A Genesis Mission Roadmap for AI-Accelerated National Breakthroughs

Catalyzing a New Age of Scientific Discovery

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U.S. DEPARTMENT of ENERGY | Office of Science

SCAC Genesis Mission Subcommittee

Securing U.S. Leadership

AI is poised to become the defining enabling technology of our era.

If we can accelerate the rate at which humanity discovers, tests, validates, and deploys new knowledge, **we can solve some of society's most consequential challenges decades sooner and at far lower cost** than otherwise possible

Nations such as China are investing aggressively in AI infrastructure, talent, and industrial deployment; **maintaining a competitive edge requires sustained national capability**

Genesis: A **national strategy to ensure American leadership** by building the scientific AI infrastructure, computing capacity, data resources, and partnerships needed to accelerate discovery across disciplines

Empowering Scientists with AI

AI will not eliminate the need for experiments, facilities, or human creativity, yet in field after field, it can substantially shorten the path to breakthrough.

- Improves hypothesis generation
- Makes new discoveries possible, particularly in data-rich fields
- Enables real-time experimental control and supports semi-autonomous laboratories
- Compresses the timeline from basic discovery to deployment
- Reduces development cycles and lowers costs
- Increases the productivity of every federal and private research dollar invested

Meeting the AI Needs of the Nation

Realizing this vision demands a new national scientific infrastructure that integrates computing, data, experimentation, and AI into a unified ecosystem for discovery.

Needs

- A balanced ecosystem that combines hardware, advanced software, specialized computing architectures, AI-ready trusted data resources and management, and distributed capabilities
- Accessible to universities, national laboratories, startups, and industry

DOE's role

DOE possesses the capabilities to create the next generation of computational infrastructure and the experimental facilities needed for data generation and validation that will underpin American leadership in science and technology

Genesis Mission Platform

The power of advanced AI depends on high-quality data and specialized hardware.

American Science Cloud

Digital fabric linking DOE's computing and experimental facilities, allowing researchers to access AI-ready datasets and train models

Improved machines

Bigger, smarter, and more agile machines to support computational demands of training models and deploying AI at national scale

Infrastructure built for science

Full-stack innovation in algorithms, computing architectures, software, data curation (or management) and governance, and energy infrastructure

Digital twins

Replacing traditional design-build-test cycles with AI-driven digital twins

Science and Technology Challenges

These challenges can deliver transformative advances that demonstrate the tangible societal benefits of AI-enabled science.

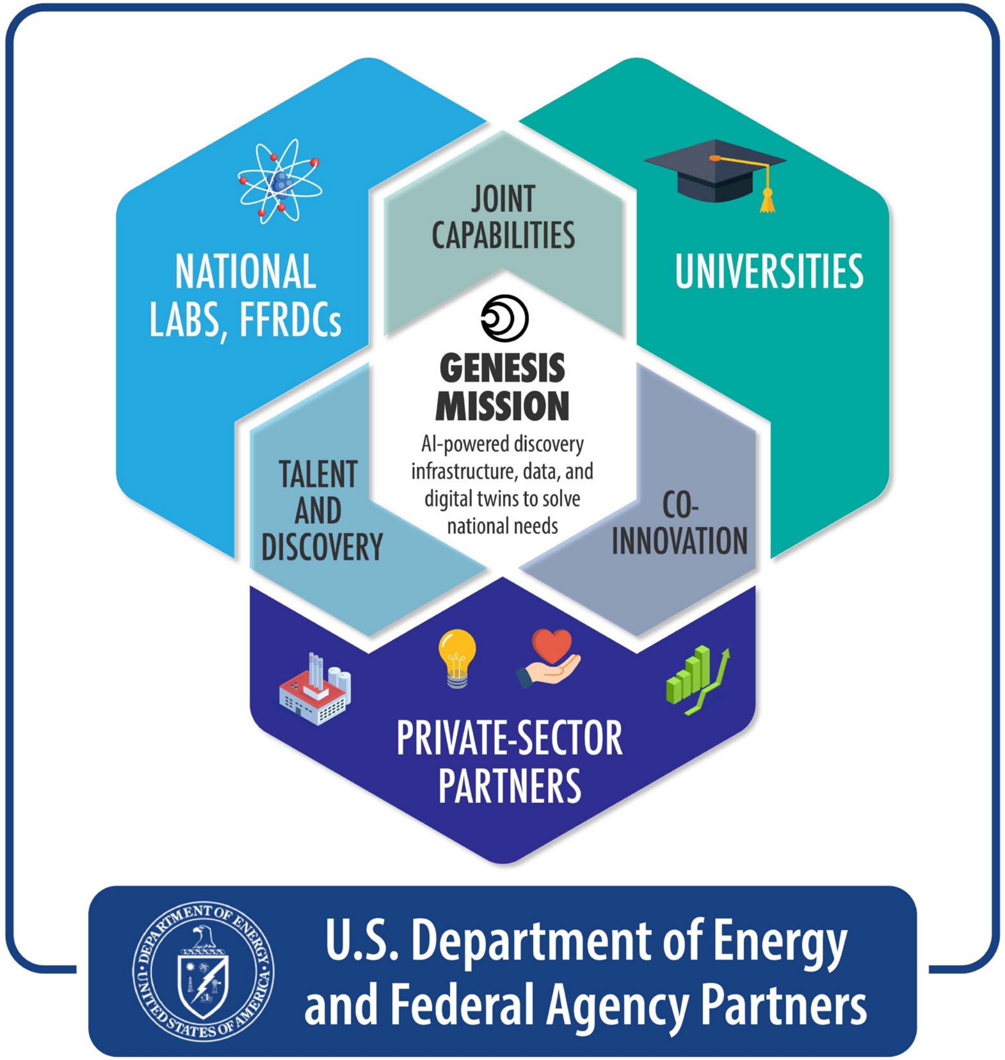
The **DOE Office of Science** is well positioned to coordinate multidisciplinary teams from various institutions to tackle high-impact **science and technology challenges** as part of the Genesis Mission

Ambitious efforts in areas such as fusion energy, resilient energy systems, advanced materials, precision health, and national security

A Collaborative Ecosystem for AI-Enabled Science

The scale of this challenge makes clear that public investment alone is insufficient.

