This paper aims at studying the European research opportunity of the Deutsches Zentrum für Luft und Raumfahrt’s (DLR) Facility of Laboratories for Sustainable Habitation (FLaSH) project. FLaSH’s main goal is to research, develop and test Life Support Systems (LSS) technologies for materially closed-loop environments, for space and terrestrial application. The core element of the FLaSH is the Habitation Module Complex (HMC), which integrates 12 interconnected modules, each one of them addressing a LSS’s domain in order to achieve a self-reliant habitat: Air, Water, Waste, Greenhouse, Food, Animal, Living, Sickbay, In Situ Resource Utilization (ISRU), Workshop and Energy. As a first step, the literature on LSS and the most relevant infrastructures dedicated to LSS development were reviewed. Successively, FLaSH’s preliminary study conducted in 2012 at the DLR’s Concurrent Engineering Facility (CEF) was analysed. The review on the LSS and FLaSH allowed for the identification of 110 candidate technologies. Finally, a survey was carried out on 172 European entities, identified as potential participants, in order to generate primary data for the FLaSH’s research opportunity study. The survey collected a total of 36 valid responses. Survey respondents revealed that 27 entities, from 15 European countries manifested a potential interest in participation and cooperation with FLaSH. The Air, Water, Waste, Greenhouse modules were identified as the most interesting. Participants’ preferred methods of collaboration comprised technology testing and development as well as advisory services. The FLaSH’s dual approach of developing closed-loop technologies for space and terrestrial applications was backboned majority of the participants.

I. INTRODUCTION

Self-reliant human habitats are vital for permanent human presence in space. NASA had already established within its major goals a crewed mission to Mars. Mars surface human exploration will inexorably involve long-duration human spaceflight [1]. For a mission duration of 1 year, 12109 kg per crewmember in life support consumables are required. Considering that the transportation costs to the lunar surface are up to U.S. 100000$ / kg. (Fiscal year 2005), thus susceptible higher for a Mars mission, just the transportation costs of human mission to the Moon or Mars will become prohibitively high under materially open-loop LSS [2].

On Earth, human demand of the biosphere’s (The LSS of Earth) regenerative resources is increasing dramatically, overcoming the biosphere’s regeneration capacity [3] and calling for the application of practices for sustainable human development.

There are parallelisms between the challenges for sustainable development on Earth and the creation of LSS for long-duration human space flight as: efficient resource utilization, i.e. careful handling of resources and their reutilization leading to the minimization of waste and the draw-down of the non-renewable process. This scenario led to the Deutsches Zentrum für Luft und Raumfahrt ‘s (DLR) initiative of designing the Facility of Laboratories for Sustainable Habitation (FLaSH). The objective of the FLaSH initiative is the creation of a terrestrial self-reliant habitat to test, mature, and improve closed-loop technologies, whether physicochemical or biological, in order to overcome the challenges of future human space exploration as well as to support the sustainable development on Earth.

II Motivation

In 2012 a preliminary study for the FLaSH was carried out at the DLR ‘s Concurrent Engineering Facility (CEF), of the Institute of Space Systems in Bremen. FLaSH will be an incubator for LSS’s closed-loop technology development, testing and demonstration, yet to this day, no specific research has been conducted in regard to the willingness, expectations and perceptions of different entities concerning a potential participation in FLASH. This research aims to fill such gap by exploring FLASH’s main features and research interest, which technologies could be included in FLaSH and surveying potential participants.

The main objective of this work is to explore the research opportunity of FLaSH within Europe at three different levels:

i) Number and profile of the interested entities in the FLaSH.

ii) Interest in the FLaSH’s modules and modules’ technologies.
In order to fulfil the overall aim it will be necessary, beforehand, to review the current FLaSH configuration and identify potential candidate technologies. This task will use as a starting point the FLaSH preliminary study carried out in 2012. The review and study of the current FLaSH configuration will allow identifying and outlining FLaSH’s mains features in comparison to other relevant LSS infrastructures. Furthermore, the proposal of candidate technologies, which were not considered in the 2012 study, will increase the FLaSH’s technology opportunities, increasing the number of participants that will be interested in participation.

