Remarks on ISRU and ISFR Technologies for Manned Missions on Moon and Mars

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Abstract

Space colonization and exploitation of extra-terrestrial natural resources could help humanity in facing various Earth problems. In this regard, production of energy and materials starting from Moon and Mars natural resources as well as the transportation of humans in space could be considered the long term remedy to issues such as overpopulation, depletion of fossil fuels, climate change as well as reduction of available natural resources. Along theses lines, two recently filed patents related to use of novel technologies for the in situ exploitation of natural resources available on Moon and Mars have been developed.

Introduction

In Situ Resource Utilization (ISRU) and In Situ Fabrication and Repair (ISFR) technologies represent core components for space exploration and colonization. ISRU technologies can provide materials for extraterrestrial life support, propellants for extravehicular activities, construction materials as well as energy to a crew deployed on a planet, Moon, or asteroid [1-7]. On the other hand the target of ISFR technologies is to satisfy requirements related to the fabrication and repair of equipment and materials at the location (*in-situ*) where the equipment operates.

Besides being a key element for the success of manned space missions, the development of ISRU and ISFR technologies, may directly suggest possible solutions to environmental issues on Earth. Examples include carbon dioxide sequestration systems, optimized water treatment processes, sewage systems, recycling of waste, controlled crop growth, etc.

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In the framework of the COSMIC project, sponsored by the Italian Space Agency since the end of 2009, a task force formed by the University of Cagliari, the National Research Council (CNR) as well as by the Centre of Research, Development and Advanced Studies in Sardinia (CRS4), is involved in a research activity aimed to the development of ISRU e ISFR technologies. In this context, two patents related to novel technologies for the in situ exploitation of natural resources available on Moon and Mars are recently filed [8-9].

The invented ISFR process

One of the patent by Cao et al. [8] consists of the development of an ISFR process for manufacturing physical assets for civil and/or industrial facilities on Moon, Mars and/or asteroid, as well as the kit of materials and apparatus needed to achieve this target. Such a kit allows to implement the process of the invention by providing all materials and apparatuses that could be applied on Moon, Mars and/or asteroid, thus advantageously and significantly reducing, both costs and payload of the materials. The invented ISFR process involves the operating steps schematically shown in Fig. 1.

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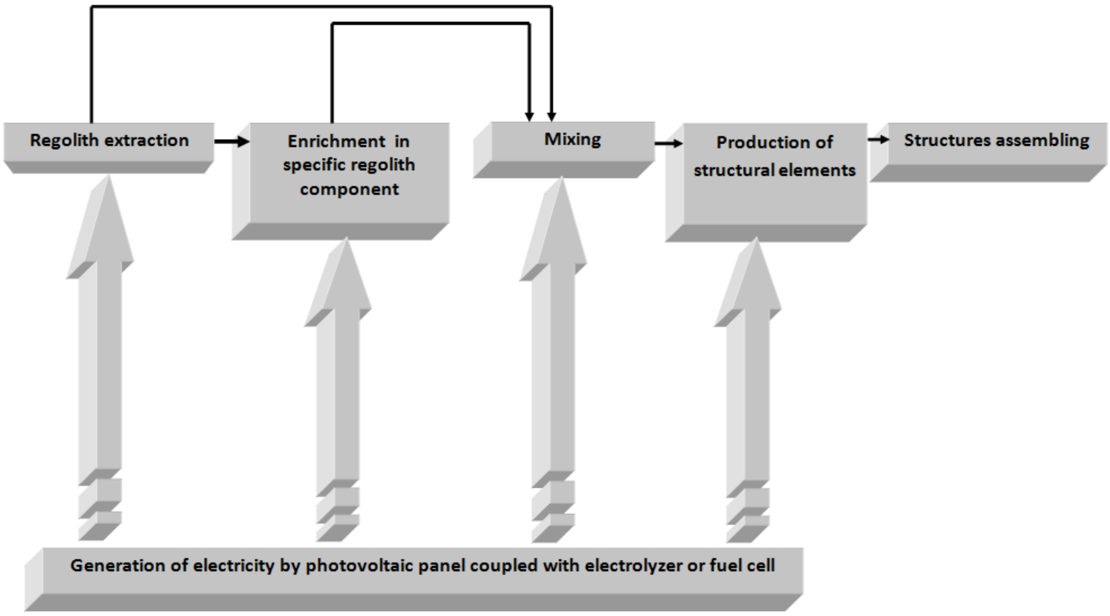

Fig. 1. Schematic flow-sheet of the process for manufacturing physical assets for civil and/or industrial facilities on Moon and Mars.

