Manufacturing Abundance

Opportunity Space

V 1.0

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CONTEXT

This document describes an early opportunity space from which we believe one or more funding programmes can emerge. We've sketched out some of our early thinking to spark your interest, and invite you to imagine relevant potential programmes with us, or suggest new directions. We'll publish updated versions of this document as our thinking evolves.

Sign up **here** to receive those updates and learn about any funding opportunities that emerge from this opportunity space.

An ARIA opportunity space should be:

+ important if true (i.e. could lead to a significant new capability for society),
+ under-explored relative to its potential impact, and
+ ripe for new talent, perspectives, or resources to change what's possible.

SUMMARY

Stone, Iron, Plastic, Silicon: ages of human history are defined by materials that solve civilizational problems and transform societies. These age-defining materials represent breakthroughs in mastery over matter: mechanical shaping, high-temperature chemistry, polymerization, and purification. The next age will be defined not by a single material, but by our ability to assemble molecules into bespoke solutions for today's great challenges and finally unlock sustainable abundance.

BELIEFS

The core beliefs that underpin/bound this area of opportunity.

1. We will assemble limited sets of available molecules into a limitless range of functionality, **without cost to planetary health**.

2. Programmable polymers will construct materials, from the nanoscale to the macroscale, **with structures that deliver tailored performance with unimaginable accuracy**.

3. Ubiquitous clean energy will unlock a new manufacturing paradigm and, in turn, be catalysed by it: **cost-competitive, precise performance arising from structure (vs. composition) and stochastic (vs. deterministic) assembly.**

4. To unlock ubiquitous manufacturing, we'll need a new biotic-abiotic tech stack that lets us programmably assemble matter like software → **creating resilient societies, unleashing innovation at scale, and shrinking lab-to-market cycles from decades to days.**

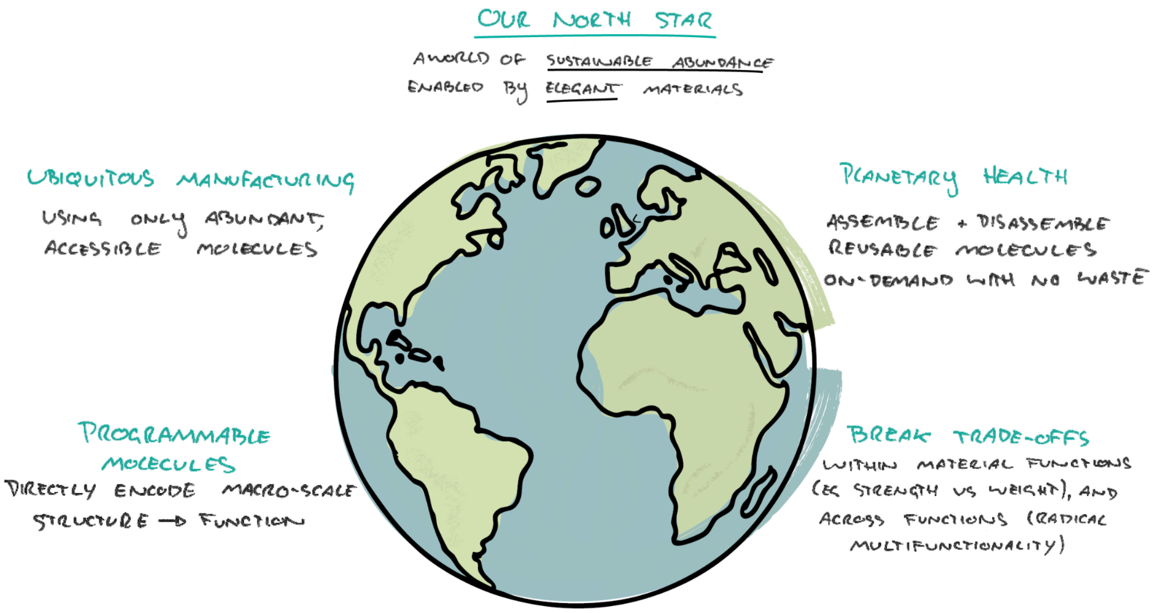
OBSERVATIONS

Some signposts as to why we see this area as important, under-explored, and ripe.