**II. Methodology**

This work involves the generation of primary data as well as the study of secondary data. The review of the current FLaSH configuration and the identification of candidate technologies have been performed based on an extensive literature review about FLaSH and LSS. For the research opportunity study primary data was generated through an online survey. The survey was conducted within four weeks in August 2014.

**II. LIFE SUPPORT SYSTEMS LITERATURE REVIEW**

LSS can be defined as the set of objects, which interact or have interdependence between each other in a very specific manner in order to sustain life [4]. Basic human needs as a breathable atmosphere, water, food and waste removal are natural functions carried in daily basis by the Earth’s biosphere. However, in order to sustain life in Space or in specific places in Earth (e.g., underwater, remote areas, etc.) those functions carried by nature must be performed by physical or mechanical equipment, or even by a small-scale replication of the Earth biosphere [5].

In human spaceflight, the human is integrated within the LSS as a system [6]. In rough numbers, a human can survive 4 minutes without oxygen, 3 days without water and close to 1 month without food. Oxygen, water and food are considered the main and basic consumables for ensuring human life. However, the LSS must include additional environmental standards to support the human health and wellbeing during the whole mission (i.e. during duty and off-duty times). Those environmental standards are referred under the term of habitability and address physiological issues (acceleration, lighting conditions, temperature and humidity, and so on.) as well as psychological aspects (interpersonal dynamics, psychological support, cognitive performance)[7][10].

### II.1 LSS classification

The LSS include functions that are not subjected to regeneration, e.g. control or monitoring, as well as regenerative functions where resources can be reused as water, air and food. A LSS system performing regenerative functions without resource reclamation is referred as an open-loop system. In an open-loop system material flows into and out of the system. An increment in the level of reclamation of used resources turns into a decrease of the amount of resupply, i.e. an increase in the closure degree. Resource reutilization within regenerative functions can be achieved by means of two types of technologies:

1. **Physicochemical (P/C)** technologies, based on physical and chemical processes.

2. **Biological** technologies, based on biological processes also known as bioregenerative technologies.

A LSS involving both types of technologies is known as a Hybrid Life Support System (HLSS). A diagram regarding LSS classification is presented in Fig. 1.

![Classification of LSS according to their degree of closure](image)

For a very short duration mission, open-loop LSS are advantageous since the initial mass of a regenerative P/C LSS is higher than a non-regenerative LSS. The break-even point occurs for mission duration longer than two weeks, where regenerative P/C LSS become more advantageous, in terms of mass, in comparison to the non-regenerative P/C LSS [7].
For long-term missions hybrid LSS, i.e. combining biological and P/C technologies, require less mass than regenerative P/C LSS. Finally, for very long duration missions (more than 5 years) the CELSS are the best option. The CELSS involving a 50% of food loop closure will be only feasible for 5 to 7 years missions whilst at least 11 to 12 years will be required to justify a food loop closure of 95%, considering 6 crew members in both cases. CELSS can become feasible for shorter mission durations by increasing the mission’s crew size, specifically a break even point between the 50% food loop closure and the 95% can be obtained in 6-7 years with a crew of 20 or more [5].

III. FLaSH REVIEW AND CANDIDATE TECHNOLOGY IDENTIFICATION

In 2012 a preliminary study was conducted by DLR within the Concurrent Engineering Facility (CEF). The FLaSH preliminary study focused in the design of the Habitat Module Complex (HCM), ensuring that its design supported modularity for system and technology exchange within the facility. The study also addressed a preliminary modules’ configuration and specified some technologies to be included for closed-loop operation test-runs.

III.I Habitat Module Complex

A total of 12 modules, each one of them representing a research domain within LSS, integrate the Habitat Module Complex: Air, Water, Waste, Food, Living, Sickbay, Animal, Greenhouse, Workshop, ISRU and Energy. The remaining module is a spare module and will include redundant technologies in case of malfunction of any of the other modules’ technologies in order to avoid stopping the closed-loop test campaign.

