2025 MIT-ENGINE BIOECONOMY WORKSHOP REPORT

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EXECUTIVE SUMMARY

The United States stands at a critical juncture in the global bioeconomy, which is estimated to be worth upwards of 30 trillion US dollars. While American research institutions continue to generate world-class discoveries in agriculture, biotechnology, and biomanufacturing, the nation struggles to translate these breakthroughs into commercial products, domestic manufacturing capacity, and economic value. This gap threatens U.S. competitiveness, supply chain resilience, climate goals, and national security. On October 31, 2025, an MIT faculty working group on the bioeconomy convened at The Engine in Cambridge, Massachusetts, a diverse group of approximately 100 stakeholders including academic researchers, national laboratory scientists, government officials, regulatory experts, industry leaders, and venture investors, to diagnose the issues and brainstorm solutions. The workshop examined the bioeconomy through two complementary lenses: the *Innovation Organization Axis* (basic R&D, education and workforce, manufacturing and distribution, policy and regulation, and investment capital) and the *Impact Axis* (supply chain durability, climate and sustainability, economic revitalization, and national security).

***Central Finding*:** The current fragmented US innovation ecosystem, in which academia, government, and industry operate largely in separate spheres with misaligned incentives, is the primary barrier to bioeconomy growth. Incremental improvements within existing structures will not suffice to maintain US competitiveness in biotechnology.

***Core Recommendation*:** Re-invent the triple-helix innovation model to institutionally integrate academia, non-profit National Labs, government, and industry (with a focus on venture capital and startups) for focused biotechnological advancement. Such integration requires aligned incentives, shared physical and digital infrastructure that includes data and models, and seamless pathways from discovery through commercialization.

This report synthesizes workshop discussions, presents major findings across innovation organization and impact domains, diagnoses current system failures, and identifies principles for institutional integration.

1. CONTEXT AND STRATEGIC IMPERATIVE

1.1 Why the Bioeconomy Matters

The bioeconomy—encompassing the production of materials, chemicals, fuels, food, and therapeutics through engineered biological systems—represents a fundamental transformation in how we manufacture, heal, feed, and build[1]. Biology offers unique advantages:

- **Ambient-condition synthesis**: Living systems operate at room temperature and pressure, dramatically reducing energy inputs compared to petrochemical processes and their hazardous byproducts
- **Precision manufacturing**: Biological systems can produce complex molecules, materials, and therapeutics impossible to synthesize chemically, sometimes referred to as "bio-better"
- **Sustainability**: Renewable domestic feedstocks and closed-loop, circular production that can replace fossil-fuel dependency
- **Distributed production**: Biomanufacturing can operate at multiple scales, enabling regional resilience
- **Supply chain autonomy**: Domestic biomanufacturing reduces dependence on foreign sources for critical materials

The National Security Commission on Emerging Biotechnology (NSCEB)[2] has emphasized that biotechnology leadership is essential for U.S. economic competitiveness, supply chain autonomy, public health preparedness, and strategic advantage. Failure to build a robust domestic bioeconomy cedes this critical domain to competitors—particularly China, which has made massive, coordinated investments in biomanufacturing infrastructure, as well as implemented highly directed, cross-sector coordination across government labs, academic institutions, and industry to realize grand challenges in biotechnology.

1.2 The Critical Role of High-Throughput Data Generation and AI-Driven Engineering Biology

Modern bioeconomy advancement requires more than individual discoveries—it demands systematic, high-throughput approaches that generate the massive datasets necessary to make engineering biology rigorous, reproducible, and reliable. Engineering biology has historically progressed through low-throughput experimentation—individual researchers making single genetic modifications and characterizing results one at a time. This approach, while scientifically valid, cannot generate the comprehensive datasets required for predictive biological engineering. High-throughput genetic manipulation platforms—enabling hundreds to thousands of genetic variants to be created, tested, and characterized simultaneously—represent a transformational capability.

These platforms combine:

- **Automated DNA synthesis and assembly**: Rapid construction of genetic variants
- **Robotic organism cultivation**: Parallel growth and testing of engineered microbial strains, plants, and algae
- **High-throughput phenotyping**: Automated measurement of organism characteristics at scale

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[1] Hodgson, Maxon, and Alper. "The US bioeconomy: charting a course for a resilient and competitive future." *Industrial Biotechnology* 18.3 (2022): 115-136.

[2] *Charting the Future of Biotechnology: An action plan for American security and prosperity*, National Security Commission on Emerging Biotechnology, April 2025 (www.biotech.senate.gov/final-report).

- **Integrated data capture**: Real-time collection of genetic, metabolic, and performance data

The NSCEB report explicitly calls for treating biological data as a strategic resource and recommends establishing cloud laboratories—highly automated facilities providing state-of-the-art instrumentation for biotechnology data collection. As the Commission notes, "Robotics and automation are redefining what is possible for large-scale, high-throughput biotechnology research and data collection."

AI Models for Predictive Engineering:
High-throughput data generation alone is insufficient; the data must feed artificial intelligence models that can predict biological behavior and guide engineering decisions. Similar to how large language models trained on vast text corpora can generate coherent language, biological AI models trained on comprehensive genetic and phenotypic datasets can predict:

- How genetic modifications will affect organism performance (across plants, microbes, and algae)
- Which metabolic pathways will optimize production of target compounds
- How engineered organisms will respond to environmental variations
- What design principles enable robust, scalable bioprocesses in microbial fermentation, aquaculture, or agriculture

The NSCEB emphasizes that "biological data lie at the heart of emerging biotechnologies" and that "biological design tools and scientific language models are trained on troves of biological data from research efforts." Making engineering biology rigorous requires:

1. **Standardized, AI-Ready Data**: Data must be collected with consistent metadata, quality controls, and formats enabling machine learning. The NSCEB recommends NIST develop standards ensuring U.S. biological data is "AI-ready"—compatible with computational platforms, accessible via APIs, and including machine-readable metadata.
2. **Comprehensive Biological Databases**: Integration of genetic sequences, protein structures, metabolic pathway information, and organism performance data. The NSCEB proposes a "Web of Biological Data" (WOBD) serving as a single entry point for accessing standardized biological data from federal, academic, and industry sources.
3. **Design-Build-Test-Learn (DBTL) Cycles at Scale**: AI-guided iteration where models predict optimal designs, automation builds and tests those designs, results feedback to improve models, and the cycle repeats at high throughput. This systematic approach replaces intuition-based engineering with data-driven prediction.
4. **Cross-Organism Learning**: Models trained on microbial data informing biomanufacturing plant engineering; mammalian cell insights improving microbial platforms; plant genotype-phenotype mapping for optimal agricultural applications across food and compound production. This requires shared data repositories and standardized characterization methods across these biological systems, ideally at a national-scale.

1.3 Historical Innovation Models and Their Limitations

American innovation has traditionally followed several models, each with distinct strengths and weaknesses:

Linear Technology Transfer (Pre-1980): Government and universities conducted basic research; industry commercialized discoveries through licensing. This model assumed a clean handoff but often failed due to lack of industry engagement and the "valley of death" between lab and market.

Bayh-Dole Era (1980–2000s): The Bayh-Dole Act allowed universities to patent federally funded research, spurring technology licensing offices and university startups. While successful in some sectors (especially IT and therapeutics), it incentivized patenting over collaborative tool-building and created fragmentation as institutions competed rather than cooperated.

Industry-Led Translation (2000s–Present): Large corporations and venture capital increasingly drive applied research and commercialization. This model excels at incremental innovation and rapid market deployment but underinvests in long-timeline, high-risk foundational research. Short capital cycles (typically 3–7 years for VC returns) misalign with bioeconomy development timelines (often 10–20 years from discovery to scale).

