U.S. AIR FORCE

USSF

AFRL

Biotechnology and Biomanufacturing for Department of Air Force

Nancy Kelley-Loughnane, Ph.D.

Biological Materials and Processing Team Lead, Biomaterial Branch

Materials and Manufacturing Directorate, 4 April 2023

At a Glance

- The Air Force Research Laboratory (AFRL) is **the primary scientific research and development center** for the Department of the Air Force.
- AFRL Headquarters is located at Wright-Patterson Air Force Base, Ohio.
- Created in October **1997** through the consolidation of four former Air Force laboratories and the Air Force Office of Scientific Research (AFOSR).
- As one lab, AFRL will now seamlessly support the Science & Technology needs of two services: the **Air Force** and the **Space Force.**
- **Workforce: ~11,200** employees (military, government civilians and contract positions)
- AFRL develops affordable warfighting technologies and delivers innovative solutions that **keep the fight unfair**.
- **Budget:** AFRL is executing **~$5 billion** in RDT&E funding (FY21).
- **Locations** in **10** States: California, Florida, Hawaii, Nevada, New Mexico, New York, Ohio, Tennessee, Texas and Virginia.
- International Sites in **3** Countries: The United Kingdom, Japan, and Chile.
- **History: 100+** years of critical research efforts.

Locations

Rapid, Non-Traditional Capability Development

U.S. AIR FORCE AFWERX

The newest member of the AFRL family

Technology
Commercial Focus

AFVENTURES
Where innovative companies take flight

Concepts
Airmen Focus

AFWERX
Airmen Empowerment

Capability
Transition Focus

AGILITY PRIME

Commander's Intent and Priorities

ACCELERATING 2030 STRATEGY IMPLEMENTATION

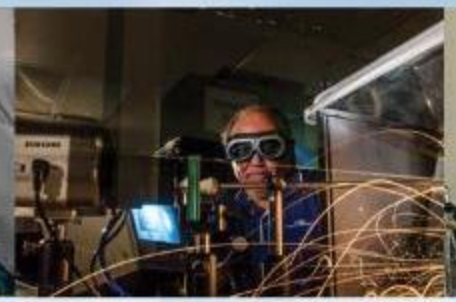
ONE AFRL supporting TWO SERVICES

AIR FORCE RESEARCH LABORATORY

U.S. AIR FORCE

USSF

BUILDING THE BEST AFRL TEAM



Investment Categories

6.1

Basic Research

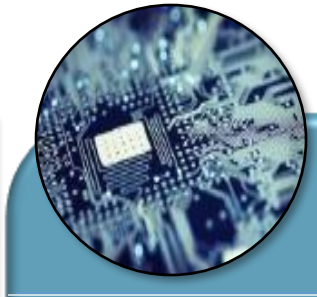
Science Knowledge

Greater knowledge or understanding fundamental aspects

Observable facts

Without specific applications toward processes or products

New Science



6.2

Applied Research

Technologies

Applying knowledge or understanding to determine the means by which a recognized and specific need may be met

Science to Application

6.3

Advanced Technology Development

Capability Concepts

The development and integration of hardware for field experiments and tests

From Application to Capability

Non S&T

Other AF Funds Executed

Operational Development / Experimentation

- Research, Development, Test and Evaluation
- Strategic Development Planning Experimentation
- Small Business Innovation Research Program
- Air Force Surgeon General