By leveraging the strengths of **national laboratories, universities, and the private sector**, the Genesis Mission will accelerate scientific breakthroughs and ensure American leadership and shared prosperity.



Building a Future with AI

The Genesis Mission offers an opportunity to demonstrate that convergent science can advance discovery and stewardship simultaneously.

Next-generation workforce

- Long-term leadership in AI-driven science and engineering ultimately depends on people
- K–12 STEM education, undergraduate programs and graduate fellowships, and postdoctoral and interdisciplinary research opportunities

AI for the public good

- Advancing technology requires meeting public expectations with transparency and accountability
- Progress must deliver science and technology breakthroughs that benefit the American people

DOE Genesis Targets

While many fields will be impacted by AI, three concrete examples illustrate how Genesis Mission efforts can advance science.

Magnet Sovereignty

Increase domestic permanent magnet capabilities, including the needed supply of critical minerals

Biology

Develop the ability to measure biology at scale, model it well enough to predict what a change will do, and manufacture it on demand

Fusion

Deliver the first U.S. fusion pilot plant—and ultimately commercial fusion energy—by 2035

Harnessing Biology at Digital Speed

A Campaign for AI-Enabled Biology

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Vision for a Biological Campaign

The biology campaign will do for "deploying biology" what sequencing did for reading it.

Goal

Develop the ability to measure biology at scale, model it well enough to predict what a change will do, and manufacture it on demand

Roadblock

Ability to sequence DNA outpaces ability to interpret meaning of genetic patterns

Solution

Build a continuous, closed-loop national AI-powered engine for biology with a single **Measure** → **Model** → **Manufacture** loop

Why Now? Why DOE?

The first nation to harness AI to interpret and design biological functions at digital speed will set a new global paradigm.

Global competitors are moving aggressively to capture the bioeconomy

The global bioeconomy could grow to $30 trillion by 2050. The U.S. can lift its share to a third—or lose ground without investment

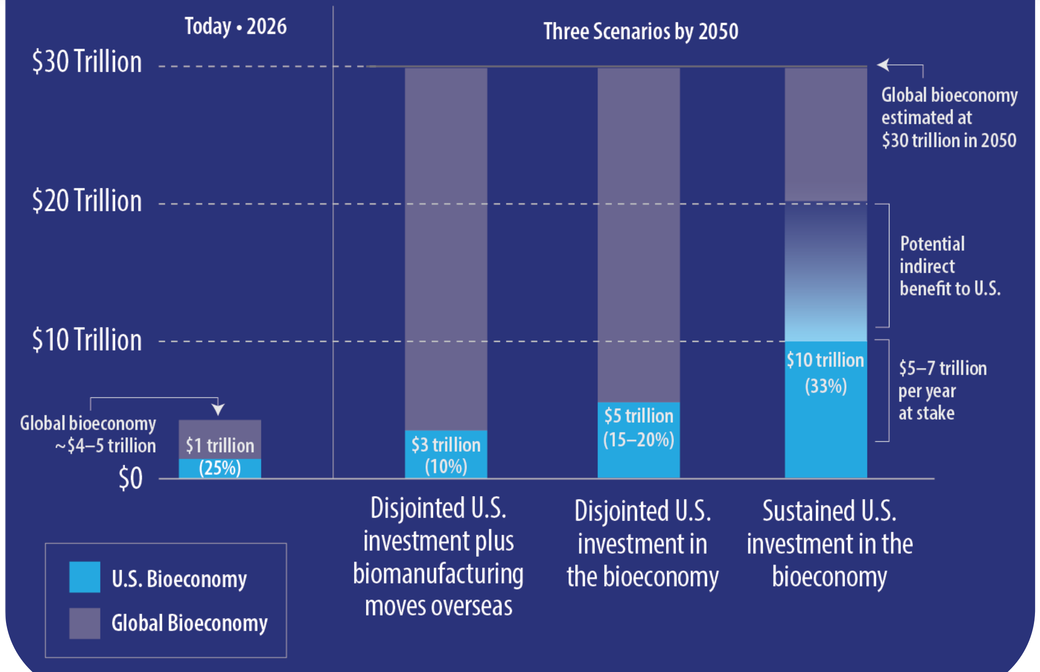
DOE, its 17 national laboratories, and the Genesis Mission are uniquely positioned to lead an AI-enabled biology campaign

National Return

10x
Larger U.S. Bioeconomy
$1 trillion today to $10 trillion by 2040, as the global market grows from $4 trillion to $30 trillion

10x
Smarter and Faster
to solve a problem with biology, in cost and time

2x
Scientific Productivity
the Genesis Mission's goal for the nation, within a decade



Sectors of National Impact

The biology campaign's new abilities to measure, model, and manufacture biology at scale do more than improve vital economic sectors; they redefine what is possible.

1. Biomanufacturing

A secure, domestic supply of advanced therapeutics, refined chemicals, and novel materials

2. Agriculture and Bioenergy

Increased bioenergy; resilient, nonfood feedstock crops tuned to biorefinery outputs; and resilient food crops

3. Human Health

DOE capabilities could resolve atomic structure and dynamics of disease-relevant proteins long considered undruggable

4. Biodefense

Can interweave biosecurity and public health monitoring into the nation's bioenergy and biomanufacturing ecosystem

Three Biology Campaign Pillars

The biology campaign establishes three interdependent capabilities that together compress the cycle between biological hypothesis and verified physical production to digital speed.

Pillar 1
AI-Enabled Measurement

- High-throughput systemic multiomics
- In-cell visual proteomics and structural dynamics

Pillar 2
AI-Enabled Modeling and Prediction

- Dynamic molecular mechanics modeling
- Whole-cell causal simulation

Pillar 3
AI-Enabled Manufacturing and Design

- Next generation biofoundries
- Predictive scale-up

AI-Enabled Measurement

This pillar envisions an overhaul of how biological data is acquired, shifting from destructive snapshots at a single instant to a live, multiomic view of systems left intact.