There is a pattern to historical progress: scarcity leads to new manufacturing, which in turn leads to abundance with unforeseen costs.

A century ago, limited by natural resources, we chemically engineered synthetic materials that underpin modern food, health, transport and entire built environments. Our inability to cost-competitively recreate the elegance of nature's production has led to a polluting manufacturing paradigm of single-use materials.

1. Why now? Our reliance on a 1900's chemical engineering paradigm has driven planetary health crises and international conflicts. (To avoid crossing tipping points, new manufacturing and materials are needed ASAP.)



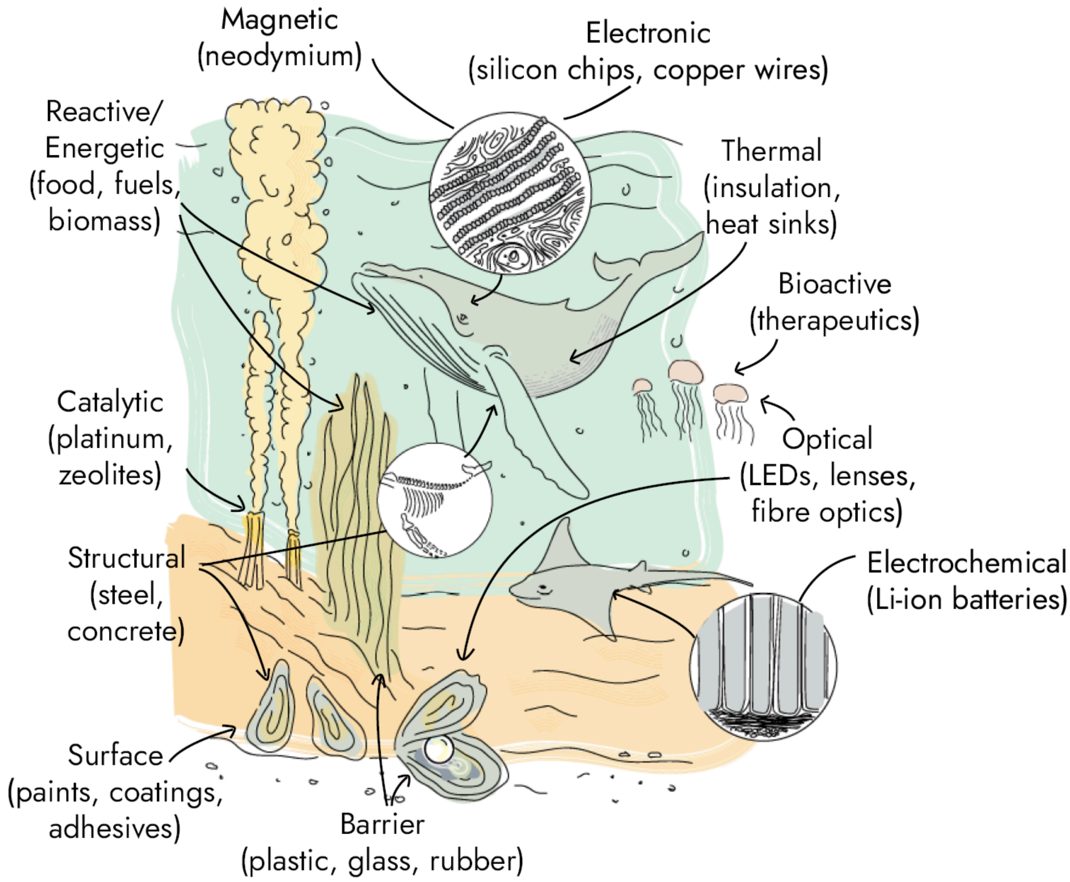
2. Why now? Rapidly reducing cost of ubiquitous, clean energy unlocks new elegant manufacturing techniques.

3. Why now? Our ability to engineer biology is advancing with exponential rates:
    + Cost of DNA sequencing and synthesis both falling faster than Moore's law.
    + Growth of global synthetic biology financial markets.
    + No. of database entries (genes, proteins).
    + Protein designability, including non-standard monomers.
    + Biomanufacturing: increasing scale, reducing cost.