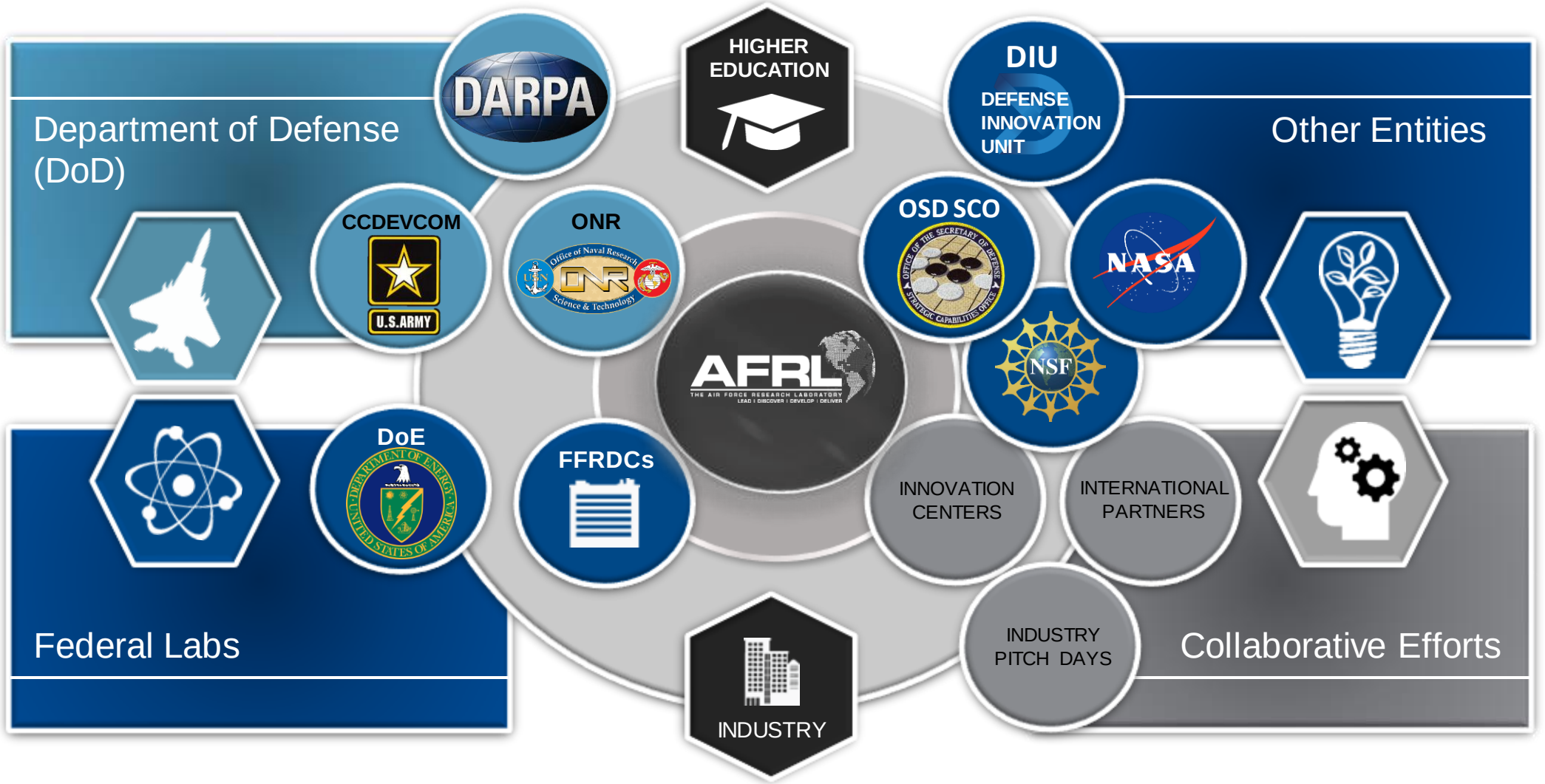
Experimentation

Science & Technology (S&T) Planning

A GUIDED, PROCESS-DRIVEN EFFORT

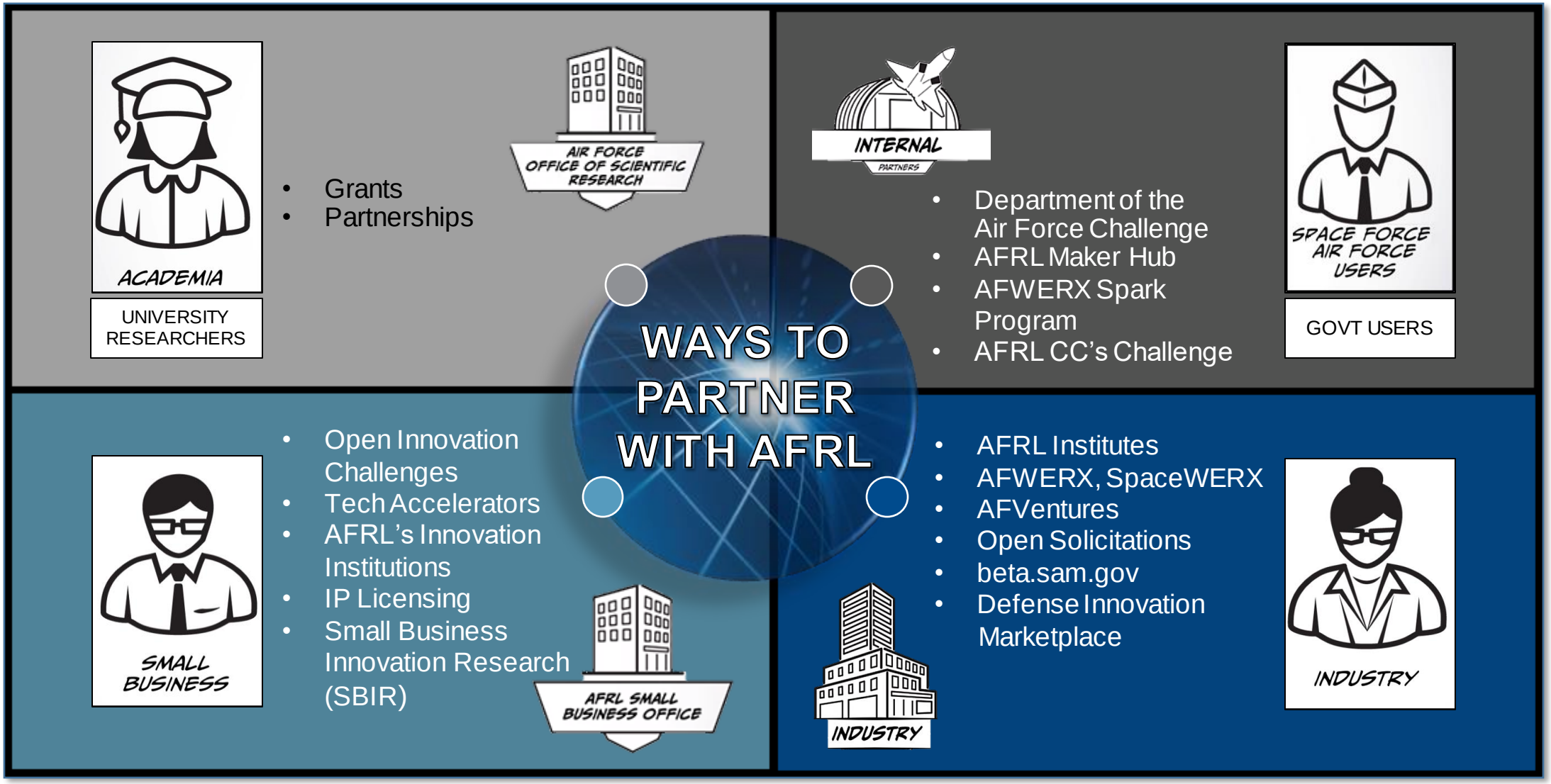
Rigorously Vetted – Department of the Air Force Level Investments

Science & Technology (S&T) Ecosystem

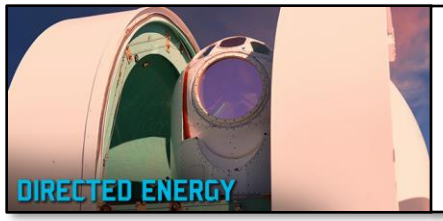
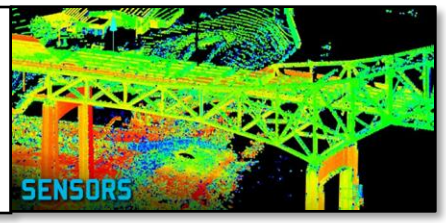


Partnering with AFRL

For more information, visit AFRESEARCHLAB.COM



Core Technical Competencies (CTC)

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

Biotechnology Interests

Biomanufacturing uses living organisms such as bacteria, yeast, and algae to make new products or replacements for current products that are more sustainable and environmentally friendly than current processes.

By harnessing the power of biology, bioindustrial manufacturing can make myriad products that Americans use every day

Enhanced military systems

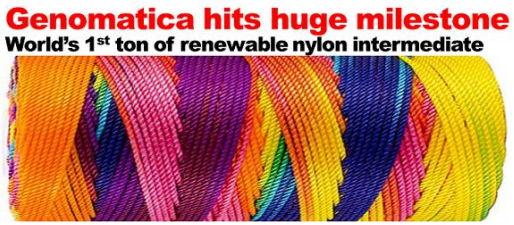
Biocement

Rare earth mining and reclamation

Optimized warfighter health and performance

Protein powder, red blood cells, bone grafts

Materials from bio building blocks



Spider silk, Nylon, composites, filters, tires

The Biomanufacturing Executive Order 14081

SEPTEMBER 12, 2022

Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy

BRIEFING ROOM ▸ PRESIDENTIAL ACTIONS

https://www.federalregister.gov/documents/2022/09/15/2022-20167/advancing-biotechnology-and-biomanufacturing-innovation-for-a-sustainable-safe-and-secure-american

Policy Framework of the EO for the Bioeconomy

Whole of Government Approach

To foster innovation and commercialization in health, climate change, energy, food security, agriculture, supply chain resilience, and national and economic security.

Central Principles

Equity, ethics, safety, and security.

Policy Objectives

Enable access in a manner that benefits all Americans and the global community and that maintains United States technological leadership and economic competitiveness.

The economic activity derived from biotechnology and biomanufacturing is "the bioeconomy."

How the EO will impact acquisition

Procuring agencies will establish a biobased procurement program

Program must be established by 12 Sept 23

Required training on biobased product purchasing

Within 2 years all appropriate staff shall complete biobased product purchasing training

Procuring agencies shall strive to increase biobased procurement by 2025

Procuring agencies will be required to report annually biobased product procurement

(i) the number and dollar value of contracts entered into during the previous fiscal year that include the direct procurement of biobased products;
(ii) the number of service and construction (including renovations) contracts entered into during the previous fiscal year that include language on the use of biobased products; and
(iii) the types and dollar values of biobased products actually used by contractors in carrying out service and construction (including renovations) contracts during the previous fiscal year. “

DoD Biomanufacturing Investments

The DoD announces $1.2 B in new investments in biomanufacturing:

$1 B in bioindustrial domestic manufacturing infrastructure **to catalyze the establishment of a domestic bioindustrial manufacturing base** accessible to U.S. innovators.

Incentivize private- and public-sector partners to expand manufacturing capacity for products important to both commercial and defense supply chains.

Additional $200 million to support enhancements to biosecurity and cybersecurity postures at these facilities.

DoD invested over $270 M for a Resilient Supply Chain program:

Turn research into products more quickly.

Support the advanced development of bio-based materials for defense supply chains, such as fuels, fire-resistant composites, polymers and resins, and protective materials.

https://www.defense.gov/News/Releases/Release/Article/3157504/new-biotechnology-executive-order-will-advance-dod-biotechnology-initiatives-fo/

https://www.whitehouse.gov/briefing-room/statements-releases/2022/09/14/fact-sheet-the-united-states-announces-new-investments-and-resources-to-advance-president-bidens-national-biotechnology-and-biomanufacturing-initiative/