Current Limitations:

- **Misaligned incentives**: Academics are rewarded for publications, not translation; investors demand quick returns; government programs operate in bureaucratic silos
- **Fragmented infrastructure**: World-class research facilities sit unused by startups; pilot-scale manufacturing is scarce; regulatory pathways are unclear
- **Capital inefficiency**: Sequential funding (government basic research → VC seed → Series A/B → scale-up) involves repeated due diligence, IP negotiations, and knowledge loss at each handoff
- **Workforce gaps**: Students train for academic careers or existing industry jobs, not emerging bioeconomy roles; mid-career transitions between sectors are difficult

1.4 Workshop Format

The workshop opened with welcoming remarks from Ben Downing, Chief Growth Officer of The Engine, followed by introductory presentations from co-organizers Mark Bathe (Professor of Biological Engineering, MIT) and Robin Scheffler (Associate Professor of Science, Technology, and Society, MIT). Bathe and Scheffler framed the workshop around two complementary analytical axes: the *Innovation Framework* needed to advance the bioeconomy (covering R&D, workforce education, manufacturing and distribution, policy and regulation, and investment capital) and the *Goals and Impacts* of the bioeconomy (including climate and sustainability, supply chain durability, economic revitalization, and national security).

Four biotechnology companies presented their missions to ground the subsequent discussions in concrete examples of innovation and commercialization challenges:

- **Foray Biosciences** is redefining plant agriculture by combining plant biology, AI, and biomanufacturing to provide lasting access to the plants and plant products the world needs.
- **Cellino Biotech** is developing cell therapy manufacturing platforms to make personalized medicine scalable and accessible.
- **Sunflower Therapeutics** is democratizing biomanufacturing by creating accessible, automated platforms that enable broader participation in biologics production.
- **Robigo** is reinventing pesticides for a healthier planet through biological alternatives that protect crops while reducing environmental and human health impacts.

Following roundtable discussions and group presentations, Will Rasky (Public Policy Advisor, The Engine) closed the workshop with a presentation on advocacy next steps. Rasky outlined potential pathways for translating workshop findings into policy action at federal, state, and local levels, emphasizing three key roles for government: funder (supporting research and economic development), enabler (setting policy that creates and shapes markets), and buyer (procurement of bioeconomy products and services). He proposed post-report action items including liaison coordination with partner institutions, development of issue briefs for policymakers, technical assistance to federal agencies, state-level engagement aligned with funding cycles, coalition building, and ongoing communication with stakeholders to advance the working group's recommendations.

1.5 Workshop Objectives

This workshop aimed to:

1. **Diagnose bottlenecks** across the innovation pipeline from basic discovery to commercial deployment
2. **Brainstorm institutional structures** that better align incentives and enable seamless collaboration
3. **Define partnership mechanisms** that preserve academic freedom, industry competitiveness, and public interest
4. **Identify a vision for the future** on realistic timelines
5. **Propose actionable recommendations** for federal/state policy, academic leadership, and industry

2. WORKSHOP STRUCTURE AND PARTICIPANTS

2.1 Roundtable Organization

Nine thematic roundtables examined, under The Chatham House Rule, complementary aspects of the bioeconomy along the axes of *innovation organization*[3] and *goals & impacts*:

Innovation Organization Axis:

- Table 1: Basic R&D (Moderators: Domitilla Del Vecchio, MIT; Jing-Ke Weng, Northeastern University)
- Table 2: Education & Workforce (Moderator: Natalie Kuldell, BioBuilder)
- Table 3: Manufacturing & Distribution (Moderators: Lily Fitzgerald, MassTech; Chris Love, MIT)
- Table 4: Policy & Regulation (Moderators: Sarah Glaven, Princeton University; Will Rasky, The Engine)
- Table 5: Investment Capital (Moderators: Kathryn Brink, BioMADE; Rachel Field, Engine Ventures)

Goals & Impact Axis:

- Table 6: Supply Chain Durability, Autonomy & Safety (Moderators: Ian Johnston, MIT Engine; Sheryl Greenberg, MIT Industrial Liaison Program)
- Table 7: Climate, Sustainability & Human Health (Moderators: Loretta Roberson, Marine Biological Laboratory; David Des Marais, MIT; Otto X. Cordero, MIT)
- Table 8: Industries, Economies & Peoples (Moderators: Ellan Spero, MIT; Ashley Beckwith, Foray Bio)
- Table 9: National Security (Moderators: Kerri Dugan, Applied Research Institute; David Markowitz, Strategic Technology & Research)

2.2 Participant Composition

Approximately 100 participants represented diverse perspectives essential for systemic change:

[3] Adapted from, Pioneering Progress: American Science, Technology, and Innovation Policy, William Boone Bonvillian, MIT Press (2024).

- **Academic researchers**: Faculty from MIT, Boston University, Northeastern University and other institutions leading basic research in synthetic biology, biomanufacturing, systems biology, and materials science
- **National laboratories**: Scientists from government research facilities developing foundational technologies and serving as translational bridges
- **Government agencies**: Representatives involved in R&D funding, regulatory oversight, and strategic planning
- **Industry R&D leaders**: Executives from biomanufacturing companies, materials startups, and established biotechnology firms
- **Venture investors**: Partners from biotech-focused VC firms and corporate venture arms
- **Policy experts**: Advisors working on biotechnology strategy, regulation modernization, and economic development
- **Workforce development professionals**: Educators and training program leaders addressing talent pipelines

This diversity ensured discussions encompassed technical feasibility, economic viability, regulatory reality, and political practicality. Participants who opted into having their names and organizations published with this report are listed in Appendix B.

3. MAJOR FINDINGS: INNOVATION ORGANIZATION AXIS

3.1 Basic R&D: Foundation for Long-Term Competitiveness

Workshop participants emphasized the need for shared infrastructure to support high-throughput, AI-enabled biological engineering, which aligns directly with NSCEB recommendations for standardization and interoperability of biological data to ensure discoveries translate reliably from laboratory to manufacturing scale.

3.1.A Goals, Opportunities & Competitive Advantages

Workshop participants identified several strengths positioning Massachusetts—and by extension, the United States—for bioeconomy leadership:

Rich Innovation Ecosystem: The concentration of world-class universities, research hospitals, national labs, and biotechnology companies in Massachusetts creates unparalleled density of expertise and cross-pollination opportunities. Proximity enables informal collaboration, rapid talent circulation, and serendipitous innovation.

Nature-Inspired Design Principles: Biological systems offer solutions from molecular to structural scales, including materials inspired by butterfly cuticles, spider silk, and extracellular matrices. Ambient-condition synthesis represents a fundamental advantage over energy-intensive, and often toxic, chemical manufacturing.

AI and Automation as Multipliers: Computational tools enable small academic labs to collectively operate with systematic rigor previously requiring large industrial facilities. Machine learning accelerates discovery of protein functions, metabolic pathways, and process optimizations. Workshop participants envisioned a "Human Genome Project for biology"—large-scale, coordinated discovery infrastructure leveraging AI.

Academic and Startup Synergy: University labs excel at curiosity-driven exploration of fundamental phenomena (e.g., CRISPR discovery from bacterial immunity studies). Startups provide focus on specific applications and market validation. When properly connected, this creates a virtuous cycle of discovery and translation.

Government Labs as De-Risking Platforms: National laboratories can serve as translational intermediaries, developing technologies to higher readiness levels before commercial handoff, speeding up the process and increasing the likelihood of success, thereby reducing risk for venture investors.

