



AFRL

DoD Biomanufacturing for Space Access, Mobility, and Logistics

Committee on Biological and Physical Sciences in Space
National Academy of Sciences, Engineering, and Medicine

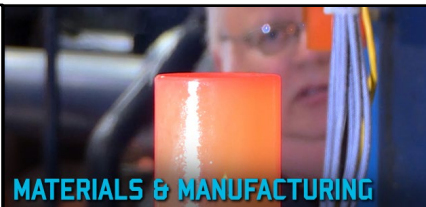
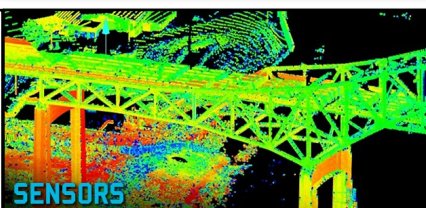
September 18th, 2025

Oscar N. Ruiz, Ph.D.
Chief, Biomaterials Branch
Fellow, Air Force Research Laboratory

Photonic, Electronic & Soft Materials Division
Materials and Manufacturing Directorate
Air Force Research Laboratory
oscar.ruiz@us.af.mil



Core Technical Competencies (CTC)

Aerospace Vehicles, Control, Power & Thermal Management, High Speed Systems, Rocket Propulsion, Turbine Engines	 AEROSPACE SYSTEMS	 DIRECTED ENERGY	Laser Systems, Weapons Modeling, Simulation & Analysis, High Power Electromagnetics (HPEM), Directed Energy and Electro Optics for Space Superiority	DIRECTED ENERGY
Training, Adaptive Warfighter Interfaces, Bioeffects, Bioengineering, Aerospace & Operational Medicine	 HUMAN PERFORMANCE	 SPACE VEHICLES	Advanced Space Resilience Technologies, Space Communication & Navigation Technologies, Space Awareness and Command & Control, Space Environment	SPACE VEHICLES
Structural Materials, Functional Materials, Manufacturing Technology, Support of Operations	 MATERIALS & MANUFACTURING	 INFORMATION	Processing & Exploitation , Connectivity & Dissemination Autonomy, Command & Control and Decision Support, Cyber Science and Technology	INFORMATION
Radio Frequency (RF) Sensing, Electro Optical (EO) Sensing, Spectrum Warfare, Trusted & Resilient Mission Systems, Multi-domain Sensing Autonomy, Enabling Sensor Devices & Components	 SENSORS	 MUNITIONS	Munitions Airframe, Guidance, Navigation & Control, Terminal Seeker Sciences, Modeling & Simulation Evaluation Sciences Ordnance Sciences	MUNITIONS
Capability & Technology Prototyping	 SDPE	 AFOSR	Engineering & Information Sciences, Physical & Biological Sciences	BASIC RESEARCH



Materials & Manufacturing Directorate: Aerospace Materials Research and Development

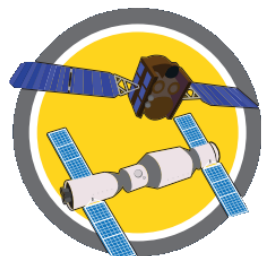


The Full Spectrum of Materials and Manufacturing Competencies

Metals - Ceramics - Polymers - Semiconductors - Composites - Biomaterials

Biomaterials Branch

DAF/USSF Operational Imperatives (OIs)



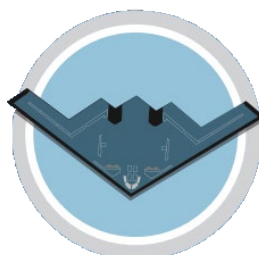
Space Order of Battle



Operationally Focused ABMS



Resilient Basing



Global Strike



Tactical Air Dominance



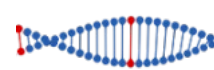
Moving Target Engagement



Readiness to Deploy and Fight

DoD Critical Technology Areas (CTAs)