The first step of the process includes the extraction of regolith from Moon or Mars by taking advantage of suitable equipment specifically designed to operate in extraterrestrial conditions. The extracted regolith is then enriched in a specific component present in significant amounts on the Martian soil, namely iron oxide, through suitable equipments. The third step is represented by the mixing of the enriched regolith with specific reactants supplied, if necessary, from Earth. The subsequent step, which is the core of the entire process, involves self-propagating high temperature combustion reactions taking place within the mixture resulting from the previous step. Details related to this process are reported in a recent paper [10]. Briefly, these reactions are characterized by the fact that, once ignited by an external energy source, they are able to self-propagate in the form of a combustion wave through the reacting mixture without requiring additional energy. This reacting step is performed in a specific reactor which constitutes the core unit of the invention and is able to operate in martian conditions (microgravity, low temperatures and rarefied atmosphere of CO_2), thus allowing the fabrication of structural elements of desired size and shape by means of proper moulds. These aspects are extremely important from the practical point of view since the process permits to obtain solid final products characterized by extremely good purity and mechanical properties by means of a very simple reaction requiring a low external power supply. A photography showing an example of structural element produced through the invented process is reported in Fig. 2.

Fig. 2. Photography of a typical structural element produced through the invented process.

Finally, as displayed in Fig. 3, the obtained structural elements may be then assembled to build civil and/or industrial facilities on Mars.

The main step of the patented process has been tested last October in Bordeaux (France) during the 53rd parabolic flight campaign where it has been possible to perform experiments under microgravity conditions on board of a suitable Airbus 300 during the 30 parabolas pertaining to each of the three missions accomplished.

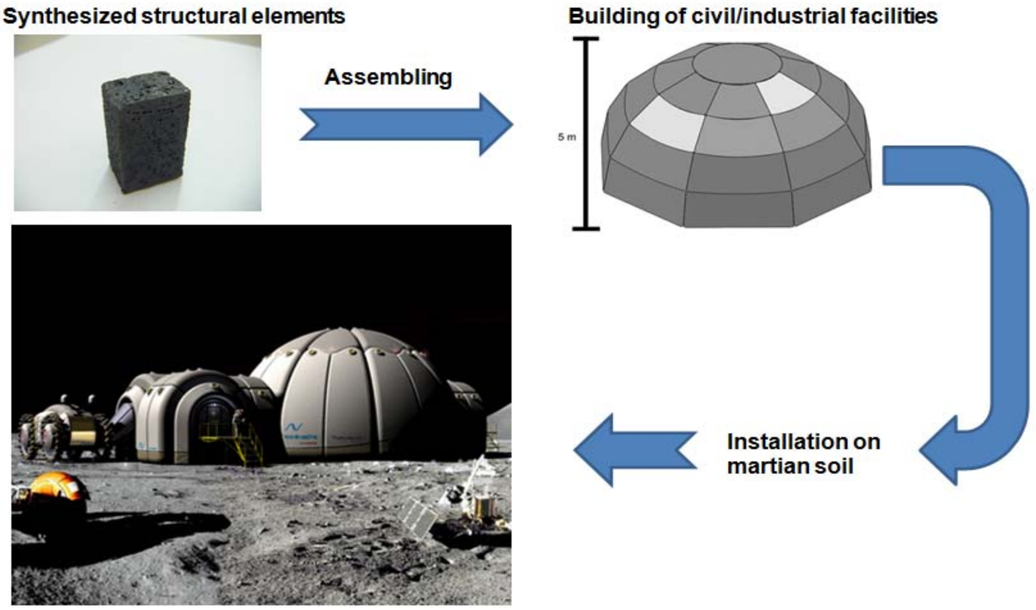

Fig. 3. Implementation of the invented process on Moon and Mars.

The invented ISRU process

Unlike ISFR technologies, the general purpose of In-Situ Resource Utilization technologies (ISRU) is to harness and use extra-terrestrial resources to produce consumables and develop services which enable to reduce significantly the payload, the cost, and the risk of near and mid-term space exploration. Mars has suitable resources available for human use, including carbon dioxide, nitrogen, argon, and traces of water vapor in the atmosphere as well as water in the regolith. Suitable ISRU processing technologies are, in principle, able to transform these raw resources into useful materials and products, thus providing multiple benefits for manned permanent missions.

In this context, the second patent developed by Cao et al. [9] refers just to a specific ISRU process synergistically coupled with a regenerative ECLSS (Environmental Control and Life Support System). The self-sustainment (in terms of material and energy needs) of a crew during a midterm manned mission on Mars may be then assured. ECLSS systems, typically employed in the International Space Station, involve a set of units that allows to maintain physiological parameter in the crew habitat (cabin) by removing organic and inorganic catabolites produced by astronauts such as exhaust atmosphere, feces, humidity as well as various type of solid and liquid wastes. The regenerative ECLSSs permit the recycling of the removed wastes and the subsequent production of useful materials such as water, oxygen and food. Although the ultimate objective of modern ECLSS systems is to achieve a closed loop able to fulfill the primary needs of the crew (in terms of oxygen, water and food), experimentations and mathematical simulations demonstrate that, to date, only a relatively small percentage [11] of the needed amount of these materials may be produced by recycling wastes.