DoD relevant on-going biomanufacturing projects

On-site production of fuels, lubricants, & critical materials

Enhanced materiel for operations in CB contested environments

Persistent marine sensors targeting UUVs

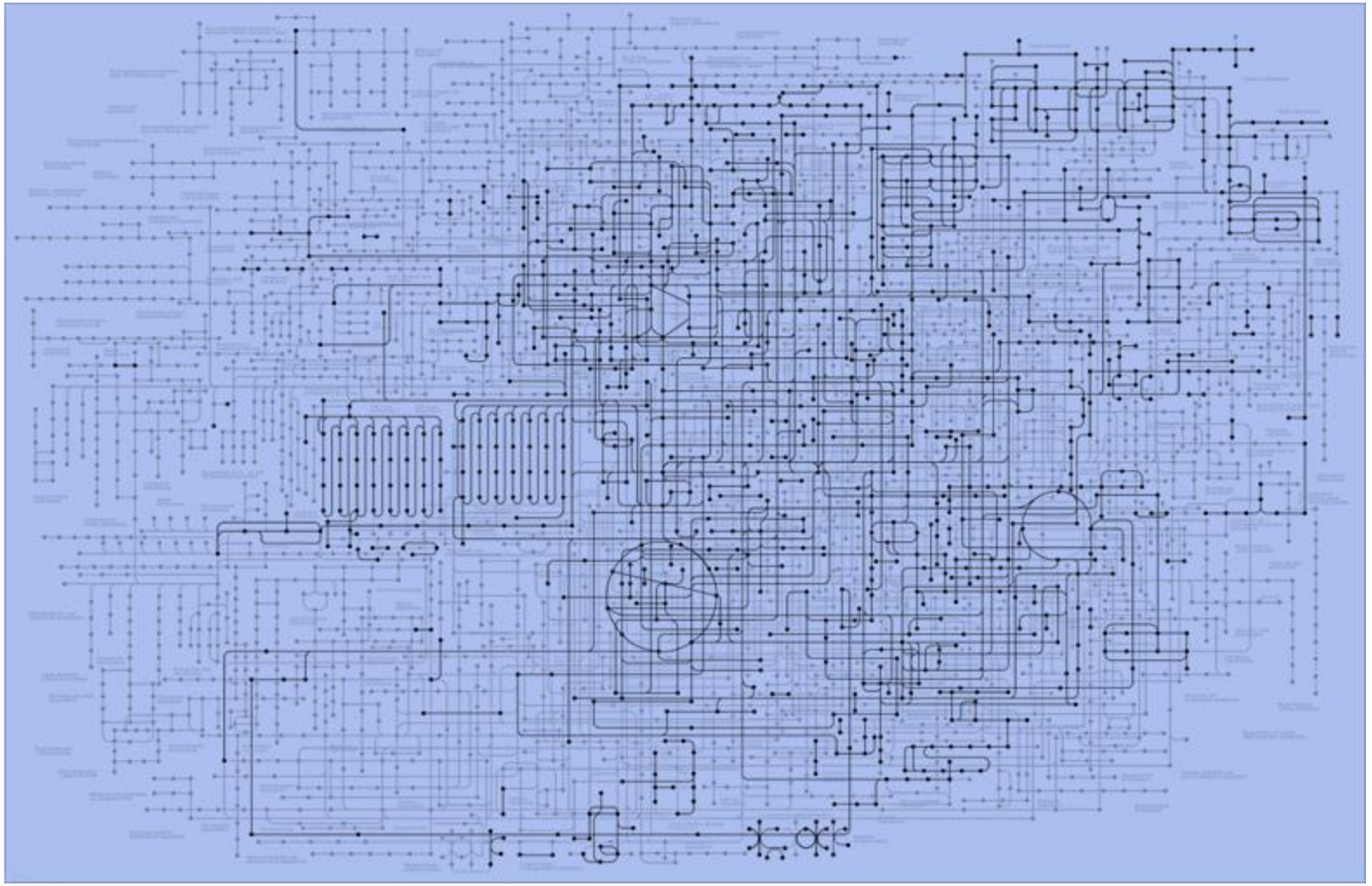
Real-time monitoring of warfighter & troop physiology and performance

Tunable paint and coatings for signature management

Growable concrete, infrastructure, and dust mitigation for sustained in-field operations

Rapid production of replacement tissues for injured warfighters

How can biology can produce materials of interest

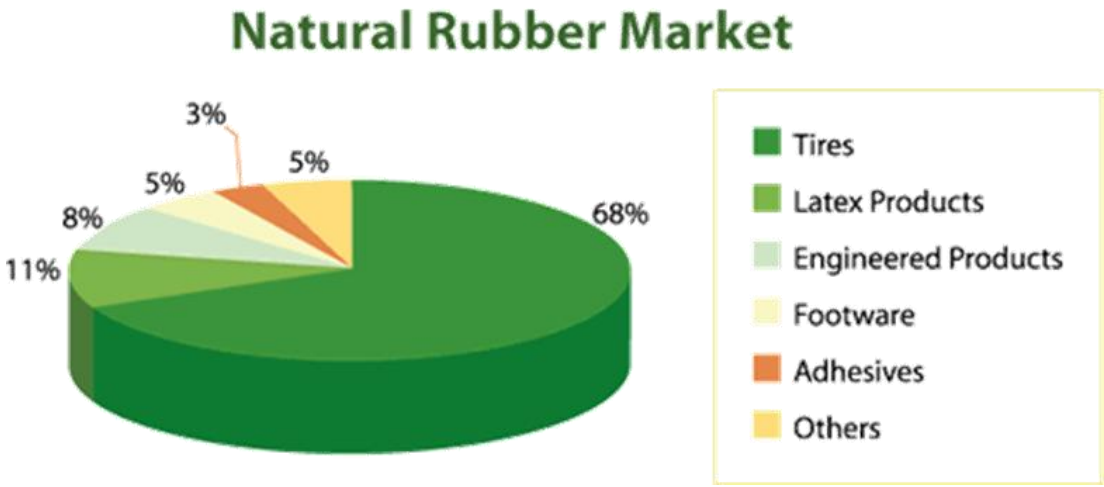


Metabolic map of E. coli K-12 MG1655

https://www.kegg.jp/kegg-bin/show_pathway?eco01100

Domestic natural rubber production

Extracting natural rubber from dandelion roots



Producing ethylene from CO_2

LanzaTech produces ethylene from CO2 in a continuous process

Breakthrough discovery to replace the barrel with synthetic biology, addressing one of the largest carbon emitters in the chemical industry

https://www.bioplasticsmagazine.com/en/news/meldungen/20221011-Lanza.php

Key Metrics

3 Commercial Plants Operating

>250,000 tons of CO2 avoided

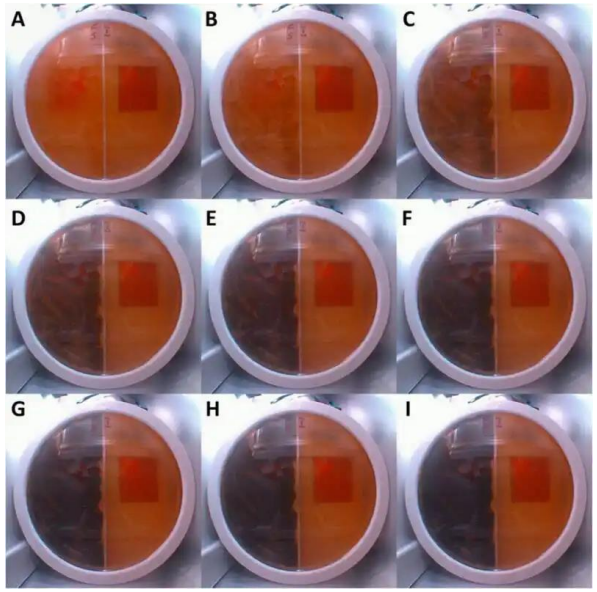
>500 chemical pathways designed

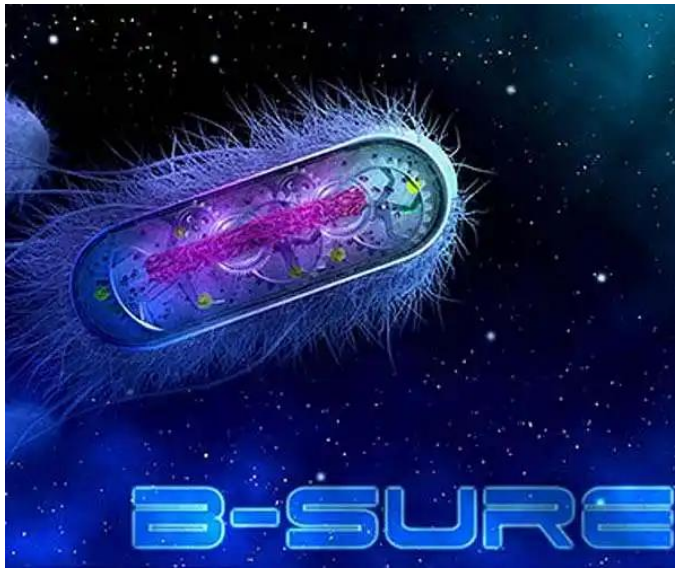
https://ir.lanzatech.com/?_ga=2.12927603.594258717.1678979270-392700372.1678979270&_gl=1*1arwn36*_ga*MzkyNzAwMzcyLjE2Nzg5NzkyNzA.*_ga_YTNWK313WH*MTY3ODk3OTI3MC4xLjEuMTY3ODk4MDM5MC4wLjAuMA..

