ESA UNCLASSIFIED – For Official Use

ESA/PB-HME(2019)30
Att: Report
Paris, 30 April 2019
(English only)

EUROPEAN SPACE AGENCY
HUMAN SPACEFLIGHT, MICROGRAVITY AND EXPLORATION PROGRAMME BOARD

Life Support System Working Group Report

Summary

Following the decision of the Director of Human and Robotic Exploration to establish a Working Group with representatives of PB-HME Delegations and chaired by ESA, the working group met 6 times to determine the way forward for Life Support Systems (LSS) in Europe in the context of E3P Period 2. Short, medium and long term exploration scenarios and corresponding LSS requirements were reviewed in order to define the LSS elements that could support these scenarios and requirements. At the same time, a comprehensive list of all currently ongoing LSS related European activities was established and analysed, and was taken into account in the ESA Technology Harmonisation Roadmap presented to IPC in January 2019 (ESA/IPC (2019) 9).

Finally, the Working Group established a portfolio of LSS activities that would benefit from funding at a European Level. However, no final consensus could be reached on the programmatic framework for technology demonstration activities responding to requirements from long term scenarios (beyond 2030).

The Working Group recommends that for E3P Period 2 these activities are included as candidate activities in the ExPeRT area of activity. The actual funding for a specific activity will however be decided on priorities set after Space19+ through the publication of the E3P P2 work Plan. The selection of the activities will be driven by several criteria such as strategic relevance of the activities, the overall level of subscription, the specific Member States contributions, and the other activities that are proposed in the frame of ExPeRT E3P period 2.

Required Action

The Human Spaceflight, Microgravity and Exploration Programme Board is invited to take note of the attached report of the Working Group on Life Support Systems.

Page intentionally left blank

Report
Working Group on Life Support Systems

Executive Summary

Mastering Life Support Systems (LSS) technology is a prerequisite for future sustainable Human Exploration of the Solar System.

For many years ESA Member States have invested in research and development of Life Support Systems, including open loop, semi closed loop and closed loop systems. As a highly visible result, ESA operates today the Advanced Closed Loop System (ACLS) on board the International Space Station. The 20 years of ESA investing in the MELiSSA project has also led to some remarkable achievements in space (e.g. ARTEMISS, Nitrimel) and on the ground , (e.g. the MELiSSA Pilot Plant and LSS applications at the Antarctic Concordia Station).

Despite the longstanding recognition of its importance by the Member States as documented in several high level reports, LSS research and development has never benefited from a stable programmatic framework and corresponding funding. In E3P Period 1, LSS have been funded through various E3P activity areas: ISS, SciSpacE and ExPeRT. LSS have also benefitted from GSTP and DPTDP funding, while in parallel some Member States have pursued projects on a national level.

Following the decision of the Director of Human and Robotic Exploration to establish a Working Group with representatives of PB-HME Delegations and chaired by ESA, the working group met 6 times to determine the way forward for Life Support Systems (LSS) in Europe in the context of E3P Period 2. Short, medium and long term exploration scenarios and corresponding LSS requirements were reviewed in order to define the LSS elements that could support these scenarios and requirements. At the same time, a comprehensive list of all currently ongoing LSS related European activities was established and analysed, and was taken into account in the ESA Technology Harmonisation Roadmap presented to IPC in January 2019 (ESA/IPC (2019) 9).

Finally, the Working Group established a portfolio of LSS activities that would benefit from funding at a European Level. However, no final consensus could be reached on the programmatic framework for technology demonstration activities responding to requirements from long term scenarios (beyond 2030).

The Working Group recommends that for E3P Period 2 these activities are included as candidate activities in the ExPeRT area. The actual funding for a specific activity will however be decided on priorities set after Space19+ through the publication of the E3P P2 work Plan. The selection of the activities will be driven by several criteria such as strategic relevance of the activities, the overall level of subscription, the specific Member States contributions, and the other activities that are proposed in the frame of ExPeRT E3P period 2.

Contents

List of Acronyms

ALiSSE	Advanced Life Support System Evaluator
E3P	European Exploration Envelope Programme
ACLS	Advanced Closed Loop Systems
BLEO	Beyond Low Earth Orbit
DPTDP	Discovery, Preparation, and Technology Development Programme
DST	Deep Space Transporter

ECLS	Environmental Control and Life Support
ExPeRT	Exploration Preparation, Research and Technology
GSTP	General Support Technology Programme
GWTU	Grey Water Treatment Unit
i-SMT	International System Maturation Team
ISRU	In-Situ Resource Utilisation
ISS	International Space Station
LEO	Low Earth Orbit
LOP-G	Lunar Orbital Platform – Gateway
MELiSSA	Micro-Ecological Life Support System Alternative
MIDASS	Microbial Detection in Air System for Space
PCU	Power Conditioning Unit
PoMP	PhDs on Melissa Project
PPP	Public-Private Partnership
RHU	Radioisotope Heater Unit
RTG	Radioisotope Thermoelectric Generator
SciSpacE	Science in Space Environment

1 Introduction

Life Support Systems (LSS) are one of the core elements that are required for Human Exploration of the Solar System. ESA Member States have for a long time invested in Life Support Systems, including open loop, semi closed loop and closed loop systems. The first technology studies on Advanced Closed Loop Systems (ACLS) started in 1985. The Micro-Ecological Life Support System Alternative (MELiSSA) project was started in 1989, almost 30 years ago, and has advanced knowledge and understanding of regenerative systems leading to a fully closed loop system. More recently, ESA invested in the ACLS system that has been launched to the ISS in September 2018. It is the first European operational system aiming to scrub the CO2 from cabin air and partially retrieve oxygen from the carbon dioxide. . The MELiSSA consortium and DLR have developed Photobioreactors for test on board the ISS. The DLR photobioreactor will be operated in conjunction with ACLS.

Figure 1: ESA astronaut Alexander Gerst installing ACLS, 600 kg of European recycling innovation, in the US 'Destiny' Module in October 2018

With the start of a new exciting Exploration Programme in Europe, decided by the Ministers in Lucern in December 2016, and the follow-on discussions with PB-HME Delegates, it became clear that a more harmonised approach towards development and operations of Life Support Systems in Europe is required to ensure that Europe's limited resources are not spent duplicating developments unnecessarily (although in some areas development of alternative technologies can be beneficial). That is why the Director of Human and Robotic Exploration Programmes (D/HRE) decided to set up a working group with interested Member States to provide ideas to the Executive how to integrate Life Support Systems, technology development and research in the proposal for the next Council meeting at Ministerial level in 2019 (SPACE19+). A list of working group members is in **Annex A**.

2 Scope of the Working Group

2.1 Life Support Systems for the scope of this report

For the purpose of this report, Life Support Systems are defined as the elements (systems, sub-systems) whose technologies and processes enable human presence and activity in the space environment.

Consequently, Life Support Systems cover the following main functions:

1. **Atmosphere revitalisation** (e.g. CO_2 removal, O_2 generation, chemical/microbial/physical contamination monitoring and control, environmental control(temperature/pressure/humidity))
2. **Water recovery and recycling** (e.g. collection, processing and quality control (microbial, chemical))
3. **Food production and preparation** (e.g. food production, transformation and storage, quality control)
4. **Waste recovery and recycling** (e.g. collection, storage and processing of organic wastes generated during the mission)
5. **In situ Resource Utilisation (ISRU)** (e.g. extraction and processing of local resources for Environmental Control & Life Support Systems (ECLSS))

A defined metric (i.e. ALiSSE: Advanced Life Support System Evaluator) based on key parameters (i.e. mass, energy, volume, efficiency, crew time and safety) is used to compare and select the ECLSS architecture which meets mission requirements.

Interfaces to other systems dealing with crew health and counter measures (e.g. medical equipment, physical fitness equipment, human factors engineering, radiation) may also be addressed but will not be discussed in detail in this report. Similarly, it is understood that all the above functions have close interfaces with other systems and functions (e.g. power management, data control,…).

2.2 Objectives of the Working Group

As announced during the ESA delegates' MELiSSA meeting on 19 April 2017 and confirmed during the PB-HME meeting on 10-11 May 2017, D/HRE has decided to start a reflection with PB-HME Delegates on a number of overarching questions related to Life Support Systems for exploration in order to prepare and focus future activities in this field in Europe.

The main objectives are:

- Identify the European existing technologies and the relevant TRL
- Establish a long-term view for Life Support technologies to be developed in Europe
- Identify which technologies can be applied to E3P planned/proposed missions
- Define the roles of the different actors being Member States, Space Industry, Research Institutions, EU, Universities and the commercial sector
- Define the roles of the existing infrastructures and research facilities
- Discuss possible funding schemes and associated governance of the overall Life Support activities
- Propose elements to be considered in the E3P Programme Proposal for SPACE19+
- Identify technology cooperation and transfer opportunities between Life Support Systems for space exploration and terrestrial applications (e.g. Circular Economy, Environment, Eco-Toxicology).
- Identify the link to education and STEM subjects
- Define an action plan based on the above results.

2.3 Meetings and Reporting

The Working Group met 6 times from September 2017 till April 2019 and provided its final report to the PB-HME in May 2019.

3 Mission Requirements for Life Support Systems in the frame of the E3P Mission Roadmap and Gateway in cis-lunar space

3.1 Introduction to the E3P Mission Roadmap

The European Space Exploration Strategy adopted at CM14 expresses the ambition to enable and sustain robotic and human operations in Low Earth Orbit (LEO), as well as on the Moon and Mars. At the same time it promotes four strategic objectives to guide Europe's exploration efforts. These objectives relate to the (1) scientific, (2) economic, (3) political (global cooperation), and (4) inspirational dimensions of space exploration. In 2014, the ESA Member States' Ministers requested to have the three ESA exploration destinations "viewed as part of a single exploration process". The European Exploration Envelope Programme (E3P) is ESA's answer to this demand. It integrates existing space exploration efforts into a single programme delivering the European Space Exploration Strategy. It fully supports the objectives of the 2016 resolution "Towards Space 4.0 for a United Space in Europe". It covers all destinations, fully in line with the vision and strategy for exploration of our international partners.

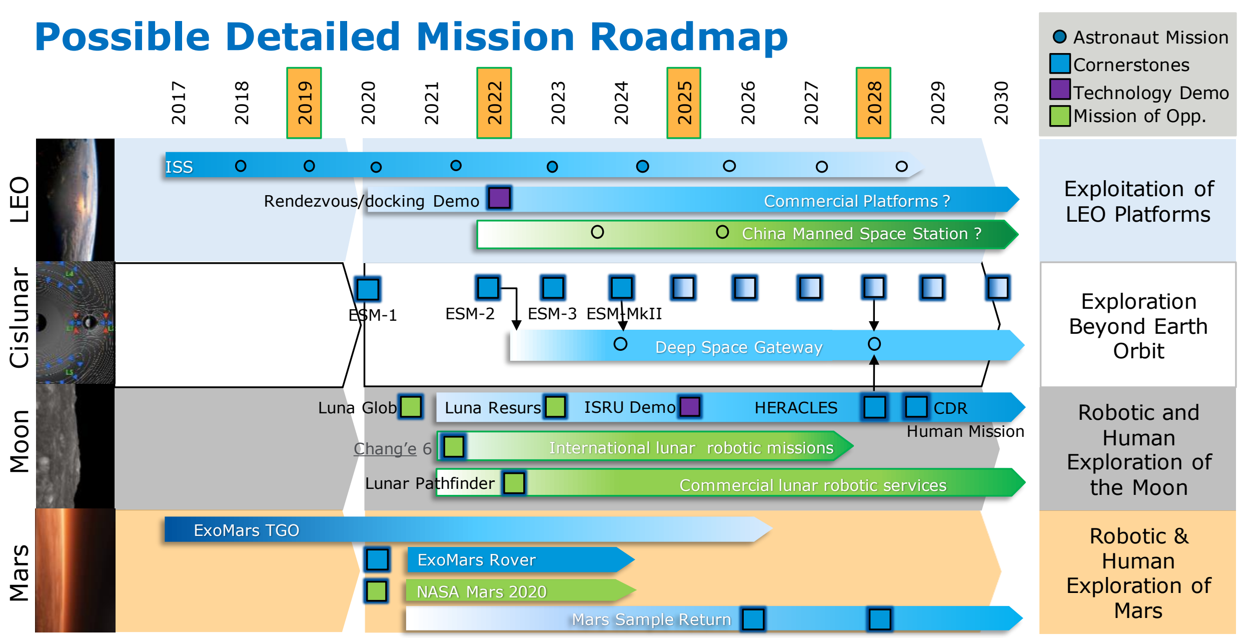


Figure 2: E3P Mission Roadmap

The Programme is conceived as an open-ended programme that can evolve, within the 2014 strategic exploration framework, accounting for evolving expectations and priorities of ESA Member States as well as potential changes and evolutions in our international partners' requirements. ESA has developed an ESA Mission Roadmap reference scenario to guide the strategic discussions on the E3P evolutions (Figure 2).

The E3P Mission Roadmap is grouping the reference scenario missions according to E3P destinations: LEO, the Moon (including lunar vicinity), and Mars. It allows exploiting synergies between destinations, so that a maximum level of affordability is reached by avoiding duplication in technology development and by assigning the right infrastructure to a diverse set of exploration objectives.

The main characteristics of these potential missions and activities are:

- **Sustainable user-driven research in LEO**. ISS operations, including regular astronaut missions, continue to 2024, likely extended using an increasingly commercialised approach. Post-ISS user-driven commercial research infrastructure(s) may emerge by the mid of the 2020's, enabling a gradual transition from ISS to the post-ISS scenario. An opportunity in LEO is cooperation with China (CMSA). The LEO platforms also enable possible technology demonstration for BLEO exploration. ISS and user driven utilisation beyond 2024 are considered core missions, whereas cooperation with CMSA on a Chinese manned space station is labelled as a mission of opportunity.
- **Engagement in early human missions BLEO.** This includes the contribution of the European Service Module (ESM) to the NASA Orion Multi-Purpose Crew Vehicle (MPCV) and contributions to the Gateway, enabling human and robotic lunar surface missions. Transportation (ESM) and the enabling hub (Gateway) are crucial capabilities for any future deep space exploration activity. Therefore, these missions are categorised as core missions.
- **Preparing for Human and Robotic Lunar Exploration.** Building on the Luna Resource experience, potential lunar exploration missions in this reference roadmap are articulated around three main objectives: (1) Support the objectives of the European lunar scientific community, (2) Ensure the build-up of a European share in the development of industrial capacity, products, and services, and (3) Develop enabling technologies for long term sustainability of exploration. Objectives 1 and 2 are covered by robotic precursor missions, e.g. a mission demonstrating at sub-scale level key technologies, capabilities and operational concepts for future lunar surface missions. Hereby international cooperation is an enabling element that would increase programmatic robustness and reduce risks of lack of affordability. Objective 3 is covered by an ISRU technology demonstration mission. Similarly the ISS is being used to demonstrate several key technologies needed for future Human and Robotic Exploration. Technology demonstrators like ACLS demonstrate operational capabilities in CO_2 removal and O_2 generation. Photobioreactors and Nitrification reactors demonstrate biological processes for waste/CO_2 processing into oxygen, water and food. METERON demonstrates key robotic system control by astronauts on an orbiting vehicle.

- **Exploration of Mars.** Building on the ExoMars 2016 and 2020 missions, the focus is on the next step: contributions to a potential NASA coordinated Mars Sample Return campaign. This is considered a core mission because the scientific value of sample return missions is extremely high, not least because new knowledge can continue to be gained many decades after the end of the mission. In the potential collaboration with NASA, ESA would provide the Sample Fetch Rover (part of the NASA Sample Return Lander mission) and the Earth Return Orbiter spacecraft to travel to Mars, capture the sample container and return it to Earth.

The E3P Mission Roadmap has a short to medium horizon, up to the end of the next decade. The Roadmap fits seamlessly into the long-term vision of expanding human presence in the Solar system from Low Earth Orbit to the Moon, Mars orbit and ultimately Mars surface.

3.2 Gateway in cis-lunar space

A lunar Gateway, a NASA led small human-tended facility placed in the lunar vicinity, plays a crucial role in the roadmap as it will enable human and robotic lunar exploration in a manner that creates opportunities for multiple users to advance key goals and foster a burgeoning presence of humans in deep space. The location contains stable orbits which are outside of Earth's deep gravity environment and provides a convenient jumping off point for reusable robotic and human lunar landing systems including refuelling and servicing between missions. Also, the environment of the lunar vicinity is equivalent to what astronauts and spacecraft will experience in deep space. Technologies, procedures and risk management protocols can be tested in relative proximity to Earth in case of an emergency.

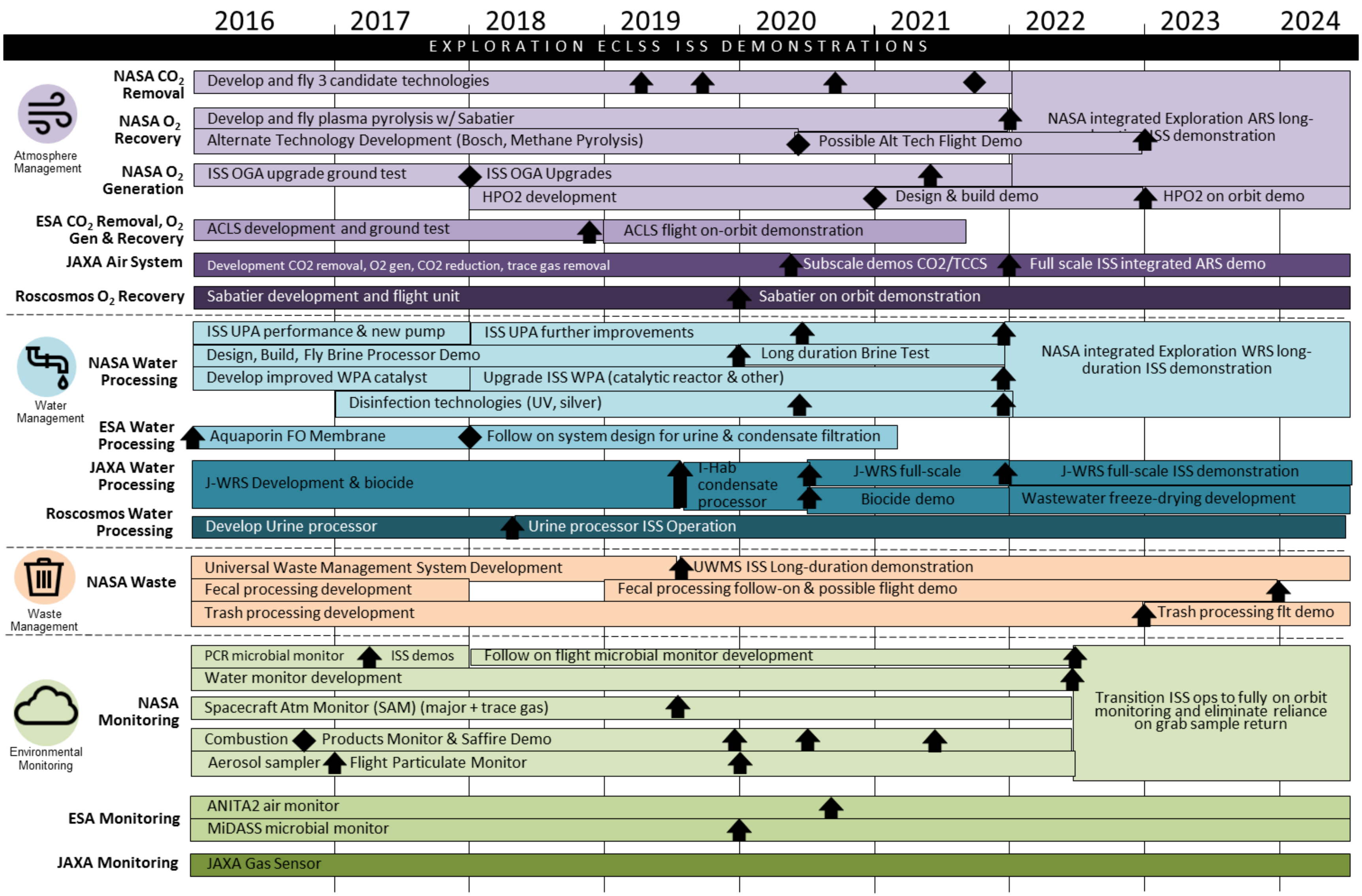


Figure 3: Exploration ECLSS ISS Roadmap

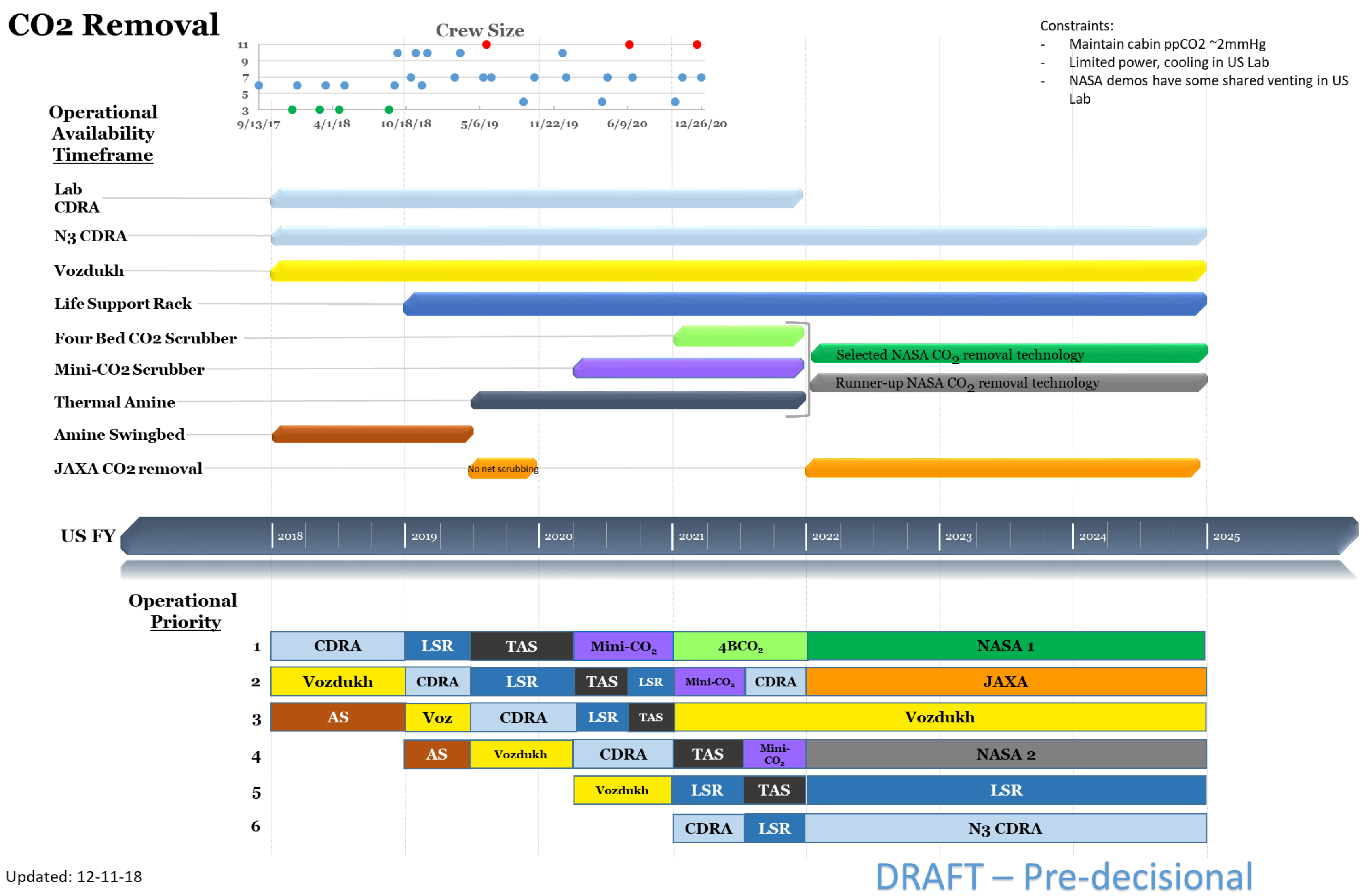


Figure 4: CO_2 Removal Schedule and Priority Order

In the first week of October 2018 the International Partners met at ESTEC for Gateway meetings as well as a Life Support i-SMT workshop. During these meetings the Partners presented overall plans for the Gateway architecture and systems as well as specific Life Support plans.

The Gateway, as currently envisioned, will start with a man tended phase in which there is no technical need for regenerative Life Support. However it is clear that the systems will need to evolve into regenerative systems for future phases. Planning for this upgrade is clearly part of the phase 1 design and accommodated by incorporating life support systems that have standardised interfaces allowing upgrades in the future or already early-on flying semi closed loop systems providing valuable operational demonstration time on orbit. There is also a plan to include non-similar redundancy which has proven life-saving for the ISS.

Currently the baseline is to integrate only operationally proven systems on the Gateway.

The Exploration ECLSS ISS roadmap in Figure 3 shows the capabilities of the Partners. The CO_2 Removal Schedule and Priority Order is illustrated in Figure 4.

This plan has developed over the last year of discussion with the international System Maturation Team (i-SMT) group. The function of this table is to define which technologies will need to fly on the ISS for demonstration purposes and to gain operational maturity.

However it should be noted that NASA has taken a US centred approach by presenting a very NASA dominated Life Support system for the Gateway, leaving little room for Partner involvement.

Primary functions proposed by NASA:

- **Atmosphere Revitalisation** including carbon dioxide removal, trace contaminant control, temperature and humidity control, cabin atmosphere composition monitoring – major and trace constituents
- **Fire Safety and Emergency Response** including smoke detection, portable fire extinguishers, personal protective equipment, combustion product monitoring (subset of trace constituent monitoring), targeted toxic gas monitoring, medical oxygen
- **ECLSS Controller** to increase reliability though a stronger Fault Detection, Isolation, and Recovery capability, and to increase autonomy with added prognostics capability
- **Potable Water Disinfection** (Common potable water biocide)
- **Wastewater Stabilisation** (Common urine pre-treatment)

Main reasons for the NASA proposal are:

- NASA corporate knowledge on the ISS developmental and operational lessons learned
- NASA investment and corporate knowledge in Orion systems (specifically Emergency equipment and Carbon dioxide removal)

- NASA investment in defining Exploration ECLSS Architectures (specifically Oxygen generation and delivery architecture, Water recovery and management systems architecture, Water systems disinfection strategy and NextSTEP modular evolving architecture)
- NASA investment in technology advancements (specifically Environmental monitoring, Trace contaminant control systems, Carbon dioxide removal systems, Temperature and Humidity Control)
- Unique NASA ECLSS testing capabilities and facilities.

The above approach has received substantial remarks from the other Partners and is subject to further discussion and negotiations. Both Europe and Japan have significant expertise in Life Support systems and will be flying several technology demonstrators to the ISS to prove the technology in the flight environment. It is therefore expected that for the later phases on the Gateway, these technologies will be considered for implementation. Europe could make a difference by pursuing for technology demonstrators on ISS Photobioreactors/Nitrification and food production. However, in view of the international competition, some urgency is required in developing European systems if we want to make optimal use of the current utilisation window and stay at the forefront.

3.3 Mission Requirements

For missions in the next 10 to 20 years, LSS requirements are mainly imposed by hubs/gateway infrastructure such as the Gateway and the transfer vehicles such as a Mars Transfer Vehicle. These systems require not only advancements in closed loop systems for water, CO_2 and O_2, contamination monitoring and control, but also waste management capabilities. The demonstration of food production as part of loop closure is also envisaged, in preparation for surface missions to the Moon and Mars. Sustainable surface missions also need in situ resource utilisation (ISRU). In addition, surface missions require to bring sustainable energy in the equation (Energy Production and Storage). For extended stays (minimum 1-2 months) food production is inevitable. However, problems with phase management (solid/liquid/gas separation) will be reduced.

On a timeline from short to long term, following progress can be envisaged.

3.3.1 Short term

Currently, the **ISS** is being and will continue to be used by the ISS International Partners for testing of a variety of alternate concepts for closure of life support systems, mainly for CO_2 removal, CO_2

processing (including additional processes aiming at CH_4 reduction), water recovery, food production, and a waste collection and treatment.

The ECLSS i–SMT tracks these activities. The objective is to identify by end 2021 the life support systems to be used on the Gateway, Phase 2, in particular in the Deep Space Transporter (DST), which will eventually bring crews to Mars. However, applications will also find a place on Moon surface operations.

Hence, in the short term, partners are focussing on demonstration of critical life support technologies in an operational environment.

3.3.2 Medium term

For the **Gateway, Phase 1** (5+ years), LSS requirements are derived from following mission characteristics:

- 4 crewmembers for 30-40 days in a microgravity environment
- Systems re-start after untended periods.

The life support type envisaged could be an open loop system, with some elements of closure at the end of the decade, once logistics systems gain traction. Corresponding life support system characteristics are:

- Power: solar < 1.5 kW;
- Water and atmosphere: primarily open loop;
- Waste management: stabilised and stored, with periodical disposal to heliocentric orbits with spent logistics vehicles;
- Food production and recycling: not required;
- ISRU: not required.

For **Moon Surface Operations** (10+ years), LSS requirements are derived from following mission characteristics:

- 4 crew members for missions of 1-2 months in two pressurised rovers in a 1/6th gravity environment;
- Systems re-start when rovers are autonomously moved to different crew landing sites in between crewed missions;
- Eventually, possibility of a fixed modular 4 crewmember habitat.

The life support type envisaged could be an open loop system for the crew landers and a closed loop system, as validated at the ISS or the Gateway Phase 2 (aiming at duration of BLEO flight with limited logistics for up to 300 days) for the rovers and fixed habitat. Corresponding life support system characteristics are:

- Power: mixed solar/battery/fuel cell, < 6.5 kW; complemented by an early use of RTG/RHU as precursors to Mars human exploration;
- Water and atmosphere: primarily parially-closed loop;
- Waste management: depending on duration and infrastructure, waste processing already providing resources could already be envisaged. Non-recycable/recycled waste will be stabilised, compacted and dumped, under the Moon surface;
- Food production and recycling: limited food production, in conjunction with ISRU.
- ISRU: early ISRU investigations are envisaged, initially through a pilot plant, on the basis of available resources at landing sites.

