Synthetic Biology for Materials and Manufacturing

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Perspectives on synthetic biology for materials and manufacturing from where I sit

Biologist

Assistant Chief Scientist

DoD Employee
Materials Research Opportunities

• Metals
• Ceramics, glasses, composites, hybrid mat’ls
• Semiconductors, electronic materials
• Quantum materials
• Polymers, biomaterials, soft matter
• Architected metamaterials
• Materials for energy, catalysis and extreme environments
• Materials for water, sustainability, and clean technologies
• Materials for thermal management
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- Precision macromolecular synthesis
- Supramolecular biomaterials (peptide amphiphiles)
- Sequence controlled polymers, incl. incorporation of non-canonical amino acids
- Self-assembly
- Biopolymers (DNA, hydrogels, cellulose, actin, microtubules)
- Bacterial cells as ‘active matter’
NAS Frontiers of Materials Research: A Decadal Study (2019)

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*Synthetic biology can provide breakthroughs in many of these areas now...esp if they rely on organic small molecules*
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*There is also great potential for SynBio to impact more complex all-bio or bio-inorganic systems*
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*SynBio enables more sustainable manufacturing*
- ‘Green’ catalysis
- Energy efficiencies
- Raw materials/feedstocks
- Recyclability
Goals for Today

1. Convey the art of the possible—today
2. Discuss what’ll be possible in 2-10 years
3. Discuss why and when synthetic biology should be considered as a tool in the materials science and manufacturing toolbox
4. Discuss how to achieve more cross-pollination between SynBio and MatSci communities
5. Understand the policy and security landscapes around SynBio
Bio ‘X’ Emphasis Areas, late 1990s

**Biomimetic and Bioinspired**
- Mimic in non-biological systems

**Biotemplating Interface Control**
- Use biological molecules to pattern, order, create composites

**Biomanufacturing (Biopolymers)**
- Use biological molecules directly

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**Moth eye structures**

**Diatoms**

**Silk**

All enabled by studying biological systems
What’s new? Massive decreases in costs of reading and writing DNA

Cost of DNA sequencing

![Cost per Raw Megabase of DNA Sequence](image)

Bioinformatics Explosion
Enormous ‘parts’ library
What’s new? Massive decreases in costs of reading and writing DNA

Cost of DNA sequencing

Cost of DNA synthesis

Bioinformatics Explosion
Enormous ‘parts’ library

Ability to ‘order up’ anything you want to try
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Bioinformatics Explosion
Enormous ‘parts’ library

Ability to ‘order up’ anything you want to try

Enhanced creativity, opportunity space, and throughput
contributing directly to advent of ‘synthetic biology’

• The application of **engineering principles** towards the construction of novel biological systems

• Integration of biological and chemical engineering, bioinformatics, computation, metabolic engineering, systems and developmental biology

• Distillation of biology into ‘parts’, ‘circuits’, systems
How does this help?

1. Choose right organism for the job (i.e., ‘chassis’)
2. Build ‘bottom up’ or ‘top down’
3. Tune timing and thus hierarchy
4. Mix/Match to optimize:
   - bio from diverse systems
   - chem + bio
   - non-canonical amino acids, nucleotides
5. Design-Build-Test-Learn
Bio ‘X’ version 2.0: SynBio expands the art of the possible

**Biomimetic and Bioinspired**
- Mimic in non-biological systems
  - Moth eye structures

**Biotemplating (Interface Control)**
- Use biological molecules to pattern, order, create composites
  - Diatoms

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  - Silk

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**Specialty small molecules**
- High throughput monomers, nanoparticles
  - *Cell-free or cell-based, ex vivo*

**Hierarchically designed, and/or composite mat’ls**
- Cellular additive manufacturing
  - *Make and die—time and place*

**Living materials**
- Cellular responsive additive mfg
  - *Make, live, respond*
Small molecule production is not really new

…we’re just better at it now

“Susterra”
1,3-propanediol
“Bioreachables”
Structural and Engineered Living Materials

Jin and Riedel-Kruse, 2018
Future solutions can come from anywhere…
There are many ways to get there from here…

Alloys
Ceramics
(Bio)Organic polymers
Composites

Chemical synthesis
Enzymatic (Bio)synthesis
Vapor deposition
Sintering
Spinning
Patterned
3D printing/additive mfg
What does biology bring to the table?

- Novel chemistries, ‘R’ groups
- Chiralities
- Templating
- Self-assembly

- Timing
- Scaling
- Purification
- ‘Green’ synthesis

- Multifunctionality
- Defect tolerance
Often less a question of *can* we make it but *why should we*? What advantages does Bio provide?
Fundamental research is still required

- Biotic/abiotic interfaces
- Microbial physiology
- Microbial community ecology
- Developmental biology
- Structure-property relationships
- Self-assembly
- Hierarchy
- Multiscale modeling and characterization
- 2D and 3D processing techniques

**Synthetic Biology Catalyst**

Better design
More variants to test
Higher throughput
Machine learning
= Accelerated development

**New Materials Synthesis, Processing, and Functionality**

- Specialty bulk materials
- Hierarchically designed & composite material
- Living materials

- Stimulus
- Stimulus

- Fundamental research is still required
In addition, large gains could be made by increasing dialogue between the communities

**Bio to Materials Science**
- Standardization of data collection and management
- High throughput analysis, characterization
- Opening up the palette of novel chemistries

**Materials Science to Bio**
- Understanding of ‘when and why bio’?
- Understanding tolerances for impurities
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Questions?
Why Bio?

Self-assembly
Hierarchy
Multifunctionality
Defect tolerance

Structural Materials
(adhesives, fibers, gels, composites)

Electronic Effect  Photonic Effect

Function

Structure

Functional Materials
(optical, electronic, sensing)

Multifunctional Materials
(sense-and-respond)