Universal Fabricators

Programme Thesis

v1.0

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CONTEXT

This document presents the core thesis of a ~£50M programme that is currently in development at ARIA within the *Manufacturing Abundance* opportunity space, **aiming to launch ~16th February 2026**. We invite you to provide feedback to help us refine our thinking.

This is not a funding opportunity, but in most cases will lead to one – sign up **here** to learn about any funding opportunities derived or adapted from this thesis.

An ARIA programme seeks to unlock a scientific or technical capability that

+ changes the perception of what's possible or valuable
+ has the potential to catalyse massive social and economic returns
+ is unlikely to be achieved without ARIA's intervention.

PROGRAMME THESIS, SIMPLY STATED

Today most protein engineers only design drugs and enzymes. If this programme is successful they will design next-gen materials across electronics, energy, infrastructure and more → proteins will become "universal fabricators".

Manufacturing with molecular precision is crucial for state-of-art material performance, and proteins represent a uniquely powerful toolkit to achieve this. Yet despite recent breakthroughs in protein engineering (*e.g., Alphafold*, de novo design, directed evolution, non-canonicals, cell-free synthesis) subsequent investment and applications have primarily been in pharmaceuticals and biocatalysis, leaving the potential of proteins in materials assembly severely underexplored.

In this programme, we challenge a new coalition of biologists, materials scientists and engineers to develop scalable processes that use proteins to template the assembly of inorganic and composite materials with structures that currently cannot be mass manufactured. If successful, the technologies developed in this programme will yield a civilization-defining material that marks the start of the 'Protein Age'.

PROGRAMME THESIS, EXPLAINED

Why this programme

Today most protein engineers only design drugs and enzymes. If this programme is successful they will design next-gen materials across electronics, energy, infrastructure and more → proteins will become "universal fabricators".

Despite advances in inorganic material synthesis, many desired electromagnetic, thermal, optical, and mechanical properties remain inaccessible. Current advanced manufacturing is trapped in a trade-off between volume and precision. Bottom-up processes like chemical vapor deposition (CVD) or sol-gel synthesis are scalable to tonnes but are inherently stochastic, resulting in defects that cap performance. Top-down techniques like extreme ultraviolet (EUV) lithography achieve <100nm feature sizes but are capital-intensive, energy-heavy, and constrained to small surface area 2D planar geometries. They also still struggle with defects at the atomic limit.

Manufacturing with molecular precision is crucial for state-of-art material performance, and proteins represent a uniquely powerful toolkit to achieve this. Yet despite recent breakthroughs in protein engineering (*e.g., Alphafold*, de novo design, directed evolution, non-canonicals, cell-free synthesis) subsequent investment and applications have primarily been in pharmaceuticals and biocatalysis. We believe these are a fraction of the socioeconomic potential of proteins. By leveraging their programmable assembly, non-equilibrium dynamics, and ability to produce deterministic outputs in ambient, stochastic environments, proteins can become the backbone for materials manufacturing across a broad range of existing applications and future functionalities (see *Appendix 1: Protein Tech Tree*). However, to unlock this future a key bottleneck must be solved — hierarchical assembly: we can't yet program proteins to organize into large, multi-functional structures or template inorganic mineralization.

The Assembly Problem

Hierarchical assembly is the next frontier of protein engineering, a challenge only recently accessible because AI has effectively "solved" the 'Protein Folding Problem'.[1] Assembly is an underdefined and underfunded gap between academic biology and industrial manufacturing, as it sits outside of the Overton window of both communities.[2]

We believe making proteins today is expensive primarily due to a lack of industrial-scale demand for non-pharma, non-enzyme applications. Transforming the Folding Problem success into a solution for the 'Protein Assembly Problem': going from a single folded protein to organizing trillions into a macroscopic material with valuable function, is necessary to unlock the mass-market demand that will collapse protein production costs.

