Leveraging biology for national security

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The Future of Sustainable Plastics
Harvard Kennedy School, Belfer Center for Science and International Affairs

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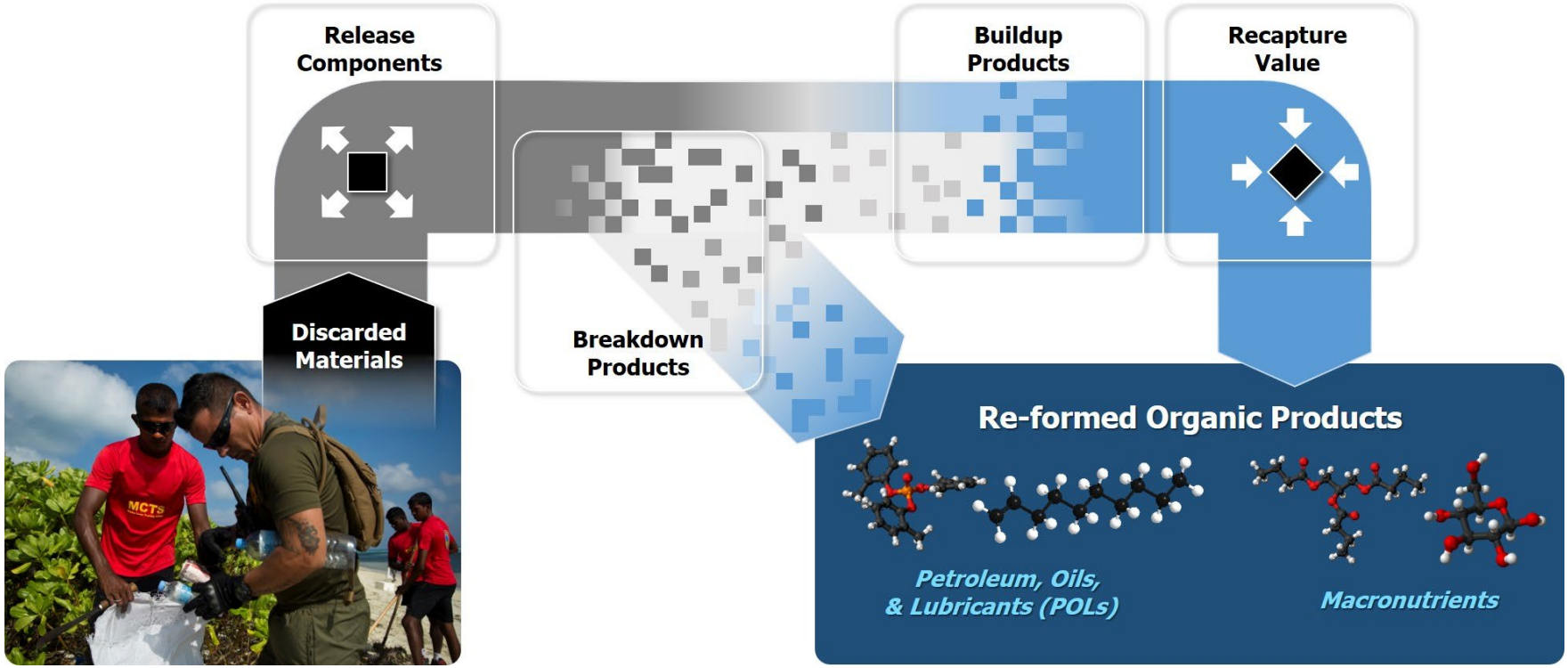
Burden to Benefit



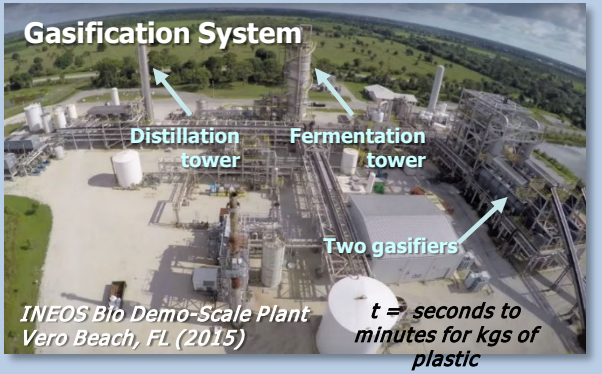
Limitations of Logistical Support and Waste Elimination