Seed Areas of Emerging Opportunity



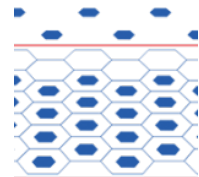
Biotechnology



Quantum Science



Future Generation Wireless Technology

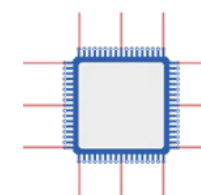


Advanced Materials

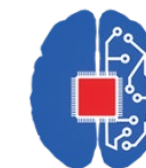
Effective Adoption Areas



Trusted AI and Autonomy



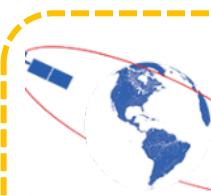
Microelectronics



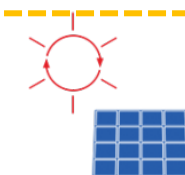
Human-Machine Interfaces



Integrated Network Systems-of-Systems



Space Technology

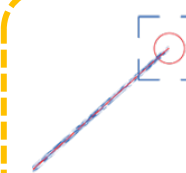


Renewable Energy Generation and Storage



Advanced Computing and Software

Defense Specific Areas



Directed Energy



Hypersonics

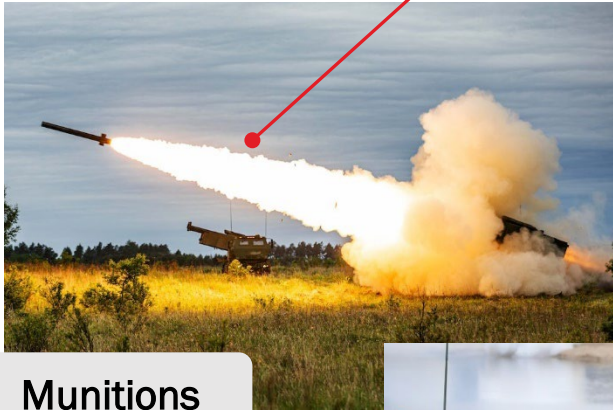


Integrated Sensing and Cyber



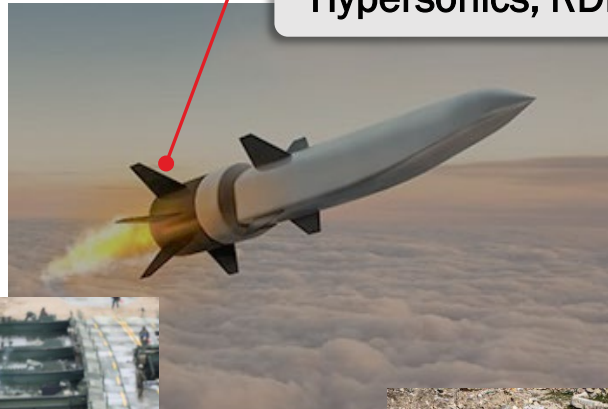
Biotechnology Provides Transformative Military Capabilities for the Battlefield of Tomorrow

Cost-Effective Production of Precursors and Propellants for Munitions



Munitions

High-Density Endothermic Biofuels



Hypersonics, RDRE

Real-time Monitoring of Warfighter Physiology and Performance

Laser Eyewear Protection

Food and Human Performance Supplements



Service Members

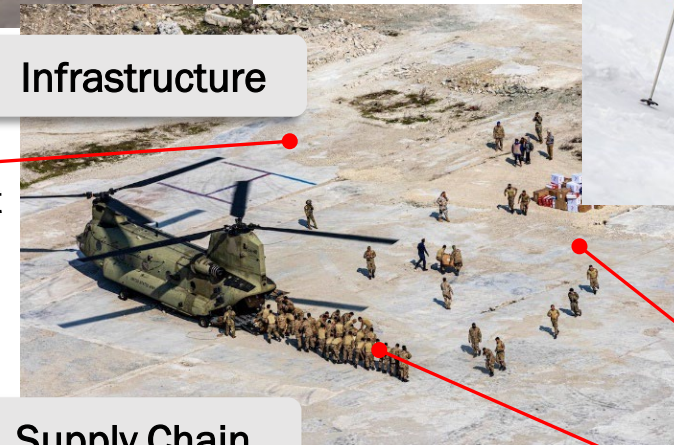


Equipment

Coatings, Composites, Adhesives, and Lubricants with Anti-fouling, Anti-corrosion, and Thermostable Properties

Infrastructure

Biocement



Supply Chain

On-site Manufacturing of Critical Materials for Sustained Operations

Domestic Production using American Agricultural Feedstocks

Orbital Energy: A Key Enabler of “Space Logistics”

Orbit Repositioning

- Move assets at will
- Decommission at end-of-life

Launch

- Increased mass
- Reduced launch cost per unit weight

Maneuver Without Regret

- Unlock spacecraft from fuel constraints that currently exist
- Maneuver and reposition assets with impunity
- Protect and defend US government, civil and commercial interests
- Enable truly persistent assets and platforms throughout XGEO

On-Orbit Servicing, Assembly & Manufacturing

- Assembly and construction of large structures
- Basis for space-based logistics chain
- Enable space commodity exchange
- Tailor structures for environment not launch

Mid-flight Refueling

- Use fuel required for the mission
- Decrease transit time/Increase revisit rate
- Fly novel flightpaths for mission requirements
- Single fuel type multi-mode propulsion
- Decrease launch mass with corresponding cost reduction.

Space Access, Mobility, and Logistics (SAML): the movement and support of military equipment and personnel *into* the space domain, *from* the space domain back to Earth, and *through* the space domain
-- USSF Space Capstone (Aug 2020)

Rocket Cargo

- Provide support for terrestrial CCMDs
- Provide global logistic support

VLEO-MEO

GEO-2xGEO

3xGEO-L1/L2



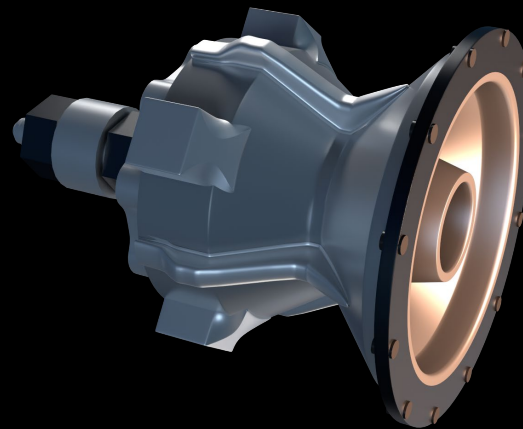
VENUS ROTATING DETONATION ROCKET ENGINE (RDRE)

THE MOST EFFICIENT ROCKET ENGINE EVER BUILT

HOW THE RDRE WORKS

The RDRE employs a detonation wave propagating around an annular combustor to generate thrust.

