- Position Paper -

Consolidating the Swiss activities and rationale for ALSS and MELiSSA development

Lausanne, August, 2019

Impressum

Authors: Théodore Besson[1, 2] & Prof. Suren Erkman[1].

1. Industrial Ecology Group, Institute of Earth Surface Dynamics, Faculty of Geosciences and Environment, University of Lausanne
2. Earth Space Technical Ecosystem Enterprises SA (ESTEE), Lausanne

This work has been supported by UNIL, EPFL and ESTEE.

How to quote this document: T. Besson, S. Erkman, “Position Paper - Consolidating the Swiss activities and rationale for ALSS and MELiSSA development”, UNIL, EPFL, ESTEE, Lausanne, August 2019.

This document has been endorsed by the following organisations (see signatures on p. 17):

- Université de Lausanne - UNIL
- École Polytechnique Fédérale de Lausanne - EPFL
- Earth Space Technical Ecosystem Enterprises SA - ESTEE
- RUAG Space Nyon
- Centre Suisse d’Electronique et de Microtechnique SA - CSEM
- EPFL+ECAL lab
- Swiss Federal Institute of Aquatic Science and Technology - Eawag
- HEI (HES-SO//Valais-Wallis)
- Hochschule Luzern - HSLU
- Haute école d'ingénerie et d'architecture Fribourg – HEIA-Fr
- Zurich University of Applied Sciences - ZHAW
- Plant Nutrition Group, ETH Zurich
- Catalytic Process Engineering group, Paul Scherrer Institute
- Oracan Sàrl
- UniSieve Ag
- Space Exploration Institute
- Mars Society Switzerland
- Vuna GmbH
- Innobridge SA
- Sofies International SA
- Leoni Corporate Advisors
- Innovaud
- CleantechAlps

Executive summary

With this Position Paper, the Swiss stakeholders active in the field of Advanced Life Support Systems (ALSS), including those directly involved in the R&D and technology transfer of related space and Earth-based solutions, would like to express their strong interest in the ongoing Micro-Ecological Life Support System Alternative (MELiSSA) project of the European Space Agency (ESA).

In the context of the preparation of the forthcoming ESA Ministerial Council Space19+, the overall objectives of this Swiss Position Paper are: (a) To develop an ALSS roadmap, encompassing the three main pillars of the Swiss Space Policy and (b) To demonstrate that the development of the field of ALSS would benefit from a consolidated and concerted effort from the Swiss stakeholders, especially within the framework of ESA's MELiSSA project.

The Swiss MELiSSA and ALSS stakeholders encompass a broad range of public and private organisations and can be considered as a cluster offering a wide spectrum of complementary scientific and technological skills and know-how. With almost thirty organisations involved and more than seventy people active in ALSS activities at the national level, it appears that the emerging and dynamic community in the field of ALSS has reached a critical size and momentum in Switzerland – and in Europe as well.

According to the conclusions of a survey on Swiss activities, interests and strengths in ALSS, the Swiss ALSS community has recently gained a clear perception of the assets and uniqueness of MELiSSA and is now demonstrating a precise understanding on the future kinds of and topics for collaboration. The active participation of the community can be demonstrated by more than 30 R&D and technology transfer projects, covering most of the dimensions and topics of investigations on ALSS. Moreover, a growing number of Swiss public organisations and private companies have expressed their willingness to be engaged further and the potential of increasing scientific and technical collaborations is significant.

As stated by most of the key Swiss players in the field of ALSS, a resolute and continued financial support for MELiSSA activities should remain within ESA. Concretely, and as evidenced in the past notably for flight experiments, the best way would be to continue financing the MELiSSA activities via the ESA Exploration programmes – currently European Exploration Envelope Programme (E3P)[1] – for the next periods (Period 2 and beyond) which should aim at:

- Maintaining a steady flow of collaborative partnerships, including non-space academic institutions and industry to engage in space activities and with ESA (spin-ins and spin-outs);
- Securing the continuity of MELiSSA technology developments in Life Support for space exploration, sustained by a robust roadmap and associated projects in the E3P programme;
- Positioning the Swiss space ecosystem at the cutting edge of the ALSS developments by delivering In Orbit Demonstrator (IOD) of building blocks (such as photobioreactors) paving the way for a credible approach towards a human settlement on the Moon, on Mars or in other space stations developed in the Solar system;
- Enabling a faster and bigger access to international manned space exploration activities.

[1] More information on E3P and Human Spaceflight and Robotic Exploration Programmes on ESA website (as per 08.08.2019): https://www.esa.int/About_Us/Ministerial_Council_2016/Human_Spaceflight_and_Robotic_Exploration_Programmes

The Swiss space and terrestrial ALSS communities are also looking towards a political support with a long-term vision and planning, with adequate funding, aiming at:

- Investigating topics relevant both for human space exploration and for their associated Earth-based applications;
- Attracting and increasing engagement of the Swiss non-space ALSS organisations (including industries) in space exploration;
- Fostering synergies between Swiss players and the MELiSSA community in order to combine their complementary skills in a concerted effort within a stable project framework;
- Further considering developing a dedicated testbed in Switzerland to experiment ALSS concept in a short to mid-term perspective, as expressed by most of the Position Paper's survey respondents;
- Leveraging on Swiss expertise in R&D, technology cooperation and transfer opportunities to better exploit ALSS knowledge and know-how for space exploration and contribute to the development of terrestrial applications beneficial to society (spin-out activities);
- Supporting the organisation of a (bi-)yearly targeted workshop that would respond to the demand of Swiss parties for increased interactions between MELiSSA activities and Swiss ALSS stakeholders. Such workshop would enable MELiSSA community to provide an overall activity report – not specific to Switzerland. Conversely, a summary of new Swiss ALSS development would be shared. This would build an essential communication channel to circulate information from the complementary activities distributed within the overall community.

In conclusion, this Position Paper shows evidence that the current timing appears highly adequate for:

- Consolidating the Swiss activities and rationale for ALSS into an active and productive cluster during the next E3P period;
- Positioning Switzerland as a key player in space and terrestrial ALSS and with a strong potential for increasing the developments and collaborations within the MELiSSA project;
- Allowing an increased international visibility for Switzerland in the field of manned space exploration, as well as for a reliable and efficient circular economy.

Therefore, for the next E3P periods, the authors, along with the organisations endorsing this Position Paper (see Impressum on p. 2 and signatures on p. 17), recommend that ALSS and MELiSSA R&D and technology transfer activities in Switzerland should continue to benefit from a stable and long-term programmatic framework with corresponding funding.

Table of content

Impressum **2**

Executive summary **3**

Table of content **5**

Abbreviations **6**

1 Position Paper - Consolidating the Swiss activities and rationale for ALSS and MELiSSA development **7**

1.1 The context of the Position Paper 7

1.2 Mapping of ALSS and MELiSSA-related activities implemented in Switzerland 9

1.3 Introducing the MELiSSA project and its connection with Swiss organizations 11

1.4 Consolidating the Swiss activities and rationale for ALSS and MELiSSA development 13

1.4.1 Major findings 13

1.4.2 Key recommendations 15

2 Annexes **18**

2.1 Annex 1 – Swiss Space and terrestrial ALSS and MELiSSA-related activities 18

2.1.1 Basic Research and Development 18

2.1.2 Flight experiments 22

2.1.3 Ground demonstration 25

2.1.4 Terrestrial applications 29

2.1.5 Education and communication 32

2.2 Annex 2 – A brief Introduction to space ALSS and their relevance for terrestrial sustainability 34

2.3 Annex 3 – SWOT analysis of the MELiSSA roadmap 37

2.3.1 Strengths 37

2.3.2 Weaknesses 38

2.3.3 Opportunities 38

2.3.4 Threats 39

2.4 Annex 4 – Survey on Swiss activities, interests and strengths in ALSS 40

2.4.1 Survey objectives 40

2.4.2 Content of the survey 41

2.4.3 Summary of survey results analysis 42

2.4.4 Full survey results analysis 49

2.5 Annex 5 – Facsimile of the Position Paper released in Spring 2019 by the MELiSSA industrial actors… 92

Abbreviations

ALiSSE: Advanced Life Support System Evaluator
ALSS: Advanced Life Support System
ARTES 5: Advanced Research in Telecommunications Systems programme 5
BLSS: Bioregenerative Life Support System
CICR: Comité international de la Croix-Rouge
CSEM: Centre Suisse d'Electronique et de Microtechnique
E3P: European Exploration Envelope Programme
EHEDG: European Hygienic Engineering and Design Group
EnRUM : Energy Resources utilization Mapping
EPFL: École Polytechnique Fédérale de Lausanne
ESTEE: Earth Space Technical Ecosystem Enterprises
ESA: European Space Agency
EXPERT: Exploration Preparation, Research and Technology
FPCU: Food Processing Characterization Unit
GSP: General Studies Programme
GSTP: General Support Technology Programme
HEI: Haute École d'Ingénierie de la HES-SO//Valais-Wallis
HEIA-Fr: Haute École d'Ingénierie et d'Architecture de Fribourg
HSLU: Hochschule Luzern
ISRU: In-Situ Resource Utilisation
LSS: Life Support System
MELiSSA: Micro-Ecological Life Support System Alternative
MPP: MELiSSA Pilot Plant
POMP: Pool of MELiSSA PhD
PRODEX: Programme de Développement d'Expériences Scientifiques
PPP: Public-Private Partnership
PSI: Paul Scherrer Institute
SciSpace: Science in Space Environment
SSO: Swiss Space Office
STEM disciplines: Science, technology, engineering, and mathematics disciplines
TRL: Technology Readiness Level
TRP : Basic Technology Research Programme
UNHCR: United Nations High Commissioner for Refugees
UNIL: Université de Lausanne
ZHAW: Zürcher Hochschule für Angewandte Wissenschaften

1 Position Paper - Consolidating the Swiss activities and rationale for ALSS and MELiSSA development

1.1 The context of the Position Paper

In June 2018, the Swiss Space Office organized a Workshop in Bern on ALSS and MELiSSA, whose objectives were to:

- Inform the Swiss community about current and future ESA programmes in space exploration;
- Provide a Status Report on the MELiSSA project of ESA;
- Create awareness of the ongoing activities in the scientific and industrial community in Switzerland;
- Discuss the state of the art in Life Support Systems;
- Elaborate scientific aspects of ALSS including circular economy;
- Reflect on potential terrestrial applications.

As a follow-up action, the University of Lausanne, with the support of Earth Space Technical Ecosystem Enterprises SA (ESTEE), and the participation of the Swiss Space Center, ETH Zurich and Eawag, has performed a survey on the national activities, interests and strengths in ALSS.

The outcome of this survey was one of the inputs to the elaboration by University of Lausanne with the support of ESTEE of a Swiss Position paper to be submitted to the Swiss Space Office.

In the context of the preparation of the forthcoming ESA Ministerial Council Space19+ (to be held in November 2019), the overall objectives of this Swiss Position Paper are:

(a) To develop an ALSS roadmap, encompassing the three main pillars of the Swiss Space Policy, which are: (1) the development and utilisation of space infrastructures to improve the quality of life of the citizens of Switzerland; (2) the sustainable engagement in exploration for the benefit of innovation and the knowledge of the society; (3) and the positioning of Switzerland as a completive and reliable partner;

(b) To demonstrate that the development of the field of ALSS would benefit from a consolidated and concerted effort from the Swiss stakeholders, especially within the framework of ESA's MELiSSA project, by:

- Showing the existence of an emergent but strong ALSS community in Switzerland;
- Demonstrating the Swiss interest in international co-operations (BEL, ITA, SPA, GER, FRA, etc.) in the ALSS field;
- Highlighting the space priority, as well as the spin-in and spin-off of non-space applications of ALSS research;
- Showing the challenges and opportunities of sustainability in the perspective of synergies between space and terrestrial R&D;
- Widening the base of the existing diverse community (academia and industry) by bringing in new actors traditionally not yet involved in the ALSS research;
- Preparing the ground for a stakeholder engagement strategy in the field of ALSS as an input for establishing a long-term view of Life Support technologies to be developed in Europe;
- Stressing the current adequate timing to position Switzerland as a key player in ALSS field.

In the following sections, this Position Paper makes the distinction between:

- "MELiSSA stakeholders", that include two distinct categories:
    - a) the MELiSSA official partners, who have signed the MELiSSA Consortium under Memorandum of Understanding for the 2015-2019 period (14 members in 2019, including UNIL and ESA)
    - b) the MELiSSA co-operating partners or MELiSSA community members, such as RUAG Space, ETHZ, Eawag, Earth Space Technical Ecosystem Enterprises SA, CSEM and HEI (HES-SO//Valais-Wallis) to mention just a few (some 40 members from 13 countries);
    - MELiSSA stakeholders of both categories have been under agreement with MELiSSA project for one or several activities (R&D project, technological transfer activities, POMP programme, event organisation, etc.).
- "ALSS stakeholders" are organisations that are involved in ALSS-related activities, but not specifically within a MELiSSA framework, such as HSLU, ZHAW, EPFL, EPFL+ECAL lab, HEIA-FR, VUNA GmbH, Innobridge SA and SOFIES SA to cite just a few.

1.2 Mapping of ALSS and MELiSSA-related activities implemented in Switzerland

The context of the Position Paper being presented, the next chapters will be dedicated to:

- Introducing the MELiSSA project and its connection with Swiss organizations (§1.3);
- Demonstrating why the Swiss emerging ALSS community stakeholders express their strong interest in the ongoing MELiSSA project (§1.4) by:
    - Presenting major findings from the mapping of ALSS and MELiSSA-related activities implemented in Switzerland (§1.4), among which the abstract of the survey (§1.4.1.1); and other major findings (§1.4.1.2).
    - Formulating key recommendations (§1.4.2).

In order to provide a detailed high-level overview of ALSS and MELiSSA-related activities implemented in Switzerland, the present Position paper also encompasses the following annexes:

- Annex 1: An overview of the Swiss Space and terrestrial ALSS and MELiSSA-related activities (§2.1);
- Annex 2: A brief introduction to space ALSS and their relevance for terrestrial sustainability (§2.2);
- Annex 3: An analysis of the strengths, weaknesses, opportunities, threats (SWOT analysis) of the MELiSSA roadmap (§2.3);
- Annex 4: The full results from the survey on Swiss activities, interests and strengths in ALSS (§2.4);
- Annex 5: T Facsimile of the Position Paper released in Spring 2019 by the MELiSSA industrial actors (§2.5).

In more details, a comprehensive list of ongoing space and terrestrial ALSS and MELiSSA-related activities implemented in Switzerland is presented in Annex 1 (§2.1), and categorized according to the following themes:

- Basic Research and Development (§2.1.1);
- Flight experiments (§2.1.2);
- Ground demonstration (§2.1.3);
- Terrestrial transfer (§2.1.4);
- Education and communication (§2.1.5).

In each of the above-listed sections, activities are discussed by:

- Listing key MELiSSA-related laboratories/research groups and private organizations, as well as additional ALSS-related research organizations, space and innovation agencies;
- Giving examples of concrete ALSS and MELISSA activities/accomplishments “made in Switzerland” in their relevant kind of activities; Where relevant, providing elements also mentioned in the 2019 Report by the Working Group on Life Support Systems (v10.1);
- Showing some of the associated Swiss strengths in space and terrestrial ALSS/MELiSSA-related activities;
- Proposing recommendations.

It should be emphasized that the above-mentioned 2019 Report by the Working Group on Life Support Systems (version 10.1) is cataloguing 57 technology datasheets, with the main contributors originating from Italy (25 datasheets), ESA (15 datasheets), but also Switzerland (8 datasheets, no. 49-55 and 57).

On the 57 received datasheets, 29 have been preliminary identified as relevant for the coming ministerial council Space19+ based on following main criteria 1) current TRL lower than 6; and 2) potential interest for life support for future missions (e.g. Gateway phase 1&2, transit phase, Moon or Mars surface).

These 29 selected fiches that were retained have then been classified as follows, with references to the Swiss datasheets in parenthesis:

- Photobioreactor (datasheet 56);
- Food precursor and characterisation (datasheets 50, 53);
- Multi-phases investigations (datasheet 57);
- Ground demonstration & operation (datasheet 53);
- Academic support (datasheets 50, 53);
- Nitrification (still Swiss competence).

The Swiss Life Support Technology Datasheets from 2019 Report from the Working Group on Life Support Systems[2] are:

- Yeast Biofactories - Food in Space, HSLU (datasheet 49, to be further processed for future mission) (see §2.1.2.2);
- Algae Biofactories, HSLU (datasheet 50, to be further processed for future mission) (see §2.1.3.2);
- Scorpius prototype - Towards a proof-of-concept of a closed habitat on-ground demonstration integrating main BLSS functions, Earth Space Technical Ecosystem Enterprises SA (datasheet 51) (see §2.1.3.2);
- BIORAT1, RUAG Space (datasheet 52, considered to be included into ESA activities) (see §2.1.2.2);
- Study of plants culture on substrate of urine origin: Roots zone focus, ETH Zurich (datasheet 53, to be further processed for future mission) (see §2.1.1.2);
- Oïkosmos, the convergence of terrestrial and space research agendas in the perspective of industrial ecology, UNIL (datasheet 54, to be harmonised with analogues and ground-demonstration facilities) (see §2.1.3.2);
- Versatile Energy, Water, Hydrogen and Oxygen Storage and production System based on a reversible Photo-Electrochemical device, EPF Lausanne (datasheet 55, to be further processed for future mission) (see §2.1.3.2);
- Efficient and light-weight gas separation based on Molecular sieving membranes for space related applications, Unisieve (datasheet 57, to be further processed for future mission) (see §2.1.4.2).

Finally, it is to be highlighted that a significant part of the elements compiled in sections of Annex 1 (§2.1) have either been collected or confirmed through the survey campaign on Swiss activities, interests and strengths in ALSS whose outcome is summarized in §1.4.1.1.

Annex 4 (§2.4) is giving a more complete description of the Survey through the following sections:

- Survey objectives (§2.4.1);
- Contents of the Survey (§2.4.2);
- Summary of Survey results analysis (§2.4.3);
- Full Survey results analysis (§2.4.4).

[2] Cross-references are given, pointing to a short datasheet description in their respective section of Examples of concrete ALSS and MELISSA activities/accomplishments “Made in Switzerland”.

1.3 Introducing the MELiSSA project and its connection with Swiss organizations

For more than 30 years, the European Space Agency (ESA) has been active in the field of regenerative Advanced Life Support Systems (ALSS), as mastering ALSS technologies is a prerequisite for future sustainable Human Exploration of the Solar System.

Consequently, ESA's Member States have invested for many years in R&D and technology transfer of ALSS, including open loop, semi-closed loop and closed-loop systems.

The MELiSSA project was conceived with the mission to achieve the highest degree of autonomy for vital resources in space for food, water and oxygen, in order to gain knowledge and know-how on regenerative system operations targeting a quasi-integral recycling and valorisation of wastes.

However, the MELiSSA project extended far beyond its original mission, including an exercise in multidisciplinary collaboration and tech transfer covering fields such as engineering, microbiology, chemistry, food science, ethics and psychology.

The achievements of the MELiSSA project are numerous, and include remarkable projects and technological developments in space (such as ARTEMISS and Nitrimel) and on the ground (the MELiSSA Pilot Plant in Barcelona and LSS applications at the Antarctic Concordia Station, as well as the Biostyr® wastewater nitrification technology, the Semilla sanitation hubs, ezCol for cholesterol reduction, the Biofacade in Paris with (XTU), the Algosolis industrial pilot facility in France, BioStimulant in Belgium, and fermentation control systems for Freixenet in Spain to name just a few in addition to the Swiss ones mentioned above).

MELiSSA technogical catalogue represents a large and solid portfolio of solutions for a human settlement on the Moon, on Mars or in any of space station spread into the Solar system. In addition, the MELISSA project's accomplishments can demonstrate a high technology and knowledge transfer potential into terrestrial applications, and reversely with parallel terrestrial developments that can converge and cross-fertilize with space developments in a mutually beneficial way.

Essentially, MELiSSA is about the development and use of space applications to preserve terrestrial resources and limit the impact of their use on the terrestrial environment, as well as to improve the quality of life for citizens, today and tomorrow. Moreover, the project is as a source of inspiration for the larger public. Therefore, MELiSSA is considered as THE European project of circular life support, recognized internationally by the scientific and technical community.

Today, ALSS expertise and assets are distributed over the various participants to the project. MELiSSA partnerships involve a large number of actors participating at the global level (e.g., space companies, local and national authorities, scientists, public organizations, private industry, students, donors, etc.). The project attracts European citizen concern and interest in sustainability as it fits well with the global trend of sustainable development and circular economy concepts. In particular, MELiSSA addresses environmental and societal challenges through creating circular material flows in the perspective of industrial ecology.

MELiSSA is an outstanding example of European excellence, driving innovation in scientific and technological fields, thus enabling human space exploration. MELiSSA activities are also fully in line with terrestrial challenges and needs, with a synergistic approach that is paving the way towards the development and implementation of a performant circular economy. The relevance for such dual approach is also confirmed by past MELiSSA workshops and international working groups (such as the International Life Support Working Group with the participation of ESA, NASA JAXA, CNSA and RSA). Recent events such as the 2016 MELiSSA Scientific Workshop and the subsequent 2016 ESA Closed Habitat Forum in Lausanne, as well as the 2018 Joint MELiSSA/Agrospace conference in Rome, have further demonstrated this international interest in ALSS initiatives.

Thanks to three decades of concerted efforts and experience, together with a long-term financial and political commitment, MELiSSA's global community has built unique capabilities, demonstrated both on earth and in space. Concretely, MELiSSA has a successful track record (e.g. spin-off companies, co-

funding, Prizes & Honors, media coverage, student master class, etc.), and thus can also be considered as a powerful tool for societal education, communication and media.

For many years, Switzerland has been developing a strong expertise on bioreactors for terrestrial and space applications (ETHZ, RUAG Space, etc.). Over the past twenty years, RUAG Space and other European leaders in space activities (Qinetiq, SENER and Thales Alenia) have built unique capabilities in the development of space applications related to MELiSSA (see in particular "MELiSSA Industrial Actors – Position Paper"[3]).

In Switzerland, space ALSS R&D and tech transfer activities are currently implemented by a diverse community (both from academia and industry). Moreover, a significant part of the Swiss ALSS projects that have been pursued and completed in the past few years took place in the framework of MELiSSA activities.

The financing of these activities has been able to amplify the knowledge and reach a return of investment in the form of additional in-kind contributions by both public and private organizations.

Since 2016, a growing number of Swiss academic organizations and private companies have expressed their willingness to be engaged further with ESA through the MELiSSA project. This was notably confirmed by a recent survey on Swiss activities, interests and strengths in ALSS, conducted in early Spring 2019 and which abstract is provided hereafter.

[3] The facsimile of the Position Paper released in May 2019 by MELiSSA Industrial Actors is available in Annex 5 (§2.5).

1.4 Consolidating the Swiss activities and rationale for ALSS and MELiSSA development

1.4.1 Major findings

1.4.1.1 Abstract of the survey

The opinions expressed in the survey on Swiss activities, interests and strengths in ALSS[4] confirm the positive indications from recent and previously mentioned ALSS events held in the past few years Switzerland, such as the MELiSSA Scientific Workshop 2016 and ESA Closed Habitat Forum 2016 in Lausanne, both characterized by a strong participation of national public and private organisations, as well as the ALSS Workshop organized by the Swiss Space Office in 2018 to the attention of Swiss organisations.

The fact that the members of this Swiss emerging cluster have been actively participating in both MELiSSA and ALSS-related activities for several years can be demonstrated by more than 30 R&D and technology transfer projects highlighted in §2.4.3 and §2.4.4, projects which cover most of the dimensions and topics of investigations on ALSS, both in space and non-space domains.

According to the conclusions of the survey, the Swiss ALSS emerging community has recently gained a clear perception of the assets and uniqueness of MELiSSA (access to expertise, synergies for connecting space compatible technologies to current terrestrial challenges, access to advanced space R&D hardware, etc.) and is now demonstrating a precise understanding on the future kinds of and topics for collaboration. A growing number of Swiss public organisations and private companies have expressed their willingness to be engaged further. In this regard, the national community has emphasised a high interest in continuing or starting to participate in MELiSSA-related activities, should it be through scientific collaboration, (applied) R&D opportunities, technology demonstration or industrial collaboration, to mention just a few of them.

It notably came out from the survey that the vast majority of the responding organisations would be interested in having access to some MELiSSA laboratory/testbed hosted in Switzerland.

Moreover, the Swiss emerging community shows a strong interest in establishing both academic and industrial partnerships with MELiSSA, for developing key scientific and technical innovations both in space and on Earth.

This notably gives a mutually beneficial opportunity to establish new collaborations between Swiss players, as well as between them and the MELiSSA community in general. In other words, the potential of increasing collaborations is significant, and the emerging community could be consolidating into an active and productive cluster during the next E3P period.

More details about the survey, its objectives, content and outcome are notably presented in Annex 2.4.

[4] The survey was conducted in early Spring 2019 in relation to this Position Paper, see abstract in §1.4.1.1 and Annex 4 (§2.4).

1.4.1.2 Other major findings

The other major findings from the survey and other elements compiled in preparation of this Position Paper also show that:

- The Swiss MELiSSA and ALSS stakeholders encompass a broad range of public and private organisations and can be considered as a cluster offering a wide spectrum of complementary scientific and technological skills and know-how (§2.1);
- Switzerland has been playing for several years a significant role in the identification of commonalities between space and terrestrial research on ALSS (§2.1.1);
- The initial financing of ALSS activities has been able to amplify the knowledge and reach a return of investment in the form of additional in-kind contributions by both public and private organisations (§1.3);
- The active participation of the community covers most of the dimensions and topics of investigations on ALSS with numerous projects related to basic R&D (§2.1.1.2), flight experiments (§2.1.2.2), ground demonstration (§2.1.3.2), terrestrial applications (§2.1.4.2) and education and communication (§2.1.5.2);
- Associated benefits and returns are demonstrated by the numerous Swiss R&D and technology transfer examples highlighted in this Paper, in space as well as on Earth (§2.1.3 and §2.1.4);
- MELiSSA now encompasses key technological and scientific activities of several Swiss organisations such as RUAG's Biorat project, the BELiSSIMA Phase A project involving notably Earth Space Technical Ecosystem Enterprises SA (ESTEE) and UNIL, the MELiSSA Food Characterisation Phase 2 project involving notably HEI (HES-SO//Valais-Wallis) and RUAG, UNIL's Oïkosmos study, the Pool of MELiSSA PhD programme, CSEM EnRUM project (within ALiSSE), and spin-off activities of start-up companies, including ESTEE, and Vuna GmbH (§2.1);
- The potential of increasing scientific and technical collaborations is significant. Such new collaborations could establish academic and industrial partnerships between Swiss players, as well as between them and the MELiSSA community in general (§2.4.3);
- Swiss ALSS activities and their developments have synergies with terrestrially-focused R&D applications, expressed as knowledge and technology transfer (§2.1);
- The signatories to this Position Paper stress specifically the importance of having an ongoing preparation of space missions that is happening along the whole range of technology readiness levels (TRL) (§2.4.4);
- The national community should continue building momentum for the ALSS programme, fostering innovation, and establishing a highly skilled future workforce (e.g. via initiatives such as ESA_LAB's IGLUNA project, coordinated by Swiss Space Center, and training courses such as EPFL "Building on Mars"/ENAC teaching unit) (§2.1.5.3).

In a nutshell, with almost thirty organisations involved and more than seventy people active in ALSS activities at the national level, it appears that the emerging and dynamic community in the field of ALSS has reached a critical size and momentum in Switzerland – and in Europe as well. Thanks to recent interactions among the community of stakeholders, a common realisation is shaping. Pursuing the current momentum could notably consolidate the current Swiss activities and rationale for ALSS and MELiSSA development, and aim at:

- Engaging additional stakeholders – notably with ESA through the MELiSSA project – and bringing together a core group of stakeholders strongly interested in joining forces to develop new activities;
- Improving the knowledge, know-how, development and commercialisation of both space and Earth-based ALSS applications, with associated societal benefits and returns.