Current Practice

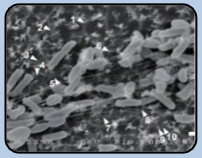
- Logistic support has a large **human cost** in contested environments
  - Established bases have food delivered and prepared onsite (i.e., "catered war")
  - Each supply run puts warfighters at risk
- Much waste is **simply burned**, without even an attempt at energy recapture

State-of-the-Art

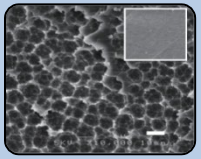
- **No ability** to produce valuable materials when & where needed
- Waste elimination is **difficult and hazardous**
  - Incinerators (<100 in the US) eliminate waste and produce electricity
  - Gasification facilities (~300 globally) convert single-stream solid waste to "synthesis gas" (CO, H_2)
- **Some ability** to bio-degrade common plastics back into precursors



Plastic Bio-Degradation



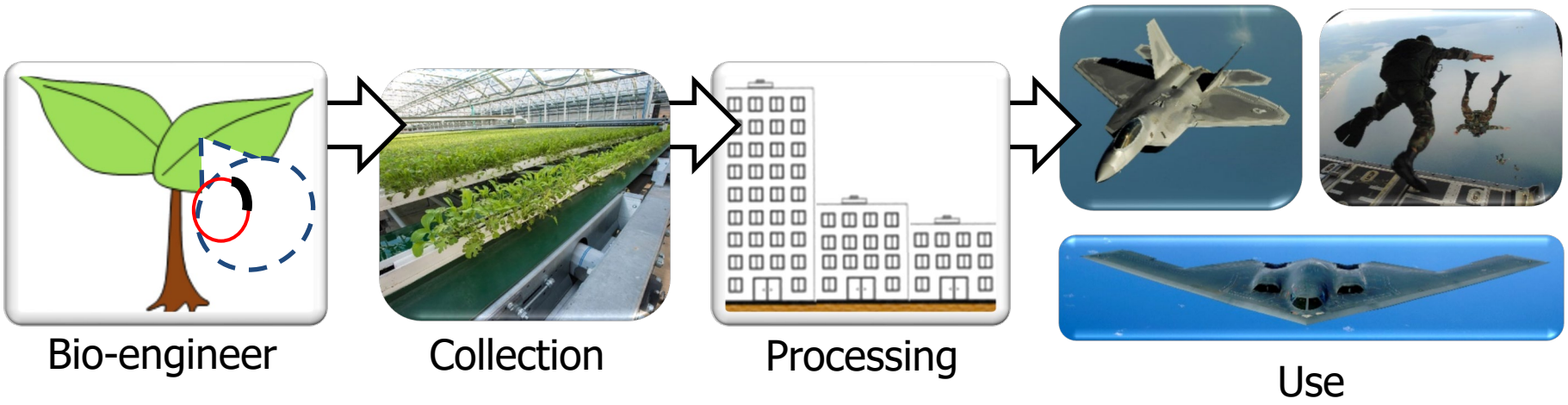
Ideonella sakaiensis PET attachment



Ideonella sakaiensis pitting of PET

***t* = months to years for kgs of plastic**

STTR: Reliable alternative natural rubber products



Envisioned Alternative Natural Rubber PIPELINE

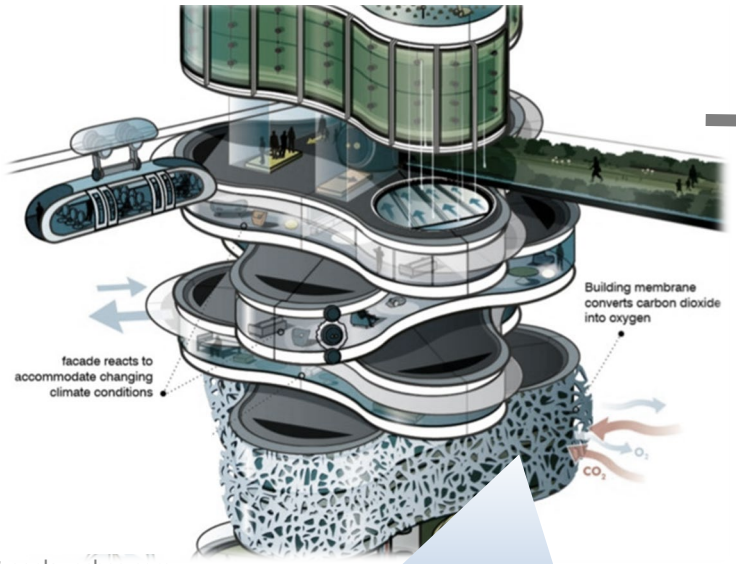
Approach

- Implement molecular circuits for enhanced rubber biosynthesis
- Utilize modern cultivation techniques of alternative rubber plants
- Improve the amount and quality of alternative natural rubber during collection
- Identify and address issues associated with alternative natural rubber extraction and/or processing