Foundational Value of Basic Science: Workshop participants emphasized CRISPR as a model of transformative discovery born from fundamental research. The CRISPR gene-editing revolution emerged from curiosity-driven studies of bacterial immunity, not from applied gene-editing programs. This exemplifies how maintaining a strong basic science enterprise in academia and government labs is essential for breakthrough technological innovation, as the most significant discoveries often arise from unexpected directions when researchers are free to pursue fundamental questions.

3.1.B Challenges, Limitations, & Gaps

Despite these strengths, fundamental obstacles impede progress:

Misaligned Incentive Structures: Academic promotion and tenure emphasize publication volume and citation metrics. Collaborative tool-building, data sharing, and translational work receive limited recognition. Scientists face pressure to pursue incremental, "safe" projects rather than high-risk foundational research. As one participant noted, "We don't reward the infrastructure builders—only the people who use the infrastructure to publish papers."

Communication Failures: The public and policymakers poorly understand the long-term value of basic research. Dramatic breakthroughs like CRISPR (discovered through fundamental bacterial immunity research, not applied gene-editing programs) are forgotten in results-driven cultures demanding immediate returns. This undermines political support for sustained basic research funding.

Fragmented Ecosystem: Despite physical proximity, deep disconnects separate basic researchers from commercial implementation. State governments and philanthropies provide limited bridging mechanisms. Federal programs (NIH, NSF, DOE, USDA) operate in silos with incompatible metrics and reporting requirements.

Policy and Regulatory Barriers: Regulatory frameworks (EPA, USDA, FDA) were designed for chemical manufacturing and agricultural products, not engineered biological systems. Misalignment among agencies creates uncertainty. For example, a fermentation-produced chemical might face EPA review as a "new chemical substance," USDA oversight if derived from agricultural feedstock, and FDA scrutiny if used in food—each with different standards and timelines.

Capital Model Misalignment: Government funding cycles respond to political pressures and voter perception rather than scientific timelines. This creates "feast or famine" dynamics undermining long-term program planning. Venture capital similarly operates on 3–7 year return horizons, far shorter than the 10–20 years often required for bioeconomy innovations.

Manufacturing Limitations: Current biomanufacturing remains batch-based, labor-intensive, and costly. Scaling from lab (milligrams) to pilot (kilograms) to commercial (tons) requires entirely different equipment, expertise, and capital. Continuous processing remains rare. As one industry participant stated, "We can make amazing molecules in a flask, but we have no pathway to make them at the volume and price the market demands."

3.1.C Vision for the Future & Recommendations

Near-term (<5 years):

- Regulatory modernization enabling platform biotechnologies rather than product-by-product review

- Widespread adoption of AI and automation to integrate discovery across institutions
- Establishment of shared biomanufacturing infrastructure accessible to academics and startups
- Seamless mobility for scientists between academia, industry, and government sectors (sabbaticals, joint appointments, rotating fellowships)

Medium-term (<10 years):

- Transition from batch to continuous biomanufacturing processes
- Public recognition of basic research's value in driving economic growth

Overall vision:

- A coordinated national effort—described by participants as a "Manhattan Project for Biology"—aligning incentives, capital, and regulation to accelerate innovation
- Biology becomes the default platform for manufacturing across sectors

3.2 Education and Workforce: Building Human Capital

3.2.A Goals, Opportunities & Competitive Advantages

The bioeconomy's breadth—spanning defense, healthcare, food, materials, and energy—offers bipartisan political appeal and the promise of good jobs with domestic supply chains. As participants noted, biology is everywhere: it will defend, heal, feed, and build. Critically, advancing biomanufacturing technologies increasingly reduce reliance on highly specialized subject-matter experts, democratizing participation.

Key insight: "We cannot out-China China" in low-cost manufacturing, but the United States uniquely excels at process innovation. AI and automation can rapidly enhance workforce sophistication, enabling technicians with community college training to operate advanced biomanufacturing facilities.

3.2.B Challenges, Limitations, & Gaps

The education roundtable confronted what members acknowledged as "the hardest problem":

Long Timeline from Investment to Benefit: Educational programs require years to develop curricula, recruit faculty, enroll students, and graduate job-ready workers. By the time programs launch, industry needs may have evolved.

Deployment Pathway Uncertainty: Training students for jobs that don't yet exist locally creates a dilemma. On one hand, educators should "skate where the puck is going." On the other, students need immediate employment to justify their investment. This creates chicken-and-egg dynamics: companies won't locate without trained workers; students won't train without local jobs.

Institutional Inertia: Educational institutions default to established programs. Launching new curricula requires faculty consensus, administrative approval, and resource reallocation—all time-consuming. The coming demographic cliff (declining college-age population) will intensify resource constraints, making change even more difficult.

Unclear Ownership: Who is responsible for workforce training? Universities focus on traditional degrees. Community colleges on vocational skills. Companies on proprietary knowledge. Government on broad economic development. This fragmentation leaves gaps unaddressed.

Discovery-to-Value Disconnect: Students rarely see how basic biological concepts connect to commercial innovation, leading to perceptions that "we already know how to do this" and discouraging entry into the field.

3.2.C Vision for the Future & Recommendations

Industry Connection Programs (0–2 years): Establish simple mechanisms for companies to engage with educational institutions. One participant cited an example: "Why did Sunflower [a local biotech company] need to accidentally discover that a Medford High School student could create excellent explainer videos? There should be formal pathways for this." Models include "Life Science Alliance," "Kelly Science & Clinical," and the Massachusetts Life Sciences Center (MLSC) intermediary functions.

Simplified Partnership Mechanisms: Streamline memoranda of understanding (MOUs) for cross-sector collaboration, reducing legal barriers to industry-education partnerships.

AI Career Guidance: Deploy digital tools providing students with region-specific information about bioeconomy jobs, career pathways, and compensation. Students "shouldn't need to be lucky to get good jobs but rather should know what jobs are in their region, what those jobs can lead to, and what those jobs pay."

Regulatory Streamlining: Develop "certified safe microbes" frameworks, enabling educational labs to work with industrially relevant organisms without burdensome oversight.

Growth Activities Connecting Discovery to Value: Develop educational activities and programs that explicitly connect basic biological concepts to commercial innovation and economic value, combating student perceptions that "we already know how to do this" and encouraging entry into bioeconomy careers.

3.3 Manufacturing and Distribution: Scaling from Lab to Market

3.3.A Goals, Opportunities & Competitive Advantages

Establish Common Standards: Develop shared process and system standards to streamline transitions from R&D to pilot, clinical, and commercial manufacturing. Standardization reduces risk, cost, and time-to-market.

Build Regional Manufacturing Hubs: Create distributed, flexible manufacturing networks giving early-stage companies and innovators affordable access to infrastructure, expertise, and workforce. This strengthens both local economies and national resilience against supply chain disruptions.

Offset U.S. Cost Structures: U.S. labor and material costs exceed competitors', particularly China. However, Germany demonstrates that high-wage economies can remain competitive through automation, workforce quality, and process innovation. The United States must develop similar models.

Advance Circular Bio-Manufacturing: Replace petroleum-derived feedstocks with renewable biological inputs, enabling closed-loop production that reduces waste and carbon intensity.

Create Biology-Unique Products: Leverage living systems' capabilities to produce materials, therapeutics, and molecules impossible to synthesize chemically, thereby avoiding direct competition with established petrochemical products.

Lower Commercialization Barriers: Innovate smaller, modular, automated facilities drastically reducing startup and operating costs, enabling faster commercialization and broader participation.