1.4.2 Key recommendations

As stated by most of the key Swiss players in the field of ALSS, a resolute and continued financial support for MELiSSA activities should remain within ESA. Concretely, and as evidenced in the past notably for flight experiments, the best way would be to continue financing the MELiSSA activities via the ESA Exploration programmes – currently European Exploration Envelope Programme (E3P)[5] – for the next periods (Period 2 and beyond) which should aim at:

- Maintaining a steady flow of collaborative partnerships, including non-space academic institutions and industry to engage in space activities and with ESA (spin-ins and spin-outs) (§2.1.1 and §2.1.2);
- Securing the continuity of MELiSSA technology developments in Life Support for space exploration, sustained by a robust roadmap and associated projects in the E3P programme (§2.1.2);
- Positioning the Swiss space ecosystem at the cutting edge of the ALSS developments by delivering In Orbit Demonstrator (IOD) of building blocks (such as photobioreactors) paving the way for a credible approach towards a human settlement on the Moon, on Mars or in other space stations developed in the Solar system (§2.1.2);
- Enabling a faster and bigger access to international manned space exploration activities (§2.1.2).

The Swiss space and terrestrial ALSS communities are also looking towards a political support with a long-term vision and planning, with adequate funding, aiming at:

- Exploiting Swiss non-space scientific and technological know-how as well as industry capacity that could be impactful and enabling various aspects of ALSS development (§2.1.1):
    - The associated fields of research include notably material loop closure, efficient food production systems, organic waste recycling and decentralised treatment concepts;
    - The associated fields of excellence and competitiveness encompass notably life sciences, biotechnology, sustainable resource management, sustainable habitat, smart monitoring and system control, microtechnology and information and communication technologies.
- Investigating topics relevant both for human space exploration and for their associated Earth-based applications (§2.1.1);
- Attracting and increasing engagement of the Swiss non-space ALSS organisations (including industries) in space exploration (§2.1.1);
- Fostering synergies between Swiss players and the MELiSSA community in order to combine their complementary skills in a concerted effort within a stable project framework (§2.1.1);
- Further considering developing a dedicated testbed in Switzerland to experiment ALSS concept in a short to mid-term perspective, as expressed by most of the Position Paper's survey respondents (§2.1.3);
- Leveraging on Swiss expertise in R&D, technology cooperation and transfer opportunities to better exploit ALSS knowledge and know-how for space exploration and contribute to the development of terrestrial applications beneficial to society (§2.1.4);
- Supporting the organisation of a (bi-)yearly targeted workshop that would respond to the demand of Swiss parties for increased interactions between MELiSSA activities and Swiss ALSS stakeholders. Such workshop would enable MELiSSA community to provide an overall activity report – not specific to Switzerland. Conversely, a summary of new Swiss ALSS development would be shared. This would build an essential communication channel to circulate information from the complementary activities distributed within the overall community (§2.1.5).

[5] More information on E3P and Human Spaceflight and Robotic Exploration Programmes on ESA website (as per 08.08.2019): https://www.esa.int/About_Us/Ministerial_Council_2016/Human_Spaceflight_and_Robotic_Exploration_Programmes

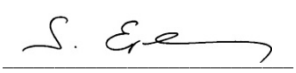
A consolidated community at national level, in coordination with SSO and MELiSSA would certainly facilitate the process and transform the motivation into additional concrete accomplishments by exploring complementary funding scheme in addition to the ESA and SSO ones, from academia (including SNF), industry, and other Swiss innovation ecosystems incentives (e.g. Innosuisse, Innovaud/Platinn, etc.) and regional development funds, private investors, and philanthropic organisations.

In conclusion, this Position Paper shows evidence that the current timing appears highly adequate for:

- Consolidating the Swiss activities and rationale for ALSS into an active and productive cluster during the next E3P period;
- Positioning Switzerland as a key player in space and terrestrial ALSS and with a strong potential for increasing the developments and collaborations within the MELiSSA project;
- Allowing an increased international visibility for Switzerland in the field of manned space exploration, as well as for a reliable and efficient circular economy.

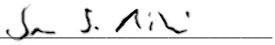
Therefore, for the next E3P periods, the Authors, along with the signatories of this Position Paper, recommend that ALSS and MELiSSA R&D and technology transfer activities in Switzerland should continue to benefit from a stable and long-term programmatic framework with corresponding funding. With the above-mentioned findings and recommendations of Position Paper, the Swiss stakeholders active in the field of Advanced Life Support Systems (ALSS), including those directly involved in the R&D and technology transfer of related space and Earth-based solutions, would like to express their strong interest in the ongoing Micro-Ecological Life Support System Alternative (MELiSSA) project of the European Space Agency (ESA).

This document has been endorsed by:



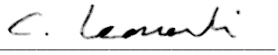
Prof. Suren Erkman
Head, Industrial Ecology Group, Faculty of Geosciences and Environment, UNIL

Mr. Théodore Besson
Managing Director, Earth Space Technical Ecosystem Enterprises SA; Research Fellow, UNIL



Prof. Sara Mitri
Department of Fundamental Microbiology, Faculty of Biology and Medicine, UNIL

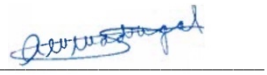
Prof. Dimitrios Lignos
Head, Resilient Steel Structures Laboratory, School of Architecture, Civil and Environmental Engineering (ENAC), EPFL



Mr. Claudio Leonardi
Project Manager Clip-Air, Lecturer, ENAC Deanship, EPFL

Mr. Damien Moscetti
General Manager, RUAG Space Nyon

Dr. Georges Kotrotsios
Vice-president, Marketing & Business Development, CSEM

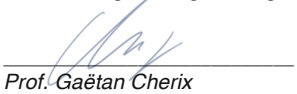


Dr. Ana Madrigal
Head of Space Program, CSEM

Mr. Nicolas Henchoz
Director, EPFL+ECAL lab

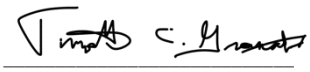
Prof. Dr. Janet Hering
Director, Eawag

Prof. Dr. Kai Udert
Process Engineering, Eawag



Prof. Gaëtan Cherix
Head, HEI (HES-SO Valais-Wallis)

Prof. Dr. Marcel Egli
Head of the Institute for Medical Engineering, HSLU

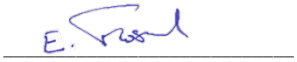


Dr. Timothy Granata
Microbial biotechnology Project Center for Bioscience and Medical Engineering, HSLU

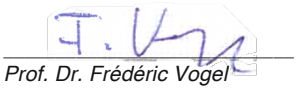
Prof. HES associé Jean-Pascal Bourgeois
Institute of Chemical Technology (ChemTech), HEIA-Fr

Prof. Dr. Rolf Krebs
Director, Institute of Natural Resource Sciences, ZHAW

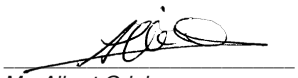
Prof. Dr. Ranka Junge
Head, Centre Ecological Engineering, ZHAW



Prof. Dr. Emmanuel Frossard
Head, Plant Nutrition Group, ETH Zurich

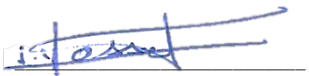


Prof. Dr. Frédéric Vogel
Catalytic Process Engineering group, PSI

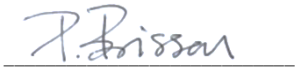


Mr. Albert Oriol
CEO, Oracan Sàrl

Dr. Elia M. Schneider
CTO, UniSieve Ag

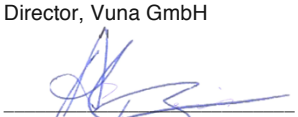


Dr. Jean-Luc Josset
Director, Space Exploration Institute

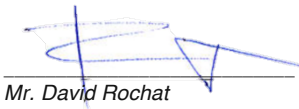


Mr. Pierre Brisson
President, Mars Society Switzerland

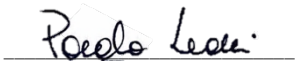
Mr. Bastian Etter
Director, Vuna GmbH



Mr. Alexandre Coquoz
Associate Director, Innobridge SA



Mr. David Rochat
CEO, Sofies International SA



Mrs. Paola Leoni
Managing partner, Leoni Corporate Advisors

Mr. Patrick Barbey
Director, Innovaud

Mr. Eric Plan
Secretary General, CleantechAlps

2 Annexes

2.1 Annex 1 – Swiss Space and terrestrial ALSS and MELiSSA-related activities

2.1.1 Basic Research and Development

2.1.1.1 Swiss MELiSSA and ALSS stakeholders

MELiSSA-related laboratories/research groups: RUAG Space, UNIL, ETHZ, Eawag, ESTEE, CSEM, HEI (HES-SO//Valais-Wallis).

Additional ALSS-related research organizations: HSLU, ZHAW, EPFL, EPFL+ECAL lab, HEIA-FR.

2.1.1.2 Examples of concrete ALSS and MELISSA activities/accomplishments "made in Switzerland"

- **4 MELiSSA-related PhD projects** (Dynamic modelling of material flows and sustainable resource use; Artificial closed ecosystem as drivers for ecoinnovation; Urine treatment; Crop production in hydroponics using recycled nutrients and microbial consortia);
- **2 MELiSSA-related post-doc projects** (Higher plant modelling of wheat root plasticity under nutrient deficiencies; Closing anthropogenic carbon loops: towards implementing a circular economy);
- Several dozens of ALSS-related publications and conference talks, on topics such as:
    - **Study of plants culture on substrate of urine origin: Roots zone focus**
        - Swiss organization: **ETH Zurich** (Swiss Life Support Technology Datasheets 53);
        - 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 nutrients availability and supply to the crops. Food crops to be tested include cereals, soybean, and presumably halophilic edible plants, which at the same time will alleviate the risk of salinization. The plants response in terms 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;
        - *Keywords*: crop, food, microbial consortia, hydroponics, urine, organic waste, phosphorus – nitrogen, plant response, root growth.
    - **Space Loop. Pyrolysis of human feces**, Biochar-based life support loop. ZHAW;
    - **Systems Engineering and Design of a Mars Polar Life Research Base** (Anne-Marlène Ruëde, EPFL Msc thesis, 2018); Living Architecture scenarios, Earth applications Liquifer Systems Group. Outreach conference : European Mars Convention, La Chaux-de-Fonds, 2018, covering ALSS.
- **Ongoing ESA project BELISSIMA phase A** (AO/1-8342/15/NL/AT) (2016-ongoing). Led by VITO (prime contractor), ESTEE SA, UNIL and UGent (subcontractors). Scope: behaviour and effects of microcompounds in closed soil-free ecosystems, behaviour and impact of microcompounds, closed system chemical contaminants, microcompound removal, water reuse/ recycling.
  Topics of investigation : 1) Microcompound behaviour (technology development for monitoring of microcompounds; Investigation of behaviour of microcompounds and of micro-organisms); 2) Water reuse/recycling (Technology development for recycling, removal, retention and/or

degradation of microcompounds, as well as for nutrient separation/recovery; adaptation of closed system bioprocesses to biorefineries); 3) Investigation of behaviour of microcompounds in food production using water recovered nutrients. Societal challenges: ecotoxicology;

- **MELiSSA Food Characterization Phase 2** (2014-2015, IPL (Belgium), and with coordination with HEI (HES-SO//Valais-Wallis) and support by RUAG Space Nyon). Hydroponic subsystem studied at scientific and engineering levels, delivery of technical requirements & completion of preliminary testing phase. Food Processing Characterization Unit (FPCU) concept and engineering requirements. HEI (HES-SO//Valais-Wallis) expertise: Food processing, HACCP, Hygienic design, Sensory evaluation;
- **EnRUM - Energy Resources utilization Mapping**, led by Sherpa and CSEM (2017). Food Loop status (Advanced Life Support System Evaluator - ALiSSE) - Simulation environment composed of an habitation (air loop, crew) and a food loop.

Other Swiss R&D activities that can be connected to ALSS and closed habitats include:

- The recent I**nternational Phosphorus Workshop 9** held at ETH Zurich in July 8-12, 2019;
- **Voucher** (Agroscope-CSEM). Soil nitrate monitoring. Proof of concept of long-term nitrate sensing in agricultural soil. CSEM expertise: Nitrate sensing platform. No space requirements. TRL2;
- **WeST** (CSEM). Wearable sweat tracker. CSEM expertise: Printed, functionalized electrochemical sensors; System engineering. No space requirements. TRL3;
- **RADAR** (CSEM-FP7 grant). Modular platform for monitoring toxins in water and food production facilities using biosensors derived from aquatic organisms. CSEM expertise: Sample preparation; Analyte extraction; Label free detection. No space requirements. TRL4;
- **Smart toilet** (CSEM). Urine analysis for health monitoring. CSEM expertise: Printed, functionalized electrochemical sensors; System engineering. Societal challenge: Personalized health monitoring. No space requirements. TRL3;
- **Nutrishield** (CSEM-H2020 grant). Urine analysis as a feedback for personalized nutrition. CSEM expertise: Printed, functionalized electrochemical sensors; System engineering. No space requirements. TRL3;
- **Optodex** (CSEM). Chemical functionalization of surfaces for antimicrobial properties. CSEM expertise: Chemical functionalization. No space requirements. TRL5;
- Multispectral imaging for plants monitoring (CSEM internal activity). CSEM expertise: Multispectral imaging (imagers, data processing), plasmonic filters, ultra-low power embedded vision systems. No space requirements. TRL3;
- **Drinking water quality monitoring by measuring inorganic and organic contaminants** (CSEM internal activity). CSEM expertise: Light scattering/turbidity, biochemical sensors (highly specific), surface coatings. Societal challenge: Drinking water safety. No space requirements;
- **Ethics of Planetary Sustainability**: Ethical assessment of space exploration regarding sustainability (Dr. Andreas Losch, University of Bern).

The following organizations responding to the survey gave a short description of how their own potential contribution to a joint project within the MELiSSA project framework would look like (Q23):

- UNIL - Prof. Sarah Mitri: “We are working on building model microbial ecosystems that we can control in a close-loop manner. We also build mathematical models that help predict dynamics in our experimental systems. These results should be highly relevant for MELiSSA.”;
- HEI (HES-SO//Valais-Wallis): “MELiSSA Food characterisation – Phase 3. Validation of the FPCU concept proposed in MELiSSA Food characterisation – Phase 2 + Impact of food processing and formulation (i.e. nutraceuticals) on nutrients bioavailability & on human

microbiote. 5 years to TRL5. Multidisciplinary expertise in : - food processing - food safety - nutraceuticals & nutrients bioavailability - hygienic design of food equipment (European Hygienic Engineering and Design Group - EHEDG) - waste & by-product valorisation - water & air management - biomaterials bioenergy - microalgae (i.e., Spirulina) production - microbiote characterization based on in vitro digestive model - real-time data acquisition & control";

- EPFL+ECAL lab: "They propose to introduce the discipline of design research to investigate the user experience and user interface dimensions for different parts of the system. This work includes understanding of user perception, with a focus on cognitive and emotional states component. They believe that new designs of scenario of uses, habitats and interfaces can open new ways in human behaviour facing closed environments. Their idea is to put an emphasis on what can be transferred on Earth and be implemented in everyday life of large group of users";
- HSLU – Center for Bio- and Medical Engineering, Tim Granata: "Development and testing of photobioreactor to produce biomaterials for additive manufacturing";
- Eawag and ETH Zurich, Dr. Joaquin Jimenez Martinez: "Soil physico-chemical processes, including microbiology and plants, in weightless conditions";
- Orphanalytics: "Genome analysis: exchange of genome islands (higher pathogenicity)";
- UNIBE – Prof. Losch: "Ethical evaluation".

Activities also mentioned in the 2019 Report by the Working Group on Life Support Systems (version 10.1) were also mentioning:

- Switzerland as a participating country (but without organization as Principal Investigator) for science funded as part of the following *SciSpacE activities*:
    - **WAPS (Study of Plants Water Transfer)**. PI: U Napoli (I), CIRIS (N). Industry: CIRIS (N). Concerned Countries: N, B, F, E, CH, I. Launch: 2020;
    - **ARTEMISS-C** (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), UCIA (F). Industry: Qinetiq (B). Concerned Countries: B, F, E, CH. Launch: 2020.
- For Fundamental support:
    - **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.

2.1.1.3 Swiss strengths in space and terrestrial ALSS and MELiSSA-related activities - Scientific and technological level

Scientific collaborations on ALSS empower a two-way exchange between terrestrial and space sciences and technologies (spin-in and spin-out, see §2.1.3.5).

As a reminder, more than 50% of the organizations responding to the survey considered the following outcomes of taking part in a Swiss community on ALSS/MELiSSA (Q18): "Scientific collaboration" (61%), "(Applied) R&D opportunities" (58%), "Participation in workshops/conferences" (55%), and "Provide scientific/technical expertise on specific ALSS topics" (52%).

At the scientific and technological levels, pursuing the current momentum on space and terrestrial ALSS-

related activities in Switzerland - especially within the MELiSSA framework - could notably aim at:

- Strengthening Swiss and European collaboration and excellence in science and technology R&D related to ALSS and closed habitat;
- Building/developing new interdisciplinary research collaborations across Europe and beyond;
- Showcasing Swiss knowledge and expertise in specialized technological fields and in specific markets of ALSS for European terrestrial & space communities;
- Addressing current technology/expertise gaps and provide advice for consolidating space and terrestrial R&D agenda and defining strategies to implement ALSS specific subsystems;
- Generating innovative solutions to the scientific and technological challenges of space exploration.

2.1.1.4 Recommendations for basic R&D

The above sections show evidence that Switzerland has been playing for several years a significant role in the identification of commonalities between space and terrestrial research on ALSS.

Therefore, Swiss ALSS community stakeholders' R&D activities should aim at:

- Maintaining a steady flow of collaborative partnerships, including non-space academic institutions and industry to engage in space activities and with ESA (spin-ins and spin-outs);
- Exploiting Swiss non-space scientific and technological know-how as well as industry capacity that could be impactful and enabling various aspects of ALSS development.
    - The associated fields of research include notably material loop closure, efficient food production systems, organic waste recycling and decentralised treatment concepts (see notably survey Q5 for examples of key ALSS R&D and tech transfer activities for Swiss respondents);
    - The associated fields of excellence and competitiveness encompass notably life sciences, biotechnology, sustainable resource management, sustainable habitat and smart monitoring and system control, microtechnology and information and communication technologies.
- Investigating topics relevant both for human space exploration and for their associated Earth-based applications;
- Attracting and increasing engagement of the Swiss non-space ALSS organisations (including industries) in space exploration;
- Fostering synergies between Swiss players and the MELiSSA community in order to combine their complementary skills in a concerted effort within a stable project framework.

2.1.2 Flight experiments

2.1.2.1 Swiss MELiSSA and ALSS stakeholders

MELiSSA-related private organization: RUAG Space, CSEM.

Additional ALSS-related research organizations: HSLU, Space Exploration Institute.

2.1.2.2 Examples of concrete ALSS and MELISSA activities/accomplishments "made in Switzerland"

- **Biorat phase B** (2015-2019, coordinated by RUAG Space, Nyon)
  - Swiss organization: **RUAG Space** (Swiss Life Support Technology Datasheet 52);
  - Pre-development and test of a flight experiment composed of a closed gas loop producing O_2 (algae photosynthesis) and consuming CO_2 from a mice "crew". Technology demonstrator for ISS that is intended to a couple photobioreactor (microalgae) with a consumer compartment, that is, in a closed-loop manner. Expertise: system, full life cycle – up to launch. Space requirements. Launch planned in 2025.
  - 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. RUAG has longstanding experience in space bioreactor design and development. Bioreactors are 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;
  - *Keywords*: Bioreactor, Photo-bioreactor, Photosynthesis, Continuous Process, Predictive Control.
- **Yeast Biofactories - Food in Space**
  - Swiss organization: **HSLU** (Swiss Life Support Technology Datasheet 49);
  - 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 the proposed bioreactors is the independence from human intervention. Therefore, 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 demonstrated the capability of a controlled cultivation of yeast cells. There were even yeast-bioreactors in space, however, just as a small-scale model. HSLU is currently working on a yeast bioreactor H/W together with RUAG Space that should be operated on the International Space Station ISS around 2020;
  - *Keywords*: Bioreactors, yeast, food supplements, continuous cultivation.

Activities also mentioned in the 2019 Report by the Working Group on Life Support Systems (version 10.1) for National, GSTP, DPTDP or E3P funding were also mentioning:

- **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
- **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

2.1.2.3 Swiss strengths in space and terrestrial ALSS and MELiSSA-related activities – Flight experiment level

At the Flight experiment level, pursuing the current momentum on space and terrestrial ALSS-related activities in Switzerland - especially within the MELiSSA framework - could notably aim at:

- Identifying, proposing and integrating elements (e.g., Swiss technologies for scientific instrumentation, or prototypes such as a proof of concept of a closed habitat) that could be considered in the E3P Programme Proposal for CM19 (e.g., EXPERT, SciSpace) and/or in Technology programme (TRP, GSP, GSTP and PRODEX , ARTES 5), including carrying out the following kind of activities:
    - Technology assessment;
    - Technology development and implementation;
    - Technology demonstration in Space through In Orbit demonstrator;
    - Technology demonstration on Earth;
    - Technology adaptation;
    - Product development;
    - Modelling, monitoring and analysis;
    - Establishment of proof of concept.

The following organizations who responded to the survey also gave a short description of how their own potential contribution to a joint project within the MELiSSA project framework would look like (Q23):

- RUAG offers capabilities to build experiments and validate part of the ALSS loop through their In Orbit Demonstrator (IOD). RUAG also offers skills in consultancy mode;
- RUAG offers capabilities to build experiments and validate part of the ALSS loop through their In Orbit Demonstrator (IOD). RUAG also offers its expertise to develop techno building blocks such as “gas-liquid-solid interface for oxygen transfer in Life Support Systems” to be used for different experiments. Finally, RUAG is able to provide skills in consultancy mode, on demand;
- CSEM offers development of specific technology bricks or adaption of CSEM technologies/know-how based on ALSS requirements/needs in order to bridge gaps between TRL 2 and TRL 7;
- Oracan Sàrl offers biotech technologies engineering/development, as well as space projects management.

In any case, “space” is perceived as a critical driver for ALSS collaborations and should continue to be clearly stated in all communications.

2.1.2.4 Recommendations for flight experiments

As stated by most of the key Swiss players in the field of ALSS, a resolute and continued financial support for MELiSSA activities should remain within ESA. Concretely, and as evidenced in the past notably for flight experiments, the best way would be to continue financing the MELiSSA activities via the ESA Exploration programmes – currently European Exploration Envelope Programme (E3P)[6] – for the next periods (Period 2 and beyond) which should aim at:

- Maintaining a steady flow of collaborative partnerships, including non-space academic institutions and industry to engage in space activities and with ESA (spin-ins and spin-outs);
- Securing the continuity of MELiSSA technology developments in Life Support for space exploration, sustained by a robust roadmap and associated projects in the E3P programme;
- Positioning the Swiss space ecosystem at the cutting edge of the ALSS developments by delivering In Orbit Demonstrator (IOD) of building blocks (such as photobioreactors) paving the way for a credible approach towards a human settlement on the Moon, on Mars or in other space stations developed in the Solar system;
- Enabling a faster and bigger access to international manned space exploration activities.

[6] More information on E3P and Human Spaceflight and Robotic Exploration Programmes on ESA website (as per 08.08.2019): https://www.esa.int/About_Us/Ministerial_Council_2016/Human_Spaceflight_and_Robotic_Exploration_Programmes

2.1.3 Ground demonstration

2.1.3.1 Swiss MELiSSA and ALSS stakeholders

MELiSSA-related laboratories/research groups and private organizations: UNIL, Eawag, ESTEE, CSEM, Innobridge.

Additional ALSS-related research organizations: EPFL, HSLU, PSI.

2.1.3.2 Examples of concrete ALSS and MELISSA activities/accomplishments "made in Switzerland"

- **Oïkosmos, the convergence of terrestrial and space research agendas in the perspective of industrial ecology** (2010-2016)
    - Swiss organization: **UNIL** (Swiss Life Support Technology Datasheet 54);
    - 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*: Report to the Rectorate of University of Lausanne on the Project Oïkosmos; PhD Thesis by Théodore Besson, under the supervision of Prof. Suren Erkman, Head, Industrial Ecology Group, Faculty of Geosciences and Environment, University of Lausanne;
    - *Keywords*: Science & technology policy, sustainability research agenda, terrestrial sustainability, industrial ecology, artificial closed ecosystems, closed habitat, terrestrial applications, circular systems quasi-cyclical economy (circular economy);
    - Societal challenge: integral recycling, resource valorisation.
- **Scorpius prototype - Towards a proof of concept of a closed habitat on-ground demonstration integrating main BLSS functions** (2017-ongoing)
    - Swiss organization: **Earth Space Technical Ecosystem Enterprises SA** (Swiss Life Support Technology Datasheet 51);
    - 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 in 2020. This proof-of-concept prototype is aimed at becoming 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 industrial support is being provided by an ongoing collaboration with MELiSSA-ESTEC, among other and academic partnerships (including with universities such UNIL and EPFL);
    - *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), including 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, combination of physical, chemical and biological processes. 99% design completion achieved in 2018;
    - *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.

- **Algae Biofactories** [under assessment by ESA]
  - Swiss organization: **HSLU** (Swiss Life Support Technology Datasheet 50);
  - 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 of bioproducts (e.g. bioplastics), and pigments for health and medical applications. Algae can recycle wastewater removing carbon dioxide and nitrogen, phosphorous and sulfur sources while producing oxygen and biomolecules;
  - *Key performances demonstrated:* The HSLU space biology group has demonstrated the effects of different irradiance spectra and intensities on two microalgal species. And has run simulated microgravity experiments on one of the species, using ground-based random positioning machine (RPM) to compare simulated microgravity to 1 g. They 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, carbohydrates, DNA. Parameters will test the effects of cosmic radiation and microgravity compared to controls and 1 g, from 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;
  - *Keywords*: Microalgae, irradiance, biomaterials, nanosatellites, bioreactors.
- **Versatile Energy, Water, Hydrogen and Oxygen Storage and production System based on a reversible Photo-Electrochemical device** [under assessment by ESA]
  - Swiss organization: **EPF Lausanne** (Swiss Life Support Technology Datasheet 55);
  - The System is based on an integrated and reversible photo-electrochemical device (IPEC) which is currently under development for terrestrial applications (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). 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 a 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 radiation through the use of solar reflectors. The latter 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);
  - Keywords: Reversible storage oxygen – water; generation of H_2, O_2, electricity and heat from water; In-Situ Resource Utilization (Moon/Mars) Habitation.

- **ESA TAS – Towards the Establishment of a Standard on Closed Habitat Specifications** (Reference 130046707) (Earth Space Technical Ecosystem Enterprises SA) (2018-ongoing)
- **Supercritical Water Oxidation of fecal sludge**, Reinvent the Toilet Challenge, Bill & Melinda Gates Foundation, led by Eawag, with participation of Paul Scherrer Institut/FHNW, TRL4-5, 1 year to TRL5
- At the Swiss level, some recent innovations in decentralized wastewater treatment integrate technologies at the level of buildings to make them operate like a closed habitat. For example, Eawag, the Swiss Federal Institute of Aquatic Science and Technology, develops new and improved sanitation systems allowing nutrient recovery from urine in order to link sanitation to food production (see also Vuna GmbH in §2.1.4.1). Such waste treatment, nutrient recovery, and micropollutant management technologies are also currently further developed and showcased in the NEST building. The latter is an innovation platform managed by EMPA, an interdisciplinary Swiss research institute for applied material sciences and technology. NEST building is carrying research from the development of new materials to the design of advanced systems and their integration at full-scale into buildings and structures under real-world conditions. This applied research, unfolding in close collaboration with partners from industry, focuses on specific areas of nanostructured materials, sustainable built environment, health and performance, natural resources and pollutants and energy.

2.1.3.3 Swiss strengths in space and terrestrial ALSS and MELiSSA-related activities – Ground demonstration

At ground demonstration level, pursuing the current momentum on space and terrestrial ALSS-related activities in Switzerland - especially within the MELiSSA framework - could notably aim at:

- Participating in the development of a MELiSSA-related state-of-the-art technological platform for eco-innovation
    - Spin-off and start-up creation & support (eco-innovation incubator)
    - Utility and facility sharing (mutualized lab equipment and surfaces)
    - Highly qualified and multidisciplinary experts on closed systems related technologies
    - « One-stop-shop » for innovative companies and industries
    - R&D services (feasibility studies, concept design, prototyping, IP licensing), similar to the CSEM (www.csem.ch) business model
- Optimizing the use of existing infrastructures and research facilities and services for showcasing and communicating societal benefits to the general public, decision makers and media.

As a reminder, 42% of the organizations responding to the survey considered as “Access to advanced space R&D facility/hardware” as one of the most interesting MELiSSA asset (Q10) and close to 50% considered as expected outcome the “Participation in technology demonstration/showcase (technological component/module, prototype, emerging technology or applications, business incubator, etc.)” (45%) (Q18).