Biomanufacturing applications for space

Growth of the Radiotrophic Fungus *Cladosporium sphaerospermum* aboard the International Space Station and Effects of Ionizing Radiation

- www.biorxiv.org/content/10.1101/2020.07.16.205534v7.full.pdf
- Growth studied over a period of 26 days aboard ISS
- Data indicated the fungus could be used as a radiation shield.





DARPA B-SURE
Biomanufacturing in space

Transitioning synthetic biology products to military applications

- "Low hanging fruit"
  - Avoid "safety of flight" applications
    - Very tight product specifications
    - Reluctance by QPL managers to try new chemistry
    - Expensive qualification process
  - Check the DLA Strategic Materials List
    - https://www.dla.mil/HQ/Acquisition/StrategicMaterials/Materials/
    - Ex. Natural rubber, energetic materials, rare earth metals
    - Freon replacement program example
- Enduring material challenges – where traditional material science has struggled
  - Light-weight flexible ballistic armor, batteries (smaller, more efficient), high temperature dielectric heat transfer fluids, thermal management
- Project calls through BioMADE
  - Gov agencies can fund project calls to address material needs
    - Allows access to military needs and ability to discuss possible solutions with the customers.

Source: https://www.army.mil/article/239415/utility_helicopter_uh_60m

Source: https://www.thefirearmblog.com/blog/2017/05/28/army-chief-milley-says-army-developed-new-bullet-defeat-level-iv-body-armor/

Finding product requirements on ASSIST

- Standards, specifications, and Data Item Descriptions (DIDs) can be found online
  - **ASSIST Quick Search — https://quicksearch.dla.mil**
- MIL-STD-#### is a military standard
  - Dictates requirements, process, and/or techniques
  - Able to be enforced contractually.
- MIL-PRF-#### is a performance specification
  - For a material to be added to the qualified products list, it must meet performance criteria.
    - Cannot exclude a material based chemical composition, only performance
- MIL-HDK-#### is a military handbook. Usually they are inactive standards.
  - Cannot be required contractually.
- DIDs give guidance on exactly what information needs to be included in contractor reports.
  - Ex. Contract may require the contractor to have a Corrosion Control Plan. The DID will detail what must be included in that document.

Quick Search ASSIST

Data updated: 27 Feb 2019. Document Details

Document ID: MIL-STD-1568 Scroll down to access document images

Overview

Title: Materials and Processes for Corrosion Prevention and Control in Aerospace Weapons Systems

Scope: This standard establishes the requirements for materials, processes and techniques, and identifies the tasks required to implement an effective corrosion prevention and control program throughout the conceptual, validation, development, production, and sustainment phases of the aerospace weapons systems life cycle. Applicable systems include fixed wing aircraft, unmanned aerial vehicles, space vehicles, rotorcraft, missile systems, air delivered guided munitions, and all related ground support equipment. Meeting or exceeding the requirements of this standard, as well as applicable program-specific technical documentation, will facilitate an optimum balance between acquisition and sustainment costs for DoD aerospace weapons systems, and ultimately enhance system reliability, supportability, and safety. Authority to exceed or amend the requirements in this standard requires permission from the Cognizant Engineering Authority (CEA).

Status: Active **Document Date:** 31-AUG-2015

Next Review Due: 29-AUG-2020

FSC/Area: MFFP **Doc Category:** Military Standard -Design Criteria Standard

Responsibilities

Lead Standardization Activity: MR Army Research Laboratory, Weapons and Materials Research Directorate

Preparing Activity: AS Naval Air Systems Command

Coordination: Full

Army Custodian: MI Aviation & Missile Command

Navy Custodian: AS Naval Air Systems Command

Air Force Custodian: 20 Air Force Research Laboratory

Changes to military standards or handbooks issued after August 1, 2003 are incorporated in the modified document.

Revision History Click on column headings for a description of column content.

Media	Document Part Description	Dist Stmt	Document Date	Pages	Size
	Revision D	A	31-AUG-2015	39	237.0 KB
	Revision C	A	12-AUG-2014	22	183.4 KB
	Revision B Notice 2 - Cancellation	A	18-JUL-1996	1	34.9 KB
	Revision B Change Notice 1	A	12-OCT-1994	15	613.8 KB
	Revision B	A	28-FEB-1989	26	1659.4 KB
	Revision A	A	24-OCT-1979	25	1210.7 KB

NOTE: It is recommended that you use Adobe Reader v7.0 or higher for optimal download performance; older versions should continue to work, but downloading large files may appear to take longer, so please be patient in those cases.

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METRIC
MIL-PRF-5606J
5 March 2018
SUPERSEDING
MIL-PRF-5606H
w/Amendment 3
7 September 2006

PERFORMANCE SPECIFICATION

HYDRAULIC FLUID, PETROLEUM BASE; AIRCRAFT, MISSILE, AND ORDNANCE

Inactive for new design after 29 March 1996. For new designs, use MIL-PRF-87257 or MIL-PRF-83282.

This specification is approved for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope. This specification describes the characteristics and provides the requirements for a petroleum base hydraulic fluid for use in the -54 °C to +135 °C temperature range (see 6.1). This fluid is identified by military symbol OHA and NATO Code No. H-515 (see 6.7).

2. APPLICABLE DOCUMENTS

2.1 General. The documents listed in this section are specified in sections 3 and 4 of this specification. This section does not include documents cited in other sections of this specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 and 4 of this specification, whether or not they are listed.

Need to find a material or product SME?

MIL-PRF-5606J

CONCLUDING MATERIAL

Custodians:
Army – AT
Navy – AS
Air Force – 68

Review activities:
Army – AR, MI, SM
Navy – OS, SA, SH
Air Force – 20
DLA – GS
DTRA - DS

Preparing activity:
Air Force – 68
(Project 9150-2018-004)

NOTE: The activities listed above were interested in this document as of the date of this document. Since organizations and responsibilities can change, you should verify the currency of the information using the ASSIST Online database at https://assist.dla.mil.

Distribution A online source for screen captures:
https://quicksearch.dla.mil/Transient/FB9840A202C443389214C3A10A59C32D.pdf

Materials properties that are essential to the application

MIL-PRF-5606J

TABLE I. *Properties of petroleum base stock*

Property	Limits	ASTM
Pour point, °C (max)	-60	D97, D5949*
Flash point, °C (min)	82	D93
Acid number, mg KOH/g (max)	0.10	D664
Color, ASTM Standard (max)	No. 1	D1500
Relative density @ 15.6/15.6 °C	Report	D1298, D4052*

With formulated products, the specification can require specific properties for the base stock. Examples include

- Color
- Toxicity
- Compatibility with other materials or drop in replacements
- Performance indicators
- Storage stability

Final formulation can have detailed requirements.