Hence in the medium term, partners are focussing on limited closed loop systems together with semi closed and open systems as operational systems and, where beneficial, demonstration of closed loop life support technologies.

3.3.3 Long term

For **Mars Transfer and Early Surface Operations** (20-30 Years) following mission characteristics determine the LSS requirements:

- 4 crew in a microgravity and 1/3rd gravity environment;
- Systems re-start when the Deep Space Transports (DST) is un-crewed and when rovers are autonomously moved to different crew landing sites in between crewed missions.

The life support type should be closed loop system, validated at the Gateway, phase 2, for the DST for the 2 years round-trip and for the 1-2 month missions in one/two pressurised rovers. Open loop systems can be envisaged for crew landers.

Corresponding life support system characteristics are:

- Power: mixed solar/battery/CO_2 fuel cells, and RTG/RHU < 6.5 kW;
- Water and atmosphere: primarily closed loop;
- Waste management: (partial) recovery of waste towards a closed loop.Non-recycable/recycled waste will be stabilised, compacted and dumped, under Mars surface;
- Food production and recycling: food production and recycling will be required in order to enable the mission, in particular for the crew transfer portion in the DST;
- ISRU: early ISRU investigations, on the basis of available resources at landing sites.

So on the long term, partners will need fully closed loop operational systems together with semi closed and open systems in specific cases.

4 Programmatic Framework

The life support system technology development activities are very diverse from various perspectives. Progress on some elements are achievable in a short term, whereas other elements require a long time horizon. In a preparatory stage, engineering breadboards are tested in ground test facilities, whereas more advanced breadboards are tested in ground analogues, e.g. as a direct preparation for subsequent preparation of flight hardware. Other developments may require a precursor payload to collect mandatory information or for in flight technology demonstration and/or system maturation, e.g. on board ISS. All these activities can be in parallel and/or successive.

Corresponding funding requirements (budget and time horizon) are equally diverse and therefore no single programmatic framework will be able to support the full portfolio of life support system development activities. In this section, the LSS related technology development activities are categorised and related to possible programmatic frameworks/funding sources. Categories differ depending on technological maturity and time horizon of the activities envisaged. The categorisation and proposed programmatic frameworks in this section is indicative. In practice, the chosen programmatic framework/funding scheme may depend on many factors and various funding schemes may be suitable to support the development activities concerned. The programmatic framework may also change over time, e.g. when activities have been matured or the timeframes have changed. In addition, co-funding of an activity from two (or more) different funding sources may be possible.

The below section specifies the different activity areas with some examples that are part of these activity areas. These examples are not exhaustive and also having them listed here does not imply that they will get funding in the next period.

4.1 Breadboard activities on ground

This category comprises “Space compatible” breadboards (power, volume, mass) to be used in ground test environments such as space analogues, in preparation of flight demonstration. Applications and technologies in this category include e.g. water recovery, cold plasma, food precursors, urine treatment units, and waste collection and processing units.

- The time to an operational model is typically less than 5 years
- Possible programmatic framework / funding sources:
  - ✓ ExPeRT activity area within E3P
  - ✓ GSTP and/or DPTDP
  - ✓ National programmes/contributions

4.2 Ground Demonstrator/Analogue

This category aims at demonstrating technologies or operational concepts in ground analogue test sites (e.g. Concordia, MELiSSA Pilot Plan (MPP), LUNA facility at EAC, Lunares (Piła, Poland), …) in order to validate the technology in realistic conditions. Activities envisage to test efficiency, system performance, operational feasibility, robustness, maintenance concepts, etc.

- The time to an operational model is typically 10+ years
- Possible programmatic framework / funding sources:
  - ✓ ExPeRT activity area within E3P
  - ✓ GSTP and/or DPTDP
  - ✓ National programmes/contributions

4.3 Focused Technology Precursors on board of ISS

This category includes flight hardware that supports characterisation of the fundamental behaviour of subsystems that will be required for an operational in-orbit Life Support System. Developments activities concerned are e.g. ARTEMISS B and C / Arthrospira, DLR Photo-Bioreactor (Interface with ACLS), URINIS A and B, WAPS, and Multiphase Processes (gas/liquid/solid- mixing/separation).

- LSS to be operational in orbit before 2024
- Possible programmatic framework / funding sources:
  - ✓ SciSpacE and/or ExPeRT activity areas within E3P for on-going activities or activities that have a real need date for ESA contributions
  - ✓ GSTP for new activities
  - ✓ National programmes/contributions (incl. Prodex)
  - ✓ Possibly also DPTDP activities (TBC, for TRL 1-4 only)

4.4 Technology Demonstrators on ISS

This category covers demonstrators that will run for limited time but will demonstrate a functionality that could possibly upgrade/improve a planned LSS. Activities in this category are e.g. GWTU/Water Recovery for one Person, Photobioreactor and Nitrification for a crew equivalent which allows scaling to an operational facility.

- Time to Orbit < 5 years
- Suggested programmatic framework / funding sources:
  - ✓ ISS Exploitation and/or ExPeRT activity areas within E3P
  - ✓ National programmes/contributions

4.5 System Maturation on board ISS

This category aims at equipment/systems that will run for extended periods and have a full system capability that can contribute to ISS resources. Systems currently falling in this category are ACLS and ANITA2. In future, an ACLS upgrade and/or a MiDASS upgrade with additional capabilities may be envisaged. MiDASS so far has concluded a successful PDR in 2013 for a microbial identification and quantification capability based on the NASBA method. A proposal for follow on activities was received in 2018 after several difficulties (amongst other the strategic change of focus in the key industry, i.e. bioMerieux), however it could not be accepted. Microbial contamination identification and quantification remain however a key topic and are necessary for safety during long term exploration missions.

- Time to Operations < 3 years
- Suggested programmatic framework / funding sources:
  - ✓ ISS Exploitation activity area within E3P

4.6 Short Term & Long Term Research Activities

This category regroups activities related to long-term research to answer fundamental questions for LSS. Examples are e.g. POMP, PCU (Plant Characterisation), System Tools. The activities shall seek to fully exploit the interaction space/non-space in order to maximise the innovation potential and return to society. Obvious counterpart for the space activities is the circular economy area and associated terrestrial products, but many other areas can be explored.

- Implementation horizon > 10-20 years
- Suggested programmatic framework / funding sources:
  - ✓ E3P Expert Activity area for transversal activities
  - ✓ Alternative Funding Sources (e.g. Life Support System Fund)
  - ✓ DPTDP, GSTP
  - ✓ National programmes/contributions

Under the Space 4.0i umbrella, innovative programmatic frameworks can be explored such as a joint venture or a public-private partnership. Various mechanisms and governance schemes are envisaged and need to be explored. The management of the portfolio of these activities could e.g. be externalised to a company or foundation. A foundation could e.g. be (partially) funded by ESA/E3P to cover part of the operational costs, as well as to provide some seed funding for PPP's. Support for specific activities could be funded using DPTDP/GSTP funding. In addition to the ESA funds, multiple new/additional funding sources need to be identified and attracted to this vehicle. These could include funds e.g. provided by academia, industry, regional development funds, private investors, philanthropic organisations, ….

A dedicated study is planned to be kicked off in 2019 Q2 with the overall objective of assessing the financial and business potential related to closed loop Life Support Systems (LSS). The results will give insights in the bankability and/or the opportunity of creating an investment fund and/or to identify an evolutionary scenario of the existing MELiSSA foundation to ensure the long-term financial sustainability. Study results should be available by the beginning E3P period 2.

5 Education and outreach

Education and outreach are an important tool in the long-term strategy of ECLS related developments. STEM related disciplines form the basis of progress, and the long-term duration of some developments necessitate that knowledge is being transferred throughout the years. Inspiration plays an important role as well, as it may unearth new concepts and ways of thinking for the general public.

Three pathways are being followed:

1. **Active involvement of the public:** By giving visibility to life support system related developments during public expositions, science related public events etc., the public awareness is raised. The active global involvement e.g. through a citizen science project called Astroplant goes a step further. The end goal is to provide an educational kit which enables young people in different ages to accomplish observations and collect data on plant growth, which then can feed back into a bigger data set. Standardisation of tools and procedures teach as well general methodologies to interested people.

Figure 5 Prototype of the Astroplant education kit

2. **Education experiments with live transmission from Space:** A good example was the 'Food from Spirulina experiment carried out by Samantha Cristoforetti during the Futura mission. 1000 experiment kits were distributed to teachers and students throughout Europe which performed the same experiment on ground as the Astronaut on-board the ISS.
3. **Focused development of academic know-how** through the funding of ECLS-related PhDs topics, called PoMP (PhD on MELiSSA Projects).

6 Technology cooperation and transfer opportunities between life support systems for space exploration and terrestrial applications

A long term life support for exploration research and development programme is particularly well suited for fostering interdisciplinary ground research. Indeed, life support systems for space exploration encompass numerous technologies that are also crucial elements for tackling terrestrial challenges such as environment, water, food, safety, ecosystems, circular economy, health, toxicology,…

Figure 6: Current projects in terrestrial sectors

The MELiSSA partnership represents 30 years of experience in this domain. While building unique European know-how in technology for long-term human space exploration, the partnership has at the same time a proven track record of addressing daily concerns of European citizens. The resulting technologies, applications and services are helping making our society more sustainable for the future generations. These successes make MELiSSA also a powerful tool for societal education and inspiration. A high-level overview of the MELiSSA socio-economic impact is given in Table 1.

Over the years many remarkable successes have been achieved. Selected examples are illustrated in **Annex B**:

- Water treatment plants across Europe apply BIOSTYR® technology to treat waste water;
- Grey water Treatment Unit implemented in the Concordia station on Antarctica;
- Water treatment plant, Kenitra, Morocco;
- ALGOSOLIS: an Industrial Pilot facility dedicated to the development of microalgae industry;
- SEMiLLA sanitation hubs;
- Koningshoeven Abbey – Brewery;
- Cholesterol reduction, ezCol BV;

- Villa Troglodyte;
- Biofacades Paris XTU;
- Local proteins production: Mooto (Congo, RDC);

Table 1: Overview MELiSSA socio-economic impact

<table>
<tr><th colspan="2">Socio-economic impact of the MELiSSA research and development programme</th></tr>
<tr><td>Stakeholders working together and creating synergies</td><td>Socio-economic Impact factors & impact examples</td></tr>
<tr><td rowspan="3">• space companies
• local & national authorities
• scientists
• public organizations
• non-space industry
• students
• donators
• pensioners
…</td><td rowspan="3">Economic growth & employment

• 3 (+1) Spin-off companies
• Commercial applications; current projects address bio-based and circular economic models e.g. in sectors
✓ Agro & Food
✓ Life Sciences & Health
✓ Waste & Water
• Co-funded research (Auvergne, Andalousia, Catalonia, Pays de la Loire, Flanders,…)
• Private sector co-investments: EZCol, IPStar, SEMiLLa, FIRMUS, up to market
• Institutional partners: Dutch water board, CNES, ASI, ANRT,..

Knowledge, Innovation and competitiveness

• 15 patents
• co-funded PhDs & Research (e.g. MPP, photobioreactor,..)
• STEM qualified workforce
• Co-funded facilities (U Guelph, Algosolis)
• Co-funded research (Auvergne, Andalousia, Catalonia, Pays de la Loire, Flanders,…)
• H2020

Inspiration & Education

• prizes & honors,
• students requests, master class
• good media coverage for the invested efforts
• high quality reputation up to a MEliSSA branding
• good level of recognition

Global impact & sustainable development goals</td></tr>
<tr><td>Multi-disciplinary nature of activities</td></tr>
<tr><td>• engineering
• microbiology
• chemistry
• food science
• philosophy
• psychology
…</td></tr>
</table>

7 Datasheets / Existing Roadmaps / Plans / Developments

7.1 LSS working group technologies datasheets

To inform the Executive on existing technology development and research related to Life Support Systems, a request for information was addressed to both delegates and relevant ESA entities using a standard questionnaire/template datasheet. The information requested through this datasheet is in Table 2.

Table 2: Datasheet information fields

1. Title
2. Life Support main function(s) addressed: □ *Atmosphere revitalization* □ *Water recovery and recycling* □ *Food production and preparation* □ *Waste recovery and recycling* □ *ISRU*
3. Short description (main characteristics, features, …)
4. Key performances demonstrated
5. Demonstration level (incl. testing conditions, duration) □ *calibrated mathematical model* □ *Lab scale proof of concept* □ *Pilot scale ground demonstration* □ *Payload/ techno. Demonstrator* □ *Space engineering model* □ *Flight model*
6. Links with other technologies (title and reference)
7. Keywords
8. Associated publications

57 datasheets have been submitted and are in **Annex D** to this report.

The information in the datasheets has been screened by ESA's technical Directorate (TEC). High level information from the datasheets and the result of the screening by TEC have been summarised in a table containing for each datasheet/technology the information listed in Table 3. The summary table can be found in **Annex C**.

Table 3: Datasheets summary information and screening results

Information collected from datasheets
A. Country: country who provided the datasheet, ESA-Dir when ESA exclusively funded development
B. LWSG ref: internal number to ease the traceability of the documents (visible in all datasheets in the footer)
C. Title: title as provided by the author
D. LS function: selections from the tick boxes provided in the template
Outcome of TEC screening
E. Overall evaluation TEC (if not considered further): stating the motivations why a technology has not been considered for further development
F. Considered already available: some technologies are indicated as reaching TRL 9 already; these technologies are therefore considered available without the need of further development
G. To be further processed: decision to keep the technology datasheet in the process; the technology is assessed as to be further developed in the current exploration scenario
H. Request for information: some additional information would be beneficial to understand the current technology maturity status
Multiple criteria classification of the proposed technologies, at the convenience of the reader , to allow multiple views of the current technology offer
I. System/subsystem: some technologies are proposed "stand-alone", similar technologies can sometimes be found in a system
J. Product: water, air, food, etc
K. Contributes to generic development: specify to which generic technology development the proposed technology is contributing.
L. Main function

A first high-level analysis shows that 41 datasheets have been submitted by 6 different countries. Another 15 datasheets have been submitted by the European Space Agency.

As shown in Table 4 and Figure 7: Repartition of technologies datasheets origins, Italy (25 datasheets) and ESA (15 datasheets) are the main contributors. The geographical distribution in Figure 7 has to be interpreted with care. The list is not exhaustive and e.g. some delegations decided to provide datasheets only for new ideas, counting on datasheets provided by ESA for technologies under TEC procurement, already broadly covering the delegations' countries interest and industrial capabilities. A limited number of datasheets from a specific country shall therefore not be interpreted as a poor interest from that country in LSS.

Table 4: Origin of technologies datasheets

Country	Datasheets
Belgium	1
ESA	15
France	4
Germany	3
Italy	25
Switzerland	8
United Kingdom	1

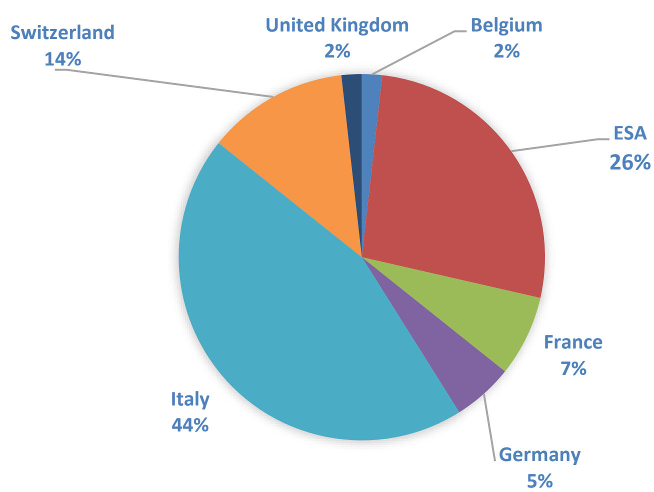


Figure 7: Repartition of technologies datasheets origins

Figure 8 shows the distribution according to the main life support functions addressed by the technologies. Many technologies address different functions simultaneously (56 technologies addressing 85 functions).

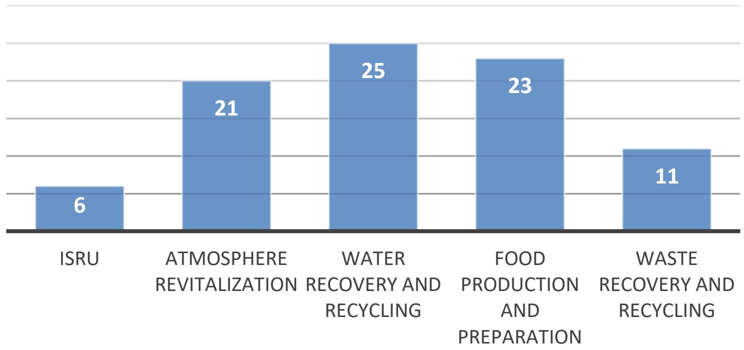


Figure 8: Life Support Functions

Analysis of the sheets reveals that 28 of the technologies relate to either already available technologies (TRL9), technologies not considered for cislunar and transit phase, or technologies which are out of the scope of life support. The remaining 29 technologies are therefore considered to be further processed.

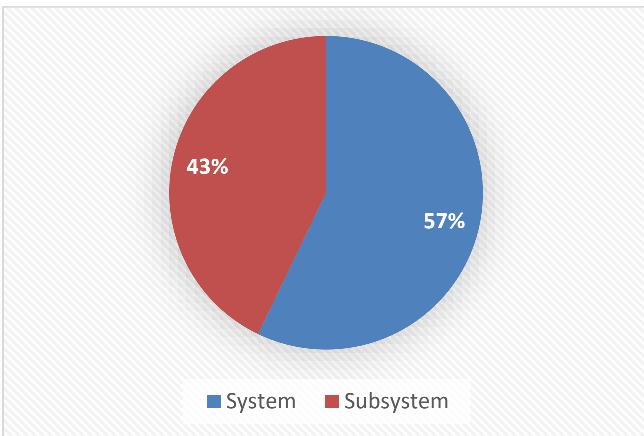


Figure 9: Further processed technologies' nature

From the 28 technologies to be further processed, 16 are at system level, whereas 12 are at subsystem level (cf. Figure 9). Figure 10 and Table 5 show the distribution of products generated by these 28 technologies. Note that a single technology may generate more than one product (e.g. food and air).

Table 5: Products generated by technologies to be further processed

Liquid	**5**
Water	15
Food	10
Air	10
Energy	1
Generic	1

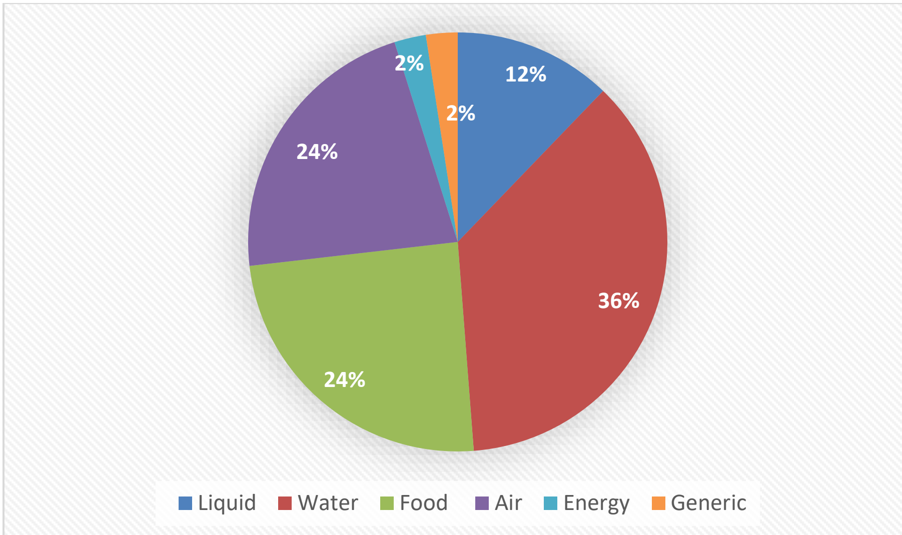


Figure 10: Products generated by technologies to be further processed

7.2 Conclusion and Roadmap

57 fiches have been received of which 29 have been preliminary identified as relevant for the coming ministerial council Space19+ based on following main criteria:

- current TRL lower than 6,
- potential interest for life support for future missions (e.g. Gateway phase 1&2, transit phase, Moon or Mars surface).

The definition of ECLSS requirements in Cislunar space for the phase 1 of the Gateway is currently ongoing work. Requirements for phase 2 will be established later. Nevertheless, taking into account the envisaged crew size (~3) and missions duration (from 1 week to 1 month) it can be assumed that the ECLSS for phase 1 will not be required to be regenerative. For phase 2 a regenerative ECLSS could be envisaged for air, water, and potentially a very limited food complement (<5% of the diet).

The 29 fiches that were retained have then been classified by

- technological objectives (i.e. air, water, food), and
- associated enablers (e.g. multi-phase investigations, ground demonstration & operation, system tools, and academic support)

A further down selection has been made line with the logic and priorities of previous ECLSS activities approved at the 2009 ESA Council at ministerial level (AURORA), and consistently confirmed at the 2012 ESA Council at ministerial level (ELIPS 4) and the 2016 ESA Council at ministerial level (ExPeRT).

This selection is also in line with the TEC harmonisation roadmap, which is the underlying backbone for all these activities. Complementary information obtained through the fiches is also feeding into the knowledge base for further iterations of the TEC harmonisation roadmap.

European ECLSS activities started in 1985, with ACLSS, followed by ANITA and MELiSSA. Based on solid engineering work, a sizing of the photo-bioreactor, nitrification and food complement were elaborated. The results justify the logic to:

- pursue the carbon dioxide transformation to oxygen and proteins as currently initiated on board ISS (e.g. ARTEMISS-Photo bioreactor);
- secure and valorise urine, via nitrification, to water and nitrogen sources (e.g. URINIS, nitrogen gas);
- consider a limited food production to demonstrate its robustness below Van Allen belts, and allow fresh production on some sensitive food source; (e.g PFPU)
- maintain the system tools and enabling tools to prepare dynamic and robust ECLSS closed loops.

A notional roadmap for implementing the retained activities is shown in Figure 11. Main elements and reference to corresponding fiches are:

- Photo bioreactor (fiches 6, 21, 23, 56);
- Nitrification (15, 22);
- Food precursor and characterisation (7, 10, 24, 50, 53);
- Multi-phases investigations (3, 11, 12, 57);
- Ground demonstration & operation (6, 7, 15, 53);
- System tools (7);
- Academic support (50, 53).

A detailed description of proposed activities for Space19+, including programmatic framework, timeframe and budget estimates are in section 8 below.

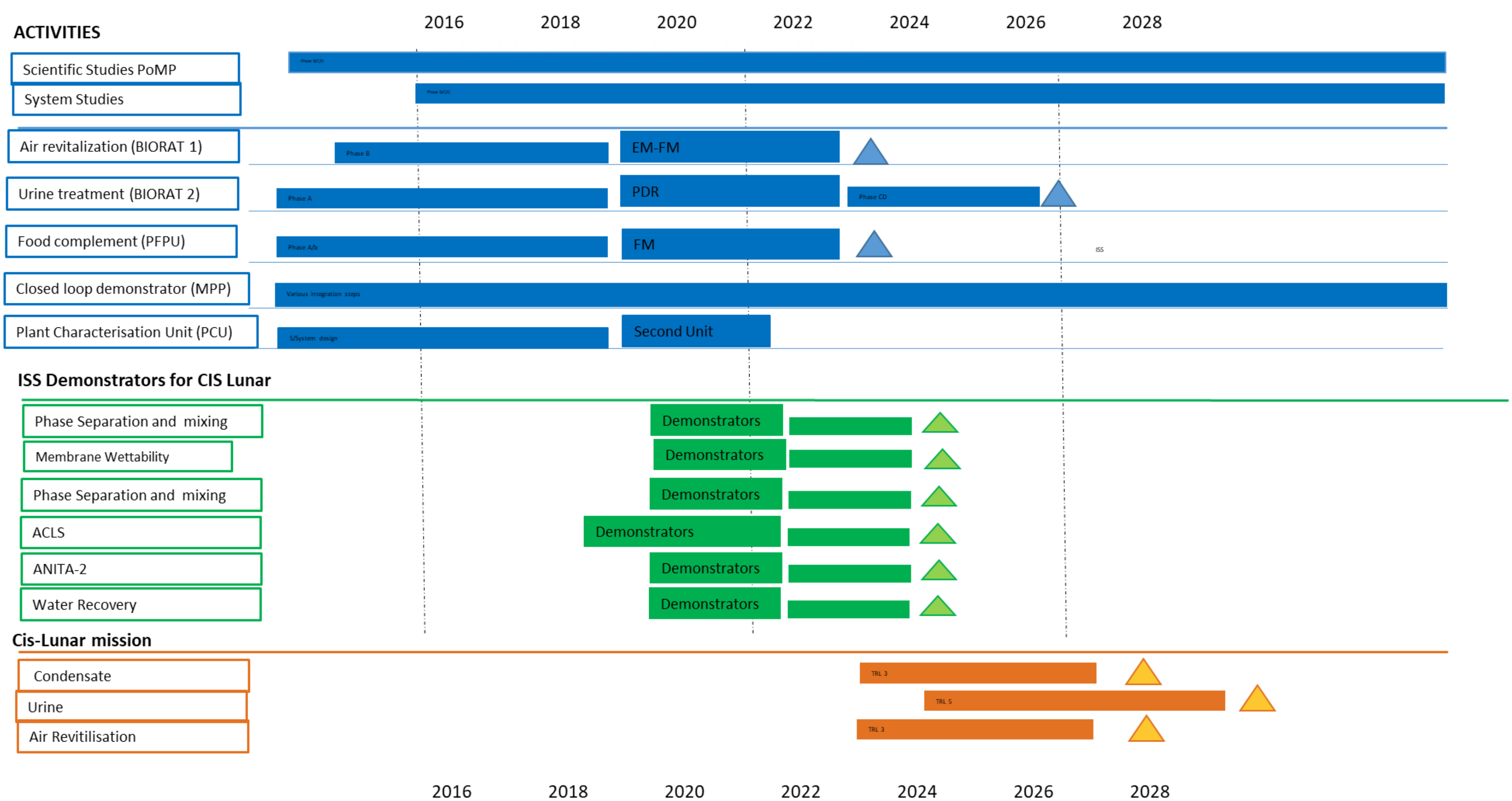


Figure 11: Proposed Roadmap for 2019-2022

8 Proposed activities Space19+ (medium / long)

The activities to be funded by E3P are summarised in this section and can be categorised as:

- Medium technology demonstration activities funded as part of ISS evolution / modernisation or funded as part of ExPeRT activities (section 8.1);
- Science funded as part of the SciSpacE Activities (result of ILSRA) (section 8.2);
- Support to ISS demos through provision of resources (integration, upload, crew time, etc…) through E3P for payloads developed under various funding sources (GSTP, national funding, E3P or others (section 8.3);
- Fundamental support as part of E3P ExPeRT activities (cf. section 8.4).

E3P ExPeRT Period 2 will continue to exploit the synergistic potential of collaborating with other ESA programmes such as the DPTD and GSTP. This is particularly so for the LSS activities. These activities can be further reinforced via national funding of technology developments. The activities that could be funded at Space19+ inside or outside the E3P envelope are in section 8.5.

The budgets mentioned are ROM estimates by ESA based on industrial studies and proposals.

8.1 Medium technology demonstration activities

These activities envisage in space demonstration within a time horizon of about maximum 5 years.

8.1.1 ACLS MkII

- ✓ ACLS was launched with HTV7 and has been commissioned in November 2018. Operational experience plus outcome of current ACLS2 studies and breadboarding will lead to the proposal of improved subsystems for ACLS. Current plans are for ground activities only in the areas of CO_2 removal (also cryogenic), and high pressure electrolysers, with engineering model quality hardware for extensive ground testing. Methane Processing will be started with breadboard activities only.
- ✓ E3P ISS activity area
- ✓ Budget: will be accomplished using budget already identified and a max. request of 3-5 ME of new budget.
- ✓ Timeframe: 2019-2021
- ✓ Additional information: The ACLS is the first integrated system flown and improvements are expected with new designs for some subsystems. Although regenerative life support is not required for the first phase of Gateway, ACLS is targeting application in later phases of exploration. Robust system demonstrated in the ISS will be necessary prior to implementation on Gateway.

8.1.2 ANITA

- ✓ Subject to confirmation of requirements for flexible trace gas sampling at the Gateway, adaptation of Anita2 to the Gateway will be started, including procurement of a Flight Unit.
- ✓ Gateway activity area
- ✓ Budget: 3 M€ as part of i-HAB Gateway
- ✓ Timeframe: 2021-2023
- ✓ Additional information: real time and flexible understanding of air quality is of large importance for man-tended infrastructures and for long term transfer human missions.

8.2 SciSpacE

The MELiSSA project has a strong mechanistic engineering approach, including a phase of scientific data collection in space environments (flight precursor experiments). Since the early days, all flight opportunities have been considered from Longue Marche to ISS. These scientific activities are already funded or will receive delta funding as a continuation in the SciSpacE activity area. For Space19+ following activities are envisaged.

8.2.1 WAPS

- ✓ Objectives: Study of Plants Water Transfer
- ✓ PI: U Napoli (I), CIRIS (N)
- ✓ Industry: CIRIS (N)
- ✓ Concerned Countries: N, B, F, E, CH, I
- ✓ Launch: 2020

8.2.2 ARTEMISS- C

- ✓ Objectives: Validation of CO_2 removal, oxygen production and biomass production in continuous mode.
- ✓ Identification and study of potential space stressors,
- ✓ PI: SCK (B), U Mons (P), UClA (F)
- ✓ Industry: Qinetiq (B)
- ✓ Concerned Countries: B, F, E, CH
- ✓ Launch: 2020

8.2.3 Urinis

- ✓ Objectives: Validation of Nitrifying function in reduced gravity in batch mode and small volumes.
- ✓ PI: U Ghent (B), U Mons (B), SCK (B)
- ✓ Industry: Qinetiq (B)
- ✓ Concerned Countries: B, F, E
- ✓ Launch: 2022

8.3 Support to ISS demos

In addition to E3P funded ISS demonstrators, it is also envisaged to continue supporting ISS demonstration activities for which the development is funded through other programmes. E3P will support these demonstrators by providing the necessary resources for integration and ISS utilisation (upload, crew time,…).