3.3.B Challenges, Limitations, & Gaps

High Input and Processing Costs: Biological feedstocks (sugars, oils, nitrogen sources) remain expensive. Downstream recovery processes—separating desired products from fermentation broths—are inefficient at scale. As one participant noted, "Beer at volume works because it doesn't require separation technologies. Most bio-products do, and that's where costs explode."

Competition with Incumbent Products: Bio-based alternatives face entrenched markets where customers prioritize cost and risk perception over sustainability. Lack of familiarity with biological manufacturing limits adoption. Petrochemical products benefit from decades of optimization and massive economies of scale.

Intellectual Property Barriers: Companies are reluctant to disclose production methods to contract manufacturers or collaborators. Process patents are notoriously difficult to defend—competitors can often achieve similar results through alternative routes. This discourages the pre-competitive collaboration needed for ecosystem growth.

Limited Flexible Infrastructure: Few facilities offer rental or shared access for GMP-grade or clinical material production. Shared facilities could foster informal knowledge exchange but raise concerns about confidentiality and competition. Most startups must build dedicated facilities, requiring tens of millions in capital before generating revenue.

Global Cost Disparities: Higher U.S. costs for labor, capital, and materials constrain domestic manufacturing competitiveness. This creates pressure to offshore production, undermining supply chain autonomy and national security objectives.

3.3.C Vision for the Future & Recommendations

Affordable, Abundant Feedstocks: Valorization of agricultural and other waste streams would would enable competitive large-scale biological manufacturing.

Complete Petroleum Replacement: Manufacturing the full range of fuels, materials, and chemicals using renewable biological inputs, establishing biology as the sustainable foundation for the materials economy.

Seamless Resource Sharing: Companies and researchers sharing tools, data, and infrastructure at key interfaces (gene/molecule → strain → process) while retaining proprietary information through trusted or federated systems.

On-Demand GMP Production: Small companies and research teams generating GMP materials rapidly, flexibly, and affordably, accelerating innovation across all bio sectors.

Universal Process Platforms: Standardized, modular production platforms accommodating microbial, plant, and mammalian systems, simplifying process development, validation, and scaling.

3.4 Policy and Regulation: Enabling Environment

3.4.A Goals, Opportunities & Competitive Advantages

Recent congressional attention to biotechnology—spurred by the NSCEB report and bipartisan recognition of strategic importance—creates policy momentum. Specific opportunities include:

Permanent White House Office: The NSCEB proposed establishing a permanent White House office for biotechnology coordination, elevating the issue to consistent executive-branch attention.

National Laboratory Expansion: Dedicating or creating national labs focused specifically on biotechnology would provide non-dilutive capital, subject-matter expertise, and translational infrastructure bridging academia and industry.

Trade Policy Alignment: Rallying around national interest enables protective measures such as eight-year sunset provisions on materials from certain countries, forcing re-shoring of manufacturing.

Leveraging U.S. Innovation Strengths: The United States excels at cutting-edge discovery and entrepreneurial commercialization. Policy should amplify these advantages rather than attempting to match competitors' state-directed industrial models.

3.4.B Challenges, Limitations, & Gaps

Partisanship and Polarization: Biotechnology increasingly becomes politicized, with debates over GMOs, gene editing, and pandemic origins creating partisan divides. This undermines sustained bipartisan support needed for long-term policy commitments.

Technical Expertise Deficit: Government agencies lack sufficient staff with deep biotechnology knowledge to provide informed oversight. Recent scale-backs in government capacity exacerbate this. As one participant stated, "A grant gets flagged for Gain of Function concerns, but no one in the review chain has the expertise to assess whether the concern is valid."

Moving Goalposts: Inconsistent signals about funding priorities make it difficult for investors to place bets. When government suddenly shifts focus areas or eligibility criteria, private capital loses confidence in co-investment opportunities.

Non-State-Run Economy: Unlike China's centrally planned biotech investments, the U.S. system relies on distributed decision-making. This offers flexibility and innovation but requires sophisticated coordination mechanisms to achieve strategic outcomes.

Public Communication Failures: Broad-based public interest and understanding of biotechnology remains limited. Without constituency pressure, politicians lack incentive to prioritize bioeconomy policies.

3.4.C Vision for the Future & Recommendations

Participants emphasized urgency, noting that "the timeline for all of these is yesterday":

Near-term (0–2 years):

- Establish a tailored policy planning and advocacy association—potentially modeled on sector-specific trade groups—to effectively navigate the advocacy ecosystem and influence policy
- Aggressive state government action seizing bioeconomy opportunities through regulatory flexibility, infrastructure investment, and workforce programs

Medium-term (2–8 years):

- Increased NIH funding specifically for translational, de-risking bench science
- Clearer coordination mechanisms between Congress and executive-branch agencies
- Leverage DoW-funded biomanufacturing activities for broader civilian sector bioeconomy
- Regulatory reform reducing time and uncertainty in product approval pathways

Long-term (5+ years):

- Return to "Bell Labs-type organizations"—large-scale, mission-driven research entities combining basic and applied work
- Not just one dedicated biotechnology national lab, but a network of ten or more distributed facilities providing regional access and specialization

3.5 Investment Capital: Funding Innovation Timelines

3.5.A Goals, Opportunities & Competitive Advantages

Capital for bioeconomy ventures is more diverse than commonly perceived:

Beyond Traditional VC: While institutional venture capital concentrates in Massachusetts, New York, and California, alternative sources include sovereign wealth funds, crowdfunding platforms, special purpose vehicles (SPVs), and distributed angel investors (often in different tax jurisdictions).

SPV Innovation: SPVs operate with different diligence standards, potentially driven by "entertainment value" or impressive moonshots rather than traditional return metrics. This creates funding pathways for ambitious projects that might not fit conventional VC models.

SAFE Structure Success: Simple Agreement for Future Equity (SAFE) instruments have streamlined early-stage fundraising, reducing legal complexity and enabling faster capital deployment.

Global Angel Networks: Massachusetts should better connect with international angel investor communities to supplement institutional capital.

3.5.B Challenges, Limitations, & Gaps

Time Horizon Mismatch (Valley of Death): Getting through pre-seed and seed stages is exceptionally difficult given capital expenditure needs and long experimentation cycles. Unlike software startups requiring minimal infrastructure, biotech ventures need lab space, equipment, materials, and specialized personnel before generating data to attract follow-on funding.

Specialized Fund Scarcity: Corporate venture capital (CVC) has developed effective models in therapeutics (e.g., "Golden Tickets" providing guaranteed acquisition paths), but not in materials, manufacturing, or other bioeconomy sectors. The bar for non-therapeutic bio-ventures can be "incredibly high."

Talent Requirements: Early-stage ventures need both deep technical expertise and business experience. Finding individuals combining scientific credibility with entrepreneurial skills and investor networks remains difficult.

Service Business Model Confusion: Some startups build product businesses; others offer services. These require different capital structures and timelines, but investors often apply inappropriate evaluation frameworks.

3.5.C Vision for the Future & Recommendations

Mission-Driven Capital: Funds explicitly accepting longer timelines and social impact alongside financial returns.

Lab-to-Pilot Funding: Dedicated capital pools for the expensive transition from laboratory proof-of-concept to pilot-scale demonstration.

Shared Facilities: Reducing direct capital needs by providing access to communal infrastructure rather than requiring each startup to build redundant capabilities.

Secondary Market Development: Creating liquidity mechanisms for tough-tech ventures that allow investors to exit on different timelines with lower IRR expectations at each stage. This also provides entrepreneurs and employees liquidity opportunities before traditional exit events.

Regulatory Clarity: Streamlined regulatory pathways giving investors more confidence at earlier stages, reducing risk premiums demanded.