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[1] Solving the first major protein challenge, protein crystal structure characterisation (1958), unlocked the Protein Folding Problem, which was defined in the 1960s and the static structure prediction component was considered 'solved' in 2020. Dynamic, contextual assembly remains an open field of research.

[2] The Overton window (window of discourse) is the range of subjects and arguments acceptable to a mainstream population at a given time.

More broadly, assembly is a frontier materials engineering challenge. We cannot yet take a material specification, such as a specific magnetic coercivity or a 2D pore distribution, and output a 'recipe' for coordinating trillions of building block interactions into a functional bulk solid. Cutting-edge AI can suggest new inorganic, metal, and ceramic crystal structures in small systems, but nothing approaching nano-to-macro complex protein assembly. Tackling this will require galvanising a new coalition of biologists, materials scientists, and systems engineers to go beyond today's perceived limits of protein engineering (*e.g.,* solutions, gels, films, fibres).

The Assembly Problem sits in an R&D whitespace between four distinct funding silos:

1. **Medical**: proteins as therapeutics and diagnostics
2. **Biomanufacturing:** scaling up protein production as industrial biocatalysts and optimisations to produce "molecules" (*e.g.,* monomers, specialty chemicals)
3. **Living materials**: producing macro-scale systems with synthetic biology, but where the production machine and/or the produced "material" is living.
4. **Inorganic materials**: advanced material science research today typically relies on further exploring existing branches of synthesis and manufacturing (*e.g.,* new rare chemistry, advanced lasers, new crystal structures / compositions)

Why now?

The concept of using biology for material fabrication is not new; nature has demonstrated the capability to manufacture high-performance materials like abalone nacre, sponge spicules, and magnetotactic bacteria for eons. The scientific pursuit of these capabilities began in earnest in the 1980s with the study of biomineralization mechanisms revealing how proteins control inorganic nucleation. The field advanced significantly in the 2000s with the advent of phage display technology (Nobel Prize 2018), which allowed researchers to evolve peptides that could specifically bind to and organize inorganic materials such as zinc sulfide and cobalt oxide for batteries.

However, these early research efforts were limited to finding peptides that happened to bind, rather than engineering the binding interface from first principles. The resulting materials often suffered from poor crystallinity, low yield, and lack of long-range order. Engineering tools today have created a pivotal inflection point; we can now create proteins with arbitrary, atomically precise geometries that do not exist in nature. We have moved from discovering biological binders to designing molecular machines.

However, molecular machines alone are insufficient. Protein structures build themselves through self-assembly, a process driven by the stochastic thermal motion of components seeking a free energy minimum. Conventional synthetic self-assembly typically operates under thermodynamic control, where structural fidelity is dictated by the Boltzmann distribution. For complex, hierarchically ordered architectures, the energy landscape is often full of kinetic traps and local minima that are energetically indistinguishable from the target state. Thus, synthetic assemblies are often plagued by defects that compromise function. Biological systems overcome this by operating far from equilibrium. They consume chemical energy to drive kinetic proofreading, error-correction cycles that amplify specificity by orders of magnitude beyond the thermodynamic limit.

To achieve mastery across multiple length scales, we must synthetically move into the regime of driven, non-equilibrium assembly systems. In lieu of biochemical energy, we can leverage advances in synthetic engineering (assembly hardware integrated programmability) to provide both the triggers for assembly and the selective pressures for fidelity. Magnetic fields, light, acoustics, and continuous flow can be used as dynamic phase-change triggers (actuators) to trap, stabilize, and guide protein interactions within non-favored energy states. Rather than "error correcting" individual molecular defects in real-time, reactor environments can provide a global energy landscape selective pressure, maintaining the assembly front in a state where the energy barrier for dissociation of non-desired bonds is lower than the barrier for programmed bonds. Combining reactor tunability with the intrinsic sequence-to-structure-to-assembly programmability of engineered proteins, will allow for the manufacture of high-regularity, low-defect inorganic and composite materials.