The detonation wave travels supersonically, enabling breakthroughs in speed, efficiency, thrust-to-weight ratio, engine size, and range.



WHAT SETS THE RDRE APART

- Scalable from 2,000 - 50,000 lbs of thrust
- Reusable
- No moving parts
- 3D-printed
- Standard materials

15%

More efficient than any
legacy rocket engine*

*For reference: The SpaceX Merlin engine is only 2% more efficient than the F1 rocket engine used during Apollo missions



VENUS ROTATING DETONATION ROCKET ENGINE (RDRE)

THE VENUS RDRE OUTPERFORMS LEGACY ROCKET ENGINES ACROSS THE BOARD

	SOLID ROCKET MOTOR	LIQUID	VENUS RDRE
Size	Small	Large	Scalable
Complexity	Simple	Complex	Less complex
Propellant	Storable & Safe	Cryogenic & Hazardous	Storable & Safe
Efficiency	Inefficient	Efficient	Highly efficient
Cost	\$\$	\$\$\$	\$
Reusable	No	Yes	Yes
Supply Chain	At risk	Stable	Resilient
Procurement and manufacturing	Long lead time for components	Long lead time for components	Short, predictable lead time for all components

CleanJoule's manufactures its superior performance rocket propellant CycloRP through a proprietary hybrid biological - chemical pathway

BIOLOGICAL PROCESS

- Robust microbes created via a decade of genetic engineering and directed evolution
- Fermentation process is highly feedstock flexible (i.e., lignocellulosic sugar, corn starch, woody biomass, energy crops)
- Production via local biomass enables energy security both domestically and in contested areas that rely on imported fossil fuels
- Fermentation directly produces a fully reduced, oxygen-free hydrocarbon for chemical processing

CHEMICAL PROCESS

- Highly selective, patented catalyst
- Highly efficient process with near stoichiometric retention of carbon and
- Low temperature and pressure process to reduce operational intensity
- All unit operation paradigms are currently in commercial use



**PROPRIETARY ENGINEERED
MICROBES**



**LIGNOCELLULOSIC SUGARS
DERIVED FROM WASTE
BIOMASS**



**HIGHLY EFFICIENT
FERMENTATION**



**PROPRIETARY CATALYSIS
AND HYDROGENATION**



DMCO

CycloRP is a superior, drop-in replacement for kerosene-based rocket propellant with increased space mission performance for both current and next-gen engines

CYCLORP HIGHLIGHTS

- Drop-in replacement for RP-1 & RP-2 with superior mission performance
- Higher volumetric and gravimetric energy densities than traditional kerosene-based fuels, enabling greater payloads
- Freezing point below -89°C and superior low temperature viscosity
- Cleaner burning to facilitate engine longevity and reuse, with low aromatics, undetectable sulfur, and undetectable olefins

INCREASED PAYLOAD AND/OR INCREASED DISTANCE

CYCLORP IMPROVEMENT	VOLUMETRIC ENERGY	GRAVIMETRIC ENERGY
Compared to RP-1	+4.3%	+1.92%
Compared to RP-2	+3.3%	+1.06%

FUELING THE RDRE REVOLUTION

- In a first-of-a-kind test, CycloRP fueled a Rotating Denotation Rocket Engine (RDRE) developed by Venus Aerospace
- Represents a significant step forward in expanding the operational flexibility of RDRE technology across dual use missions





Spacecraft Risks and Needs

Space Environment Hazardous to Biology

- Vacuum
- Atomic oxygen (LEO)
- UV Radiation
- Particulate or Ionizing Radiation
- Plasma
- Temperature Extremes and Thermal Cycling
- Micrometeoroid
- Orbital Debris Impacts
- Light Extremes
- Gravity
- Launch
- EM fields
- Lack of consumables e.g., fuel
- Lack of energy
- Testing in/for space

