

BISRU: SYNTHETIC MICROBES FOR MOON, MARS AND BEYOND.

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Introduction: Whole genome assembly [1] and the reliable control of biological systems that synthetic biology hopes to achieve [2, 3] will likely bring a new range of designer organisms into being. One such application of genetically engineered organisms is the utilization of resources in space for the support of human settlement such as the production of biofuel from Martian CO₂. The term “*in situ* resource utilization” or ISRU is being extended to BISRU or “biological *in situ* resource utilization”[4].

Why biology is the right tool for the job: Biology can be viewed as a low mass, self-reproducing manufacturing technology that is very efficient at utilizing resources. Although physical and chemical ISRU could do the job of turning local materials into resources for human settlement, the infrastructure needed to support non-self-replicating systems such as these would likely be much larger than that needed for biology. Naturally occurring organisms already make many useful products and are being used for a number of industrial applications such as those detailed below and shown in Figure 1. If these naturally occurring organisms can be evolved or engineered to enhance their tolerance to extreme environments or increase their synthesis of useful products in such environments they will become useful cellular chassis for other applications. A concept mission is shown in Figure 1, where an automated drilling photobioreactor could land on a planetary surface to extract raw materials and convert them into biofuels for future collection.

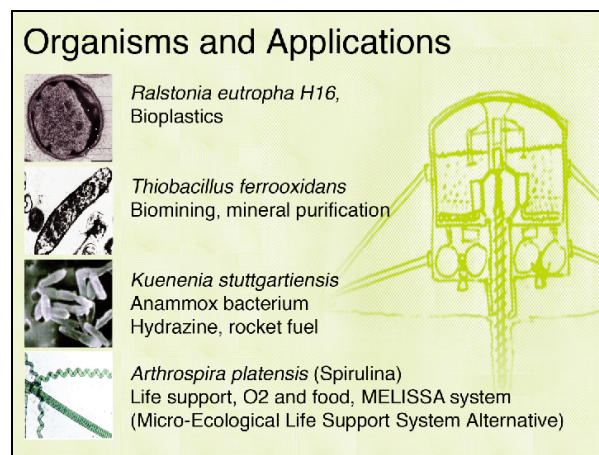


Figure 1: Artists conception of drilling photobioreactor. Potential organisms for use in BISRU. Image: Eric Stackpole, NASA Ames.

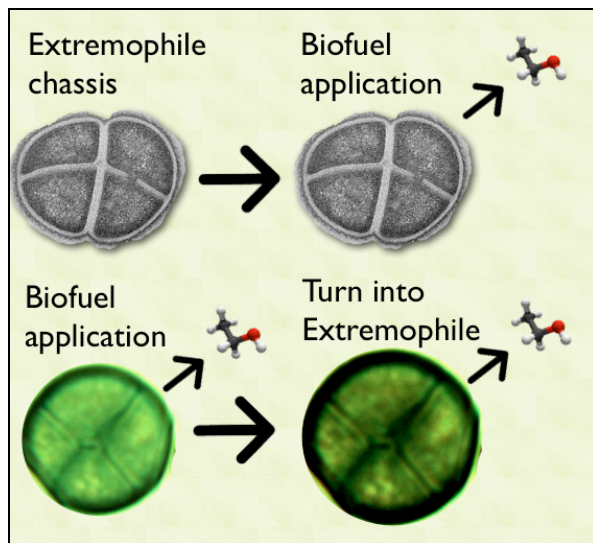


Figure 2: Above are two possible options for engineering organisms for BISRU.

Chassis or application optimization? Two approaches could be taken to producing organisms for space applications as shown in Figure 2. The first is to find organisms that are tolerant of extreme environments on earth. These organisms could then be adapted via engineering or evolutionary approaches to harden them to space environments. Alternatively these organisms could be shielded against the extreme environments of space inside bioreactors. Such organisms would then become chassis organisms which could be engineered to perform different functions or to synthesize different products. The second approach would be to make an organism that already performs a useful function or synthesizes a useful product then capable of reproduction in a space environment.

Preventing forward contamination and release:

To protect against forward contamination and to protect organisms from the extreme environments of space, efforts to take biology into space for settlement will likely begin by housing microbes inside bioreactors. Only after a planet is found to be free of endogenous life might an engineered organism be released onto the surface.

Applications of organisms in bioreactors:

Human life support. Photosynthesis provides oxygen for human consumption via the splitting of water and the production of food in the form of sugars. Such

application has been previously demonstrated on the Mir space station [5] and forms a part of the European Space Agencies closed loop system MELISSA (Micro-Ecological Life Support System Alternative) [6] which uses a variety of microbial cultures to form an artificial ecosystem.

Biofuels. If propellant for spacecraft could be produced *in situ* rather than needing to take it from earth then one of the largest costs of space travel would be reduced. There are numerous attempts at producing biofuels here on earth such as ethanol, hydrogen, methane, butanol and even hydrazine. If these are successful then the production of biofuels on other solar bodies will also be possible.

Biomining. The extraction of minerals from regolith such as the extraction of copper by the bacteria *Thiobacillus ferrooxidans* would be useful for the purification of *in situ* minerals [7].

Biomaterials. Bioplastics are currently produced by bacteria such as *Ralstonia eutropha* H16 [8] These could provide the ability to produce construction materials *in situ*.

Industrial chemical synthesis. Many other products exist that would provide utility to space settlement and could be produced via biological means. Such as nitrogen-based explosives for mining or the production of lubricants to support robotic missions.

Synthetic microbes: The price of synthesizing whole genomes will likely fall significantly in the next decade [9]. If a designer organism could be created for release onto the surface of the Moon or Mars, what abilities would it need in order to survive and reproduce there? In order to survive extreme cold temperatures, organisms could be equipped with cold adapted elements that have been identified in other species such as, chaperones, antifreeze proteins [10], ice-nucleating/ice binding proteins [11] or enzymes that increase membrane fluidity [12]. Preliminary work has already shown that it is possible to cold shift the growth curve of *E.coli* by overexpression of a psychrophilic chaperone [13]. To protect against radiation, mechanisms to shield the organism from UV damage could be imported such as a stress response that synthesizes UV-absorbing pigments, antioxidants or extracellular polysaccharides. DNA repair pathways from other organisms could be imported, such as direct reversal, base excision repair, nucleotide excision repair, mismatch repair, non-homologous end joining and recombinational repair. As DNA repair is a complex system, evolving organisms for radiation resistance may be a better approach in this case. To deal with low pressure, organisms could be engineered with gas-permeable water-impermeable membranes.

Beyond the moon and Mars: Planets, moons and asteroids with the potential for life are also potential targets for BISRU. Key requirements are a carbon source, energy source and water. Dead comets hold much promise. These asteroids have a darker reflectance than normal, are thought to be dormant comets and may contain pockets of ice and other elements inside. There are over 200 identified dead comets within two years travel time of earth with a two year orbital period [14]. Jupiter's moon Europa, containing water ice and an oxygenated atmosphere [15] is another obvious target, as is Titan, since the identification of liquid ethane [16] and an internal ocean [17] Enceladus, the sixth largest moon of Saturn is likely water rich with plumes having been observed venting from the south pole, indicating an internal heat source, possible sub-surface liquid water and current geological activity [18]. Our solar system is primed for taking life with us, if it is not already there now.

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