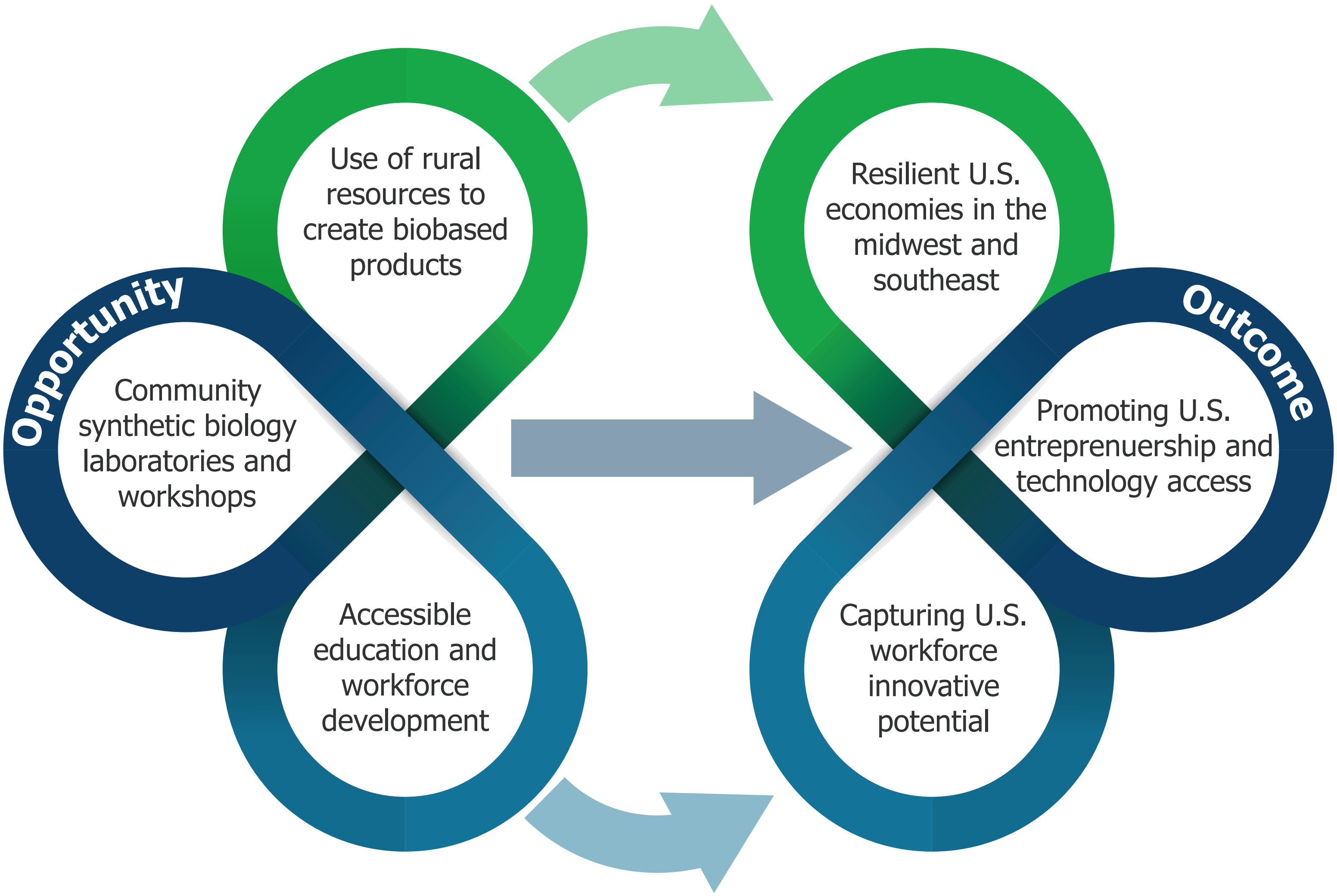
EBRC Engineering Biology Research Consortium