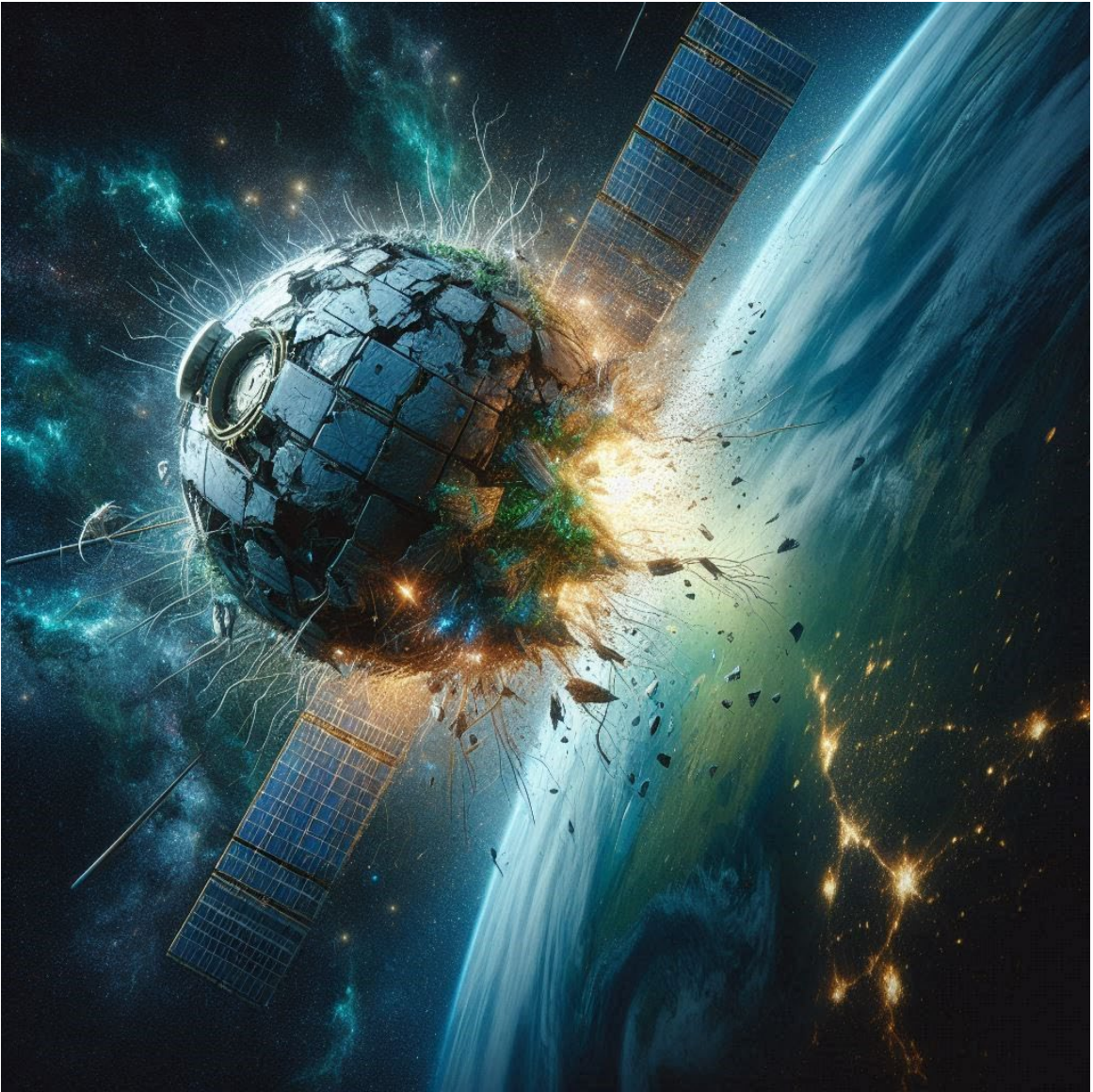
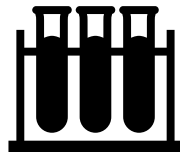


Image Creator from Designer

What resources do we have?



ISS
10,600 Kg per
year

Of CO₂, H₂, CH₄,
blackwater and
solid trash¹

1. From a crew of 6

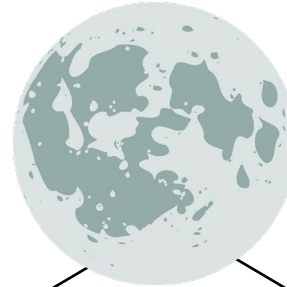


Earth Orbits

3,356 total inactive
satellites
~10,000 Tons

- ~33% decrease in average separation between satellites in GEO
- 20% increase in orbital launches in 2023

2. 2023 Slingshot Aerospace Report



Lunar Surface

Natural Resources at
the Lunar South Pole³

- ~2M tons of solid CO₂
- ~136M tons of solid H₂O

Apollo left 187 tons
on the surface



Inspiration Dr. Ibey
Image Creator from Designer

Slide Courtesy of Dr. Andrew Younger, AI image added

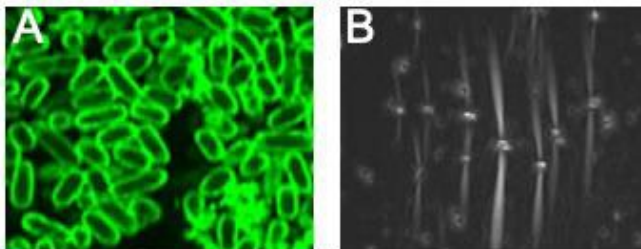
AFOSR Space Biosciences

Benefit to Warfighter: The Space Force can deter aggression through improved satellite maneuverability, domain awareness, capability redundancies, self-protection and hardening of assets, in orbit upgrades and improvements, disaggregation, multi-functionality and flexible operations.

Challenge: Future USSF mission areas have basic research needs not being addressed by other space users. The intersection of biology and space domain operations provides unique opportunity to achieve and sustain peace in the space domain by providing solutions for supply line and logistics challenges. Examples include Sustained Dynamic Operations and Radiation Hardened Microelectronics.