Rationally designed living materials

ELM

Architect's Concept: a building with a *living* facade that adjusts porosity according to weather, while capturing CO_2 and respiring O_2



ELM Technology

Specify Design Elements

- Dimensions
- Strength / Flexibility
- Added bio-functions, *e.g.*
  - Tunable porosity
  - CO_2 capture
  - Self-repair

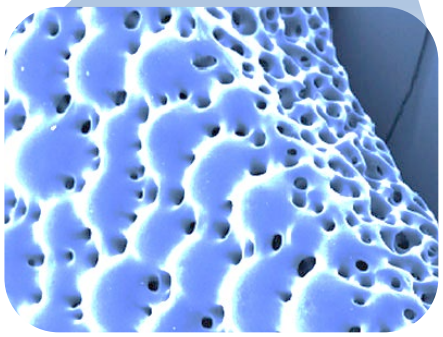
Implement Design

- Choose chassis organism(s) and/or scaffolds
- Use genetics to control
  - development
  - sense and response
  - physical attributes

Grow Materials

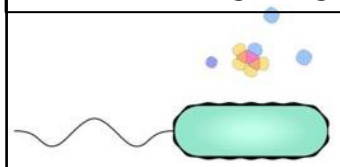
- Progenitor cells
- Growth medium
- Scaffolding materials

Manufacturing

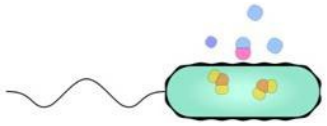


A contingent of natural bacteria bind aggregate with calcium carbonate (calcite)

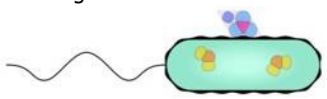
CONCEPT: Using biological processes to perform the chemistry of calcite formation



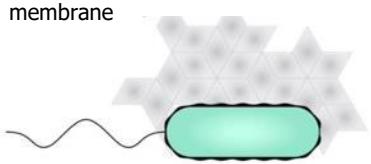
Bacteria in solution with urea and calcium ions



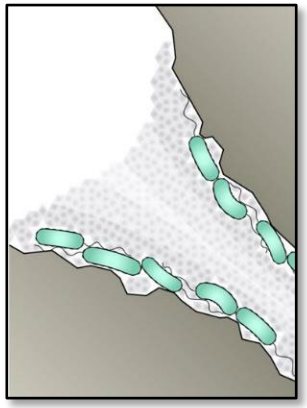
Bacteria hydrolyzes urea molecule leaving carbonate at the cell membrane



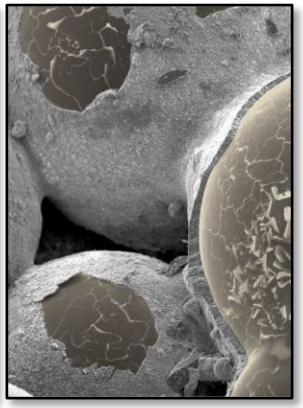
Carbonate ion combines with calcium ion to form a calcium carbonate crystal on cell membrane



Progressive crystal formation entombs bacterial cell



Progressive crystal formation creates meniscus cement, bonding underlying aggregate particles into structural material



Micrograph of biocement meniscus between aggregate particles (400-micron scale; glass bead aggregates false colored)

bacteria nutrients

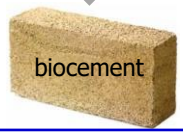
+

sand/gravel insoluble particles

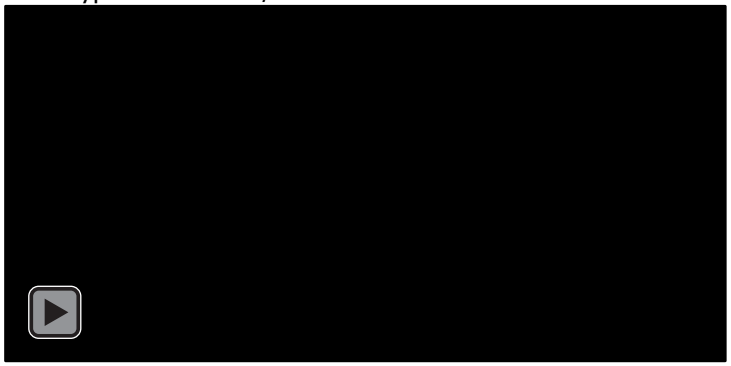
+

calcium source carbon source water

GOAL: To produce hardened dust-mitigated surfaces using minimal resources, equipment, and labor