Challenge

Data-scarcity gap in genomics, proteomics, and metabolomics

Current measurement techniques destroy cells

AI Advantage

- Cut the time and cost of multiomic profiling
- Automatically connect to AI-ready data lakehouse
- Create routine data-ingestion pipeline to feed U.S. models

Image mechanics of life inside intact cells without chemical tags that distort or destroy them

AI-Enabled Biology: AlphaFold2

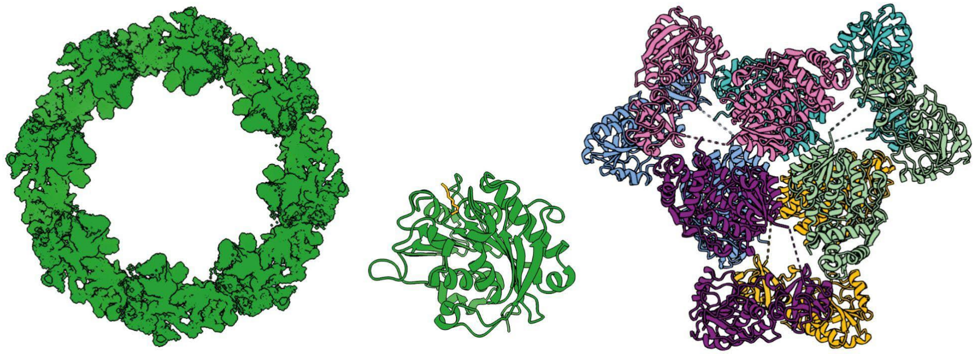
Tools like AlphaFold2 show AI can learn deep rules of molecular biology.

Won the 2024 Nobel Prize in Chemistry for predicting a protein's 3D structure from its sequence, cracking a 50-year grand challenge

Predicted structures for almost every protein known to science (200 million); trained on the Protein Data Bank, the global structure archive DOE helps support

Limits define the biology campaign's work; AlphaFold2 captures static structures, not how molecules move or behave once engineered

CASP, a blind community benchmark, made progress measurable and fundable; DOE can bring this accountability to biology's next frontier



AI-Enabled Modeling and Prediction

Modeling turns the data streams Pillar 1 produces into predictive, physically grounded simulators.

Challenge

Models capture static structures, not how biology moves and works

Whole-cell modeling bottleneck

AI Advantage

- Models capture dynamic cellular processes instead of static structures at a single timepoint
- Bring predictive power to RNA and mRNA in addition to proteins
- Blend AI and physics to predict behavior of engineered molecules and bypass extensive testing

- Bridge disparate modeling regimes into one multiscale virtual-cell causal simulator that acts as a self-correcting discovery engine
- Compress months of experimentation into hours of modeling

AI-Enabled Manufacturing and Design

Manufacturing closes the loop, converting designs into physical outputs and products whose results flow back to sharpen the next cycle.

Challenge

Scale-up of traditional laboratory strains has historically floundered

AI Advantage

- Develop a network of autonomous DBTL loops that produce robust industrial organisms
- Can design the metabolic pathway and the cell's resilience at the same time

- Pair multiomics data with bioreactor physics to predict how physical forces will affect cellular performance in industrial-scale vats
- Enables scaling of complex bioproducts on the first attempt

A Compounding National Advantage

The first nation to industrialize biology at digital speed will set the rules for this century's largest emerging economy.

The three pillars form a single self-reinforcing engine: measurement feeds models, models direct manufacturing, and manufacturing returns hard data that sharpens the next cycle.

By 2035, that engine can place the United States at the center of a predictive bioeconomy, designing crops, fuels, materials, medicines, and biomedical countermeasures *in silico* and building them on the first attempt.

AI-Accelerated Fusion Energy

Accelerating the Path to Fusion by Five Years

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Vision for AI-Accelerated Fusion Energy

Accelerate discovery, enable faster engineering, reduce technical risk, and forge a path to the first U.S. fusion pilot plant

Goal

Deliver the first U.S. fusion pilot plant and ultimately commercial fusion energy.

Roadblocks

R1: Fusion engineering is too slow, fragmented, and computationally intensive.
R2: Fusion science is nonlinear, multiscale, and multiprocess.

Solution

DOE accelerates fusion development 10 to 100x through ecosystem-wide AI orchestration—coordinating national data infrastructure, digital twins, advanced modeling, and experimental capabilities across institutional boundaries.

Why Now? Why DOE?

AI can compress decades of fusion engineering into years.

Fusion is at an inflection point.

Scientific breakthroughs and unprecedented private investment have created a unique opportunity to accelerate commercial fusion.

DOE is building the enabling infrastructure.