Biological Mechanisms, Products, Processes, Materials for Space

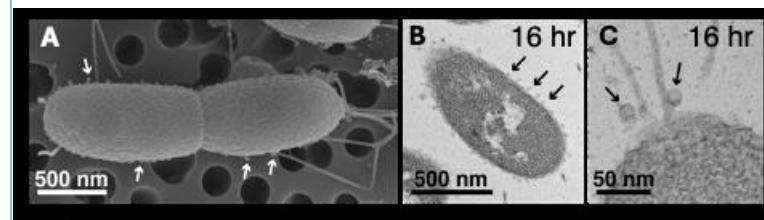
- Uniquely advantageous in the space domain through increased capability or reduced upmass.
- Self-healing mechanisms
- Extreme condition harvesting processes, e.g. radiation, light, temperature



Silicatein-expressing *E. coli* with polysilicate coating.

Living Systems in Space

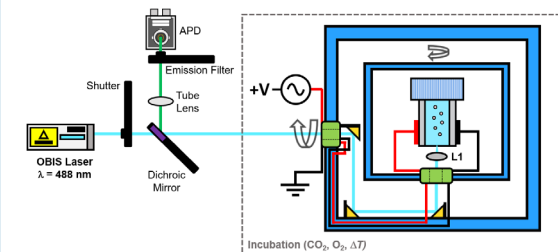
- Provide continuing operations support
- Biotic- Abiotic Teaming
- Autonomous Maintenance
- Homeostasis under space conditions
- Monitoring systems in space
- Growth in space



V. fischeri forming outer membrane vesicles

Testing/Evaluation in Space Conditions

- Simulation/Modeling/ Testing/Evaluation improving high-throughput biological experiments in space-like environments.

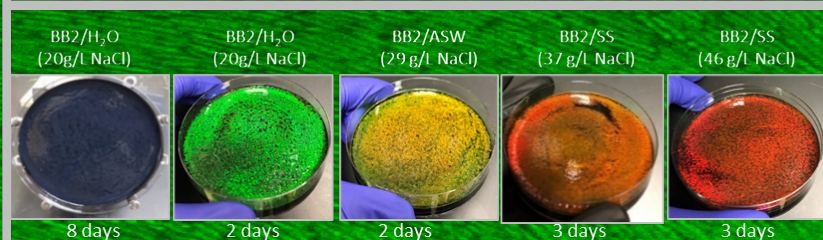


Microgravity electroporator with integrated fluorometric sensing

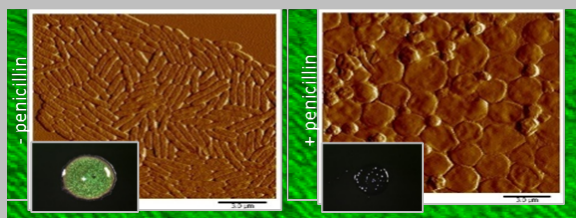
Iridescent biofilms: A Versatile Platform for Advanced Materials

Sullivan, et al, *Sci Rep* 13, 13192 (2023). <https://doi.org/10.1038/s41598-023-38797-0>

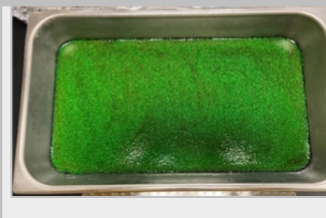
Color



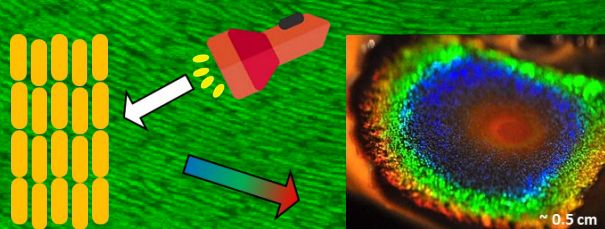
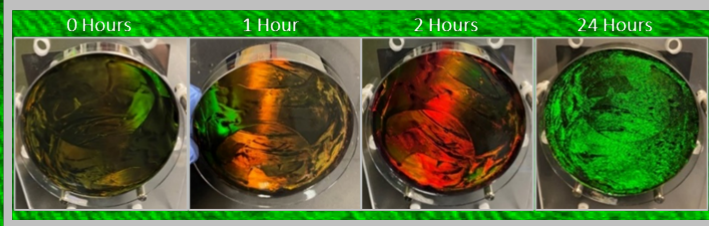
Morphology



Scale



Time

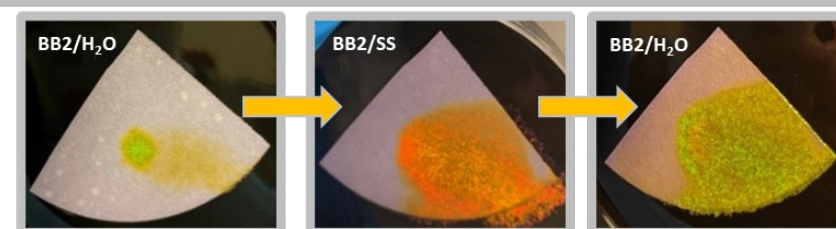


Tech Opportunities

Templated ceramics and photonic inks



Living sensors with reporting via color



Pigments for paints and coatings



Confocal image courtesy of Dr. Chia Hung, AFRL/RXEB



Domestic Natural Rubber Production

Goodyear and **Farmed Materials** are accelerating commercialization of a domestic source of natural rubber sourced from TK dandelions



PC: Farmed Materials



PC: Farmed Materials

This project will produce aircraft tire retreads and tires which will be tested against existing military detail specifications.