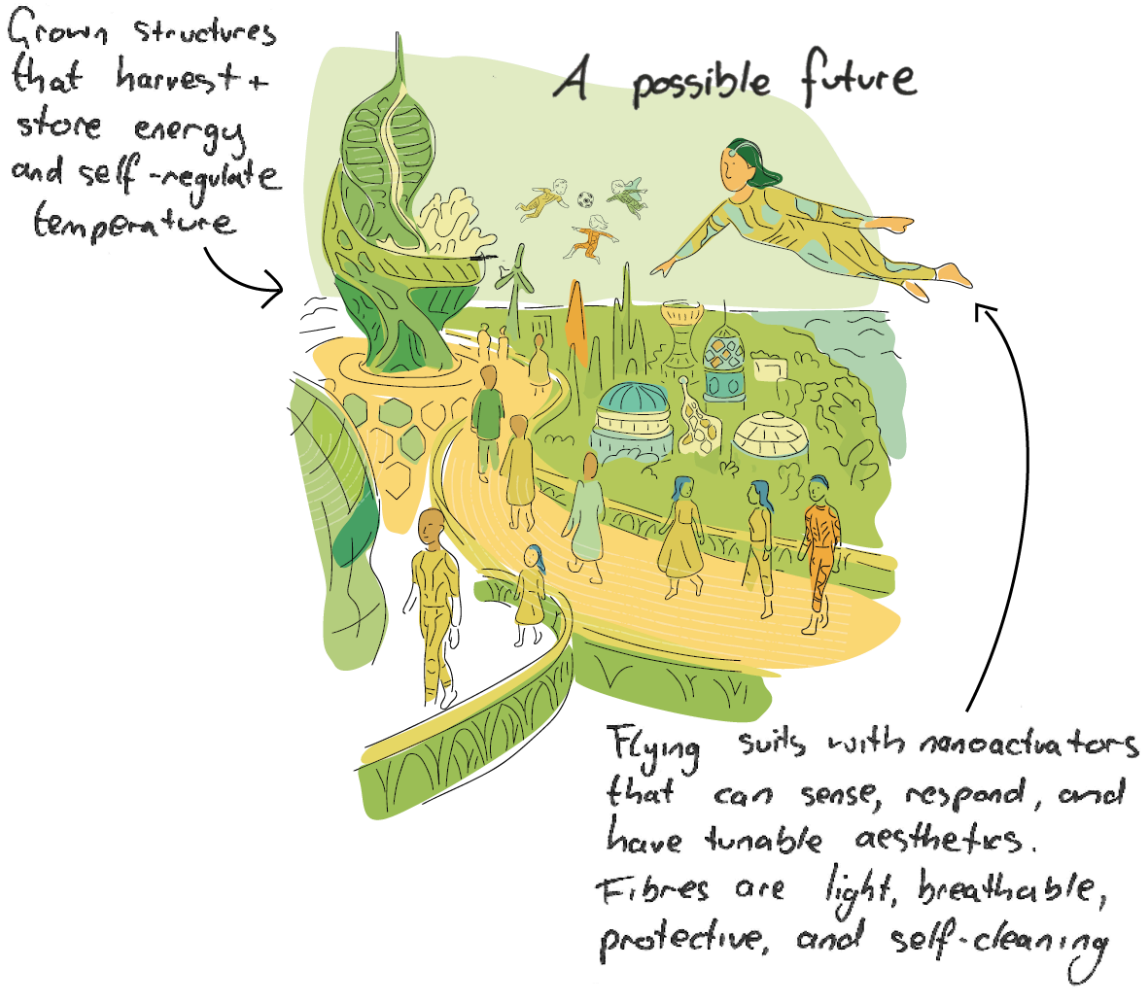
4. Biology proves it is possible to assemble almost any function from only locally abundant molecules (20 amino acids plus a handful of other organic molecules and inorganic salts).

    Nature has already engineered all 11 of today's essential material functions, each a market valued at >£100 billion, from only oceanic building blocks (>70% of our planet!).

5. Almost all biomanufacturing efforts today focus on therapeutics, catalysts, and food. (We can massively improve the other 8 essential functions.)