Proteins in nature can organize matter with atomic precision over macroscopic distances. Recapitulating and expanding this capability synthetically would break the precision-volume trade-off that defines modern manufacturing. Success would attract potential customers spanning almost every industry that suffers from material performance currently capped by one or more of 4 manufacturing bottlenecks: stochasticity, scale, security, and/or sustainability.

What we hope to achieve

Programme Goal: develop scalable processes that use proteins to program the assembly of materials with structures that currently cannot be mass manufactured.

Our programme goal can be broken down into 3 high-level programme objectives (PO):

- **PO1.** **Solve the "Protein Assembly Problem"**: build a programmable instruction set for proteins to organise themselves into large, multi-functional structures.
- **PO2.** **Make state-of-art inorganic materials:** at least one highly-valuable use case where protein-programmed manufacturing produces a functional material that clearly supersedes the currently manufacturable state-of-art.
- **PO3.** **Make protein-programmed manufacturing scalable (TRL4-5, MRL4):** sufficiently derisk the resilience and volume required to transition protein-based manufacturing to industrial-scale production.

Our programme will shift the paradigm from proteins as consumable drugs and catalysts to proteins as non-living architectural fabricators that assemble civilizational infrastructure *i.e., 'universal fabricators'*. We will use proteins as sacrificial or structural templates for non-living, solid-state manufacturing (*e.g.,* fibres, membranes, magnets etc.). Success will shift demand from kilograms to kilotons, volume that would necessitate and justify the deployment of agricultural-scale biomanufacturing infrastructure. The 'Assembly Problem' is the gateway; without the ability to make macroscopic assemblies proteins remain confined to the "molecules" market rather than the "materials" market.

On a more technical level, our progress towards these high-level programme objectives can be measured by quantitative metrics such as described in **Table 1**. We aim to derive/aggregate these general metrics from data measured by each creator project we fund. With the help of the broader community, we will continue to develop their reliability and interpretability over the course of the programme.

Table 1: Preliminary high-level programme metrics. For proteins to demonstrate value as general purpose fabricators, we need to achieve the Minimum targets. Stretch targets are aspirational and likely require subsequent investment.

PO	Metrics	Minimum	Stretch
1. PROTEIN	**1.1. Hierarchical Scale Ratio:** between the smallest controlled feature and largest structural dimension (*e.g.*, 10 nm precision in a 1 cm structure).	10^6	10^8
	1.2. Structural fidelity: defect-free rate in incorporating proteins correctly into the final macroscopic structure.[3]	*TBD*	*TBD*
	1.3. Predictive Accuracy: between physical geometry and simulated prediction.	±25%	±10%
2. INORGANIC	**2.1. Interfacial precision:** feature roughness at the organic-inorganic boundary.	<10 nm	<1 nm
	2.2. Phase & feature uniformity: variation in the primary functional feature (*e.g.*, crystal grain size or diameter)	<5%	<1%
	2.3. Programmable tunability (span): range that material properties (*e.g.*, magnetic coercivity, optical attenuation) can be tuned by altering protein sequence.	2x	10x
3. PROCESS	**3.1. Input tolerance**: purity of protein and inorganic precursors required to achieve target functional specifications.	*Not required*	<90%
	3.2 Throughput: total solid-state material or continuous 1D material produced per month	>1g or >10m	>1kg or >10km
	3.3 Reproducibility: process reproducibility rate across 10 independent runs.	>70%	>90%

[3] We know this is important to characterise and measure, we are not sure yet how best to do so. Maybe scattering or measuring functional performance as a proxy.