Example requirements

- Operational temperature range
- Relevant mechanic properties
  - Bulk modulus, viscosity, sheer stability…
- Chemical compatibility with relevant materials
  - Rubber swell, corrosion prevention…
- Performance indicators
  - Lubricity, heat capacity, dielectric strength…
- "Gold standard" tests for properties
  - What data your customer will expect to see

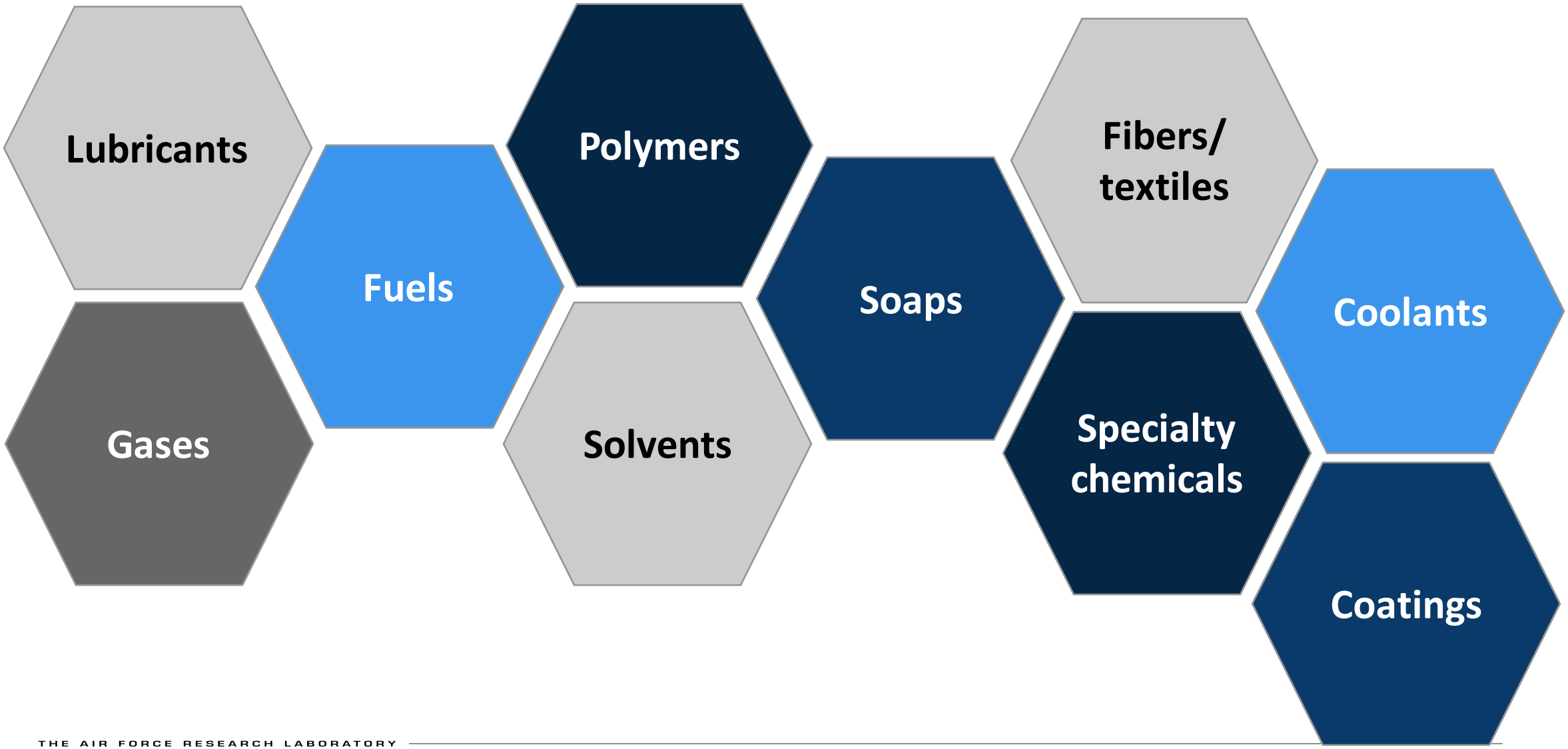
Distribution A online source for screen captures:
https://quicksearch.dla.mil/Transient/FB9840A202C443389214C3A10A59C32D.pdf

Recommended reading on ASSIST

- DSP-CS-21 The Air Force Fuel Conversion Program
  - Case study to switch from JP-8 to Jet A
- MIL-STD-1568 Materials and Processes for Corrosion Prevention and Control in Aerospace Weapons Systems
  - Example of what I envision for a future biomanufacturing best practices standard
  - Lists relevant material specifications for aerospace
- Examples of various material/product specs
  - MIL-PRF-32287 Packing, preformed, petroleum hydraulic fluid resistant
  - MIL-PRF-32295B Cleaner non-aqueous, low-VOC, HAP-free
  - MIL-PRF-81733D Sealing and coating compound, corrosion inhibitive
  - MIL-PRF-7179B Finishes, coatings, and sealants, for the protection of aerospace weapons systems and support equipment
  - MIL-STD-186 Protective Finishing for Army Missile Weapon Systems

Distribution A online source for standards and specifications: https://quicksearch.dla.mil

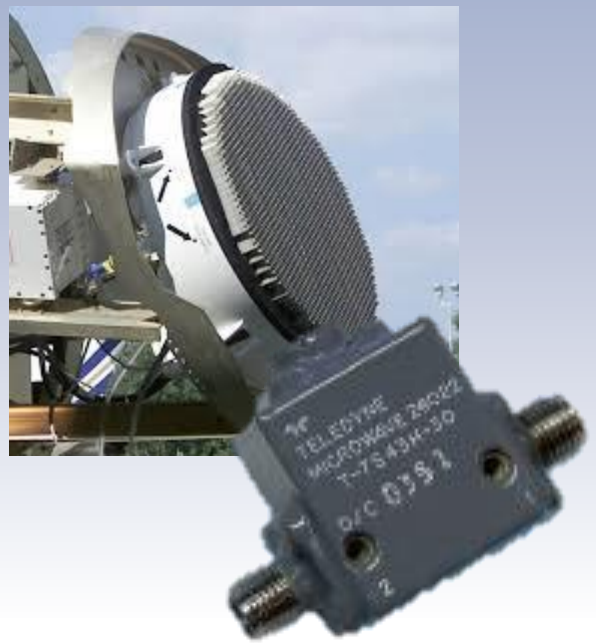
What is possible to produce with biomanufacturing? More than you think



Without DAF Materials & Manufacturing

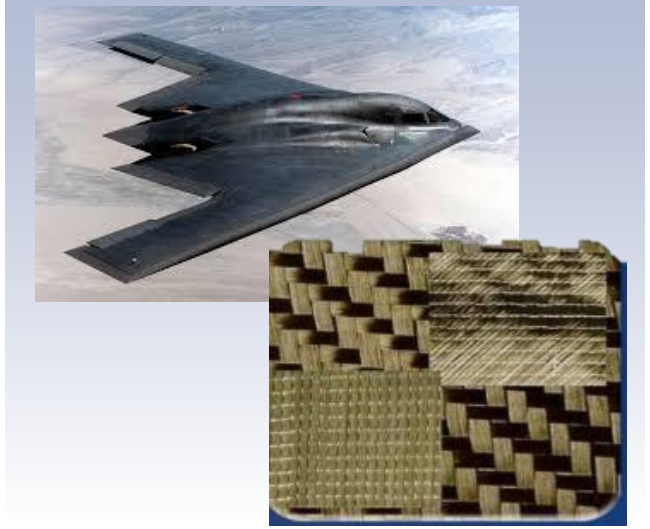
Rare Earth Magnets

We wouldn't have high-end RF systems



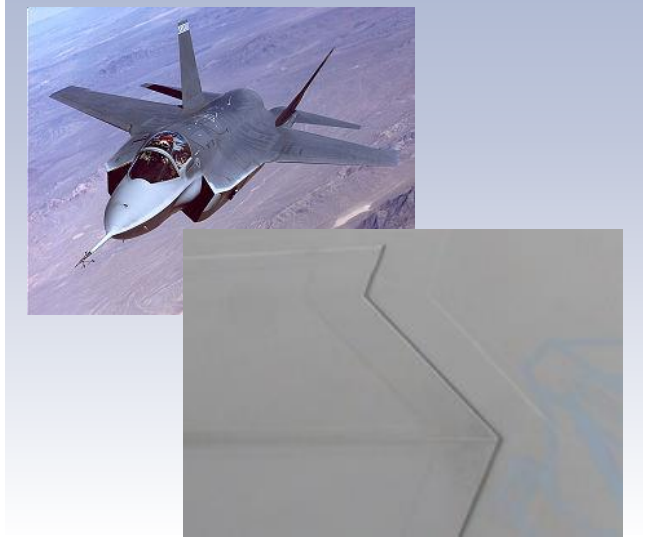
Composites

We wouldn't have lighter weight, higher performance systems (airframes & satellites)



Specialty Coatings

We wouldn't have survivable weapon systems in contested environments



Cost-imposing M&M becomes the "magic" that enables delivery of transformational and disruptive technology