8.4 Fundamental support

8.4.1 Pool of MELiSSA PhD 3 (PoMP 3)

- ✓ Generation of scientific and engineering input data for further development and validation of selected mechanistic models required for regenerative processes, provide inputs for validation in flight;
- ✓ Programmatic Framework E3P
- ✓ E3P ExPeRT activity area
- ✓ Budget : 2 M€
- ✓ Timeframe : 2020-2023
- ✓ Application scenario: e.g. gateway, lunar surface
- ✓ Additional information: Highest priority for continuation of MELiSSA activities because these models provide scalability and predictability capabilities and contribute to the reliability assessment of the technologies and therefore support the definition of the redundancy strategy

8.4.2 System tools

- ✓ Opening of the existing virtual ALiSSE methodology and model platform to all users.
- ✓ E3P ExPeRT activity area
- ✓ Budget : 1 M€
- ✓ Timeframe : 2020-2022
- ✓ Application scenario: Any mission including life support system
- ✓ Additional information: High Priority because the tool and associated methodology have been developed for comparison of life support systems architecture, only tool available for multi-criteria comparison
- ✓ Other funding: GSTP, TRP, national funding/initiatives

8.5 National, GSTP, DPTDP or E3P funding

8.5.1 Photobioreactor phase C/D (previous BIORAT1)

- ✓ Flight demonstrator of a regenerative process for air loop closure and food supplement production (i.e. protein rich biomass)
- ✓ Budget: 5 M€

- ✓ Timeframe: 2020-2023
- ✓ Application scenario: Gateway, lunar surface
- ✓ Additional information: in orbit demonstration for next generation of closed air loop regenerative life support system

8.5.2 Nitrification phase A/B (Previous BIORAT2)

- ✓ Fight demonstrator of a regenerative process for air loop closure, improved water loop closure (i.e. urine treatment), and food supplement production (i.e. protein rich biomass)
- ✓ Budget: 1 M€
- ✓ Timeframe: 2020-2023
- ✓ Application scenario: Gateway, lunar surface
- ✓ Additional information: in orbit demonstration for next generation of closed air and water loop regenerative life support system

8.5.3 Portable Water Recovery Unit

- ✓ Further development of Water Recovery unit for exploration based on ongoing activity with DAC.
- ✓ Budget : 1 M€, new budget
- ✓ Timeframe : 2019-2021
- ✓ Additional information: This is proving to be a promising technology that can be used for several exploration mission applications.

8.5.4 Precursor of Food Production Unit (water loop demonstration)

- ✓ Phase B/C/D of the major sub-systems of PFPU
- ✓ Budget: 2 M€
- ✓ Timeframe: 2020-2022
- ✓ Application scenario: Gateway, lunar surface
- ✓ Additional information: several operational scenarii investigated during EDEN-ISS analogue campaign, PFPU technologies development supported by various actors (industrial internal, EC H2020, ESA)

8.5.5 Plant Characterisation Unit (PCU)

- ✓ Manufacturing and commissioning of the second PCU unit
- ✓ Budget: 1 M€
- ✓ Timeframe: 2020-2022
- ✓ Application scenario: any mission including a food production demonstration
- ✓ Additional information: facility for ground plant research, supports the development of scientific network and ground based facilities around plant research for space mission

8.5.6 Phase Separation and Mixing

- ✓ Feasibility and validation of multiphase processes
- ✓ Budget: 4 M€
- ✓ Timeframe: 2020-2024

- ✓ Application scenario: any process entailing multi-phase flows (gas/liquid/solid)
- ✓ Additional information: necessary to validate basic process principles to be applied to regenerative life support systems

8.5.7 MELiSSA Pilot Plant (MPP)

- ✓ Technology development, progressive integration of the MELiSSA loop, continuous operation of life support systems for ground demonstration and provision of inputs for space adaptation (focus on gas-liquid-solid connection of C3+C4A+C5, liquid connection C3+C4B, gas connection C4A+C4B+C5)
- ✓ Budget : 4 M€
- ✓ Timeframe : 2020-2023
- ✓ Application scenario : multiple application scenarii, as more or less comprehensive life support systems are/will be demonstrated (e.g air revitalisation, urine treatment, food production, ….)
- ✓ Additional information : highest priority because the MPP is a unique facility in Europe, including a real consumer; huge and unique expertise has been built over the years and relies on continuity

9 Conclusions

LSS research and development has never benefited from a stable programmatic framework and corresponding funding despite the longstanding recognition of its importance by the Member States as documented in several high level reports. In E3P Period 1, LSS have been funded through various E3P activity areas: ISS, SciSpacE and ExPeRT. LSS have also benefitted from GSTP and DPTDP funding, while in parallel some Member States have pursued projects on a national level.

Short, medium and long term exploration scenarios and corresponding LSS requirements were reviewed in order to define the LSS elements that could support these scenarios and requirements. At the same time, a comprehensive list of all currently ongoing LSS related European activities was established and analysed, and was taken into account in the ESA Technology Harmonisation Roadmap presented to the IPC.

Finally, the Working Group established a portfolio of LSS activities that would benefit from funding at a European Level. However, no final consensus could be reached on the programmatic framework for technology demonstration activities responding to requirements from long term scenarios (beyond 2030).

The Working Group recommends that for E3P Period 2 these activities are included as candidate activities in the ExPeRT area. The actual funding for a specific activity will however be decided on priorities set after Space19+ through the publication of the E3P P2 work Plan. The selection of the activities will be driven by several criteria such as strategic relevance of the activities, the overall level of subscription, the specific Member States contributions, and the other activities that are proposed in the frame of ExPeRT E3P period 2.

Annexes

Annex A – Working Group Members

Annex B – MELiSSA terrestrial success stories

Annex C – Life Support Technology Datasheets – Summary and screening results

Annex D – Life Support Technology Datasheets

Annex E – Life Support definition and TRL definition

Annex A – Working Group Members

Libby Jackson - UKSA

Jean Blouvac - CNES

Tom Verbeke - BELSPO

Pierre Coquay - BELSPO

María del Pilar Román Fernandez - CDTI

Carlos Castaño Climent - CDTI

Oliver Angerer - DLR

M. Braun - DLR

Marino Crisconio - ASI

Beata Mikolajek-Zielinska - Ministry of Science and Higher Education

Oliver Botta - Swiss Space Office

Silvia Ciccarelli - ASI

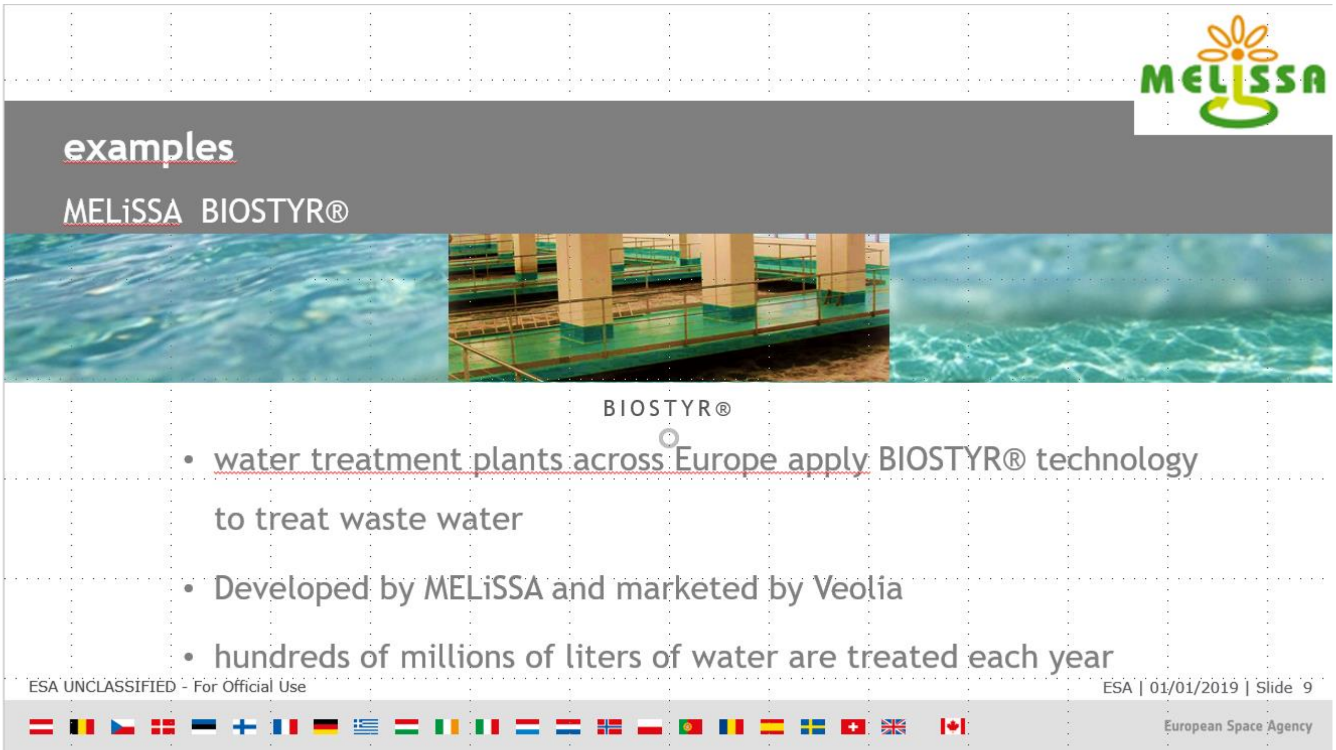
Manfredi Porfilio - ASI

Gabriele Mascetti - ASI

Marianne Vinje-Tantillo – Norwegian Space Centre

Agnieszka Kuczala - Ministry of Science and Higher Education

Annex B – Terrestrial success stories

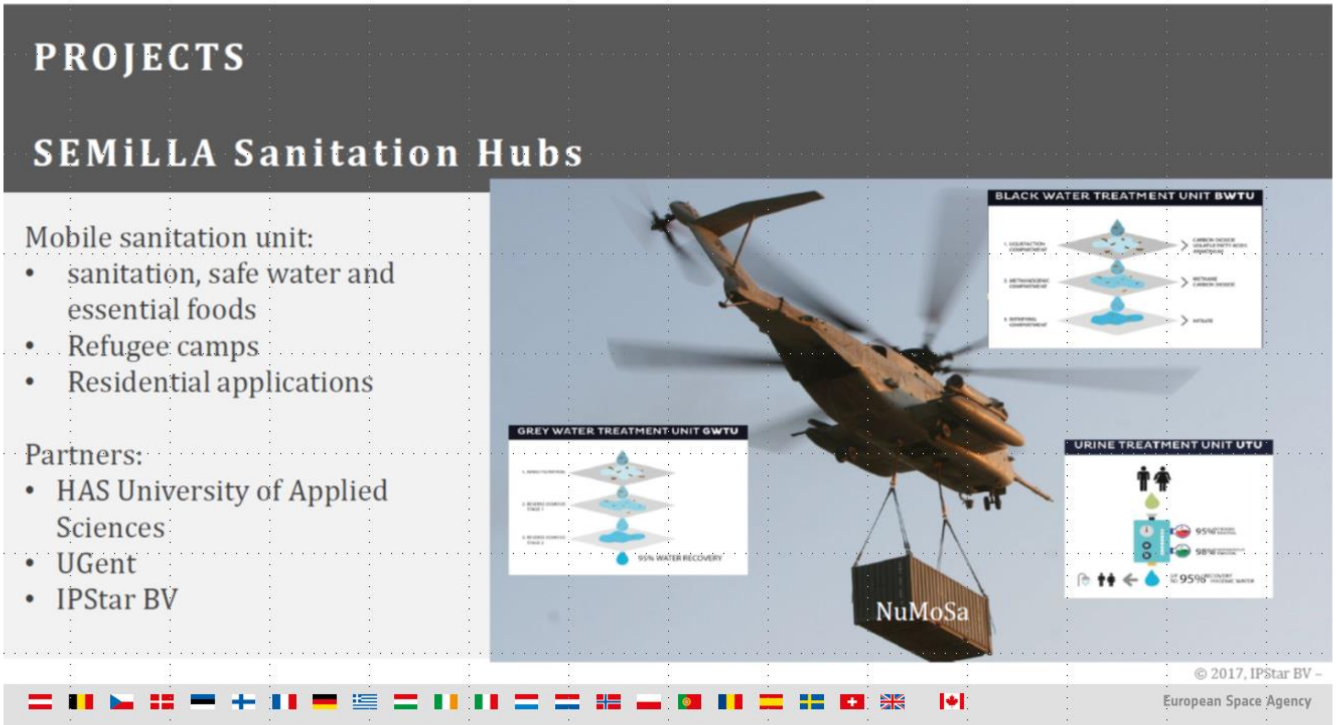


For more info: http://technomaps.veoliawatertechnologies.com/biostyr/en/

For more info: http://blogs.esa.int/concordia/2013/03/15/recycling-water-in-concordia/

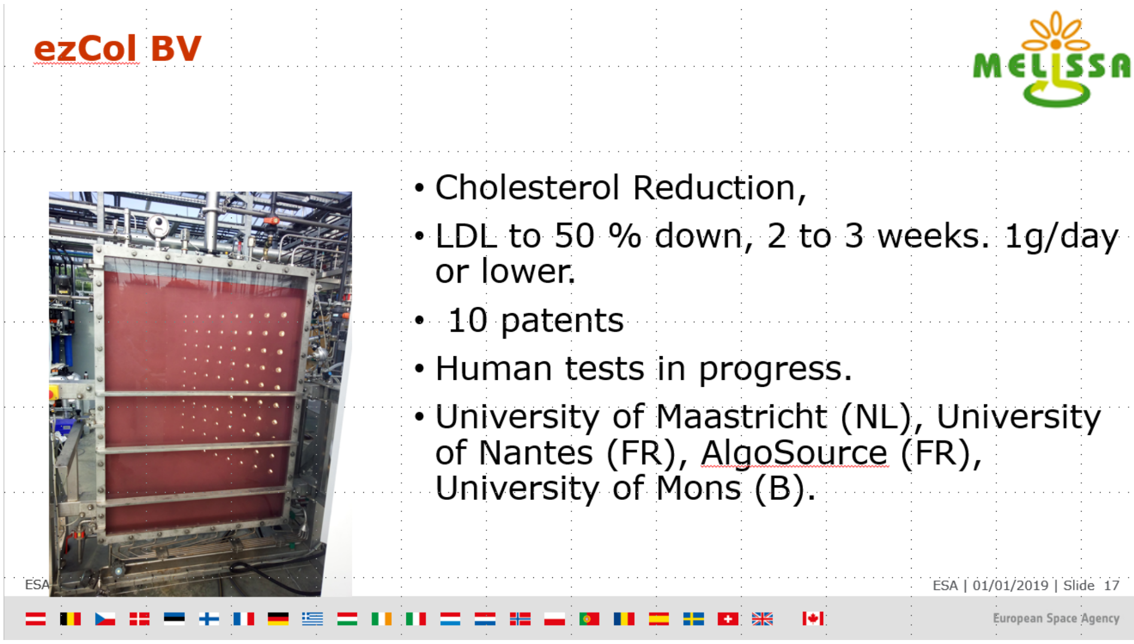
For more info:
http://www.esa.int/Our_Activities/Human_Spaceflight/Research/Space_brings_fresh_water_to_Morocco

More info: http://www.melissafoundation.org/page/photobioreactor



More info: www.semillasanitationhubs.com/

More info: http://www.biopolus.net/2018/11/biopolus-wins-2018-dutch-water-innovation-prize/



More info:
http://www.esa.int/Our_Activities/Human_and_Robotic_Exploration/Research/Red_bacteria_fighting_cholesterol_for_you

La villa Troglodyte, seule labellisée « BDM »... pour l'instant

Pour l'heure, la villa Troglodyte – encore en construction à l'angle de l'avenue Hector-Otto et de la rue Honoré-Labande – s'avère être l'unique construction labellisée « Bâtiments Durables Méditerranéens » à Monaco. Au niveau le plus élevé, « Or », de surcroît. Pensé par les architectes Jean-Pierre Lott et Patrick Raymond et bâti par J.B. Pastor&Fils, le projet se veut vertueux sur bien des points. Et ce, même si le lieu (proto)historique choisi avait suscité des saillies négatives sur les réseaux sociaux *(lire notre édition du 16 septembre 2017)*.

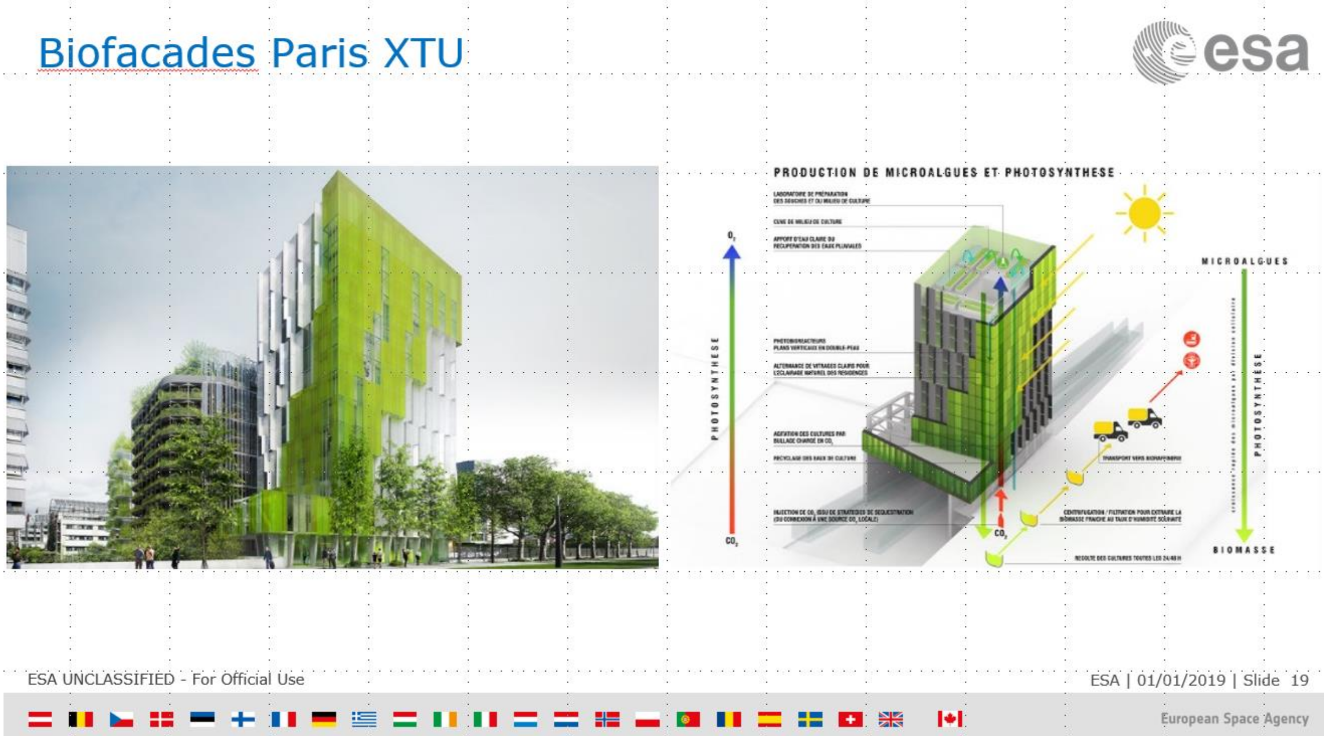
« Des matériaux nobles et purs »

Les enjeux durables du projet, présentés lors de la réunion interprofessionnelle du 23 octobre, promettent *« un projet qui se fond dans le site : creuser et non démolir, préserver et replanter, et restituer une ambiance »* mais aussi l'utilisation *« de matériaux nobles et purs avec la généralisation du bois massif, l'exploitation des ressources locales et le recyclage. »*
Sur les rochers, à la fois reconstitués et existants, des jardinières seront intégrées sur cinq strates paysagères. L'arrosage se fera avec de l'eau recyclée. Quant au volet énergie, la production photovoltaïque sera de 1400 kWh par an, grâce au 10,5m² de surface de panneaux, et l'éclairage LED se fera par détection de présence.

Dans le projet de la villa sera intégré une installation miniaturisée de recyclage des eaux grises, à savoir les eaux des bains, douches et lavabos, ainsi que celles du lave-linge. Soit 459 litres d'eau récupérables par jour. *« Le traitement ayant un rendement de 70 à 80 %, le volume d'eau recyclée sera compris entre 321 et 367 litres par jour, soit 40 % des consommations totales »*, peut-on lire dans la brochure de présentation. Enfin, sur les matériaux, il s'agit là de naturels et recyclés : rochers recyclés en granulats, parquets issus du recyclage, sous-couche acoustique en liège, béton bas carbone, escaliers et portes en bois massifs, isolants en liège, toiture végétalisée, peinture à la chaux...

La Villa Troglodyte a été labellisée « Or » pour sa phase conception, en attendant les autres commissions.

More info:
https://transition-energetique.gouv.mc/content/download/456577/5206513/file/BDM%20Villa%20Troglodite%20Conception.pdf



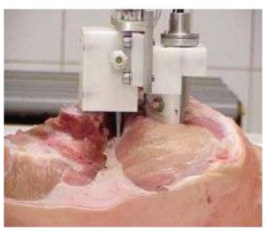
More info: http://www.melissafoundation.org/page/photobioreactor

FRESH AIR FOR ALL

Airgloss, a start-up company created in 2013 hosted by the ESA Italian Business Incubation Centre develops two advanced devices, a professional unit and a kit designed for domestic consumers, aimed at improving indoor environmental quality and well-being, a cost-effective solution for sensing air quality in closed environments on Earth, detecting and measuring a wide range of indoor contaminants.

More info: http://youbenefit.spaceflight.esa.int/fresh-air-for-all/

Better hams with space technology



Space tech to sniff hams: Space technology is now being used to help Spanish ham experts ensure that hams awarded the highly prized ‘jamon’ label are worthy of the name. Technology used to measure the liquid shift that occurs in an astronaut’s body in microgravity has been developed to measure the water retention in cured hams.

More info: https://phys.org/news/2008-09-hams-space-technology.html

Electronic nose sniffs health hazards

Stockholm metro train

An advanced ‘electronic nose’ system, first developed to monitor the air quality inside space stations, is now being used to save lives on the ground. The system was successfully operated on two ESA missions to the Mir space station in 1995 and 1997. It proved its worth when it ‘smelled’ the early signs of a potentially deadly fire on board.

More info:
http://www.esa.int/kids/en/learn/Technology/Useful_space/Electronic_nose_sniffs_health_hazards

Annex C – Life Support Technology Datasheets – Summary and screening results

Country	LSWG ref	Title	LS Function (as provided in the datasheet)	Overall evaluation TEC (if not further processed)	considered already available	to be further processed	request for information	system/ subsystem	product	contributes to generic development	main function
Belgium	1	Lunar Volatiles Mobile Instrumentation	ISRU	not considered for CIS-lunar and transit phase		N					
ESA- HRE	2	ACLS	atmosphere revitalization	already available at TRL 9	y	N		system	air		air revitalisation
ESA- HRE	3	Small water recovery unit	water recovery and recycling			Y	additional information on perfornance would be beneficial	system	water	membrane technologies	production of potable water from condensate/urine
ESA- HRE	4	ANITA	atmosphere revitalization	already available at TRL 9	y	N		subsystem	air		monitoring of chemical composition
ESA - HRE	5	Life Support System (non-regenerative)	atmosphere revitalization	already available at TRL 9	y	N		system	air		atmosphere control and distribution
ESA-TEC	6	Photobioreactor	atmosphere revitalization water recovery and recycling food production and preparation			Y		system	food/air	(photo)bioreactor	integrated functions: air revitalisation, food production
ESA-TEC	7	Higher Plant chamber	atmosphere revitalization food production and preparation water recovery and recycling			Y		system	food/air/ water		integrated functions: air revitalization, food production, water recycling
ESA-TEC	8	trace gas contamination control system	atmosphere revitalization waste recovery and recycling			Y		subsystem	air/gas phases		control of chemical contamination in gas phases
ESA-TEC	9	Waste collection unit	waste recovery and recycling			Y		system	waste		collection and storage of faecal matter
ESA-TEC	10	antimicrobial surface	atmosphere revitalization water recovery and recycling			Y		subsystem	generic		material surface designed to prevent microbail development on wet surfaces
ESA-TEC	11	water condenser	water recovery and recycling			Y		subsystem	water/liq uids		microgravity condenser for water collection and redistribution
ESA-TEC	12	gas trap	water recovery and recycling			Y		subsystem	water/liq uids	multiphasic fluid management	free gas extractor from liquid stream for microgravity water system
ESA-TEC	13	water disinfection systen	water recovery and recycling			Y		subsystem	water		control of microbial contamination in water lines
ESA-TEC	14	Grey Water Treatment Unit	water recovery and recycling			Y		system	water	membrane technologies	production of hygienic and potable water from condensate, grey waters
ESA-TEC	15	Urine treatment Unit	water recovery and recycling			Y		system	water	bioreactor	
ESA-TEC	16	Microbial Air Sampler	atmosphere revitalization			Y		subsystem	air/gas phases		sampling of air/gas phases for futher microbial

Country	LSWG ref	Title	LS Function (as provided in the datasheet)	Overall evaluation TEC (if not further processed)	considered already available	to be further processed	request for information	system/ subsystem	product	contributes to generic development	main function
											contamination monitoring
France	17	Endothelial dysfunction survey		out of scope of LS technologies		N					
France	18	Water recovery and recycling	water recovery and recycling	already demonstrated in Space	y	N		subsystem	water/liquids		monitoring of microbial quality
France	19	Waste destruction/recycling	water recovery and recycling waste recovery and recycling	not considered for CIS-lunar and transit phase		N					
France	20	Food production	food production and preparation	would make sense at surface deployment and intensive diet production		N					
Germany	21	ModuLES Photobioreactor - a modular microalgae-based high-performance photobioreactor	atmosphere revitalization water recovery and recycling ISRU			Y	additional information on perfornance would be beneficial	system	food/air	(photo)bioreactor	integrated functions: air revitalisation, food production
Germany	22	CROP	waste recovery and recycling	to be re-evaluated for surface deployment		N					
Germany	23	Photobioreactor technology for microalgae cultivation to support humans in space with oxygen and edible biomass	atmosphere revitalization food production and preparation			Y		system	food/air	(photo)bioreactor	integrated functions: air revitalisation, food production
Italy	24	ASI 9 - Controlled ripening module	food production and preparation			y		subsystem	food		controlled ripening module
Italy	25	ASI 1 - Cyanobacterium-based technology to link ECLSS to in situ resources	ISRU	not considered for CIS-lunar and transit phase		N					
Italy	26	ASI 23 - BIOWYSE - Recovered Water Microbial Control Unit	water recovery and recycling	to be further evaluated versus other biowyse related fiches and other similar technologies		y		system	water		microbial contamination control, long-term storage and dispensing of water
Italy	27	ASI 20 - Condensate Recovery Unit derived from ACLS technologies	water recovery and recycling			y		system	water		decontamination (microbial and chemical), storage and buffering of recovered water
Italy	28	ASI 24 - Flexible Bacteriostatic Reservoir	water recovery and recycling waste recovery and recycling			y		subsystem	water/liquids		bacteriostatic storage of water/liquids
Italy	29	ASI 19 - Food Production/Complement Unit	food production and preparation			y		system	food/air/ water		integrated functions: air revitalisation, food production
Italy	30	ASI 22 - Metallic Reservoir for water storage in microgravity	water recovery and recycling waste recovery and recycling	already produced for MPCV-Orion	y	N		subsystem	water		

Country	LSWG ref	Title	LS Function (as provided in the datasheet)	Overall evaluation TEC (if not further processed)	considered already available	to be further processed	request for information	system/ subsystem	product	contributes to generic development	main function
Italy	31	ASI 21 - PTFE Bellows Water Storage System	water recovery and recycling waste recovery and recycling			y		subsystem	water/liquids		storage of water/liquids
Italy	32	ASI 25 - Waste Water Recovery System	water recovery and recycling			y		system	water		water recovery from urine, condensate and hygiene water
Italy	33	ASI 17 - CO_2 buffering system for BLSS	atmosphere revitalization food production and preparation			y	additional information on perfornance would be beneficial	subsystem	air/gas phases		carbon dioxyde buffering unit
Italy	34	ASI 15 - Environmental control in BLSS for quality and safety of plant food products.	atmosphere revitalization food production and preparation	not considered for CIS-lunar and transit phase		N					
Italy	35	ASI 16 - Pollutant elimination (wrong title in the fiche)		not considered for CIS-lunar and transit phase		N					
Italy	36	ASI 18 - New plant “ideotypes” for farming in the space	food production and preparation	not considered for CIS-lunar and transit phase		N					
Italy	37	ASI 7 - Cooking platform with multiple heating sources	food production and preparation	not considered for CIS-lunar and transit phase		N					
Italy	38	ASI 8 - Machine vision-guided plant sensing system	food production and preparation	not considered for CIS-lunar and transit phase		N					
Italy	39	ASI 11 - Food preparation, preservation and analysis technologies for human space flight	food production and preparation			y	the datasheet provides a company description; information on technologies should be provided	subsystem	food		
Italy	40	ASI 10 - ISSpresso, the capsule-based espresso system	food production and preparation	already available at TRL 9	y	N		subsystem	food		
Italy	41	ASI 2 - GEALED	food production and preparation	not considered for CIS-lunar and transit phase		N					
Italy	42	ASI 14 - ACLS (Advanced Closed Loop System) Avionics Subsystem	atmosphere revitalization	TRL8 already achieved, no need for further development	y	N		subsystem	air		
Italy	43	ASI 12 - Bioreactors for edible plant seeds germination	food production and preparation	not considered for CIS-lunar and transit phase		N					
Italy	44	ASI 13 - MIDASS (Microbial Detection in Air System for Space)	atmosphere revitalization	ITT in progress, no decision can be taken yet regarding the future of this techno		N					