This fact implies the need of a continuous replenishment of these materials from Earth, thus affecting the economic and technical feasibility of a manned mission on Mars due to the very expensive interplanetary journeys. On the other hand IRSU technologies may help to overcome these drawbacks since they can produce the required materials through the exploitation of *in-situ* available natural resources. The invention by Cao et al. [9] works just in this direction. Along these lines, the baseline concept of the filed patent for the synergic combination of ECLSS and ISRU is shown in Fig. 4.

In particular, the invention by Cao et al. [9] has the purpose to produce energy, breathable oxygen, water for drinking and washing, hydrogen and ammonia to be used as propellants, nitric acid and ammonium nitrate as fertilizers as well as edible biomass starting from martian atmosphere and soil. In this regard, the ISRU plant is conceptually divided into two interacting sections: the chemical-physical one and the biological one (cf. Fig. 5).

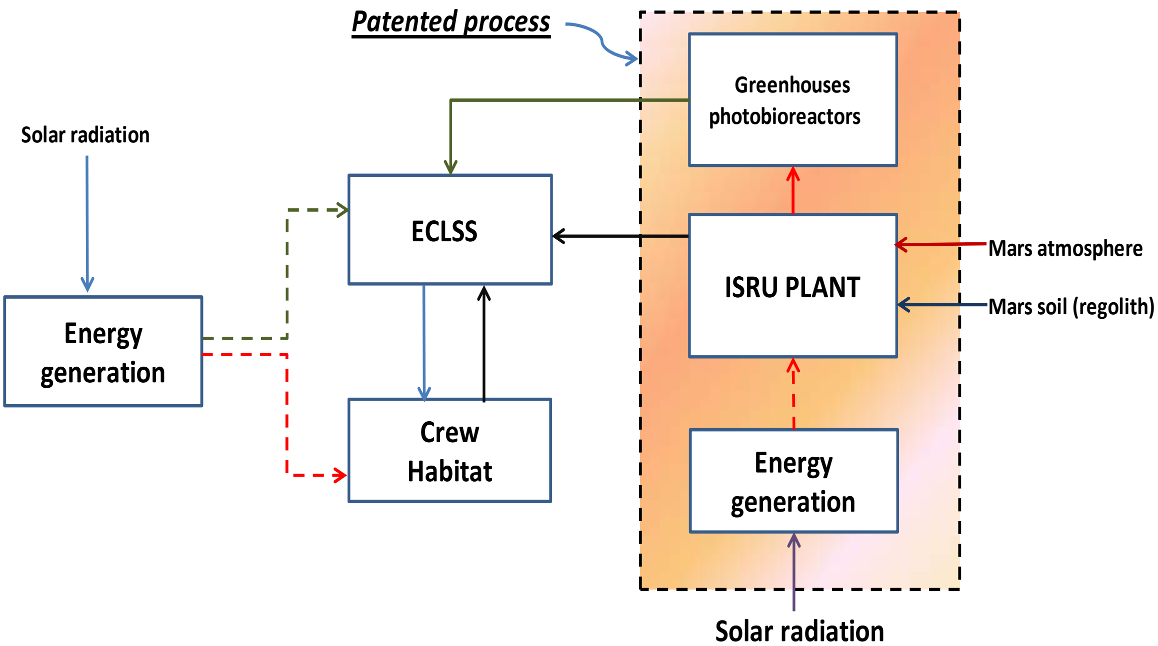

Fig. 4. Schematization of baseline concept for the synergic combination of ISRU and ECLSS systems.