It also notably came out of the survey that almost 80% of the responding organisations would be interested in having access to some MELiSSA laboratory/testbed hosted in Switzerland (Q20).

The following survey responding organizations gave a short description of how their own potential contribution to a joint project would look like (Q23):

- Innobridge: Hosting a testbed or MELiSSA laboratory on Agropole site (agritech & foodtech hub in development in Canton de Vaud);
- Earth Space Technical Ecosystem Enterprises main goal is to build a proof of concept of a closed habitat

2.1.3.4 Recommendations

The above section shows evidence that an ALSS testbed could help preventing a lack of continuous involvement as well as short project duration for Swiss organisations involved in specific ALSS development activities.

Therefore, ground demonstration activities should aim at:

- Further considering developing a dedicated testbed in Switzerland to experiment ALSS concept in a short to mid-term perspective, as expressed by most of the Position Paper's survey respondents.

2.1.3.5 On the spin-out and spin-in pathways of space technologies

Space technologies often "spin-out" or "trickle down" to Earth applications. The reduction of the technology readiness level (TRL) of a space technology is the removal of requirements dictated only by flight and space-mission conditions, which are not encountered on Earth. These requirements are not necessary to be met for a technology to perform properly on Earth. Specifically, this reduction involves the adaptation of a space technology with a high TRL (above 6) to a terrestrial variant with a lower TRL (below 6). This reduction is essential for the increase of the mass appeal and marketability of a technology, due to its higher affordability and lower complexity for applications relevant to ground environments.

There are countless examples of "reduced" space technologies that have spun out to terrestrial applications, including those in the areas of computing, imaging, navigation, and medical devices. It is also expected that many of the space-oriented technologies developed as part of life-support systems have the potential for spin out.

For ALSS, even though such spin out is possible, co-development for Earth and Space with usually common requirements can happen, typically until TRL 5. Then, above TRL 5, space and terrestrial development are following different technological trajectories. One example is the Biostyr nitrification technology, which was originally co-developed by MELiSSA and Veolia, and is currently marketed by Veolia in Europe for use in wastewater treatment plants.

It should be noted that apart from spin-out, a "spin-in" phenomenon is observed, in which, naturally, terrestrial technologies are adapted for use in space. Nitrification of urine also constitutes an example of a spin-in technology, which, having been originally developed for terrestrial applications, is currently adapted for use in life-support systems in space.

Finally, it should be mentioned that some technologies can undergo an iteration of successive/parallel spin-in and spin-out - and reversely - during their specific technological development, including in the framework of space and terrestrial life-support system development.

The emerging Swiss community addresses both directions of these spin-in and spin-out pathways, thanks to its innovation ecosystem in place.

2.1.4 Terrestrial applications

2.1.4.1 Swiss MELiSSA and ALSS stakeholders

MELiSSA-related laboratories/research groups and private organizations: UNIL, ESTEE, CSEM, Eawag.

Additional ALSS-related research and private organizations: CombaGroup, Vuna GmbH, Innobridge SA, ESA BIC Switzerland, Unisieve, Oracan, Climeworks, SOFIES.

In addition to above-listed stakeholders, a number of large international Swiss companies are interested in space as well as terrestrial applications of ALSS and closed habitats, in the following sectors: food/health sector (Nestlé), sanitation (Geberit), construction (Implenia), cosmetics (Firmenich), and pharmaceuticals (Novartis).

The same applies to many Swiss SMEs and start-ups that are keen to contribute to ALSS and closed habitats, like, ESTEE, Vuna, CombaGroup, Climeworks, Oracan, Gjosa, Enoki, etc.

2.1.4.2 Examples of concrete ALSS and MELISSA activities/accomplishments "made in Switzerland"

- **Key Technology Transfers**:
  - Earth Space Technical Ecosystem Enterprises SA: could be considered as UNIL/MELiSSA spin-off company: from a conceptual artificial closed ecosystem to the establishment of a proof of concept of a closed habitat (see Scorpius Prototype in §2.1.3.2), in connection with Oïkosmos study (see §2.1.3.2 and §2.2);
  - Urine Treatment Unit, Vuna GmbH.
- **ESA Study for the Assessment of the Financial and Business Potentials of the Life Support Systems (LSS) Technologies** (AO/1-9556/18/NL/AT), led by Leoni Corporate Advisors (ITA/CH), Earth Space Technical Ecosystem Enterprises SA (subcontractor) (started in 07.2019);
- **SCIMA Connected Autonomous Monitored Greenhouse**: INTERREG project led by Earth Space Technical Ecosystem Enterprises SA on the Swiss side (with the participation of UNIL and Grangeneuve), food production in constrained environments;
- Other Technology Transfers related to ALSS:
  - **Efficient and light-weight gas separation based on Molecular sieving membranes for space related applications** [under assessment by ESA]
    - Swiss organization: **Unisieve** (Swiss Life Support Technology Datasheet 57);
    - Separation membrane technology via molecular sieving 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: CO_2/ CH_4, C_3H_6/C_3H_8, H_2/CH_4, H_2/CO_2, Xe/Air; membrane that can be integrated as industrial standard membrane modules, which can be exchanged easily;
    - *Key performances demonstrated*: UniSieve has produced and tested several m^2 of selective membrane sheets with high selectivity and permeance (flow) and has proven the scale-up capability;
    - *Keywords*: Membrane, separation, gas, molecular sieving, methane recovery unit, MELiSSA, Sabatier.
  - **SOFIES SA**: founded by Prof. Suren Erkman, offers a set of professional skills to public and private stakeholders allowing for sustainable economic development, integrating the

preservation of natural resources based on the concepts of industrial ecology and circular economy;

- Over last years, some private organisations started business ventures providing the market with large scale greenhouses using LSS-related hydroponics. As an example, Swiss agro-tech startup **CombaGroup SA** offers innovative aeroponics production systems to the processed-salad industry and is considered as one of the top agro-tech start-ups in the country. Its **CombaFarm**: Aeroponic farming solutions for lettuce and aromatic plants, aims at decreasing the water consumption, increasing food security, and the efficient production and elimination of contaminants;
- **Ecorobotix**: completely autonomous smart weeding machine, field-test site.

2.1.4.3 Swiss strengths in space and terrestrial ALSS and MELiSSA-related activities – Technology-transfer level

Swiss survey responding organizations consider Terrestrial applications as one of the most interesting ALSS activity in the survey summarized above (Q5). In addition, “Industrial collaboration” (48%) and “Technology transfer” (42%) are part of their biggest expected outcomes from taking part of a Swiss community on ALSS/MELiSSA (Q18).

Partnerships including the full Swiss and European spectrum of industrial and academic actors, within both space and non-space domains, are key for developing innovation in space and on Earth.

Consequently, bridging scientific outputs to industrial needs, as well as patenting, can demonstrate concrete mid-term value and potential for the economy.

Swiss industry provided strong technological contributions in the framework of E3P notably for bioreactors, wastewater treatment and food production. Moreover, Swiss party could typically address system interfaces dealing with crew health and countermeasures such as medical sensors and instrumentation, physical fitness equipment, human factors engineering.

Partnerships including the full Swiss and European spectrum of industrial and academic actors, within both space and non-space domains, are key for developing innovation in space and on Earth.

Consequently, bridging scientific outputs to industrial needs, as well as patenting, can demonstrate concrete mid-term value and potential for the economy.

Enabling ALSS and MELiSSA-related technology transfers for terrestrial applications has also a positive impact on the Swiss economy, thanks to the many local suppliers providing key infrastructures and equipment to companies such as ESTEE or CombaGroup.

Therefore, it seems highly relevant to continue to take benefit from their potential for terrestrial applications of space closed life support to circular economy, waste management, environment, (eco)toxicology and health, as there is nowadays a high demand for a concrete implementation of the circular economy concept.

At the technology-transfer level, pursuing the current momentum on space and terrestrial ALSS-related activities in Switzerland - especially within the MELiSSA framework - could notably aim at:

- Promoting ideas or opportunities for collaborative partnerships with the non-space LSS industries, which could either be followed up bilaterally or channelled through the currently elaborated ESA framework for strategic partnerships with the private sector in the field of space exploration;
- Creating a steady flow of collaborative partnerships projects for:
  - Increasing the amount of technology transfers using spin-in and spin-off commercialization respectively of terrestrially-developed and space exploration-derived technologies;

    - Developing public-private partnerships and new businesses such as in applications addressing global challenges;
    - Connecting space compatible technologies to current terrestrial challenges.
- Generating new technology transfer “success stories” through inspiring innovation and creativity among the non-space sector;
- Putting particular attention to potential contribution to critical technologies identified for rescuing civil population in emergency situations (natural disasters, conflicts, etc.). EssentialTech Center at EPFL is an example of such programme in technology innovation for development and humanitarian action. Potentially interested organisations include CICR and UNHCR.

The following organizations responding to the survey also gave a short description of how their own potential contribution to a joint project would look like (Q23):

- Vuna: Detailed practical knowledge on nutrient recovery systems;
- SOFIES SA: Bring in one of their industrial clients, test innovative solutions in the organic waste management field, contribute by managing / facilitating multi-stakeholder processes, management of pilot projects, etc.

2.1.4.4 Recommendations

Activities related to terrestrial applications should aim at:

- Leveraging on Swiss expertise in R&D, technology cooperation and transfer opportunities to better exploit ALSS knowledge and know-how for space exploration and contribute to the development of terrestrial applications beneficial to society (spin-out activities, see §2.1.3.5), so that it could consequently be useful for:
    - Identifying additional promising terrestrial applications and generating new technology transfer “success stories” through inspiring innovation and creativity among the non-space sector;
    - Boosting innovation, competitiveness and growth in potentially new commercial sectors not yet explored by the space industry for the benefit of society;
    - Positioning Switzerland at the front edge of a reliable and efficient circular economy.

2.1.5 Education and communication

2.1.5.1 Swiss MELiSSA and ALSS stakeholders

MELiSSA-related laboratories/research groups and private organizations: UNIL, ETHZ, Eawag, ESTEE.

Additional ALSS-related research organizations, Space and innovation agencies: EPFL+ECAL lab, ZHAW, EPFL, HEAD, eSpace, Swiss Space Center, CleantechAlps, Innovaud.

In addition to the public and private (research) organizations listed above, several innovation agencies (both public and private) are promoting the development and the industrialization of ALSS-related activities, such as Innobridge, CleantechAlps, Platinn, Innovaud and Eqlosion.

2.1.5.2 Examples of concrete ALSS and MELISSA activities/accomplishments "made in Switzerland"

- **ESA Closed Habitats Forum 2016,** co-organized by ESA, UNIL and ESTEE (with support from Swiss Space Office and Swiss Space Center)**.** Over 130 participants. Sustainable resource management, sustainable habitats, smart monitoring and system control;
- Co-organization of **MELiSSA Scientific Workshop** (2016) by ESA, UNIL and ESTEE;
- Lecture, teaching and co-organisation of **EPFL ENAC Building on Mars teaching unit** (since 2012), EPFL, UNIL, ESTEE;
- Coordination of **ESA_Lab / IGLUNA** (2018-ongoing) by Swiss Space Center, with participation of the following Swiss parties: EPFL, ESTEE, UNIL, ZHAW (i.e., SWAG-System (smart waste-based agriculture growing system)).

2.1.5.3 Swiss strengths in space and terrestrial ALSS and MELiSSA-related activities – At various communication and educational levels

Regarding the *expected outcomes* from taking part to a Swiss community on ALSS/MELiSSA, the survey responding organizations considered (Q18) notably "Network/community building around ALSS" (52%) and "Participation to working groups or advisory bodies" (39%) and "Raise of awareness (dissemination of ALSS knowledge)" (36%).

Therefore, the national community should continue building momentum for the ALSS programme, fostering innovation, and establishing a highly skilled future workforce (e.g. via initiatives such as ESA_LAB's IGLUNA project, coordinated by Swiss Space Center, and training courses such as EPFL "Building on Mars"/ENAC teaching unit) or design project such as "Habiter l'espace extraterrestre" at HEAD Geneva).

At educational and communication levels, pursuing the current momentum on space and terrestrial ALSS-related activities in Switzerland - especially within the MELiSSA framework - could notably aim at:

- Raising public awareness of the spin-off potential of investments in space exploration (e.g., space applications for socioeconomic development, closed-loop systems and sustainable resource management) through a sustained promotion/communications campaign;
- Using the inspirational nature of ALSS and closed habitats to encourage a new generation of scientists and engineers and to contribute to the emergence of new fields of research;
- Strengthening interdisciplinary research for space exploration and fostering high quality academic publications;
- Engaging students in funding challenges for innovators to work on the key items which need to be developed to enable ALSS and closed habitat for space applications.

- Identifying additional scientific and technical research of common space/non-space interest and increase awareness of the downstream added-value chains benefiting society;
- Strengthening the position of organizations such as UNIL, EPFL, ETHZ, EAWAG, CSEM and HEI (HES-SO//Valais-Wallis) and ESTEE as key members/partners of the MELiSSA project;
- Federating other stakeholders to become active members, thus furtherly extending the community with actors such as private organizations (SMEs, startups, etc.) - should the latter be originally space-driven or not - or university hospitals;
- In the framework of STEM disciplines-related activities, using the high MELiSSA attraction pool for environment, ecology, high tech education and societal behaviour;
- Incentivizing Swiss non-space industry to engage in space ALSS activities and with ESA;
- Diversifying and broadening Swiss space stakeholders and ESA's user-base and engagement with the private sector;
- Facilitating the elaboration of concrete projects proposals of joint terrestrial and space interest;
- Taking benefit from the strong potential of ALSS for sustainability research and applications;
- Exploiting synergies between research in space and on Earth to enhance the benefits of space exploration for society and to leverage on terrestrial research for space.

2.1.5.4 Recommendations

Activities related to education and communication should aim at:

- Supporting the organisation of a (bi-)yearly targeted workshop that would respond to the demand of Swiss parties for increased interactions between MELiSSA activities and Swiss ALSS stakeholders. Such workshop would enable MELiSSA community to provide an overall activity report – not specific to Switzerland. Conversely, a summary of new Swiss ALSS development would be shared. This would build an essential communication channel to circulate information from the complementary activities distributed within the overall community (§2.1.5).
    - Consequently, such targeted workshop would would:
        - facilitate the definition of topics of investigation;
        - legitimate working groups (including ESA ones);
        - secure long-term roles;
        - exchange best practices and lessons learned;
        - facilitate technology transfers and spin-in & spin-out entities creation
        - enable innovative ground demonstration and mission concepts;
        - contribute to sustainability of space;
        - close knowledge gaps.
- Allowing an increased swiss visibility at the International level of manned space exploration.

2.2 Annex 2 – A brief Introduction to space ALSS and their relevance for terrestrial sustainability

Théodore Besson1, 2 & Prof. Suren Erkman1, April 2019
1. Industrial Ecology Group, Faculty of Geosciences and Environment, University of Lausanne.
2. Earth Space Technical Ecosystem Enterprises SA, Lausanne

Life Support Systems (LSS) are developed to provide the necessary conditions to sustain human life in a hostile environment over prolonged periods of time. Advanced Life Support Systems (ALSS) features found in manned spacecrafts such as the International Space Station are used 1) to control and revitalize the atmosphere composition, 2) to regulate pressure and temperature, relying today mainly on physico-chemical processes, 3) for water recovery and management, 4) for human waste management and 5) for fire detection and suppression. These functions require periodic resupply of fungible materials (consumables), such as the upload of food from Earth.

Because of the high cost and complexity of space logistics, r*e*supply is a major problem for the feasibility of long-term planetary missions. Such missions would benefit from a new generation of bioregenerative LSS. At the present time, BLSS subsystems are mainly developed by the space community, including national space agencies, because of their relevance - if not necessity – for being used during manned interplanetary missions or during any other long-term space missions, on lunar bases for instance.

A space ALSS, being a particular case of Artificial Closed Ecosystem (ACE), can also be considered as a simplified and miniaturized ecosystem. It uses biological organisms (bacteria, algae, plants, etc.) to regenerate air, water and food with the objective of complete self-sufficiency. It must provide extensive features that are essential and vital for the survival of the crew and also necessary to the fulfilment and achievement of space missions. Microorganisms cultures are employed to recycle water from wastes; higher plants are an essential source of fresh food through cultivation and harvesting, water is also partly recycled through plant evapotranspiration, and oxygen is produced by higher plants or microalgae photosynthesis. More specifically, the system ensures 1) the supply of water (drinking water and personal hygiene); oxygen and food (essentially vegetal biomass) for the crew, and 2) the recycling, the regeneration and/or the valorization of organic wastes (faeces, non-edible parts of plants), air (exhaled CO_2) and wastewater (including urine). ALSS recycling processes take place in a highly controlled environment, with immediate time horizon, and focus in particular on carbon, hydrogen, oxygen, nitrogen, sulfur, and phosphorus contents, that represent 95% of the matter being recycled. Nevertheless, taking into account the crucial role of numerous trace elements, their study is also necessary.

Space ALSS are characterized by: 1) isolation, boundedness, closedness, 2) (relative) simplicity, 3) limited space and weight, 4) high reliability and stable functioning, 5) reduced operating time scale, 6) limited resources and difficult resource replenishment (self-sufficiency necessary), 7) limited carrying capacity and fragile environment, 8) tight link between sustainability and survival.

The goal of ALSS is very ambitious, since the unpredictable dynamics of living communities constitute a serious challenge in terms of deterministic behavior of the system. These systems are highly non-linear, with a high level of uncertainty in their behavior, making it impossible to perform a complete analytical modelling of the processes. It is therefore necessary to develop, in parallel with the biochemical and physiological studies, new approaches to system control.

Many of the issues identified for ACEs (such as analytics, monitoring, impact assessment, removal of contaminants, etc.), also apply to the circular life support concepts studied in the context of long-haul space missions. The Micro-Ecological Life Support System Alternative (MELiSSA) is for instance a contained short-cut compartmentalized ecological system that combines organic waste biotransformation and food production. Like in natural ecosystems and in artificial closed loop systems, the behavior and effects of organic micropollutants in an ALSS like MELiSSA are largely unknown. Short cycle times and small buffer volumes make circular LSS interesting platforms to study (eco)toxicological effects of

micropollutants on micro-organisms, plants and food under 'accelerated' conditions.

Within the European Space Agency (ESA), space-related R&D activities focusing on closing material loops (such as the ones in progress at the MELiSSA Pilot Plant[7] in Barcelona) could be seen as enabling activities to foster the convergence between space and terrestrial communities working on applied R&D and technology transfer in the field of wastewater recycling, closed-loop system monitoring and food production.

Main BLSS subsystems directly related to MELiSSA include collection of organic wastes in the cabin (inedible biomass, human wastes, etc.) and packaging, etc.; collection, stabilization and treatment of wastewater (yellow, grey, black, vegetal fibres); recovery (C, N, P, oligo-elements), storage, transport and supply of drinking water for the consumption and the personal hygiene of the crew.

Convergence of space and terrestrial R&D and technological transfer agenda

Space BLSS represent an interesting poly-functional laboratory for engineering sustainable, quasi-closed-loop systems, functioning in a reliable and stable manner with limited resources, and in a very limited amount of space. Because one of their most interesting aspects is their capacity to recycle (human) wastes such as urine, this technology could also be used in terrestrial applications. As microbial contamination is a major issue, a safe urine recycling system tested in quasi-closed-loop systems would represent an extremely interesting technological innovation.

Figure 1 shows a typical terrestrial R&D agenda to be implemented in a ground simulator for ALSS demonstration, and has been described in UNIL Oïkosmos study on space and terrestrial research synergies. Such hybrid testbed can be seen as an unprecedented experimental platform to improve environmental performance of recycling systems. Therefore, Oïkosmos study views ALSS simulators not only as tools that can help explore specific aspects of industrial and natural ecosystems, but also as test facilities where researchers can control the parameters of an almost entirely closed habitat. In the long run, this type of simulator could be used to design larger-scale strategies and help bring industrial systems more in line with the principles of sustainable development. A "sustainability laboratory" could therefore be developed in parallel to the space program, given the intrinsic potential that this facility would have for terrestrial research on ecosystems – including the extreme types of ecosystems represented by ACEs.

In conclusion, it appears that expertise acquired in space ALSS projects can be adapted for terrestrial applications. Earth-based applications of closed-loop systems are geared to operate in contexts with significant constraints and/or in extreme conditions: in built-up ecosystems (city infrastructures, residential and industrial areas, hospitals, places hosting large events, hotels and resorts, etc.); in ecosystems suffering from resources shortage (water, phosphorus, etc.) and/or pollution (contaminated resources), in remote regions, as well as in confined and isolated habitats (islands, mountains ecosystems, (Ant)arctic, large ships, bunkers, etc.). Other specific terrestrial applications of LSS, ACE and closed habitats are described in Figure 2.

[7] Some of the challenges of the MELiSSA pilot Plant are listed on www.melissafoundation.org/page/melissa-pilot-plant

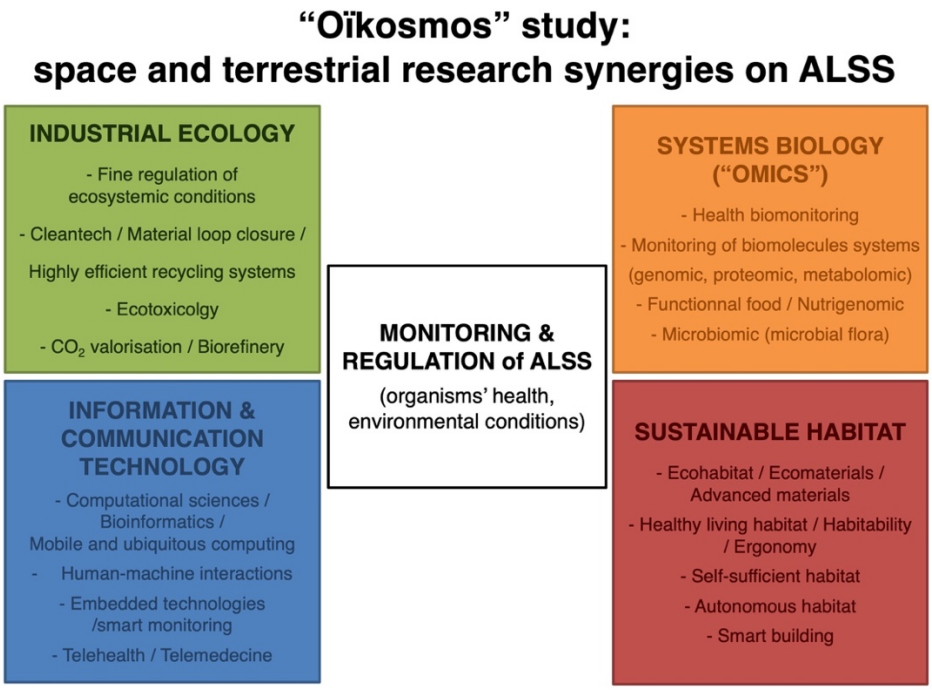


Figure 1: Oïkosmos study covers space and terrestrial research synergies related to ALSS ground demonstration. The associated R&D fields can be grouped in four main areas: 1) industrial ecology, 2) systems biology ("omics sciences"), 3) Information and communication technology, 4) sustainable habitat. All of them are playing a crucial role for monitoring and regulating closed-loop systems and circular LSS running in a closed habitat.

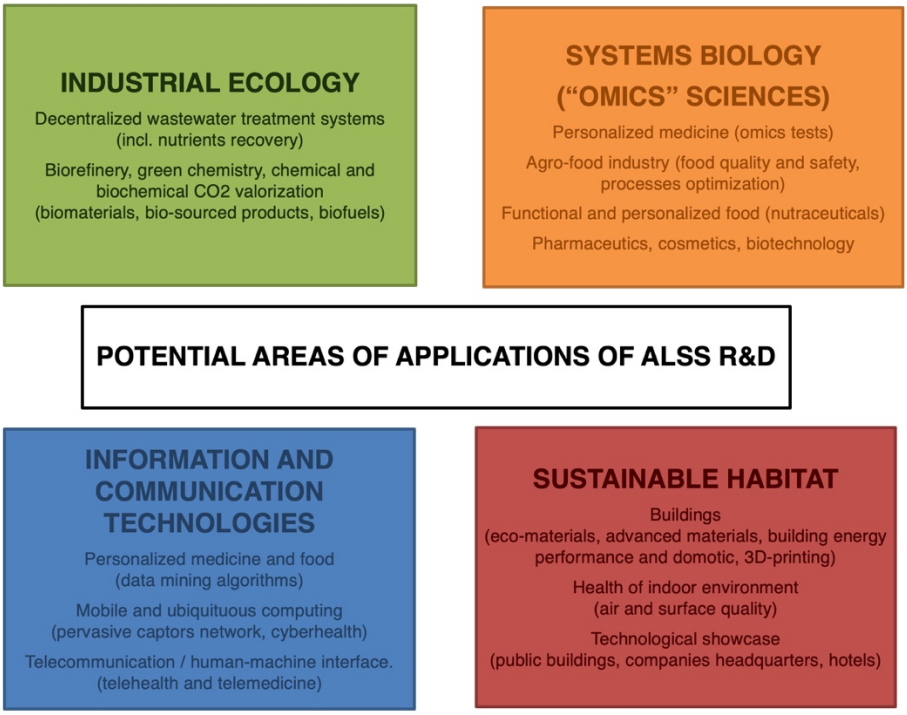


Figure 2: Potential areas of applications by synergizing the R&D and technological transfer on ALSS.

2.3 Annex 3 – SWOT analysis of the MELiSSA roadmap

Théodore Besson[1, 2] & Prof. Suren Erkman[1], August 2019
1. Industrial Ecology Group, Faculty of Geosciences and Environment, University of Lausanne
2. Earth Space Technical Ecosystem Enterprises SA, Lausanne

An analysis of the strengths, weaknesses, opportunities, threats (SWOT analysis) of the MELiSSA roadmap is presented below[8]. It provides a focus on the roadmap strengths with an awareness of the weaknesses, while minimising the threats and taking the greatest advantage of opportunities. The SWOT analysis also integrates elements and point of view specific to the Swiss ALSS context and emerging community.