III.II Study of relevant LSS infrastructures

In Table 1 are listed the main LSS infrastructures and their main characteristics, including FLaSH. The features studied for each facility included main mission drivers for the LSS design: the crew size, the time mission, the Floor Area (FA) available per crewmember or the Pressurized Volume (PV) per crewmember depending on the gravity environment. In gravity environments (Earth based infrastructures) is preferable to measure the space available in terms of FA whilst in microgravity (orbital based infrastructures) environments PV provides a more suitable unit of measure. In addition to those characteristics the study also revealed other relevant features as the loops under closure and closure indexes whenever information about it was available. [8]

Facilities studied on Earth are: underwater habitats, space analogues, remote area settlements as Antarctic research stations and Closed Ecological Life Support Systems (CELSS). Space based infrastructures studied included past and present space stations. It must be remarked that all the Earth-based infrastructures presented in this work are, in fact, space analogues, since they involve features or are placed in environments that emulate, at some extent, the living conditions of the space. Nevertheless, in this work only infrastructures with the specific purpose of recreating planetary living conditions have been considered as space analogues.

In comparison to the rest of facilities, the underwater habitats studied are characterized by low space availability per crewmember and short mission durations. The Tektite habitats endured the longest mission duration achieving a total of 60 days. Almost all the facilities operated under open-loop LSS, with the exception of the BIOSUB, which addressed CO₂ reduction and O₂ regeneration by means of an algae reactor.

CELSSs involved higher crew size values than the underwater habitats, with 8 crewmembers in the Biosphere 2. Besides, Biosphere 2 also endured the longest mission duration amongst all the facilities with a total of 720 days. According to Table 1, CELSS are characterized by their high closure indexes, being the BIOS III the facility with the highest closure index, up to a 91%. Indeed, CELSS’s main objective is to attain the maximum degrees of material closure.

Within the space analogues studied, draws the attention the 500 days mission duration for the Mars 500. Despite the fact that the Mars 500’s LSS operated under open loop conditions during the whole mission, it provided invaluable data for research on the effects of confinement and isolation in the human body during long duration human spaceflight. Mars 500 main purpose was to emulate the living conditions on a round trip crewed mission to Mars, being that the reason for the reduced space available per crewmember. All the crews for space analogues are integrated by 6 crewmembers, following the recommendations from Mars reference missions [9].

The Antarctic bases operate with the biggest crew sizes (9 and 16), amongst the studied infrastructures, during mission durations of 270, which is the time in which no resupply mission is possible due to climatological conditions. In regard to loop closure and resource
regeneration the Concordia station includes regenerative LSS for black and grey water regeneration by means of biological as well as P/C technological solutions [10].

Space facilities include early efforts of extending human presence in space as the soviet space station Salut and the U.S. Skylab. The MIR was the first real long-term habitation space station, which started operation during 1986 and was continuously occupied until 1999. The MIR’s LSS addressed atmosphere and water regeneration. However, it required from food, water and nitrogen resupply. Nowadays, the ISS is the only space station in active, merging efforts from Russia, U.S., Europe and Japan. In terms of the closure index, the ISS achieves a 100% of air regeneration and reclamation. Despite water is completely reclaimed, waste water is used for water electrolysis in order to generate oxygen reducing water closure loop down to 63% [11].

In terms of material closure, the ambitious FLaSH’s closure index of 95 % places it within the CELSS group. In order to attain a 95%, bioregenerative technologies for food production are necessary [6]. However, CELSS exclusively rely in the utilization of bioregenerative technologies for carrying out the regenerative functions (since bioregenerative technologies are necessary to close the food loop). Regenerative physicochemical technologies present higher reliability than the bioregenerative technologies, making them excellent candidates for emergency scenarios. FLaSH aims to include all type of technologies in order to generate knowledge and evaluate the interaction between the different type of technologies.