4. MAJOR FINDINGS: GOALS & IMPACTS AXIS

4.1 Supply Chain Durability, Autonomy, and Safety

4.1.A Goals, Opportunities & Competitive Advantages

Domestic Vertical Integration: Building supply chain resilience through in-house production of every component—from raw materials to finished products. This controls quality, reduces dependency on external suppliers, and mitigates geopolitical and market disruption risks.

Proven Examples of Supply Chain Re-Shoring Through Bioeconomy:

Essential Medicines via Fermentation: The FDA's List of Essential Medicines includes numerous compounds currently sourced through complex international supply chains vulnerable to disruption. Biological manufacturing offers pathways to domestic production:

- **Insulin and biologics**: Recombinant protein production in microbes and mammalian cells, already established for diabetes treatment, demonstrates the broader potential for producing complex therapeutics through fermentation rather than extraction or chemical synthesis.
- **Future candidates**: Active pharmaceutical ingredients (APIs) for antibiotics, antivirals, and other essential medicines could be produced via engineered microbes or plant cell cultures, reducing dependence on foreign pharmaceutical manufacturing concentrated in China and India.

The COVID-19 pandemic demonstrated critical vulnerabilities when API supply chains concentrated in Asia faced disruptions, threatening U.S. medical preparedness. Domestic biomanufacturing provides strategic resilience.

Automation for Precision and Efficiency: Fully automated manufacturing ensures product consistency while reducing long-term costs and reliance on labor-constrained or offshore partners.

Re-Shoring and "Biologizing" Manufacturing: Many agricultural chemical and industrial supply chains currently depend on international sources. Biology-driven manufacturing can bring production back to the U.S., enhancing both supply security and sustainability. Participants called for "a map to identify where bioeconomy can hop into the supply chain."

Innovation Hub Leverage: Regional ecosystems anchored near universities and research institutions offer synergistic advantages. Physical proximity accelerates collaboration, technology transfer, and workforce development critical to durable, secure supply chains.

4.1.B Challenges, Limitations, & Gaps

Limited Regulatory Agility: Few adaptive or fast-track pathways exist for piloting regulated products. This slows domestic biomanufacturing progress and limits ability to safely test, iterate, and validate technologies.

Public Perception and Trust Deficit: Historical incidents involving GMOs, PFAS, and chemical safety have shaped public skepticism. This limits social license to operate for emerging bio innovations, requiring stronger communication, transparency, and safety-by-design frameworks.

Domestic Scaling Costs: Building durable, autonomous supply chains requires balancing domestic manufacturing costs with scalability. Consortium models (e.g., BioMADE) that share infrastructure and reduce early-stage expenses are promising but are underutilized.

IP and Standardization Gaps: Ambiguity around intellectual property ownership in shared manufacturing environments discourages collaboration. Lack of standardized frameworks for integrating biology into industrial supply chains hinders coordination.

Talent Bottlenecks: Deep regulatory and GMP expertise is scarce and commands premium compensation. Startups face barriers hiring experienced professionals and accessing technical knowledge needed to build compliant facilities.

Infrastructure and Knowledge Mismatch: A shortage of mid-scale GMP facilities, coupled with limited know-how in their design and operation, leaves startups stranded between prototype and production. This stifles scalability and weakens supply chain autonomy.

4.1.C Vision for the Future & Recommendations

Integrated Scalability Ecosystem: Streamlined startup access to capital, technical advisors, and engineering leadership (including VP-level support) to bridge the prototype-to-production gap.
Specialized Talent Acceleration: National efforts connecting and training niche experts—GMP specialists, process engineers, regulatory veterans—for participation in early-stage ventures.
Distributed Biomanufacturing Network: Remotely managed biomanufacturing hubs across the country providing flexible capacity and redundancy to strengthen supply chain durability and regional resilience.
Continuous Training Programs: Industry-led incubators and recertification initiatives—similar to medical training models—helping upskill engineers, technicians, and operators as manufacturing technologies evolve.

4.2 Climate, Sustainability, and Human Health

4.2.A Goals, Opportunities & Competitive Advantages

Sustainable Feedstock Introduction: Replacing existing materials (e.g., bioplastics) and reducing competition with human food supply (e.g., non-food soy applications). Opportunities include:

- Nature-based solutions tied to existing projects (e.g., offshore wind platforms supporting seaweed cultivation)
- Waste feedstock valorization (agricultural residues, food waste, wastewater)
- Underutilized marine resources (Sargassum seaweed, algae)

4.2.B Challenges, Limitations, & Gaps

Scaling Transition to Low-Margin, High-Volume Production: Climate impact requires large scale and low margins. This fundamentally misaligns with market incentives. Example: "How can a bioplastic company compete with the economy of scale of oil-derived products?" Petrochemicals benefit from century-old infrastructure and massive global production volumes.
Feedstock Variability: Natural feedstocks like Sargassum vary by season and location in composition, moisture content, and contaminants. This complicates standardized processing.
Supply Chain Development: Building reliable collection, transportation, and preprocessing systems for dispersed feedstocks requires coordination across multiple stakeholders.

4.2.C Vision for the Future & Recommendations

Non-Profit Supported R&D: Recognizing that climate-focused bio ventures may not generate VC-compatible returns, philanthropic and government support becomes essential for slow development timelines and commercialization.
Regulatory Agility: Pre-approved testbeds enabling faster iteration without full regulatory review for each modification.
Real-Time Needs Database: Centralized knowledge of available feedstocks and gaps between current and potential value. Participants asked, "What are the most promising feedstocks in Massachusetts?" This basic information should be readily accessible.

4.3 Impact on Industries, Economies, and Peoples

4.3.A Goals, Opportunities & Competitive Advantages

"Glocal" Production: Distributed biomanufacturing can revitalize regional economies, particularly rural and post-industrial communities. Unlike centralized factories, bio-facilities can operate at various scales, creating local employment and economic activity.

Regional Partnerships: Reducing brain drain by creating opportunities for skilled workers to remain in or return to their home regions rather than concentrating in major metro areas.
Pilot Demonstrations: Making bioeconomy impact tangible through visible, fast projects. Digital twins and testbeds with corporate sponsorship can accelerate proof-of-concept to deployment timelines.

4.3.B Challenges, Limitations, & Gaps

Asymmetrical Regional Opportunity: Innovation ecosystems concentrate in major metros, while rural communities lack access to capital, expertise, and infrastructure.
Investment-Return Tension: Investors demand returns at scales that may not align with regionally focused ventures serving smaller markets.
Public Understanding Gap: Outside specialist audiences, biotechnology understanding remains limited. This is especially problematic for political decision-makers and general publics whose support is essential for policy and social license.

4.3.C Vision for the Future & Recommendations

Short-term (5 years): People—workers, community members, politicians, decision-makers—understand bioeconomy technologies and opportunities, moving from awareness to advocacy.
Medium-term (10 years): Successful green market alliances (supply chain, manufacturing, knowledge sharing) serve to de-risk and amplify bioeconomy growth.
Long-term (1 generation): Revitalization and thriving of rural communities through distributed biomanufacturing employment and economic activity.