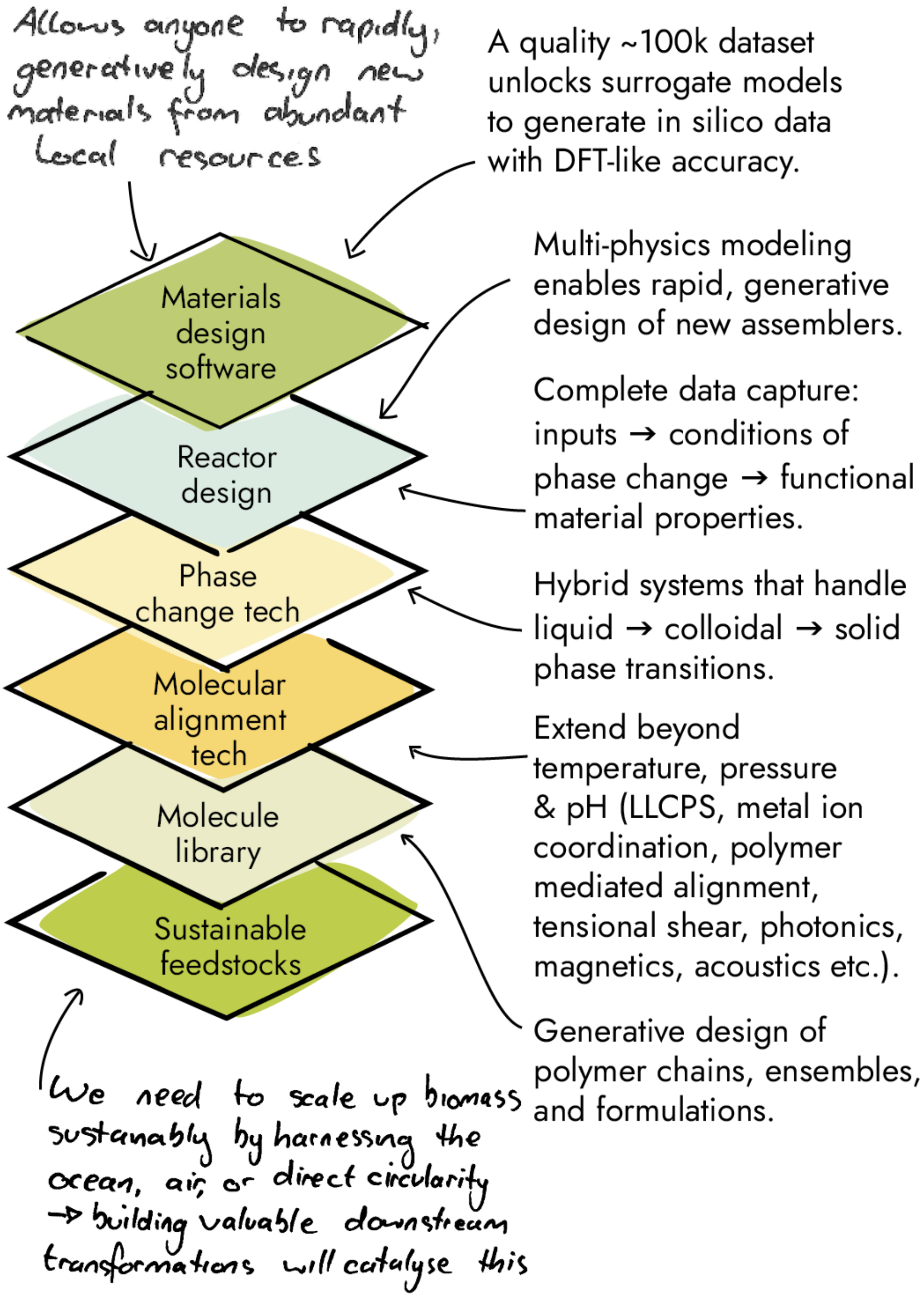
6. Valuable material functions continuously evolve. New manufacturing paradigms create new >£1T markets e.g., silicon purification to electronic materials. (Programmable molecular assembly → Von Neumann materials?)



7. Existing manufacturing is centralised, large-scale, bespoke for specific material classes and inflexible. This contributes to our perennial materials scale-up problem: a historical 50 year gap from lab discovery to productisation. (Democratised manufacturing where assembly instructions are sent as software will solve this!)