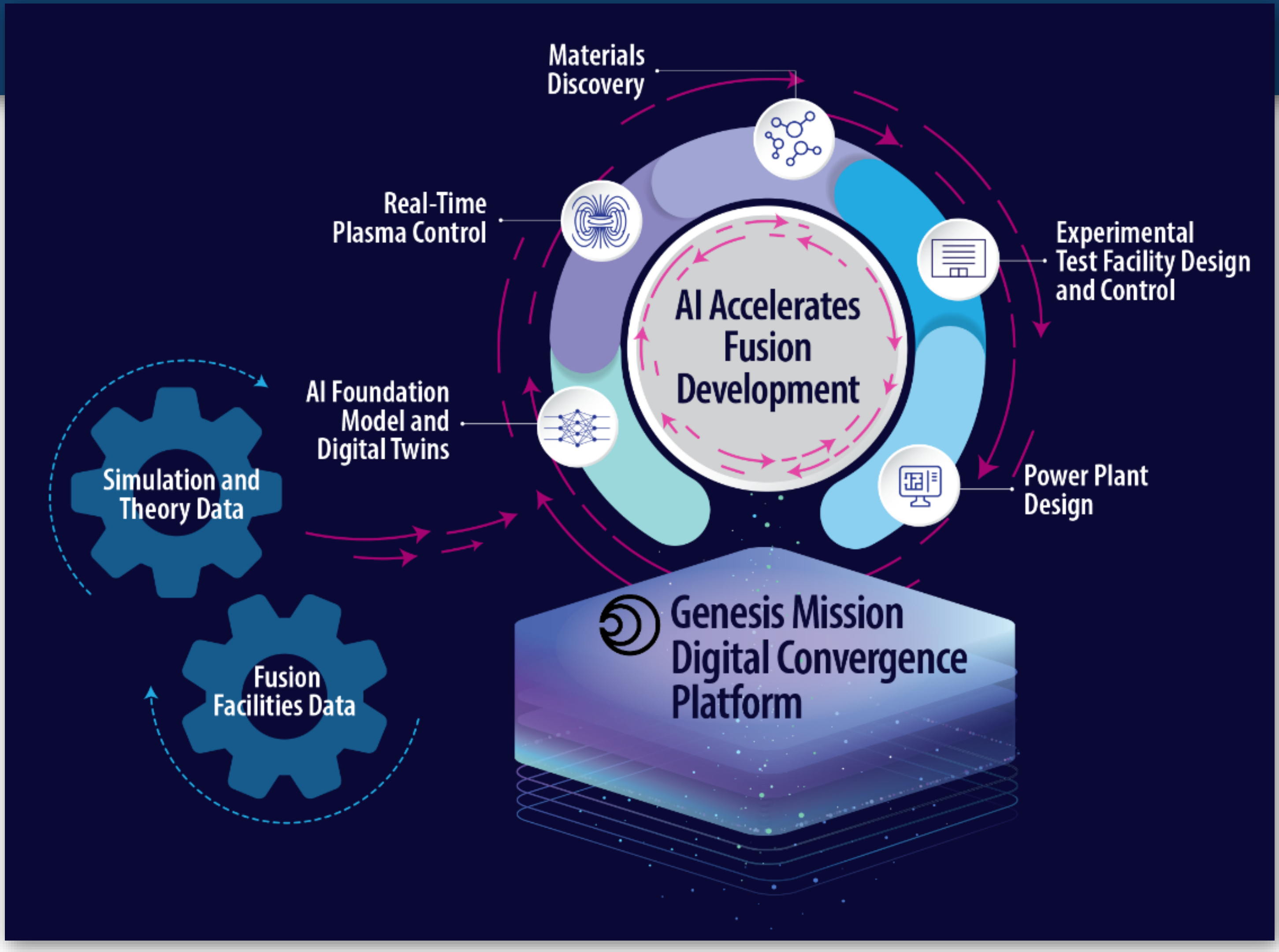
The Genesis Mission and DOE Fusion S&T Roadmap establish the national platform of AI, supercomputing, scientific data, and experimental capabilities needed to accelerate progress.

AI is the force multiplier.

DOE is integrating AI across the fusion lifecycle—from data and diagnostics to digital twins, engineering design, and manufacturing—to compress the development timescale.

The AI-Convergence Flywheel

Experimental data from 100+ fusion facilities, AI foundation models and digital twins, real-time plasma control, materials discovery, and power plant design, with the Genesis Mission DCP as the integrating national platform, work together in a dynamically configured, multi-institutional, multi-domain feedback loop to achieve AI–fusion convergence.



Measurement and Data

Harness decades of experimental data to power AI-driven discovery

Create a National Fusion Data Ecosystem

- Connect data from 100+ fusion facilities
- Standardize and make data interoperable
- Enable cross-facility learning
- Integrate with numerical simulations

Build AI Foundation Models

- Train on decades of experimental and simulation data
- Recover scientific value from legacy experiments
- Create digital representations of existing facilities

Enhance Diagnostics Using AI

- Reconstruct missing measurements
- Predict plasma evolution
- Reduce dependence on costly physical sensors

Bottom Line: Better data → Better models → Faster development

Modeling, Prediction, and Validation

Accelerate prediction, simulation, and control through AI-enabled modeling

Accelerate Simulation

- AI surrogate models reduce computation from hours to milliseconds
- Enables real-time engineering decisions
- Use ML to accelerate and improve subgrid physics

Autonomous Plasma Control

- Predict instabilities before they occur
- Prevent disruptions through AI-driven control systems

Universal Digital Twin

- High-fidelity virtual fusion reactor
- Integrates experimental data and physics models
- Supports design, optimization, and uncertainty quantification

Bottom line: AI transforms fusion simulation into an engineering tool for designing and operating pilot plants.

Making, Manufacturing, and Delivering

Advance the materials, manufacturing, and infrastructure required for fusion deployment

Materials Discovery

- Design radiation-tolerant materials faster
- Predict performance before fabrication
- Shorten development cycles

Fusion Fuel Cycle

- Advance tritium breeding
- Develop blanket technologies
- Validate fuel-cycle systems

Manufacturing and Supply Chains

- Scale critical fusion components
- Support public-private partnerships
- Build domestic manufacturing capability

Bottom Line: AI reduces engineering risk while accelerating commercialization.

Roadmap to 2035

Near-Term Goals

Pillar 1
Integrated fusion datasets; AI-ready diagnostics

Pillar 2
Real-time plasma control systems; first fusion foundation model

Pillar 3
Plasma-material interactions tests; AI-driven materials discovery pipeline

Mid-Term Goals

Pillar 1
Operational universal data-based simulator

Pillar 2
Operational universal digital twin

Pillar 3
Digital twin-guided reactor design

Long-Term Goals

Pillar 1
Validated AI-integrated diagnostic and simulation suites

Pillar 2
Intent-driven ecosystem-wide orchestration

Pillar 3
First U.S. fusion pilot plant and path to commercial fusion energy

2026 → 2027 → 2030 → 2035

Why Invest Now?

Sustained investment in AI-fusion convergence is needed to move from scientific achievement to commercial deployment and U.S. leadership in fusion energy.

Breakthrough ready.