Italics denote open/difficult issues

2.3.1 Strengths

- Access to advanced space R&D facility/hardware (e.g., MELiSSA has unique facilities such as the MELiSSA Pilot Plant; its partners have state-of-the-art lab facilities)
- Access to advanced expertise in linking and interfacing the individual loop components/processes
- Access to a platform of knowledge exchange (MELiSSA has state-of-the-art knowledge of core processes of circular systems)
- Access to ESA label and space network (MELiSSA's space aspect appeals to the popular image of science)
- Access to a unique group of multidisciplinary experts experienced in working together in the field of circular LSS
- Access to unique expertise of multiphase processes in reduced gravity and space
- MELiSSA uniqueness: closed-loop LSS set up coupling organic waste valorisation to nutrient recovery and food production
- Participation in project connecting space compatible technologies to current terrestrial challenges (e.g., sustainable use of resources, decentralised (wastewater) treatment systems, micropollutant diffusion)
- MELiSSA as a driver for the development of high-tech solutions and equipment
- Unique initiative with long term commitments (>25 years) from ESA and National Space Agencies and offices
- High-grade mimicked closed ecosystem set-up addressing organic waste valorisation, nutrient recovery, food production. Uniqueness (USP): closed-loop system offering meso-complexity level
- Possibility to tune to stakeholder interests (subtopics)

[8] Partly adapted from BELiSSIMA phase A – TN 118.1.6

2.3.2 Weaknesses

- *Some of the hardware and technologies are still at low TRL (< TRL 5)*
- Some ESA heavy administrative procedures, sometimes with lack of flexibility
- *ESA rules are not elaborated to facilitate direct agreement/collaboration with industry, including for confidentiality*
- Obligation to fulfil space interests and geographical returns sometimes seen as challenging for "terrestrial" parties
- *MELiSSA technologies sometimes easier to sell at subsystem or individual level compared to complete loop one. Reversely, MELiSSA system tools sometimes easier to sell at complete loop level compared to subsystem or individual ones*
- *Validated methods and test systems required for legislation*
- *Artificial complex ecosystem may not bring sufficient added value for external parties*
- Too many partners with too spread budget
- No investment capacity for self-financing public-private partnerships
- Not enough return on investment from spin-off technologies for terrestrial applications (to be able to finance faster new R&D and tech transfer activities)
- No ground demonstrator of a large-scale proof of concept project
- Better understanding needed by some stakeholders of how space technologies could be beneficial to terrestrial applications for some ALSS topics
- *As a result of not being a completely integrative ESA project, MELiSSA has developed into a complex structure sometimes seen as resilient to change*
- Lack of a clear political declaration of commitment for MELiSSA project

2.3.3 Opportunities

- Initiate PPP for a large-scale proof of concept ground demonstrator project
- Hosting a Swiss ALSS spot where all the related R&D can be tested and demonstrated
- ALSS empower a two-way exchange between terrestrial and space sciences and technologies (spin-in and spin-out)
- Diversification of funding scheme (through external financing routes, not just via Swiss delegation)
- Increasing number of stakeholders from industry, giving some perspective to be more tech-transfer-oriented and market-oriented
- Open link between industry and space R&D
- Links to ongoing Swiss ALSS-related activities – either space or terrestrial-oriented - and initiatives can be made
- "Sell" the "brand" ESA to attract partners in order to consolidate the emerging Swiss community
- ALSS as space-relevant topic and attracting lots of attention
- Links to ongoing activities and initiatives can be made
- Fit with regional smart specialisation strategies
- Exchange best practices and lessons learned
- Gain in reactivity, speed of progress through synergies
- Many foreseen tangible benefits in terms of potential partnerships, ESA label, knowledge-sharing, networking

2.3.4 Threats

- Necessity to cover the full innovation value chain (R&D, TT, prototype, pilot plant, market diffusion)
- *The envisaged hardware of the MELiSSA (sub)project sometimes fits only limited needs*
- Some MELiSSA investigations requires high-grade hardware
- *Running hardware/studies requires skilled/trained people*
- *Only subtopics fit with terrestrial interest, not overall topic*
- Some expected MELiSSA funding does not materialize (ie. BELiSSIMA)
- Stakeholders do not take risk to enter long term collaboration
- Space brings too many requirements: no interest in even more costly test facilities
- Sometimes limited interest in 'artificial' closed ecosystem studies or hardware
- Sometimes no immediate economic benefits
- End of the project if no public motivation, so to make the public dream keeps mandatory (cf SpaceX communication)
- *ESA does not declare clearly its interest in MELiSSA*
- *The available hardware fits only limited needs or is not representative of upper-scale processes (i.e., for wastewater treatment)*
- Limited time to secure co-funding
- Stakeholders might not take the risk to enter long term MELiSSA collaboration
- Stakeholders might find it difficult to understand MELiSSA scope (scope perceived as too broad or unclear)
- Possible insufficient interest of stakeholders
- No match between space and terrestrial approaches
- No translation of higher-level scientific objectives into technical requirements
- Risk of conflict of interest among stakeholders
- Industry might hardly accept to invest without confidentiality
- Impossible to match aspects of MELiSSA MoU and other funding options/organizations, including confidentiality and IP
- Impossible to match contract conditions of ESA/MELiSSA and of the partner organizations
- Industry might hardly invest intensively for 30 years without shorter return

2.4 Annex 4 – Survey on Swiss activities, interests and strengths in ALSS

2.4.1 Survey objectives

A 32-question survey was sent in early April to a list of over 80 public and private organisations (over 110 recipients[9]), spread in the following categories:

- Category 1: Existing MELiSSA community (23 organizations, 36 recipients);
- Category 2: Organizations that are active on ALSS-related activities and/or that have been approached in the framework of an ALSS/MELiSSA project (including some participating as consultants) (28 organizations, 38 recipients);
- Category 3: Potential future MELiSSA community members (31 organizations, 43 recipients).

The motive for approaching the first and second categories of the Survey recipients, was to get an up-to-date perspective of their organization's interests (and strengths) on ALSS/MELiSSA-related activities.

For the third category, the organizations were informed that they had been identified as potentially interested in joining an ALSS/MELiSSA community, so that the Survey would be a way to introduce them to the field. In this perspective, a brief introduction to space Advanced Life Support Systems, and their relevance for terrestrial sustainability was attached to the Survey cover email (see §2.2).

Concretely, the objectives of the Survey were to:

- Map the interests of the organization in ALSS/MELiSSA-related topics
- Register past and ongoing activities of the organization related to ALSS/MELiSSA
- Explore the areas of interests for possible future collaboration opportunities in the field of ALSS

The survey mostly consisted of multiple-choice questions and checkboxes. Approximately 15 minutes were required to complete it, except for the responders that already had project descriptions to enter, sometimes collected in parallel to the Survey. The (facultative) short listing of relevant projects that the responding organizations had achieved, are pursuing, or envisage to start in the field of ALSS, both as space and terrestrial levels, was one of the main objectives of the process.

Category 1 and category 2 stakeholders all received a follow-up call or email from one of the following organizers of the survey:

- Prof. Suren Erkman, University of Lausanne
- Dr. Tatiana Benavides, Swiss Space Center
- Dr. Petros Dimitriou-Christidis, Earth Space Technical Ecosystem Enterprises SA
- Grace Cain, ETH Zurich
- Valentin Faust, Eawag
- Théodore Besson, University of Lausanne / Earth Space Technical Ecosystem Enterprises SA

The purpose of the follow-up communication was to be available to guide the organization as efficiently as possible in the collection of their feedback.

The survey ended on the 16th of May, 2019, with 33 respondents from 27 organizations.

[9] Note that several departments/laboratories/entities of the same organization could respond to the survey

2.4.2 Content of the survey

The 31 questions of the survey (Q1-Q31) were formulated to gather information on the following topics:

- Organization profile (Q1-Q4)
- Organization's interests in ALSS and MELiSSA-related R&D and/or tech-transfer activities (Q5-Q6)
- Topics mapping for industrial applications (Q7), sustainable resource management (Q8), smart monitoring and system control (Q9)
- MELiSSA assets and uniqueness (Q10)
- Swiss activities connected with MELiSSA technologies (Q11)
- Current involvement in an ALSS/MELiSSA research or technology transfer (Q12)
- Known funding options (Q13)
- Past and present involvement in ALSS/MELiSSA projects (Q14-Q16)
- Interest in participating in MELiSSA-related activities (Q17) and associated expected outcomes (Q18-Q19)
- Interest in having access to some MELiSSA laboratory/testbed hosted in Switzerland (Q20)
- Interest in participating in MELiSSA-related activities at supranational level (Q21)
- Potential to set up new collaborations on ALSS/MELiSSA-related activities within the next two years (Q22)
- Description of how a potential contribution to a joint project with MELiSSA would look like (Q23)
- Preferred collaboration model (Q24)
- Envisioned levels of involvement (Q25)
- Considered kinds of contribution (Q26)
- Potential difficulties/bottlenecks (in terms of R&D, funding, etc.) and associated solutions perceived (Q27)
- Swiss stakeholders in the private sectors in the responding organisations' network which could be interested in MELiSSA/ALSS (Q28)
- Interest in being involved in a Swiss ALSS/MELiSSA community/network (Q29)
- Interest in participating in a workshop/conference on ALSS by mid 2020 (Q30)
- Complementary suggestions/comments (Q31)

2.4.3 Summary of survey results analysis

The analysis of the survey results is based on responses provided by 33 respondents from 27 organizations (Q1).

Among them, respondents with space-related organizations background comprise 47% of the respondents (Q2).

More than half of the organizations are active in R&D; 24% are private organizations; 9% of the organizations act in applied R&D; finally, 9% of the organizations are innovation agencies/platforms (Q3).

Regarding the *sector of activity* of the organizations, a third are academic/university, more than 20% are from the environment and cleantech sectors, and another third is spread among the sectors of farming/agriculture, aerospace, biotechnology and engineering (Q4).

Swiss organization's interests are covering the full spectrum of *ALSS and MELiSSA-related R&D and/or tech-transfer listed activities* (15 in total) (Q5). The top-7 interests are: 1) Terrestrial applications (47%); 2) Modelling and system design (41%); 3) Water quality and safety (35%); 4) Societal impacts and education related to terrestrial sustainability (35%); 5) Organic waste processing and refinery (32%); 6) Closed habitat/ Sustainable housing (materials, energy, environmental footprint, ergonomy) (32%); 7) Ground demonstrators and analogue testing (32%). Only one activity (Air quality and safety) is exhibited by fewer than 23% of the respondents.

In addition, 12 out of the above 15 activities are considered to be of *main interest* (=ranked 1st) by at least one respondent (Q6), with notably plant characterization, edible biomass production (5 times 1st), Physical, chemical, and microbial contaminants and Terrestrial applications (4 times 1st) and Closed habitat/Sustainable housing, Yellow and grey water treatment and recycling, Water quality and safety, Modelling and system design (3 times 1st). After weighting, the ranking of the responding organisations' interest in ALSS/MELiSSA-related R&D and/or tech-transfer activities are as follows:

Q6 (incl. vote weighting)	33 answers					
Ranking	**1**	**2**	**3**	**Total ranking 1, 2 or 3**	**Total ranking [weighted*]**	**% answers [weighted*]**
Terrestrial applications	4	2	7	13	**23**	12%
Plant characterization, edible biomass production	5	2	1	8	**20**	10%
Water quality and safety	3	4	1	8	**18**	9%
Modelling and system design	3	2	3	8	**16**	8%
Physical, chemical, and microbial contaminants	4	1	2	7	**16**	8%
Closed habitat/ Sustainable housing (materials, energy, environmental footprint, ergonomy)	3	2	1	6	**14**	7%
Societal impacts and education related to terrestrial sustainability	0	5	3	8	**13**	7%
System monitoring and control	0	4	4	8	**12**	6%
Yellow and grey water treatment and recycling	3	1	1	5	**12**	6%
Organic waste processing and refinery	1	3	2	6	**11**	6%
Ground demonstrators and analogue testing	2	1	2	5	**10**	5%
Flight experiments and space technology demonstrators	1	3	1	5	**10**	5%
Food quality, processing, and human nutrition	2	2	0	4	**10**	5%
Societal impacts and education related to space exploration	2	0	1	3	**7**	4%
Air quality and safety	0	1	2	3	**4**	2%
	** 6 pts distributed per answer: 1st=3pts, 2nd=2pts, 3rd=1pt*					

Of the topics mapping for *industrial applications* (Q7), the following collected more than 30% of responses: Bioreactor development and biomass production (42%) and Life sciences (35%); Decentralized waste(water) management (39%); Urban farming (39%), Food production (32%); and Intensive bioprocess optimisation and control (35%).

Of the topics mapping for *sustainable resource management* (Q8), the following notably collected more than 30% of responses: Closed-loop system/approach (51%), Sustainable habitat (51%), Recycling (48%), Water (45%), Coupling waste valorization with food production (42%), Ecosystem (42%), Self-sufficient/autonomous/autarchic habitat waste (39%), industrial ecology/circular economy resource valorization (36%).

Of the topics mapping for *smart monitoring and system control* (Q9), the following collected more than 30% of responses: Sensing and detection technologies (48%), Real-time monitoring (48%), Control system (45%), System modelling and simulation tools (42%), Quality of life / habitability (36%) and Healthy habitat (30%).

On the MELiSSA-related assets and uniqueness (Q10) of notable importance, the following were mentioned: Access to experts in the field of circular LSS collected 67% of the replies; Participation in projects/synergies for connecting space compatible technologies to current terrestrial challenges reached 64%.

The following assets gathered between 30% and 48% of the expressed opinions (in order of descending percentage of expressed opinions):

- Access to a platform of knowledge exchange (MELiSSA has state-of-the-art knowledge of core processes of circular systems)
- Access to advanced space R&D facility/hardware (e.g. MELiSSA has unique facilities such as the MELiSSA Pilot Plant; its partners have state-of-the-art lab facilities)
- MELiSSA as a driver for the development of high-tech solutions and equipment
- MELiSSA uniqueness: closed-loop LSS set up coupling organic waste valorization to nutrient recovery and food production
- Access to advanced expertise in linking and interfacing the individual loop components/processes

Swiss organization's activities are connected with a broad range of MELiSSA-related technologies (Q11), the following technologies being indicated by more than 30% of the respondents: Closed-loop systems and circular ALSS (53%), Water and waste quality analysis (43%), Advanced control systems (e.g. model based) (43%); Removal of chemical contaminants (37%), Urine treatment unit (33%) and Nutrient recovery and delivery (33%).

82% of the respondents are *currently* not involved in an ALSS/MELiSSA research or technology transfer (Q12). The active organizations that replied to the survey are:

- ETH Zurich - Group of Plant Nutrition (both at the national and international level)
- Eawag - Group of Source Separation and Decentralization (mainly at the international level)
- RUAG Space Nyon (mainly at the national level)
- Earth Space Technical Ecosystem Enterprises SA (both at the national and international level)
- University of Lausanne - Group of Industrial Ecology (both at the national and international level)

Other Swiss organizations that recently performed an activity related to ALSS/MELiSSA include: EPFL ENAC, HEI (HES-SO//Valais-Wallis), PSI, SCAHT, CentreEcotox.

The funding schemes (Q13) for ALSS that the respondents are aware are mainly the ones of SSO through ESA and InnoSuisse (47% each), as well as the ones from SNF (44%) and SSO national (25%). The other funding schemes include Eurostar, Horizon 2020, INTERREG, and institutional funding scheme (UNIL rectorate, EPFL, HES-SO) Swiss Space Center (sponsor of the Closed Habitat Forum 2016) and IDK.

A list of over 30 projects could be gathered (with a few redundancies due to the participation of several Swiss organizations) (Q14-15-16) (MELiSSA-related activity underlined and **MELiSSA-related achievement in bold**):

- **Biorat Phase B (2015-2019, coordinated by RUAG Space Nyon)**
  Pre-development and test of a flight experiment composed of a closed gas loop producing O_2 (algae photosynthesis) and consuming CO_2 of a mice crew. Technology demonstrator for ISS that is intended to a couple photobioreactor (microalgae) with a consumer compartment in a closed-loop fashion, led by RUAG. Expertise: system, full life cycle - up to launch. Space requirements. Launch planned in 2025;
- **MELiSSA Food Characterization Phase 2 (2014-2015, IPL (Belgium), and with coordination of HEI (HES-SO//Valais-Wallis) and support by RUAG Space Nyon). Hydroponic** subsystem studied at scientific and engineering levels, delivery of technical requirements & completion of preliminary testing phase. FPCU concept and engineering requirements. HEI (HES-SO//Valais-Wallis) expertise: Food processing, HACCP, Hygienic design, Sensory evaluation;
- **Oïksmos project: space and terrestrial research synergies (2010-2016).** UNIL expertise: artificial closed ecosystems, terrestrial sustainability, terrestrial applications, circular systems, closed habitat, report to the UNIL rectorate of UNIL from industrial ecology group. Societal challenge: integral recycling, resource valorization;
- **Dynamic Modelling of Material Flows and Sustainable Resource Use. Case Studies in Regional Metabolism and Space Life Support Systems (2010-2012).** UNIL PhD thesis. Sustainable resource use, material flow analysis, space life support systems, dynamic modelling, Closed-loop systems modeling Regional metabolism, subsystems interfacing and integration. Space requirements;
- PhD on artificial closed ecosystem as drivers for eco-innovation (UNIL);
- Participation to ESA/MELiSSA working groups (UNIL);
- Closing anthropogenic carbon loops: towards implementing a circular economy, UNIL post-doc (MELiSSA POMP programme). In-situ resource utilization (ISRU), resource reutilization, carbon dioxide recycling, carbon capture and utilisation, technology-enabled carbon cycles, carbon input-output accounts and modeling, anthropogenic systems, terrestrial applications. Expertise: industrial ecology, resource valorization terrestrial sustainability. Societal challenge: coupling CO_2 valorization with food production and/or microalgae production;
- POMP II. Urine treatment (2017-ongoing), PhD thesis led by Eawag. Optimization of a urine treatment reactor, food production using urine fertilizer;
- Crop production in hydroponics using recycled nutrients and microbial consortia (2018-ongoing). Topics: hydroponics, urine, soybean, nitrogen, PhD thesis at ETH Zurich - Group of Plant Nutrition (POMP);
- Higher plant modelling of wheat root plasticity under nutrient deficiencies. Topics: investigation of wheat root system plasticity under nutrient deficiencies, led by ETH Zurich - Group of Plant Nutrition;
- Scorpius Prototype (SP1) - Towards a proof-of-concept of a closed habitat on-ground demonstration integrating main BLSS functions, led by Earth Space Technical Ecosystem Enterprises SA (2017-ongoing). Topics: 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. 99% of design completed in 2018;
- **BELISSIMA – Phase A (AO/1-8342/15/NL/AT) (2016-ongoing).** Led by VITO (prime contractor), Earth Space Technical Ecosystem Enterprises SA, UNIL and UGent (subcontractors). Topics: behaviour and effects of microcompounds in closed soil-free ecosystems, behaviour and impact

of microcompounds, closed system chemical contaminants, microcompound removal, water reuse/ recycling. Societal challenges: ecotoxicology;

- ESA Study of the Assessment of the Financial and Business Potentials of the Life Support Systems (LSS) Technologies (AO/1-9556/18/NL/AT), led by Leoni Corporate Advisors (ITA/CH), Earth Space Technical Ecosystem Enterprises SA (subcontractor) [started in 07.2019];
- **ESA Closed Habitats Forum 2016, Co-organized by ESA, UNIL and Earth Space Technical Ecosystem Enterprises SA** (with support from Swiss Space Office and Swiss Space Center)**. Over** 130 participants. Sustainable resource management, sustainable habitats, smart monitoring and system control;
- **Co-organization of MELiSSA Scientific Workshop (2016) by ESA, UNIL and Earth Space Technical Ecosystem Enterprises SA**;
- Lecture, teaching and co-organisation of EPFL ENAC Building on Mars teaching unit (since 2012); EPFL, UNIL, Earth Space Technical Ecosystem Enterprises SA;
- Participation to ESA Lab / Igluna (2018-ongoing), EPFL, Earth Space Technical Ecosystem Enterprises SA, ZHAW (i.e., SWAG-System (smart waste-based agriculture growing system))
- **ESA TAS – Towards the Establishment of a Standard on Closed Habitat Specifications** (Reference 130046707) (Earth Space Technical Ecosystem Enterprises SA) (2018-ongoing);
- Space Loop. Pyrolysis of human fecens, ZHAW;
- Supercritical Water Oxidation of fecal sludge, Reinvent the Toilet Challenge, Bill & Melinda Gates Foundation, led by Eawag, with participation of Paul Scherrer Institut/FHNW, TRL 4-5, 1 year to TRL 5;
- Voucher (Agroscope-CSEM). Soil nitrate monitoring. Proof of concept of long-term nitrate sensing in agricultural soil. CSEM expertise: Nitrate sensing platform. No space requirements. TRL2;
- WeST (CSEM). Wearable sweat tracker. CSEM expertise: Printed, functionalized electrochemical sensors; System engineering. No space requirements. TRL3;
- RADAR (CSEM-FP7 grant). Modular platform for monitoring toxins in water and food production facilities using biosensors derived from aquatic organisms. CSEM expertise: Sample preparation; Analyte extraction; Label free detection. No space requirements. TLR4;
- Smart toilet (CSEM). Urine analysis for health monitoring. CSEM expertise: Printed, functionalized electrochemical sensors; System engineering. Societal challenge: Personalized health monitoring. No space requirements. TLR3;
- Nutrishield (CSEM-H2020 grant). Urine analysis as a feedback for personalized nutrition. CSEM expertise: Printed, functionalized electrochemical sensors; System engineering. No space requirements. TLR3;
- Optodex (CSEM). Chemical functionalization of surfaces for antimicrobial properties. CSEM expertise: Chemical functionalization. No space requirements. TLR5;
- Multispectral imaging for plants monitoring (CSEM internal activity). CSEM expertise: Multispectral imaging (imagers, data processing), plasmonic filters, ultra-low power embedded vision systems. No space requirements. TRL3;
- Drinking water quality monitoring by measuring inorganic and organic contaminants (CSEM internal activity). CSEM expertise: Light scattering/turbidity, biochemical sensors (highly specific), surface coatings. Societal challenge: Drinking water safety. No space requirements;
- SCIMA Connected Autonomous Monitored Greenhouse: INTERREG project led by Earth Space Technical Ecosystem Enterprises SA on its Swiss side (with the participation of UNIL and Grangeneuve), food production in constraints environments;
- Comba Farm: Aeroponic farming solutions for lettuce and aromatic plants, led by CombaGroup. Decrease the water consumption, increase food security, efficient production, elimination of contaminants;
- Ecorobotix: complete autonomous smart weeding machine, field-test site;

- Systems Engineering and Design of a Mars Polar Life Research Base (Anne-Marlène Ruëde, EPFL Msc thesis, 2018); Living Architecture scenarios, Earth applications Liquifer Systems Group. Outreach conference : European Mars Convention, La Chaux-de-Fonds, 2018, covering ALSS;
- Ethics of Planetary Sustainability: Ethical assessment of space exploration regarding sustainability (Dr. Andreas Losch, University of Bern).

Globally, 97% of the respondents are interested in participating in MELiSSA-related activities, among which 61% are highly interested (Q17).

Regarding the *expected outcomes* from taking part in a Swiss community on ALSS/MELiSSA (Q18), more than 50% organizations considered the following expected outcomes from taking part in a Swiss community on ALSS/MELiSSA: Scientific collaboration (61%), (Applied) R&D opportunities (58%), Participation in workshop/conference (55%), Provide scientific/technical expertise on specific ALSS topics and Network/community building around ALSS (52% each).

The responding organizations also considered the following expected outcomes: Industrial collaboration (48%), Participation in technology demonstration/showcase (technological component/module, prototype, emerging technology or applications, business incubator, etc.) (45%), Technology transfer (42%), Participation to working groups or advisory bodies (39%), Raise of awareness (dissemination of ALSS knowledge) (36%), Benefit for the MELiSSA scientific and engineering expertise and Training courses organization / Continuous education (30% each).

10 out of these 18 same kind of collaborations on ALSS with MELiSSA were ranked as 1st choice by at least one respondent (Q19), with notably Scientific collaboration (13 times 1st), (Applied) R&D opportunities (7 times 1st) and Participation in technology demonstration/showcase, Network/community building around ALSS, Raise of awareness (dissemination of ALSS knowledge) (2 times 1st). After weighting, the ranking of the responding organisations' for the top-3 kinds of collaborations are as follows:

Q7 (incl. vote weighting)	33 answers					
Ranking	**1**	**2**	**3**	**Total ranking 1, 2 or 3**	**Total ranking [weighted*]**	**% answers [weighted*]**
Scientific collaboration	13	1	1	15	**42**	21%
(Applied) R&D opportunities	8	3	3	14	**33**	17%
Participation in technology demonstration/showcase (technological component/module, prototype, emerging technology or applications, business incubator, etc.)	2	4	5	11	**19**	10%
Industrial collaboration	2	3	4	9	**16**	8%
Provide scientific/technical expertise on specific ALSS topics	1	4	2	7	**13**	7%
Participation to working groups or advisory bodies	0	4	3	7	**11**	6%
Participation in workshop/conference	1	2	3	6	**10**	5%
Network/community building around ALSS	2	2	0	4	**10**	5%
Raise of awareness (dissemination of ALSS knowledge)	2	1	1	4	**9**	5%
Spin-off commercialization of ALSS terrestrial applications	0	3	1	4	**7**	4%
Benefit for the MELiSSA scientific and engineering expertise	0	2	2	4	**6**	3%
Training courses organization / Continuous education	1	0	2	3	**5**	3%
Technology transfer	0	1	2	3	**4**	2%
Test/benchmark/validation of methodologies (services)	0	1	1	2	**3**	2%
Spin-in commercialization of ALSS space applications	0	1	1	2	**3**	2%
Use/operation of ALSS hardware	1	0	0	1	**3**	2%
Technology watch	0	0	1	1	**1**	1%
Investment opportunities	0	0	0	0	**0**	0%
	** 6 pts distributed per answer: 1st=3pts, 2nd=2pts, 3rd=1pt*					

Almost 80% of the responding organisations would be interested in having access to some MELiSSA laboratory/testbed hosted in Switzerland (Q20).

27% of the organisations that replied are already participating in MELiSSA-related activities at

supranational level and 45% would be interested in participating (Q21). Only 27% are not especially aspiring to participate at supranational level at the moment.

47% of the responding organisations consider as high their potential to set up new collaborations on ALSS/MELiSSA-related activities within the next two years (Q22). 35% foresee a moderate potential, and only 18% a low potential.

The following organizations gave a short description of how their own potential contribution to a joint project would look like (Q23):

- RUAG offers capabilities to build experiments and validate part of the ALSS loop through their In Orbit Demonstrator (IOD). RUAG also offers its expertise to develop techno building blocks such as “gas-liquid-solid interface for oxygen transfer in Life Support Systems” to be used for different experiments. Finally, RUAG is able to provide skills in consultancy mode, on demand;
- UNIL - Prof. Sarah Mitri: “We are working on building model microbial ecosystems that we can control in a close-loop manner. We also build mathematical models that help predict dynamics in our experimental systems. These results should be highly relevant for MELiSSA.”;
- CSEM: Development of specific technology bricks or adaption of CSEM technologies/knowhow based on ALSS requirements/needs - Bridge gaps between TRL 2 and TRL 7;
- Innobridge: Hosting a testbed or MELiSSA laboratory on Agropole site (agritech & foodtech hub in development in Canton de Vaud);
- HES-SO VS: MELiSSA Food characterisation – Phase 3. Validation of the FPCU concept proposed in MELiSSA Food characterisation – Phase 2 + Impact of food processing and formulation (i.e. nutraceuticals) on nutrients bioavailability & on human microbiote. 5 years to TRL5. Multidisciplinary expertise in : - food processing - food safety - nutraceuticals & nutrients bioavailability - hygienic design of food Equipment (EHEDG) - waste & by-products valorization - water & air management - biomaterials bioenergy - microalgae (i.e., spirulina) production - microbiote characterization based on in vitro digestive model - real-time data acquisition & control;
- EPFL+ECAL lab: They propose to introduce the discipline of design research to investigate the user experience and user interface dimension for different parts of the system. This work includes understanding of user perception, with a focus on cognitive and emotional state component. They believe that new designs of scenario of uses, habitats and interfaces can open new ways in human behaviour facing closed environment. Their idea is to put an emphasis on what can be transferred on Earth and be implemented in everyday life of large audience;
- Vuna: Profound practical knowledge on nutrient recovery systems;
- SOFIES SA: Bring in one of their industrial clients, test innovative solutions in the organic waste management field, contribute by managing / facilitating multi-stakeholder processes, management of pilot projects, etc.;
- Oracan Sàrl: Biotech technologies engineering/development; Space projects Management;
- HSLU – Center for Bio- and Medical Engineering Tim Granata: Development and testing of photobioreactor to produce biomaterials for additive manufacturing;
- Eawag and ETH Zurich, Dr. Joaquin Jimenez Martinez: Soil physico-chemical processes, including microbiology and plants, in weightless conditions;
- UNIBE – Prof. Losch: Ethical evaluation
- Orphanalytics: Genome analysis: exchange of genome islands (higher pathogenicity);
- Anne-Marlene Rüede: Architecture, Systems engineering knowledge;
- Mars Society Switzerland: just speaking about it and spreading the progress you are making to the Public.

45% of the respondents prefer joint bilateral development as a collaboration model (Q24), and 39% large collaborative ones.

The envisioned levels of involvement of the responding stakeholders (Q25) are 1) steering (as partner or

subcontractor) and 2) contributing (developing, advising, etc., as a supplier or consultant), each with more than 50% of the respondents' expressed opinions. A third also envisage to be an observing member. 24% would be ready to lead a project (as core leader or prime contractor) among which RUAG, Eawag (2x), Earth Space Technical Ecosystem Enterprises SA, CSEM, eSpace Center and HSLU.

On the kinds of contribution that would be considered by the respondents (Q26), more than 60% chose the MELiSSA foundation and in-kind contributions, and almost 20% cash involvement (Earth Space Technical Ecosystem Enterprises SA, eSpace, ZIPAR, Eawag, HSLU)

The potential difficulties/bottlenecks (in terms of R&D, funding, etc.) and associated solutions perceived by the respondents (Q27) have been integrated into a strengths, weaknesses, opportunities, threats (SWOT) analysis of the MELiSSA roadmap (§2.3).

The Swiss stakeholders in the private sectors in the responding organisations' network which could be interested in MELiSSA/ALSS (Q28) that were mentioned but not listed in the Swiss ALSS/MELiSSA stakeholders database were duly added to the latter.

The vast majority of the responding organizations (85%) would be interested in being involved in a Swiss ALSS/MELiSSA community/network (Q29).

Almost 90% of the respondents would be interested in participating in a workshop/conference on the same topic by mid 2020 (Q30).

The complementary suggestions/comments that were mentioned by the respondents (Q31) have been integrated into a strengths, weaknesses, opportunities, threats (SWOT) analysis of MELiSSA roadmap (§2.3).