Policy Paper

Actions to Enable an Equitable and Innovative U.S. Bioeconomy

Creating Equitable Biotechnology Innovation Regions throughout the United States

May 2022



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doi.org/10.25498/E4X59D

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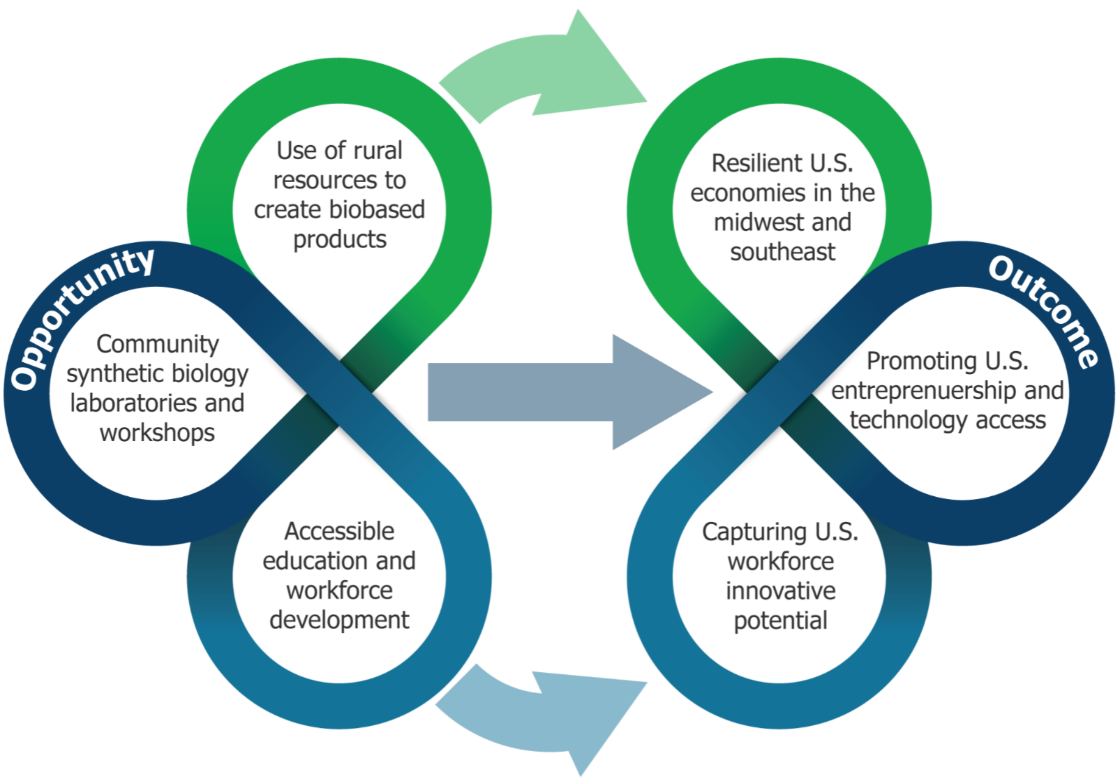

Summary

The fourth industrial revolution, categorized as involving the fusion of physical, digital, and biological technologies, will likely be fueled by operationalizing engineering biology research and biomanufacturing. Advancing the bioeconomy, (the share of the economy based on products, services, and processes derived from biological resources), can position the United States to capture promising economic opportunities across diverse demographics in a sustainable way. Critical to maximizing the benefit of these opportunities is the development of a diverse workforce with a plethora of perspectives to cultivate the disruptive technologies that address national and global needs. Distributing the benefits, services, and opportunities that come with the emerging bioeconomy also creates a more equitable science and technology enterprise where participants have an equal opportunity to pursue economic prosperity. If the goals of a future U.S. bioeconomy are to create an internationally competitive ecosystem, harness the full innovative potential of the United States, and create economic resilience in historically underserved communities; then investments should aim to establish accessible workforce development opportunities, community synthetic biology labs, and focus on the ability to transform rural biomass resources into biobased products. By developing a bioeconomy that is equitable and inclusive, the United States can address moral imperatives and the enterprise opportunity to ensure the

prosperity of all citizens and fully leverage the strengths of the United States to be technologically competitive for the next generation.

Key Points

Several government agencies, (including the Economic Development Administration and the National Science Foundation), and philanthropy organizations are examining ways to develop the regional capacity of different parts of the country to better cultivate and economically benefit from technology development. These agencies and organizations can harness the incredible economic opportunities emerging from advances in engineering biology, biotechnology, and biomanufacturing through targeted developmental strategies:

1. **Investments should incorporate accessible workforce opportunities in biotechnology, biomanufacturing, and engineering biology;**
2. **Investments should focus on building up the capability of these rural, midwest, and southeastern regions to cultivate and transform their biomass resources into biobased products;**
3. **Investments should encourage the development of local community spaces that teach synthetic and engineering biology.**

Investment in the Bioeconomy

Engineering biology is a promising field that draws upon chemistry, biology, computer science, and engineering to harness the powers of nature to create valuable products and services through biotechnology. (*1*) Although biotechnology is often first thought of as focused on health and medicine, it in fact impacts a large diversity of economic sectors, including industrial chemicals and materials, energy, environment, food, and agriculture. (*2*) The comprehensive diversity of economic sectors that engineering biology can impact, collectively termed the bioeconomy, makes it an incredibly valuable area of investment to catalyze resilient economic growth. In 2020, a report from the National Academies of Sciences, Engineering, and Medicine estimated the 2016 U.S. bioeconomy[1] accounted for $959.2 billion, or 5%, of GDP. (*3*) Alongside this large effect on GDP is a concordant increase in jobs. For example, USDA's BioPreferred Program, which expands and develops the market for biobased products, determined that the biobased industry accounted for 1.68 million job opportunities. (*4*) Furthermore, a 2020 report from McKinsey determined that the upcoming biotechnology revolution could add $2-4 trillion to annual direct economic potential globally in 2030–40 and that up to 60% of the world's physical inputs, such as industrial chemicals, could be made through biological means. (*5*)