Recent breakthroughs have demonstrated that commercial fusion is increasingly attainable.

National framework exists to tap AI advantage.

The Genesis Mission and DOE Fusion S&T Roadmap provide strategy and infrastructure, while new AI tools are transforming how fusion systems are measured, modeled, designed, and operated.

U.S. leadership in fusion is contested.

Fusion is a strategic technology—we need decisive action to maintain leadership.

A National Strategy for AI-Accelerated Fusion

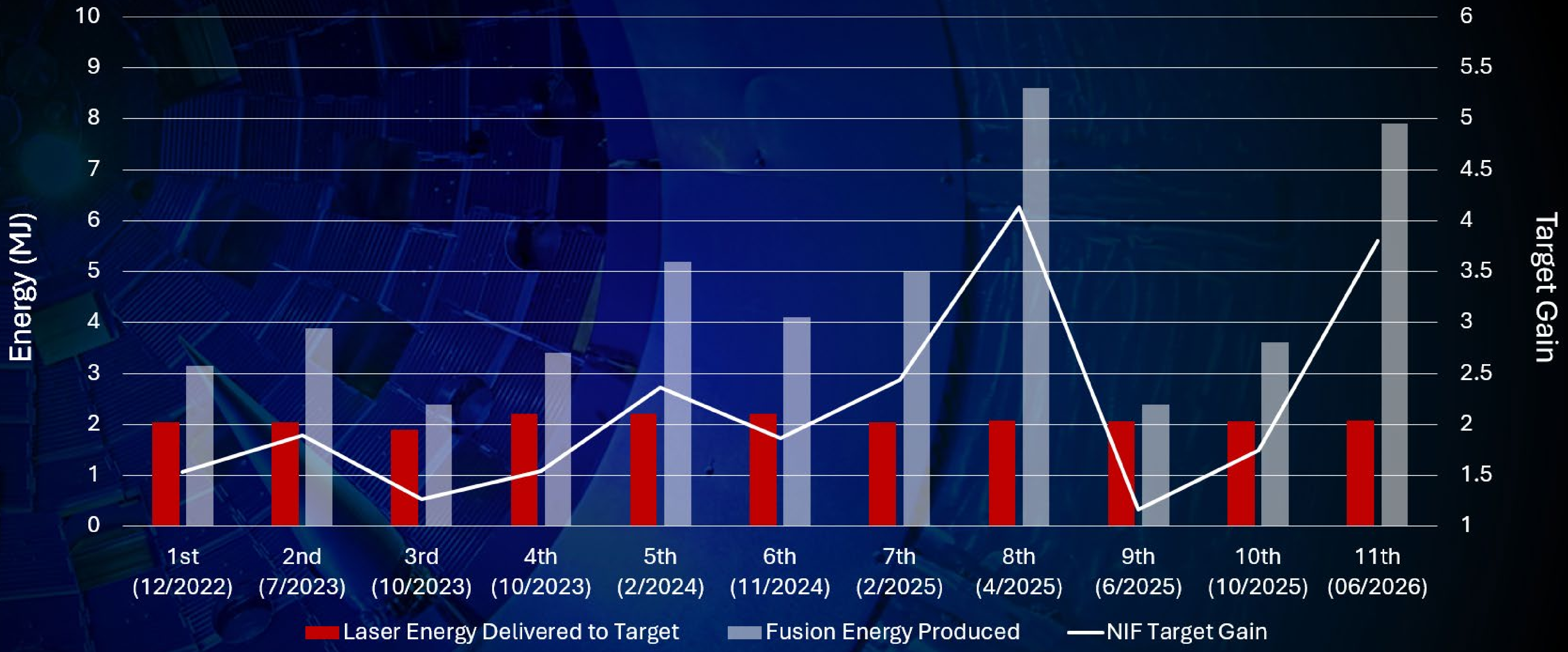
AI is not simply another tool for fusion research—it is the enabling capability that can transform how quickly fusion technologies are discovered, engineered, and deployed.

AI shortens the timeline from scientific discovery to engineering deployment.

DOE provides the national data, computing, research facilities, and partnerships that make AI-enabled fusion possible.

Scientific breakthroughs, private investment, and coordinated federal leadership have created an unprecedented opportunity to achieve a U.S. fusion pilot plant by 2035.