All the final considerations were ticked by at least 90% of the responding organizations.

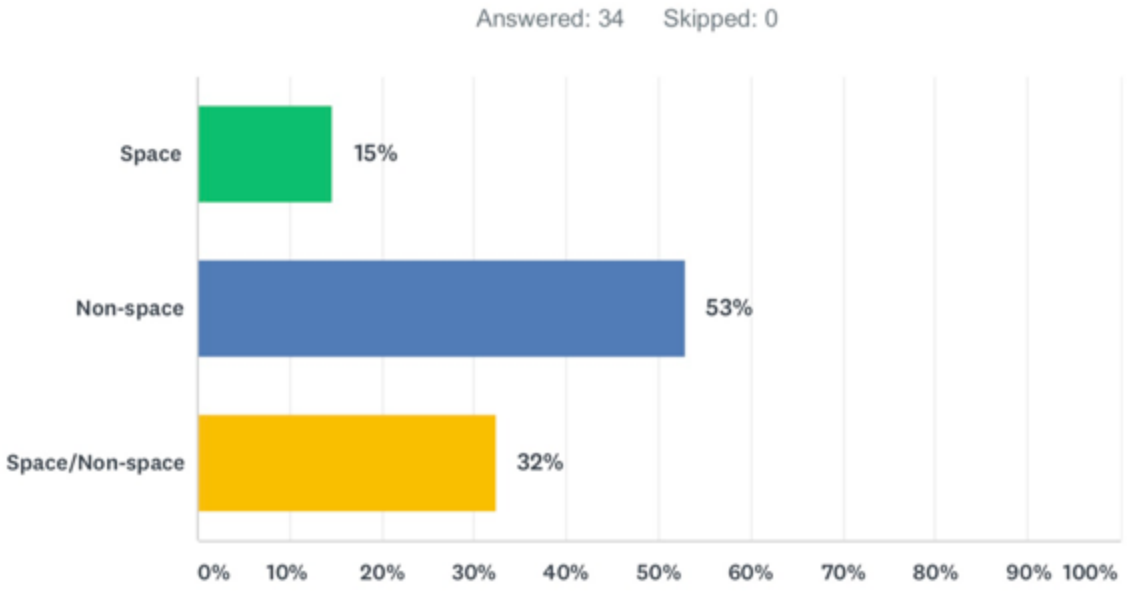
2.4.4 Full survey results analysis

2.4.4.1 Q1: About the respondents

Below is the list of the survey responding organizations (27) and respondents (33 + 1 duplicate).

Swiss Community stakeholders - Advanced Life Support Systems/MELiSSA				
Company / Organisation name				*Several entries shall be separated by commas*
CONTACT INFORMATION				
AFFILATION	TITLE	FIRST NAME	LAST NAME	EMAIL
Centre suisse d'électronique et de microtechnique - CSEM	Mr.	Rafael	Pennese	rafael.pennese@csem.ch
Centre suisse d'électronique et de microtechnique - CSEM	Dr.	Georges	Kotrotsios	georges.kotrotsios@csem.ch
CleantechAlps	Mr.	Eric	Plan	eric.plan@cleantech-alps.com
Earth Space Technical Ecosystem Enterprises SA	Mr.	Théodore	Besson	theodore.besson@est2e.com
EAWAG	Dr.	Joaquin	Jimenez-	joaquin.jimenez@eawag.ch
EAWAG (Udert Group)/ETH Zurich	Mr.	Valentin	Faust	Valentin.Faust@eawag.ch
EAWAG/ETH Zurich	Prof.	Kai	Udert	kai.udert@eawag.ch
École Polytechnique Fédérale de Lausanne - EPFL	Prof.	Rizlan	Bernier-	rizlan.bernier-latmani@epfl.ch
École Polytechnique Fédérale de Lausanne - EPFL	Mrs.	Anne-	Ruëde	annemarlene.ruede@yahoo.com
École Polytechnique Fédérale de Lausanne - EPFL	Dr.	Pierre	Zurbruegg	pierre.zurbruegg@epfl.ch
École Polytechnique Fédérale de Lausanne - EPFL	Prof.	Alain	Nussbaumer	alain.nussbaumer@epfl.ch
École Polytechnique Fédérale de Lausanne - EPFL	Mr.	Claudio	Leonardi	claudio.leonardi@epfl.ch
EPFL+ECAL lab	Mr.	Nicolas	Henchoz	nicolas.henchoz@epfl.ch
ESA BIC Switzerland	Mrs.	Nania	Stecker	nanja.strecker@sl.ethz.ch
eSpace - Space Engineering Center EPFL	Dr.	Sonia	Ben Hamida	sonia.benhamida@epfl.ch
eSpace - Space Engineering Center EPFL	Dr.	Muriel	Richard	muriel.richard@epfl.ch
eSpace - Space Engineering Center EPFL	Prof.	Jean-Paul	Kneib	jean-paul.kneib@epfl.ch
ETH Zurich	Dr.	Astrid	Oberson	astrid.oberson@usys.ethz.ch
ETH Zurich	Prof	Emmanuel	Frossard	emmanuel.frossard@usys.ethz.c
ETH Zurich	Mrs.	Grace	Crain	grace.crain@usys.ethz.ch
Haute école d'ingénerie et d'architecture Fribourg	Prof.	Jean-Pascal	Bourgeois	Jean-Pascal.Bourgeois@hefr.ch
HEI (HES-SO//Valais-Wallis)	Prof.	Laurence	Nicolay	laurence.nicolay@hevs.ch
Hochschule Luzern - HSLU	Prof.	Marcel	Egli	marcel.egli@hslu.ch
Hochschule Luzern - HSLU	Dr.	Timothy	Granata	timothy.granata@hslu.ch
Innobridge	Mr.	Alexandre	Coquoz	alexandre.coquoz@innobridge.c
Institut agricole de Grangeneuve	Mrs.	Ivanna	Crmaric	pierre.aeby@fr.ch,
Mars Society Switzerland	Mr.	Pierre	Brisson	pierre_brisson@yahoo.com
Oracan Sàrl	Mr.	Albert	Oriol	oracan@hispeed.ch
Orph'Analytics	Dr.	Claude-Alain	Roten	car.orphanalytics@gmail.com
PSI	Prof.	Frédéric	Vogel	frederic.vogel@psi.ch
RUAG Space	Dr.	Stefano	Nebuloni	Stefano.Nebuloni@ruag.com
RUAG Space	Mr.	Sandro	Liberatoscioli	Sandro.Liberatoscioli@ruag.co
RUAG Space	Mr.	Damien	Moscetti	damien.moscetti@ruag.com
SOFIES SA	Mr.	David	Rochat	david.rochat@sofiesgroup.com
Swiss Center for Applied Human Toxicology - SCAHT / Uni Basel	Dr.	Rex	Fitzgerald	rex.fitzgerald@unibas.ch
Swiss Space Center	Mrs.	Tatiana	Volkova	tatiana.volkova@epfl.ch
Université de Berne - UNIBE	Dr	Andreas	Losch	andreas.losch@theol.unibe.ch
Université de Berne - UNIBE	Prof.	Urs	Feller	urs.feller@ips.unibe.ch
Swiss Space Center	Prof.	Volker	Gass	volker.gass@epfl.ch,
Université de Lausanne - UNIL	Dr.	Nathalie	Chèvre	nathalie.chevre@unil.ch
Université de Lausanne - UNIL	Prof.	Sarah	Mitri	sara.mitri@unil.ch
Université de Lausanne - UNIL	Prof.	Suren	Erkman	suren.erkman@unil.ch
VUNA	Mr.	Bastian	Etter	bastian.etter@vuna.ch
ZIPAR - Zurich Institute of Public Affairs Research	Dr.	Marko	Kovic	marko.kovic@zipar.org
Zürcher Hochschule für Angewandte Wissenschaften - ZHAW	Mr.	Phillip	Osterwalder	osterph1@students.zhaw.ch
Zürcher Hochschule für Angewandte Wissenschaften - ZHAW	-	Andreas	Schönborn	andreas.schoenborn@zhaw.ch

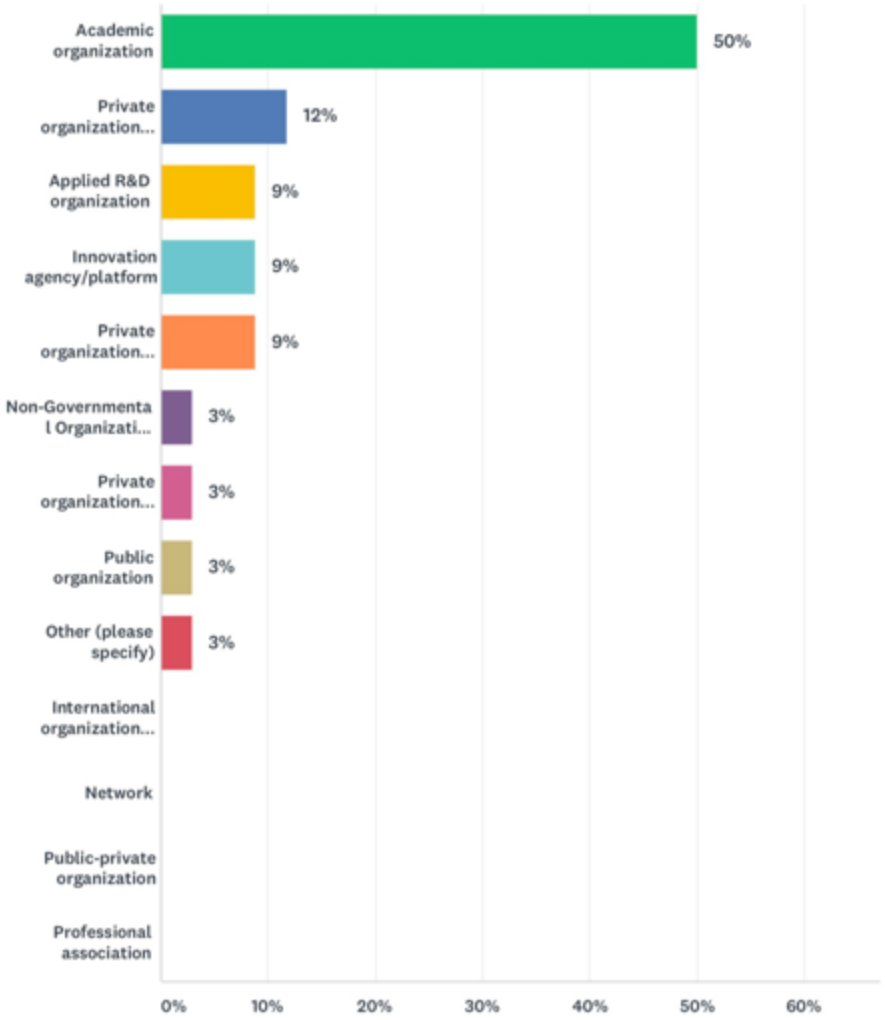
2.4.4.2 Q2: Organization background



Space-related organizations background reaches 47% (both space only and space/non-space)

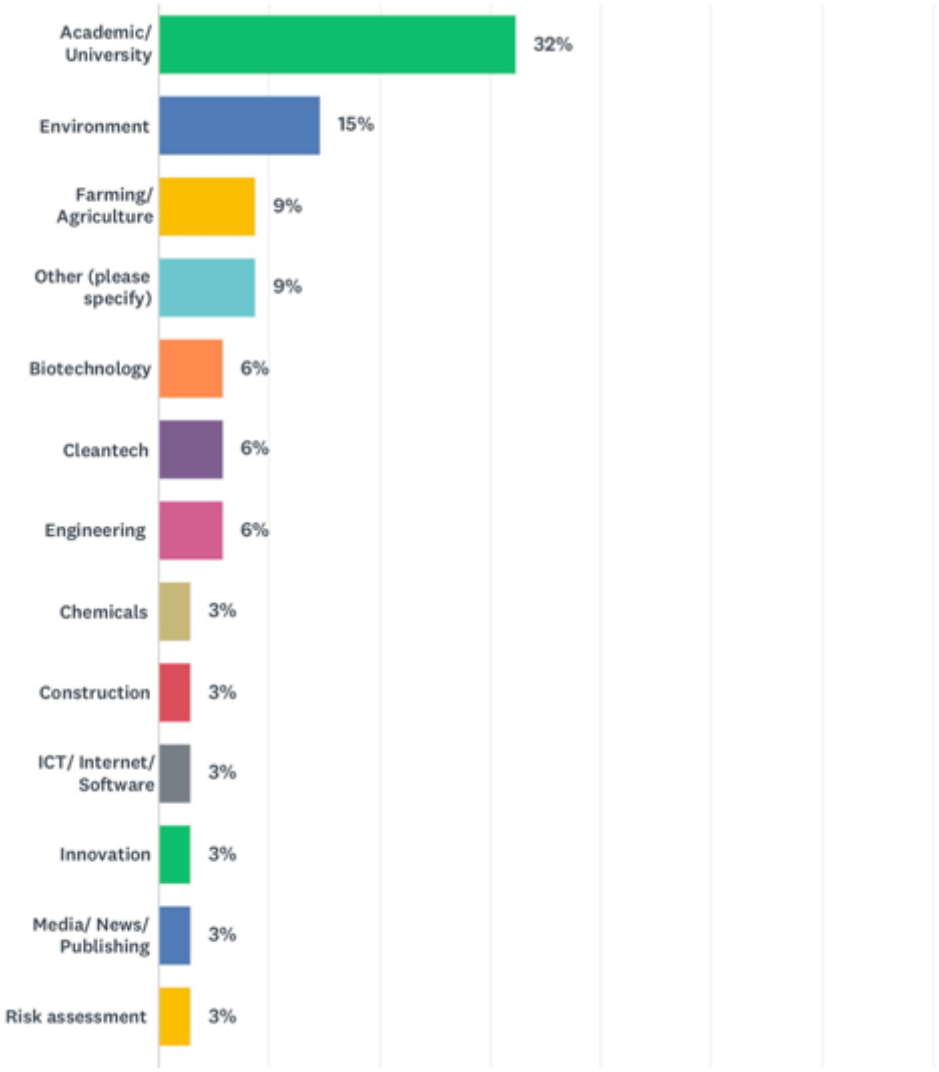
2.4.4.3 Q3: Kind of organization

More than half of the respondents are active in R&D organizations; 24% of the respondents are private organizations; Applied R&D organizations and innovation agencies/platforms counts each for 9%



ANSWER CHOICES	RESPONSES	
Academic organization	50%	17
Private organization – SME	12%	4
Applied R&D organization	9%	3
Innovation agency/platform	9%	3
Private organization – Start-up	9%	3
Non-Governmental Organization (NGO)	3%	1
Private organization – Multinational	3%	1
Public organization	3%	1
Other (please specify)	3%	1

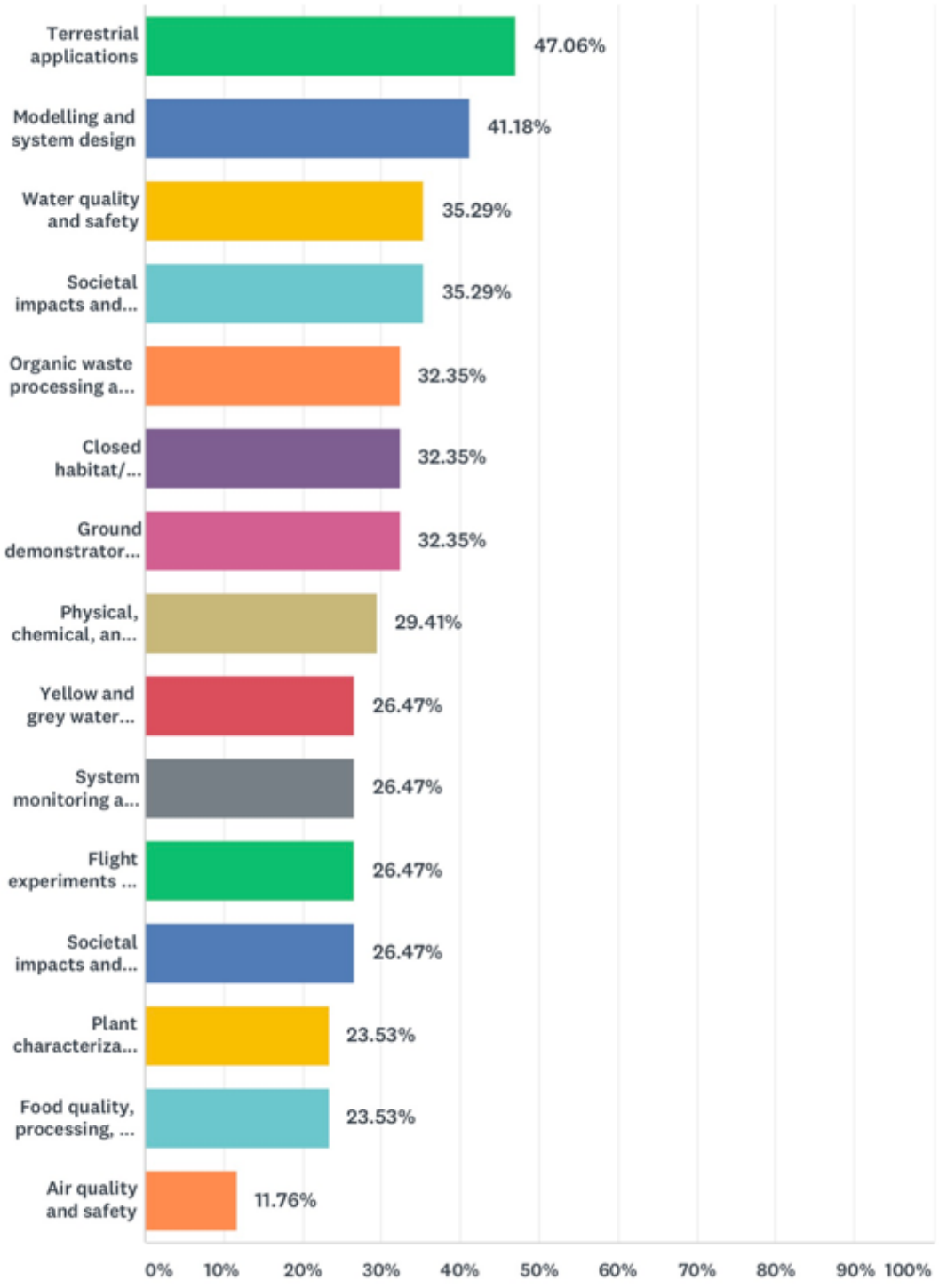
2.4.4.4 Q4: Sector of activity



Others: 6% replied aerospace and 3% plant physiology

A third of the respondents is coming from academic/university, more than 20% are from the environment and cleantech sectors, and another third is spread between farming/agriculture, aerospace, biotechnology and engineering sectors.

2.4.4.5 *Q5: What is your main interest in Advanced Life Support Systems (ALSS) and MELiSSA-related R&D and/or tech-transfer activities?*

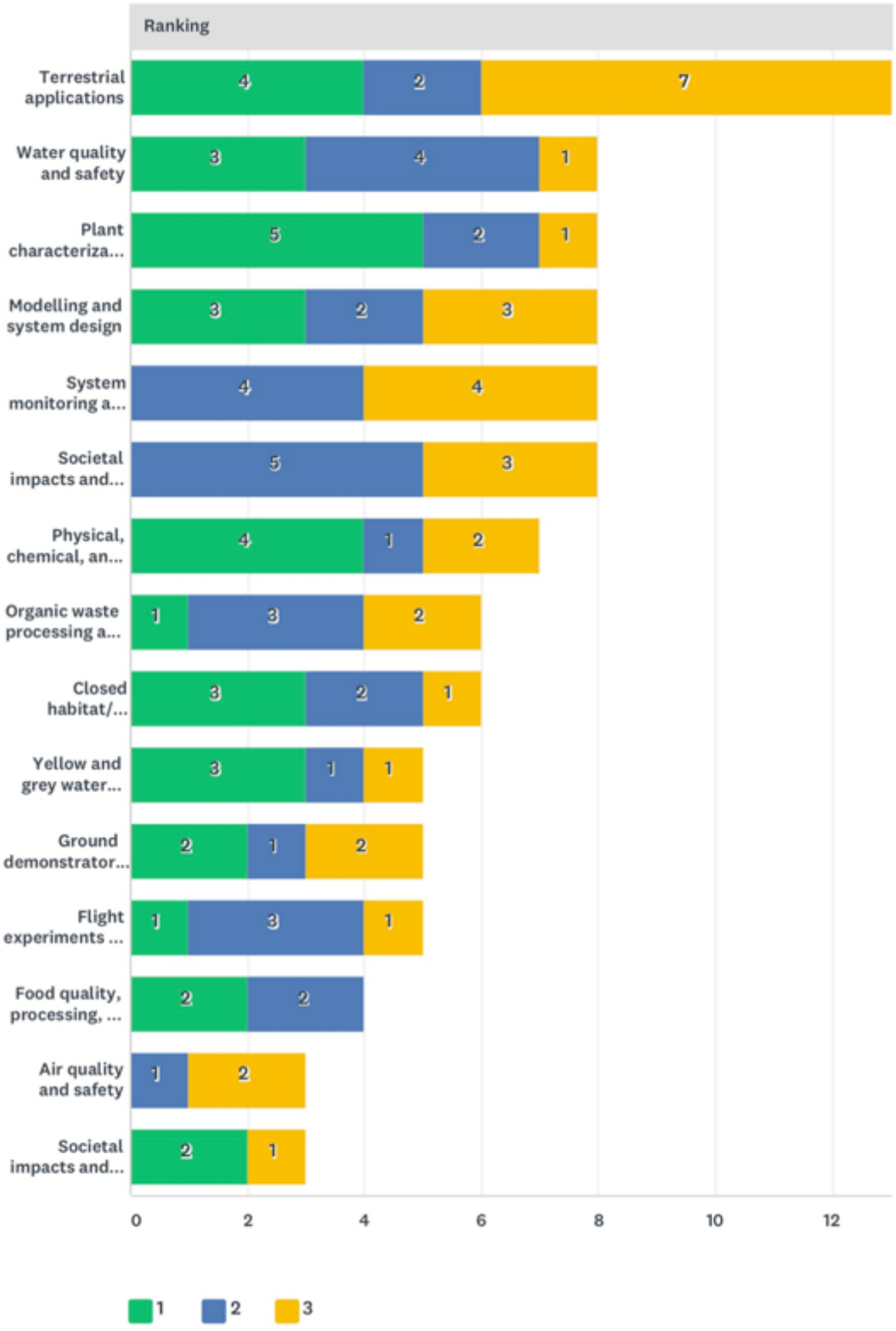


Swiss organization's interests are covering the full spectrum of ALSS and MELiSSA-related R&D and/or tech-transfer listed activities (15 in total). The top 7 interests are: 1) Terrestrial applications (47%) and 2) Modelling and system design (41%), 3) Water quality and safety (35%), 4) Societal impacts and education related to terrestrial sustainability (35%), 5) Organic waste processing and refinery (32%), 6) Closed habitat/ Sustainable housing (materials, energy, environmental footprint, ergonomy) (32%), 7) Ground demonstrators and analogue testing (32%). Only 1 activity (Air quality and safety) is collected less than 23% of the expressed opinions.

In more detail:

- 2 out of 15 activities have been ticked by at least 40% of the respondents:
    - Terrestrial applications
    - Modelling and system design
- 7 out of 15 activities have been ticked by at least 30% of the respondents, adding to the above listed interested:
    - Water quality and safety
    - Societal impacts and education related to terrestrial sustainability
    - Organic waste processing and refinery
    - Closed habitat/ Sustainable housing (materials, energy, environmental footprint, ergonomy)
    - Ground demonstrators and analogue testing
- 12 out of 15 activities have been ticked by at least 25% of the respondents, adding to the above listed interested:
    - Physical, chemical, and microbial contaminants
    - Yellow and grey water treatment and recycling
    - System monitoring and control
    - Flight experiments and space technology demonstrators
    - Societal impacts and education related to space exploration

2.4.4.6 *Q6: Could you also please specify the top 3 interests to you (by order of descending importance)?*



The top 3 interests for ALSS/MELiSSA-related activities were then specified by order of descending importance:

12 out these same 15 activities are considered to be of main interest (i.e. ranked 1st) by at least one respondent, with notably plant characterization, edible biomass production (5 times 1st), Physical, chemical, and microbial contaminants and Terrestrial applications (4 times 1st) and Closed habitat/Sustainable housing, Yellow and grey water treatment and recycling, Water quality and safety, Modelling and system design (3 times 1st).