Country	LSWG ref	Title	LS Function (as provided in the datasheet)	Overall evaluation TEC (if not further processed)	considered already available	to be further processed	request for information	system/ subsystem	product	contributes to generic development	main function
Italy	45	ASI 3 - RobotFarm	food production and preparation	not considered for CIS-lunar and transit phase		N					
Italy	46	ASI 4 - Innovative clothes for astronauts	atmosphere revitalization waste recovery and recycling	out of scope of LS technologies		N					
Italy	47	ASI 5 - 3D Food Printer for space applications	food production and preparation	not considered for CIS-lunar and transit phase		N					
Italy	48	ASI 6 - SMAT expertise for ECLLS	atmosphere revitalization water recovery and recycling food production and preparation	expertise for ground applications only		N					
Switzerland	49	yeast biofactories - food in Space	food production and preparation	part of generic bioreactor development		Y	additional information on perfornance would be beneficial	system	food		
Switzerland	50	algae biofactories	water recovery and recycling waste recovery and recycling ISRU	part of generic bioreactor development		y		system	food	(photo)bioreactor	
Switzerland	51	scorpius prototype	atmosphere revitalization water recovery and recycling food production and preparation waste recovery and recycling	not considered for CIS-lunar and transit phase but to be harmonised with analogues and ground-demonstration facilities		N					
Switzerland	52	Ruag	atmosphere revitalization food production and preparation	included into ESA activities		N					
Switzerland	53	study of plants culture on substrate of urine origin: roots zone focus	food production and preparation	considered included into ESA activities		Y	This fiche should be further considered only if other than ESA fundings are involved; if not, then it is considered part of ESA activities	system	food		
Switzerland	54	oikosmos	waste recovery and recycling ISRU	not considered for CIS-lunar and transit phase but to be harmonised with analogues and ground-demonstration facilities		N					
Switzerland	55	versatile energy, water, hydrogen and oxygen storage and production system based on a reversible Photo-Electrochemical device	atmosphere revitalization water recovery and recycling ISRU			y		system	water/air / energy	multiphasic fluid management	versatile production and storage of water, energy, oxygen and hydrogen

Country	LSWG ref	Title	LS Function (as provided in the datasheet)	Overall evaluation TEC (if not further processed)	considered already available	to be further processed	request for information	system/ subsystem	product	contributes to generic development	main function
UK	56	UV decontamination Module (photoreactor)	atmosphere revitalization water recovery and recycling food production and preparation waste recovery and recycling			Y	additional information on performance would be beneficial	subsystem	water/liquids		control of microbial quality of water/liquids
Switzerland	57	Efficient and light-weight gas separation based on Molecular sieving membranes for space related applications	atmosphere revitalization			Y		subsystem	gas/gas	fluid management	gas phases management

Annex D - Life Support Technology Datasheets

Life Support Technology					
Reference	LUVMI-SA-WP8-Sheet100	Version	1.0.0	Date	11/5/2018
Title: Lunar Volatiles Mobile Instrumentation					
Life Support main function(s) addressed (see definition in annex), please precise specific function					
□ Atmosphere revitalization □ Water recovery and recycling □ Food production and preparation □ Waste recovery and recycling x ISRU	Prospecting of volatiles for utilization in Life Support Systems				
Short description (main characteristics, features, …) Prospection is a key step in the identification of ISRU resources. The Moon is believed to hold vast amounts of volatiles, including those with potential for Life Support of Humans in Exploration missions. The LUnar Volatiles Mobile Instrumentation (LUVMI) provides a smart, low mass, innovative, modular mobile payload comprising surface and sub-surface sensing with an in-situ sampling technology capable of depth-resolved extraction of volatiles, combined with a volatiles analyser (mass spectrometer) capable of identifying the chemical composition of the most important volatiles. The sampling and analysis system is optimized to maximize sample transfer efficiency and minimize sample handling and potential alteration, and to enable areal and sub-surface coverage for modest mass. This will allow LUVMI to: traverse the lunar surface prospecting for volatiles; sample sub-surface up to a depth of 10 cm (with a goal of 20 cm); extract water and other loosely bound volatiles; identify the chemical species extracted; access and sample permanently shadowed regions (PSR).					
Key performances demonstrated Detection and characterization of volatiles that can potentially be used in the future for Life Support					

Demonstration level (please precise testing conditions, duration)	
□ calibrated mathematical model *□ Lab scale proof of concept* *□ Pilot scale ground demonstration* *x Payload/ techno. Demonstrator* *□ Space engineering model* *□ Flight model*	*Instruments: tested in vacuum conditions, hour-day scale* *Robotic platform: tested in earth-based analogues, day-week scale*
TRL level (refer to definition in annex)	*Instruments: TRL 6* *Robotic platform: TRL 4-5*
Links with other technologies (title and reference)	
Keywords *Lunar volatiles, ISRU, Moon, Lunar Poles, prospection*	
Associated publications *LUVMI: an innovative payload for the sampling of volatiles at the Lunar poles IAC Adelaide, Australia, 26 Sept 2017* *LUVMI: Sampler IAC, Adelaide, Australia, 26 Sept 2017* *LUVMI – Volatile Extraction and Measurements in Lunar Polar Regions HEMS, CA, USA, 20 Sept 2017LUVMI / ProsPA volatile characterisation on the moon ESA LEID, ESTEC, 19 Sept 2017* *In-Situ Thermal Extraction and Analysis of Lunar Volatiles with the Lunar Volatiles Scouting InstrumentELS, Amsterdam, May 2016*	

Life Support Technology					
Reference	*2- ACLS*	*Version*	*1*	*Date*	*28/06/2018*
Title: Life Support Rack/Advanced Closed Loop System					
Life Support main function(s) addressed (see definition in annex), please precise specific function					
X Atmosphere revitalization *□ Water recovery and recycling* *□ Food production and preparation* *□ Waste recovery and recycling* *□ ISRU*					
Short description (main characteristics, features, …) *Technology Demonstrator sized for 3 crewmembers to cover the functions of CO2 Removal, CO2 Reprocessing and Oxygen production.*					
Key performances demonstrated *CO2 Removal and Oxygen Production for 3 crew members* *O2 recovery from CO2* *Water management (preparation of feed water for steam generators from condensate, UV treatment for microbial control, potable water feed for electrolyser)* *Operation of three processes as integrated system* *CO2 and H2 interfaces for additional experiments*					
Demonstration level (please precise testing conditions, duration)					
□ calibrated mathematical model *□ Lab scale proof of concept* *□ Pilot scale ground demonstration* *□ Payload/ techno. Demonstrator* *X Space engineering model* *X Flight model*	*FM has been qualified on ground; it is installed in HTV7 ready for flight in September 2018.* *EM is available as ground reference model for supporting tests.*				
TRL level (refer to definition in annex) *8-9*					

Links with other technologies (title and reference)
Keywords ***Regenerative Air Revitalisation***
Associated publications *Status of the Advanced Closed Loop System ACLS for Accommodation on the ISS, Klaus Bockstahler, Ruediger Hartwich, Daniele Laurini, Scott Hovland, Johannes Witt and Sebastian Markgraf, ICES 2018*

<table>
<tr><th colspan="6">Life Support Technology</th></tr>
<tr><td>Reference</td><td>3-Small WRU</td><td>Version</td><td>1</td><td>Date</td><td>28/06/2018</td></tr>
<tr><td colspan="6">Title: Small Water Recovery Unit</td></tr>
<tr><td colspan="6">Life Support main function(s) addressed (see definition in annex), please precise specific function</td></tr>
<tr><td colspan="3">□ Atmosphere revitalization
X Water recovery and recycling
□ Food production and preparation
□ Waste recovery and recycling
□ ISRU</td><td colspan="3">Production of potable water from condensate/urine.</td></tr>
<tr><td colspan="6">Short description (main characteristics, features, …)

The unit consists of two membrane modules: in the first one, based on Aquaporine technology, pure water is extracted from urine/condensate into a salt solution. In the second step the water is extracted from the salt solution.</td></tr>
<tr><td colspan="6">Key performances demonstrated

Lab tests have demonstrated the first step, i.e. the extraction of pure water from polluted water with very high selectivity. The second step, extraction of pure water from the intermediate salt solution by membrane distillation has been demonstrated but needs performance improvements.</td></tr>
<tr><td colspan="6">Demonstration level (please precise testing conditions, duration)</td></tr>
<tr><td colspan="3">□ calibrated mathematical model
X Lab scale proof of concept
□ Pilot scale ground demonstration
□ Payload/ techno. Demonstrator
□ Space engineering model
□ Flight model</td><td colspan="3">Breadboard level testing performed.</td></tr>
<tr><td colspan="3">TRL level (refer to definition in annex) 3 - 4</td><td colspan="3"></td></tr>
<tr><td colspan="6">Links with other technologies (title and reference)</td></tr>
</table>

Keywords

Water Recovery, Water Recycling, Membranes

Small Water Recovery Unit Breadboard, Kim Kleinschmidt, Jörg Vogel, Johannes Witt, Hans Henrik Dahlmann and Maja Bender Tommerup, ICES 2018

Life Support Technology					
Reference	*4- ANITA*	*Version*	*1*	*Date*	*28/06/2018*
Title: ANITA					
Life Support main function(s) addressed (see definition in annex), please precise specific function					
X Atmosphere revitalization *□ Water recovery and recycling* *□ Food production and preparation* *□ Waste recovery and recycling* *□ ISRU*	*Trace Gas Monitoring in Spacecraft Atmoshpere*				
Short description (main characteristics, features, …) *Anita consists of a FTIR spectrometer with atmosphere sampling system and its software allows automatic, simultaneous and continuous monitoring of at least 33 contaminants.*					
Key performances demonstrated *ANITA1 has been operating on ISS in 2007/2008. It demonstrated the capability of simultaneous monitoring of trace gases and the capability to detect and identify unexpected gases.* *ANITA 2 will provide improved stability and autonomy in operation.*					
Demonstration level (please precise testing conditions, duration)					
□ calibrated mathematical model *□Lab scale proof of concept* *X Pilot scale ground demonstration* *□ Payload/ techno. Demonstrator* *X Space engineering model* *X Flight model*	*ANITA1 has been operated in space. The optical system of ANITA2 has been tested successfully on ground. PDR: June 2017. Flight planned 2020.*				
TRL level (refer to definition in annex) 9					
Links with other technologies (title and reference)					

Keywords ***Air Quality Monitoring***
ANITA2 Flight Model Development – First ground test results of the Trace Gas Analyser for the ISS (and beyond), Timo Stuffler, Atle Honne, Johannes Witt and Armin Stettner, ICES 2018

Life Support Technology					
Reference	*5 – ECLS System*	*Version*	*1*	*Date*	*28/06/2018*

Title: Life Support System (Non Regenerative)

Life Support main function(s) addressed (see definition in annex), please precise specific function

X Atmosphere revitalization

□ Water recovery and recycling

□ Food production and preparation

□ Waste recovery and recycling

□ ISRU

Short description (main characteristics, features, …)

Columbus/ATV Life Support System providing the functions of ventilation, temperature and humidity control, air monitoring, pressure control, vacuum and venting system for payloads,

Key performances demonstrated

The following functions have been developed, manufactured and qualified in Europe:

Overall ECLS System Design

Fans and ventilation System Design

Condensing Heat Exchanger with hydrophilic antimicrobial coating

Condensate Water Separator

Liquid Carryover Sensor

CO2, O2 and Humidity Sensors

Valves

Demonstration level (please precise testing conditions, duration)

□ calibrated mathematical model *□ Lab scale proof of concept* *□ Pilot scale ground demonstration* *□ Payload/ techno. Demonstrator* *X Space engineering model*	*Columbus ECLS is operating reliably on ISS since more than 10 years.* *ATV systems operated successfully on 5 missions.*

X Flight model	
TRL level (refer to definition in annex) 9	
Links with other technologies (title and reference)	
Keywords ***ECLS System, CHX, CWSA, Fan,***	
Associated publications	

Life Support Technology					
Reference	*TEC-MMG 6*	*Version*	*2*	*Date*	*31/07/2018*

Title: Photobioreactor

Life Support main function(s) addressed (see definition in annex), please precise specific function

■ *Atmosphere revitalization* □ *Water recovery and recycling* ■ *Food production and preparation* □ *Waste recovery and recycling* □ *ISRU*	*The main function fulfilled by the technology is the atmosphere revitalization. However, in specific cases, the technology can also contribute to food production.*

Short description (main characteristics, features, …)

The photobioreactor technology is focusing at the CO2 capture and oxygen production using photosynthetic process, which side product is proteins-rich biomass (potential food complement). Within the MELiSSA project, expertise on photo-bioreactor design and control has been developped over several decades and the technology available today is quite broad.

Several features are available

<u>Ground laboratory photobioreactors</u>

Photo-bioreactors of various volume (from 50 ml to few liters), various geometries (i.e. cylindrical, parallelepipedic, flat panel), various types (i.e. stirred tank, airlift, membrane bioreactor) and with external or internal lighting system.

<u>Ground pilot scale photobioreactors</u>

80 l riser-downcomer column airlift type, external lighting

<u>µg photobioreactor</u>

- *stirred tank type flat cylinder, equipped with membrane, external lighting. (Project ARTHROSPIRA)*
- *stirred tank type flat cylinder, equipped with external gas exchange membrane module, external lighting. (Project BIORAT 1)*

Key performances demonstrated

<u>Calibrated mathematical model</u>

The mathematical model, which predicts the photosynthetic performances (i.e. CO2 consumption, oxygen production, biomass production) in function of the light, has been calibrated and validated on externally illuminated photobioreactors (i.e. ground laboratory, ground pilot, and µg) in ground conditions. In *addition, it has been preliminarily validated in µg conditions for the 50 ml bioreactor in batch production mode (ARTHROSPIRA-B, early 2018) and is planned to be validated for the same bioreactor in continuous production mode (ARTHROSPIRA-C, 2020-2021).*

Lab scale proof of concept

Photo-bioreactor with internal lighting has demonstrated a 10 fold increase in oxygen production performances compared to externally illuminated photobioreactors.

Pilot scale ground demonstration

***Stand-alone:** production of O2 demonstrated over months around 2.5-2.8 gO2/h, depending on light conditions, liquid flow; hardware currently under refurbishment to increase light intensity and therefore O2 production.*

***Closed air loop** (i.e. predictive control of oxygen production to match dynamically the consumer oxygen demand) between a photobioreactor and a consumer has been demonstrated continuously, in axenic conditions, during several months fulfilling various oxygen set-points (i.e. oxygen concentration requirements in the consumer habitat: 18%, 19%, 20%, 21%).*

Payload (ARTHROSPIRA-B)

4 subsequent batches of 7-10 days each, in gas loop open to ISS air cabin or gas loop closed on BIOLAB incubator (both scenarios occurred during experiment execution), 6 mgO2/(L.h) per photobioreactor and per batch. Axenicity, gas/liquid separation, kinetics production and mathematical model were validated.

Techno demonstrator (BIORAT 1)

***Stand-alone:** Designed for average 10 gO2/day, performance demonstrated at breadboard level. Maximum performance achievable by design is 0.96 g/h*

***Closed air loop:** (i.e. predictive control of oxygen production to match dynamically the consumer oxygen demand) between a photobioreactor and a consumer has been demonstrated for 2mice during 3 weeks maintaining the oxygen concentration in the consumer habitat at 20%.*

Demonstration level (please precise testing conditions, duration)	
■ *calibrated mathematical model* ■ *Lab scale proof of concept* ■ *Pilot scale ground demonstration* ■ *Payload/ techno. Demonstrator* □ *Space engineering model* □ *Flight model*	
TRL level (refer to definition in annex)	*Depends on the item considered*
Links with other technologies (title and reference)	

Food preparation unit *Urine treatment unit*
Keywords
Associated publications *Publication on closed air loop demonstration in the MELiSSA Pilot Plant under review.*

Life Support Technology					
Reference	*TEC-MMG 7*	*Version*	*2*	*Date*	*23/07/2018*

Title: Higher Plant Compartment (HPC)

Life Support main function(s) addressed (see definition in annex), please precise specific function

■ *Atmosphere revitalization* ■ *Water recovery and recycling* ■ *Food production and preparation* □ *Waste recovery and recycling* □ *ISRU*	*The main function targeted by the technology is the food production (edible biomass). In addition, due to its multifunctional nature, the technology can also contribute to air revitalization and water recycling. However, the technology produces wastes which need to be managed.*

Short description (main characteristics, features, …)

The HPC technology is focusing at the CO_2 capture, nitrogen compounds capture (nitrate, ammonium, N_2 in specific cases) and food production using higher plants biological processes. By products of this technology are O_2 (obtained by photosynthesis), cleaned water (obtained by transpiration) and vegetable wastes.

Several features are available

<u>Ground laboratory plant growth chamber</u>

Several types (walk-in chamber, closed controlled environment chambers), various sizes and various instrumentation available to investigate and characterize the plant processes (i.e CO_2 capture, O_2 production, water transpiration, edible biomass production).

Latest development for photosynthesis, shoot transpiration and root respiration investigations is currently in development (i.e. Plant Characterisation Unit)

<u>Ground Pilot scale HPC</u>

Prototype of a closed controlled environment chamber, 5 m2 production area, hydroponic system (here nutrient film technique), standard lighting (fixed spectrum, fixed irradiance).

<u>µg HPC:</u>

- *Parabolic flight unit for spinach transpiration investigations (project ANTHEMS)*
- *Biolab experimental container for water transport investigations in bean plants (project WAPS)*
- *Rack-like unit for potato production demonstration (project Precursor Food Production Unit)*

Key performances demonstrated

<u>Calibrated mathematical model</u>

Complete structure of the mathematical model has been defined and include all the main processes of the plant growth.

Mathematical model of CO2 capture and biomass production for lettuces and beetroot has been calibrated for various scales of ground production surfaces in both batch and staggered production mode.

Mathematical model for transpiration preliminary validation in parabolic flight.

Full plant growth mathematical model validation is planned as a results of the investigations performed with the Plant Characterisation Unit.

Lab scale proof of concept

Proof of concept for the critical modules of a Precursor of a Food Production Unit

Pilot scale ground demonstration

Several operational tests and design improvements of the prototype since 2008. Current design improvement focuses on overall pressure management in preparation of integrated operations.

Payload

ANTHEMS flown and preliminarily demonstrates the validity of the mathematical model describing transpiration in µg as well as the measurement protocol

WAPS under development and planned to be flown 2020-2021

Demonstration level (please precise testing conditions, duration)	
■ *calibrated mathematical model* ■ *Lab scale proof of concept* ■ *Pilot scale ground demonstration* □*Payload/ techno. Demonstrator* □ *Space engineering model* □ *Flight model*	
TRL level (refer to definition in annex)	*Depends on the item considered*

Links with other technologies (title and reference)

Urine treatment unit

Wastes recycling unit

Food processing unit

Photobioreactor

Keywords
Associated publications

Life Support Technology					
Reference	*LSWG 8*	*Version*	*1.0*	*Date*	*30/06/2018*
Title: Trace gas contamination control system					
Life Support main function(s) addressed (see definition in annex), please precise specific function					
x Atmosphere revitalization *□ Water recovery and recycling* *□ Food production and preparation* *x Waste recovery and recycling* *□ ISRU*					
Short description (main characteristics, features, …) *The technology is a chemical contaminant control system using Activated Carbon felt as a trap, based on denuder technology (patented).* *Trap can be regenerated using temperature and pressure swing; segregation of trapped contaminats by class (i.e. alcohols, ketones, fatty acids, etc.) during regeneration feasible.* *Originally intended as a gas clean up system for the exhaust gases of the MELiSSA waste compartment allowing purifying produced CO2, the technology can also be used as a TCCS for habitat.*					
Key performances demonstrated *Based on extensive analyses of exhaust gases from the MELiSSA waste compartment, the feasibility has been demonstrated on gases with similar composition (limited to main classes of identified contaminants); pure CO2 was obtained.* *Regeneration of the trap and segregation of trapped contaminants was proven feasible, thereby allowing the possibility of further treatment/transformation/recycling of these contaminants.*					
Demonstration level (please precise testing conditions, duration)					
□ calibrated mathematical model *x Lab scale proof of concept* *□ Pilot scale ground demonstration* *□ Payload/ techno. Demonstrator* *□ Space engineering model* *□ Flight model*	*Lab scale demonstration*				
TRL level (refer to definition in annex)	*2-3*				
Links with other technologies (title and reference)					

MELiSSA waste compartment, Waste Collection Unit (odor capture)
Keywords ***Gas clean up***
Associated publications

Life Support Technology					
Reference	*LSWG 9*	*Version*	*1.0*	*Date*	*30/06/2018*
Title: Waste Collection Unit					
Life Support main function(s) addressed (see definition in annex), please precise specific function					
□ *Atmosphere revitalization* □ *Water recovery and recycling* □ *Food production and preparation* x *Waste recovery and recycling* □ *ISRU*					
Short description (main characteristics, features, …) *Breadboard that allows:* - *Non-gravity driven, segregated urine and faecal matter collection;* - *Faecal material containment within biodegradable waste bags, automatically sealed after collection;* - *Non-gravity driven transport of closed faeces bag from collection point(i.e. toilet bowl) to temporary, built-in cold storage area (up to 10 collections), pending further processing* - *Regular steam sterilization of the storage area;* - *Disinfection of toilet seat by UV-LEDs after toilet closure* *Detailed urine collection device, urine stabilization and storage not implemented in current demonstrator*					
Key performances demonstrated *Segregated human metabolic waste collection* *Containment of faecal material into dedicated biodegradable bags* *Non-gravity driven transport of faecal bag to temporary storage area* *Disinfection of toilet seat by UV LEDs after toilet closure* *No use of water required for faecal matter collection*					
Demonstration level (please precise testing conditions, duration)					
□ *calibrated mathematical model* □ *Lab scale proof of concept* x *Pilot scale ground demonstration* □ *Payload/ techno. Demonstrator* □ *Space engineering model* □ *Flight model*	*Toilet has been used for 1 month daily at developer facility*				

TRL level (refer to definition in annex)	*3-4*
Links with other technologies (title and reference) ***MELiSSA waste compartment***	
Keywords ***Metabolic waste collection***	
Associated publications	

Life Support Technology					
Reference	*TEC-MMG 10*	*Version*	*1*	*Date*	*31/07/2018*
Title: Antimicrobial surface					
Life Support main function(s) addressed (see definition in annex), please precise specific function					
□ *Atmosphere revitalization* □ *Water recovery and recycling* □ *Food production and preparation* □ *Waste recovery and recycling* □ *ISRU*					
Short description (main characteristics, features, …) *Due to human beings or pre-flight contamination, microorganisms are common inhabitants on surfaces of spacecraft. Microorganisms can colonize a very wide range of materials and are able to form microbial biofilm on surfaces which could trigger biodegradation and corrosion. The selection of antimicrobial material presents therefore many interest.*					
Key performances demonstrated *The activity is in progress. Preliminary results demonstrated feasibility.*					
Demonstration level (please precise testing conditions, duration)					
□ *calibrated mathematical model* □ *Lab scale proof of concept* □ *Pilot scale ground demonstration* □*Payload/ techno. Demonstrator* □ *Space engineering model* □ *Flight model*					
TRL level (refer to definition in annex)					
Links with other technologies (title and reference)					

Keywords

Water recovery, humidity control, microbial safety

Associated publications

Life Support Technology					
Reference	*TEC-MMG 11*	*Version*	*1*	*Date*	*31/07/2018*

Title: Water condenser

Life Support main function(s) addressed (see definition in annex), please precise specific function	
□ Atmosphere revitalization *■ Water recovery and recycling* *□ Food production and preparation* *□ Waste recovery and recycling* *□ ISRU*	*Micro-gravity condenser for water collection and re-distribution*

Short description (main characteristics, features, …)

Innovative water vapor condenser concept using pervaporation on hydrophilic membrane allows a decrease in energy demand for collection of water vapor present in the atmosphere.

Key performances demonstrated

<u>Calibrated mathematical model</u>

Functional mathematical model is planned to be defined within the current phase of the work (up to 2020)

<u>Lab scale proof of concept</u>

Condenser using hollow fiber membrane was conceived. A breadboard will be built and tested within the current phase of the work (up to 2020).

<u>Techno demonstrator</u>

System requirements for a techno demonstrator including the selected micro-gravity condenser is planned to be achieved in 2020

Demonstration level (please precise testing conditions, duration)	
□ calibrated mathematical model *□ Lab scale proof of concept* *□ Pilot scale ground demonstration* *□Payload/ techno. Demonstrator*	

□ *Space engineering model* □ *Flight model*	
TRL level (refer to definition in annex)	*2*
Links with other technologies (title and reference) *Everywhere where water needs to be condensed*	
Keywords	
Associated publications	

Life Support Technology					
Reference	*TEC-MMG 12*	*Version*	*1*	*Date*	*31/07/2018*

Title: Gas trap

Life Support main function(s) addressed (see definition in annex), please precise specific function

□ *Atmosphere revitalization* ■ *Water recovery and recycling* □ *Food production and preparation* □ *Waste recovery and recycling* □ *ISRU*	*Free gas extractor from liquid stream for microgravity water system*

Short description (main characteristics, features, …)

Hollow fibre polymeric membrane contactor (low delta pressure, no fluid acceleration)

Key performances demonstrated

Calibrated mathematical model

Functional mathematical model planned in the current phase of the work (up to 2020)

Lab scale proof of concept

*COTS gas trap (LiquiCel, 0.75*1 Micromodule) was successfully tested in the breadboard of the Nutrient Module (Precursor Food Production Unit). Further tests for quantitative and systemic performances assessment are planned within the current phase of the work (up to 2020)*

Techno demonstrator

System requirements for a techno demonstrator including the selected gas trap is planned to be achieved in 2020

Demonstration level (please precise testing conditions, duration)

□ *calibrated mathematical model* ■ *Lab scale proof of concept* □ *Pilot scale ground demonstration* □*Payload/ techno. Demonstrator* □ *Space engineering model*	

□ *Flight model*	
TRL level (refer to definition in annex)	*3-4*
Links with other technologies (title and reference)	
Urine treatment unit *Wastes recycling unit* *Food processing unit* *Photobioreactor* *In any biphasic system*	
Keywords	
Associated publications	

Life Support Technology					
Reference	*TEC-MMG 13*	*Version*	*1*	*Date*	*31/07/2018*

Title: Water disinfection system

Life Support main function(s) addressed (see definition in annex), please precise specific function

□ *Atmosphere revitalization* ■ *Water recovery and recycling* □ *Food production and preparation* □ *Waste recovery and recycling* □ *ISRU*	*control of microbial contamination in water lines*

Short description (main characteristics, features, …)

The aim of the technology is to allow for a reduction of the microbial contamination load down to the level which fulfills the requirements of the water use selected.

Several techniques of disinfection are investigated.

Ground laboratory

Ozonolysis, UV (usually UVC), Photo-ozonolysis (combination of UVC treatment and ozone treatment), membrane filtration.

µg technique

UVC-LED for the treatment of condensate water and higher plant nutritive solution.

Membrane filtration

Key performances demonstrated

Calibrated mathematical model

Not yet defined.

Lab scale proof of concept

- *Commercial ozonizer (Sanders, Certizone C25), which delivers 23.8 mgO_3/h, was tested with regards to microbial contamination reduction and water chemical quality impact. Tests performed on Bacillus subtilis, demonstrated a 3 log reduction after 1 hour. Water chemical quality impacted after 10 min (exact impact to be characterized).*
- *Commercial UVC-LED (265-285 nm) unit (Aquisens, PearlAqua 6D), which delivers 1-2.3 $mJ.cm^{-2}.s^{-1}$, was tested with regards to the water chemical quality stability during treatment.*

Maximum Residence time in the unit was defined for the water stream tested. Unit requires further detailed investigations of microbial contamination reduction for various water flow rates and water compositions. Several modifications of the commercial product are required for appropriate use in a payload/technology demonstrator.

- *Membrane filtration is standard practice: choice depends on the water chemical composition and the water use after treatment.*

Pilot scale ground demonstration

Water recycling system (based on membrane separation technologies and oxonia addition) installed in Concordia ensures water sterilisation. System in operation for the last 10 years without microbial breakthrough event.

Demonstration level (please precise testing conditions, duration)

□ *calibrated mathematical model* ■ *Lab scale proof of concept* ■ *Pilot scale ground demonstration* □*Payload/ techno. Demonstrator* □ *Space engineering model* □ *Flight model*	
TRL level (refer to definition in annex)	*Depends on the item considered*

Links with other technologies (title and reference)

Urine treatment unit

Wastes recycling unit

Food processing unit

Photobioreactor

Keywords

Associated publications

0'sLife Support Technology

Reference	TEC-MMG 14	Version	1	Date	31/07/2018

Title: Grey Water Treatment Unit

Life Support main function(s) addressed (see definition in annex), please precise specific function

□ *Atmosphere revitalization* ■ *Water recovery and recycling* □ *Food production and preparation* □ *Waste recovery and recycling* □ *ISRU*	*Hygiene water recovery from grey waters and cabin condensates*

Short description (main characteristics, features, …)

The aim of the technology is to produce water meeting ESA quality standards (hygiene and potentially potable) from all sources of grey waters (showers, hand wash, even kitchen water, laundry waters) and cabin condensates.

Several steps of membrane filtration are involved. Oxonia is used to ensure a long-lasting disinfection effect.

Studies were initiated in the 90's, from lab testing till development of a fully automated test-bed. A ground demonstration/industrial unit has been developed and is in operation in Concordia Antarctic Station since 2005.

Integration of grey waters and yellow waters treatment has been demonstrated as well at pilot scale in the frame of the Water Treatment Unit Breadboard ESA activity.

Critical items regarding adaptation to space have been studied at conceptual design level.