11 Ignition Experiments



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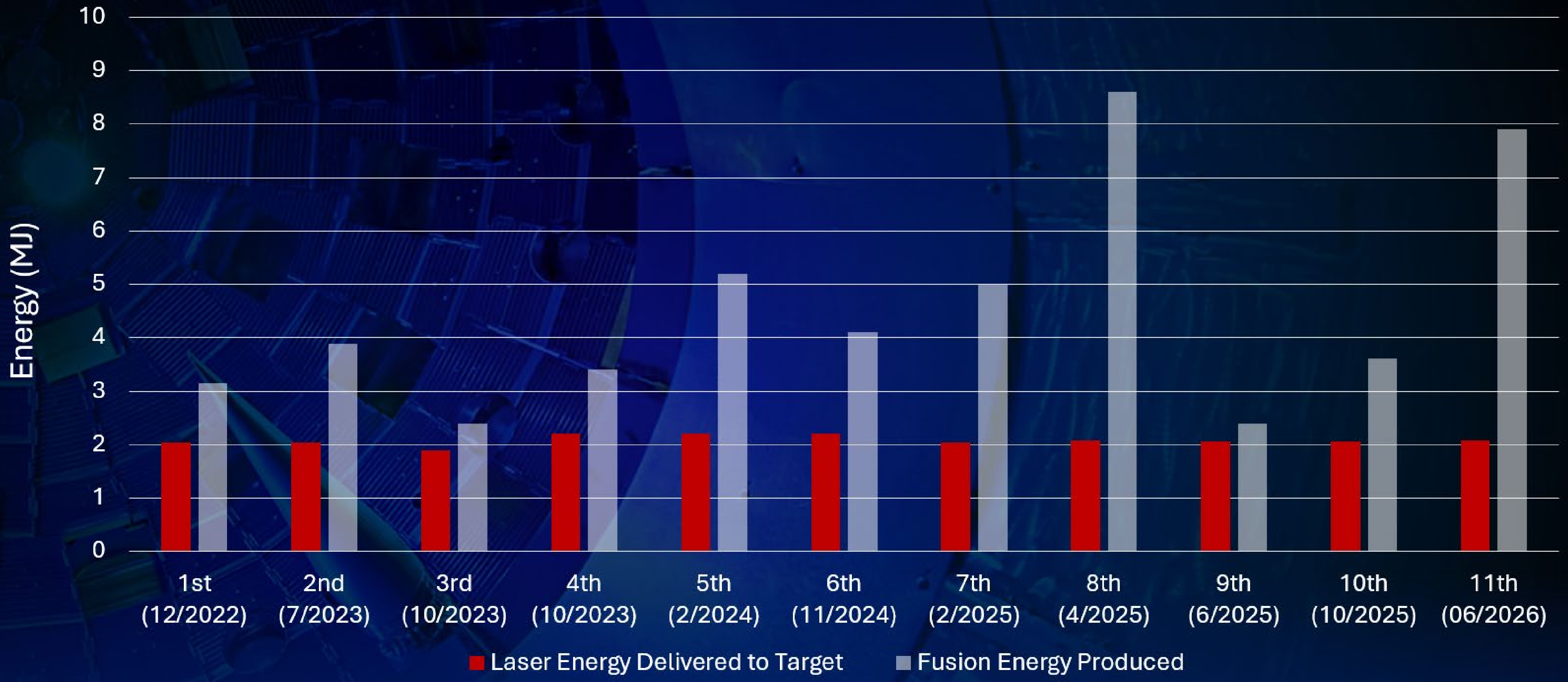

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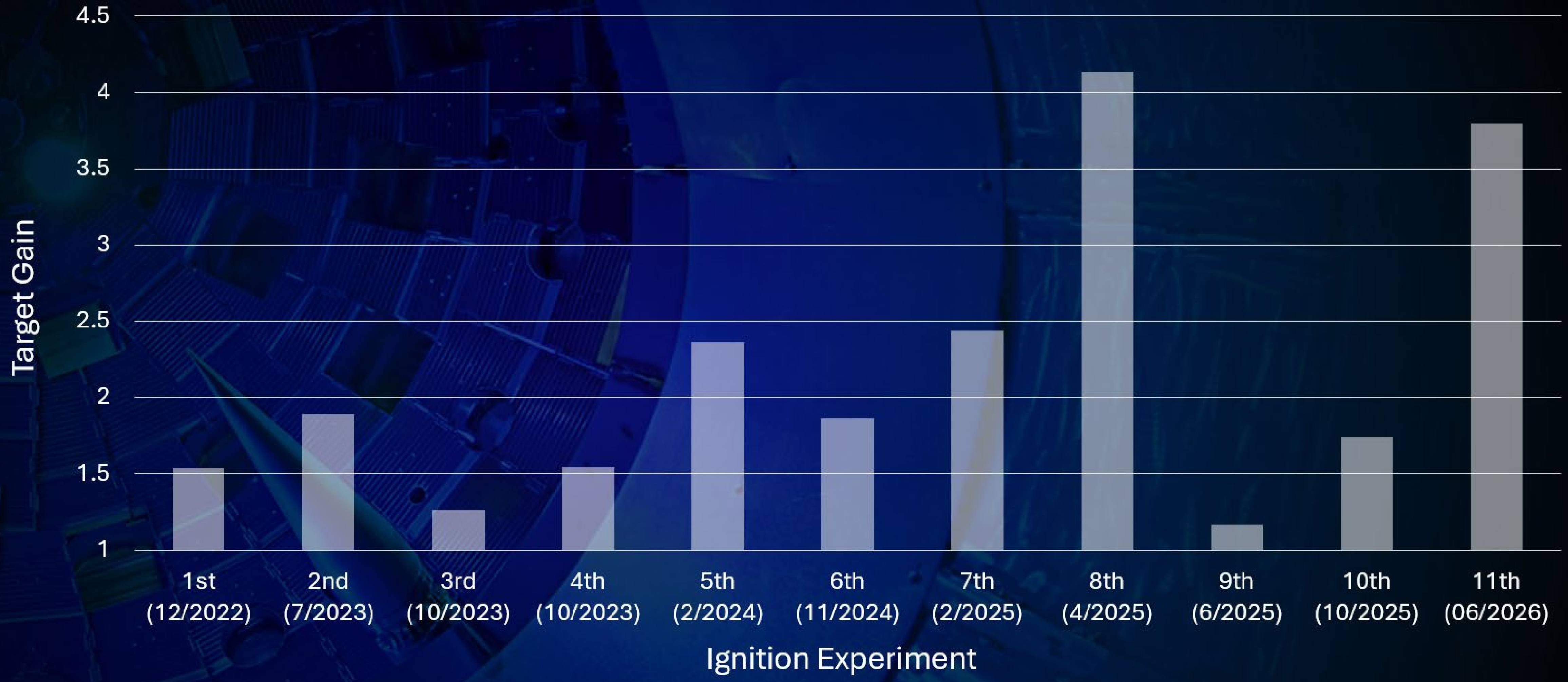

Magnet Sovereignty

A Five-Year AI Mission to Rebuild
U.S. Permanent-Magnet Capability

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Why This Matters

Magnet sovereignty means securing a domestic supply of critical magnetic materials and manufacturing capabilities.

Permanent magnets are essential to U.S. defense, grid security, and manufacturing.