AFRL Materials and Manufacturing Directorate (AFRL/RX)

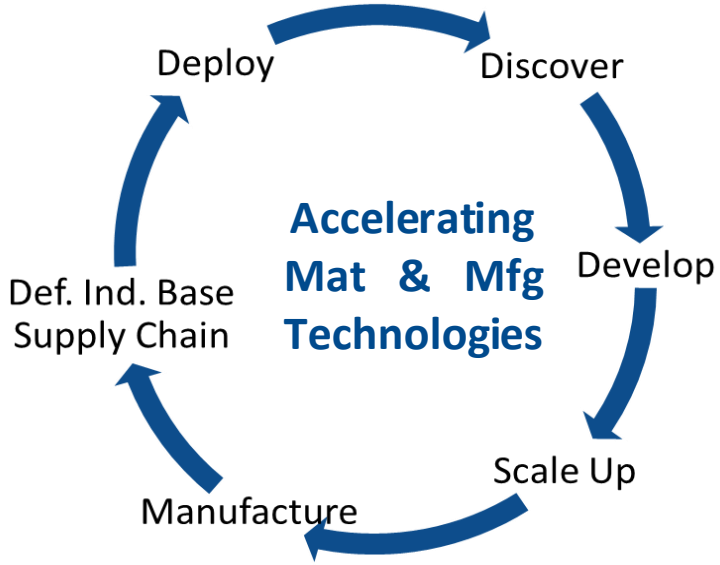
AFRL

Vision

Invent the ***Stuff*** that ***Makes*** the ***Future***

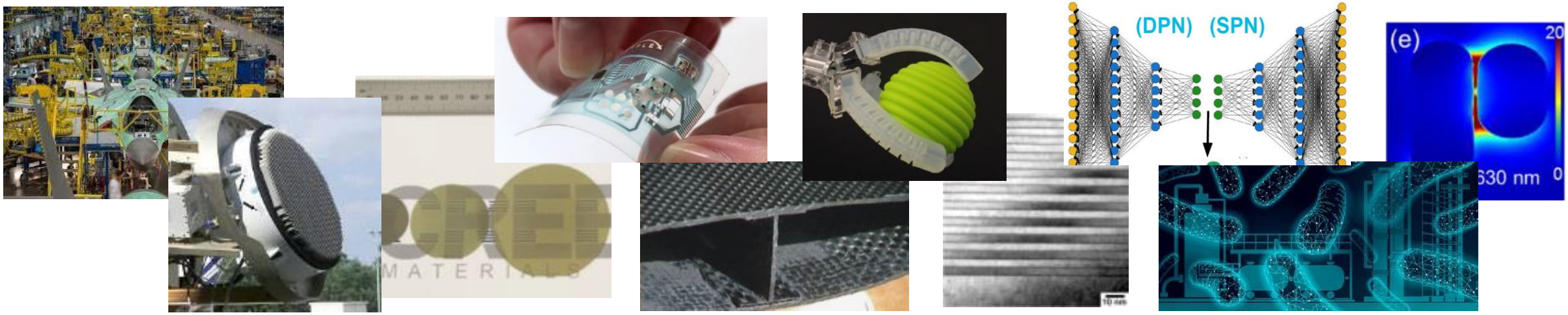
Wright Patterson AFB, OH

600 $M Total Resources (FY20)
430 Gov. Staff (393 civ/30 mil), 50% PhD
500+ FTE On-site Staff, 50% PhD
400 k sqft, 9 Bldgs (55% Labs)



Mission: Accelerate the availability of advanced and cost-imposing materials & manufacturing technologies for the Airman and Guardian by driving the state of the possible and uniting the community

World-Class In-House Expertise, Program Leadership, Community Creation, Trusted Technical Support to Ops



Cost-Imposing Technological Superiority Begins with Advanced Materials & Manufacturing

Competencies of the Biological Materials Team

From the bench….

…to biotechnology-based solutions

Pre-Synbio ARAP

- Molecular biology and Microbiomes
- Materials characterization
- Biotic/abiotic interfaces
- Biosensing

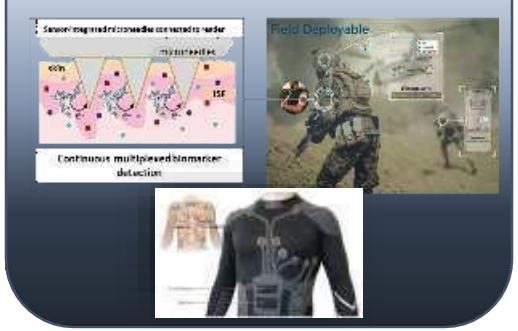
Current Competencies

- Biomaterials and Synthetic Biology
- Bioprospecting and Bio-curation
- Modeling and Bioinformatics
- Biomaterials Characterization and Processing
- HTP screening / functionalization
- Programmable, self-assembled ordered materials'

Application Areas

Agile Infrastructure and Logistics

Airman Performance



Advanced Materials

Supply Chain

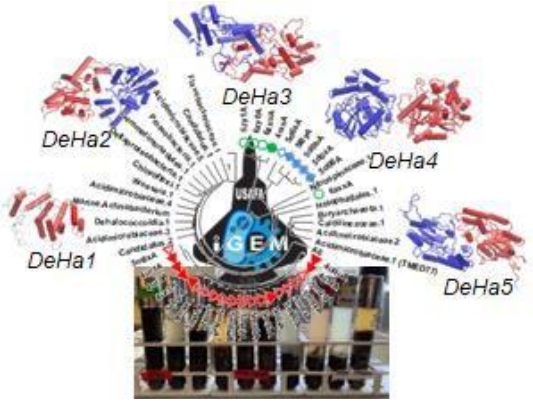
Biological Materials and Processing

Apply biotechnology to accelerate materials development, protect Department of the Air Force assets from the environment, and address critical supply chain gaps for future capabilities.

Dr. Nancy Kelley-Loughnane
Nancy.Kelley-loughnane.1@us.af.mil

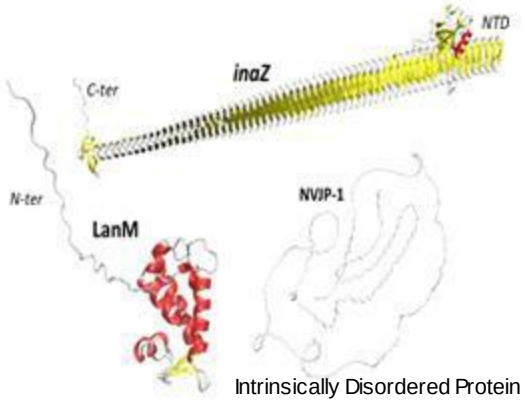
Technical Thrusts

- **Bio-directed synthesis for capabilities and resilient manufacturing**
  - Programmable, self-assembled templates for ordered materials; Energetic and catalytic materials
  - Bioprospecting of microbiomes for discovery, material synthesis, and structural materials
- **Bioprocessing to harness resources**
  - High throughput screening and functionalization of materials
  - Engineering pathways for process optimization
  - Characterization of material properties per mil spec
- **Materials for warfighting systems interfaces**
  - Characterization and prediction of biomaterial-material interactions for integration of sensing elements for applications in airman performance and environmental monitoring



Bioprospecting for function and biotech workforce development

Characterization and processing of biopolymers



Intrinsically Disordered Protein

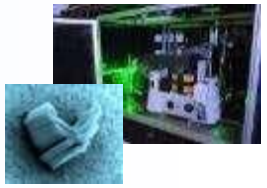
De novo modeling of protein structures

In-field biodirected synthesis of materials

Unique / World-Class Laboratory Facilities

AFRL

Autonomous Research Systems (ARES)



- 1st-ever Robot Researcher for carbon nanotube synthesis using artificial intelligence and automation
- Capable of conducting experiments, analyzing results and deciding which experiments to do next

Coatings, Corrosion, and Erosion Lab (CCEL)

- Whirling arm rain erosion—"Gold Standard" for ASTM testing
- Supersonic rain erosion-- propels 0.5-2 mm raindrops to Mach 2.3
- Hot Erosion --hot environmental particles impact targets > 1200ºC
- Unbiased, neutral ISO 17025 facility available with CRADA

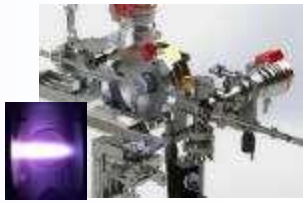
Laser Hardened Materials Evaluation Laboratory (LHMEL)

- High-temp characterization of mat'ls exposed to laser sources
- Nation's largest Continuous Wave (CW) CO2 Infrared (IR) Laser

Microbe-Materials Interaction Lab

- Supports growth and analysis of microbial (fungal, bacterial) cultures and biofilms capable of material degradation
- Only BioSafety Level-2 (BSL-2) lab in AFRL

High Throughput, Multifunctional Epitaxial Growth System



- One-of-a-kind deposition system to create extremely high-quality electronic materials for agile and high power RF/microwave systems

Materials Characterization Facility

- NanoCT 50 nm spatial resolution -1st in US academic/gov't setting
- 8 electron microscopes, 6 x-ray scattering systems, 3 surface sci
- 3D reconstruction, analytics, data, etc.