8. Why now? Exponentially improving AI has unlocked design of complex material spaces from proteins to inorganic crystals to nascent work in synthetic polymers.

9. Elegant materials sit outside of existing material classes. Without an elegant assembly tech stack, AI-design is trapped in discrete siloes. (We will need to span the full synthetic-biological spectrum.)

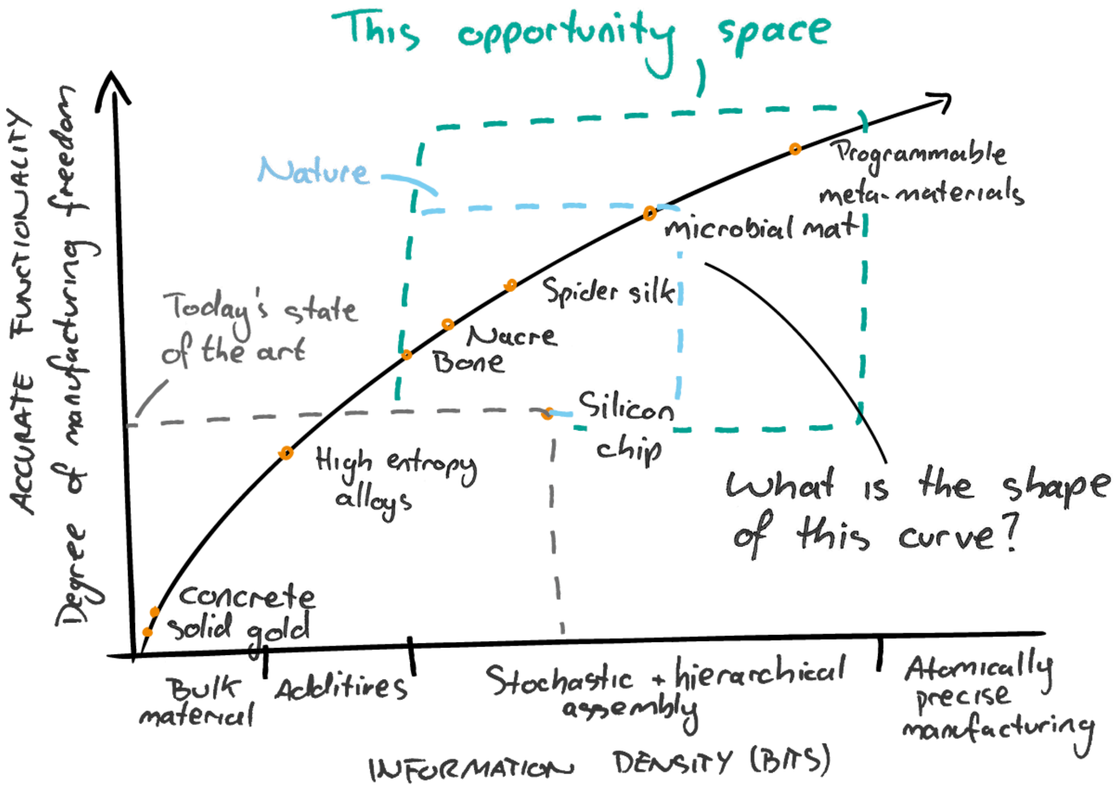


10. Why now? Ride the tailwinds of movements towards decentralisation and self-sufficiency. Success means that anyone, anywhere can assemble almost anything. (No more fragile, polluting global supply chains!)

11. Why now? The digital world underwent a stochastic paradigm shift. It's now crossing over to the physical world: cultivating complexity to achieve robust, high performance.
    + Digital: randomised algorithms, probabilistic models.
    + Materials: high-entropy alloys, composites, heteropolymers, 4D printing, generative design.
    + Biotech: directed evolution, engineered living materials, CAR-T therapy, gut microbiome tech.
    + Agriculture: precision agroecology, soil microbiome tech.

12. Randomness is a core feature of our universe that nature harnesses to build precise, adaptive, and antifragile systems. Humanity's obsession for deterministic control has created brittle, unsustainable systems from monoculture farms to semiconductor fabs intolerant to a single spec of dust. (Programmable information-rich materials and stochastic manufacturing will lead to bespoke outcomes at speed, scale and competitive cost.)