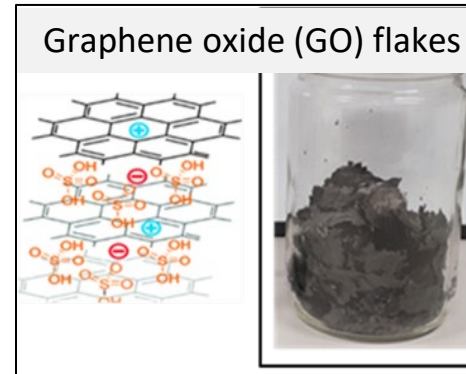
Aircraft tires are constructed from natural rubber. Natural rubber is on the DLA Strategic Materials list.



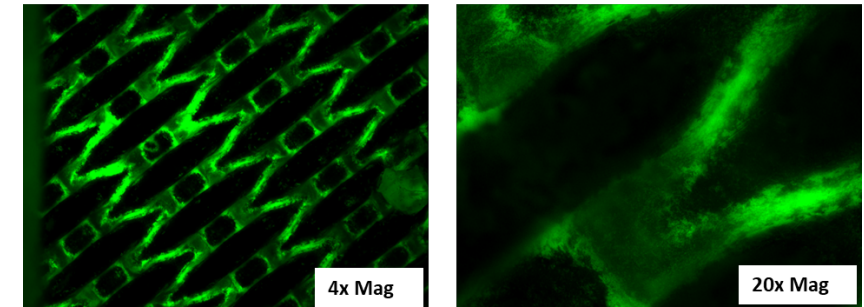
PC: Air Force

Modular Solid Nano-Bioreactors for Point-of-Need Biomanufacturing

Payoff: Solid GO bioreactors have considerable advantage over liquid batch fermenters by providing continuous flow fermentation and easy purification of secreted bioproduct (e.g., isoprene) as cells are irreversibly immobilized onto the nanomaterial. GO enhances formation of thick biofilms that drastically increase biomass for the biomanufacturing process and titers.



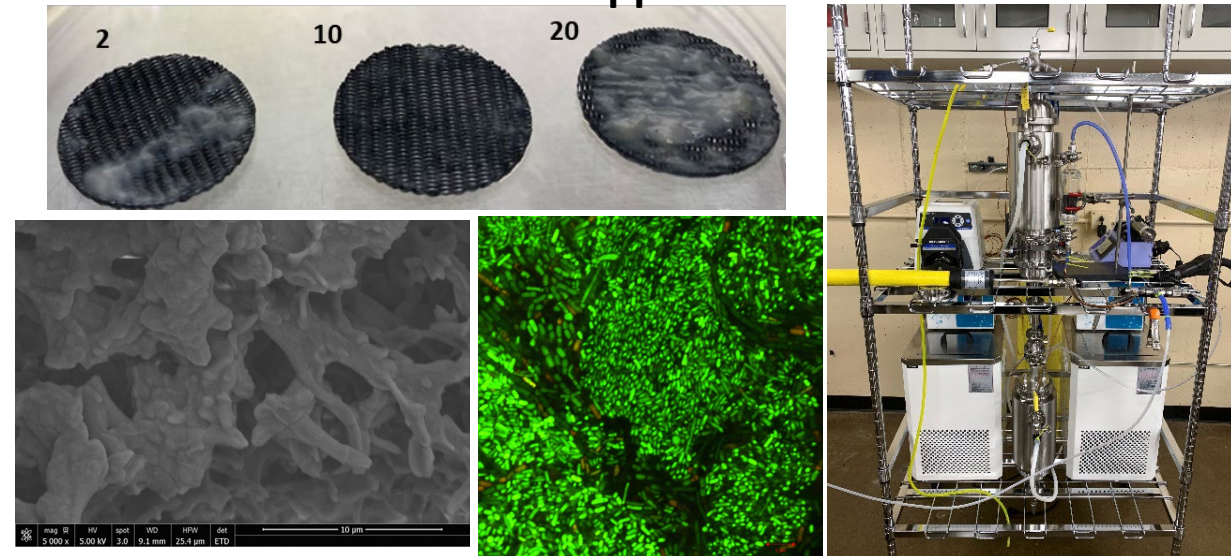
GFP *E. coli* on GO Coated Metal Mesh Discs



Why do we care? What is the specific impact?

- Agile manufacturing in distributed applications
- Lower fermentation inputs, simpler purification
- Advantageous for point-of-need manufacturing, developing fermentation facilities near feedstock sources, and automated biomanufacturing processes
- Ability to perform biomanufacturing in austere environment (e.g., space) with reduced liquids/water use
- 90% less water required
- 15% higher fermentation performance than batch reactors
- U.S. Patents: 9,403,112; 18/637,872; 18/235978; 18/235985; 18/235984; 18/235,981