4.4 National Security Implications

4.4.A Goals, Opportunities & Competitive Advantages

Ensure Critical Security: Protecting supply chain, agriculture, and health security while supporting national security missions.
Bioconvergence: Integrating biology with engineering, electronics, data science, and AI creates novel capabilities unavailable through any single domain.
Democratization: Distributed biomanufacturing capabilities reduce dependence on vulnerable centralized facilities and foreign supply chains.
Enabling Platforms: Technologies for low-batch manufacturing and rapid Design-Build-Test-Learn (DBTL) cycles enable quick response to emerging threats.
Competitive Advantages:

- Funding ecosystem combining pre-competitive R&D and venture capital
- Institutions promoting multidisciplinary work
- Workforce quality (though this advantage may be diminishing relative to competitors)

4.4.B Challenges, Limitations, & Gaps

Patient Capital Scarcity: National security timelines often extend beyond commercial investment horizons, requiring specialized funding mechanisms.
Product-Market-Mission Alignment: Difficulty finding ventures that simultaneously serve commercial markets and national security needs with sustainable business models.
Public Perception: Limited "bio-literacy" and receptiveness to biological technologies, particularly following polarized pandemic debates.

Biosecurity Itself: Dual-use concerns and risks from democratized biological capabilities require parallel investment in detection, mitigation, and governance.
Unfocused Policy and Investment: Lack of coordinated legislative and regulatory strategy; absence of specialized bioeconomy investment funds with national security mandates.
Missing Common Playbook: Absence of aligned vision and coordinated actions across government, academia, and industry.

4.4.C Vision for the Future & Recommendations

Near-term (precision interventions possible now): Understand regulatory reforms, incentives needed for bioeconomy from Government, industry, and academic perspectives.
Medium-term (5–10 years, requires political will): Establish funding mechanisms that complement government R&D with sustained, patient capital.
Long-term (decadal execution, national priority): Launch mission-focused "Apollo Project" for biosecurity and the bioeconomy, potentially including a "Golden Dome" initiative for biothreat detection and mitigation or bio-based solutions for logistics and supply chain.

5. THE TRIPLE-HELIX INNOVATION MODEL: DIAGNOSIS & INTEGRATION PRINCIPLES

5.1 Current System Failures

The workshop identified fragmentation as the root cause of underperformance. Despite world-class capabilities in academia, government labs, and industry, these sectors operate largely independently:
Academia pursues curiosity-driven research rewarded by publications and citations. Collaboration with industry often involves transactional licensing deals rather than sustained partnerships. Shared tool development receives limited recognition. Graduate students train primarily for academic careers or industrial careers alternative to biotechnology outside of medicine.
Government funds basic and applied research through mission-specific agencies (NIH, NSF, DOE, DARPA, USDA) with incompatible reporting requirements and limited coordination. Regulatory agencies operate independently, creating uncertainty for technologies crossing jurisdictional boundaries. Government labs conduct excellent research but lack clear pathways for technology transfer.
Industry and Venture Capital focus on near-term returns and commercialization-ready products. Early-stage companies struggle to access academic facilities and expertise. Large corporations conduct internal R&D but rarely engage in pre-competitive collaboration. VC funding cycles misalign with bioeconomy development timelines.

This fragmentation creates:

- **Redundant infrastructure**: Unused academic equipment sits beside startups building duplicate capabilities
- **Knowledge loss**: Technology transfer involves repeated due diligence, IP negotiations, and personnel turnover
- **Misaligned incentives**: What benefits one sector may harm another (e.g., academic patenting may slow knowledge diffusion)
- **Capital inefficiency**: Sequential funding stages each demand full re-evaluation rather than continuous support
- **Workforce mismatches**: Training programs disconnected from employment needs

5.2 Principles for Triple-Helix Integration

The workshop identified essential principles that any successful triple-helix innovation model must embody. These principles provide guidance for designing institutional structures that can overcome current fragmentation:

Shared Physical Infrastructure:

Effective integration requires co-location and shared resources:

- Research institutes bringing together academic labs, government translational centers, and industry R&D facilities
- Biomanufacturing pilot plants accessible to academics, startups, and established companies
- High-throughput screening facilities, AI/computational infrastructure, and analytical equipment operated as shared resources
- GMP-grade production capabilities for clinical and commercial material generation

Aligned Incentive Structures:

Institutional integration demands fundamental changes to reward systems:

- Academic promotion criteria recognizing translational impact, tool-building, and collaborative science alongside traditional publications
- Government funding mechanisms supporting continuity from discovery through scale-up rather than requiring repeated proposal competitions
- Industry commitments to pre-competitive collaboration, data sharing, and workforce development
- Joint appointment structures enabling personnel to work simultaneously across sectors, and alternate between industry and academia as commonly performed in other industrial nations that promote manufacturing innovation such as Germany

Integrated Funding Mechanisms:

Sustainable support requires coordinated capital flows:

- Public-private investment vehicles combining government de-risking capital with VC discipline and industry expertise
- Multi-PI center grants spanning academic discovery, government translation, and industry validation
- Sustained funding for shared infrastructure independent of individual project success/failure
- Mechanisms for startups to access facilities and expertise at affordable rates

Seamless Knowledge Flow:

Reducing friction in technology transfer and translation:

- Formal pathways for technology maturation from TRL 1–2 (basic research) through TRL 7–8 (system prototype in operational environment)
- Standardized material transfer agreements, IP frameworks, and collaboration templates reducing legal friction
- Rotation programs enabling researchers to spend time in different sectors, building relationships and understanding
- Open-access databases for biological parts, strains, processes, and performance data (with appropriate IP protections)

End-to-End Continuity:

Eliminating handoff failures through sustained engagement:

- Organizational structures responsible for entire innovation pipelines

- Project management expertise bridging scientific discovery, engineering development, regulatory strategy, and commercialization
- Early industry input shaping research directions toward practical applications
- Academic involvement in late-stage optimization and troubleshooting

5.3 Implementation Considerations

Workshop discussions identified several approaches that could embody triple-helix principles, each with distinct advantages and challenges:

5.4 Key Design Principles

Regardless of specific implementation, successful triple-helix models must:

Preserve Sectoral Strengths:

- Maintain academic freedom and curiosity-driven research that is core to US creativity
- Retain industry's market discipline and commercialization expertise
- Leverage government's patient capital and public-interest mission
- National Labs' ability to mature TRL 2–7 technology at scale and bring together, in a non-competitive way, the deeply technical communities in academia and small startups

Balance Competition and Collaboration:

- Define clear boundaries between pre-competitive (shared) and competitive (proprietary) domains
- Protect legitimate IP interests while enabling knowledge flow
- Create mechanisms for companies to collaborate on foundational capabilities while competing on products

Ensure Accessibility:

- Small startups and academic labs must have affordable access to shared infrastructure
- Geographic distribution prevents over-concentration in major metros
- Digital tools and remote operation expand access to physical facilities

Build Institutional Capacity:

- Permanent staff operating shared facilities (not dependent on individual PIs' grants)
- Professional technology transfer and project management expertise
- Long-term funding commitments enabling multi-year projects

Measure and Adapt:

- Clear metrics for innovation outputs, economic impact, and workforce development
- Regular assessment and course correction
- Learning from international models (e.g., Germany's mission-centric Fraunhofer Institutes, Singapore's integrated approach)

6. FINDINGS & IMPLICATIONS FOR POLICY

The workshop identified critical needs across federal policy, state action, academic institutions, and industry. While specific implementation models require further development, certain enabling actions are essential regardless of the institutional approach chosen.

6.1 Federal Policy Priorities

Coordination and Strategy:

1. **Establish Permanent White House Biotechnology Office**: Following NSCEB recommendations, create sustained executive-branch coordination across agencies.

2. **Regulatory Modernization**: Direct EPA, FDA, and USDA to develop coordinated frameworks for platform biotechnologies, reducing agency misalignment.
3. **Pre-Competitive R&D Funding**: Establish multi-agency programs supporting projects spanning discovery through demonstration with sustained support.