13. To increase performance characteristics (strength, conductivity, hydrophobicity etc.), humans use rare and toxic additives. In contrast, nature programs polymers to assemble information dense architectures from the nano-scale to the macro-scale.



SOURCES

A compiled, but not exhaustive list of works helping to shape our view and frame the opportunity space (for those who want to dig deeper).

1. Materials and Manufacturing Underpin Civilization
2. Fundamental Manufacturing Process Innovation Changes the World
3. The Alchemy of Air
4. Getting materials out of the lab
5. We're creating a treasure map to progress
6. Manufacturing matters: The cornerstone of a competitive green economy
7. What Happened to Molecular Manufacturing?
8. A Billion Years of Evolution in a Single Afternoon
9. Dozens of Nobel-Worthy Innovations Awaiting Biomanufacturing 2.0
10. The Case for Cultured Meat Has Changed
11. The future is made of energy
12. To Conquer the Primary Energy Consumption Layer of Our Entire Civilization
13. How to Produce Green Hydrogen for $1/kg

14. Fields of the future: where will tomorrow's harvests be grown?
15. Wind and Solar Energy Are Cheaper Than Electricity from Fossil-Fuel Plants
16. The case for synthetic fuels
17. Spark ablation for nanoporous material production
18. Clean energy future to be 'built in Britain'
19. Mapping the chemical complexity of plastics
20. The scale of the problem of replacing 'forever chemicals' PFAS
21. Our world in data - Air Pollution
22. The cooling dilemma amid climate change
23. Colossal barocaloric effects with ultralow hysteresis in two-dimensional metal–halide perovskites
24. Seaweed: Hidden champion of the ocean
25. Biomimetics — a review
26. Biological Materials Processing: Time Tested Tricks for Sustainable Fiber Fabrication
27. From vesicles to materials: bioinspired strategies for fabricating hierarchically structured soft matter
28. Fluid protein condensates for bio-inspired applications
29. Flow-induced crystallisation of polymers from aqueous solution
30. A Protein Printer
31. 3D printing of self-healing longevous multi-sensory e-skin
32. Biomineralization strategy: from material manufacturing to biological regulation
33. Biomaterials for organically generated habitats beyond Earth
34. Bio-Optics and Bio-Inspired Optical Materials
35. Shannon Information and Kolmogorov Complexity
36. The coming of age of de novo protein design
37. Multi-functional liquid crystal elastomer composites
38. Hierarchically structured bioinspired nanocomposites
39. Hierarchically-structured metalloprotein composite coatings biofabricated from co-existing condensed liquid phases
40. Silk and Synthetic Polymers: Reconciling 100 Degrees of Separation
41. Protein-Based Biological Materials: Molecular Design and Artificial Production
42. Process Principles for Large-Scale Nanomanufacturing
43. Elucidating interplay of speed and accuracy in biological error correction
44. Stochasticity in materials structure, properties, and processing—A review
45. Functional composites by programming entropy-driven nanosheet growth
46. Population-based heteropolymer design to mimic protein mixtures
47. Using coherence to enhance function in chemical and biophysical systems
48. The anti-fragile factory explained
49. Antifragility from an engineering perspective
50. Sparks: Multi-Agent Artificial Intelligence Model Discovers Protein Design Principles
51. Generative design and molecular mechanics characterization of silk proteins based on unfolding behavior
52. The AI-Native Operating System for Protein Engineering
53. A review of large language models and autonomous agents in chemistry

54. Accelerated data-driven materials science with the Materials Project
55. Self-Driving Labs Transforming Material Research
56. Self-Driving Laboratory for Polymer Electronics
57. Self-Replicating Robots and the Future of Fabrication
58. Discrete robotic construction
59. Ubiquitous manufacturing: Current practices, challenges, and opportunities
60. How the World Ran Out of Everything
61. Makers: The New Industrial Revolution
62. The Third Industrial Revolution: How Lateral Power is Transforming Energy, the Economy, and the World

ENGAGE

Our next step is to formulate a programme within this opportunity space that will direct funding across research disciplines and institutions toward a focused objective. In order to ensure we select the right first challenge, we want to hear from you.

Complete this form to provide feedback on the opportunity space and inform the development of our programme thesis - we will read anything you send.