Furthermore, FLaSH is the only infrastructure studied that addressed the possibility of replacing and testing several LSS technologies for the same purpose. This means that for the other studied infrastructures the LSS configuration is predetermined and in case of unsolvable malfunction the test campaign must end, and undergo long inoperative periods until the system is ready to work properly again [12].

**III.III Modules’ function, current technologies and candidate technologies identification and classification**

The candidate technologies (i.e. new technologies identified by the author) identification process was based on an extensive research on LSS’s literature. Forecasting a high number of technologies the technologies were categorized following the European Space Agency (ESA) Technology Tree in order to provide a systematic classification framework [13].

The ESA Technological Tree is a three-level structure classification system. The first level includes 26 Technology Domains (TD), which are subsequently divided into Technology Subdomains (TsD) and these are thoroughly subdivided into Technology Groups (TGs).

From the 26 domains of the classification system the TD number 22 represents the domain of interest for the present work, which include 2 TsDs:

2. TsD-B: In-Situ Resources Reutilization (ISRU).

The TGs of the ECLSS technology subdomain are:

- **I- Environmental Control & Monitoring.** Addresses technologies for air, water and food quality control and monitoring in terms of microbial and chemical contaminants.
- **II- Regenerative LSS.** Covers all the technologies related to air revitalization, water and waste reclamation as well as food preparation and production by means of P/C and biological processes.
- **III- Habitability.** Covers all the technologies employed for the design and implementation of human habitat, aiming for crew-well-being, crew motivation and optimal performance, including definition of key psychological factor.
- **IV- Integrated ECLSS covers all associated aspects and associated technologies for integrated human habitats and life support systems, including ground based test-beds and overall simulation tools and methods.**

The TGs of the ISRU technology subdomain are:

- **ECLSS consumables:** covers all technologies for collecting and processing fluids and gases to be used as consumables for the ECLSS in human habitats.
- **Fuels:** covers all technologies for collecting and processing fluids and gasses to be used as consumables for propulsion and energy production.
- **Storage and distribution:** covers all technologies for fluids and gasses storage and distribution.
<table>
<thead>
<tr>
<th>Environment</th>
<th>Name</th>
<th>Crew</th>
<th>Mission time [days]</th>
<th>FA [m²] or PV [m³]</th>
<th>Loops with closure</th>
<th>Closure Index [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underwater Habitat</td>
<td>TEKTITE I &amp; II</td>
<td>4</td>
<td>60</td>
<td>7</td>
<td>Open-loop</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>La Chalupa</td>
<td>4</td>
<td>30</td>
<td>6</td>
<td>Open-loop</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>ConShelf-III</td>
<td>6</td>
<td>21</td>
<td>5</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>AQUABIO</td>
<td>1</td>
<td>12</td>
<td>9</td>
<td>Air</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Aquarius</td>
<td>6</td>
<td>14</td>
<td>7</td>
<td>Open-loop</td>
<td>0</td>
</tr>
<tr>
<td>CELSS</td>
<td>CEEF</td>
<td>2</td>
<td>21</td>
<td>55</td>
<td>Water, air &amp; food</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Moon Palace 1</td>
<td>3</td>
<td>105</td>
<td>40</td>
<td>Water, air &amp; food</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>LMRS</td>
<td>4</td>
<td>91</td>
<td>22</td>
<td>Water, air &amp; food</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>BIOS-III</td>
<td>3</td>
<td>180</td>
<td>32</td>
<td>Water, air &amp; food</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>Biosphere 2</td>
<td>8</td>
<td>730</td>
<td>1750</td>
<td>Water, air &amp; food</td>
<td>80</td>
</tr>
<tr>
<td>Analogue testing</td>
<td>Mars 500</td>
<td>6</td>
<td>500</td>
<td>35</td>
<td>Open-loop</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>MDRS</td>
<td>6</td>
<td>14-30</td>
<td>21</td>
<td>Open-loop</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>HI-SEAS</td>
<td>6</td>
<td>120</td>
<td>24</td>
<td>Open-loop</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>FMARS</td>
<td>6</td>
<td>122</td>
<td>15</td>
<td>Open-loop</td>
<td>0</td>
</tr>
<tr>
<td>Remote Areas</td>
<td>Concordia</td>
<td>16</td>
<td>270</td>
<td>94</td>
<td>Water</td>
<td>~55</td>
</tr>
<tr>
<td></td>
<td>Neumayer III Station</td>
<td>9</td>
<td>270</td>
<td>206</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Facility under study</td>
<td>FLaSH</td>
<td>8</td>
<td>365</td>
<td>445 (dome included)</td>
<td>Water, air &amp; food</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>Salyut</td>
<td>3</td>
<td>180</td>
<td>33</td>
<td>Water &amp; air</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td>Skylab</td>
<td>3</td>
<td>84</td>
<td>107</td>
<td>Water &amp; air</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td>MIR</td>
<td>3</td>
<td>180</td>
<td>116</td>
<td>Water &amp; air</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td>ISS</td>
<td>6</td>
<td>180</td>
<td>52</td>
<td>Water &amp; air</td>
<td>100% air loop</td>
</tr>
</tbody>
</table>