Large Volume Robotic Characterization System (LEROY)

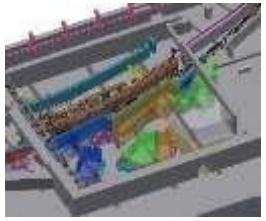
- Unique robotic system for macro-to-mesoscale 3D characterization of microstructure, chemistry, and crystalline texture

High Bay Materials Processing Facility

- Improved aerospace materials processing
- Computer controlled extrusion

Change Picture

In-operando Scattering Facilities (NSLSII, CHESS)



- World-unique equipment for use at synchrotron beam lines, providing real-time, measurements during testing

•Advanced Photon Source (APS), Cornell High Energy Synchrotron Source (CHESS)

- Tri-Service & Industrial Co-Development
- RAMS – highT complex load frame, texture, residual strain
- Polymer & Composite Additive – printers in beam

Special Test and Research (STAR) Lab

- One-of-a-kind facility to provide the US government with independent capability for specialty material development, evaluation, and failure analysis

50+ Unique Facilities, 30+ CRDAs, 80+ Int. Agreements, 20+ EPAs, Minority Leaders COE, 5+ Interagency Agreements

QUESTIONS?

Air Force Research Laboratory – Quick Facts

AFRL

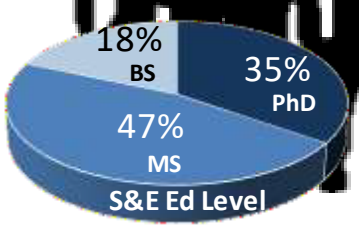
BUDGET

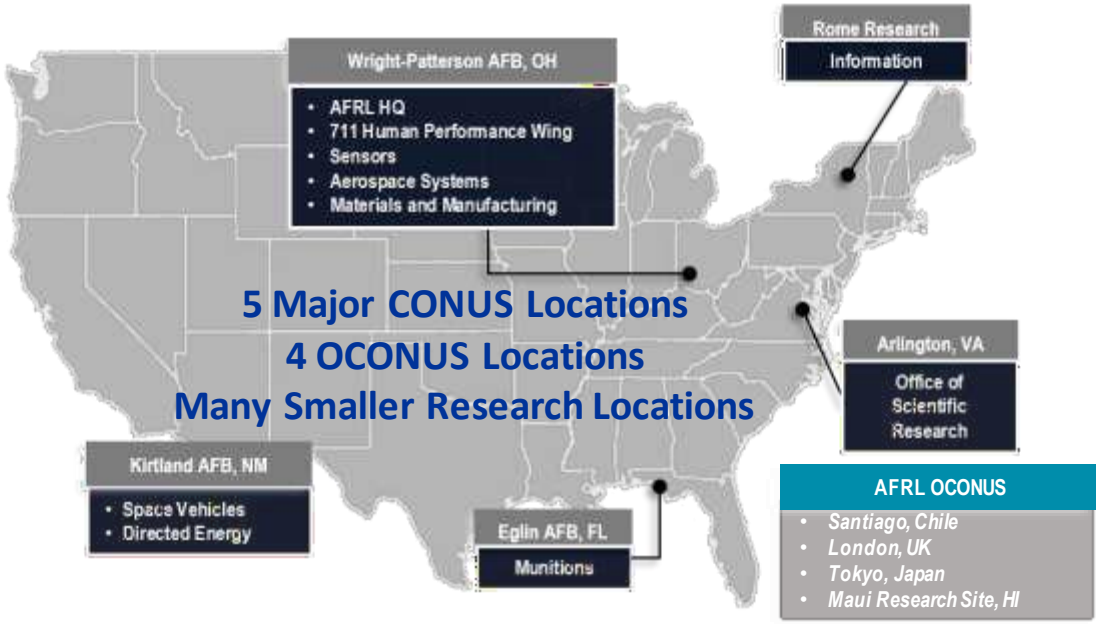
$4.9 Billion

$2.6B – Core

$2.3B - Customer

	Employees	Civilian	Military
S&Es	3,611	3,041	570
Total	6,260	5,038	1,222



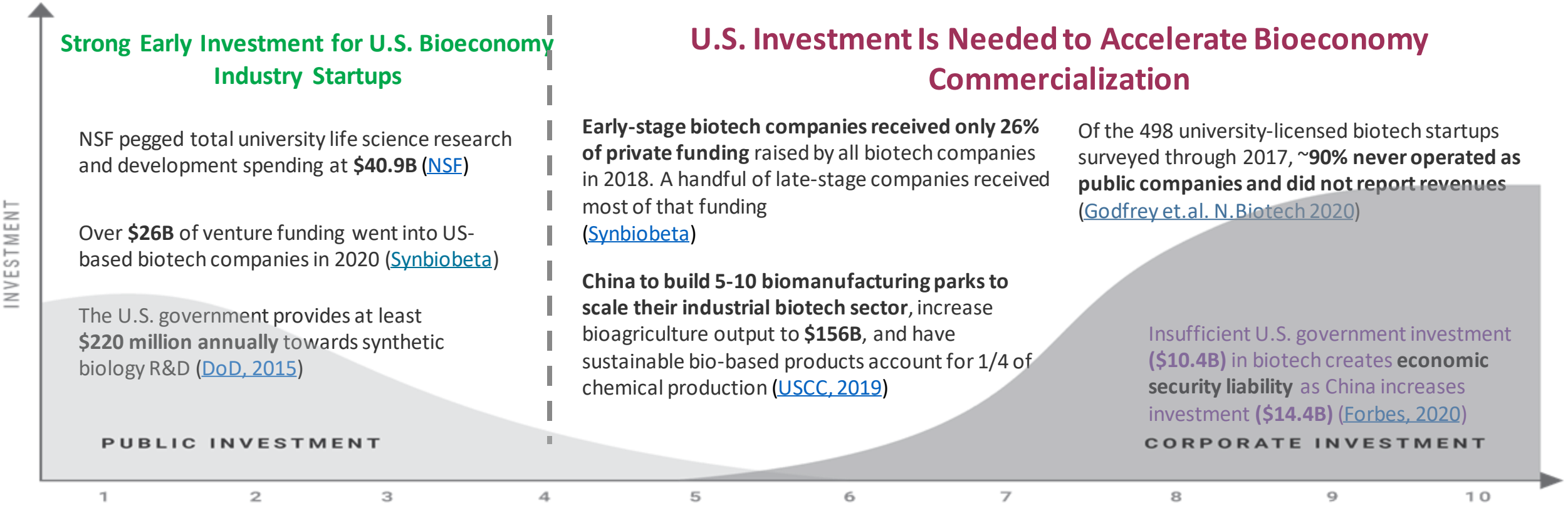


About BioMADE

BioMADE launched in 2020 and is an independent non-profit, public-private partnership sponsored by the U.S. Department of Defense. In partnership with our members, we are securing America's future through biomanufacturing innovation, education, and collaboration by:

- Propelling new biotechnology products from the laboratory to the commercial market
- Creating a more robust and resilient supply chain and helping the U.S. become more self-sufficient
- Ensuring that the workforce of the future is prepared and ready to fill new jobs
- Bringing together a range of member organizations to bridge the gap between lab-scale research and at-scale manufacturing