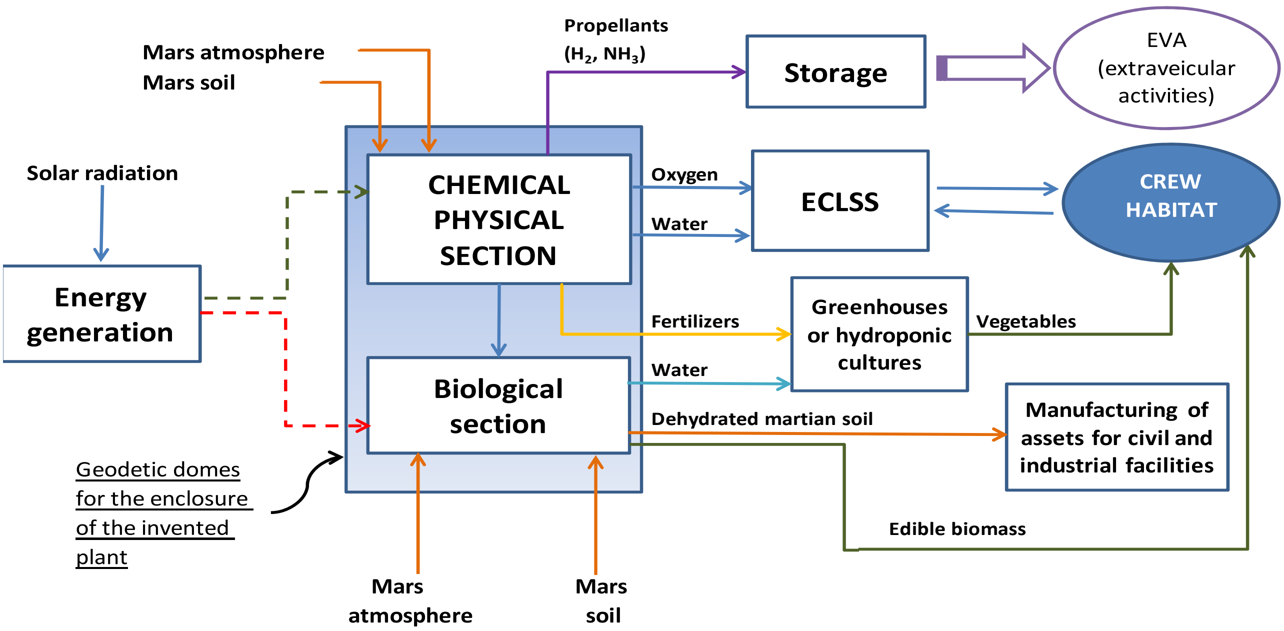

Fig. 5. Schematic flow-sheet of the invented ISRU process.

In the first section, the combination and juxtaposition of different plant units specifically designed to operate in Martian conditions, allows for the production of water, oxygen, and propellants needed by a crew of up to six members as well as suitable amounts of fertilizers to be used in biological section. The set-up of the optimal values of operating parameters has been identified through appropriate mathematical models.

Briefly, the main plant units involved in the chemical physical section are – geodetic domes, water adsorption reactors [12], solid state compressors, temperature swing adsorbers [13], water and CO_2 electrolyzers, electrosynthesis reactors, magnetrons [14], absorption mini-towers and catalytic reactors [15] as well as photovoltaic panels for energy supply.

The biological section receives, as inputs, either natural resources (CO_2 from atmosphere and regolith) and synthetic products from the chemical physical section to produce edible biomass and photosynthetic oxygen by using photobioreactors and greenhouses. As an example, the amounts of consumables and energy produced by the ISRU plant relatively to a specific design case are reported in Table 1.

Table 1
Summary of the energy and consumables produced with the patented invention for a specific design case.

Output from the ISRU plant	Unit	Value	Use
Oxygen	kg/h	41.66	Air revitalization and/or combustion
Water	kg/h	3.85	Drinking and/or washing
Ammonia	kg/h	2.00	Propellant and/or fertilizer
Mixture of CO + CO_2	kg/h	78.86	Propellant
Nitric acid	kg/h	0.13	Fertilizer and/or leaching solution
Ammonium nitrate	kg/h	0.25	Fertilizer
Hydrogen	kg/h	0.04	Propellant and/or precursor for water production
Buffer gas	kg/h	0.03	Air revitalization and/analytical instrumentation
Nutrient solution	kg/h	100.00	Greenhouses irrigation and/or water production
Edible biomass	kg/h	0.09	Food for crew members feeding
Dehydrated regolith	kg/h	4888.49	Manufacturing of assets for industrial or civil facilities
Energy	kW	538.47	Self-sustainment of ISRU plant

In order to examine the technical and economic feasibility of such process, it is necessary to calculate the payload of the entire ISRU plant. The synopsis of the payload of such a plant is shown in Table 2.

Table 2
Summary of the payloads for the patented plant for a specific design case*

Element	Unit	Payload
Dome for the chemical physical section	kg	86
Dome for the biological section	kg	118
Dome for the biological-photobioreactor section	kg	300
Plant units for the chemical physical section	kg	73809
Plant units for the overall biological section	kg	11056
Total	kg	85369

*Photovoltaic plant is not considered in the calculation of the overall payload

It is worth noting that, since SpaceX is planning to build a variant of Falcon 9 (a rocket-powered spaceflight launch system) able to transport up to 25 tons of payload [16], the entire ISRU plant could be, in principle, transported on Mars with only four journeys, thus guaranteeing the actual feasibility of the process.

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