Infrastructure and Translation:

4. **National Biomanufacturing Infrastructure**: Fund distributed facilities providing affordable access to pilot-scale equipment, GMP capabilities, and technical expertise, along the lines of PECAST recommendations and BIOMADE[4].
5. **Cloud Laboratory Network**: Support automated, high-throughput facilities generating AI-ready biological data as recommended by NSCEB.
6. **Web of Biological Data**: Implement NSCEB recommendation for unified data infrastructure connecting federal, academic, and industry sources.

Economic Incentives:

7. **Government Procurement**: Use federal purchasing power to create guaranteed markets for bio-based materials, fuels, and chemicals.
8. **Re-Shoring Incentives**: Tax credits, tariffs, or sunset provisions encouraging domestic biomanufacturing.
9. **Public-Private Investment Vehicles**: Launch sovereign wealth fund or government investment corporation providing patient capital for long-timeline ventures.

Workforce and Biosecurity:

10. **Workforce Development**: Federal funding for community college and university programs training bioeconomy technicians and engineers.
11. **Biosecurity Investment**: Parallel funding for biothreat detection, mitigation, and governance as capabilities expand.

6.2 State and Regional Priorities

Infrastructure and Coordination:

1. **State Biomanufacturing Coordination**: Create state entities coordinating shared facilities, workforce training, regulatory flexibility, and economic development.
2. **Regulatory Sandboxes**: Establish pre-approved testing frameworks enabling faster iteration on bio-based products.
3. **Multi-University Frameworks**: State higher education leadership facilitates governance agreements among universities for:
    - Faculty appointment and promotion recognition across institutions
    - Graduate student training programs
    - IP ownership and licensing frameworks
    - Joint research program management

Capital and Workforce:

4. **State Co-Investment Funds**: Match private VC with state capital for bioeconomy ventures.
5. **University-Industry Centers**: State funding for facilities co-locating academic and industry R&D.
6. **K-12 and Community College Pathways**: Formal educational pipelines connecting students to bioeconomy careers.

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[4] *Biomanufacturing to Advance the Bioeconomy*, Report to the President, President's Council of Advisors on Science and Technology, December 2022; *Bioindustrial Manufacturing Innovation Institute* (BioMADE), established October, 2020, launched April, 2021.

7. **Interstate Compacts**: Coordinate neighboring states on workforce training, regulatory approaches, and shared infrastructure.

6.3 Academic Institutional Priorities

Incentive Reform:

1. **Promotion Criteria**: Explicitly recognize translational research, tool-building, and collaborative science in tenure and promotion decisions.
2. **Joint Appointments**: Create mechanisms for faculty to hold appointments spanning institutions and sectors including industry and government labs.
3. **Shared Facility Investment**: Commit institutional resources to core facilities accessible to external users, operated by professional staff.

Collaboration Enablers:

4. **Pre-Competitive Consortia**: Organize multi-university collaborations on foundational tools, databases, and standards.
5. **Standardized Agreements**: Develop template MTAs, research agreements, and IP frameworks reducing legal friction and loss of academic-industrial cooperative agreements.
6. **Graduate Program Integration**: Develop programs explicitly preparing students for diverse career paths across academia, industry, government, and startups.
7. **Industry Advisory Integration**: Embed industry experts in research direction-setting.

6.4 Industry and Investment Priorities

Corporate Engagement:

1. **Pre-Competitive Collaboration**: Participate in consortia sharing foundational capabilities, standards development, and workforce training.
2. **Facility Sharing**: Make underutilized manufacturing capacity available to startups and academics.
3. **Workforce Partnerships**: Formal relationships with educational institutions providing internships, equipment donations, and curriculum input.
4. **Long-Term Research Support**: Corporate R&D programs with longer timelines and tolerance for fundamental research.

Investment Evolution:

5. **Specialized Bioeconomy Funds**: Create investment vehicles designed for 10–15 year timelines and mission-driven returns.
6. **Syndication Networks**: Formal mechanisms for co-investment across rounds.
7. **Secondary Market Development**: Build liquidity mechanisms enabling longer company development timelines.
8. **Shared Infrastructure Models**: Industry-funded facilities providing pilot and demonstration capabilities to multiple users.

6.5 Cross-Cutting Enablers

Data and Digital Infrastructure:

1. **Biological Parts Registry**: Open-access databases for characterized genetic parts, strains, and biological materials.
2. **Process Database**: Anonymized data on bioprocess performance, costs, and challenges.
3. **Feedstock Mapping**: Real-time information on available biological feedstocks.

4. **Career Pathway Tools**: AI-powered platforms providing job information and skill requirements.

Communication and Engagement:

5. **Public Education Campaign**: Sustained effort building bio-literacy and explaining long-term value.
6. **Pilot Demonstrations**: Highly visible projects showcasing bioeconomy impact.
7. **Policy Advocacy Organization**: Focused biotechnology advocacy effectively navigating legislative processes.

Metrics and Assessment:

8. **Innovation Metrics**: Move beyond publication counts to measure translation outputs, economic impact, workforce development, and supply chain resilience.
9. **Regular Assessment**: Systematic evaluation of program effectiveness with willingness to redirect resources.

7. CONCLUSION: FROM DIAGNOSIS TO ACTION

The United States possesses extraordinary bioeconomy assets: world-class research universities, innovative companies, sophisticated investors, talented workforce, and enabling policies. Yet these assets remain fragmented, operating at cross-purposes rather than in concert. The resulting inefficiency threatens U.S. competitiveness as other nations—particularly China—make coordinated investments in integrated bioeconomy capabilities.

The MIT-Engine Bioeconomy Workshop revealed both the scale of the opportunity and the institutional barriers preventing its realization. Biology can transform how we manufacture materials, produce energy, grow food, and deliver healthcare. Achieving this potential requires not incremental improvements but fundamental restructuring of how academia, government, and industry collaborate.

This report has diagnosed the fragmentation problem and identified principles for effective triple-helix integration:

- **Shared physical infrastructure** reducing redundant investments and enabling collaboration
- **Aligned incentive structures** rewarding translational impact alongside traditional metrics
- **Integrated funding mechanisms** supporting continuity from discovery through scale
- **Seamless knowledge flow** through standardized agreements and rotation programs
- **End-to-end continuity** eliminating handoff failures in the innovation pipeline
- **Coordinated data sharing** treating biological data as the strategic resource it represents
- **Regional and national coordination** balancing local needs with grand challenges

Workshop participants emphasized urgency. As one noted, "The timeline for all of these recommendations is yesterday." Global competitors are not waiting. Supply chain vulnerabilities, climate change, and national security threats demand action.

The bioeconomy is not a distant future possibility—it is emerging now. Pioneering companies already demonstrate how biological manufacturing can re-shore critical supply chains and reduce vulnerabilities to foreign disruption. These examples show what's possible when innovation ecosystems function effectively.

The question is whether the United States will lead this transformation through coordinated institutional innovation, or whether fragmented approaches will cede leadership to nations with more integrated systems. This report provides diagnosis and principles. Specific implementation models—including detailed proposals for institutional structures that embody these principles—will be addressed in future workshops and reports.

The participants in this workshop demonstrated both the expertise and the willingness to engage in transformational work. Now it is time to translate workshop insights into institutional reality. The foundations exist; what's required is commitment to building integrated structures at scale.

America's bioeconomy leadership is not inevitable—it must be deliberately constructed through new institutional models that align our fragmented capabilities into coordinated action. The diagnosis is clear. The principles are established. The path forward awaits our collective will to pursue it.