Investment is needed to Accelerate Bioeconomy Commercialization



Strong Early Investment for U.S. Bioeconomy Industry Startups

NSF pegged total university life science research and development spending at **$40.9B** (NSF)

Over **$26B** of venture funding went into US-based biotech companies in 2020 (Synbiobeta)

The U.S. government provides at least **$220 million annually** towards synthetic biology R&D (DoD, 2015)

U.S. Investment Is Needed to Accelerate Bioeconomy Commercialization

Early-stage biotech companies received only 26% of private funding raised by all biotech companies in 2018. A handful of late-stage companies received most of that funding (Synbiobeta)

China to build 5-10 biomanufacturing parks to scale their industrial biotech sector, increase bioagriculture output to **$156B**, and have sustainable bio-based products account for 1/4 of chemical production (USCC, 2019)

Of the 498 university-licensed biotech startups surveyed through 2017, **~90% never operated as public companies and did not report revenues** (Godfrey et.al. N.Biotech 2020)

Insufficient U.S. government investment **($10.4B)** in biotech creates **economic security liability** as China increases investment **($14.4B)** (Forbes, 2020)

U.S. Investments that Enabled Bioeconomy Startups

MRL

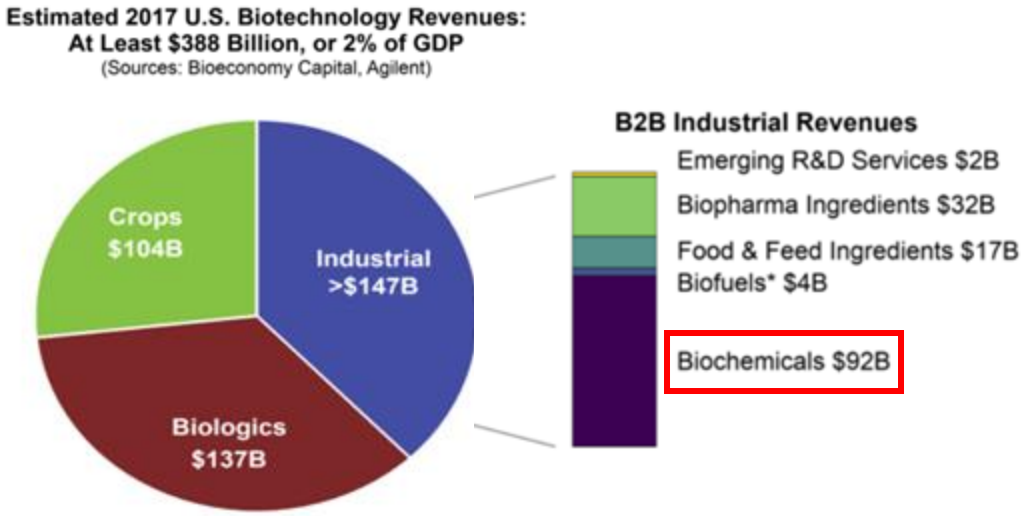
3 Bioenergy Research Centers (DoE)
Increased Venture Capital
SynBERC (NSF)
Living Foundries (DARPA)
Agile Biofoundry (DoE)
Somatic Cell Genome Editing (NIH)
URoL - Syn Cell (NSF)
Cell Manufacturing (NSF)
Center for Biorenewable Chemicals (NSF)

U.S. and Foreign Biotech Commercialization Efforts

BioMADE (USA)
National Biologics Manufacturing Centre (UK)
Pilots4U (EU)
Industrial Biotechnology Innovation Centre (UK)
Shared Pilot Facilities (EU)
BioFabUSA (USA)
NIIMBL (NIST)
Biotechnology Innovation Platforms (CN)
Institute of Synthetic Biology (CN)

35

The domestic bioeconomy is growing



U.S. Bioeconomy

is **sustainably diversified** between crops, biologics, and industrial biotechnology

U.S. Strategic Bioeconomy Assets:

- **United States attracts talented international students** who study and work for our university labs.
- **Powerful basic research programs** that support the early research that generates start ups.
- **50% of patents filed by U.S. life science researchers are judged to have commercial potential**.
- Incredible potential for **massive cultivable biomass** feedstocks.

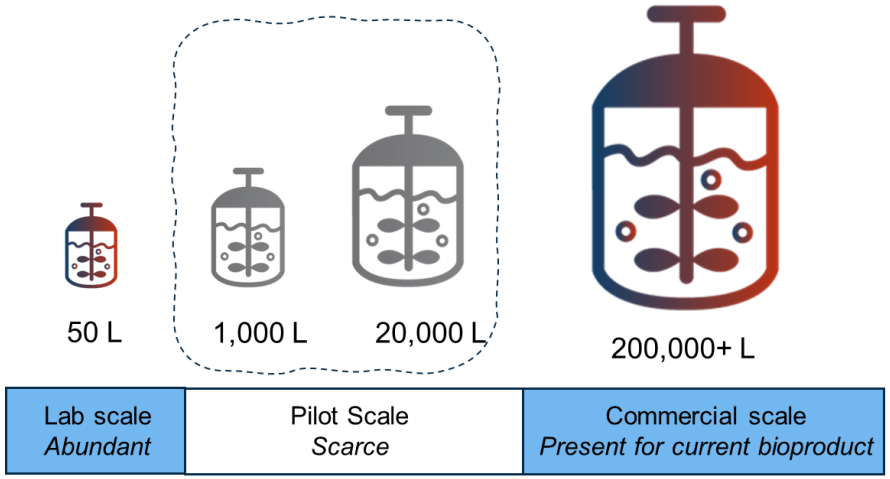
U.S. Bioeconomy is robust and growing:

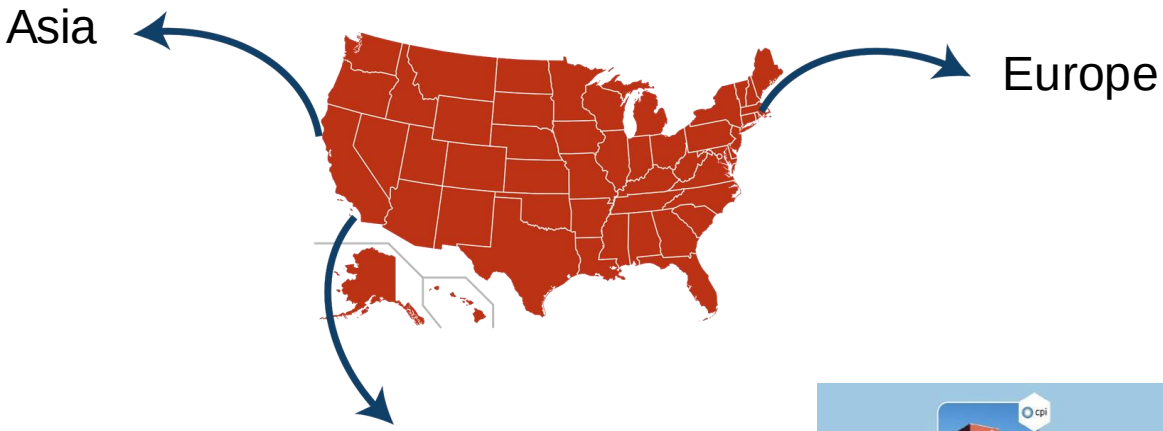
- **1.7 Million Jobs** provided by USDA BioPreferred Products in 2016.
- **$388B (>2% GDP) of US-biotech revenue** in 2017.
  - for reference, 2017 *worldwide* revenues for semiconductors was ~$400B.
- $14B across 74 deals for total biotech IPOs in 2020.
- $26B of Venture Capital Funding for US-biotech Companies in 2020.
- 2,562 Biotechnology Firms across the United States in 2016.

References: National Academies, *Safeguarding the Bioeconomy (2020)*; 2020 Synbiobeta Market Report; Carlson and Wehbring (2021), *Two Worlds, Two Bioeconomies National Security Report*

American IP going overseas for scale-up

Lack of domestic scale-up facilities forces U.S. innovators to look elsewhere to scale or manufacture their biotechnology innovations





An Existing Network of Pilot Facilities in Europe