What we expect to fund

Teams will target one of three platform technology engineering challenges (**Table 2 & Figure 1**), each making progress towards the programme objectives. Challenges were selected to have:

1. moonshot technical feasibility within 3-5 years
2. many existing industrial applications and future functionalities that proteins are uniquely leveraged to manufacture (see *Appendix 1: Protein Tech Tree*)
3. a "killer" example use case to target with clearly defined specifications and minimal system integration challenges *i.e.,* an existing system plug-in replacement

We expect the programme to concurrently push the frontiers of protein structural assembly and functional materials processing, towards producing one of three Overton window-shifting materials demonstrations in collaboration with industrial partners. These challenges span the programmable assembly of 1D, 2D, and 3D structures, the mineralisation of abundant inorganic elements across the period table (*e.g.,* Si, Fe, Zr), and the production of amorphous inorganics, crystalline inorganics, and composite materials. While we expect to fund flexible platform protein-enabled manufacturing technologies that will eventually branch out into many applications, this portfolio was designed to keep the programme focused to maximise success; across the 3 challenges derisking unforeseen, bespoke technical challenges for any specific structure, mineralisation, function, or commercial market. Success in a single challenge would demonstrate a solution to the Assembly Problem, and we believe will consequently yield a civilization-defining material that marks the start of the 'Protein Age'.

This programme will be split into two phases. In the first phase, these 3 challenges and their respective use cases are tentative and will continue to be developed in parallel with preliminary programme progress, in collaboration between our ARIA programme team, our funded ARIA creators, and industry advisory groups.

Table 2: Portfolio of platform technology programme targets

Protein Engineering Challenges	Example Application
Fibre biomineralisation (1D)	Hollow-core optical fibres
Isoporous, defect-free metal-protein frameworks (2D)	Ultra-high purity lithium hydroxide extraction membranes
Monodisperse nanocrystal templating in anisotropic composites (3D)	Rare-earth free magnets