In more detail:

Ranked 1st:

- 5 times:
  - Plant characterization, edible biomass production
- 4 times:
  - Physical, chemical, and microbial contaminants
  - Terrestrial applications
- 3 times:
  - Closed habitat/ Sustainable housing (materials, energy, environmental footprint, ergonomy)
  - Yellow and grey water treatment and recycling
  - Water quality and safety
  - Modelling and system design
- 2 times:
  - Ground demonstrators and analogue testing
  - Food quality, processing, and human nutrition
  - Societal impacts and education related to space exploration
- 1 time:
  - Organic waste processing and refinery
  - Flight experiments and space technology demonstrators

Ranked 2nd:

- 5 times:
  - Societal impacts and education related to terrestrial sustainability
- 4 times:
  - System monitoring and control
  - Water quality and safety
- 3 times:
  - Organic waste processing and refinery
  - Flight experiments and space technology demonstrators
- 2 times:
  - Terrestrial applications
  - Plant characterization, edible biomass production
  - Modelling and system design
  - Closed habitat/ Sustainable housing (materials, energy, environmental footprint, ergonomy)
  - Food quality, processing, and human nutrition
- 1 time:
  - Physical, chemical, and microbial contaminants
  - Yellow and grey water treatment and recycling
  - Ground demonstrators and analogue testing
  - Air quality and safety

Ranked 3rd:

- 7 times:
  - Terrestrial applications
- 4 times:
  - System monitoring and control
- 3 times:
  - Modelling and system design
  - Societal impacts and education related to terrestrial sustainability
- 2 times:
  - Physical, chemical, and microbial contaminants
  - Organic waste processing and refinery
  - Ground demonstrators and analogue testing
- 1 time:
  - Water quality and safety
  - Plant characterization, edible biomass production
  - Closed habitat/ Sustainable housing (materials, energy, environmental footprint, ergonomy)
  - Yellow and grey water treatment and recycling
  - Flight experiments and space technology demonstrators Air quality and safety
  - Societal impacts and education related to space exploration

When cumulating the activities that were listed as top 3 either as 1st, 2nd and 3rd interests:

- Terrestrial applications were selected by 31% of the respondents

In addition, the following activities were selected:

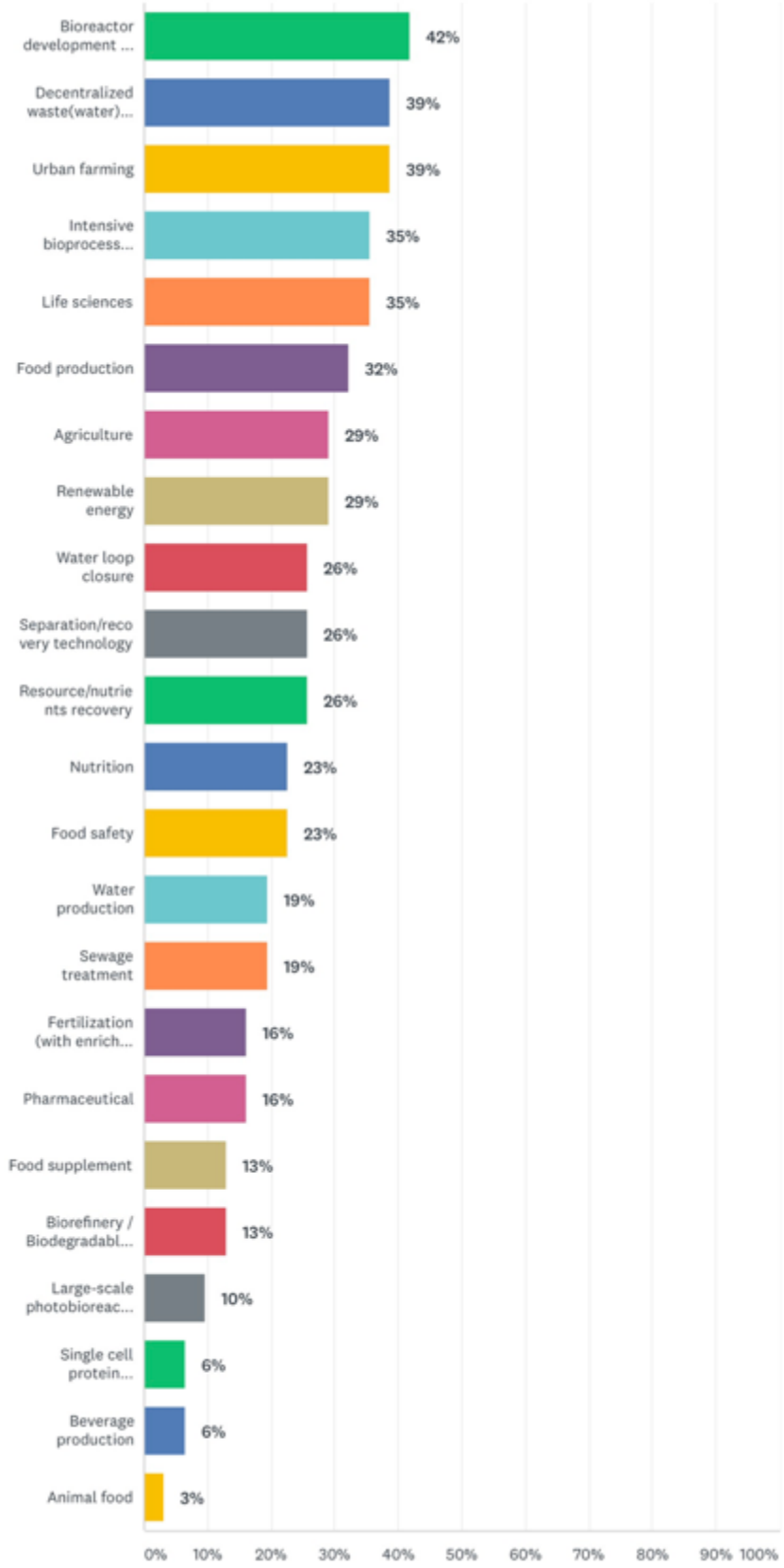
- by more than 20% of the respondents:
  - Plant characterization, edible biomass production (24%, ranked 1st 5 times)
  - Water quality and safety (24%, ranked 1st 3 times)
  - Modelling and system design (24%, ranked 1st 3 times)
  - System monitoring and control (24%)
  - Societal impacts and education related to terrestrial sustainability (24%
  - Physical, chemical, and microbial contaminants (21%, ranked 1st 4 times)
- by more than 15% of the respondents:
  - Organic waste processing and refinery
  - Closed habitat/ Sustainable housing (materials, energy, environmental footprint, ergonomy)
  - Yellow and grey water treatment and recycling
  - Ground demonstrators and analogue testing
  - Flight experiments and space technology demonstrators Air quality and safety

After weighting (1st rank giving 3 points, 2nd 2 points and 3rd 1 point), the ranking of the interest in ALSS/MELiSSA-related R&D and/or tech-transfer activities are as follows:

Q6 (incl. vote weighting)	33 answers					
Ranking	**1**	**2**	**3**	**Total ranking 1, 2 or 3**	**Total ranking [weighted*]**	**% answers [weighted*]**
Terrestrial applications	4	2	7	13	**23**	12%
Plant characterization, edible biomass production	5	2	1	8	**20**	10%
Water quality and safety	3	4	1	8	**18**	9%
Modelling and system design	3	2	3	8	**16**	8%
Physical, chemical, and microbial contaminants	4	1	2	7	**16**	8%
Closed habitat/ Sustainable housing (materials, energy, environmental footprint, ergonomy)	3	2	1	6	**14**	7%
Societal impacts and education related to terrestrial sustainability	0	5	3	8	**13**	7%
System monitoring and control	0	4	4	8	**12**	6%
Yellow and grey water treatment and recycling	3	1	1	5	**12**	6%
Organic waste processing and refinery	1	3	2	6	**11**	6%
Ground demonstrators and analogue testing	2	1	2	5	**10**	5%
Flight experiments and space technology demonstrators	1	3	1	5	**10**	5%
Food quality, processing, and human nutrition	2	2	0	4	**10**	5%
Societal impacts and education related to space exploration	2	0	1	3	**7**	4%
Air quality and safety	0	1	2	3	**4**	2%
	** 6 pts distributed per answer: 1st=3pts, 2nd=2pts, 3rd=1pt*					

2.4.4.7 Q7: Industrial applications

Which ones of the following topics would be associated and relevant with your involvement in an ALSS-related technology cooperation (for space exploration and/or terrestrial applications)?



On the topics mapping for *industrial applications* (Q7), the following topics collected more than 30% of responses: Bioreactor development and biomass production (42%) and Life sciences (35%); Decentralized waste(water) management (39%); Urban farming (39%), Food production (32%); and Intensive bioprocess optimisation and control (35%).

In more detail:

Above 40% of responses for:

- Bioreactor development and biomass production

Between 30% and 39%:

- Decentralized waste(water) management
- Urban farming
- Intensive bioprocess optimisation and control
- Food production
- Life sciences

Between 20% and 29%:

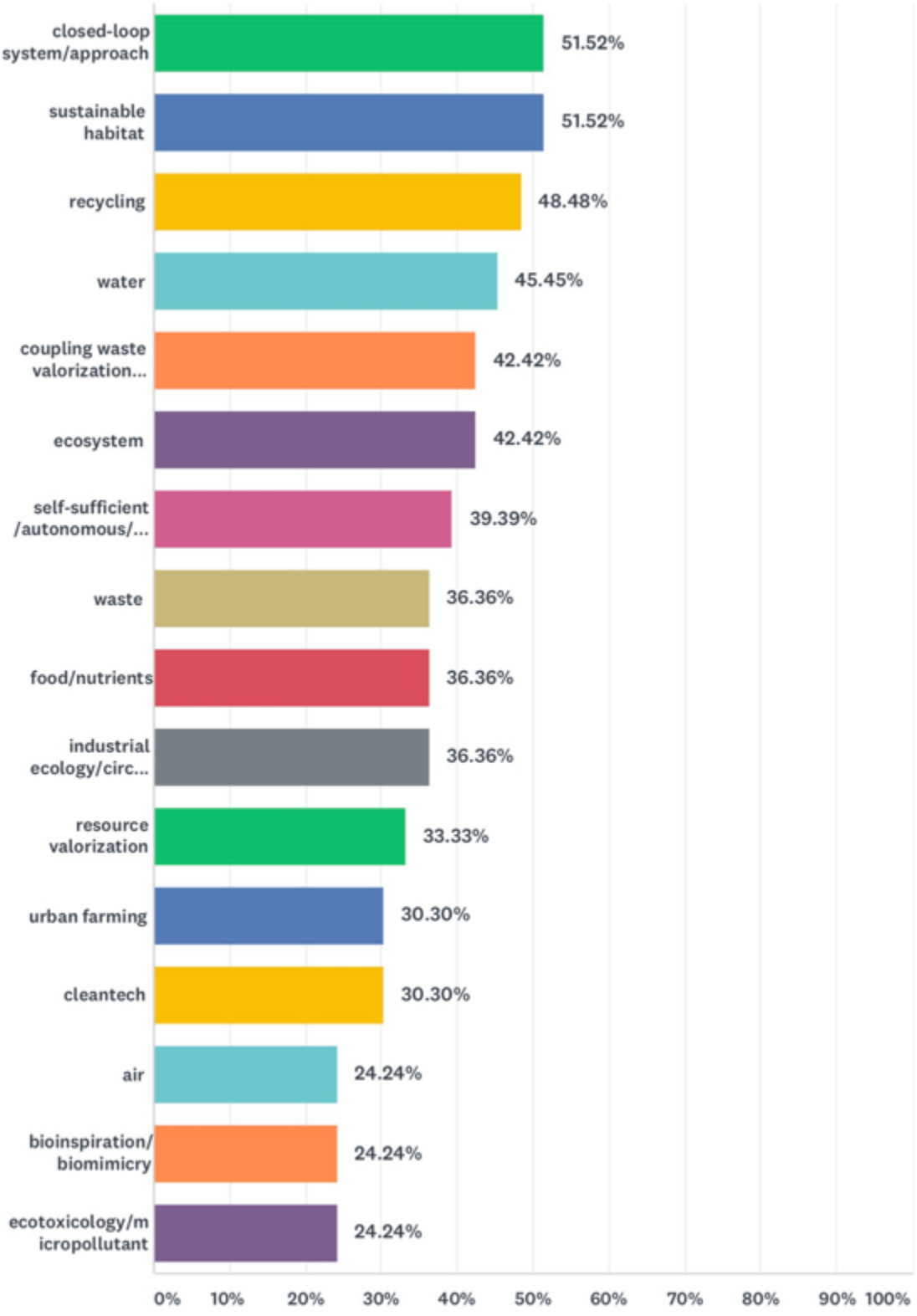
- Water loop closure
- Separation/recovery technology
- Resource/nutrients recovery
- Renewable energy
- Agriculture
- Nutrition
- Food safety

Between 10% and 19%:

- Sewage treatment
- Water production
- Fertilization (with enriched by-products)
- Pharmaceutical
- Food supplement
- Biorefinery / Biodegradable plastics / Biofuels

2.4.4.8 Q8: Sustainable resource management

Which ones of the following topics would be associated and relevant with your involvement in an ALSS-related technology cooperation (for space exploration and/or terrestrial applications)?



On the topics mapping for *sustainable resource management* (Q8), the following topics notably collected more than 30% of responses: Closed-loop system/approach (51%), Sustainable habitat (51%), Recycling (48%), Water (45%), Coupling waste valorization with food production (42%), Ecosystem (42%), Self-sufficient/autonomous/autarchic habitat waste (39%), industrial ecology/circular economy resource valorization (36%).

In more detail:

Above 50% of responses for:

- closed-loop system/approach
- sustainable habitat

Between 40% and 49%:

- water
- recycling
- coupling waste valorization with food production
- ecosystem

Between 30% and 39%:

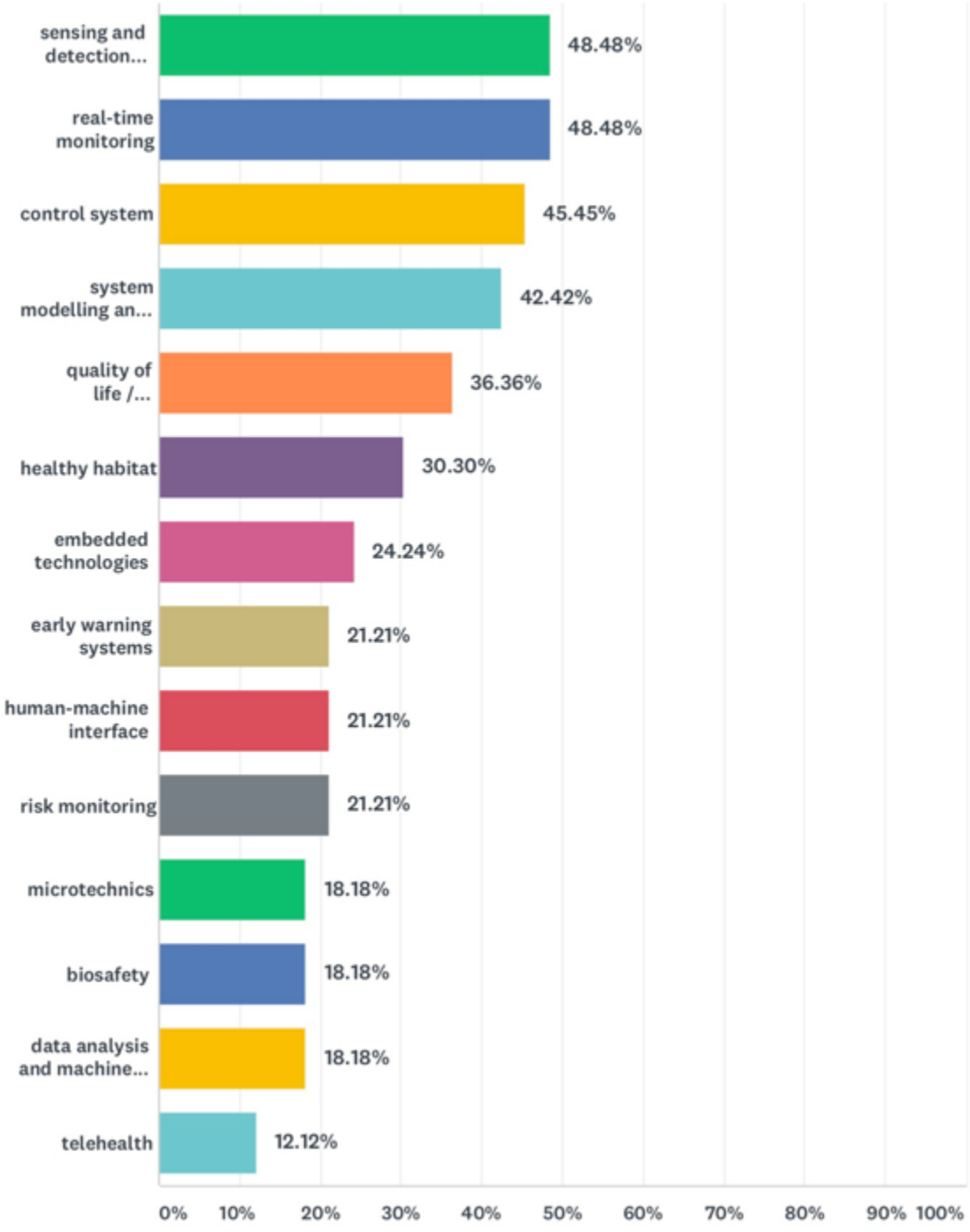
- self-sufficient/autonomous/autarchic habitat waste
- food/nutrients
- industrial ecology/circular economy resource valorization
- urban farming
- cleantech
- cleantech

Between 20% and 29%:

- air
- bioinspiration/ biomimicry
- ecotoxicology/micropollutant

2.4.4.9 Q9: Smart monitoring and system control

Which ones of the following topics would be associated and relevant with your involvement in an ALSS-related technology cooperation (for space exploration and/or terrestrial applications)?



On the topics mapping for *smart monitoring and system control* (Q9), the following topics collected more than 30% of responses: Sensing and detection technologies (48%), Real-time monitoring (48%), Control system (45%), System modelling and simulation tools (42%), Quality of life / habitability (36%) and Healthy habitat (30%).

In more detail:

Above 40% of responses for:

- sensing and detection technologies
- real-time monitoring
- control system
- system modelling and simulation tools

Between 30% and 39%:

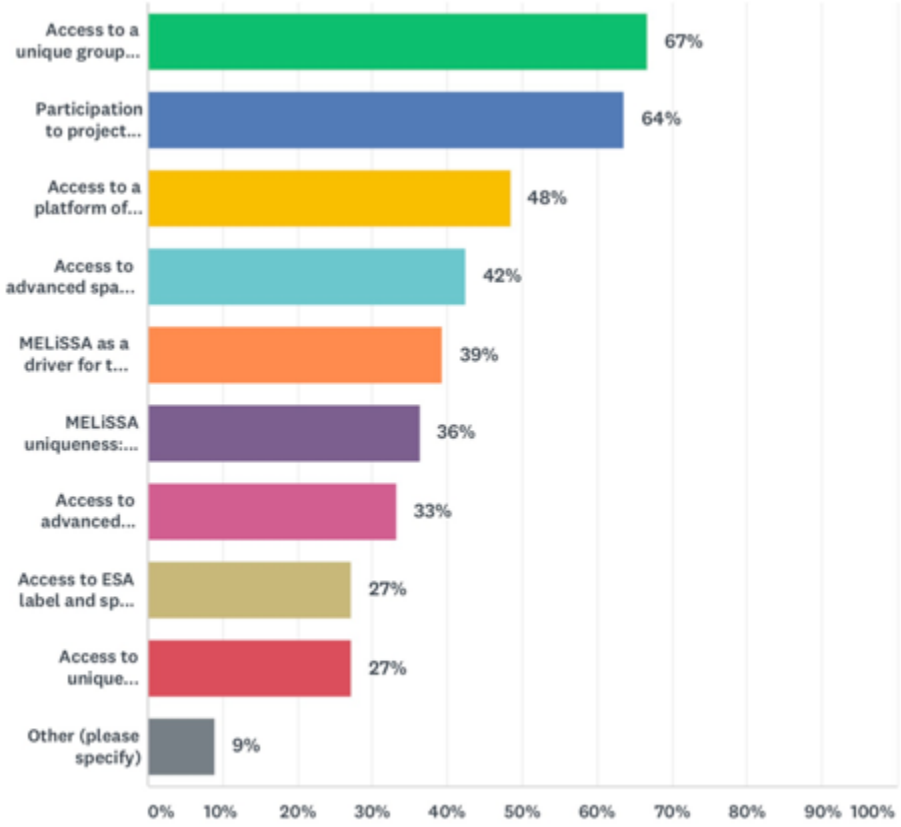
- healthy habitat
- quality of life / habitability

Between 20% and 29%:

- embedded technologies
- early warning systems
- human-machine interface
- risk monitoring

2.4.4.10 Q10: Uniqueness of MELiSSA

Which ones of the following MELiSSA-related assets is of interest for your organization activities?



On the MELiSSA-related assets and uniqueness.

- Access to experts in the field of circular LSS collected 67% of the replies
- Participation in project/synergies for connecting space compatible technologies to current terrestrial challenges reached 64%

The following assets gathered between 30% and 48% of the expressed opinions (by descending order):

- Access to a platform of knowledge exchange (MELiSSA has state-of-the-art knowledge of core processes of circular systems)
- Access to advanced space R&D facility/hardware (e.g., MELiSSA has unique facilities such as the MELiSSA Pilot Plant; its partners have state-of-the-art lab facilities)
- MELiSSA as a driver for the development of high-tech solutions and equipment
- MELiSSA uniqueness: closed-loop LSS set up coupling organic waste valorization to nutrient recovery and food production
- Access to advanced expertise in linking and interfacing the individual loop components/processes

Between 20 and 29%:

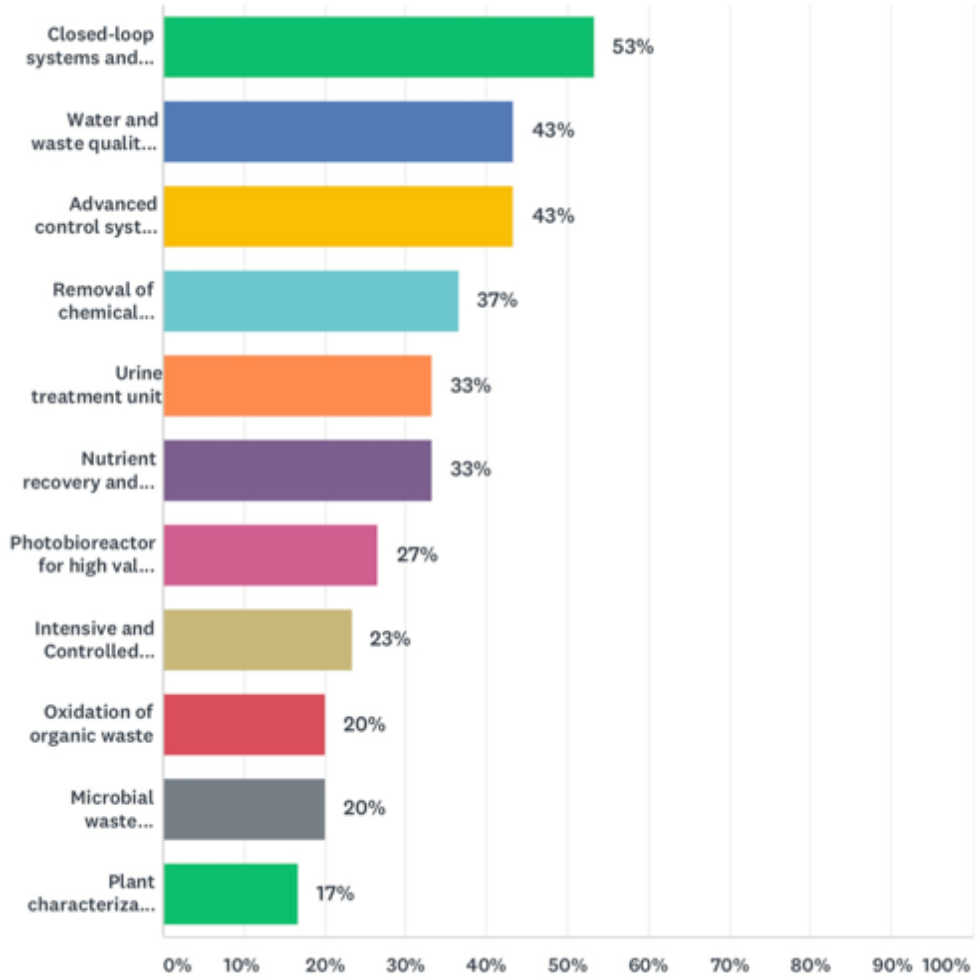
- Access to ESA label and space network (MELiSSA's space aspect appeals to the popular image of science)
- Access to unique expertise of multiphases processes in reduced gravity and space

“Other”: 2 additional interests were specified:

- Innobridge: Possibility to have a testbed on Agropole site
- HSLU: Microbial Biofactories

2.4.4.11 Q11: MELiSSA technologies

Which ones of the following MELiSSA-related technologies are connected with your organization activities?



Swiss organization's activities are associated with a broad range of MELiSSA-related technologies (Q12), the following technologies being ticked by more than 30% of the respondents: Closed-loop systems and circular ALSS (53%), Water and waste quality analysis (43%), Advanced control systems (e.g. model based) (43%); Removal of chemical contaminants (37%), Urine treatment unit (33%) and Nutrient recovery and delivery (33%).

In more detail:

All MELiSSA activities have been ticked and at least 5 times each (with a maximum of 16 expressed opinions, corresponding to more than 50% of the respondents for this question).

The following technologies are connected for more than 40% of the respondents' organization activities:

- Closed-loop systems and circular ALSS
- Water and waste quality analysis
- Advanced control systems (e.g. model based)

Between 30% and 39% of expressed opinions for:

- Removal of chemical contaminants
- Urine treatment unit

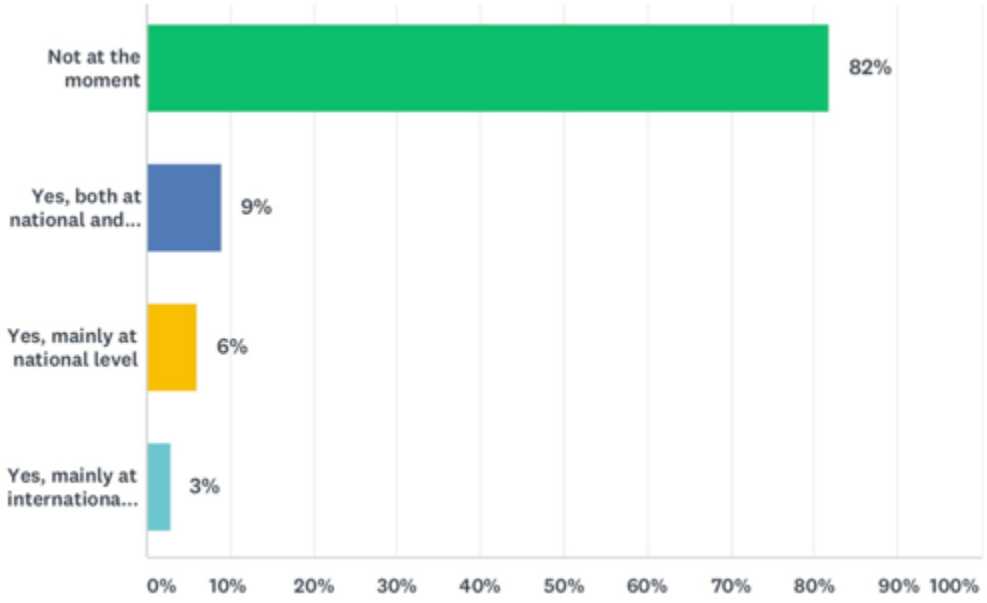
- Nutrient recovery and delivery

Between 15% and 29% of expressed opinions for:

- Photobioreactor for high values compounds and/or food production (incl. biofacades) Microbial waste degradation
- Oxidation of organic waste
- Intensive and Controlled greenhouse systems for food production (e.g., aeroponics, vertical/urban farming)
- Plant characterization and Modelling (e.g. plant exchange in aerial and root zones)

2.4.4.12 Q12: Funding possibilities

Are you currently involved in co- funded ALSS/MELiSSA research and technology transfer?



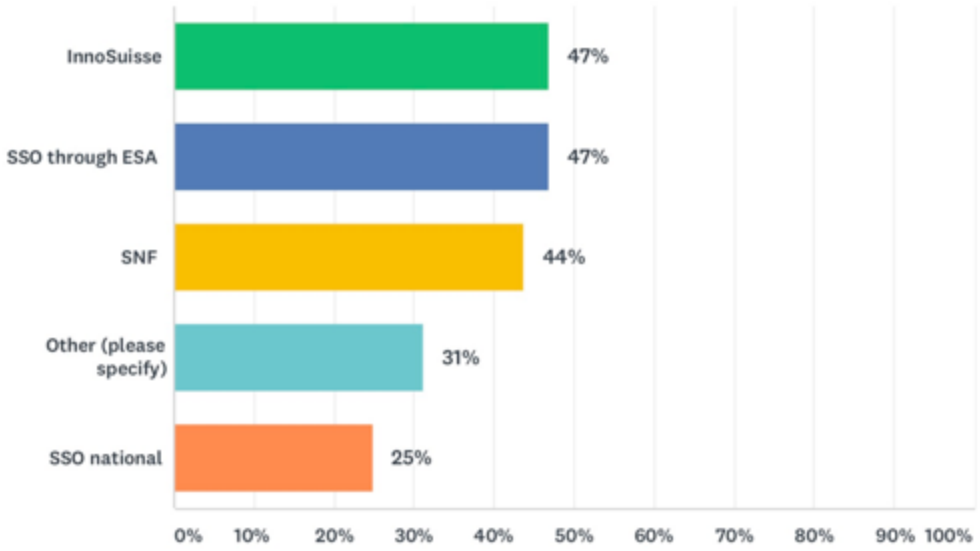
A little bit more than 80% of the respondents are *currently* not involved in an ALSS/MELiSSA research or technology transfer

The active organizations that replied to the survey are:

- ETH Zurich - Group of Plant Nutrition (both at national and international)
- Eawag - Group of Source Separation and Decentralization (mainly at international level)
- RUAG Space Nyon (mainly at national level)
- Earth Space Technical Ecosystem Enterprises SA (both at national and international)
- University of Lausanne - Group of Industrial Ecology (both at national and international)

Other Swiss organizations that recently achieved an activity related to ALSS/MELiSSA include: EPFL ENAC, HEI (HES-SO//Valais-Wallis), PSI, SCAHT, CentreEcotox (see also Q13).

2.4.4.13 Q13: Which ongoing funding initiatives and new funding options for ALSS are you aware of?



The funding schemes for ALSS that the respondents are aware of are mainly the ones of SSO through ESA and InnoSuisse (47% each), as well as the ones from SNF (44%) and SSO national (25%).

Other funding schemes include Eurostar, Horizon 2020, INTERREG, and institutional funding (UNIL rectorate, EPFL, HES-SO) Swiss Space Center (sponsoring of Closed Habitat Forum 2016) and IDK.

2.4.4.14 Q14-Q15-Q16. Project examples 1-2-3

What are the past and present ALSS/MELiSSA-related projects in which your organization has been involved?

