BRIEFING 05 · DARPA

Atomically precise: DARPA APM and the road from atoms to products

A deep dive into atomically precise manufacturing: from Feynman's 1959 vision and DARPA's 2015 Atoms to Product program to the 2026 Atomically Precise Molecules program and its programmable precision polymers.

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A deep dive into atomically precise manufacturing: from Feynman's 1959 vision and DARPA's 2015 Atoms to Product program to the 2026 Atomically Precise Molecules program and its programmable precision polymers.

1959	2015	36 months	Apr 2027
Feynman: 'Plenty of Room at the Bottom'	Atoms to Product: 10 performers	APM program, two phases	assumed APM start

Key takeaways

- Atomically precise manufacturing means building materials and devices where the position of every atom or monomer is controlled.
- DARPA's Atoms to Product (A2P, 2015) tried to carry nanoscale properties up to millimeter-scale products.
- DARPA's Atomically Precise Molecules (APM, 2026) targets programmable precision polymers, controlling sequence, orientation and composition, with nonlinear optical materials as a first target.
- Biology already does this: proteins and DNA are sequence-defined polymers; APM aims to bring that control to synthetic chemistry at scale.
- Scale-up and cost are the main challenges; AI-driven design plus automated chemistry is the likely path.

Background

In 1959 Richard Feynman's lecture "There's Plenty of Room at the Bottom" imagined arranging atoms one by one. Decades later, scanning tunneling microscopes made it literal: IBM researchers spelled their company's name with 35 xenon atoms in 1989. In 1986 Eric Drexler's *Engines of Creation* popularized molecular manufacturing. Since then, chemistry has moved toward precision from the other direction: DNA origami, sequence-defined polymers and engineered proteins.

Atoms to Product (2015)

DARPA's A2P program aimed to develop ways to assemble atomic-scale pieces into larger products while keeping their nanoscale properties, closing the "assembly gap" in two steps: from atoms to microns, then microns to millimeters [1][2]. DARPA selected 10 performers in December 2015, including work on top-down, atomically precise fabrication [2]. The lesson from A2P was that precision is possible at small scales but expensive and slow to scale up.

APM: Atomically Precise Molecules (2026)

- **Goal:** synthesis approaches that deliver **programmable precision polymers**, controlling the sequence, orientation and composition of molecules [3].

- **First target:** nonlinear optical materials, materials whose optical behavior changes with light intensity and that matter for lasers, sensing and optical communication [4].
- **Structure:** a two-phase, 36-month effort: Phase 1 develops new chemistries, Phase 2 applies them to materials and devices, with demonstration milestones through the program [3][4].
- **Logistics:** solicitation DARPA-PS-26-141 published 25 September 2026, proposers day 30 September 2026, abstracts due 27 October 2026; program manager John M. Hoffman in DARPA's Multi X Office [3] [4].
- **Open to biology:** DARPA's Q&A indicates biological or biochemical approaches are welcome if they meet the goals and metrics [4].

How precision polymers work

Most plastics are made by chain reactions that join monomers randomly, giving chains of varying length and order. **Sequence-defined polymers** place each monomer in a chosen order, the way a ribosome builds a protein. Approaches include iterative step-by-step synthesis on solid supports, templated synthesis (using DNA or another template), and engineered enzymes that accept non-natural building blocks. Precise sequence means precise properties: how the chain folds, which molecules it binds, how it conducts light or charge.

How it could change life

- **Water and environment:** membranes that filter specific pollutants or extract lithium from brine.
- **Energy:** catalysts that waste less energy, better battery electrolytes and separators.
- **Medicine:** drug-delivery materials that release exactly where and when needed.
- **Optics and communication:** nonlinear optical materials for faster, lower-power photonic devices, linking APM to photonic computing.

Future scenarios

2028
New chemistries that place monomers in defined sequences at useful quantities.

2030
First devices using precision polymers: optical materials, sensors, membranes.

2035
AI-designed sequences made by automated chemistry, "compile a material".

2040+
Programmable materials manufactured at industrial scale for selected high-value uses.

- **Optimistic:** precision polymers become a design platform like software, with libraries of reusable sequences.
- **Base case:** high-value niches (optics, medical, separation) adopt them first.
- **Pessimistic:** cost and scale keep precision chemistry in the lab.

Effects and risks

- **Scale:** grams in the lab versus tons in industry.
- **Cost:** step-by-step synthesis is slow and expensive.
- **Safety:** new materials need toxicology and end-of-life planning.
- **Dual use:** precise chemistry can enable both protective and harmful materials; oversight matters.

What to watch

- APM awards and first-phase chemistry results.
- Throughput (monomers per hour) and yield of precise synthesis.
- AI models that predict polymer properties from sequence.
- Integration of APM optical materials into photonic devices.

My take

APM is a sign that materials science is becoming programmable. The pattern I expect mirrors software delivery: a specification (the sequence), an automated build (synthesis), and automated tests (characterization), with AI in the loop. The bottleneck will be throughput and observability of the "build", which is exactly the kind of pipeline problem engineers know how to attack.

Key players & programs

DARPA APM (2026)	Programmable precision polymers; first target nonlinear optical materials [3] [4]
DARPA A2P (2015)	Assembling nanoscale pieces into millimeter-scale products; 10 performers [1][2]
Zyvex	A2P performer working on top-down atomically precise fabrication [2]

Frequently asked questions

What is DARPA APM?
Atomically Precise Molecules, a 2026 DARPA program to develop synthesis methods for programmable precision polymers, controlling sequence, orientation and composition, with nonlinear optical materials as a first target.

What was DARPA Atoms to Product?
A 2015 DARPA program to assemble atomic-scale pieces into millimeter-scale products while keeping nanoscale properties. It selected 10 performers in December 2015.

What are precision polymers?
Polymers where each monomer is placed in a defined order, like a protein, rather than joined randomly as in most plastics.

Why does atomic precision matter?
Precise structure gives precise properties, enabling better membranes, catalysts, optical materials and drug-delivery systems.

Glossary

Monomer: A small molecule that links with others to form a polymer.

Sequence-defined polymer: A polymer whose monomers are arranged in a specific, controlled order.

Nonlinear optical material: A material whose optical response depends on light intensity, used in lasers and optical signal processing.

Scanning tunneling microscope: An instrument that images and manipulates individual atoms on surfaces.

References

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