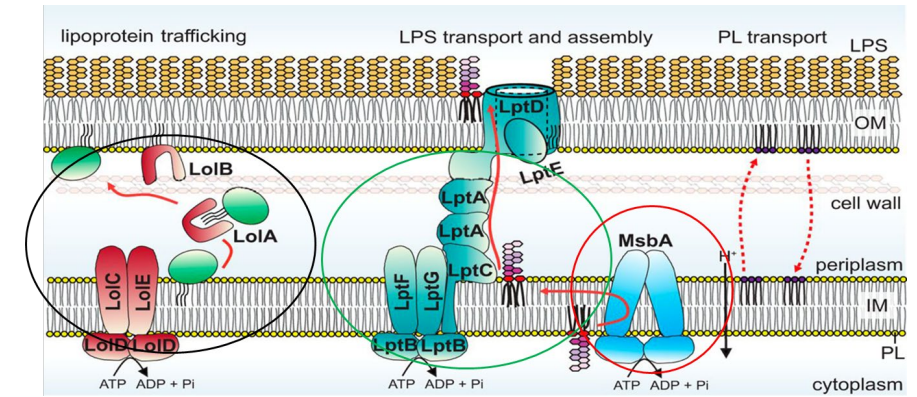
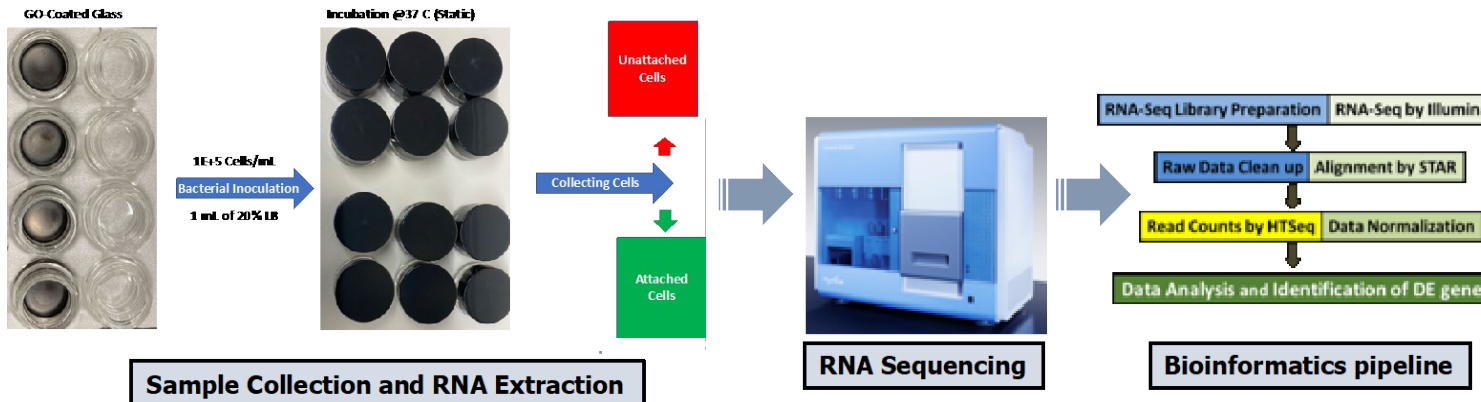
Biofilm-enabled biomanufacturing for >21 days on GO Supports



Fundamental Understanding of Biofilm Formation

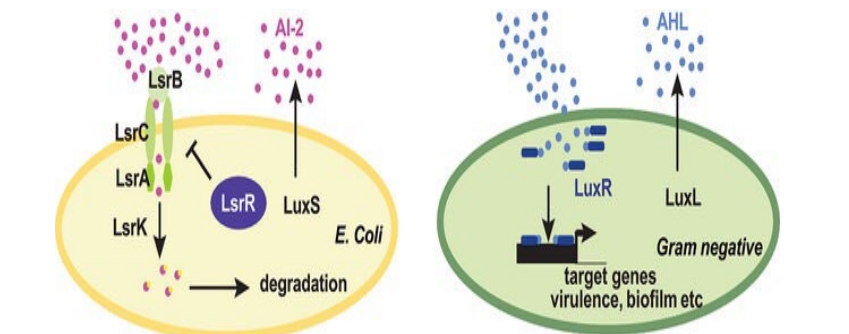
Enhanced Biofilm Formation and Cell Viability with GO Supports

- Data shows expression of genes involved in cell division and surface attachment, cell membrane and LPS modification, biofilm formation, Phosphate transportation and phospholipids, quorum sensing and global regulators (ArcA, Crp, Fis, Fnr, Ihf, Lrp, and NarL) directly modulate the expression of about one-half of all genes.



BssS and BssR are negative biofilm formation which are down in GO-coated glass compared with uncoated glass (both top/bottom)

Biofilm regulator	bssS	-1.900
Biofilm regulator	bssS	-5.202
Repressor of biofilm formation by indole transport regulation	bssR	-3.674
Repressor for bhsA(ycfR)	ycfQ	-1.064
Biofilm, cell surface and signaling protein	bhsA	-4.215



AI-2 system in E. coli and AHL system in gram negative bacteria

S-ribosylhomocysteine lyase	luxS	1.696
S-ribosylhomocysteine lyase	luxS	0.737



Isoprene Synthesis On-orbit Space Technology and Advanced Research ISOSTAR/USAFA-2501