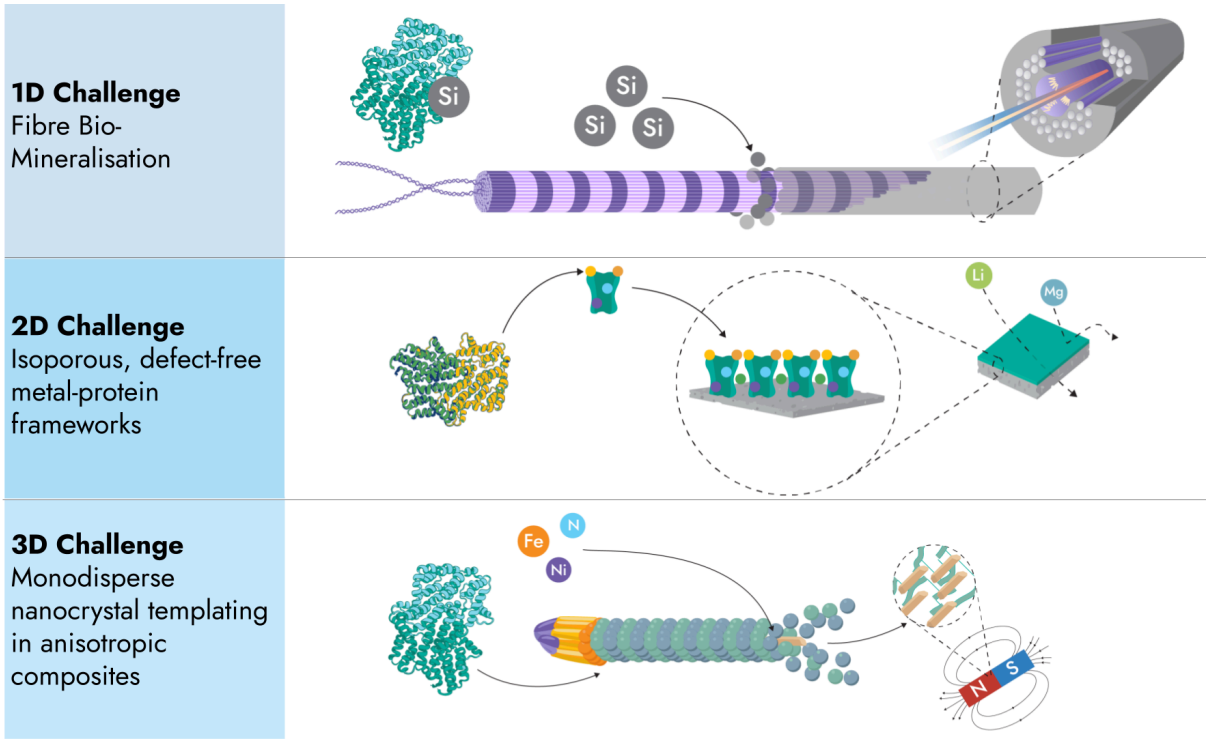

Figure 1. Schematics illustrating the 3 programme challenges (1D, 2D, 3D) and potential example use cases (hollow-core optical fibre, ultra-high purity lithium hydroxide extraction membranes, Rare-earth free magnets).

Phase 1: Protein-programmed materials manufacturing platforms (Month 0 - 36)

In the first 3 years of our programme we will fund 3 challenges and expect creator teams to apply to only one of these challenges, but we encourage, although do not mandate, the sharing of fundamental learnings and enabling technologies.

1D Challenge — Fibre biomineralisation

Proteinaceous fibres (including filaments and fibrils) underlie a broad array of material types, from natural fibers used since ancient times, to increasingly specialised and engineered ones used as building blocks of everything from textiles, film and hydrogels to artificial tendons and controlled drug dispensers. The broader space of 1D materials extends well beyond those directly accessible to proteins alone, such as semiconductor nanowires, photonic/phononic waveguides and high-strength ceramic fibres.

In all applications, these fibres exploit anisotropy through hierarchical structures to express and enhance performance along a single dimension. These structures are all governed by the same rules of physical constraints and manufacturing requirements: longitudinal coherence, radial symmetry and precision, surface perfection, and the suppression of defects along extreme aspect ratios.

In the long term, fibrous materials can in principle encode complex or responsive functionality (such as stimuli-responsive fibres). However, this programme focuses on establishing the manufacturing foundations required to achieve this regime of precision and uniformity. So by targeting fibres with simpler, well-defined functions, we aim to unlock a generalisable platform for fabricating high-performance 1D materials across multiple application domains.

Example use case — Hollow-core optical fibres

We selected silica biomineralisation into hollow-core optical fibres as the target application. Hollow-core optical fibres guide light through interference-based confinement, achieved via photonic bandgaps or anti-resonant reflection in the surrounding microstructured cladding. As a result, optical loss and mode purity are set primarily by how faithfully this interference condition is realised along the fibre length. This imposes some of the most stringent manufacturing requirements in photonics: angstrom-level control of radial geometry and surface quality, precise hierarchical structuring, and kilometre-scale longitudinal uniformity.

We believe one approach (of many) could be to combine relatively mature technologies such as protein-based fibre spinning with naturally occurring silica templating. With this, fusion protein engineering, controlled flows in spinning and mineralisation, and extensive post-processing of sacrificial protein templates can be used to reliably realise complex hollow-core architectures.

The manufacturing and quality-control capabilities developed through this challenge are expected to generalise beyond optics, enabling defect-suppressed 1D structures for electronic, structural, and fluidic applications, as well as complementing parallel efforts in 2D and 3D materials.

2D Challenge — Defect-free metal-protein frameworks

Nature offers a distinct class of engineerable 2D materials beyond the fluid lipid bilayer: the crystalline protein lattices (such as S-layers) that serve as protective coats and molecular sieves for bacteria and archaea, periodic photonic crystals that serve as structural colorants or crystal/cytoplasm multilayers that serve as mirror lenses. Fundamentally, the manufacturing principles that govern selective transport across membranes mirror those that govern wave propagation in 2D materials. While selectivity can arise without order, controlling periodicity, symmetry, and defect suppression at the nano-to-micro-scale, where lattice architecture defines energy landscapes, is what enables deterministic transport. In this regime, the same processes for crystalline assemblies are transferable; they could be programmed not only to filter molecules, but to sculpt optical, electronic, or magnetic band structures, yielding lenses, filters, and other functional 2D devices.