Key performances demonstrated

Lab scale proof of concept/test-bed for future lab testing

- *Fully automated unit available with 4 stages of membrane filtration, (ultrafiltration/nanofiltration/ 2 stages of reverse osmosis), using oxonia for microbial stabilization, sized for treatment of 20l/h.*
- *Water recovery demonstrated: 95%*
- *9 logs reduction of microbial contamination(virus, bacteria) during intentionally provoked "microbial accidents"; no contamination detected at the output of the unit*

Pilot scale ground demonstration/production unit

- *Water recycling system (technology based on the previously described test-bed) installed in Concordia Antarctica Station.*
- *System in operation for the last 13 years without microbial breakthrough event.*
- *Water recovery > 83%;*

- *average production of 225 l/h;*
- *(polymeric) membrane lifetime between 3 and 5 years.*

Demonstration level (please precise testing conditions, duration)

□ *calibrated mathematical model* ■ *Lab scale proof of concept* ■ *Pilot scale ground demonstration* □*Payload/ techno. Demonstrator* □ *Space engineering model* □ *Flight model*	*<u>Lab scale proof of concept/test-bed for future lab testing</u>* - *Tested in continuous operation with real grey waters over several runs of hundreds of hours;* *<u>Pilot scale ground demonstration/production unit</u>* - *13 years of continuous operation* - *With real grey waters from the whole station (13 to 70 persons)* - *Evolution of the membranes selection in line with adaptation of all the chemicals, personal care products used in the Station*
TRL level (refer to definition in annex)	*9 for terrestrial application, 3 for space applications*

Links with other technologies (title and reference)

Urine treatment unit

Keywords

Associated publications

Life Support Technology					
Reference	*TEC-MMG 15*	*Version*	*1*	*Date*	*31/07/2018*
Title: Urine Treatment Unit					
Life Support main function(s) addressed (see definition in annex), please precise specific function					
☐ *Atmosphere revitalization* ☒ *Water recovery and recycling* ☒ *Food production and preparation* ☒ *Waste recovery and recycling* ☐ *ISRU*					
Short description (main characteristics, features, …) *Water is, after air, the key element needed by a crew to live aboard a spacecraft and the most critical with regards to mass. Today, water recycling aboard the ISS is limited to condensate recovery and processing to either hygiene or potable water quality. Urine presents a lot of interest for water recovery but as well for Nitrogen recovery either to balance gas leak, food production. The proposed technology is based on nitrification which present several advantages: stabilization without addition of toxic chemical compounds, Urea transformation to Nitrates and/or Nitrogen gas, rejection of ammonium traces during filtration. One shall note that any waste recycling process will produce ammonium and consequently nitrification cane be used as a complementary step too.*					
Key performances demonstrated *Calibrated Model: Mechanistic model has been elaborated and demonstrated at pilot scale. Predictive control a law has been demonstrated during several months.* *Lab scale: Pilot scale bioreactor has been demonstrated in continuous operation during several months.* *Payload: Microbial strains were flown during several week on board PHOTON, Performances have been demonstrated after return on ground of exposed strains.*					
Demonstration level (please precise testing conditions, duration)					
☒ *calibrated mathematical model* ☒ *Lab scale proof of concept* ☒ *Pilot scale ground demonstration* ☒ *Payload/ techno. Demonstrator* ☐ *Space engineering model* ☐ *Flight model*					
TRL level (refer to definition in annex)					
Links with other technologies (title and reference)					

Atmosphere management, Water recycling, Food Production, Waste recycling.
Keywords *Urine, Water, Nitrification, Nitrogen, Gas leak, food production*
Associated publications *Refinery and concentration of nutrients from urine with electrodialysis enabled by upstream precipitation and nitrification. Jolien De Paepe et al., Water resources 2018.*

Life Support Technology					
Reference	*TEC-MMG 16*	*Version*	*1*	*Date*	*31/07/2018*

Title: Microbial Air Sampler

Life Support main function(s) addressed (see definition in annex), please precise specific function

■ *Atmosphere revitalization*

■ *Water recovery and recycling*

□ *Food production and preparation*

□ *Waste recovery and recycling*

□ *ISRU*

Short description (main characteristics, features, …)

In a closed environment such as a space habitat, various contaminants (chemicals, microbes) have to be controlled to minimize the risks for the crew and equipment. Over the last decades of manned missions a few observations have been made :-microbial contamination, including pathogens was observed, -a higher susceptibility of the crew to allergies, -several pieces of hardware were biodegraded.

Key performances demonstrated

The Air sampler has been demonstrated up to TRL 5, with the following performances: high percentages of collection, high percentage of biomass recovery, compatibility with biomolecular identification and quantification analyser including MIDASS hardware (first generation), non-cross contamination.

Demonstration level (please precise testing conditions, duration)

□ *calibrated mathematical model*

■ *Lab scale proof of concept*

■ *Pilot scale ground demonstration*

□ *Payload/ techno. Demonstrator*

□ *Space engineering model*

□ *Flight model*

TRL level (refer to definition in annex)	

Links with other technologies (title and reference)

- *MIDASS: Microbial identification for Air on Board ISS*
- *Water Sampler for microbial identification and quantification in water.*

Keywords *Microbiology, Risk, safety, contamination, pathogen, virulence, PCR, DNA, RNA.*
Associated publications

Life Support Technology					
Reference	*17 - PIVO*	*Version*	*1*	*Date*	*07/06/2018*

Title: Endothelial dysfunction survey

Life Support main function(s) addressed (see definition in annex), please precise specific function

□ *Atmosphere revitalization* □ *Water recovery and recycling* □ *Food production and preparation* □ *Waste recovery and recycling* □ *ISRU*	

Short description (main characteristics, features, …)

Noninvasive detection of Red Blood Cell aggregates through photo-acoustic measurement

Key performances demonstrated

Demonstration made on ground on mice

Parabolic flight foreseen in fall 2018

Demonstration level (please precise testing conditions, duration)

X calibrated mathematical model *X Lab scale proof of concept* *X Pilot scale ground demonstration* *X Payload/ techno. Demonstrator*	

□ *Space engineering model* □ *Flight model*	
TRL level (refer to definition in annex)	
Links with other technologies (title and reference)	
Keywords ***Aggregates, red blood cell, photoacoustic, in vivo***	
Associated publications	

Life Support Technology					
Reference	*18 – PB Aquapad*	*Version*	*1*	*Date*	*07/06/2018*
Title: Water recovery & recycling, Microbial/bacterial detection in drinking water					

Life Support main function(s) addressed (see definition in annex), please precise specific function	
□ *Atmosphere revitalization* *X Water recovery and recycling* □ *Food production and preparation* □ *Waste recovery and recycling* □ *ISRU*	

Short description (main characteristics, features, …)

Microbial/bacterial detection in drinking water:

- *Full range detection in 1ml*
- *Coliform detection in 100ml*

Key performances demonstrated

1ml detection is flight-proven by Aquapad 1ml

100ml detection is under process and should be ready for demonstration in 4T2018 with Aquapad 100ml

Demonstration level (please precise testing conditions, duration)	
□ *calibrated mathematical model* □ *Lab scale proof of concept* □ *Pilot scale ground demonstration* □ *Payload/ techno. Demonstrator* *X Space engineering model for Aquapad 100ml, first prototype demonstrated on 0G plane 09/2017* *X Flight model for Aquapad 1ml*	
TRL level (refer to definition in annex) 8-9	

Links with other technologies (title and reference) ***Same base technology should be used in near future for ground application (for catastrophic event such as floods and for para pharmacology uses)*** ***Extensions under consideration:*** • ***Human diseases detection,*** • ***Surface contamination detection,*** • ***Air contamination detection.***
Keywords ***Dry pads microbial/bacterial detection***
Associated publications

Life Support Technology					
Reference	*19- SCOW*	*Version*	*1*	*Date*	*07/06/2018*
Title: waste destruction / recycling					
Life Support main function(s) addressed (see definition in annex), please precise specific function					
□ *Atmosphere revitalization* *X Water recovery and recycling* □ *Food production and preparation* *X Waste recovery and recycling* □ *ISRU*					
Short description (main characteristics, features, …) *SuperCritical Oxidation Water process utilization for waste treatment*					
Key performances demonstrated *Process under study*					
Demonstration level (please precise testing conditions, duration)					
X calibrated mathematical model *X Lab scale proof of concept* □ *Pilot scale ground demonstration* □ *Payload/ techno. Demonstrator* □ *Space engineering model*					

□ *Flight model*	
TRL level (refer to definition in annex)	
Links with other technologies (title and reference)	
Keywords ***Supercritical oxidation waste***	
Associated publications	

Life Support Technology					
Reference	*20- PB Food*	*Version*	*1*	*Date*	*07/06/2018*
Title: Food production					
Life Support main function(s) addressed (see definition in annex), please precise specific function					
□ Atmosphere revitalization *□ Water recovery and recycling* *X Food production and preparation* *□ Waste recovery and recycling* *□ ISRU*					
Short description (main characteristics, features, …) *Full meal automated preparation from basic ingredients, including some from recycling loop (such as spirulina).* *This food "robot" concept is derivated from existing ones (e.g. Moley).*					
Key performances demonstrated *Gastronomical and biological qualities of Special Event Meals delivered by CNES will remain the base of this new concept.*					
Demonstration level (please precise testing conditions, duration)					
□ calibrated mathematical model *□ Lab scale proof of concept* *X Pilot scale ground demonstration* *□ Payload/ techno. Demonstrator* *□ Space engineering model*					
TRL level (refer to definition in annex) *5-6*					
Links with other technologies (title and reference)					

This food robot will be included into the recycling loop by using ingredients coming from the loop and waste recycling.
Keywords ***Automated food processing in link with recycling loop.***
Associated publications

Life Support Technology					
Reference	*21 - ModuLES*	*Version*	*1*	*Date*	*05/06/2018*
Title: ModuLES Photobioreactor – a modular microalgae-based high-performance photobioreactor					

Life Support main function(s) addressed (see definition in annex), please precise specific function

X *Atmosphere revitalization*

X *Water recovery and recycling*

□ *Food production and preparation*

□ *Waste recovery and recycling*

X *ISRU*

Short description (main characteristics, features, …)

The ModuLES PBR was designed to convert carbon dioxide into oxygen and biomass in a most efficient manner (turbostatic mode). It comprises of a media-recycling, a gas-exchange, a harvesting unit and a sensory unit monitoring oxygen production and nutrient contents. The PBR can continuously produce biomedical chemicals and pharmaceuticals. The modular design allows for an upscaling of the volume and, thus, an output according to the actual needs. ModuLES PBR can be coupled to a urine-degradation/biofiltration system like C.R.O.P. using its solutions as nutrients. It can also be used to produce microalgae biomass to convert Moon regolith into substrate for agriculture applications (BIO-ISRU).

Key performances demonstrated

Subsystems like the harvesting and media-recycling unit as well as different designs of the bioreactor chamber of the ModuLES PBR have been tested in the relevant ground laboratory environment as well as on parabolic flight campaigns.

Demonstration level (please precise testing conditions, duration)

□ *calibrated mathematical model*

X *Lab scale proof of concept*

□ *Pilot scale ground demonstration* □ *Payload/ techno. Demonstrator* □ *Space engineering model* □ *Flight model*	
TRL level (refer to definition in annex)	*TRL-4*

Links with other technologies (title and reference)
Keywords *Regenerative Life Support, modular photobioreactor, oxygen production, pharmaceuticals, exploration*
Associated publications *Wagner I., Braun M., Slenzka K., Posten C.: Photobioreactors in Life Support Systems, Adv. Biochem. Eng. Biotechnol. 153, pp. 143–184, 2016.*

Life Support Technology					
Reference	*22 – DLR- CROP*	*Version*	*1.0*	*Date*	*May 2018*

Title: C.R.O.P.® - Combined Regenerative Organic-food Production

Life Support main function(s) addressed (see definition in annex), please precise specific function	
□ Atmosphere revitalization *□ Water recovery and recycling* *□ Food production and preparation* *X Waste recovery and recycling* *□ ISRU*	

Short description (main characteristics, features, …)

The DLR C.R.O.P. ® system is a bioregenerative filter for converting human and/or animal wastes into a plant fertilizer solution for closed environments. The C.R.O.P ® system needs no supply with chemicals or high energy amounts and can be also used for removing of xenobiotica in closed systems.

Key performances demonstrated

See Bornemann et al. 2015 and Bornemann et al. 2018

Demonstration level (please precise testing conditions, duration)	
□ calibrated mathematical model *X Lab scale proof of concept* *X Pilot scale ground demonstration* *□ Payload/ techno. Demonstrator*	*See Bornemann et al. 2018*

□ *Space engineering model* □ *Flight model*	
TRL level (refer to definition in annex)	*TRL 6-7*

Links with other technologies (title and reference)

Keywords

Waste recycling, Human urine, Bioregenerative filter, Plant growth, Xenobiotica, Food Production

Associated publications

Bornemann, G., Waßer, K., Tonat, T., Moeller, R., Bohmeier, M., & Hauslage, J. (2015). Natural microbial populations in a water-based biowaste management system for space life support. Life sciences in space research, 7, 39-52.

Bornemann, G., Waßer, K., & Hauslage, J. (2018). The influence of nitrogen concentration and precipitation on fertilizer production from urine using a trickling filter. Life Sciences in Space Research, 18, 12-20.

Life Support Technology					
Reference	*23 – IRS*	*Version*	*1*	*Date*	*30.05.2018*

Title: *Photobioreactor Technology for Microalgae Cultivation to Support Humans in Space with Oxygen and Edible Biomass*

Life Support main function(s) addressed (see definition in annex), please precise specific function	
X Atmosphere revitalization	*CO_2 removal, O_2 generation*
□ Water recovery and recycling	
X Food production and preparation	*Food production*
□ Waste recovery and recycling	
□ ISRU	

Short description (main characteristics, features, …)

At the Institute of Space Systems (IRS) – University of Stuttgart, research on algae cultivation and Photobioreactor Technology focused on supporting human in Space has been carried out since 2008. The first studies included a selection of the algae species to be used, potential designs for the reactor, design of the entire system, including the technology required to provide the algae the resources required, cultivation techniques etc. The used algae is Chlorella vulgaris, a spherical unicellular organism of 4-10 µm diameter. The knowledge gained has lead the research into a technology demonstrator flight experiment which will fly to ISS in November 2018 to probe the feasibility and stability of an algae based Hybrid Life Support System. The main current work areas are:

Experience with Earth-based reactors (FPA - Flat Panel Airlift)

Flat Panel Airlift reactors from the company Subitec® have been used to cultivate algae for long periods of time (up to a couple of years), to gain knowledge on the cultivation technics and carry out several experiments to evaluate the influence of several parameters (i.e. influence of light)

Experience with µg Photobioreactor

The ongoing project PBR@LSR (PhotoBioReactor @ Life Support Rack), in cooperation with DLR and Airbus DS, will test in November 2018 the first Hybrid Life Support System technology (combining physico-chemical with biological systems).

Experience with Down Stream Processing

The next step after cultivating the algae is processing them to edible biomass. For that 3 different steps are being studied at IRS:

- *Studying the composition of the biomass (analysis are being carried out in cooperation with the ETH Zurich).*
- *Cross-flow filtration: concentration of the algae contained in a reactor.*
- *Ultrasonic processing: breaking the algae cell wall to make it digestible.*

Key performances demonstrated

Cultivation of the microalgae Chlorella vulgaris:

- *µg-600ml-reactor able to process about 0.6 g/day CO_2, producing 0.25 g/day O_2*
- *Non-axenic (within a clean environment)*
- *At high biomass concentration (dry mass up to 14 g/L, OD 60)*
- *For long periods of time (over ½ year)*
    - *FPAs several cultivations more than 5 years*
    - *µg-reactor 180 days (two experiments on the lab, flight experiment coming in November)*

Post-processing of the algae for Edible Biomass production – Down Stream Processing proof of concept:

- *Cross flow filtration: proof of principle prototype. A 6L-reactor can be harvested, filtered and concentrated automatically.*
- *Feasibility study for the ultrasonic processing*

Demonstration level (please precise testing conditions, duration)

□ *calibrated mathematical model* *X Lab scale proof of concept* □ *Pilot scale ground demonstration* *X Payload/ techno. Demonstrator* □ *Space engineering model* □ *Flight model*	*Photobioreactor (technology demonstrator):* • *Years of experience with long-term cultivation with Earth-based systems (>300 days periods)* • *Experiments at laboratory conditions successful for 180 days in µg design.* • *Experiment to be tested in space environment (ISS) in November 2018.* *Down-stream Processing (proof of concept):* • *Experiments with a prototype in the lab*
TRL level (refer to definition in annex)	

Links with other technologies (title and reference)

On-going experiments with coupling of a PBR system with C.R.O.P.® (DLR) at SpaceShip EAC

Keywords

Hybrid LSS, Microalgae, Photobioreactor, System Design

Associated publications

Journal Publications

- *Ganzer B., Messerschmid E.: Integration of an algal photobioreactor into an environmental control and life support system of a space station, DOI: 10.1016/j.actaastro.2009.01.071, Acta Astronautica, Vol. 65 (248-261), Issue 1-2, **2009**.*

- *Belz S., Ganzer B., Messerschmid E., Friedrich K.A., Schmid-Staiger U.: Hybrid life support systems with integrated fuel cells and photobioreactors for a lunar base, DOI: 10.1016/j.ast.2011.11.004, Aerospace Science and Technology, Vol. 24 (169-176), Issue 1, Elsevier, **2013**.*
- *Belz S., Buchert M., Bretschneider J., Nathanson E., Fasoulas S.: Physicochemical and biological technologies for future exploration missions, DOI: 10.1016/j.actaastro.2014.04.023, Acta Astronautica, Vol. 101 (170-179), **2014**.*

Conference Papers

- *Belz S., Ganzer B., Detrell G., Messerschmid E.: Synergetic Hybrid Life Support System for a Mars transfer Vehicle, IAC-10-A1.6.7, 61st International Astronautical Congress, Prague, Czech Republic, **2010**.*
- *Ganzer B., Belz S., Messerschmid E.: Hybrid Life Support as Integrated System Applying Fuel Cell and Algal Photobioreactor, IAC-10-B3.7.6, 61st International Astronautical Congress, Prague, Czech Republic, **2010**.*
- *Ganzer B., Belz S., Messerschmid E.: Life Support Systems Utilizing Photobioreactors and Fuel Cells to Enhance Mass and Power Efficiency for Long Duration Exploration Missions, GLEX-2012.10.1.8x12552, Global Space Exploration Conference 2012, Washington D.C., USA, **2012**.*
- *Belz S., Ganzer B., Messerschmid E., Fasoulas S., Henn N.: Synergetic Integration of Microalgae Photobioreactors and Polymer Electrolyte Membrane Fuel Cells for Life Support: Tests and Results, AIAA-2012-3522, 42nd International Conference on Environmental Systems, San Diego, USA, **2012**.*
- *Buchert M., Belz S., Messerschmid E., Fasoulas S.: Cultivating Chlorella vulgaris for Nutrition and Oxygen Production During Long Term Manned Space Missions, 63rd International Astronautical Congress, IAC-12-A1.6.4, Naples, Italy, **2012**.*
- *Belz S., Buchert M., Bretschneider J., Nathanson E., Fasoulas S.: Physicochemical and Biological Technologies for Future Exploration Missions, 64th International Astronautical Congress, IAC-13-A1.6.6, Peking, China, **2013**.*
- *Bretschneider J., Nathanson E., Belz S., Buchert M., Fasoulas S.: Development and Parabolic Flight Testing of a closed Loop Photobioreactor System for algae Biomass Production in Hybrid Life Support Systems, 65th International Astronautical Congress, IAC-14-A1.6.9, Toronto, Canada, **2014**.*
- *Nathanson E., Bretschneider J., Fasoulas S.: Development and Testing of Liquid-Gas Separation for an Algal Photobioreactor System for Future Hybrid Life Support Systems, IAC-14.B3.7.9, 65th International Astronautical Congress, Toronto, Canada, **2014**.*
- *Belz S., Bretschneider J., Helisch H., Detrell G., Keppler J., Burger W., Yesil A., Binnig M., Fasoulas S., Henn N., Kern P., Hartstein H., Matthias C.: Preparatory Activities for a Photobioreactor Spaceflight Experiment Enabling Microalgae Cultivation for Supporting Humans in Space, IAC-15-A1.7.7, 66th International Astronautical Congress, Jerusalem, Israel, **2015**.*
- *Bretschneider J., Belz S., Helisch H., Detrell G., Keppler J., Fasoulas S., Henn N., Kern P.: Functionality and setup of the algae based ISS experiment PBR@LSR, ICES-2016-203, 46th International Conferences on Environmental Systems, Vienna, Austria, **2016**.*
- *Helisch H., Keppler J., Bretschneider J., Belz S., Fasoulas S., Henn N., Kern P.: Preparatory ground-based experiments on cultivation of Chlorella vulgaris for the ISS experiment PBR@LSR, ICES-2016-205, 46th International Conference on Environmental System, Vienna, Austria, **2016**.*
- *Belz S., Bretschneider J., Detrell G., Helisch H., Keppler J., Nathanson E., Fasoulas S., Ewald R., Henn N., Kern P., Hartstein H., Adrian, A.: Microalgae cultivation in space for future exploration missions: Results of the preparatory activities for a spaceflight experiment on the International Space Station, IAC-16-A1.6.4, 67th International Astronautical Congress, Guadalajara, Mexico, **2016**.*
- *Belz S., Keppler J., Helisch H., Bretschneider J., Detrell G.: Innovative biological and physico-chemical recycling of CO2 in human spaceflight, ICES-2017-147, 47th International Conference on Environmental Systems, Charleston, USA, **2017**.*

- *Detrell G., Belz S.: ELISSA – a comprehensive software package for ECLSS technology selection, modelling and simulation for human spaceflight missions, ICES-2017-190, 47th International Conference on Environmental Systems, Charleston, South Carolina, USA, **2017**.*
- *Keppler J., Helisch H., Belz S., Bretschneider J., Detrell G., Henn N., Fasoulas S., Ewald R., Angerer O., Adrian A.: From breadboard to protoflight model - the ongoing development of the algae based ISS experiment PBR@LSR, ICES-2017-180, 47th International Conference on Environmental Systems, Charleston, USA, **2017**.*
- *Belz S., Helisch H., Keppler J., Detrell G., Martin J., Ewald R., Henn N., Adrian A.; Hartstein H., Angerer, O.: Microalgae cultivation in space for future exploration missions: Results of the breadboard activities for a long-term photobioreactor spaceflight experiment on the International Space Station, IAC-17-A1.7.6, 68th International Astronautical Congress, Adelaide, Australia, **2017**.*
- *Detrell G., Belz. S., Bretschneider J., Ewald R., Fasoulas S.: A Hybrid Life Support System for a Moon Base, 68th International Astronautical Congress, Adelaide, Australia, **2017**.*
- *Keppler J., Belz S., Detrell G., Helisch H., Martin J., Henn N., Fasoulas S., Ewald R., Angerer O., Hartstein, H., The final configuration of the algae-based ISS experiment PBR@LSR, ICES-2018-141, 48th International Conference on Environmental Systems, Albuquerque, USA, **2018**. Paper accepted.*
- *Detrell G., Belz S., Bretschneider J., Kittang Jost A., Mejdell Jakobsen Ø., Design of a test platform for algae cultivation research at different gravitation levels, ICES-2018-145, 48th International Conference on Environmental Systems, Albuquerque, USA, **2018**. Paper accepted.*
- *Helisch H., Belz S., Keppler J., Detrell G., Henn N., Fasoulas S., Ewald R., Angerer O., Non-axenic microalgae cultivation in space – Challenges for the membrane µgPBR of the ISS experiment PBR@LSR, ICES-2018-186, 48th International Conference on Environmental Systems, Albuquerque, USA, **2018**. Paper accepted.*
- *Keppler J., Detrell G., Helisch H., Belz S., Martin J., Henn N., Ewald R., Fasoulas S., Hartstein H., Angerer O.: Microalgae cultivation in space for future exploration missions: a summary of the development progress of the spaceflight experiment PBR@LSR on the international space station ISS. 69th International Astronautical Congress, Bremen, Germany, **2018**. Abstract accepted.*
- *Detrell G., Keppler J., Helisch H., Martin J., Belz S., Henn N., Ewald R., Fasoulas S., Hartstein H., Angerer O.: PBR@LSR experiment – ready to fly, 69th International Astronautical Congress, Bremen, Germany, **2018**. Abstract accepted.*

Presentations and Posters

- *Belz S., Ganzer B., Messerschmid E., Friedrich K. A.: Hybrid Life Support Systems with integrated Fuel Cells and Photobioreactors, Presentation, Lunar Base Symposium, 12.-13.05.2009, Kaiserslautern, Germany, **2009**.*
- *Belz S., Ganzer B., Buchert M., Messerschmid E.: Lunar Mission 2025 – Preparatory Experiments for Synergetic Life Support Using :envihab, Poster, 1st International :envihab Symposium, 22.-24.05.2011, Cologne, Germany, **2011**.*
- *Fasoulas S., Messerschmid E., Belz S., Bretschneider J., Buchert M., Nathanson E.: Synergetische Integration von Algen-Photobioreaktoren und Brennstoffzellen zur Unterstützung von Lebenserhaltungssystemen, Presenation, Workshop Gravimeeting 2012, 28.11.2012, Erlangen, Germany, **2012**.*
- *Belz S., Ganzer B., Buchert M., Messerschmid E., Fasoulas S.: Lunar Mission 2025 - Experiments for Synergetic Life Support using :envihab, Poster, Envihab-Symposium, Bonn, Germany, **2011**.*
- *Ganzer B.: Effiziente Massenkultivierung von Mikroalgen mittels µg-adaptierter Photobioreaktorgeometrie, Presenation, 11. Gravimeeting, 01.-02.12.2011, Erlangen, Germany, **2011**.*
- *Belz S., Fasoulas S., Messerschmid E.: Coupling of Polymer Electrolyte Membrane Fuel Cells with Life Support Systems, Poster, IAC-12-B3.7.13, 63rd International Astronautical Congress, Naples, Italy, **2012**.*

- *Henn N., Belz S.: Technologies for Humans in Space and with terrestrial Application to test in the :envihab test facility at DLR Cologne, Presentation, 19th IAA Humans in Space Symposium, 07.-13.07.2013, Cologne, Germany, **2013**.*
- *Henn N., Belz S.: Regenerative Lebenserhaltungssysteme, Presenatiotn, Gravimeeting, 04.12.2013, Erlangen, Deutschland, **2013**.*
- *Belz S., Bretschneider J., Buchert M., Nathanson E.: Fuel Cells, Electrolyzers, and Microalgae Photobioreactors: Technologies for Long-Duration Missions in Human Spaceflight, Presentation, F4.7-0001-14, 40th COSPAR Scientific Assembly, Moscow, Russia, **2014**.*
- *Belz S., Henn N.: Technologies For Humans In Space With Terrestrial Application For Testing In :Envihab, Poster, F4.2-0023-14, 40th COSPAR Scientific Assembly, Moscow, Russia, **2014**.*
- *Belz S.: Microalgae enhancing closed loop life support systems for humans in space, Presentation, ISLSWG Workshop "Bioregenerative Life Support" 18.-19.05.2015, International Space Life Sciences Working Group, Turin, Italy, **2015**.*
- *Belz S., Henn N.: Cultivation of microalgae for advanced closed life support systems as a technical and biological challenge, Presentation, ESA MELiSSA Workshop Session 3: Air Recycling, 08.-09.06.2016, Lausanne, Switzerland, **2016**.*
- *Belz S., Bretschneider J., Helisch H., Keppler J.: In Space: Mikroalgen erobern den Weltraum, Presentation, 9. Bundesalgenstammtisch, 26.-27.09.2016, Jülich, Germany, **2016**.*
- *Helisch H.: Experiments on cultivation of Chlorella vulgaris in µg adapted photobioreactors for future space application, Presentation, 16. Erlanger Gravimeeting 08.-09.12.2016, Erlangen, Germany, **2016**.*
- *Detrell G., Belz S., Schwinning M.: PBR@Moon: Research on Algae Photobioreactors for a Moon Base, Poster, 5th European Lunar Symposium, Münster, Germany, **2017**.*
- *Belz S., Helisch H., Keppler J., Detrell G., Fasoulas S., Ewlad R., Henn N.: Photobioreactor Technology for Microalgae Cultivation to Support Humans in Space with Oxygen and Edible Biomass, Presentation, 51st ESLAB Symposium: "Extreme Habitable Worlds". ESTEC, Noordwijk, Netherlands, **2017**.*
- *Detrell G., Keppler J., Helisch H., Belz S., Henn N., Hartstein H., Angerer O.: PBR@LSR – A Hybrid Life Support System Experiment and Technology Demonstrator at the ISS, Presentation, AgroSpace-MELiSSA Workshop Rome, Italy, **2018**.*
- *Detrell G., Keppler J., Helisch H., Belz S., Henn N., Hartstein H., Angerer O., Ewald R., Fasoulas S.: PBR@LSR: A Hybrid Life Support System Experiment at the ISS, 42nd COSPAR Scientific Assembly, F4.2-0015-18, Pasadena, USA, **2018**. Abstract Accepted.*

Life Support Technology					
Reference	altran	*Version*	*0.0*	*Date*	*05/04/2018*

Title: Controlled ripening module

Life Support main function(s) addressed (see definition in annex), please precise specific function

□ *Atmosphere revitalization* □ *Water recovery and recycling* ☑ *Food production and preparation* □ *Waste recovery and recycling* □ *ISRU*	*Function is preservation of vegetables and fruits and control of climacteric fruits ripening evolution. So far targeted to ground application.*

Short description (main characteristics, features, …)

The project aims to develop new systems that allow to control ripening process and shelf-life of fruits and vegetables, ensuring a high level of sensorial and nutritional quality.

The device allows to accelerate and to delay the ripening thanks to the application of sensors and a control system.

The device is able to:

- monitor the relevant process parameters (e.g.: humidity, temperature, ethylene);

- monitor the ripening stages;

- recognize the types of fruit/vegetables;

- modulate the relevant process parameters on the bases of sensors' data.

Key performances demonstrated

Vision recognition system to identify and monitor:

- *the types of fruit/vegetable;*
- *the ripening stage.*

Demonstration level (please precise testing conditions, duration)	
□ *calibrated mathematical model* ☑ *Lab scale proof of concept* □ *Pilot scale ground demonstration* □ *Payload/ techno. Demonstrator* □ *Space engineering model* □ *Flight model*	
TRL level (refer to definition in annex)	

Links with other technologies (title and reference)
Plant growth chambers

Keywords
Ripening, fruits, vegetables

Associated publications
Tömmers S., Model-Based Process Control of Fruit Ripening. 2009. PhD Thesis. Jacobs Univeristy, School of Engineering and Science.