A list of over 30 projects could be gathered (with a few redundancies due to the participation of several Swiss organizations) (Q14-15-16):

(MELiSSA-related activity underlined and **MELiSSA-related achievement in bold**)

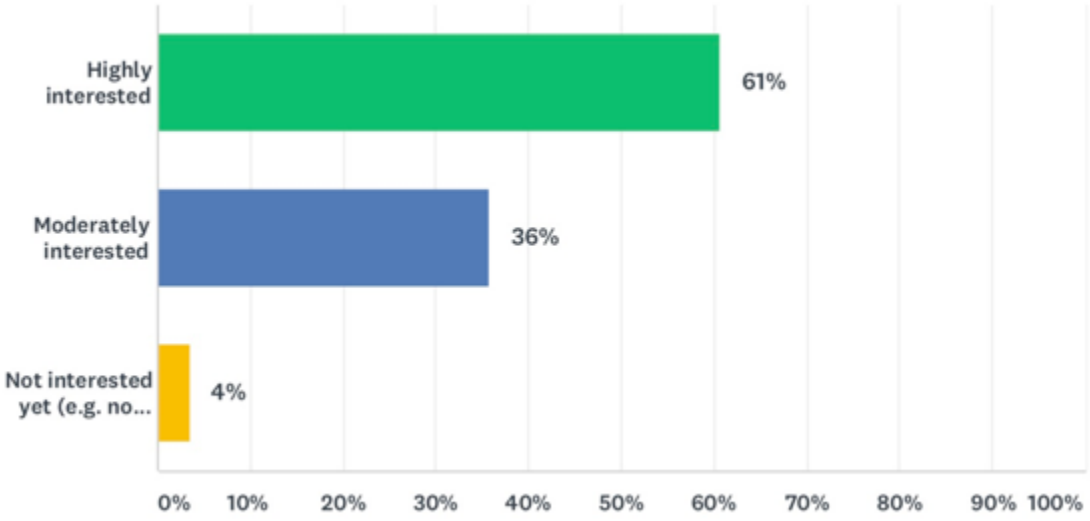
- **Biorat Phase B (2015-2019, coordinated by RUAG Space Nyon)**
  Pre-development and test of a flight experiment composed of a closed gas loop producing O_2 (algae photosynthesis) and consuming CO_2 of a mice crew. Technology demonstrator for ISS that is intended to a couple photobioreactor (microalgae) with a consumer compartment in a closed-loop fashion, led by RUAG. Expertise: system, full life cycle - up to launch. Space requirements. Launch planned in 2025;
- **MELiSSA Food Characterization Phase 2 (2014-2015, IPL (Belgium), and with coordination of HEI (HES-SO//Valais-Wallis) and support by RUAG Space Nyon).** Hydroponic subsystem studied at scientific and engineering levels, delivery of technical requirements & completion of preliminary testing phase. FPCU concept and engineering requirements. HEI (HES-SO//Valais-Wallis) expertise: Food processing, HACCP, Hygienic design, Sensory evaluation;
- **Oïkosmos project: space and terrestrial research synergies (2010-2016).** UNIL expertise: artificial closed ecosystems, terrestrial sustainability, terrestrial applications, circular systems, closed habitat, report to the UNIL rectorate of UNIL from industrial ecology group. Societal challenge: integral recycling, resource valorisation;
- **Dynamic Modelling of Material Flows and Sustainable Resource Use. Case Studies in Regional Metabolism and Space Life Support Systems (2010-2012).** UNIL PhD thesis. Sustainable resource use, material flow analysis, space life support systems, dynamic modelling, Closed-loop systems modeling Regional metabolism, subsystems interfacing and integration. Space requirements;
- PhD on artificial closed ecosystem as drivers for eco-innovation (UNIL);
- Participation to ESA/MELiSSA working groups (UNIL);
- Closing anthropogenic carbon loops: towards implementing a circular economy, UNIL post-doc (MELiSSA POMP programme). In-situ resource utilization, resource reutilization, carbon dioxide recycling, carbon capture and utilisation, technology-enabled carbon cycles, carbon input-output accounts and modeling, anthropogenic systems, terrestrial applications. Expertise: industrial ecology, resource valorization terrestrial sustainability. Societal challenge: coupling CO_2 valorization with food production and/or microalgae production;
- POMP II. Urine treatment (2017-ongoing), PhD thesis led by Eawag. Optimization of a urine treatment reactor, food production using urine fertilizer;
- Crop production in hydroponics using recycled nutrients and microbial consortia (2018-ongoing). Topics: hydroponics, urine, soybean, nitrogen, PhD thesis at ETH Zurich - Group of Plant Nutrition (POMP);
- Higher plant modelling of wheat root plasticity under nutrient deficiencies. Topics: investigation of wheat root system plasticity under nutrient deficiencies, led by ETH Zurich - Group of Plant Nutrition;
- Scorpius Prototype (SP1) - Towards a proof-of-concept of a closed habitat on-ground demonstration integrating main BLSS functions, led by Earth Space Technical Ecosystem Enterprises SA (2017-ongoing). Topics: 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. 99% of design completed in 2018;

- BELISSIMA – Phase A (AO/1-8342/15/NL/AT) (2016- ongoing). Led by VITO (prime contractor), Earth Space Technical Ecosystem Enterprises SA, UNIL and UGent (subcontractors). Topics: behaviour and effects of microcompounds in closed soil-free ecosystems, behaviour and impact of microcompounds, closed system chemical contaminants, microcompound removal, water reuse/ recycling. Societal challenges: ecotoxicology;
- ESA Study of the Assessment of the Financial and Business Potentials of the Life Support Systems (LSS) Technologies (AO/1-9556/18/NL/AT), led by Leoni Corporate Advisors (ITA/CH), Earth Space Technical Ecosystem Enterprises SA (subcontractor) (started in 07.2019);
- **ESA Closed Habitats Forum 2016, Co-organized by ESA, UNIL and Earth Space Technical Ecosystem Enterprises SA** (with support from Swiss Space Office and Swiss Space Center)**. Over** 130 participants. Sustainable resource management, sustainable habitats, smart monitoring and system control;
- **Co-organization of MELiSSA Scientific Workshop (2016) by ESA, UNIL and Earth Space Technical Ecosystem Enterprises SA**;
- Lecture, teaching and co-organisation of EPFL ENAC Building on Mars teaching unit (since 2012); EPFL, UNIL, Earth Space Technical Ecosystem Enterprises SA;
- Participation to ESA Lab / Igluna (2018-ongoing), EPFL, Earth Space Technical Ecosystem Enterprises SA, ZHAW (i.e., SWAG-System (smart waste-based agriculture growing system))
- **ESA TAS – Towards the Establishment of a Standard on Closed Habitat Specifications** (Reference 130046707) (Earth Space Technical Ecosystem Enterprises SA) (2018-ongoing);
- Space Loop. Pyrolysis of human fecens, ZHAW;
- Supercritical Water Oxidation of fecal sludge, Reinvent the Toilet Challenge, Bill & Melinda Gates Foundation, led by Eawag, with participation of Paul Scherrer Institut/FHNW, TRL 4-5, 1 year to TRL 5;
- Voucher (Agroscope-CSEM). Soil nitrate monitoring. Proof of concept of long-term nitrate sensing in agricultural soil. CSEM expertise: Nitrate sensing platform. No space requirements. TRL2;
- WeST (CSEM). Wearable sweat tracker. CSEM expertise: Printed, functionalized electrochemical sensors; System engineering. No space requirements. TRL3;
- RADAR (CSEM-FP7 grant). Modular platform for monitoring toxins in water and food production facilities using biosensors derived from aquatic organisms. CSEM expertise: Sample preparation; Analyte extraction; Label free detection. No space requirements. TLR4;
- Smart toilet (CSEM). Urine analysis for health monitoring. CSEM expertise: Printed, functionalized electrochemical sensors; System engineering. Societal challenge: Personalized health monitoring. No space requirements. TLR3;
- Nutrishield (CSEM-H2020 grant). Urine analysis as a feedback for personalized nutrition. CSEM expertise: Printed, functionalized electrochemical sensors; System engineering. No space requirements. TLR3;
- Optodex (CSEM). Chemical functionalization of surfaces for antimicrobial properties. CSEM expertise: Chemical functionalization. No space requirements. TLR5;
- Multispectral imaging for plants monitoring (CSEM internal activity). CSEM expertise: Multispectral imaging (imagers, data processing), plasmonic filters, ultra-low power embedded vision systems. No space requirements. TRL3;
- Drinking water quality monitoring by measuring inorganic and organic contaminants (CSEM internal activity). CSEM expertise: Light scattering/turbidity, biochemical sensors (highly specific), surface coatings. Societal challenge: Drinking water safety. No space requirements;
- SCIMA Connected Autonomous Monitored Greenhouse: INTERREG project led by Earth Space Technical Ecosystem Enterprises SA on its Swiss side (with the participation of UNIL and Grangeneuve), food production in constraints environments;

- Comba Farm: Aeroponic farming solutions for lettuce and aromatic plants, led by CombaGroup. Decrease the water consumption, increase food security, efficient production, elimination of contaminants;
- Ecorobotix: complete autonomous smart weeding machine, field-test site;
- Systems Engineering and Design of a Mars Polar Life Research Base (Anne-Marlène Ruëde, EPFL Msc thesis, 2018); Living Architecture scenarios, Earth applications Liquifer Systems Group. Outreach conference : European Mars Convention, La Chaux-de-Fonds, 2018, covering ALSS;
- Ethics of Planetary Sustainability: Ethical assessment of space exploration regarding sustainability (Dr. Andreas Losch, University of Bern).

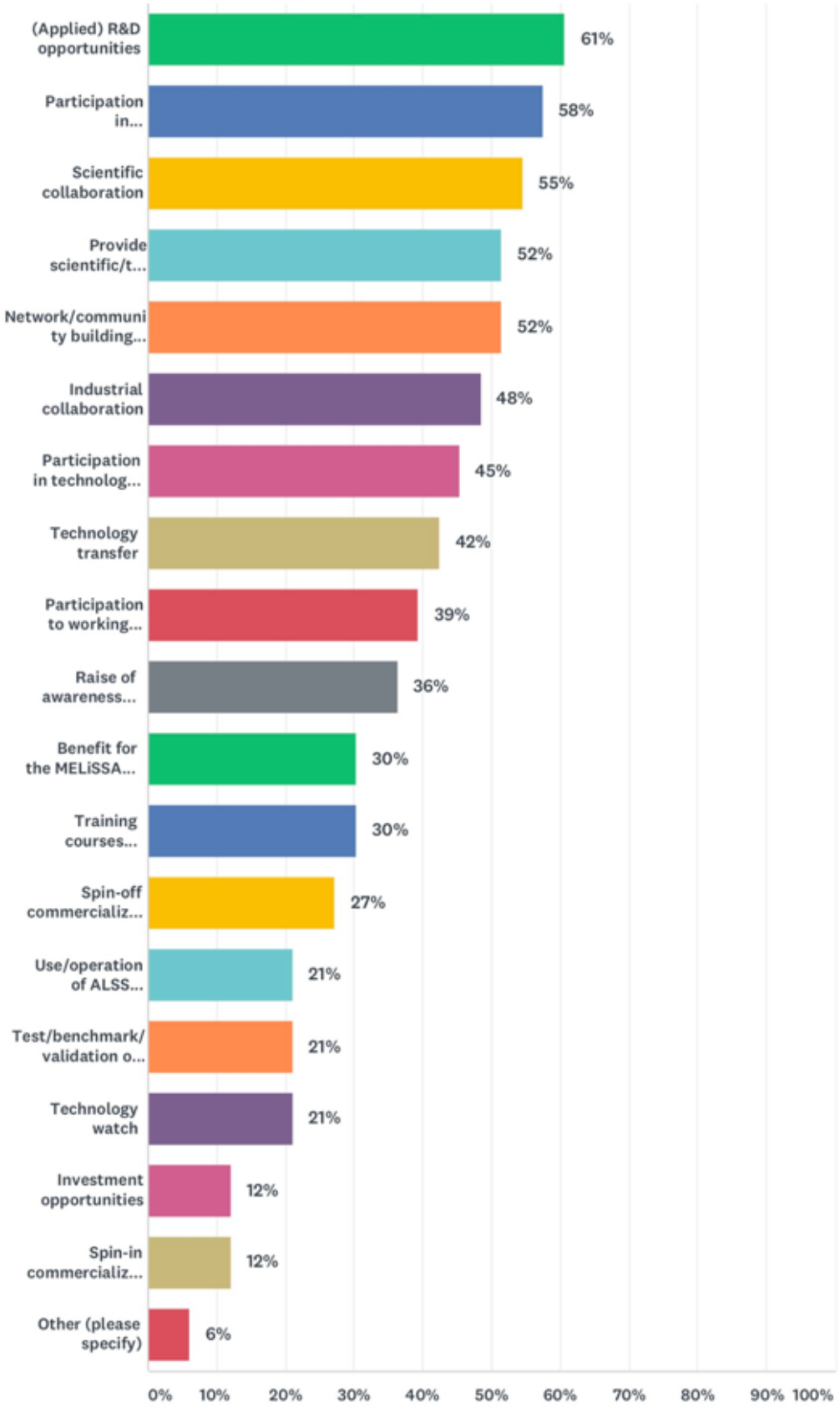
2.4.4.15 Q17: Only for organizations that are not involved yet in ALSS-related activities

In principle, would you be interested in participating in MELiSSA-related activities?



Globally, 97% of the respondents are interested in participating in MELiSSA-related activities, among which 61% are highly interested.

2.4.4.16 *Q18: What would be your expected outcomes from taking part of a Swiss community on ALSS/MELiSSA?*



Regarding the *expected outcomes* from taking part in a Swiss community on ALSS/MELiSSA (Q18), more

than 50% organizations considered the following expected outcomes from taking part in a Swiss community on ALSS/MELiSSA: Scientific collaboration (61%), (Applied) R&D opportunities (58%), Participation in workshop/conference (55%), Provide scientific/technical expertise on specific ALSS topics and Network/community building around ALSS (52% each).

The responding organizations also considered the following expected outcomes: Industrial collaboration (48%), Participation in technology demonstration/showcase (technological component/module, prototype, emerging technology or applications, business incubator, etc.) (45%), Technology transfer (42%), Participation to working groups or advisory bodies (39%), Raise of awareness (dissemination of ALSS knowledge) (36%), Benefit for the MELiSSA scientific and engineering expertise and Training courses organization / Continuous education (30% each).

In more detail:

More than 50% organizations considered the following expected outcomes from taking part of a Swiss community on ALSS/MELiSSA:

- Scientific collaboration
- (Applied) R&D opportunities
- Participation in workshop/conference
- Provide scientific/technical expertise on specific ALSS topics
- Network/community building around ALSS

30% to 49% of the responding organizations considered the following expected outcomes from taking part of a Swiss community on ALSS/MELiSSA:

- Industrial collaboration
- Participation to working groups or advisory bodies
- Participation in technology demonstration/showcase (technological component/module, prototype, emerging technology or applications, business incubator, etc.)
- Raise of awareness (dissemination of ALSS knowledge)
- Technology transfer
- Benefit for the MELiSSA scientific and engineering expertise
- Training courses organization / Continuous education

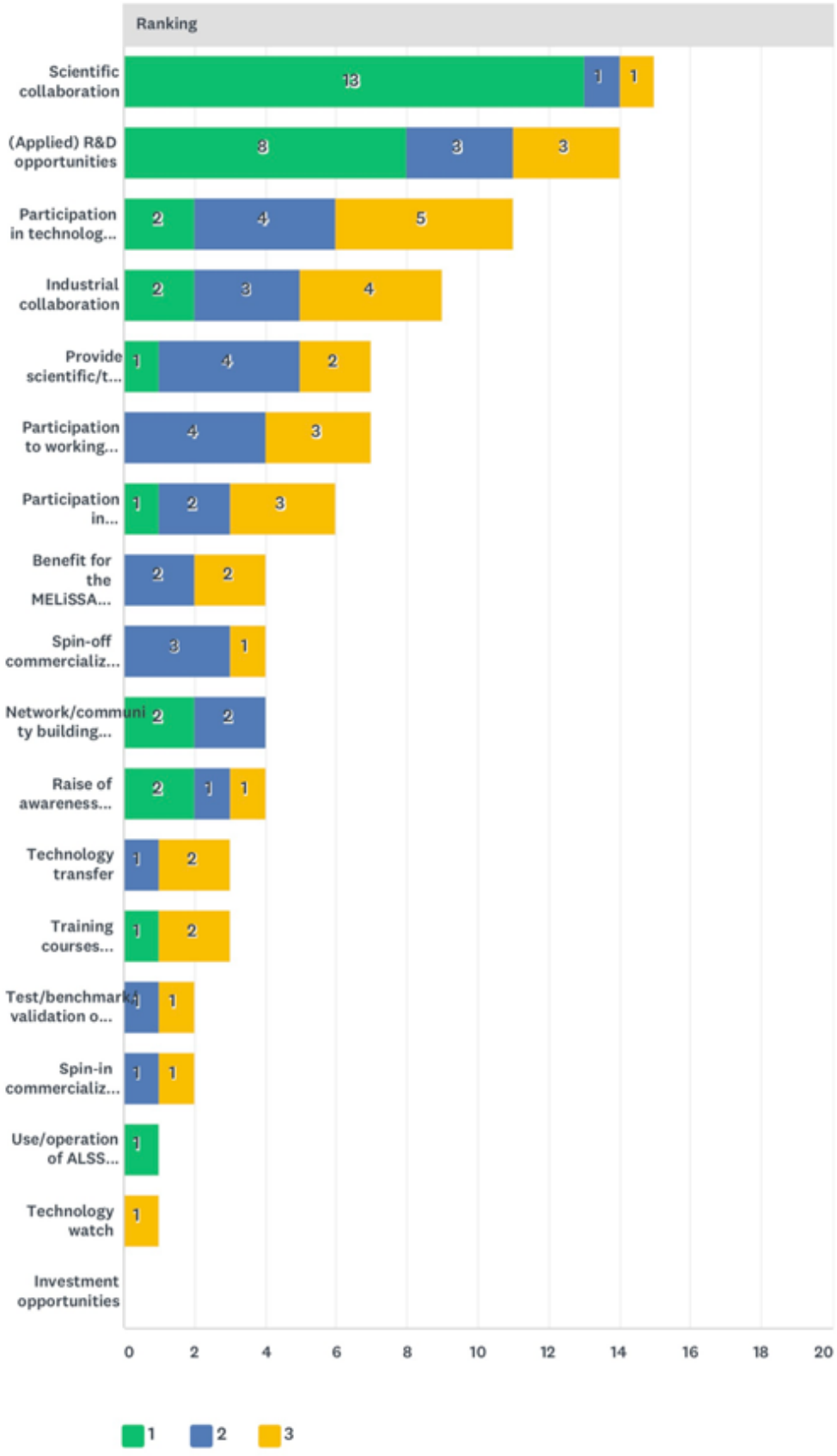
All the other expected outcomes have been considered at least by 10% and up to 29% of the respondents:

- Spin-off commercialization of ALSS terrestrial applications
- Use/operation of ALSS hardware
- Test/benchmark/validation of methodologies (services)
- Technology watch
- Investment opportunities
- Spin-in commercialization of ALSS space applications

Two organizations added the following expected outcomes:

- Develop the user experience dimension through design research
- Mainly to host MELiSSA pilot systems and operate it

2.4.4.17 Q19: Among the list below, what would be your top-3 ranking for kind of collaborations on ALSS with MELiSSA?



The top 3 kinds of collaboration on ALSS with MELiSSA were then specified by order of descending importance:

Ranked 1st:

- 13 times:
  - Scientific collaboration
- 7 times:
  - (Applied) R&D opportunities
- 2 times:
  - Participation in technology demonstration/showcase (technological component/module, prototype, emerging technology or applications, business incubator, etc.)
  - Network/community building around ALSS
  - Raise of awareness (dissemination of ALSS knowledge)
- 1 time:
  - Industrial collaboration
  - Provide scientific/technical expertise on specific ALSS topics
  - Participation in workshop/conference
  - Training courses organization / Continuous education
  - Use/operation of ALSS hardware

Ranked 2nd:

- 4 times:
  - Provide scientific/technical expertise on specific ALSS topics
  - Participation to working groups or advisory bodies
- 3 times:
  - (Applied) R&D opportunities
  - Participation in technology demonstration/showcase (technological component/module, prototype, emerging technology or applications, business incubator, etc.)
  - Industrial collaboration
- 2 times:
  - Benefit for the MELiSSA scientific and engineering expertise
  - Network/community building around ALSS
  - Participation in workshop/conference
  - Spin-off commercialization of ALSS terrestrial applications
- 1 time:
  - Scientific collaboration
  - Raise of awareness (dissemination of ALSS knowledge)
  - Technology transfer
  - Test/benchmark/validation of methodologies (services)
  - Spin-in commercialization of ALSS space applications

Ranked 3rd:

- 5 times:
  - Participation in technology demonstration/showcase (technological component/module, prototype, emerging technology or applications, business incubator, etc.)
- 3 times:
  - (Applied) R&D opportunities
  - Industrial collaboration
  - Participation to working groups or advisory bodies
  - Participation in workshop/conference
- 2 times:

  - Provide scientific/technical expertise on specific ALSS topics
  - Benefit for the MELiSSA scientific and engineering expertise
  - Technology transfer
  - Training courses organization / Continuous education
- 1 times:
  - Scientific collaboration
  - Raise of awareness (dissemination of ALSS knowledge)
  - Spin-off commercialization of ALSS terrestrial applications
  - Test/benchmark/validation of methodologies (services)
  - Technology watch

When cumulating the activities that were listed as top 3 either as 1st, 2nd and 3rd preferred kind of collaborations:

- Scientific collaboration was selected by 48% of the respondents
- (Applied) R&D opportunities by 42% of the respondents
- Participation in technology demonstration/showcase (technological component/module, prototype, emerging technology or applications, business incubator, etc.) by 32% of the respondents.

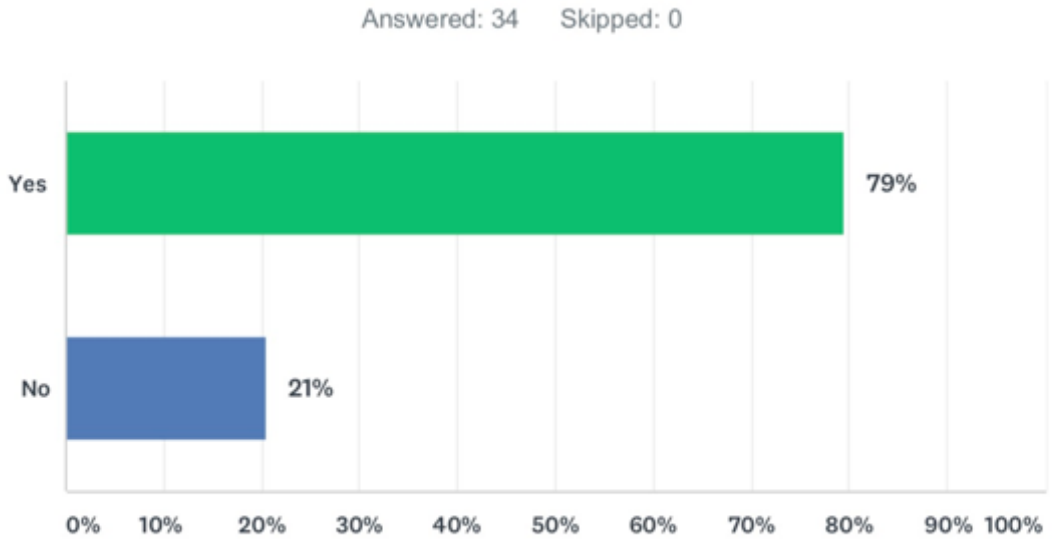
In addition, the following activities were selected by more than 20% of the respondents:

- Industrial collaboration
- Provide scientific/technical expertise on specific ALSS topics
- Participation to working groups or advisory bodies

After weighting (1st rank giving 3 points, 2nd 2 points, and 3rd 1 point), the ranking of the kinds of collaboration on ALSS with MELiSSA are as follows:

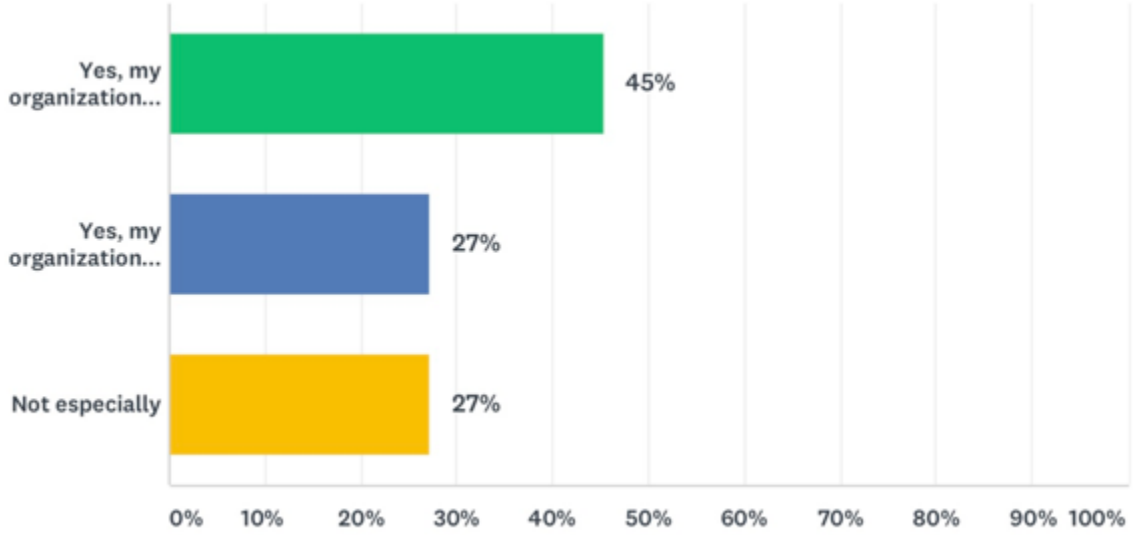
Q7 (incl. vote weighting)	33 answers					
Ranking	**1**	**2**	**3**	**Total ranking 1, 2 or 3**	**Total ranking [weighted*]**	**% answers [weighted*]**
Scientific collaboration	13	1	1	15	**42**	21%
(Applied) R&D opportunities	8	3	3	14	**33**	17%
Participation in technology demonstration/showcase (technological component/module, prototype, emerging technology or applications, business incubator, etc.)	2	4	5	11	**19**	10%
Industrial collaboration	2	3	4	9	**16**	8%
Provide scientific/technical expertise on specific ALSS topics	1	4	2	7	**13**	7%
Participation to working groups or advisory bodies	0	4	3	7	**11**	6%
Participation in workshop/conference	1	2	3	6	**10**	5%
Network/community building around ALSS	2	2	0	4	**10**	5%
Raise of awareness (dissemination of ALSS knowledge)	2	1	1	4	**9**	5%
Spin-off commercialization of ALSS terrestrial applications	0	3	1	4	**7**	4%
Benefit for the MELiSSA scientific and engineering expertise	0	2	2	4	**6**	3%
Training courses organization / Continuous education	1	0	2	3	**5**	3%
Technology transfer	0	1	2	3	**4**	2%
Test/benchmark/validation of methodologies (services)	0	1	1	2	**3**	2%
Spin-in commercialization of ALSS space applications	0	1	1	2	**3**	2%
Use/operation of ALSS hardware	1	0	0	1	**3**	2%
Technology watch	0	0	1	1	**1**	1%
Investment opportunities	0	0	0	0	**0**	0%
	** 6 pts distributed per answer: 1st=3pts, 2nd=2pts, 3rd=1pt*					

2.4.4.18 *Q20: Would you be interested in having access to some MELiSSA laboratory/testbed hosted in Switzerland?*



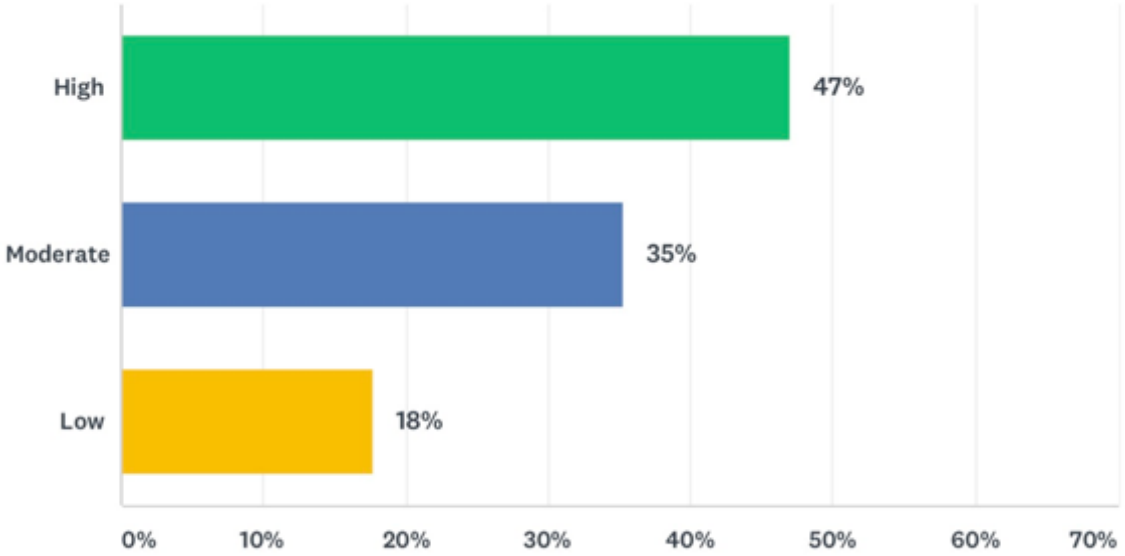
Almost 80% of the responding organisations would be interested in having access to some MELiSSA laboratory/testbed hosted in Switzerland.