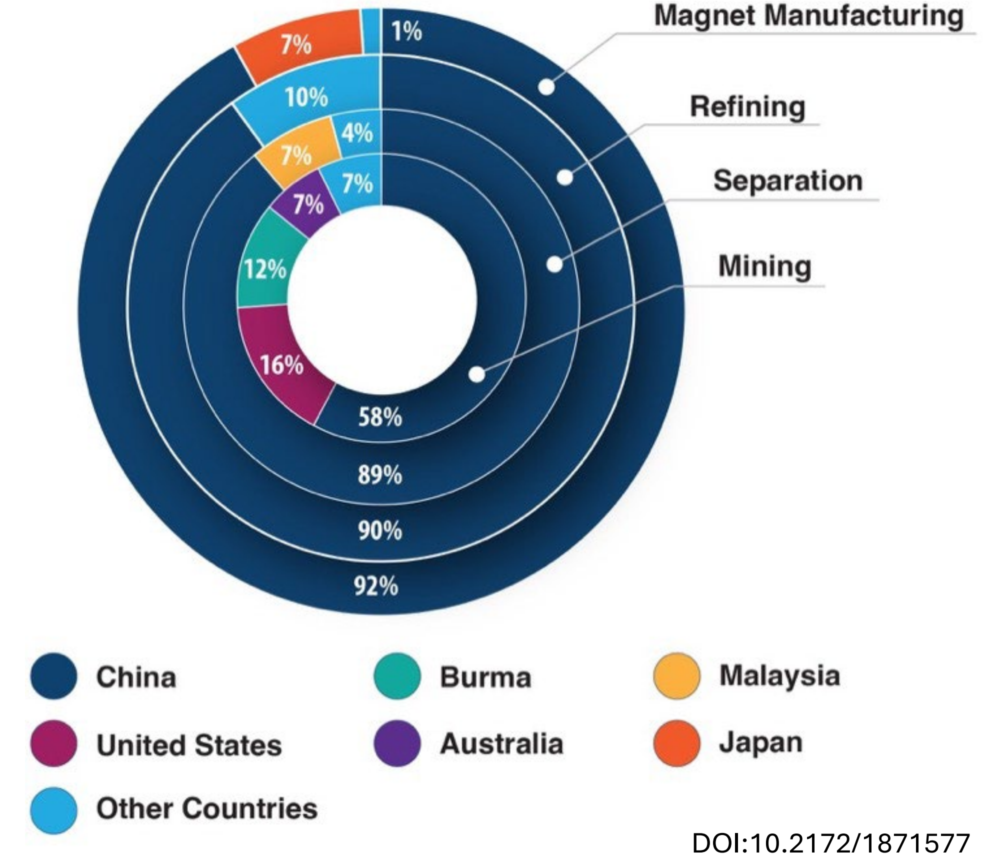
NdFeB magnets are in nearly every cell phone, F-35 fighter jet, military drone, and hybrid vehicle.

Four rare earth elements (REEs) power most commercial magnets and have no ready substitutes.

The United States relies on China for every step in the supply chain.

Concentration of Supply Chain Stages for Sintered NdFeB* Magnets

*Neodymium-Iron-Boron



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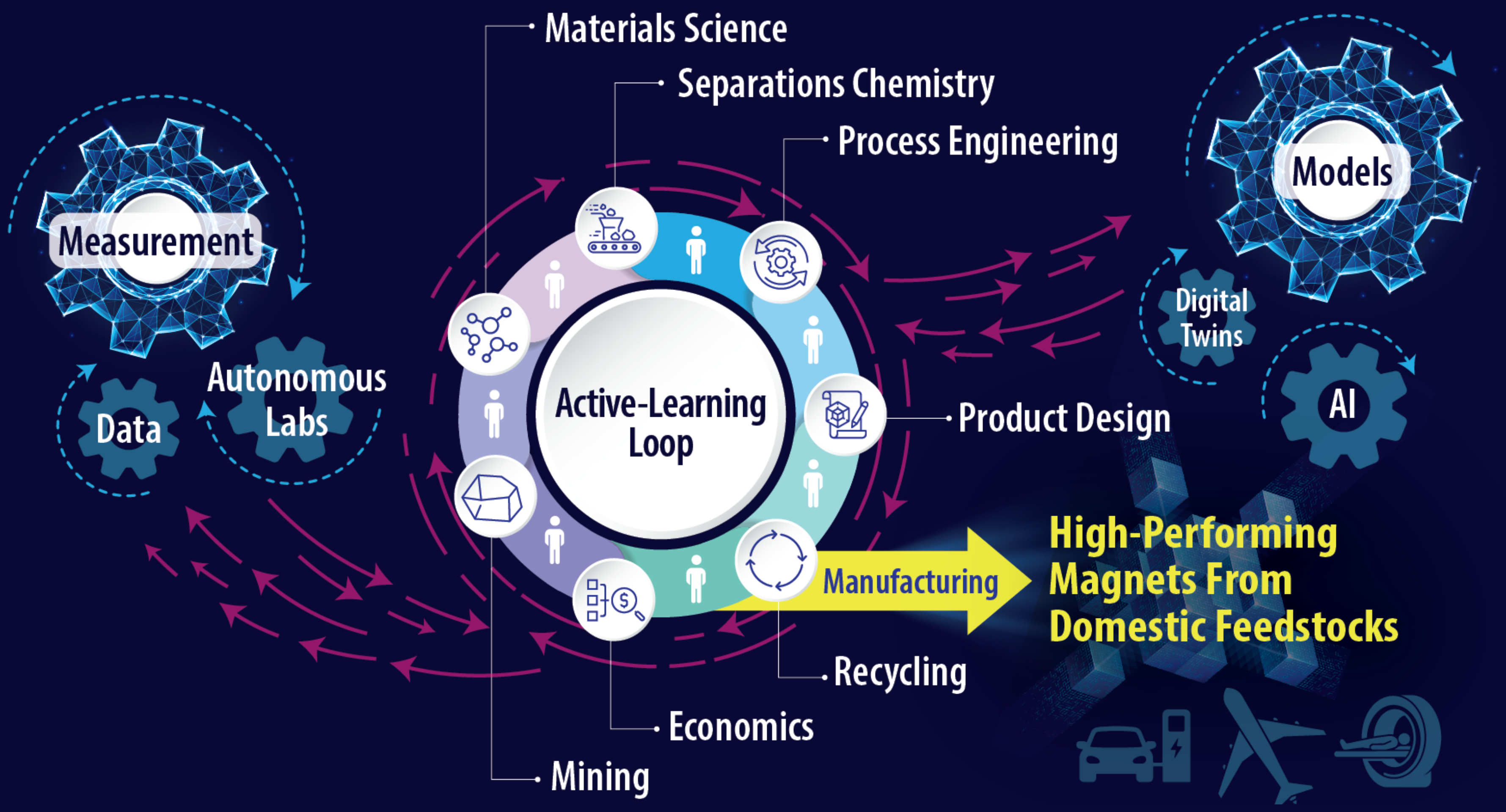
Leveraging AI to integrate siloed disciplines, data, and models

AI tools outpace traditional experiments for faster and smarter discovery.