<table>
<tr><th colspan="6">Life Support Technology</th></tr>
<tr><td>Reference</td><td>Daniela Billi University of Rome Tor Vergata</td><td>Version</td><td>1</td><td>Date</td><td>21/03/2018</td></tr>
<tr><td colspan="6">Title: Cyanobacterium-based technology to link ECLSS to in situ resources</td></tr>
<tr><td colspan="6">Life Support main function(s) addressed (see definition in annex), please precise specific function</td></tr>
<tr><td colspan="2">□ Atmosphere revitalization
□ Water recovery and recycling
□ Food production and preparation
□ Waste recovery and recycling
X ISRU</td><td colspan="4"></td></tr>
<tr><td colspan="6">Short description (main characteristics, features, …)

The overall goal is to use a cyanobacteria-based technology to extract and processing of in situ available resources for Environmental Control and Life Support System by means of in situ resources utilization. Cyanobacteria are known to have bioleaching abilities and some of them strains can grow and perform oxygenic photosynthesis by using distilled water and Lunar or Martian mineral analogues, plus fixed nitrogen, when they can not fix nitrogen. The rationale is to growth on Lunar and Martian soil simulants extreme-tolerant cyanobacteria that were used in experiments outside the International Space Station in the contest of the EXPOSE-R2 space mission, and use their lysate to feed already developed CLSS.</td></tr>
<tr><td colspan="6">Key performances demonstrated

The capability of selected extreme-tolerant cyanobacteria to growth on Lunar and Martian soil simulants has been verified..</td></tr>
<tr><td colspan="6">Demonstration level (please precise testing conditions, duration)</td></tr>
<tr><td colspan="2">□ calibrated mathematical model
X Lab scale proof of concept
□ Pilot scale ground demonstration
□ Payload/ techno. Demonstrator
□ Space engineering model
□ Flight model</td><td colspan="4">On-going experiments to be integrated to ECLSS within 3 -4 years</td></tr>
<tr><td colspan="2">TRL level (refer to definition in annex)</td><td colspan="4"></td></tr>
<tr><td colspan="6">Links with other technologies (title and reference)</td></tr>
</table>

Hortextreme *prototype developed by ENEA for cultivation of* microgreens in hydroponic conditions.

Keywords

Cyanobacteria, ISRU, off-ground cultivation

Associated publications

Billi D, Verseux C, FMagliarone C, Baquè , Rothschild L, de Vera J-P (2016). Cyanobacteria under space and planetary simulations: a tool to support human space exploration. 7th International AgroSpace Workshop, 26th - 27th May, Sperlonga, Italy.

Billi D, Verseux C, FMagliarone C, Baquè , Rothschild L, de Vera J-P (2016). Cyanobacteria under space and planetary simulations: a tool to support human space exploration. 7th International AgroSpace Workshop, 26th - 27th May, Sperlonga, Italy.

Billi D, Baqué M, Verseux C, Rothschild LJ, de Vera J-P. (2017). Desert Cyanobacteria - Potential for Space and Earth applications. In: *Adaption of Microbial Life to Environmental Extrem*es second edition (eds Stan-Lotter H, Fendrihan F) Springer pp 133-146.

Cockell, C.S. (2010). Geomicrobiology beyond earth: microbe-mineral interactions in space exploration and settlement. *Trends Microbiol.* 18,308–314.

Olsson-Francis K, Cockell CS CS(2010) Use of cyanobacteria for in-situ resource use in space applications. Planetary and Space Science 58,1279–1285

Verseux C, Baqué M, Lehto K, de Vera J-P, Rothschild LJ, Billi D (2016a). Sustainable life support on Mars - the potential roles of cyanobacteria. *International Journal of Astrobiology* 15, 65-92.

Verseux C, Paulino-Lima IG, Baqué M, Billi D, Rothschild LJ (2016b) Synthetic Biology for Space Exploration: Promises and Societal Implications. *In*: Ambivalences of Creating Life. Societal and Philosophical Dimensions of Synthetic Biology (eds Hagen K, Engelhard M, Toepfer G). Series Ethics of Science and Technology Assessment, Springer, Heidelberg.pp 73-100

ThalesAlenia Space

Water Disinfection Unit

Reference	TASI-CDU	Version	1	Date	11.04.2018

Title: BIOWYSE - Recovered Water Microbial Control Unit

Life Support main function(s) addressed (see definition in annex), please precise specific function

□ Atmosphere revitalization *x Water recovery and recycling* *□ Food production and preparation* *□ Waste recovery and recycling* *□ ISRU*	*Microbial contamination control of water for potable use via:* • *Microbial contamination prevention* • *Microbial contamination on-line monitoring* • *Microbial contamination active reduction* *Potable water dispending*

Short description (main characteristics, features, …)

The BIOWYSE system is intended as post-processing after recovered waste water chemical/physical treatment to potable water standards. BIOWYSE is then capable to store the product water for long periods (more than 6 months) by maintaining the microbial contamination of the water under control by multiple means: prevention of microbial growth via dedicated bacteriostatic materials, active disinfection via UVC LEDs, online monitoring of ATP content. A water dispensing system provides delivery to the end user.

Key performances demonstrated

- *Reservoir capacity of 3.5 L*
- *Water delivery rate of 1 L/min*
- *Acceptable inlet water quality:*
  - *ATP < 10 pg/ml*
  - *EC < 700µS/cm*
  - *TDS < 350 mg/l*
  - *TOC < 300 mg/l*
  - *Mic. load < 1e5 CFU/ml*
  - *Particle size <10 µm*
- *Limit of detection <0.2 pg/L of ATP*
- *Bacteria load reduction >4log per single pass in the UV disinfection module with up to 1L/min*

Demonstration level (please precise testing conditions, duration)

□ calibrated mathematical model *□ Lab scale proof of concept* *X Pilot scale ground demonstration* *□ Payload/ techno. Demonstrator* *□ Space engineering model* *□ Flight model*	*A demonstrator sized for 1 crew member daily potable water consumption needs has been built and tested at subsystem level. System level testing is on-going.*
TRL level (refer to definition in annex)	*3-4*

Links with other technologies (title and reference)

PTFE Bellows Water Storage System– Ref. TASI-BWS

Flexible Bacteriostatic Reservoir– Ref. TASI-FBR

Food Production Unit - Ref.TAS-FPU

Keywords

Microbial contamination control, potable water, condensate recovery, BIOWYSE

Associated publications

None – a paper was just submitted to the International Conference on Environmental Systems (ICES 2018).

ThalesAlenia Space	*Condensate Recovery Unit*				
Reference	*TASI-CRU*	*Version*	*1*	*Date*	*11.04.2018*

Title: Condensate Recovery Unit derived from ACLS technologies

Life Support main function(s) addressed (see definition in annex), please precise specific function

☐ *Atmosphere revitalization* *x Water recovery and recycling* ☐ *Food production and preparation* ☐ *Waste recovery and recycling* ☐ *ISRU*	*Main functions (for microgravity use):* • *Water storage and buffering* • *Free gas removal* • *Ionic contamination removal* • *Organics removal* • *Disinfection and bacteria filtration* • *Electrical conductivity monitoring*

Short description (main characteristics, features, …)

The Condensate Recovery Unit was derived from the technologies developed for the ACLS (Advanced Closed Loop System) flight system. It allows removal of multiple types of contaminants from recovered condensate to achieve potable and technical water standards.

Key performances demonstrated

- *Inlet water quality EC < 2000 µS/cm*
  - *Free Gas < 5%*
  - *Micr. Load < 1E5 CFU/ml*
  - *TOC < 150ppm*
  - *Iodine Conc. < 6ppm*
- *Outlet water quality EC < 3 µS/cm*
  - *Free Gas < 0.1%*
  - *Micr. Load < 50 CFU/ml*
  - *TOC < 10ppm*
  - *Iodine Conc. < 0.1ppm*
- *Operative Flow Rate 180 ml/min*
- *Maximum Design Pressure 3.1 barg*
- *Compatibility with flight environment of key water recovery technologies*
- *Compatibility with launch thermal and mechanical loads of key water recovery technologies*

Demonstration level (please precise testing conditions, duration)

☐ *calibrated mathematical model* ☐ *Lab scale proof of concept* *x Pilot scale ground demonstration* ☐ *Payload/ techno. Demonstrator* ☐ *Space engineering model* ☐ *Flight model*	*Full system breadboard available and tested in laboratory environment.* *Single key water recovery technologies developed up to flight model, to be launched with ACLS in mid.2018.*
TRL level (refer to definition in annex)	*8 for single key water recovery technologies, 4 for complete system*

Links with other technologies (title and reference) *PTFE Bellows Water Storage System– Ref. TASI-BWS* *Flexible Bacteriostatic Reservoir– Ref. TASI-FBR* *Condensate Disinfection Unit – Ref. TASI-CDU*
Keywords *Condensate recovery, microgravity, potable water production, water storage, water disinfection*
Associated publications *G. Boscheri et al, "Development Status of WMS Sub-Assembly for water treatment within the ACLS Rack", 44th International Conference on Environmental Systems, 2014.*

ThalesAlenia Space	Flexible Bacteriostatic Reservoir				
Reference	TASI-FBR	Version	1	Date	11.04.2018
Title: Flexible Bacteriostatic Reservoir					

Life Support main function(s) addressed (see definition in annex), please precise specific function	
□ Atmosphere revitalization	Storage of potable water
x Water recovery and recycling	Storage of concentrated nutrient solution for crops
□ Food production and preparation	Storage of waste water
x Waste recovery and recycling	Possible use for radiation protection
□ ISRU	

Short description (main characteristics, features, …)

The Flexible Bacteriostatic Reservoir provides bacteriostatic storage of potable water in microgravity. If water does not contain a microbial control agent a version is available with embedded bacteriostatic properties provided by inlet surface material under patent request. Another version is available if iodine or ionic silver are used as disinfectant. The bag is foldable after use for low volume disposal, and it is reusable for waste water storage (with possible radiation shielding function). The bag operates at ambient pressure.

Key performances demonstrated

- Maximum Design Pressure of 0.5 barg
- Long term (6 months) compatibility with silver/iodine disinfected water
- Compatibility with launch mechanical an thermal loads

Demonstration level (please precise testing conditions, duration)	
□ calibrated mathematical model □ Lab scale proof of concept x Pilot scale ground demonstration □ Payload/ techno. Demonstrator □ Space engineering model □ Flight model	Multiple size prototypes have been tested in laboratory environment. Vibration testing has been performed for one 2L prototype. Some prototype is being tested in Antarctica as space-analog test site.
TRL level (refer to definition in annex)	5 up to 2L (also random vibration test performed); 4 up to 10L

Links with other technologies (title and reference)

Food Production Unit - Ref.TAS-FPU

Condensate Recovery Unit - Ref.TAS-CRU

Condensate Disinfection Unit - Ref.TAS-CDU

Keywords

Water storage, flexible, bacteriostatic, microgravity

Associated publications

No associated publication (product under patent request)

ThalesAlenia Space		Food Production Unit			
Reference	TASI-FPU	Version	1	Date	11.04.2018

Title: Food Production/Complement Unit

Life Support main function(s) addressed (see definition in annex), please precise specific function

□ Atmosphere revitalization □ Water recovery and recycling x Food production and preparation □ Waste recovery and recycling □ ISRU	Main function: production of food complement via higher plants growth Side functions: CO2 recovery via photosynthetic activity; water recovery via phyto-depuration

Short description (main characteristics, features, …)

The facility shall represent an increment with respect to current flight capabilities represented by the NASA Veggie system, mainly in terms of:

- *Higher available growth surface (0.5-1,0 m² range)*
- *Longer production cycle possible by complete nutrient solution circulation (and not only watering of substrate with slow release fertilization)*
- *Robust and reliable safe and high quality food production (while Veggie control capability may be considered limited)*
- *Taller crop can be accommodated (up to 60 cm available for tall growth chamber shoot zone)*

Key performances demonstrated

- *Capability to grow Lettuce, Rucola, Dwarf tomato and Chinese Cabbage in two independently controlled growth chambers of 0.24m2 each*
- *Nutrient solution mixing and distribution with controlled pH (5-7, ±0.5) and EC (0-2000±200 µS/cm)*
- *Air temperature (18-26±1.5°C) and relative humidity (60-90±5%) control*
- *Control of the microbial contamination*
- *Control of the trace gases concentration in the growth chambers*

Demonstration level (please precise testing conditions, duration)

□ calibrated mathematical model □ Lab scale proof of concept x Pilot scale ground demonstration □ Payload/ techno. Demonstrator □ Space engineering model □ Flight model	Laboratory testing of full scale rack-like demonstrator tested in laboratory environment. Test in Antarctica is ongoing, planned for all duration of 2018.
TRL level (refer to definition in annex)	4

Links with other technologies (title and reference)

Condensate Disinfection Unit – Ref. TASI-CDU *PTFE Bellows Water Storage System– Ref. TASI-BWS* *Flexible Bacteriostatic Reservoir– Ref. TASI-FBR*
Keywords *Bioregenerative life support, Food Production Unit, Higher Plants, MELiSSA*
Associated publications *Boscheri, G., et al., "Main performance results of the EDEN ISS Rack-Like Plant Growth Facility" 47th International Conference on Environmental Systems, 2017.* *Boscheri, G., Guarnieri, V., Locantore, I., Lamantea, M., Lobascio, C., Schubert, D., "The EDEN ISS Rack-Like Plant Growth Facility" 46th International Conference on Environmental Systems, 2016.*

ThalesAlenia Space	*Metallic Reservoir for water storage in microgravity*				
Reference	*TASI-MPR*	*Version*	*1*	*Date*	*11.04.2018*
Title: Metallic Reservoir for water storage in microgravity					
Life Support main function(s) addressed (see definition in annex), please precise specific function					
□ *Atmosphere revitalization* x *Water recovery and recycling* □ *Food production and preparation* x *Waste recovery and recycling* □ *ISRU*	*Storage of potable water* *Storage of waste water*				
Short description (main characteristics, features, …) *The metallic Bellows Water Storage System provides storage of water in microgravity for the MPCV-Orion program. The material is selected to minimize long term effect on the quality of water with silver biocide. It consists into a Titanium Ti6Al4V shell equipped with Stainless Steel AISI 316L bellows for potable tank storage.*					

Key performances demonstrated
 	
• *Max Volume: 74 lt*
• *Maximum Design Pressure: 6 bar*
• *Operative temperature: 5-50 ºC*
• *Fluid compatibility (tested): Potable water*
• *Level sensor options:*
  ○ *Quantity level*
  ○ *Potentiometer technology (used for MPLM and Columbus accumulators) – Firstmark controls (US/NC), e.g. type 162-2735.*					

Demonstration level (please precise testing conditions, duration)					
□ *calibrated mathematical model* □ *Lab scale proof of concept* x *Pilot scale ground demonstration* □ *Payload/ techno. Demonstrator* □ *Space engineering model* □ *Flight model*	*MPCV reservoir flight unit has been produced and tested*				
TRL level (refer to definition in annex)	*7*				
Links with other technologies (title and reference)					

Food Production Unit - Ref.TAS-FPU *Condensate Recovery Unit - Ref.TAS-CRU* *Condensate Disinfection Unit - Ref.TAS-CDU*
Keywords *Potable water storage, microgravity, chemical compatibility, exploration missions*
Associated publications *None*

<table>
<tr><td colspan="6">PTFE Bellows Water Storage System</td></tr>
<tr><td>Reference</td><td>TASI-BWS</td><td>Version</td><td>1</td><td>Date</td><td>11.04.2018</td></tr>
<tr><td colspan="6">Title: PTFE Bellows Water Storage System</td></tr>
<tr><td colspan="6">Life Support main function(s) addressed (see definition in annex), please precise specific function</td></tr>
<tr><td colspan="2">□ Atmosphere revitalization
x Water recovery and recycling
□ Food production and preparation
x Waste recovery and recycling
□ ISRU</td><td colspan="4">Storage of potable water
Storage of nutrient solution for crops
Storage of waste water</td></tr>
<tr><td colspan="6">Short description (main characteristics, features, …)
The PTFE Bellows Water Storage System provides storage of water in microgravity. The material is selected to minimize long term effect on the quality of any water contained (from potable water with silver/iodine biocide), to waste water, to nutrient solutions for crops.</td></tr>
<tr><td colspan="6">Key performances demonstrated
• Maximum Design Pressure of 1.0 barg
• Long term (6 months) compatibility (chemical and microbiological) with silver/iodine disinfected water as well as nutrient solution for crops
• Fill and drain cycles >10000</td></tr>
<tr><td colspan="6">Demonstration level (please precise testing conditions, duration)</td></tr>
<tr><td colspan="2">□ calibrated mathematical model
□ Lab scale proof of concept
x Pilot scale ground demonstration
□ Payload/ techno. Demonstrator
□ Space engineering model
□ Flight model</td><td colspan="4">Multiple size prototypes have been tested in laboratory environment. A prototype is being tested in Antarctica as space-analog test site.</td></tr>
<tr><td colspan="2">TRL level (refer to definition in annex)</td><td colspan="4">4</td></tr>
<tr><td colspan="6">Links with other technologies (title and reference)
Food Production Unit - Ref.TAS-FPU
Condensate Recovery Unit - Ref.TAS-CRU
Condensate Disinfection Unit - Ref.TAS-CDU</td></tr>
</table>

Keywords *Water storage, microgravity, chemical compatibility*
Associated publications *Boscheri, G., et al., "Main performance results of the EDEN ISS Rack-Like Plant Growth Facility" 47th International Conference on Environmental Systems, 2017.*

ThalesAlenia Space	*Waste Water Recovery System*				
Reference	*TASI-WRS*	*Version*	*1*	*Date*	*11.04.2018*
Title: Waste Water Recovery System					

Life Support main function(s) addressed (see definition in annex), please precise specific function	
□ Atmosphere revitalization *X Water recovery and recycling* *□ Food production and preparation* *□ Waste recovery and recycling* *□ ISRU*	*Main functions (for microgravity use):* • *Waste water storage* • *Product water storage* • *Urine recovery* • *Hygiene water recovery* • *Condensate recovery*

Short description (main characteristics, features, …)

The system exploits a first distillation step to recover water from multiple waste water streams, including urine, hygiene water and condensate. The system is studied to operate in microgravity within a standard payload rack. The system is sized to recover up to 12L/day of waste water. It includes also a Multi-filtration Unit, a Reverse Osmosis Unit, a Photocatalytic Unit.

Key performances demonstrated

The system is under development and the technical details cannot be disclosed at this moment.

Demonstration level (please precise testing conditions, duration)	
□ calibrated mathematical model *X Lab scale proof of concept* *□ Pilot scale ground demonstration* *□ Payload/ techno. Demonstrator* *□ Space engineering model* *□ Flight model*	*Single principles were tested in laboratory on partially representative breadboards.* *Laboratory testing of first prototype will be completed in 2018.*
TRL level (refer to definition in annex)	*3*

Links with other technologies (title and reference)

Condensate Recovery Unit - Ref.TAS-CRU

Condensate Disinfection Unit - Ref.TAS-CDU

Keywords *Waste water storage, Product water storage, Urine recovery, Hygiene water recovery, Condensate recovery*
Associated publications *None, the Intellectual Property is kept within the company for possible patent pending aspects*

Life Support Technology					
Reference	*CNR Istituto di Biologia Agroambientale e Forestale, Alberto Battistelli*	*Version*	*1*	*Date*	*13/04/2018*

Title: CO_2 buffering system for BLSS.

Life Support main function(s) addressed (see definition in annex), please precise specific function

X Atmosphere revitalization *□ Water recovery and recycling* *X Food production and preparation* *□ Waste recovery and recycling* *□ ISRU*	

Short description (main characteristics, features, …)

CO_2 has to be recycled in BLSS but fluxes of production (by the crew and by the organic material degradation facilities) and photosynthetic fixation by plants are not necessarily coordinated. CO_2 delivery to plants has to be finely tuned to avoid plant damage and inefficient photosynthesis. We have built and tested a chemical system that would be a buffer for CO_2 control in the BLSS. The system can fix and release CO_2 depending on physico-chemical conditions easily tunable depending on needs.

Key performances demonstrated

CO_2 fixation from air stream at ambient conditions (CO_2 partial pressure and temperature)

CO_2 release at high partial pressure under modified conditions, activation of release in less than one minute

Demonstration level (please precise testing conditions, duration)

□ calibrated mathematical model *X Lab scale proof of concept*	

□ *Pilot scale ground demonstration* □ *Payload/ techno. Demonstrator* □ *Space engineering model* □ *Flight model*	
TRL level (refer to definition in annex)	
Links with other technologies (title and reference) ***Link with CO2 control in manned habitats for space.***	
Keywords ***Control of CO2, plant growth, Carbonic fertilisation***	
Associated publications	

Life Support Technology					
Reference	*CNR Istituto di Biologia Agroambientale e Forestale, Alberto Battistelli*	*Version*	*1*	*Date*	*13/04/2018*

Title: Environmental control in BLSS for quality and safety of plant food products.

Life Support main function(s) addressed (see definition in annex), please precise specific function

□ *Atmosphere revitalization* □ *Water recovery and recycling* *X Food production and preparation* □ *Waste recovery and recycling* □ *ISRU*	

Short description (main characteristics, features, …)

Past research on food production for space application has focused mainly on basic nutrients like carbohydrate proteins and fat, we have focused or research efforts on nutritionally relevant key quality components of plant produce, namely: carbohydrates (monomeric, oligomer and polymeric), vitamins, mineral salts, chlorophylls, carotenoids, anthocyanin, nitrate, oxalate, organic acids, amino acids, polyphenols, antioxidants, prebiotics and so on. All these components affect directly and indirectly the human wellbeing and are crucial for the correct nutrition of astronauts, taking into account their special food quality and safety requirements. Furthermore, the accumulation of many of this nutritionally relevant plant component is modulated be growth environment parameters such as light (intensity, duration and spectrum), temperature, relative humidity, CO2 partial pressure. We have demonstrated many of these effects under pilot scale conditions, and on flight on the ISS. This aspect has to be further investigated and included in procedures and models for plant food production in space and for optimal implementation of plant into BLSS.

Key performances demonstrated

Effects of microgravity on quality of E. sativa seedling grown on board of the ISS (mission ENEIDE)

Effects of light intensity, duration and spectrum on productivity and quality attributes of different horticultural species. (In house research, various projects including EDEN ISS, published and unpublished results)

Effects of growing temperature, on productivity and quality attributes of different horticultural species. (In house research, various projects, published and unpublished results).

Effects of CO2 partial pressure, on productivity and quality attributes of different horticultural species. (In house research, various projects, published and unpublished results).

Effects of the interaction of the aforementioned growing environmental conditions on productivity and quality attributes of different horticultural species. (In house research, various projects, published and unpublished results).

Demonstration level (please precise testing conditions, duration)	
□ *calibrated mathematical model* □ *Lab scale proof of concept* *X Pilot scale ground demonstration* □ *Payload/ techno. Demonstrator* □ *Space engineering model* □ *Flight model*	
TRL level (refer to definition in annex)	

Links with other technologies (title and reference)

Link with all aspects of environmental control in BLSS.

Keywords

Food quality and safety, nutritional value, carbohydrates, vitamins, antioxidants, prebiotics, nitrate

Associated publications

Zabel, P., Bamsey, M., Zeidler, C., Vrakking, V., Johannes, B. W., Rettberg, P., ... & Hoheneder, W. (2015). Introducing EDEN ISS-A European project on advancing plant cultivation technologies and operations. In International Conference on Environmental Systems (pp. 1-13).

Proietti, S., Moscatello, S., Giacomelli, G. A., & Battistelli, A. (2013). Influence of the interaction between light intensity and CO2 concentration on productivity and quality of spinach (Spinacia oleracea L.) grown in fully controlled environment. Advances in Space Research, 52(6), 1193-1200.

Proietti, S., Moscatello, S., Famiani, F., & Battistelli, A. (2009). Increase of ascorbic acid content and nutritional quality in spinach leaves during physiological acclimation to low temperature. Plant Physiology and Biochemistry, 47(8), 717-723.

Fallovo, C., Rouphael, Y., Cardarelli, M., Rea, E., Battistelli, A., & Colla, G. (2009). Yield and quality of leafy lettuce in response to nutrient solution composition and growing season. J. Agric. Food Environ, 7, 456-462.

Proietti, S., Moscatello, S., Colla, G., & Battistelli, Y. (2004). The effect of growing spinach (Spinacia oleracea L.) at two light intensities on the amounts of oxalate, ascorbate and nitrate in their leaves. The Journal of Horticultural Science and Biotechnology, 79(4), 606-609. Rivera, C. M., Battistelli, A., Moscatello, S., Proietti, S., Rouphael, Y., Cardarelli, M., & Colla, G. (2006). Influence of simulated microgravity on growth, yield, and quality of leafy vegetables: lettuce and rocket. European Journal of Horticultural Science, 45-51.

Colla, G., Battistelli, A., Proietti, S., Moscatello, S., Rouphael, Y., Cardarelli, M., & Casucci, M. (2007). Rocket seedling production on the international space station: Growth and nutritional properties. Microgravity Science and Technology, 19(5-6), 118-121.

Life Support Technology					
Reference	*CNR Istituto di Biologia Agroambientale e Forestale, Alberto Battistelli*	*Version*	*1*	*Date*	*13/04/2018*

Title: CO2 buffering system for BLSS.

Life Support main function(s) addressed (see definition in annex), please precise specific function

X Atmosphere revitalization *□ Water recovery and recycling* *X Food production and preparation* *□ Waste recovery and recycling* *□ ISRU*	*To pick-up and*

Short description (main characteristics, features, …)

Pollutants can rise in concentration in water and gas streams, in manned premises in space. Plants have the ability to pick up some of the pollutants and metabolize them. We have tested a multi-disciplinary and multi-analytical approach to follow the fate of alcohols (polluting ISS cabin crew condensate water) to demonstrate the pollutant metabolism ability of hydroponically grown E. sativa in the short time scale (minutes).

Key performances demonstrated

Demonstration of pollutant absorption by the plant

Demonstration of pollutant accumulation/non accumulation by the plant

Demonstration of pollutant metabolism to other metabolites

Demonstration of pollutant metabolism to CO2

Demonstration of pollutant release in the ambient

Demonstration of pollutant derived metabolites in the environment.

Demonstration level (please precise testing conditions, duration)

□ calibrated mathematical model *X Lab scale proof of concept* *□ Pilot scale ground demonstration* *□ Payload/ techno. Demonstrator* *□ Space engineering model* *□ Flight model*	
TRL level (refer to definition in annex)	

Links with other technologies (title and reference)

Pollutant elimination

Keywords

Plant metabolism, pollutants

Associated publications

Unpublisced

Life Support Technology					
Reference	*Eugenio Benvenuto* *ENEA*	*Version*	*1*	*Date*	*10/04/2018*
Title: *New plant "ideotypes" for farming in the space*					

Life Support main function(s) addressed (see definition in annex), please precise specific function

□ Atmosphere revitalization *□ Water recovery and recycling* *X Food production and preparation* *□ Waste recovery and recycling* *□ ISRU*	

Short description (main characteristics, features, …)

The advances in agricultural research, such as "soil-less" culture (hydroponics) allow to breed plants in places and spaces once considered impossible. One of the most extreme imaginable place for growing plants is certainly the International Space Station, a multidisciplinary laboratory ideal for the realization of methods of intensive cultivation and self-consistent for recycling of vital resources (bio-regenerative technologies). Future human habitation of space, implying enormous distances from Earth (i.e. Mars outpost), will require a controlled ecological life-support systems to basically re-create a proper atmosphere (generating oxygen and fixing carbon dioxide), purify water (through transpiration) and possibly sow seeds for human food. In Environmental Control and Life Support System (ECLSS) photosynthetic algae and higher plants will therefore exert the essential functions of primary productivity and, in combination of physicochemical and bio-regenerative processes, may be used to provide air revitalization, water and waste recycling, CO_2 scrubbing and, last but not least, food production. For cultivation in a ECLSS, plants' selection and breeding must be based on both the nutritional and agronomic performances. Technologies for selection of higher plants to be grown in such conditions can be found at the ENEA Biotechnology Laboratories. We possess an experimental greenhouse facility and special chambers (completely isolated from the outside) in which we perform experiments aimed at engineering new plant "ideotypes" suitable for extra-terrestrial life, challenging the harsh environment conditions of the space (i.e. ionizing and non ionizing radiations, microgravity, altered light and photoperiod conditions, ect.). Through applications of advanced biotechnology we can also obtain and grow in sterile conditions roots appropriately engineered to become a "biofactory" of drugs and bioactive "ready-to-use" molecules for the crew during space missions.

Of special interest is HORTEXTREME, a prototype ideated for multilevel "microgreens" cultivation in which plants are bred with a close loop hydroponics, designed to minimize the amount of water waste. Equipped with management and control systems, based on advanced ICT and IoT technologies, the structure is an innovative prototype of a resource-efficient, aseptic and closed plant production system in which, portability, ease and speed of installation/removal are the major assets. Ideally, this prototype, made of purpose-built materials, can be placed and used anywhere and anytime, where there is need to establish on-site production of healthy fresh vegetables, especially when environmental conditions are limiting factors, requiring a limited amount of water and electricity supply.

Multiple cutting-edge platforms of molecular biology, biochemistry, "omics" sciences, plant and animal cell biology, irradiation facilities support ongoing projects for "space horticulture".

Key performances demonstrated *These research study tools are fundamental for evaluating the ability to grow plants in orbiting stations or space missions and allow to select plant systems endowed with the best capacities to adapt and live into the extreme conditions encountered.*

Demonstration level (please precise testing conditions, duration)	
□ calibrated mathematical model *X Lab scale proof of concept* *□ Pilot scale ground demonstration* *□ Payload/ techno. Demonstrator* *□ Space engineering model* *□ Flight model*	
TRL level (refer to definition in annex)	*4*

Links with other technologies (title and reference)
Cyanobacterium-based technology to link ECLSS to in situ resources.

Keywords
Bio-regenerative technologies, hydroponics, novel space-adapted plant ideotypes, space biotechnology

Associated publications
Villani ME, Massa S, Lopresto V, Pinto R, Salzano AM, Scaloni A, Benvenuto E, Desiderio A.
Effects of high-intensity static magnetic fields on a root-based bioreactor system for space applications. Life Sci Space Res (Amst). 2017 Nov;15:79-87. doi: 10.1016/j.lssr.2017.09.002. Epub 2017 Sep 28. PubMed PMID: 29198317.