| Table 1: Properties and characteristics of earth-based and space-based similar facilities [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35]. |

The ESA technological tree technology domain number 22 addresses the classification of the technologies considering whether the technologies are used for regenerative functions or non-regenerative as control and monitoring. However, it does not specify whether if the technology is itself regenerative or non regenerative. In regard to the regeneration capability, the technology will be classified as:

- **Regenerative**, technology involved in a LSS regenerative function addressing resource reclamation.
- **Non-regenerative**, a technology involved in a LSS regenerative function with no resource reclamation.
- **Non-applicable (N/A)**, in the case of technologies performing functions as control, monitoring, storage and management.

In order to ease differentiation between the technologies that were already considered in the 2012 FLaSH’s preliminary study and the new proposed technologies by the author, the following terminology was employed:

- **Current technology**: term employed for designating a technology that was already identified and suggested in the 2012 FLaSH’s preliminary study. The sources accessed are based on the FLaSH preliminary study report.
• Potential Candidate technology: term to indicate a potential technology identified by the author based on bibliographic research.

Additionally, technologies are classified according to their physicochemical and biological nature. In Table 2 it is presented an excerpt of the table used for the Air module’s technology identification and classification. Two functions are presented: the CO2 removal and the Nitrogen (N) provision. The technologies addressing those 2 functions are within the ESA’s TsD A and TG II since those functions belong to the ECLSS technology subdomain (TsD A) and they address air revitalization (TG II). For the nitrogen provision function the author suggests only one non-regenerative candidate technology, in addition to the current technology, also non-regenerative, identified in the 2012 FLaSH’s study. However, for the carbon dioxide removal the author proposed a total of 15 candidate technologies. Amid the candidate technologies suggested 12 are regenerative technologies and 3 non-regenerative. Besides, 3 current technologies were identified in the 2012 FLaSH’s study, being 2 of them based on biological processes and 1 in physicochemical processes. As for the remaining modules, the same procedure was followed, with the exception of the Energy module whose configuration was not defined in the 2012 FLaSH’s study.

This work identified a total of 41 functions, within the HMC’s modules, and classified them as regenerative and non-regenerative functions. Regenerative functions represent the 43% of the total amount of identified functions. Regenerative functions are distributed within the Air, Water, Waste, Greenhouse, Food and Animal modules. Therefore, considering that closed-loop technologies (regenerative technologies) are applicable in regenerative functions those modules present higher opportunities for closed-loop technology applications.

Finally, after filtering the number of candidate technologies, eliminating repeated counts of a same technology applied for different functions, can be concluded that this work contributed to identify a total of 110 candidate technologies.

IV. RESEARCH OPPORTUNITY STUDY

This work aimed at studying the research opportunity at the three levels previously described. For that purpose and considering that no prior data was available, a survey was implemented in order to generate primary data.

IV.I Sample description

The population under study is characterized by:

• European entities whose activities or technologies were linked to the FLaSH’s modules or modules’ technologies.