Prototype 1 untreated/treated surfaces constructed

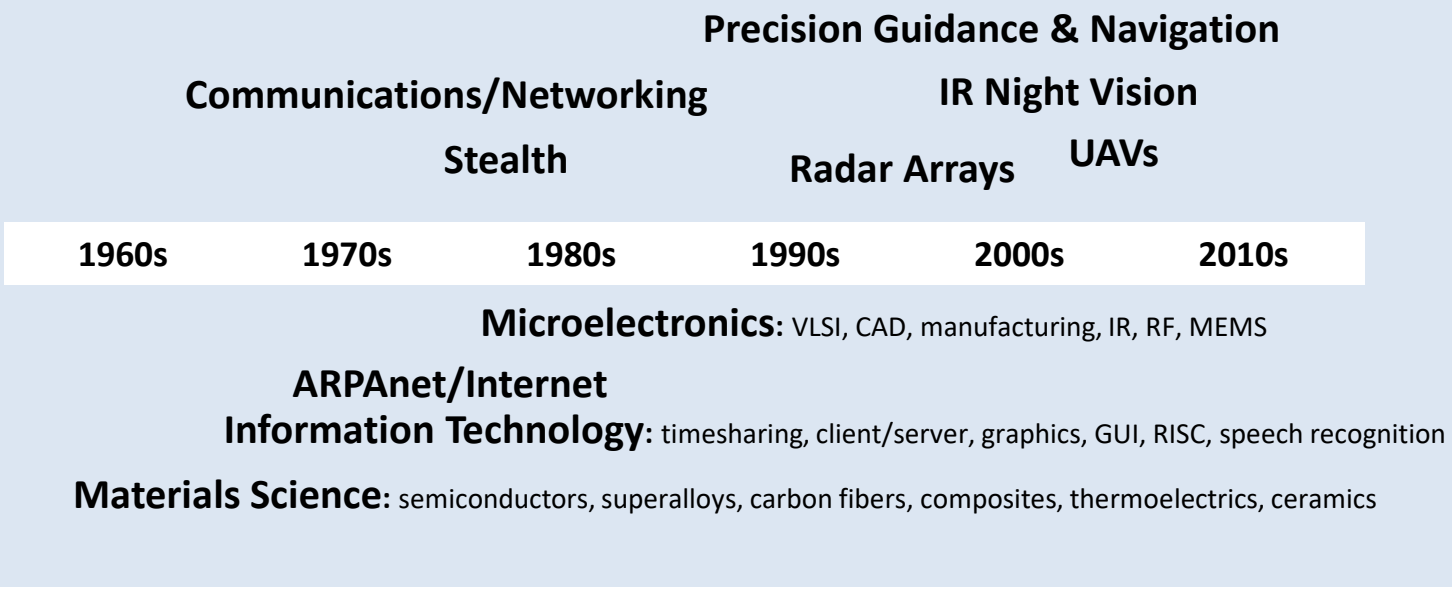


bioMASON Prototype 3 Deployment – Yuma, AZ

130’ x 130’ control and treated surfaces 48-hours post-install

DARPA's mission

Breakthrough Technologies for National Security



New capabilities require a healthy ecosystem across Service S&T, universities, and industry

DARPA's role: pivotal early investments that change what's possible

The Heilmeier Catechism

DARPA operates on the principle that generating big rewards requires taking big risks. But how does the Agency determine what risks are worth taking?

George H. Heilmeier, a former DARPA director (1975-1977), crafted a set of questions known as the "Heilmeier Catechism" to help Agency officials think through and evaluate proposed research programs.

1. What are you trying to do?
2. How is it done today, and what are the limits of current practice?
3. What is new in your approach and why do you think it will be successful?
4. Who cares? If you are successful, what difference will it make?
5. What are the risks?
6. How much will it cost?
7. How long will it take?
8. What are the mid-term and final “exams” to check for success?

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