Life Support Technology					
Reference	altran	*Version*	*1*	*Date*	*11/04/2018*
Title: Cooking platform with multiple heating sources					

Life Support main function(s) addressed (see definition in annex), please precise specific function	
□ *Atmosphere revitalization* □ *Water recovery and recycling* ☑ ***Food production and preparation*** □ *Waste recovery and recycling* □ *ISRU*	*Function is efficient and fast food thermal cooking. So far targeted to ground application.*
Short description (main characteristics, features, …)	
The primary aim of the research project is to develop a new oven platform capable to maximize energy efficiency and cooking results (in terms of performances and cooking time), exploiting solid state cooking (SSC) technology and integrating different heating technologies (microwave heating, induction heating, convection and radiant heating, steam heating)	
Key performances demonstrated	
• *Decrease in cooking time, respect to traditional cooking, thanks to multi-source heating system.* • *High efficiency power delivery to the food load* • *Flexible cooking process* • *Use of more compact electric components with reduced weight (solid state microwave generator vs traditional magnetron)* • *Development of enhanced cooking algorithms allowed by the use of solid state technology, impossible with standard MWOs based on magnetrons*	
Demonstration level (please precise testing conditions, duration)	
□ *calibrated mathematical model* ☑ ***Lab scale proof of concept***	

□ *Pilot scale ground demonstration* □ *Payload/ techno. Demonstrator* □ *Space engineering model* □ *Flight model*	
TRL level (refer to definition in annex)	

Links with other technologies (title and reference)

Keywords *Oven, cooking, multi-source heating system, solid state cooking, microwave oven, induction oven, induction cooktop,*

Associated publications

Life Support Technology					
Reference	altran	*Version*	*00*	*Date*	*6 April 2018*

Title:

Machine vision-guided plant sensing system

Life Support main function(s) addressed (see definition in annex), please precise specific function

□ *Atmosphere revitalization* □ *Water recovery and recycling* ☑ *Food production and preparation* □ *Waste recovery and recycling* □ *ISRU*	*Function is real-time monitoring and control applications in automated greenhouses for crop farming ('smart' or 'precision farming'). So far targeted for on-earth applications*

Short description (main characteristics, features, …)

This is a machine vision- guided device for plant sensing and monitoring, designed to detect temporal, color and morphological changes of crops for real-time control of greenhouse environmental parameters (temperature, lighting, relative humidity, pH, etc.), as well as variable-rate irrigation, fertigation and treatment systems.

The machine vision system consists of two main components: a robotic camera and an image processing module. The system extracts plant features (such as color, shape, surface texture, growth rate, etc.) to determine overall plant growth rate and health status. It is capable of recording plant morphological, textural and temporal features autonomously, without any human supervision.

Data collected are then used both as input and as feedback for environmental control system with closed-loop control. An array of actuators tunes the physical and chemical parameters inside the greenhouse to create the optimal conditions for a healthy growth and an efficient harvest of fresh produce, preventing common diseases and maximizing sensory and nutritional properties. For example, the ability to control the environmental conditions in an automated greenhouse irrigation system means that small changes in intricate plant geometric relationships can be detected in real time and correlated to a specific cause (e.g., light or water stress).

Applications of machine vision systems to plants in a greenhouse environment include automatic irrigation management, enhanced fruit harvesting, fruit and flower grading, early treatment of diseases, etc.

Key performances demonstrated
- *Increase of growth rate and overall crop yields* - *Enhancing of sensory and nutritional properties* - *Early detection and treatment of plant diseases* - *Optimization of plant growth cycles for steady outputs of fresh produce* - *Optimized use of resources (e.g., energy, water, fertilizer)* - *Food waste reduction* - *Water waste reduction* - *Lower costs (compared to traditional precision-farming sensors)* - *Low risk of mechanical failure* - *Customization over time (thanks to machine learning)*

Demonstration level (please precise testing conditions, duration)	
□ *calibrated mathematical model* ☑ *Lab scale proof of concept* □ *Pilot scale ground demonstration* □ *Payload/ techno. Demonstrator* □ *Space engineering model* □ *Flight model*	
TRL level (refer to definition in annex)	

Links with other technologies (title and reference)
CRM Module – Controlled Ripening Module (ref. ___________)

Keywords

Image processing, machine vision, real-time crop monitoring, fruit grading, greenhouse crops, pest early detection, disease detection, smart farming, biology computing, environmental control, artificial neural network

Associated publications

(none)

Life Support Technology					
Reference	*ARGOTEC, Filomena Iorizzo*	*Version*	*Issue 1*	*Date*	*12 April 2018*

Title: Food preparation, preservation and analysis technologies for human space flight

Life Support main function(s) addressed (see definition in annex), please precise specific function

□ Atmosphere revitalization

□ Water recovery and recycling

x Food production and preparation

□ Waste recovery and recycling

□ ISRU

Short description (main characteristics, features, …)

Argotec is developing technologies for the food production, preservation and analysis able to support current and future human exploration missions. Such technologies will allow astronauts to grow and prepare foods directly with the ingredients available on board the space modules. In addition to these activities, the food preservation and analysis are also under investigation in order to provide technologies for the food storage and monitoring. In particular, the study focuses on the real-time control of the food quality by means of simple devices that can monitor the main parameters (appearance, colour, nutritional values, adulterants, and contaminants) in order to understand occurrence of any physicochemical changes during processing or storage and to ensure safety of the food products at the time of consumption.

Key performances demonstrated

Argotec has experience in the food production and preparation on Ground; in fact Argotec is responsible of the Space Bonus Food development and supply for European astronauts on the International Space Station. Argotec developed independently a new research area for the study of nutritional food dedicated to the astronauts, the Space Food Lab. In this laboratory Argotec prepares food with a shelf-life of at least 18-24 months, 100% organic and without salt. A food processing technique based on thermostabilization was selected and tuned in order to decrease the amount of sodium content in food and adapt a method of preservation that would not alter the colour, fragrance and flavour of food. Thanks to its know-how and experience, Argotec is developing a technology for food processing and storage. A feasibility study has been completed in order to define the system architecture considering the safety issues for the integration of the technology in a manned module. Main drivers for the design of the device is the minimization of mass, volume and crew time.

Regarding the food preservation and analysis, different solutions have been analysed in order to provide a simple and reliable device that can help crew analysing quality of food during their missions.

Argotec has already developed technologies compatible with food. For example, ISSpresso is the first capsule-based espresso system able to work in microgravity conditions. ISSpresso can provide the crew with coffee, hot beverages, and broth for food hydration.

Demonstration level (please precise testing conditions, duration)	
□ *Calibrated mathematical model* □ *Lab scale proof of concept* *x Pilot scale ground demonstration* □ *Payload/ techno. Demonstrator* □ *Space engineering model* □ *Flight model*	
TRL level (refer to definition in annex)	***TRL 4***
Links with other technologies (title and reference) -	
Keywords *Food preparation, food preservation, food analysis, food hydration, Space Food, ISSpresso*	
Associated publications *V. Di Tana, J. Hall, ISSpresso development and operations, Journal of Space and Safety Engineering, June 2015.*	

Life Support Technology					
Reference	*ARGOTEC, Filomena Iorizzo*	*Version*	*Issue 1*	*Date*	*12 April 2018*

Title: ISSpresso, the capsule-based espresso system

Life Support main function(s) addressed (see definition in annex), please precise specific function

□ *Atmosphere revitalization*

□ *Water recovery and recycling*

x Food production and preparation

□ *Waste recovery and recycling*

□ *ISRU*

Short description (main characteristics, features, …)

ISSpresso is a stand-alone payload for the preparation of hot beverages based on a single cup capsule brewer on board the ISS. The ISSpresso project has been developed by Argotec, an Italian space company, with the partnership of Lavazza and the sponsorship of the Italian Space Agency.

ISSpresso is designed to increase and regulate the water pressure and temperature for the beverage brewing without creating crew hazards, according to the NASA Safety standards. Isspresso is mainly composed of a thermo-hydraulic system for the hot beverage brewing, and an electronic unit designed to collect and process telemetries, distribute and convert power. ISSpresso is also a technology demonstrator of innovative systems for the fluid handling. Indeed the water is provided by an innovative mechanism, which is approved and qualified by the NASA MSWG, based on a dual-stage pump able to pressurize the water and compress air for an air flush blown at the end of the brewing process in order to clean the hydraulic system and prevent any fluid spillage. Moreover ISSpresso offers the opportunity to study some physical phenomena related to the fluid dynamics of liquids at high pressure and temperature, and the foam formation in microgravity.

ISSpresso is currently onboard ISS having been successfully operated for the first time during Expedition 43 (2015). Prior to ISSpresso, the crew only had access to instant coffee inside a drink pouch, which is then filled with hot water. The ISSpresso infuses espresso coffee from capsules conveniently modified to prevent burst if exposed to vacuum, and properly packaged to avoid coffee powder dispersion. ISSpresso can also produce hot beverages and consommé (such as chicken broth) for food hydration and it represents a key step for the preparation of hot beverages and food on possible future human exploration missions beyond Low Earth Orbit to the Moon or Mars.

Key performances demonstrated

ISSpresso was successfully operated for the first time on board the International Space Station on May 2015 (Expedition 43). ISSpresso demonstrated the capability of:

- *Brewing hot liquids using a capsule based system;*
- *Cleaning hydraulic circuit reducing water consumption and preventing bacterial growth;*
- *Managing high pressure and temperature without creating crew hazards;*
- *Providing the crew with hot beverages.*

Moreover, ISSpresso provided scientific results on the study of fluid mixture behavior, bubble generation, and capillary action.

Demonstration level (please precise testing conditions, duration)	
□ *Calibrated mathematical model* □ *Lab scale proof of concept* □ *Pilot scale ground demonstration* □ *Payload/ techno. Demonstrator* □ *Space engineering model* *x Flight model*	
TRL level (refer to definition in annex)	***TRL 9*** *(International Space Station, Expedition 43-54)*

Links with other technologies (title and reference) -
Keywords *ISSpresso, coffee machine, food hydration, Space Food*
Associated publications *V. Di Tana, J. Hall, ISSPRESSO DEVELOPMENT AND OPERATIONS, Journal of Space Safety Engineering, Vol. 2 No. 1, June 2015* *V. Di Tana, L. Facciolati, M. Tarifa, (2016), Dispensing assembly for machines for the preparation of liquid food products, WO 2016/051290 A1* *D. Bolognese et al., (2016), A dispensing assembly for machines for preparing liquid product by means of capsules, WO 2016/038474 A1*

Life Support Technology					
Reference	*Giorgia Pontetti* *G&A Engineering*	*Version*	*1*	*Date*	*27/03/2018*
Title: GEALED					

Life Support main function(s) addressed (see definition in annex), please precise specific function	
□ Atmosphere revitalization *□ Water recovery and recycling* *x Food production and preparation* *□ Waste recovery and recycling* *□ ISRU*	

Short description (main characteristics, features, …)

Solid State custom, new generation, lighting system for indoor cultivation, on Earth or Space.

New type of lighting device based on solid-state LED technology; it provides a multi-spectral distribution optimized for plant growth, commanding the emission of light on the necessary and appropriate wavelengths for cultivation, being able to modify the radiative intensity (in µmol x m^{-2} x s^{-1}) necessary for the correct growth in each phenological phase, allowing the management of lighting cycles (variability over time in terms of radiation and intensity), implementing also the thermal control.

Key performances demonstrated

- *New LED lighting system*
- *Multi-spectral array*
- *Fully electronically controlled*
- *Integrated thermal management*
- *Wavelengths: 450 nm, 660 nm, 730 nm + White with Green*
- *Cooling System: Air or/& Water*
- *Dimming: 0% to 100%*

Demonstration level (please precise testing conditions, duration)	
□ calibrated mathematical model *□ Lab scale proof of concept* *□ Pilot scale ground demonstration* *x Payload/ techno. Demonstrator*	

□ *Space engineering model* □ *Flight model*	
TRL level (refer to definition in annex)	*6*

Links with other technologies (title and reference)
RobotFarm, indoor hydroponic appliance (www.robotfarm.tech) *CHEF Project, Container Vertical Farm*
Keywords
Hydroponic, cultivation, indoor growing, food production, LED, lighting
Associated publications

Life Support Technology					
Reference	*Kayser Italia, Alessandro Donati*	*Version*	*1*	*Date*	*13/04/2018*
Title: ACLS (Advanced Closed Loop System) Avionics Subsystem					
Life Support main function(s) addressed (see definition in annex), please precise specific function					
X Atmosphere revitalization *□ Water recovery and recycling* *□ Food production and preparation* *□ Waste recovery and recycling* *□ ISRU*					

Short description (main characteristics, features, …)

The ACLS is an ISPR Facility designed & qualified for implementation on ISS within the US-Lab Module. The ACLS is based on three assemblies, which are the Carbon Dioxide Concentration Assembly (CCA), the Carbon Dioxide Removal Assembly (CRA) and the Oxygen Generation Assembly (OGA). All these ACLS assemblies are supported and controlled by a dedicated ACLS Avionics.

Kayser Italia, as subcontractor of AIRBUS DS, is responsible for the complete Avionics Subsystem, including software, harness, and EGSE.

The objective of ACLS is to demonstrate with regenerative processes:

- *the provision of the capability for carbon dioxide removal from the module atmosphere;*
- *the return supply of breathable oxygen within a closed-loop process;*
- *the conversion of the hydrogen, resulting from the oxygen generation via electrolysis, to water.*

The goal of the ACLS is to provide - for a 3-men crew - CO_2 removal from cabin air, O_2 generation and the conversion of H_2 with CO_2 to CH_4 and H_2O, as an inherent combined function of ACLS. Further, it will be possible to provide the CO_2 removal function and the O_2 generations function independently from each other.

Each of the ACLS assemblies has its own self-standing mechanical and electro-mechanical configuration and they have its own process equipment consisting of hydraulic assemblies, actuators and sensors. All of these assemblies is supported and controlled by the ACLS Avionics and control function.

ACLS avionics is compatible with the 6 kW (120V_{DC} MAIN Power) and 1.44 kW (120V_{DC} AUXILIARY Power) ISPR UIP inside the US-Lab Module.

The main tasks of the ACLS Avionics Subsystem are:

- *ACLS to US-Lab interface:*
  - *Reception and conversion of 120V_{DC} Main and Auxiliary power;*
  - *Electrical isolation from the US-Lab Main and Auxiliary power busses;*
  - *Communication via nominal or redundant P/L Local Area Network (LAN);*
  - *Provision of EWACS data to US-Lab;*
  - *Standard maintenance switch interface.*

- *ACLS process assemblies:*
  - *Provision of 120V_{DC} and 24V_{DC} electrical power outlets;*
  - *Provision of 120V_{DC} and 24V_{DC} heaters commands and powers;*
  - *Provision of 24V_{DC} valves and others devices commands and controls;*
  - *Oxygen generator stack control;*
  - *Communication to the ACLS process assemblies via serial RS485 links;*
  - *Discrete command interfaces to ACLS process assemblies;*
  - *Monitoring of the ACLS processes;*
  - *A hardwired safety layer for safety relevant monitoring and commands.*

- *ACLS avionics itself:*
  - *CAN based communication Bus between avionics subsystems (PSMs and SCS/IMU) and ACLS System Controller (ASC);*
  - *LAN based communication between Data Acquisition Units (DAUs) and ACLS System Controller (ASC);*
  - *Provision of a dedicated hardwired safety layers within each PSMs to avoid safety critical operations;*
  - *Control of the ACLS processes by ASC;*
  - *Communication between ACLS process assemblies and US-Lab module via LAN ASC.*

Key performances demonstrated

The ACLS system, including Avionics subsystem, has completed qualification/acceptance tests and is actually in the delivery phase for integration and launch inside HTV-7.

Demonstration level (please precise testing conditions, duration)	
□ *calibrated mathematical model* □ *Lab scale proof of concept* □ *Pilot scale ground demonstration* □ *Payload/ techno. Demonstrator* □ *Space engineering model*	

X Flight model	
TRL level (refer to definition in annex)	*TRL 8*
Links with other technologies (title and reference)	
Keywords *ACLS, Life Support Systems, Atmosphere, Carbon Dioxide Removal, Oxygen Generation, Breathable Oxygen, Closed-Loop, Avionics, Power Conversion, Power Distribution, Data Acquisition, Process Control Software, Computer Unit, Motor Drivers, Actuator Drivers*	
Associated publications *N/A*	

Life Support Technology					
Reference	*Kayser Italia, Alessandro Donati*	*Version*	*1*	*Date*	*13/04/2018*
Title: Bioreactors for edible plant seeds germination					

Life Support main function(s) addressed (see definition in annex), please precise specific function	
□ Atmosphere revitalization *□ Water recovery and recycling* *X Food production and preparation* *□ Waste recovery and recycling* *□ ISRU*	

Short description (main characteristics, features, …)

To date two different bioreactors has been developed and tested in space missions onboard ISS featuring plant seeds germination in space:

1) *KEU-AT, developed for Arabidopsis thaliana seeds, it is suitable for plant germination related studies. It is equipped with reservoirs for chemicals (water, fixatives) and one culture chamber allowing seed germination. The scientific protocol is operated manually by the astronaut. At the end of the experiment the KEU-AT Experiment Unit can be stowed at controlled temperatures (freezer). After stowage and re-entry on Earth, plantlets can be recovered and analyzed by microscopy techniques as well as molecular biology-based approaches for genomic, transcriptomic and proteomic studies. Each KEU-AT Experiment Unit (EU) is made of a semi-crystalline thermoplastic polymer with excellent mechanical and chemical resistance properties, biologically inert. Cross contamination among the chambers is avoided due to proper sealing gaskets. The EU itself provides two Levels of Containment (LoC) that is increased to three by using a specific container. The experiment protocol required actions are manually performed by one crew member by using a dedicated available qualified tool. On request, the hardware can be made fully automatic with minor modifications. The fluidic concept carries out the KEU-AT experimental protocol which relies on three main steps, namely Arabidopsis thaliana seeds hydration, seeds germination, and plantlets fixation. On the whole, the actions performed by the fluidic system are led by manual linear actuators that push the plungers inward displacing the fluids (Activator or Fixative) contained into the chemicals reservoirs (Activator or Fixative reservoir) towards the Culture Chamber (CC). Short channels connect the reservoirs to the CCs so that seeds are watered or fixed. To guarantee fluid injections within the CC a dedicated inner system of channels and valves leads the air behind the plungers' reservoirs.*

2) *KEU-Y2: The KEU-Y2 Experiment Unit is a device capable of performing automatic yeast cell culture of adherent cells on top of agar slab or edible plant seeds germination in Oasis disks for the support of the seeds development in microgravity. It is equipped with reservoirs for chemicals (culture medium, or fixatives) and a culture chamber allowing cell growth or seeds germination. The KEU-Y2 is equipped with a permeable membrane to grant for extinguish of CO_2 overpressure, making the KEU-Y2 ideal for fermenting cells or seeds germination. The scientific protocol is led by the KEU-Y2 electronic controller following a predefined timeline. At the end of the experiment the KEU-Y2 Experiment Unit can be stowed at controlled temperatures (freezer). After stowage and re-entry on Earth, cell cultures can be analyzed with molecular biology-based approaches for genomic, transcriptomic and proteomic studies or*

morphological investigations. The fluidic concept carries out the experimental protocol which relies basically on two main steps, i.e. cell growth or seeds germination on solid feeding medium, and fixation. On the whole, the actions performed by the fluidic system are achieved by preloaded springs activated electrical actuators. Such mechanism releases the pistons inward displacing the fluids (Fixative) contained into the chemicals reservoirs (Fixative reservoir) towards the Culture Chamber (CC). An inner system of channels and valves connect independently each reservoir to the corresponding CC so that cells are fixed. Each CC is linked to an expandable volume located behind the piston to allow fluid injection. Short channels along with a permeable membrane also provide the release of CO_2*.*
Key performances demonstrated 1) *The KEU-AT has been adopted in the AT-SPACE experiment (PI: Klaus Palme, U. Freiburg) and ArabidopsISS (PI: Stefano Mancuso, U. Florence). The KEU-AT allowed the germination of Arabidopsis thaliana seeds onboard ISS during the BIO3 ESA mission (Launch on October 2007 with Soyuz TMA-11 15S) for the AT-Space experiment and during the ASI DAMA mission (Launch on May 2011 with NASA STS-134) for the ArabidopsISS experiment.* 2) *The KEU-Y2 has been adopted for the YING B-2 yeast experiment (PI: Ronnie Willaert, U. Bruxelles and Luk Daenen, U. Leuven) and for the MULTI-TROP carrot seeds germination experiment (PI: Giovanna Aronne, U. Naples). The KEU-Y2 allowed yeast growth onboard ISS (YING B-2, Launch on September 2009 with Soyuz 20S) and carrot seeds germination on board ISS during the ASI VITA mission (MULTI-TROP, Launch on December 2017 with SpaceX CRS-13).*

Demonstration level (please precise testing conditions, duration)	
□ *calibrated mathematical model* □ *Lab scale proof of concept* □ *Pilot scale ground demonstration* □ *Payload/ techno. Demonstrator* □ *Space engineering model* *X Flight model*	
TRL level (refer to definition in annex)	*TRL 9*

Links with other technologies (title and reference) *Kayser Italia has developed a whole fleet of automated bioreactors that support scientific experiment execution in space with a proven track of experimental success.* *For an overview of the developed hardware for biological space investigation please visit:* *http://www.kayser.it/index.php/catalog*

Keywords *Bioreactor, scientific protocol execution, seeds germination, vegetables*
Associated publications *N/A*

Life Support Technology					
Reference	*Kayser Italia, Alessandro Donati*	*Version*	*1*	*Date*	*13/04/2018*
Title: MIDASS (Microbial Detection in Air System for Space)					

Life Support main function(s) addressed (see definition in annex), please precise specific function	
X Atmosphere revitalization *□ Water recovery and recycling* *□ Food production and preparation* *□ Waste recovery and recycling* *□ ISRU*	

Short description (main characteristics, features, …)

The purpose of the MIDASS (Microbial Detection in Air System for Space) system is the monitoring of microbial risks in the closed environments. The system operation is based on molecular biology techniques that detects and identifies relevant microbes. Two techniques are applied to the system in order to detect microbial contamination:

1) ***BOOM****, based on magnetic beads, to extract and purify Nucleic Acid (NA); implemented in the Sample Preparation Module.*
2) ***NASBA****, which uses the activity of enzymes to create copies of the NA and molecular fluorescent beacons to measure in real time the fluorescence signal related to the biological reaction; implemented in the Detection Module.*

The system utilizes a peppermill-type collection device for air sampling, cellular lysis and nucleic acid purification. A separate NASBA card, which contains primers and probes/beacons, is used to amplify the purified rRNA targets. Amplification takes place in 60-90 minutes, and the system detects both bacteria and fungi. The time to result is 3 hours. A table-top instrument is used to process the peppermill and the amplification card. Total viable counts are obtained not in the form of colony forming units (cfu), but in gene copies or genomic equivalents (Geqs). Sensitivity is estimated at 1 cfu (or 1 Geq) per cubic meter of air or per 25 square cm for fungi, and 20 cfu (20 Geqs) per 25 square cm for bacteria. Finally, the system is considered to be non-destructive, where the purified nucleic acid material may be stored for further analysis, such as microbial identification.

The MIDASS ground model has been developed by KAYSER ITALIA with Biomerieux under an ESA contract.

Key performances demonstrated

The Sample Preparation Module and the Detection Module have already been developed at prototypal stage as two separate instrument modules, with their own PC and software. Those prototypes are used to

validate a new implementation of techniques for extraction, amplification and detection of nucleic acid (NA) based on proprietary technology of BioMerieux.

Demonstration level (please precise testing conditions, duration)	
□ *calibrated mathematical model* □ *Lab scale proof of concept* □ *Pilot scale ground demonstration* *X Payload/ techno. Demonstrator* □ *Space engineering model* □ *Flight model*	
TRL level (refer to definition in annex)	*TRL 4*

Links with other technologies (title and reference)
More recent linked technologies that could be applied to Life Support Systems: FilmArray technology from Biomerieux http://www.biomerieux-diagnostics.com/filmarrayr-multiplex-pcr-system

Keywords
Microbes, biocontamination control, air sampling, molecular biology

Associated publications
N/A

Life Support Technology					
Reference	*Giorgia Pontetti* *G&A Engineering*	*Version*	*1*	*Date*	*27/03/2018*
Title: RobotFarm					
Life Support main function(s) addressed (see definition in annex), please precise specific function					
□ Atmosphere revitalization *□ Water recovery and recycling* *x Food production and preparation* *□ Waste recovery and recycling* *□ ISRU*					
Short description (main characteristics, features, …) *Hydroponic indoor greenhouse appliance.* *A new generation appliance for fresh & clean food directly in your home.* *High-Quality, Good Natural, Healthy Fresh & Live Products* *No daily check, No expertise, just seed and wait until RobotFarm cultivates for you.*					
Key performances demonstrated - *New generation appliance* - *Standard appliance dimensions* - *Fully computerized hydroponic greenhouse* - *Entire automatic growth management, from seed to harvest* - *Custom HMI for interactions with the machine* - *Reduction in water consumption* - *Lowered environmental impact* - *No Pesticides Needed* - *Improved Health & Nutritional Values* - *Indoor, all-the-year* - *From kitchen to table*					
Demonstration level (please precise testing conditions, duration)					
□ calibrated mathematical model *□ Lab scale proof of concept* *□ Pilot scale ground demonstration*					

x Payload/ techno. Demonstrator *□ Space engineering model* *□ Flight model*	
TRL level (refer to definition in annex)	*9 (Earth Market)* *2 (Space Market)*
Links with other technologies (title and reference) *RobotFarm, indoor hydroponic appliance (www.robotfarm.tech)* *CHEF Project, Container Vertical Farm*	
Keywords *Hydroponic, cultivation, indoor growing, food production, new generation appliance*	
Associated publications	

Life Support Technology					
Reference	*Liliana Ravagnolo, ALTEC*	*Version*	*1*	*Date*	*29.03.2018*

Title: Innovative clothes for astronauts

Life Support main function(s) addressed (see definition in annex), please precise specific function

X Atmosphere revitalization *□ Water recovery and recycling* *□ Food production and preparation* *X Waste recovery and recycling* *□ ISRU*	*The project studies innovative clothes for astronauts with antibacterial properties able to provide microbial contamination monitoring and control. In addition, the use of such innovative clothes will reduce the amount of waste on ISS and will be important for Exploration purposes.*

Short description (main characteristics, features, …)

During their on orbit routine operations, Astronauts have a limited amount of clothes that are obliged to use intensively also during fitness and workout activities, resulting in build up of sweat and smell due to bacteria proliferation. ALTEC would like to propose the experimentation of innovative tissues with anti-bacterial properties (silver fibers, carbon fibers, wool, etc…) that could reduce the bacteria proliferation, increase the crew comfort and improve quality of the ISS atmosphere reducing smell and dirt accumulation. This will allow usage of the same clothes for more extended time, therefore resulting in a limited quantity of clothes sent on orbit, stored and then destroyed as waste.