This challenge is inspired by bacteria and archaea with naturally occurring isoporous structures which demonstrate that proteins alone can form mechanically resilient, perfectly uniform filtration barriers. We anticipate that selectivity will be encoded not by the supporting lattice alone, but by engineered transport

channels templated within a defect-free protein membrane, analogous to metal-organic frameworks. The membrane provides a perfectly ordered scaffold, while the channel interiors are tuned to create the precise physical and ionic environments required for discrimination.

We see this as the foundation for a general-purpose separation technology that could eventually replace energy-intensive thermal distillation and indiscriminate reverse osmosis across the chemical, pharmaceutical, and water industries. However, to drive this platform from lab-scale curiosity to industrial necessity, we must initially tackle a separation challenge that existing synthetic membranes struggle to solve efficiently.

Example use case — Isoporous selective membranes towards ultra-high purity lithium polishing

We selected direct lithium extraction (DLE), in particular the challenging polishing step of separating ultra-high purity lithium from magnesium, as the forcing function. The extreme similarity in ionic radii between Li^+ and Mg^{2+} demands a membrane with angstrom-level pore precision and absolute defect intolerance. By engineering protein assemblies that integrate these selective channels and remain stable under harsh ionic conditions, we aim to validate a manufacturing platform capable of creating truly "perfect" 2D materials for any molecular separation need.

3D Challenge — Monodisperse nanocrystal templating in anisotropic composites (3D)

The ultimate frontier for a Universal Fabricator is the construction of three-dimensional, functional bulk solids. While synthetic chemistry excels at producing inorganic powders, it often struggles with the next step: organising those powders into cohesive, high-performance macroscopic devices without destroying their nanoscale properties. Biology, however, seamlessly integrates nucleation, growth, and assembly (as seen in the synthesis of bone, nacre, and magnetosomes) to create composites where the organic matrix dictates the inorganic structure.

We view protein-directed biomineralisation as a general-purpose engine for 3D manufacturing. By utilising proteins as identical, molecularly-precise reactors, we can achieve monodisperse nanocrystals with exact control over size, shape, and crystalline phase. Furthermore, these protein-coated crystals can be organised into complex 3D composites. The protein matrix can serve as a permanent structural binder (creating tough, flexible composites) or as a sacrificial scaffold, to be removed during post-processing to leave behind dense, nanostructured ceramics or metals. This capability unlocks a vast array of downstream applications, from high-efficiency catalytic converters and optical metamaterials to ultra-hard structural coatings and caloric refrigerants.

Example Use case – Rare-earth free magnets

To validate this platform technology, we have selected a challenge that is notoriously resistant to traditional metallurgical and ceramic processing: high-performance rare-earth free permanent magnets. The transition away from critical supply-chain materials like neodymium and dysprosium requires us to unlock the magnetic potential of abundant elements (such as iron or cobalt) through precise nanostructuring. Theoretical candidates for these magnets (*e.g.*, cobalt ferrites and iron nitrides) exist, but they lose their magnetic properties if grains grow too large or are randomly oriented. This application demands simultaneous mastery of three conflicting constraints:

+ Phase & Size Control: synthesising single-domain nanocrystals to maximise coercivity.
+ Protection: preventing oxidation and sintering during consolidation.
+ Anisotropy: aligning these crystals physically and magnetically across the macro-scale.

We believe that by exploiting magnetically-directed self-assembly, where the protein shield allows nanocrystals to be fluidly aligned by an external field before being locked into position, we may be able to bypass the thermodynamic limits of traditional sintering. Solving this challenge would not only secure a critical component for the green energy transition but would prove that protein-based manufacturing can dictate the physics of bulk matter.