Considering that no prior database of this type of entities existed, the author created a directory of 172 potential participants evaluating their available information in order to determine their nationality and whether any of their research fields, services and technologies were connected with the FLaSH’s modules domains and / or modules’ technologies.

IV.II Results discussion: i) Number and profile of the interested entities in the FLaSH

The survey revealed that a total of 27 entities are interest in participation. In Fig. 2 is depicted the geographical distribution of participants interested in participation in FLaSH. The geographical distribution shows that entities around 15 European countries could benefit from participation in FLaSH. Regarding the type of entity a total of 9 SMEs are interested in participation. The only big industry participant (entity with more than 250 employees) declared that was no possible to evaluate the outcome at this stage of the project. The number of interest entities in research organizations and academia increases up to 15 interested entities out of 16. As for the public bodies 3 out of 4 participants stated interest in collaboration.

Research organizations and academia responses in regard to their technological relevance were concentrated in the high relevancy values (scoring themselves with more than 7) in contrast to the industry’ participant’s opinions, see Fig. 3. Therefore, it is an unexpected result to obtain a higher number of research organizations and academia’s respondents interested in participation than within the industry.

It is worth to note that for the public bodies and agencies the trend observed in industry and research organizations is inverted: despite the majority of respondents from this type of entity stated as low their technological relevance, 3 out of the 4 surveyed entities stated interest of participation.
**Table 2**: Excerpt of the LSS technology identification and classification for the Air module.

<table>
<thead>
<tr>
<th>Functions</th>
<th>TsD</th>
<th>TG</th>
<th>Regeneration</th>
<th>Process</th>
<th>Current technologies</th>
<th>Current technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₂ provision</td>
<td>A</td>
<td>II</td>
<td>Non-Regenerative</td>
<td>Physicochemical</td>
<td>-</td>
<td>-Thermal Catalytic dissociation of Hydrazine</td>
</tr>
<tr>
<td>Biological</td>
<td>-Algae reactor</td>
<td>-Higher Plants</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Two Bed Molecular Sieve</td>
<td>- Four bed molecular Sieve</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Sabatier reactor</td>
<td>- Amine liquid sorbent</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Amine liquid sorbent</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Electrochemical CO₂ Concentrator Depolarized Cell</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Air Polarized CO₂ Concentrator Cell (ADC)</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ removal and reduction</td>
<td>A</td>
<td>II</td>
<td>Regenerative</td>
<td>Physicochemical</td>
<td>-</td>
<td>-Metal-Oxides</td>
</tr>
<tr>
<td></td>
<td>-Membranes Osmotic</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Electro active carriers</td>
<td>-Ion-Exchange electro dialysis</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Bosch reactor</td>
<td>-CO₂ Electrolysis</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>-Advance Carbon Reactor System</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Regenerative</td>
<td>Physicochemical</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-Lithium Hydroxide</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Sodasorb</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Superoxide</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Considering that some agencies included in the sample as the European Space Agency (ESA) this is not surprising result. ESA aims at redistributing 85% of its budget in the form of contracts with the industry, therefore relying technology manufacturing and development in other type of entities as industry [36]. Unfortunately, the survey responses were anonymous and no conclusion can be made regarding the specific role in technology development of the public bodies and agencies respondent group.

From the 27 participants with interest of participation, 21 participants had previous experience in human self-reliant habitats while 6 did not have any experience.

The research opportunity study provided with the profile of the most suitable entities for collaborating in

**Fig. 2** Geographical distribution of entities interested in participation.

FLaSH, defined as entities expecting a positive outcome and stating a high perception of their technological relevance within self-reliant human habitats. The survey
results have shown that 23 out of 36 participants fall within that definition. They are considered as the most suitable because they provide the most desirable collaboration frame where both parts could benefit from each other; FLaSH will benefit from their technological relevance to operate under closed-loop conditions and the participants will use FLaSH for developing, testing or demonstrating their technologies.

Fig. 3 Entities self-evaluation of their technological relevance.