APPENDIX A: WORKSHOP TABLES & MODERATORS

Innovation Organization Axis:

Table 1: Basic R&D
Moderators: Domitilla Del Vecchio, MIT; Jing-Ke Weng, Northeastern University

Table 2: Education & Workforce
Moderator: Natalie Kuldell, BioBuilder

Table 3: Manufacturing & Distribution
Moderators: Lily Fitzgerald, MassTech; Chris Love, MIT

Table 4: Policy & Regulation
Moderators: Sarah Glaven, Princeton University; Will Rasky, The Engine & Mass Ave Strategies

Table 5: Investment Capital
Moderators: Kathryn Brink, BioMADE; Rachel Field, Engine Ventures

Impact Axis:

Table 6: Supply Chain Durability, Autonomy & Safety
Moderators: Ian Johnston, The Engine; Sheryl Greenberg, MIT Industrial Liaison Program

Table 7: Climate, Sustainability & Human Health
Moderators: Loretta Roberson, Marine Biological Laboratory; David Des Marais, MIT; Otto X. Cordero, MIT

Table 8: Industries, Economies & Peoples
Moderators: Ellan Spero, MIT; Ashley Beckwith, Foray Bio

Table 9: National Security
Moderators: Kerri Dugan, Applied Research Institute; David Markowitz, Strategic Technology & Research

APPENDIX B: WORKSHOP PARTICIPANTS[5]

Name	Affiliation	Title
Adam Caparco	Northeastern University	Assistant Professor of Chemical Engineering
Aimee Rose	Activate	Executive Managing Director
Alex Li	Wyss Institute	Business Development
Andee Wallace	Robigo	CEO & Founder
Ashley Beckwith	Foray Bio	CEO & Founder
Bharti Singhla	Momentum Capital	Principal Investor
Catarina Madeira	MIT	Director, MIT Startup Exchange
Chloe Chong	Singapore Economic Development Board	Regional Director
Chris Love	MIT Initiative for New Manufacturing	Professor of Chemical Engineering
Christine Ortiz	MIT	Professor of Materials Science and Director, Technology & Policy Program
Cullen Buie	MIT	Professor of Mechanical & Biological Engineering
Dan Morden	Veteran; Prior Founder	Managing Partner
David Des Marais	MIT	Associate Professor of Civil & Environmental Engineering
David Markowitz	Strategic Technology & Research	Chief Scientist
Deepa Rao	Engine Ventures	Associate
Domitilla Del Vecchio	MIT	Professor of Mechanical & Biological Engineering
Don Pinkerton	Ragon Institute	Director of Education and Outreach
Elizabeth Kennedy	Activate	Director of Government Relations
Ellan Spero	MIT	Instructor, Technology and Policy Program & Materials Science & Engineering
Felicity Meyer	BoxOne Ventures	Investment Manager - Cleantech
Floris Engelhardt	Kano Therapeutics	CEO & Co-founder
Gabriella Carolini	MIT	Associate Professor of Urban Studies
Hemai Parthasarathy	The Engine	Executive in Residence
Ian Johnston	The Engine	VP of Tech Translation and Ecosystem

[5] Workshop participants who opted in to be listed as contributors to this report from approximately 100 workshop attendees.

Jared Auclair	Northeastern University	Dean, CPS and Director Bioinnovation
Jing Cox-Orrell	American Student Assistance	Associate Director, Youth Initiatives
Jing-Ke Weng	Northeastern University	Professor of Chemistry & Chemical Biology & Bioengineering
John Vroom	Kano Therapeutics	Chief Business Officer & Co-founder
Julie Diop	MIT	Executive Director, MIT Initiative for New Manufacturing
Kamesh Narasimhan	N/A	Scientist
Kathryn Brink	BioMADE	Associate Director, Strategic Initiatives
Kevin Statz	Pirouette Pharmaceuticals	Vice President of Commercialization
Kerri Dugan	Applied Research Institute	Senior Vice President for Biotechnology Programs
Kitty Sahin	Avantor (former)	Former EVP / Strategic Advisor
Liana Frey	MIT	Managing Director, Climate Project
Lily Fitzgerald	MassTech Collaborative	Director, Center for Advanced Manufacturing
Loretta Roberson	Marine Biological Laboratory	Associate Scientist
Mae Tobin-Hochstadt	Year Up United	Senior Director, Solution Development
Marika Ziesack	Wyss Institute	Senior Scientist
Mark Bathe	MIT	Professor of Biological Engineering
Mathias Kolle	MIT	Associate Professor
Natalie Kuldell	BioBuilder Educational Foundation	Founder and Executive Director
Nate Tedford	Ginkgo Bioworks	Senior Vice President, Foundry and Operations
Norman Wen	PHAB Products	Founder
Olek Pisera	Synlibris	Founder
Otto X. Cordero	MIT	Associate Professor of Civil & Environmental Engineering
Rachel Field	Engine Ventures	Principal
Rebecca Sherbo	Northeastern University	Assistant Professor of Chemistry and Chemical Biology
Robin Wolfe Scheffler	MIT	Associate Professor of Science, Technology & Society

Ryan Macpherson	AccelR8 Ventures	Partner
Sanjay Krishna Ravichandran	SeiaBio	R&D Intern
Sarah Glaven	Princeton University	Gerhard R. Andlinger Visiting Fellow
Sheryl Greenberg	MIT Industrial Liaison Program	Director
Timothy Brister	T.West Consult	Principal Consultant and Entrepreneur
Vinny Beranek	Engine Ventures	Partner
Will Rasky	Mass Ave Strategies & MIT Engine	Policy Advisor
Willie Reaves	Cellino	Head of Public Engagement
Wilson Wong	Boston University	Professor of Biomedical Engineering
Yuri Ramos	MIT Industrial Liaison Program	Director

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APPENDIX C: ADDITIONAL FRAMEWORKS AND CONCEPTS

Innovation Organization: The framework adapted from Bill Bonvillian's book, Pioneering Progress: American Science, Technology, and Innovation Policy, MIT Press (2024) that describes the essential ingredients for any industrial transformation. The subset of these factors that were the focal points of discussion in this workshop pertinent to advancing the bioeconomy were:

1. Basic R&D: Foundational research and discovery
2. Education & Workforce: Human capital development
3. Manufacturing & Distribution: Production and delivery systems
4. Policy & Regulation: Enabling legal and regulatory environment
5. Investment Capital: Funding mechanisms across development stages

Goals & Impacts: These were the four domains of societal benefit of the bioeconomy that were chosen as major topics of discussion at the workshop by participants, motivating the advancement of the bioeconomy for US prosperity:

1. Supply chain durability, autonomy, and safety
2. Climate, sustainability, and human health
3. Industries, economies, and peoples (regional revitalization)
4. National security

Technology Readiness Levels (TRL):

- TRL 1-3: Basic research, proof-of-concept
- TRL 4-6: Validation, prototype, demonstration
- TRL 7-9: System prototype, qualification, production

Valley of Death: The gap between promising laboratory research and commercial viability where many innovations fail due to lack of translation funding, scale-up expertise, and patient capital.

Triple-Helix Model: Innovation system integrating three institutional spheres:

- Academia: Discovery, talent, open science
- Government: Funding, translation, regulation, strategy, research & development
- Industry: Commercialization, manufacturing, markets

End of Report

This high-level report synthesizes discussions from the MIT-Engine Bioeconomy Workshop held October 31, 2025 at The Engine in Cambridge, Massachusetts, USA. The workshop was carried out under The Chatham House Rule. It represents the collective insights of the workshop participants, but it does not reflect the official positions of MIT, The Engine, participating institutions, or individual attendees. *We are grateful to The Engine for hosting the event and assisting with logistics, and to the MIT Human Insight Collaborative (MITHIC) for providing food and refreshments at the workshop.*