Biomaterials out of thin air: in situ, on-demand printing of advanced biocomposites

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Potential Impacts

This application could dramatically expand manufacturing capabilities on Earth and in space:

• Upmass is the single most significant limitation of our current space mission capability. Although biomaterials and biocomposites have mass, strength, flexibility, and self-healing properties that could significantly reduce upmass, their use is limited by the following drawbacks:

• Expensive, specific production. Many biomaterials can only be produced as part of significant support ecosystem.

• Inaccessible functional customization. The grain of wood, the porosity of bone, and so on are an integral part of the materials' desired mechanical properties, but are not deterministic when the material is naturally grown.

• Limited compositions. Most biomaterials (unlike metal, plastic, etc.) cannot be easily combined or modified to produce new materials.

This project builds on recent advances in:

• Synthetic biology. Libraries of standardized genetic parts which can be used for controlled cellular material production, delivery, and binding.

• 3D printing. Commercial off-the-shelf components which can be used to make of a pico- to nanoliter cell deposition system.

• Tissue engineering. Proven cell-compatible support hydrogels and scaffolds can be modified to bind the deposited biomaterials of interest.

Objectives

• Feasibility and benefit analysis. Two mission contexts span the concept's scope (see below).

• Proof-of-concept demonstration. A simple grid of two proteins, fluorescent for easy detection, to validate the core technology concept.

• Proposed implementations for follow-on work. Avenues for future work on each core component (host cell, production control, material delivery, material binding, etc.).

• Complementary studies exploration. A survey of other emerging areas (in situ resource utilization, protein engineering, etc.) with the potential to multiply our technology's impact.

In situ resource utilization. A far greater range of materials and products will be available from the limited palette offered by in situ resource extraction techniques.

• Reduced equipment and material upmass for off-Earth habitats. Ready-to-use highly specialized construction materials (radiation hardened, compressive/tensile, light or dense) from an extremely low starting mass.
• Structured biomaterial production. New ready-to-use macro, micro, and molecular manufacturing techniques for traditional biomaterials such as wood, bone and shell.
• New and novel biocomposite creation. The ability to create completely novel material composites from any base material that cells can be engineered to produce.

Suggested Mission Contexts
• ISS part manufacturing. A ‘minimal working example’ making a finished biomaterial part aboard the International Space Station.
• A long-term Mars habitat. ‘Cradle-to-grave’ use at a hypothetical Mars habitat, covering everything from tools to construction materials.

Alternate Abstract:
Imagine being able to print anything from tools and composite building materials to food and human tissues. Imagine being on Mars with the ability to replace any broken part, whether it's a part of your spacesuit, your habitat, or your own body. We propose a technique that would allow just that. By printing 3D arrays of cells engineered to secrete the necessary materials, the abundant in situ resources of atmosphere and regolith become organic, inorganic, or organic-inorganic composite materials. Such materials include novel, biologically derived materials not previously possible to fabricate.