The role of metrology, software development and biomanufacturing

During this phase we also expect to fund smaller shared and open ecosystem service technologies, including for software tools aimed at protein engineering and assembly. We are not aiming to directly solve or fund scaling engineered protein production (biomanufacturing), but we expect to fund biomanufacturing efforts as are needed to produce sufficient engineered protein yields and iteration speeds to achieve the programme objectives and target demonstrations.

On metrology, creators will have to routinely characterise both proteinaceous and inorganic building blocks, their dynamic directed self-assembly processes and the resulting complex, multi-scale structures they form. We expect a 2-tiered characterisation approach:

1. Rapid iterative in-house: standard equipment & automated proxy measurements
2. External high-resolution and bespoke application benchmarking: once the key structural and functional assays become clear for each platform technology and application, we plan to work with advanced (industrial and/or academic) metrology teams to ensure that decisions about development directions are made based on as high quality and complete data as possible.

We expect that a key enabler towards protein-based materials manufacturing will be to incorporate this characterisation data into hybrid mechanistic- and data-driven AI/ML models that can accurately predict how the engineered proteins will fold, assemble and

function under different process conditions and how the resulting templated structures will translate to macroscopic properties. During the programme we will actively look to support relevant fully open data ontology, database and predictive modelling projects, and help form a joint ecosystem that can assist our creators with structuring and utilising their own data.

Phase 2 - Scaling to specific application demands

We expect Phase 1 to conclude with teams having successfully developed general-purpose protein-programmed manufacturing technologies, and have demonstrated strong progress towards the outlined industrial application.

For Phase 2 of the programme, we expect interested teams to partner with industry, to further develop application-specific functionality and robustness of a particular material, as well as to jointly start work towards a scalable and cost-competitive assembly process.

Who we expect to fund

The team descriptions here are intended to guide proposals towards achieving the goals of the programme. ARIA welcomes proposals with alternative team compositions, if we are convinced they maximise the likelihood of achieving our programme objectives.

We're looking for creators that are highly iterative and adaptable. This programme is designed to expand the Overton window in this domain: to move from biology into first-principles manufacturing approaches. It is difficult to pre-empt specific project challenges and application pathways as teams progress. As such, adaptability of application and metric specificities are deliberate, core programme features. Accordingly, adaptability is a key trait we are looking for in the people funded by this programme. ARIA's principle is people first, then projects – we are looking for scientists and engineers who are excited to become universal fabricators! Teams must be willing to adapt/pivot rather than fixate on a specific application.

We anticipate funding a variety of Creator team structures. Programme success will require both deep expert knowledge and systematic integration of know-how from a number of fields that could span: material science, condensed and solid state physics, biology and bioinformatics, chemistry, process engineering, computer science, and more. Because of this we expect teams to be deeply cross-functional across these fields, likely via collaboration (or new hiring). This means startups, frontier research organisations and contractors, academic research groups & new spinouts, independent individuals, and integrated teams of the above, to tackle the various challenges from multiple angles, and to plant the seeds for a lasting collaborative ecosystem in materials process discovery and development.

ENGAGE

Our next step is to launch a funding opportunity derived or adapted from this programme thesis. Click here to register your interest, or to provide feedback that can help improve this programme thesis.

Success in the programme requires multidisciplinary teams. For groups or individuals interested in joining or building a team, you can register your capabilities and missing expertise to ARIA's teaming tool here, allowing us to support matching with other registered teams.

APPENDIX

Appendix 1: Protein Technology Tree

Building upon an incredible body of knowledge in protein engineering, starting from intrinsic mechanical, biochemical and electrical properties leading to specific binding kinetics to ions, molecules, surfaces and other proteins, our internal material science team has put together an initial roadmap of the potential ability for proteins organise matter in novel ways, to achieve unprecedented material structures or realise alternative, cheaper, cleaner and more robust manufacturing processes towards existing difficult materials. Our **protein-enabled materials technology tree** below (**Fig. A1**) is a starting point that we expect to develop further during the programme, with input from internal and external experts, incorporating the learnings from the funded creator teams, and inviting feedback from the broader academic and industrial research and translational communities.