Experiment Technical Information

Apogee: 422 +/- 10 km

Perigee: 413 +/- 10 km

Inclination: 51.6

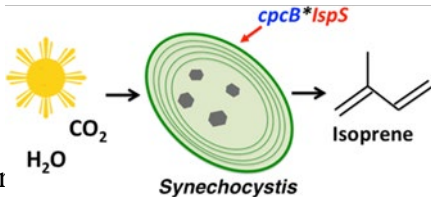
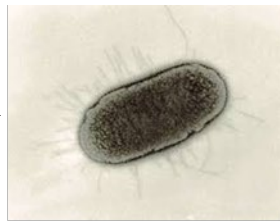
Mass: ≤1kg

Dimensions: 11 x 11 x 8cm

Power: 3W

Requested Services:

- Launch
- Host Vehicle
- Mission Operations
- Astronaut Support
 - Setup & monitor



Experiment Retrieval Required? Yes

Repetitive Flights? No

Sponsor: AFRL

Partners: USAFA

End Users: AFRL

Experiment Type: Biomanufacturing

Category: Hosted Payload

Flight Ready Date: Dec 2025

Objective

1. Compare and evaluate the feasibility of applying a modular solid nano-bioreactor to the production of platform molecule isoprene in space.
2. Determine how space conditions affect the growth, biofilm formation and isoprene production of a bioengineered *E. coli* strain.
3. RNA sequencing analysis of gene expression changes in bacteria grown in microgravity.

Military Relevance

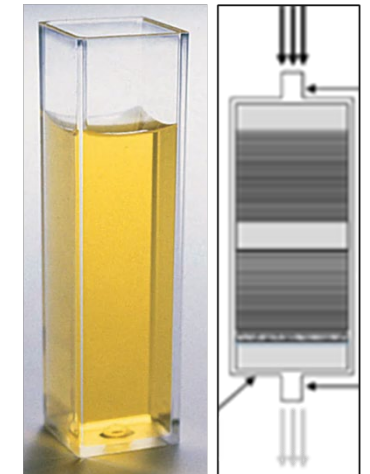
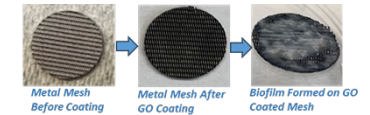
Sustainable Resource Production for Extended Missions
Advancing Biomanufacturing Capabilities
Enhancing Space Resilience and Readiness
Dual-Use Technology Development

Tech Transition

Operationalize space-based biomanufacturing for future missions and sustainability.

Previous Priority:

NA



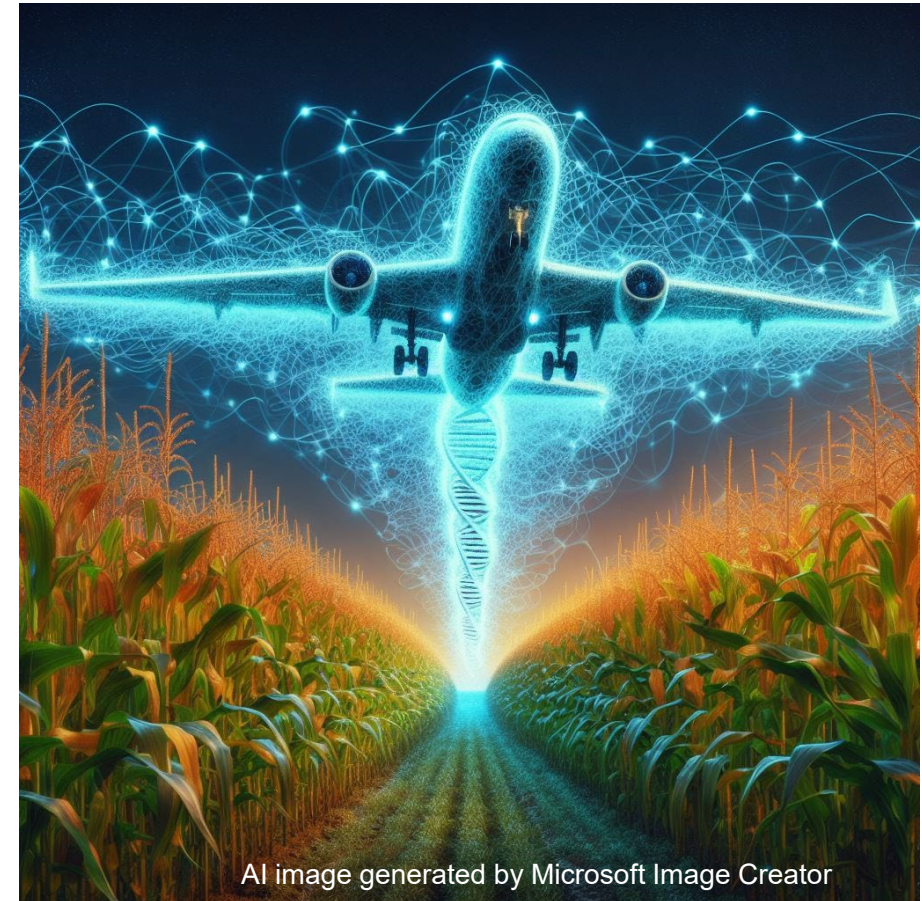
E. coli in cuvette mimics liquid batch fermentation

E. coli in cuvette with nano-bioreactor mimics continuous fermentation with minimal liquid use





Thank you! Any questions?



AI image generated by Microsoft Image Creator