IV. Main results: ii) Interest in the FLaSH’s modules and modules’ technologies

Air, Water, Waste and Greenhouse modules are the most preferred modules in terms of the number of interested participants, Fig. 4. This result was in tune with findings obtained in the modules’ technology identification, where was concluded that Air, Water, Waste, Greenhouse and Animal modules presented a higher number of opportunities for closed-loop technology testing since they involved all the regenerative functions.

Survey’s answers revealed a total of 16 technologies without any interested participant. In two cases those technologies are utilised for providing basic LSS functions: trace contaminant control and urine treatment. These circumstances do not suppose a threat for the facility operationalization since other technological options to carry those functions, identified within this work accounted for at least one interested participant. Nevertheless, they represent a loss of research opportunities.

Research organizations, industry and SMEs as well as public bodies share interest in the same technologies across several modules. This is an encouraging finding considering that FLaSH seeks to promote the scenario in which the three types of entities share interest in modules’ technologies, enabling knowledge transfers across organizational boundaries, hence matching with one of the goals of the Horizon 2020 program.

IV. IV Main results: iii) Entities’ expectations and perceptions in regard to the FLaSH operationalization and utilization.

On the basis of the results yielded in the FLaSh survey can be concluded that participant’s perception of their technological relevance is rather high with 78% the participants scoring their technological relevance as 5 or higher. Only 8 participants considered their technological relevance as low or very low (scoring it less than 4). The results also denoted different perceptions of the technological relevance across the entity types. Research organizations and academia showed a higher perception of their technological relevance with 75% of the participants scoring their relevance as 6 or higher. SMEs presented higher variation in the grades but 3 SMEs participants presented the highest perception amongst all the participants, scoring as 10 their technological relevance.

Participant’s responses showed that they agree with the FLaSH collaboration methods suggested. Considering that the FLaSH main goal objective is to provide a technology incubator for closed-loop technologies it is a positive result that 19 participants are willing to collaborate by using the facility for technology development, test and demonstration. Other suggestions from respondents included scientific collaboration and research and development. Regarding the wide range of activities covered by scientific collaboration and lacking from a more concise definition it has been considered as another independent method, see Fig. 5.
A total of 26 participants reinforced the dual approach of FLaSH developing closed-loop technologies for terrestrial and space applications. Another interesting result is the 6 responses stating a higher development of life support closed-loop technologies for Earth application in front of the 2 stating a higher development of closed-loop technologies for Space applications.

V. LIMITATIONS

This study has 2 major limitations. The first one was encountered in the FLaSH’s candidate technology identification process and classification and the sampling techniques used to study the FLaSH’s research opportunity. The second major limitation of this work resides in the sampling techniques employed in the research opportunity study. Both sampling techniques, judgmental and snowball are non-probabilistic sampling methods. Therefore, obtained results are not statistically projectable to the entire population under study, although may provide a relevant insight concerning to the characteristics of respondents [37].

VI CONCLUSIONS

The review on FLaSH and the identification of candidate technologies concluded that Air, Water, Waste, Greenhouse, Animal and Food modules are the most interesting taking into consideration the main goal of the facility as an incubator for closed-loop technology. These modules involve the majority of the regenerative functions. Furthermore, the research opportunity study determined that, according to the entities surveyed, those modules are the most interesting in addition to the ISRU module. Besides, the research opportunity study concluded that 27 European entities, from over 15 European countries would benefit from participation in FLaSH. In specific, 9 SMEs, 15 research organizations and 3 public bodies. Moreover, 23 out of 27 participants have a high perception of their technological relevance and expect a positive outcome from their participation in FLaSH initiative, hence their definition as ideal potential participants.

The distribution of participants evidenced that FLaSH will provide a proper scenario for enabling collaboration across geographical boundaries as well as organizational boundaries between research organizations, industry and public bodies / agencies. Entities preferences concerning the participation methods supported the FLaSH’s intention of providing an arena for technology development, testing and demonstration, although participants preferred collaboration method was as advisory services providers.

Finally, according to respondent’s expectations, self-reliant human habitats will achieve higher development for both environments: space and terrestrial applications.

References