2.4.4.19 *Q21: Would you be interested in participating in MELiSSA-related activities at supranational level?*



27% of the organisations that replied are already participating in MELiSSA-related activities at supranational level and 45% would be interested in participating. Only 27% are not especially aspiring to participate at supranational level at the moment.

2.4.4.20 *Q22: How do you assess the potential to set up new collaborations on ALSS/MELiSSA-related activities within the next two years?*



47% of the responding organisations consider as high their potential to set up new collaborations on ALSS/MELiSSA-related activities within the next two years. 35% foresee a moderate potential, and only 18% a low potential.

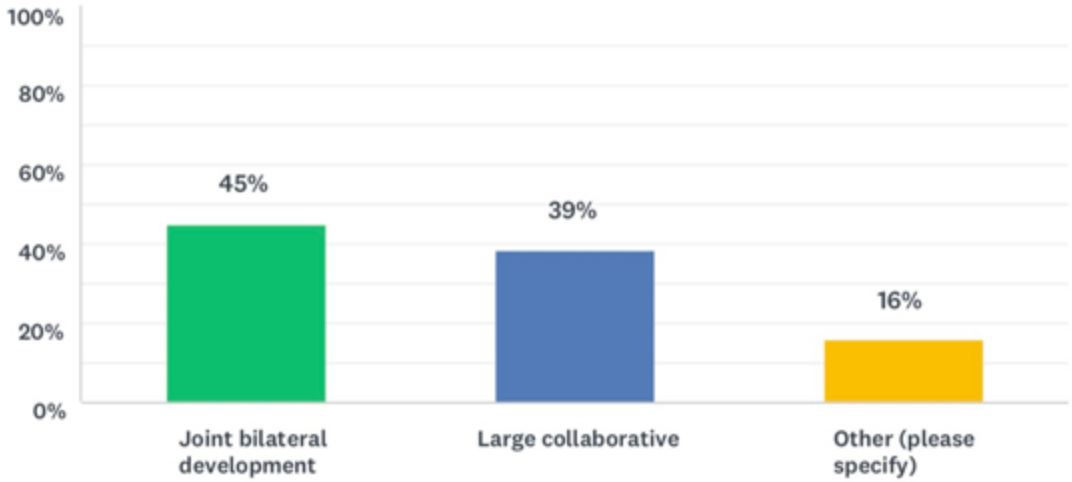
2.4.4.21 Q23: (Optional, and mainly addressed to organizations that are not involved yet in MELiSSA/ALSS-related activities)

What would your potential own contribution to a joint project look like?

The following organizations gave a short description of how their own potential contribution to a joint project would look like (Q23):

- RUAG offers capabilities to build experiments and validate part of the ALSS loop through their In Orbit Demonstrator (IOD). RUAG also offers its expertise to develop techno building blocks such as “gas-liquid-solid interface for oxygen transfer in Life Support Systems” to be used for different experiments. Finally, RUAG is able to provide skills in consultancy mode, on demand;
- UNIL - Prof. Sarah Mitri: We are working on building model microbial ecosystems that we can control in a close-loop manner. We also build mathematical models that help predict dynamics in our experimental systems. These results should be highly relevant for MELiSSA;
- CSEM: Development of specific technology bricks or adaption of CSEM technologies/knowhow based on ALSS requirements/needs - Bridge gaps between TRL 2 and TRL 7;
- Innobridge: Hosting a testbed or MELiSSA laboratory on Agropole site (agritech & foodtech hub in development in Canton de Vaud);
- HEI (HES-SO//Valais-Wallis): MELiSSA Food characterisation – Phase 3. Validation of the FPCU concept proposed in MELiSSA Food characterisation – Phase 2 + Impact of food processing and formulation (i.e. nutraceuticals) on nutrients bioavailability & on human microbiote. 5 years to TRL5. Multidisciplinary expertise in : - food processing - food safety - nutraceuticals & nutrients bioavailability - hygienic design of food Equipment (EHEDG) - waste & by-products valorization - water & air management - biomaterials bioenergy - microalgae (i.e., spirulina) production - microbiote characterization based on in vitro digestive model - real-time data acquisition & control;
- EPFL+ECAL lab: They propose to introduce the discipline of design research to investigate the user experience and user interface dimension for different parts of the system. This work includes understanding of user perception, with a focus on cognitive and emotional state component. They believe that new designs of scenario of uses, habitats and interfaces can open new ways in human behaviour facing closed environment. Their idea is to put an emphasis on what can be transferred on Earth and be implemented in everyday life of large audience;
- Vuna: Profound practical knowledge on nutrient recovery systems;
- SOFIES SA: Bring in one of their industrial clients, test innovative solutions in the organic waste management field, contribute by managing / facilitating multi-stakeholder processes, management of pilot projects, etc.;
- Oracan Sàrl: Biotech technologies engineering/development; Space projects Management;
- HSLU – Center for Bio- and Medical Engineering Tim Granata: Development and testing of photobioreactor to produce biomaterials for additive manufacturing;
- Eawag and ETH Zurich, Dr. Joaquin Jimenez Martinez: Soil physico-chemical processes, including microbiology and plants, in weightless conditions;
- UNIBE – Prof. Losch: Ethical evaluation
- Orphanalytics: Genome analysis: exchange of genome islands (higher pathogenicity);
- Anne-Marlene Rüede: Architecture, Systems engineering knowledge;
- Mars Society Switzerland: just speaking about it and spreading the progress you are making to the Public.

2.4.4.22 Q24: Which models of collaboration do you prefer?

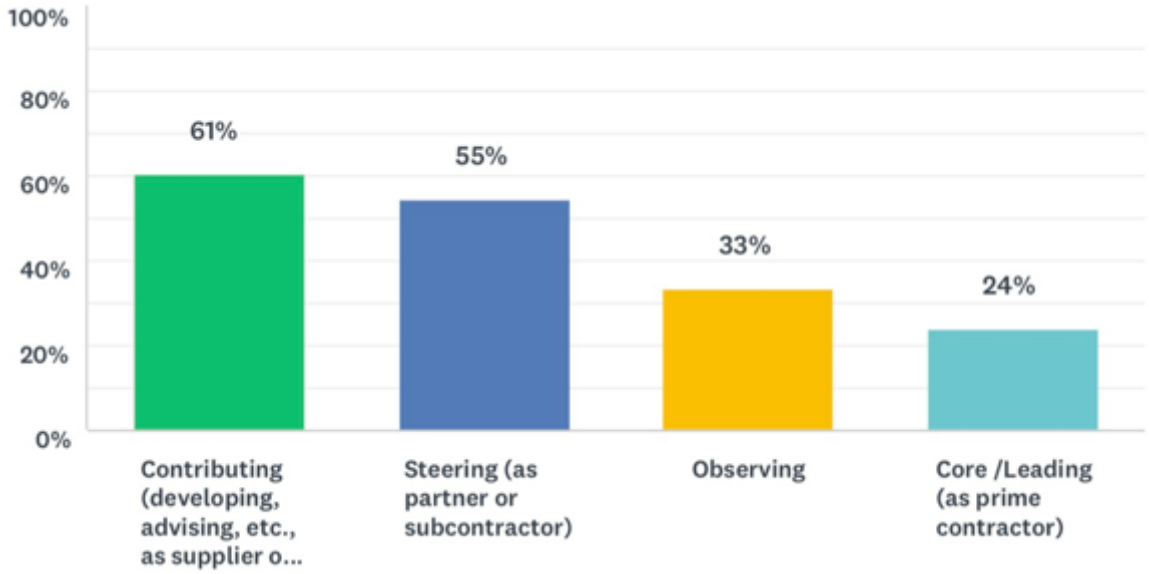


45% of the respondents prefer joint bilateral development as a collaboration model, and 39% large collaborative ones.

Eawag said it would depend on the specific topic and scale of the project.

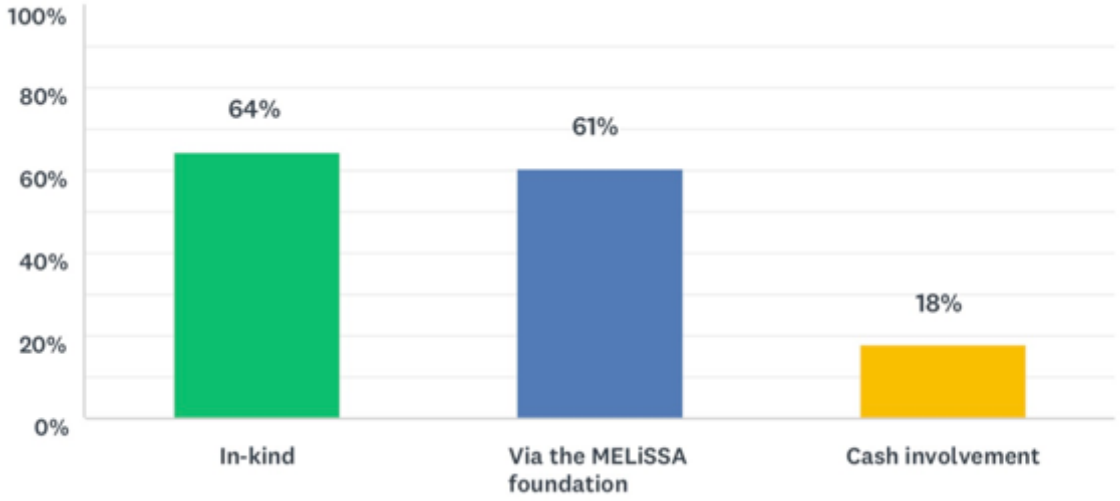
RUAG prefers to be prime-sub with responsibility that are clearly identified.

2.4.4.23 Q25: What would be your level(s) of involvement?



The envisioned levels of involvement of the responding stakeholders (Q25) are 1) steering (as partner or subcontractor) and 2) contributing (developing, advising, etc., as a supplier or consultant), each with more than 50% of the respondents' expressed opinions. A third also envisage to be an observing member. 24% would be ready to lead a project (as core leader or prime contractor) among which RUAG, Eawag (2x), Earth Space Technical Ecosystem Enterprises SA, CSEM, eSpace Center and HSLU.

2.4.4.24 Q26: Which kind(s) of contribution would you consider?



On the kinds of contribution that would be considered by the respondents, more than 60% chose the MELiSSA foundation and in-kind contributions, and almost 20% cash involvement (Earth Space Technical Ecosystem Enterprises SA, eSpace, ZIPAR, Eawag, HSLU)

2.4.4.25 *Q27: Where do you see potential difficulties/bottlenecks (in terms of R&D, funding, ...)? Which solutions can you think of?*

On the perceived potential difficulties/bottlenecks (in terms of R&D, funding, etc.) and associated solutions, the respondents notably noted:

- RUAG: Funding needs to stay within European Exploration Envelope Programme (E3P);
- CSEM: Difficult to gain access to Prodex funding in Switzerland; Identification and understanding of promising terrestrial applications are key to advancing ALSS for space exploration; tech transfer opportunities to non-ALSS fields must be extensively listed (market assessment);
- HEIA-FR: open the funding to project and not only PhD salary;
- HEI (HES-SO//Valais-Wallis): Lack of continuous involvement in ALSS development activities and short project duration. Solutions: development of a pilot plant to experiment ALSS concept(s) thanks to a stable project consortium;
- EPFL+ECAL Lab: Although new methodologies of design research bring a crucial contribution for sustainable innovation by addressing user perception, the latter does not belong to traditional disciplines. Moreoever, it does not have specific funding sources and is usually not considered by existing funding bodies;
- Eawag (Prof. Udert): Restrictions by commercial interests;
- Vuna: Lack of strategy, dispersed partners, uncoordinated efforts cause high investment with limited return. Create a clear strategy and slick project teams;
- UNIL (Prof. Mitri): Their main limitation is that of time. They are working at the fundamental level, and taking the time to bring this to a level where it can be applied will be time-consuming
- CleantechAlps: Key is to be able to demonstrate concrete mid-term value for the economy;
- Mars Society Switzerland: Progress should be made known. Do not hesitate to communicate to the general public. Support will ultimately come from them;
- OrphAnalytics SA: Slow decision process on space organisation;
- ZHAW (Philipp Osterwalder): Sponsorship, Communication and Network.

The above-mentioned elements perceived by the respondents have been integrated into a strengths, weaknesses, opportunities, threats (SWOT) analysis of the MELiSSA roadmap (§2.3).

2.4.4.26 Q28: Swiss stakeholders in the private sector

Do you think some of your Swiss partners or stakeholders* in your network could be interested in MELiSSA/ALSS? Which ones (and why)?

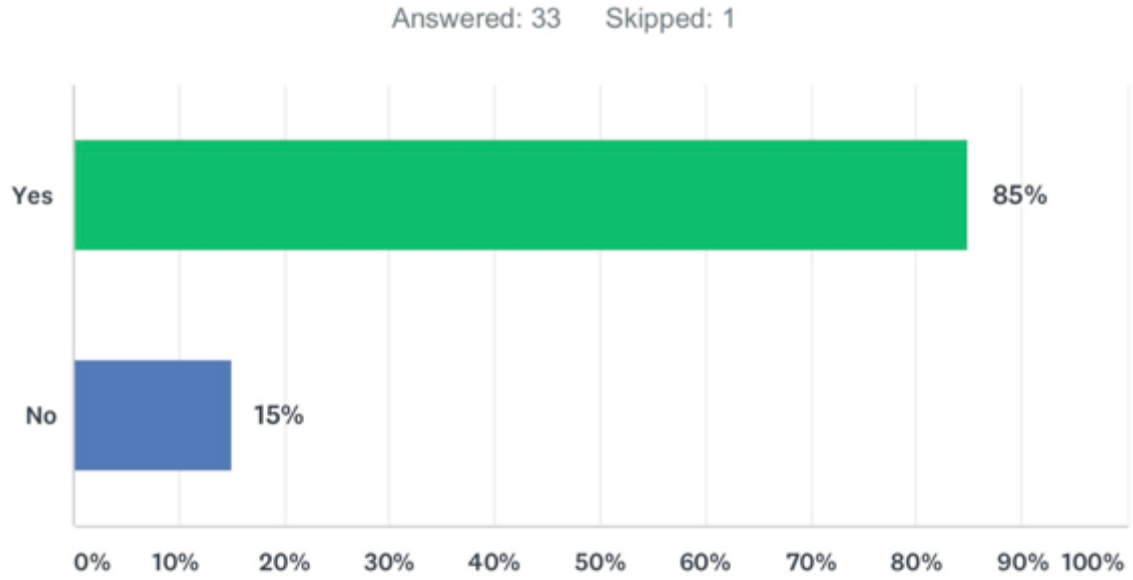
*In particular start-ups, SMEs and industrials for technology transfer, commercialization and/or supply of ALSS components, devices and subsystems

The following Swiss stakeholders in the private sector from the responding organisations' network which could be interested in MELiSSA/ALSS were mentioned:

- RUAG Space Nyon;
- Earth Space Technical Ecosystem Enterprises SA;
- CSEM;
- Eawag;
- Sofies;
- regenHU (high interest in space 3D bioprinting);
- CombaGroup;
- ricolab.ch (Benjamin Gräub);
- European Hygienic Engineering and Design Group (EHEDG) members ;
- Companies through EPFL Innovation Park + Creative industries could also be involved in the project;
- VUAN GmbH;
- HEPIA (Roberto Putzu, responsable filière Génie Mécanique) ;
- Bioscience and Medical Engineering Competence Center, HSLU;
- ORACAN;
- SpaceTek;
- Entomos;
- UMAMI.

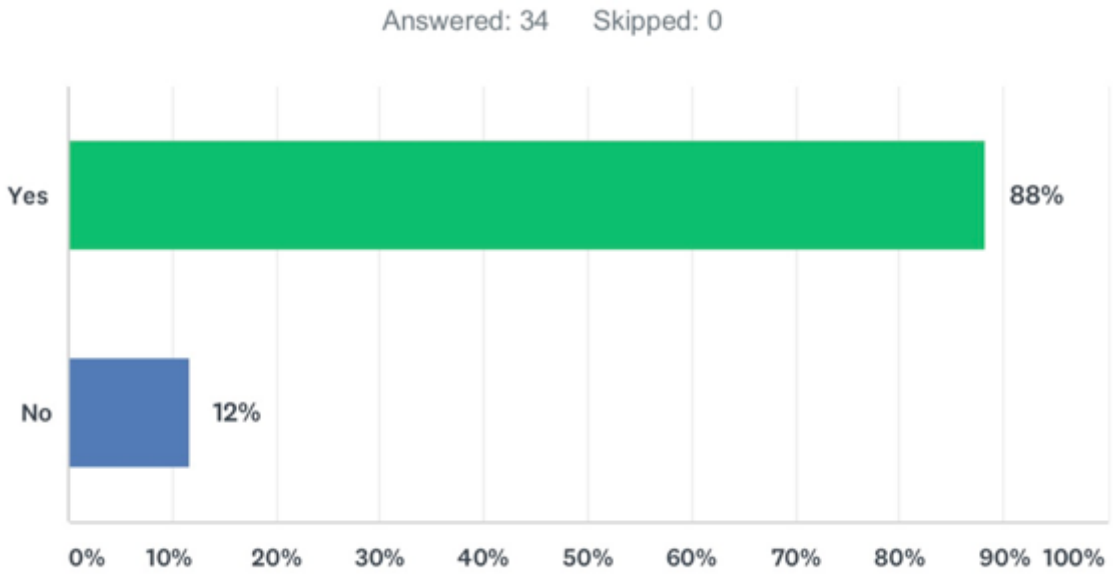
The above-mentioned ones that were not listed in the Swiss ALSS/MELiSSA stakeholders were duly added to the list.

2.4.4.27 Q29: Would you be interested in being involved in a Swiss ALSS/MELiSSA community/network?



The vast majority of the responding organizations (85%) would be interested in being involved in a Swiss ALSS/MELiSSA community/network.

2.4.4.28 *Q30: Would you be interested in participating in a workshop/conference on the same topic by mid 2020?*



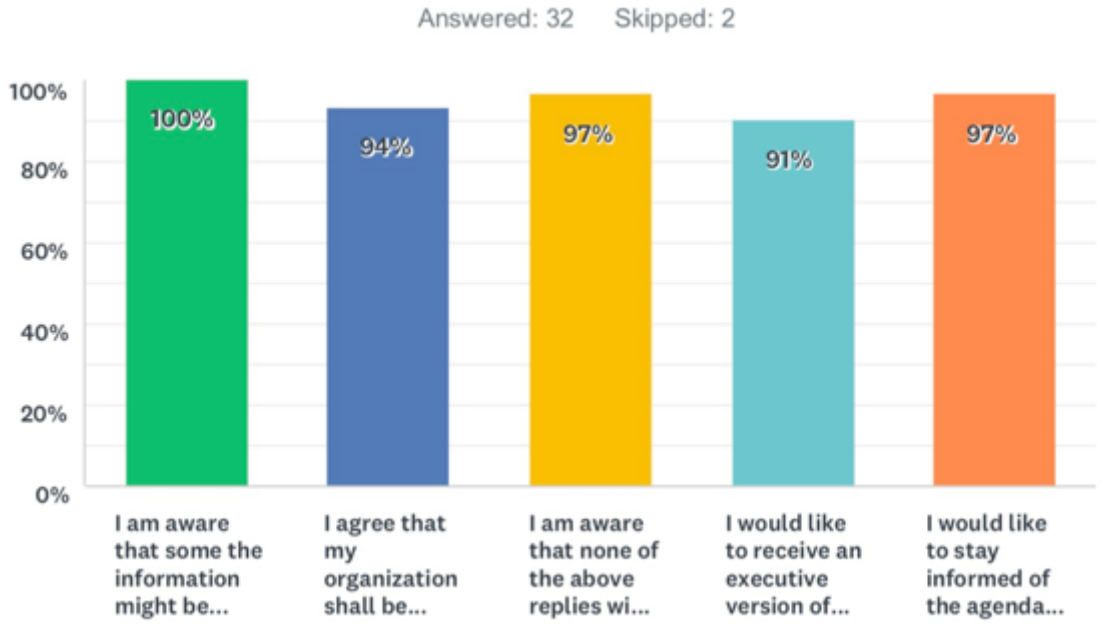
Almost 90% of the respondents would be interested in participating in a workshop/conference on the same topic by mid 2020.

2.4.4.29 Q31: Any other complementary suggestions/comments?

The following complementary suggestions/comments were mentioned:

- Eawag (Prof. Udert): “I highly appreciate this initiative and I am confident that Switzerland can build up a strong network with expertise on LSS especially but not only with a focus on terrestrial applications.”;
- RUAG is happy to support in a "subcontractor" mode;
- Innobridge: having a spot in Switzerland where all the related aR&D can be tested and demonstrated will have a great value;
- SCAHT: “We do human health regulatory risk assessments for pharmaceuticals and chemicals. Environmental chemical contaminants generally do not present major risks for human health, compared to human pathogens (closed system example Staphylococcus on ISS). So I'm not sure what useful contribution we could make, but if you need human health risk assessment for chemical contaminants, SCAHT could certainly help.”;
- EPFL+ECAL Lab: “As we represent an emerging discipline, we would be open for a discussion with Melissa in order to define specific/pragmatic topics as case study.”;
- Vuna: “Due to limited resources, our company can only commit to clear mandates with adequate compensation.”;
- CleantechAlps: “Go for it!”.

2.4.4.30 Q32: Final considerations



All the final considerations were ticked by at least 90% of the responding organizations.

- I am aware that some of the information might be shared, but only within the framework of the elaboration of a Swiss position paper for ALSS/ MELiSSA. An executive summary of the report will be shared between the ALSS/MELiSSA Swiss community and will not be published online.
- I agree that my organization shall be mentioned as interested and/or already involved parties (if in consistency with your survey replies)
- I am aware that none of the above replies will be taken for any kind of commitments towards any ALSS/MELiSSA parties.
- I would like to receive an executive version of the Swiss Position Paper on ALSS/MELiSSA.
- I would like to stay informed of the agenda of such Swiss community/network related to ALSS/MELiSSA activities.

2.5 Annex 5 – Facsimile of the Position Paper released in Spring 2019 by the MELiSSA industrial actors

MELiSSA Industrial Actors – Position Paper

The European space industries involved in the Micro-Ecological Life Support System Alternative (MELiSSA) would like to express their strong support to the on-going Program.

MELiSSA now encompasses key technological and scientific activities, including **PFPU, Artemiss, WTUB, WC-MEC, Urinis, Biorat, GWRU and WQA.**

We stress specifically the importance of the ongoing preparation of space missions, in continuity of the on-going activities mentioned above and the new ones such as Phases Separation Units, all of the described in the Annex.

Industry seeks a political support with a long-term planning and adequate funding to:

- Secure the continuity of MELiSSA technology developments for Space exploration Life Support, sustained by a robust roadmap and associated projects in the E3P Programme;
- Improve the European industry technical excellence and competitiveness in this key enabling field for human Space Exploration.

Industry believes that partnerships including the full European ecosystem of industrial and academic actors, within both space and non-space domains, are a key for developing innovation in space as on Earth.

Furthermore MELiSSA projects activities are fully in line with terrestrial challenges and needs, representing a major example of cooperation for developing circular economy capabilities and European non-dependency in space as on Earth, which should be increased to reap the full benefits of these cooperations.

MELiSSA is a perfect example of European excellence, driving innovation in scientific and technological fields, thus enabling human space exploration.

MELiSSA continues to generate economic, political and societal benefits and returns associated to the development of a circular economy, in space as on Earth, as demonstrated by all the developments and the technology transfer projects highlighted in the attached annex.

Annex

Why Industry supports MELiSSA

For more than 30 years, The European Space Agency has been active in the field of regenerative life support systems. MELiSSA is THE European project of circular life support, known and appreciated worldwide by the scientific and technical community for the advancement of bioregeneration. It has been established to gain knowledge on regenerative systems, achieving the highest degree of autonomy for vital resources, food, water and oxygen, from mission wastes.

MELiSSA is about the development and use of space applications to improve the quality of life for citizens, today and tomorrow. MELiSSA is not only a source of inspiration for the larger public, it represents a credible solution for a human lunar settlement.

Thanks to > 25 years efforts and a long-term commitment, its community has built unique capabilities, demonstrated both on earth and in space.

Key achievements today include:

- **GreenMOSS** (2012 – 2014, coordinated by Thales Alenia Space)
  Study of a Lunar Greenhouse for food production, one of the key building blocks of the "Moon Village".

- **PFPU** (2014 - 2020, coordinated by Thales Alenia Space)
  Design and development of key technologies for a Precursor of Food Production Unit, for tubers growth in microgravity, targeting demonstration on ISS and cis-lunar space.

- **Artemiss** (2011-2018, coordinated by QinetiQ)
  First photobioreactor that produced oxygen and edible biomass in space.

- **WTUB** (2014-2015, coordinated by University of Ghent with QinetiQ)
  Water treatment unit for producing hygienic water from urine, condensate and grey water proved an efficiency of 95% over 2 months of operation in laboratory.

- **WC-MEC** (2018, coordinated by University of Ghent with QinetiQ)
  Improvement of the Waste Compartment (and Microbial Electrolytic Cell), one of the building blocks of MELISSA. Laboratory tests.

- **Urinis** (2017, coordinated by University of Ghent with QinetiQ, SCK and University of Mons)
  Urine treatment compartment, one of the building blocks of MELISSA. Laboratory tests.

- **Biorat** phase B (2015-2019, coordinated by RUAG with QinetiQ)
  Pre-development and test of a flight experiment composed of a closed gas loop producing O2 (algae photosynthesis) and consuming CO2 of a mice crew.

- **MELiSSA Food Characterization Phase 2** (2015-2016, coordinated by HES-SO Valais and supported by RUAG)
  Hydroponic sub-system studied at scientific and engineering levels, delivery of technical requirements & completion of preliminary testing phase.

- **GWRU** (2006-2008, coordinated by SENER Ingeniería y Sistemas S.A., form. NTE)
  Grey Water Recycling Unit design and analysis activities and technology demonstrator activities.

- **MELISSA adaptation for Space** (2001-2008, coordinated by SENER Ingeniería y Sistemas S.A., formerly NTE)
  Identification of critical technologies for the adaptation, establishment of new control system, study, demonstration of MELISSA techniques for space application.

- **MiDASS** Phase B (2011-2014, coordinated by BioMèrieux with SENER Ingeniería y Sistemas S.A., formerly NTE)
  Preliminary design activities of space instrument for the microbial detection in air, in closed space habitats.

- **WQA, RCW, OLAA** (2011-2017, coordinated by SENER Ingeniería y Sistemas S.A.)
  Removal of specific contaminants in water including metals (Ag, Cu,…) and specifically ammonium analyzer tested by means of laboratory demonstrators.

Key Technology Transfers:

- Algosolis Platform, Algae production, St Nazaire, France
- BioFacades: XTU, Paris, France
- Water quality Control, Kenitra, Marocco
- EZ Col Company, Cholesterol, The Netherlands
- Organic Wastes & Water, La Trappe, Berkel-Enschot, The Netherlands
- Vila Troglodytes, Water, Monaco
- BioStimulant, Mons, Belgium
- Biostyr Nitrification, Veolia, France
- Fermentation Control, Freixenet, Spain
- Urine Treatment Unit, Vuna, Switzerland & Belgium
- ESTEE Spin-off Company, Switzerland
- Grey Water Treatment Unit, Hotel F., Monaco
- Circular Hub, Malaga, Spain.

On-going / future activities of strategic importance to be supported to maintain and increase competitiveness are:

- **PFPU** - flight demonstrator and IOD of a critical subsystems (Nutrient Module), including novel mixed-phase management and separation technologies
- Study of a **Food Production Unit** for demonstration in cis-lunar space
- **Biorat** - flight demonstrator for air recycling demonstration (Carbon capture and Oxygen production), with advanced fluid dynamics based technologies for mass transfer enhancement
- **Phases Separation Units (Gas/Liquid, Solid/Liquid) -** Technology demonstrator enablers
- **Urinis** - flight demonstrator and IOD of a critical subsystems
- **Artemiss** - improvement of flight hardware and continued flight tests
- **WTUB** - IOD of critical subsystems
- **WQA** - IOD of water quality analysis technologies

The Industrial Actors supporting MELiSSA are:

- Qinetiq
- RUAG Space Nyon
- SENER Ingeniería y Sistemas S.A.
- Thales Alenia Space