

Manufacturing Abundance

Opportunity space

v1

Ivan Jayapurna, Programme Director

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 civilisational problems and transform societies. These age-defining materials represent breakthroughs in mastery over matter: mechanical shaping, high-temperature chemistry, polymerisation, 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 unprecedented 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 → new manufacturing → 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. 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.

Almost all efforts today focus on therapeutics, catalysts, and food.

we can massively improve the other 8 essential functions

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

Biology proves it is possible to assemble almost any function from only locally abundant molecules.

3. Rapidly reducing cost of ubiquitous, clean energy unlocks new elegant manufacturing techniques.

2. Our reliance on a 1900's chemical engineering paradigm has driven planetary health crises and international conflicts.

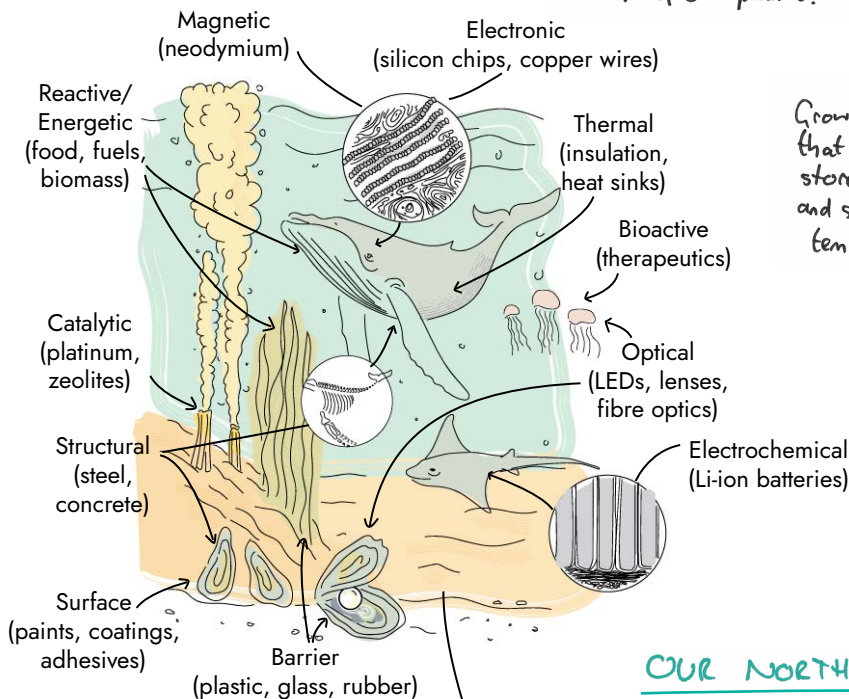
To avoid crossing tipping points, new manufacturing + materials are needed ASAP

20 amino acids + handful of other organic molecules & inorganic salts

Valuable material functions continuously evolve. New manufacturing paradigms create new >£1T markets (e.g. silicon purification → electronic materials).

Programmable molecular assembly → Von Neumann materials?

>70% of our planet!



Grown structures that harvest + store energy and self-regulate temperature



Flying suits with nanoactuators that can sense, respond, and have tunable aesthetics. Fibres are light, breathable, protective, and self-cleaning

OUR NORTH STAR

A WORLD OF SUSTAINABLE ABUNDANCE ENABLED BY ELEGANT MATERIALS

UBIQUITOUS MANUFACTURING

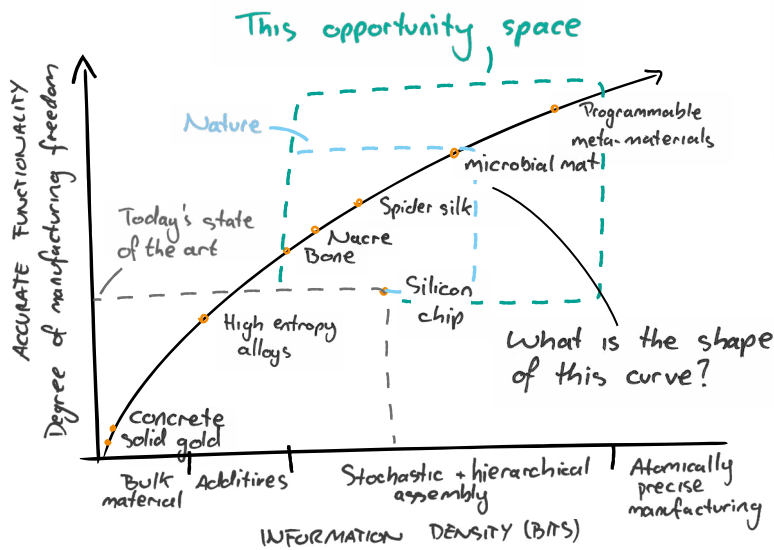
USING ONLY ABUNDANT, ACCESSIBLE MOLECULES

PLANETARY HEALTH

ASSEMBLE + DISASSEMBLE
REUSABLE MOLECULES
ON-DEMAND WITH NO WASTE

PROGRAMMABLE MOLECULES
DIRECTLY ENCODE MACRO-SCALE
STRUCTURE → FUNCTION

BREAK TRADE-OFFS
WITHIN MATERIAL FUNCTIONS
(E.G. STRENGTH VS WEIGHT), AND
ACROSS FUNCTIONS (RADICAL
MULTIFUNCTIONALITY)



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.

Programmable information-rich materials + stochastic manufacturing = bespoke outcomes at speed, scale, and competitive cost

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.

no more fragile, polluting global supply chains!

6. 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.

5. Ride the tailwinds of movements towards decentralisation and self-sufficiency.

Success = anyone, anywhere can assemble almost anything

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

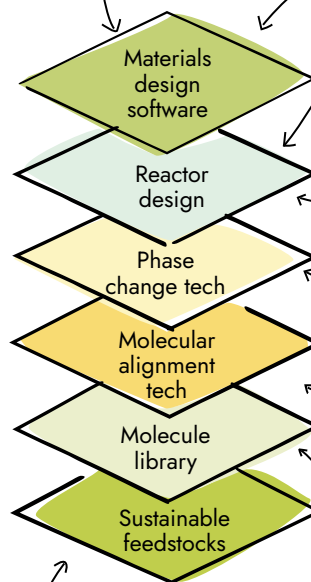
WHY NOW?

Democratised manufacturing where assembly instructions are sent as software will solve this!

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 production.**

Allows anyone to rapidly, generatively design new materials from abundant local resources

A quality ~100k dataset unlocks surrogate models to generate in silico data with DFT-like accuracy.



Multi-physics modeling enables rapid, generative design of new assemblers.

Complete data capture: inputs → conditions of phase change → functional material properties.

Hybrid systems that handle liquid → colloidal → solid phase transitions.

Extend beyond temperature, pressure & pH (LLCPS, metal ion coordination, polymer mediated alignment, tensional shear, photonics, magnetics, acoustics etc.).

Generative design of polymer chains, ensembles, and formulations.

We need to scale up biomass sustainably by harnessing the ocean, air, or direct circularity → building valuable downstream transformations will catalyse this

Elegant materials sit outside of existing material classes. Without an elegant assembly tech stack, AI-design is trapped in discrete siloes.

Will need to span the full synthetic-biological spectrum

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. [Biomaterialization 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.