Key performances demonstrated

- *Reduce bacteria proliferation, reducing smell and dirty accumulation*
- *Increase lifetime usability of clothes*
- *Improve crew wellness and ISS atmosphere*
- *Reduce amount of clothes launched to ISS, stored on board and destroyed as waste.*
- *Test technological solutions suitable for Exploration and for terrestrial market (athletes for extreme sports, extreme environmental conditions like Antarctica missions, etc…)*

Demonstration level (please precise testing conditions, duration)

□ calibrated mathematical model *□ Lab scale proof of concept* *□ Pilot scale ground demonstration* *X Payload/ techno. Demonstrator*	*ALTEC wants to propose the use of dedicated sport kits (composed of underwear, t-shirt and shorts) provided in different technological tissues to be tested on board ISS during a long duration mission. The crew feedbacks and the analysis of selected samples retrieved after the mission will be important to assess the overall tissues performances considering both antibacterial properties and comfort.*

□ *Space engineering model* □ *Flight model*	
TRL level (refer to definition in annex)	*TRL 6 to 9*

Links with other technologies (title and reference) *Chemical/microbial/physical contamination monitoring and control.*
Keywords *Innovative tissues* *Anti-bacteria properties* *Exploration* *Athletes* *Waste*
Associated publications

Life Support Technology					
Reference	*Liliana Ravagnolo, ALTEC*	*Version*	*1*	*Date*	*27.03.2018*

Title: 3D Food Printer for space applications

Life Support main function(s) addressed (see definition in annex), please precise specific function

□ Atmosphere revitalization *□ Water recovery and recycling* *X Food production and preparation* *□ Waste recovery and recycling* *□ ISRU*	*Provide innovative methods to produce food in space*

Short description (main characteristics, features, …)

The 3D Food printer "Foodini" has been developed for the terrestrial market by a Spanish company named Natural Machines. ALTEC collaborates with Natural Machines to develop a space model that will allow to the crew to print their own food starting from row-lyophilized ingredients that will be mixed and cooked on board, using recipes developed by ground chefs and dieticians or even the crew families. The space development foresees:

- *the use of by-phasic capsules able to mix the lyophilized food with the water at the last moment before printing*
- *an homogenizing mechanism able to avoid lumps formation*
- *a cooking mechanism based on laser able to cook the food inside the printing machine*
- *analysis or testing able to demonstrate that the machine will print and cook in microgravity without having problems.*

Key performances demonstrated

- *Lyophilized food will increase the food shelf life from the current 18 months up to 5 years as required for the Exploration programs.*
- *Reduction of waste since only row-lyophilized ingredients will be sent on orbit and they can be used for several different recipes.*
- *Crew health will be monitored closely because the machine at the login will record the precise nutrition intake. These data will be made available to flight surgeons.*
- *Increased operational flexibility will improve the Crew wellness by enabling the possibility to select their food day by day and not one year before flight, as per the current baseline process for the International Space Station.*

Demonstration level (please precise testing conditions, duration)

□ calibrated mathematical model *□ Lab scale proof of concept*	*The initial idea was to test the machine on a Parabolic flight to insure the capability of printing in microgravity. Currently this test is no longer planned but ground tests will be performed instead during the qualification for flight (eg. vibration, under vacuum, printing upside down, etc…) to*

□ Pilot scale ground demonstration *□ Payload/ techno. Demonstrator* *X Space engineering model* *□ Flight model*	*demonstrate compatibility with the launch loads and microgravity environment.*
TRL level (refer to definition in annex)	*3D Food Printer machine currently TRL 6 to be brought to TRL 8. By-phasic capsules currently TRL 5 to be brought to TRL 8.*

Links with other technologies (title and reference)

3D Printing technologies, Additive layer manufacturing

Keywords

Food, Print, Capsules, Flexibility, Cooking

Associated publications

<table>
<tr><th colspan="6">Life Support Technology</th></tr>
<tr><td>Reference</td><td>Lorenza MEUCCI, SMAT SpA</td><td>Version</td><td>1</td><td>Date</td><td>April, 09 2018</td></tr>
<tr><td colspan="6">Title: SMAT expertise for ECLLS</td></tr>
<tr><td colspan="6">Life Support main function(s) addressed (see definition in annex), please precise specific function</td></tr>
<tr><td colspan="3">x Atmosphere revitalization
x Water recovery and recycling
x Food production and preparation
□ Waste recovery and recycling
□ ISRU</td><td colspan="3"></td></tr>
<tr><td colspan="6">Short description (main characteristics, features, …)
Atmosphere revitalization: SMAT carried out analyses (for TAS-I) on an exhausted air filter from ISS for microbiological characterization of the particulate on filter surface.
SMAT participated with AERO SEKUR and CNR as contractor in esa project “Biocide Management for Long Term Water Storage” for microbiological characterization and biocide efficacy assessment; SMAT is partner of PERSEO ASI ongoing project “PErsonal Radiation Shielding for interplanetary missiOns”
Water recovery and recycling: SMAT is part of the ongoing H2020 BIOWYSE project (Biocontamination Integrated cOntrol of Wet sYstems for Space Exploration)
Food production and preparation: SMAT produced and analysed for TAS-I the drinking water to supply ISS during ATV1, ATV3, ATV4 and ATV5 missions</td></tr>
<tr><td colspan="6">Key performances demonstrated
Drinking water production and monitoring
Production and monitoring of water for special uses
Terrestrial applications
Dissemination</td></tr>
<tr><td colspan="6">Demonstration level (please precise testing conditions, duration)</td></tr>
<tr><td colspan="3">□ calibrated mathematical model
x Lab scale proof of concept
□ Pilot scale ground demonstration
x Payload/ techno. Demonstrator
□ Space engineering model</td><td colspan="3">Lab scale proof of concept: throughout the entire ongoing BIOWYSE project
Payload/ techno. Demonstrator: PERSEO project, VITA mission (Nespoli, 2017)</td></tr>
</table>

□ *Flight model*	
TRL level (refer to definition in annex)	

Links with other technologies (title and reference)

Keywords

Water for human consumption, monitoring, water for special uses, stability, recovery, safety, bone and teeth mineralization protection, disinfection

Associated publications

C. LOBASCIO, G. BRUNO, L. GRIZZAFFI, L. MEUCCI, M. FUNGI, D.GIACOSA

Quality of ATV potable water for ISS crew consumption

ICES 2004 -01- 2491

34th International Conference on Environmental Systems, 19-22 July 2004, Colorado Springs, Colorado

L. GRIZZAFFI, C. LOBASCIO, P. PARODI, A.SEVERINO, I. LOCANTORE, D. PERRACHON, D.GIACOSA, S. SAMPO'

Post-flight analyses of Columbus HEPA filter

ICES 2011 DOI 102514/6.2011-5265

41st International Conference on Environmental Systems, 17-21 July 2011, Portland, Oregon

Baiocco G., Giraudo M., Bocchini L., Barbieri S., Locantore I., Brussolo E., Giacosa D., Meucci L., Steffenino S., et. al. A water-filled garment to protect astronauts during interplanetary missions tested on board the ISS. Submitted.

Amalfitano S., Levantesi C., Giacosa D., Bersani F., Garrelly L., Perrin E., Mengoni A., Fani R., Rossetti S. Detecting microbes in space waters: current methods for future applications. – Zagreb (Croatia), 03-08/09/2017.

Amalfitano S., Levantesi C., Giacosa D., Bersani F., Garrelly L., Perrin E., Mengoni A., Fani R., Rossetti S. Detecting microbes in space waters: new insights by flow cytometry. XXXV Conferenza Nazionale di Citometria – Paestum (IT), Oct 03-06/10/2017.

Garrelly L., Simons R., Bersani F., Giacosa D. UV and ATPmetry as complimentary technologies for rapid water treatment and quality monitoring. 9th IUVA World Congress – Dubrovnik (Croatia), 17-20/09/2017.

Life Support Technology					
Reference	*Egli, M*	*Version*	*1*	*Date*	*15.06.2018*
Title: Yeast Biofactories – Food in Space					

Life Support main function(s) addressed (see definition in annex), please precise specific function	
□ *Atmosphere revitalization* □ *Water recovery and recycling* x *Food production and preparation* □ *Waste recovery and recycling* □ *ISRU*	

Short description (main characteristics, features, …)

Design and validation of yeast bioreactors for continuous cultivation under microgravity conditions. The idea is to equip space habitats or stationary settlements on planets/moons with autonomously running bioreactors used to produce food supplements, food components etc. on site. The bioreactors will be designed in a way so that various organisms like yeast, fungi, algae etc. can be cultivated depending on the needs of the space travelers or the inhabitants of the settlements. The main characteristic of our proposed bioreactors are is the independence of human interactions. Therefore, our bioreactors need to run with an intelligent software that has full control over most of the processes running in the reactors. A post-processing unit of the biomass produced in the bioreactors is envisaged and will be realized in a second step.

Key performances demonstrated

The HSLU space biology group has demonstrate the capability of a controlled cultivation of yeast cells. There were even yeast-bioreactors in space, however, just as a small-scale model. We are currently working on a yeast bioreactor H/W together with RUAG Space that should be operated on the International Space Station ISS around 2020.

Demonstration level (please precise testing conditions, duration)	
□ *calibrated mathematical model* X *Lab scale proof of concept* □ *Pilot scale ground demonstration* □ *Payload/ techno. Demonstrator* □ *Space engineering model* X *Flight model*	*Yeast bioreactor were already operated in space.*

TRL level (refer to definition in annex)	*TRL 2-3 (for the food bioreactor)*

Links with other technologies (title and reference)

Keywords

Bioreactors, yeast, food supplements, continuous cultivation

Associated publications

- *Walther I, Cogoli M, Egli M (2013) Microgravity Cell Culture Systems and Bioreactors: Current Status and Future Developments. Current Biotechnology 2: 244-249.*
- *Walther I, Cogoli A (2003) Basic Research, Biotechnology, Tissue Engineering, and Instrument Development. Chimia 57:321–324.*
- *Walther I, Van der Schoot B, Boillat M, Cogoli A (2001) Bioreactors for Space: Biotechnology of the Next Century. Engineering and Manufacturing for Biotechnology 241-251.*

<table>
<tr><td colspan="6">Life Support Technology</td></tr>
<tr><td>Reference</td><td>Granata,T.C.</td><td>Version</td><td>1</td><td>Date</td><td>15.06.2018</td></tr>
<tr><td colspan="6">Title:Algae Biofactories</td></tr>
<tr><td colspan="6">Life Support main function(s) addressed (see definition in annex), please precise specific function</td></tr>
<tr><td colspan="3">□ Atmosphere revitalization
x Water recovery and recycling
□ Food production and preparation
x Waste recovery and recycling
x ISRU</td><td colspan="3"></td></tr>
<tr><td colspan="6">Short description (main characteristics, features, …)

Design and validation of algal photobioreactors to grow specific species of microalgae that produce different biomolecules. The idea is to match irradiance spectra and intensities to each species specific photosystem requirements and to optimize turbulent mixing so cell "see" a high, time averaged light field that promotes high growth and biomass rich in either pigments, proteins, lipids and/or carbohydrates. Lipids can be purified for biofuel (i.e. oil), proteins for food and enzymes, carbohydrates for a variety bioproducts (e.e. bioplastics), and pigments for health and medical applications. Algae can recycles waste water removing carbon dioxide and nitrogen, phosphorous and sulfur sources while producing oxygen and biomolecules.</td></tr>
<tr><td colspan="6">Key performances demonstrated

The HSLU space biology group has demonstrate the effects of different irradiance spectra and intensities on two microalgal species. And has run simulated microgravity experiments on one of the species, using our ground based random positioning machine (RPM) to compare simulated microgravity to 1 g.

We are also working with CSEM to develop a prototype bioreactor module for a nanosatellite using the same species that was tested on the RPM. This bread-board of the nanosatellite module with 8 different experiments to determine parameters such as growth rate, biomass and concentrations of pigment, lipids, proteins, carhobydrates, DNA. Parameters will test the effects of cosmic radiation and microgravity compared to controls and 1 g, ground station data. The final nanosatellite will be able to download data and upload commands making remote experiments possible. This would be the first ever algal nanosatellite.</td></tr>
<tr><td colspan="6">Demonstration level (please precise testing conditions, duration)</td></tr>
<tr><td colspan="3">□ calibrated mathematical model
x Lab scale proof of concept
x Pilot scale ground demonstration
□ Payload/ techno. Demonstrator
□ Space engineering model
□ Flight model</td><td colspan="3">Ground testing completed for microalgae irradiance. Construction and testing of bread-board satellite module by December 2018. PRODEX proposal for nanosatellite is completed but will not submitted until funding is available.</td></tr>
</table>

TRL level (refer to definition in annex) *TRL3-4*	
Links with other technologies (title and reference) IGLUNA-ESA_Lab@ (Life Support Project)	
Keywords Microalgae, irradiance, biomaterials, nanosatellitles, bioreactors	
Associated publications	

Granata, T. 2017. The dependency of algal biofuel production on biomass and the relationship to yield and bioreactor scale-up for biofuels. BioEnergy Res., 10(1): 267-287. doi:10.1007/s12155-016-9787-2 http://link.springer.com/article/10.1007/s12155-016-9787-2

Granata, T. and M. Egli. 2016. Biological Nutrients: In: Sustainable Materials Concept. 2016 ESA Report (AO/1-7707/13/NL/R), T324-001QT.

Granata, T. P. Habermacher, V. Härri, M. Egli, The influence of bio-optical properties of Emiliania huxleyi and Tetraselmis sp. on lipid production for light spectra and intensities of an adjustable LED array and standard light sources. Submitted. Bioresources and Bioprocessing. www.springeropen.com/journals.

Life Support Technology					
Reference	*Scorpius Prototype (SP1)*	*Version*	*1.0*	*Date*	*14.06.2018*

Title: Scorpius Prototype - Towards a proof-of-concept of a closed habitat on-ground demonstration integrating main BLSS functions

Life Support main function(s) addressed (see definition in annex), please precise specific function

x Atmosphere revitalization

x Water recovery and recycling

x Food production and preparation

x Waste recovery and recycling

□ ISRU

Short description (main characteristics, features, …)

The Scorpius Prototype (SP1) is an autonomous terrestrial solution integrating existing and emerging BLSS - related technologies. This prototype of a (semi-)closed system has been fully designed in 2017-2018 and its building is about to be started. This proof-of-concept is aimed to become a first step

towards the on-ground development of a BLSS simulator, in order to enhance the preparation on Earth of manned space missions.

Main high-level specs:

- *2 crew members*
- *Designed for long-duration missions (up to 1 year of autonomy)*
- *Loop closure as high as possible*
- *Limited budget (time and money), all covered by company own funds*
- *Planetary base orientation/inspiration*

Technical support is being provided by an ongoing collaboration with MELiSSA-ESTEC, among other industrial and academic partnership.

Key performances demonstrated

- *Atmosphere revitalisation: CO_2 removal, O_2 generation, chemical/microbial/physical contamination monitoring and control, environmental control.*
- *Water recovery and recycling: collection, processing and quality control (microbial, chemical); incl. membrane filtration and other physico-chemical processes.*
- *Food production and preparation: food production, transformation and storage, quality control.*
- *Waste recovery and recycling: collection, storage and processing of organic wastes generated during the R&D campaign; combination of physical, chemical and biological processes.*

Demonstration level (please precise testing conditions, duration)

x calibrated mathematical model

x Lab scale proof of concept

x Pilot scale ground demonstration *□ Payload/ techno. Demonstrator* *□ Space engineering model* *□ Flight model*	
TRL level (refer to definition in annex)	*TRL 2-5 (6)* *(depending on the technological module/system component)*

Links with other technologies (title and reference)

- *Oïkosmos, the convergence of terrestrial and space research agendas in the perspective of industrial ecology*

Keywords

Ground demonstration, terrestrial to Space technology transfer (spin-in), BLSS modules interfacing and integration, automation and control command, short to long term manned R&D campaign, user experience monitoring, closed habitat specification definition.

Associated publications

- *PhD Thesis by Théodore Besson, under the supervision of Prof. Suren Erkman, Head, Industrial Ecology Group, Faculty of Geosciences and Environment, University of Lausanne.*
- *Publications in preparation (not public yet).*

Life Support Technology					
Reference	*RUAG Nyon*	*Version*	*1.0*	*Date*	*13.06.18*
Title:					
Life Support main function(s) addressed (see definition in annex), please precise specific function					
x Atmosphere revitalization *□ Water recovery and recycling* *x Food production and preparation* *□ Waste recovery and recycling* *□ ISRU*					
Short description (main characteristics, features, …) *Continuous regeneration of CO_2 into O_2 using a photosynthetic process (algae photo-bioreactor), including predictive control of O_2 and generation of edible biomass. [BIORAT 1]* *RUAG has longstanding experience in space bioreactor design and development. Bioreactors a technological building blocks for all the life support processes within the MELiSSA loop.*					
Key performances demonstrated - *Continuous bioreactor operation (BBM level tests)* - *Confirmation of mathematical/engineering process model with experimental results (BBM level tests)* - *Intermediary scale-up*					
Demonstration level (please precise testing conditions, duration)					
x calibrated mathematical model *x Lab scale proof of concept* *x Pilot scale ground demonstration* *x Payload/ techno. Demonstrator* *□ Space engineering model*					

□ Flight model	
TRL level (refer to definition in annex)	*4*

Links with other technologies (title and reference)

Keywords

Bioreactor, Photo-bioreactor, Photosynthesis, Continuous Process, Predictive Control

Associated publications

Work presented at MELiSSA WS Lausanne 2016 and Rome 2018.

Life Support Technology					
Reference	*Oberson/Frossard*	*Version*	*1.0*	*Date*	*13.6.2018*

Title: Study of plants culture on substrate of Urine origin: Roots zone focus

Life Support main function(s) addressed (see definition in annex), please precise specific function

□ *Atmosphere revitalization* □ *Water recovery and recycling* *x Food production and preparation* □ *Waste recovery and recycling* □ *ISRU*	

Short description (main characteristics, features, …)

The objective of the project is the development of food crop production in a hydroponic system, either as crop sequence or multicropping system, based on mineral nutrient supply from nitrified urine and other wastes produced in the MELiSSA loop. Nutrient solutions will be stabilized using microbial consortia, which at the same time will support the nutrient availability and supply to the crops. Food crops to be tested include cereal, soybean, and presumably halophilic edible plants, which at the same time will alleviate the risk of salinization. The plant response in term of shoot and root growth, yield and nutritional quality of edible parts, and nutrient use efficiency will be investigated.

Key performances demonstrated

Production of food crops based on nutrients recycled in the MELiSSA loop

Demonstration level (please precise testing conditions, duration)

□ *calibrated mathematical model* *x Lab scale proof of concept* □ *Pilot scale ground demonstration* □ *Payload/ techno. Demonstrator*	

□ *Space engineering model* □ *Flight model*	
TRL level (refer to definition in annex)	

Links with other technologies (title and reference)

Urine Treatment in the MELiSSA loop: PhD project of Valentin Faust, with Prof. Dr. K. Udert (Eawag). The microbial consortia will be developed in collaboration with the University of Ghent.

Keywords

Crop – food – microbial consortia – hydroponics - urine – organic waste - phosphorus – nitrogen – plant response – root growth

Associated publications

Bonvin C, Etter B, Udert KM, Frossard E, Nanzer S, Tamburini F, Oberson A (2015) Plant uptake of phosphorus and nitrogen recycled from synthetic source-separated urine. Ambio 44: S217-S227.

Brod E, Øgaard AF, Krogstad T, Haraldsen TK, Frossard E, Oberson A (2016) Drivers of phosphorus uptake by barley following secondary resource application. Frontiers in Nutrition 3.

Clauwaert P, Muys M, Alloul A, De Paepe J, Luther A, Sun X, Ilgrande C, Christiaens MER, Hu X, Zhang D, Lindeboom REF, Sas B, Rabaey K, Boon N, Ronsse F, Geelen D, Vlaeminck SE (2017) Nitrogen cycling in Bioregenerative Life Support Systems: Challenges for waste refinery and food production processes. Progress in Aerospace Sciences 91: 87-98.

Douxchamps S, Frossard E, Bernasconi SM, van der Hoek R, Schmidt A, Rao IM, Oberson A (2011) Nitrogen recoveries from organic amendments in crop and soil assessed by isotope techniques under tropical field conditions. Plant Soil 341: 179-192.

Lemming C, Oberson A, Hund A, Jensen LS, Magid J (2016) Opportunity costs for maize associated with localised application of sewage sludge derived fertilisers, as indicated by early root and phosphorus uptake responses. Plant Soil 406: 201-217.

Meyer G, Bünemann EK, Frossard E, Maurhofer M, Mäder P, Oberson A (2017) Gross phosphorus fluxes in a calcareous soil inoculated with Pseudomonas protegens CHA0 revealed by 33P isotopic dilution. Soil Biol Biochem 104: 81-94.

Nanzer S, Oberson A, Berger L, Berset E, Hermann L, Frossard E (2014a) The plant availability of phosphorus from thermo-chemically treated sewage sludge ashes as studied by 33P labeling techniques. Plant Soil 377: 439–456.

Nanzer S, Oberson A, Huthwelker T, Eggenberger U, Frossard E (2014b) The molecular environment of phosphorus in sewage sludge ash: Implications for bioavailability. J Environ Qual 43: 1050-1060.

Oberson A, Tagmann HU, Langmeier M, Dubois D, Mader P, Frossard E (2010) Fresh and residual phosphorus uptake by ryegrass from soils with different fertilization histories. Plant Soil 334: 391-407.

Sheridan C, Depuydt P, De Ro M, Petit C, Van Gysegem E, Delaere P, Dixon M, Stasiak M, Aciksöz SB, Frossard E, Paradiso R, De Pascale S, Ventorino V, De Meyer T, Sas B, Geelen D (2017) Microbial

Community Dynamics and Response to Plant Growth-Promoting Microorganisms in the Rhizosphere of Four Common Food Crops Cultivated in Hydroponics. Microbial Ecology 73: 378-393.

Life Support Technology					
Reference	*54 - Erkman*	*Version*	*1*	*Date*	*18/06/2018*

Title: Oïkosmos, the convergence of terrestrial and space research agendas in the perspective of industrial ecology

Life Support main function(s) addressed (see definition in annex), please precise specific function	
□ Atmosphere revitalization *□ Water recovery and recycling* *□ Food production and preparation* *□X Waste recovery and recycling* *□ ISRU*	*NA (not applicable)*

Short description (main characteristics, features, …)

The project «Oïkosmos» at UNIL aims at developing a research agenda at the convergence of space and terrestrial research activities, in the perspective of sustainable evolution of the industrial system (within the conceptual framework of industrial ecology)

Key performances demonstrated

1) *Report to the Rectorate of University of Lausanne on the Project Oïkosmos*
2) *PhD Thesis by Théodore Besson, under the supervision of Prof. Suren Erkman, Head, Industrial Ecology Group, Faculty of Geosciences and Environment, University of Lausanne.*
3) *Spin off: creation of a company, ESTEE, with Th. Besson as executive manager, developing technologies related to life support systems.*

Demonstration level (please precise testing conditions, duration)	
□ calibrated mathematical model *□ Lab scale proof of concept* *□ Pilot scale ground demonstration*	*NA*

□ *Payload/ techno. Demonstrator* □ *Space engineering model* □ *Flight model*	
TRL level (refer to definition in annex)	*NA*

Links with other technologies (title and reference) NA

Keywords

Science & Technology policy ; sustainability research agenda ; industrial ecology ; quasi-cyclical economy (circular economy)

Associated publications

Report of the Oïkosomos project (in French), by Théodore Besson and Suren Erkman, available upon request.

Life Support Technology					
Reference		Version	A	Date	12.07.2018

***Title**: Versatile Energy, Water, Hydrogen and Oxygen Storage and production System based on a reversible Photo-Electrochemical device*

Life Support main function(s) addressed (see definition in annex), please precise specific function

X Atmosphere revitalization X Water recovery and recycling □ Food production and preparation □ Waste recovery and recycling X ISRU	Production of O_2 from water and storage Production of water in dark operations and storage in-Situ H_2 & O_2 production

Short description (main characteristics, features, …)

The System is based on an Integrated and reversible Photo-ElectroChemical device (IPEC) which is currently under development for terrestrial application (TRL 5/6).
This system uses concentrated solar energy for the generation of H_2, O_2, electricity and heat from water in forward operation mode (in-sun operations) and allows the production of water, electricity and heat in its backward operation mode (in-dark operations).
The Hydrogen and Oxygen generation is at high pressures (between 30 to 150 bar) facilitating **its processing for storage**

Thanks to its **reversibility,** this system can be used for the continuous generation of heat and electricity in a closed loop configuration i.e day/night operation modes are continuously alternated with the same water content alternately **stored as water and/or H_2 and O_2.**
In an open loop operation mode, this system can produce fuel (H_2 & O_2) or breathable Oxygen from water supply. This mode is particularly adapted to In-Situ Resource Utilization (Moon/Mars) for habitation.

Key performances demonstrated

The fully integrated IPEC system is compact, lightweight and highly efficient. It nevertheless requires highly concentrated solar radiations through the use of solar reflectors. These later can be designed as lightweight reflecting deployable structures

Detailed multiphysics non-isothermal 2 dimensional model
Highest photo electrochemical current density (0.9A/cmEC 2, 6A/cmPV2)
Solar to hydrogen efficiency =~17,2% (@ 474 Suns)

Demonstration level (please precise testing conditions, duration)

□ calibrated mathematical model □ Lab scale proof of concept X Pilot scale ground demonstration □ Payload/ techno. Demonstrator □ Space engineering model □ Flight model	This versatile and innovative system is currently under development for terrestrial application (TRL 5/6), full scale demonstrator will be in operation in Q3 2018.
TRL level (refer to definition in annex)	TRL 2

Links with other technologies (title and reference)

None

Keywords

Reversibility Storage Oxygen - water
Generation of H_2, O_2, electricity and heat from water
In-Situ Resource Utilization (Moon/Mars) Habitation

Associated publications

Dumortier, Tembhurne et al. EES 2016
Tembhurne et al., JES 2016

Conference presentation:
IHTC August 2014, Kyoto
ECS October 2014, Cancun
ECS May 2016. San Diego
ECS may 2017, New Orleans

Life Support Technology					
Reference	*56 - Aquisense*	*Version*	*1.0*	*Date*	*21/03/2018*

Title: UV Decontamination Module (photoreactor)

Life Support main function(s) addressed (see definition in annex), please precise specific function

X Atmosphere revitalization *X Water recovery and recycling* *X Food production and preparation* *X Waste recovery and recycling* *□ ISRU*	*The main function of the technology is the disinfection of fluids, e.g. final stage security measure for potable water. Further, the technology may be used for upstream microbial control (waste recovery), within non-consumable water rejuvenation systems (e.g. food production), in air handling systems (atmosphere revitalization), or as a microbial control measure in closed-loop wet systems. UV may also be used in chemical dissociation/degradation in photochemical processing systems.*

Short description (main characteristics, features, …)

The UV Decontamination Module applies deep-UV LEDs (250 – 300 nm peak wavelength) to a flow cell irradiation chamber, through which a fluid may be passed and so irradiated by the UV radiation. The action of UV radiation on organic molecules (e.g. genetic material, proteins) is dissociation and damage, primarily resulting in the inactivation of microbial species so irradiated. UV disinfection is distinct from chemical or physical processes, since the microbes remain after treatment, though damaged to the point of inhibiting reproduction/infectivity.

Typical system mass of 0.1 – 10 kg and required input power of 5 – 50 W (12 – 28 V DC).

Key performances demonstrated

Instantaneous disinfection of fluids, requiring no consumable materials whilst introducing no known restricted by-products. Flow rates between 0.1 and 100 lpm.

Low-maintenance, low power, digitally controlled systems capable of maintaining low microbial contamination levels.

Demonstration level (please precise testing conditions, duration)

□ calibrated mathematical model *□ Lab scale proof of concept* *X Pilot scale ground demonstration* *X Payload/ techno. Demonstrator* *□ Space engineering model* *□ Flight model*	*Terrestrial units in volume production, critical function independently verified.* *Ground demonstration breadboard validation in progress (Apr. 2018); vibration testing and suitability for payload integration planned for mid-2018 – BIOWYSE project*
TRL level (refer to definition in annex)	*5/6*

Links with other technologies (title and reference)

ACLS (UV-C unit demonstrating disinfection of a process water loop)

BIOWYSE (ground demonstration of a water management system, using UV disinfection)

Microgravity Science Glovebox (application of deep-UV LEDs for disinfection on-orbit)

EDEN-ISS (UV disinfection of condensate water for higher plant cultivation)

Keywords

Disinfection

UV-C LEDs

Consumables-free

Decontamination

Wet systems

Associated publications

(Upcoming presentation and manuscript at ICES 2018)

Life Support Technology					
Reference	*UniSieve*	*Version*	*V1*	*Date*	*12.10.2018*

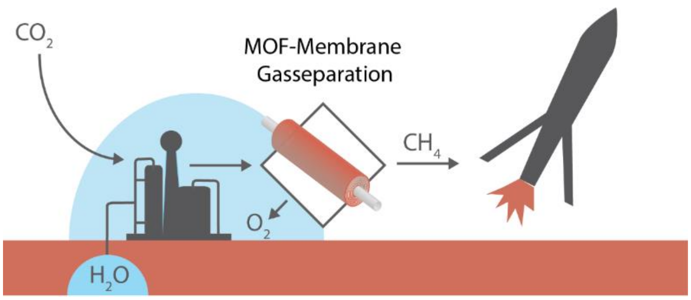
Title: Efficient and light-weight gas separation based on Molecular sieving membranes for space related applications

Life Support main function(s) addressed (see definition in annex), please precise specific function

X Atmosphere revitalization *□ Water recovery and recycling* *□ Food production and preparation* *□ Waste recovery and recycling* *X ISRU*	***Atmosphere revitalization**:* *1. Sabatier output upgrading (separation: H_2O from CH_4)* *2. Methane recovery unit output hydrogen stream purification (separation: H_2 from CH_4).* *3. Further applications to be determined* ***ISRU**:* *1. Sabatier output upgrading (separation: H_2O from CH_4)*

Short description (main characteristics, features, …)

- *Separation via molecular sieving membrane technology based on metal organic frameworks (MOFs)*
- *Molecular sieving membranes separate molecules (gases, liquids) according to size (kinetic diameter)*
- *UniSieve membrane technology is an energy-efficient, modular and light-weight solution for gas separation problems*
- *Low pressure applications possible (i.e. 1-2 barg)*
- *Wide range of different gas pairs can be separated, for example: CH_4/CO_2, C_3H_6/C_3H_8, H_2/CH_4, H_2/CO_2, Xe/Air*
- *Membrane can be integrated as industrial standard membrane modules, which can be exchanged easily*



Key performances demonstrated

UniSieve has produced and tested several m² of selective membrane sheets.

Membrane performance is defined by selectivity (α) and by the permeance (flow):

- *For the separation of CH_4/CO_2 an α of >10 has been measured*
- *For the separation of H_2/CO_2 an α of >8 has been measured*
- *For the separation of H_2/CH_4 an α of >15 has been measured*
- *Scale-up capability proven*

Demonstration level (please precise testing conditions, duration)

□ calibrated mathematical model	
X Lab scale proof of concept	*Room temperature (25°C controlled)*
□ Pilot scale ground demonstration	*Pressure range: 1-4 bars pressure difference*
□ Payload/ techno. Demonstrator	*Single gas and mixed gas permeance measured*
□ Space engineering model	*Time: 12 h*
□ Flight model	
TRL level (refer to definition in annex)	*TRL 4*

Links with other technologies (title and reference)

UniSieve and ESA:
https://www.esa.int/Our_Activities/Space_Engineering_Technology/TTP2/UniSieve_Revolutionizing_the_separation_market_by_drastically_lowering_the_process_energy_consumption_and_CO2_emissions_at_SLUSH_2018

Methane recovery unit:
www.esa.int/Our_Activities/Space_Engineering_Technology/Shaping_the_Future/Development_of_a_Methane_Recovery_Unit/(print)

ISRU on Mars: Propellant production
https://www.politesi.polimi.it/bitstream/10589/134061/1/TESI%20Daniele%20Scaramella.pdf

Keywords

Membrane, separation, gas, molecular sieving, methane recovery unit, MELiSSA, Sabatier,

Associated publications

[1] Hess, S. C., Grass, R. N. & Stark, W. J. MOF Channels within Porous Polymer Film: Flexible, Self-Supporting ZIF-8 Poly(ether sulfone) Composite Membrane. Chem. Mater. ***28****, 7638–7644 (2016).*

Annex E - Life Support definition and TRL definition

Life Support definition

Definition: Life Support Systems encompass all technologies and processes which enable human presence and activity in space environment.

Consequently, Life Support Systems cover the following main functions:

1. Atmosphere revitalisation (e.g. CO_2 removal, O_2 generation, chemical/microbial/physical contamination monitoring and control, environmental control (temperature/pressure/humidity)
2. Water recovery and recycling (e.g. collection, processing and quality control (microbial, chemical))
3. Food production and preparation: (e.g. Food production, transformation and storage, quality control)
4. Waste recovery and recycling (e.g. collection, storage and processing of organic wastes generated during the mission)
5. ISRU (e.g. extraction and processing of local resources for ECLSS)

A defined metric based on key parameters (i.e. mass, energy, volume, efficiency, crew time and safety) is used to compare and select the ECLSS architecture which meets mission requirements.

Interfaces to other systems dealing with crew health and counter measures (e.g. medical equipment, physical fitness equipment, Human Factors Engineering) can be addressed but not the details of these other systems.

TRL definition (see ECSS-E-HB-11A, 01/03/2017, for complete description)