The main aim of this programme is to demonstrate protein capabilities beyond traditional and actively researched fields, such as biopharmaceutical, biomedical, agricultural and enzymatic use cases, therefore some capabilities and numerous downstream applications have been excluded from this figure. Furthermore, the nodes and connections currently included have been heavily biased by our team's focus on elucidating the transformative potential of protein-based assembly technologies, and the sufficiency of the application fields to serve as truly galvanising examples that would propel protein-enabled manufacturing forward, and help bring about a 'Protein Age'.

Figure A1: Protein-enabled materials technology tree

LEGEND

PROTEIN-ENABLED CAPABILITIES

INORGANIC INPUTS

RESULTING MATERIAL CLASS

EXAMPLE APPLICATION FIELD

Intrinsic Protein Properties & Dynamics

Protein Atom / Ion / Molecule Interactions

Protein-Protein Interactions

Protein-Surface Binding

Protein Folding / Unfolding / Allosteric Switching Dynamics

Carbon / Metal

Engineered Ferroelectric and Phononic Properties

Protein Enzymatic / Catalytic Activity

Silicon, Semiconductors

Multi-protein 2D Sheet formation

Supramolecular Complexes

Multi-protein 3D Lattice Coordination

Liquid-liquid phase separation

Calcium Carbonate, Calcium Phosphate

Silicon Dioxide

Multi-protein 1D Filament Formation

Stimuli-responsive Actuation

Selective Transport Dynamics

Anisotropic Thermal / Electric Conductivity

Uniform Porosity Proteinaceous Membranes

Protein-Masked Lithography

Catalytic Complexes

Protein Cage Formation

Active Epitaxial Regulation

Polymer-induced Liquid Precursors

Sol-gel Polycondensation

Hierarchical Channel-forming

Multi-seed Coordinated Crystal Growth

Controlled Growing-edge Crystal Growth

Meso-crystalline Biomineralisation

Defect-free Protein-Metal Frameworks

Monodisperse Nanocrystal Templating

Anisotropic Nanocrystalline Composite Solids

Porous 3D Materials

Silica Biomineralisation

Fibre Biomineralisation

Environmental Sensing & Actuation Materials

Caloric Molecules

Caloric Nanoparticles

Magnetic Atoms

Single-domain Magnetic Nanoparticles

Molecularly Selective, High-flow Filtration

High Surface Area Catalytic Crystals

High Surface Area Flow-through Solid-state Catalysts

Large Single Crystals

High-toughness composites

Structured Amorphous Glass

High Tensile Strength Fibers

Semiconductor Nanowires

Photonic/Phononic Waveguides

Rare-Earth-Free Magnets

Soft Robotics

Phase-Change Materials

Responsive Drug Dispensing

Multi-caloric Materials

CO2 capture for flue gases

Municipal Waste Plant Filtration

Direct Lithium Extraction

Non-Aqueous Solvent Membranes (eg for iono-calorics)

Photovoltaic Solar Panels

Advanced Chips

PFAS Filtration and degradation

Electric Vehicles and Motors

Generators (eg wind turbines)

Hydrogen Electrolysis or Fuel Cells

Electrochemical CO2 reduction

Optical Crystals and Metamaterials

Advanced Electronics (eg Diamond Wafers, via heteroepitaxy)

Aerospace Parts

Wind Turbine Blades

Hydrogen Tanks

Interposers

Hollow-core Optical Fibers

Flexible, Self-powering Electronics

Advanced Aerospace Insulators

Appendix 2: Selected Bibliography

General

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1D Challenge – Fiber biomineralisation

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