How AI Benefits Magnet Sovereignty

A single learning system would empower the United States to repeatedly discover, make, qualify, recover, and improve magnets.

Shorter Timeline

Connecting across disciplines and manufacturing stages in one feedback loop is crucial to shortening the timeline for a domestic permanent magnet supply from decades to years.

Data-First Decisions

Active learning can evaluate which materials perform best **and** which can be made from domestic feedstocks at scale and at an acceptable cost.

Why DOE

High-performing magnets are central to U.S. energy security—they are essential to planes, vehicles, medical equipment, and more.

DOE's user facilities provide ground truth data to verify models and capture the atomic-scale interactions underpinning magnet performance.

DOE's deep expertise, world-leading computing capabilities, demonstrated ability to connect various disciplines and sectors, and ability to scale materials discoveries create a uniquely resourceful research infrastructure.

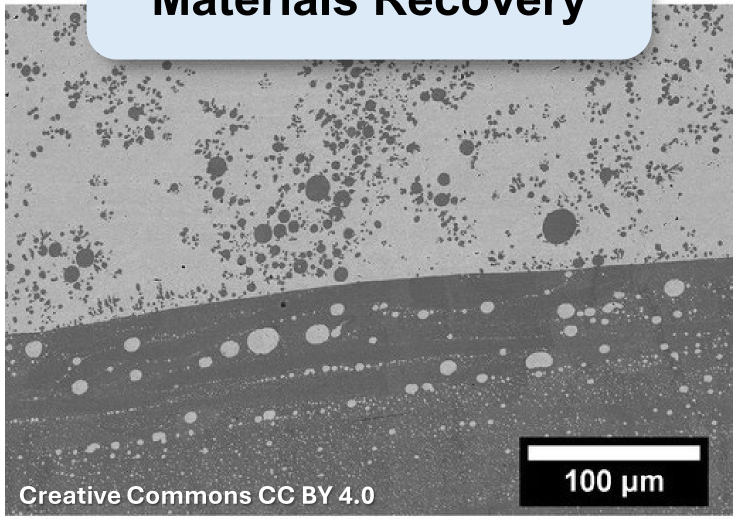
AI Pillars for Magnet Sovereignty

Goal: *Identify, synthesize, and pilot high-performance permanent magnet compositions co-designed for domestic manufacturability and end-of-life recyclability.*

AI-Accelerated Materials Discovery

AI-Driven Manufacturing

AI-Enabled Materials Recovery



AI-Accelerated Materials Discovery

Goal: *Discover viable magnet compositions that reduce supply chain constraints.*

Challenge	AI Advantage	Five-Year Outcome
• Minimize dysprosium and terbium requirements • Replace REEs with abundant elements • Engineer neodymium magnets to tolerate impurities • Purify REEs from domestic sources (e.g., ore, mine tailings, and recycled magnets)	• Fast approximation models make vast composition spaces tractable • Active learning ensures each experiment improves the model • Cost-penalized optimization embeds constraints into candidate ranking	*Demonstrate an impurity-tolerant NdFeB magnet from viable domestic-grade feedstock* *Pilot a minimal REE high-performance magnet*

AI-Driven Manufacturing

Goal: *AI-driven control that can adapt in real time and synthesize variable input data.*

Challenge	AI Advantage	Five-Year Outcome
Flag defects before they compound	• Digital twins for real-time quality control • Computer vision to detect defects at speed	*AI-based processing models and digital twins deployed for pilot strip casting, powder production, or sintering lines*
Ensure consistent output	• Cross-domain models deployed at processing sites	
Adapt to feedstock variability	• Sensor data in manufacturing lines integrated with machine learning to adjust process parameters at speed	

AI-Enabled Materials Recovery

Goal: *Recover and reintroduce rare earths into U.S. production at a scale that meaningfully reduces import dependence.*

Challenge	AI Advantage	Five-Year Outcome
Rapidly identify, sort, and assess heterogeneous end-of-life product streams at scale	• Computer vision identifies magnet-containing products • Predictive models assess REE composition • AI-guided disassembly maximizes recovery yield	*Validate a full collection-to-recovered-material pipeline, with recovered REE content feeding a domestic alloying or magnet-manufacturing line*
Advance separations chemistry to industrial scale	• Self-driving labs reach optimized protocols in a fraction of the conventional time	
Maximize recovery of critical element life cycle, from mining to finished material	• Digital twins can identify steps where meaningful utilization-efficiency gains are most likely	

What Success Looks Like

High-performance permanent magnets designed and manufactured at pilot scale using domestic feedstocks.

- **Faster, more impactful discovery:** 10-fold reduction in experiments; model confidence exceeding 80%; 75% autonomy for routine experimental cycles.
- **A transformative pipeline:** A collection-to-recovered-material recycling system, paired with qualification protocols trusted by end users.
- **AI-controlled manufacturing:** Reduced scrap and improved lot-to-lot consistency.
- **Broad scientific impact:** Shared data repositories and robust modeling infrastructure that keeps improving is the foundation for sustained magnet sovereignty and a reusable U.S. capability for other strategic materials challenges.

Investing in the US Future

Investments in AI and data infrastructure for magnetic technology serve as a foundation for broader U.S. AI-for-materials and AI-for-science research capabilities.