition of the food chain,
- Preliminary identification of critical issues,
- Preliminary identification of technologies for raw biomass transformation,
- Preliminary elaboration of recipes,
- Participation to Bed Rest,
- Creation of a food data base
Participation in Bedrest

- 24 subjects (women).
- 3 groups: Controls - Exercise - Nutrition.
- Duration: 106 days for each successive period.
Preliminary Space Experiments
State of the Art

- MESSAGE 1: flown in October 2002
- MESSAGE 2: flown in October 2003
- BASE: flown in September 2006 and October 2009
State of the Art

- **BIORAT (1997-today):**
  - Laboratory demonstration was completed early 2000
  - Accommodation study for integration within ISS was completed late 2001
  - Prototype development started in 2004, currently under tests
Schedule of future ISS Flight Experiments

- **Artemiss** (expected flight in 2014): Photobioreactor

- **Biorat 1** (expected flight in 2017): Coupling Photobioreactor compartment with a consumer compartment

- **Biorat 2** (expected flight in 2020), Biorat 1+coupling of the nitrifying compartment
Integration for Ground Demonstration
ESA strategy

• 3 and potentially 4 facilities:
  – In progress:
    • ESA:
      – MELISSA Pilot Plant (Barcelona)
    • Non-ESA:
      – Concordia Station (South pole)
      – BIOS (Russia)

  – At feasibility level
    • a new European integrated facility
      (In Spain ?)
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.
Concordia Station

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

French settlement
Construction plan carried out by the French-Italian joint (IPEV-PNRA)
Technology Transfer

• Within ESA project (ATV, MIDASS)
• Terrestrial Application:
  – Two Spin-off companies:
    • IP Star,
    • EZ Col,
Microbial Safety (MiDASS)

- Fast Microbial Identification and quantification <3 hours
- Pan fungi, pan bacteria,
- Fully automated,
- Unique technology in the world,
- Large terrestrial market: from hospital to pharmaceutical industry
- Major Industrial investment
- Spanish industry is performing its Space adaptation (NTE/SENER)
ATV: The European cargo
Quelques références

**BIOSTYR**

**EAUX USÉES**

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Water Recycling for Airbus
Roadmap

Phase 1: BASIC R&D

- Selected technologies
  - microbial model C+N
  - microbial Control model (C+N)
  - plant model C+N
  - plant control model (C+N)
  - CHNOSP Model
  - CHNOSP Control

All technologies for multi-phase management

Phase 2: PRELIMINARY FLIGHT EXPERIMENT

- Artemiss and BIORAT 1&2 are ISS Experiments
- science data collection
- technology demonstration

- Artemiss
- BIORAT 1
- BIORAT 2
- Moon Lander

Phase 3: GROUND & SPACE DEMONSTRATION

- Ground Demonstration
  - With animal
  - With Humans

- Space
  - System study
  - Engineering model
  - Flight Hardware
  - Module 1
  - Module 2
Conclusion

- Very high level of challenges,
- An existing community and 20 years of research,
- Objectives in line with Terrestrial and Space R&D evolution,
- Need to enlarge the MELiSSA community with key technical and political leaders, able to share the vision, and the risks.