As many of the resource inputs for biotechnology involve plants and microorganisms, the resulting industry is actively positioned to provide a sustainable form of enterprise development using renewable and environmentally friendly inputs. Given this sustainability angle, the bioeconomy is seen as a promising vehicle to address inequity barriers, provide job opportunities, and address sustainable development goals. To better improve workforce access, bioeconomy policy coalitions are examining ways to mitigate barriers to workforce entry and increase job access with historically excluded communities. To achieve these goals, agencies and organizations should examine how investments critically affect underserved populations. Additionally, policymakers should engage in meaningful dialogue with those regionally affected by potential investment to ensure that all participants are achieving mutually beneficial impact. A bioeconomy that serves and benefits all of society must meet participants where they are and provide every citizen a chance to compete in the new enterprise. Bioeconomy funders, such as philanthropists and government entities, can incorporate many different strategies to engage in equitable bioeconomy investment. Chief among these are identifying, developing, and sustaining collaborations with minority-owned businesses, minority-serving institutions, and regional development councils outside of traditional venture capital areas.

[1] The National Academies of Sciences, Engineering, and Medicine defines the bioeconomy as "economic activity that is driven by research and innovation in the life sciences and biotechnology, and that is enabled by technological advances in engineering and in computing and information sciences." It generally divides the bioeconomy into three domains, agricultural, biomedical, and bioindustrial.

Federal Activity for Bioeconomic Advancement

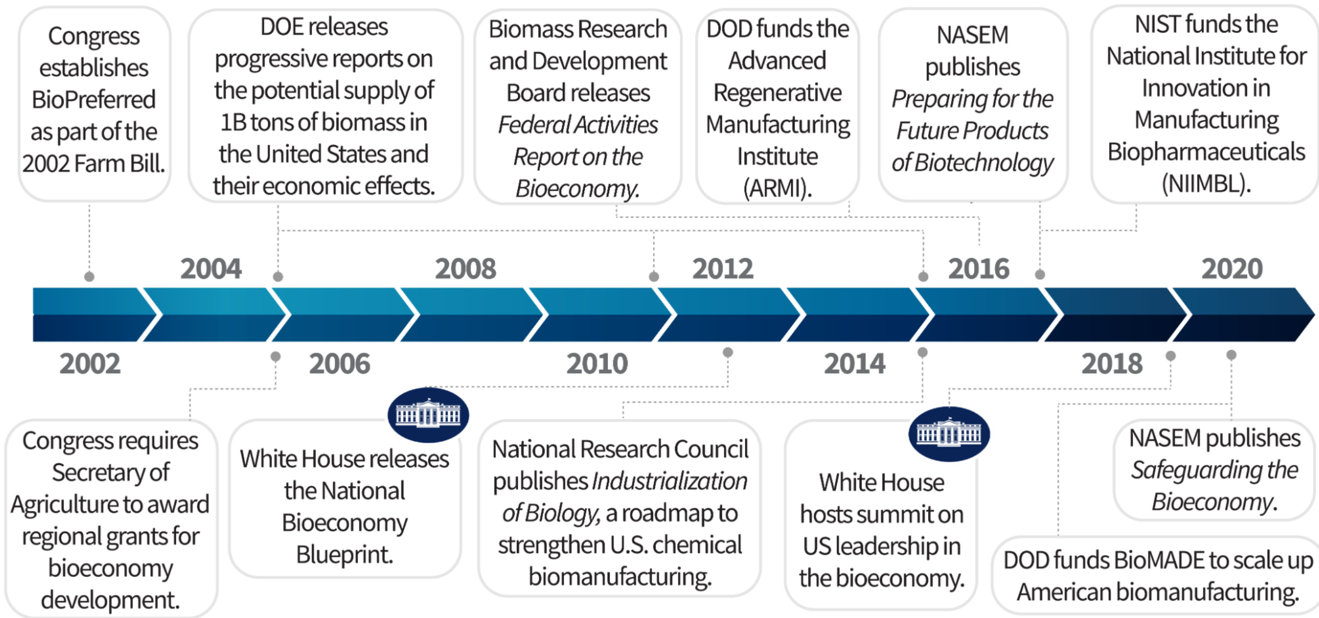

Figure 1. Notable Activities Relating to the Bioeconomy. A nonexhaustive timeline showing actions to promote the U.S. bioeconomy. Many of these developments have been aiding the engineering biology and biomanufacturing enterprise to scale up from fundamental research efforts to become commercially viable. Strategic, informed investments towards development can further aid the ability of the bioeconomy to address national and global needs by more equitably distributing funding and taking advantage of America's diverse workforce. The acronyms are DOE: Department of Energy, DOD: Department of Defense, NASEM: National Academies of Sciences, Engineering, and Medicine, and NIST: National Institute of Standards and Technology.

Over the past decades, the pace of federal activity relating to the development of the U.S. bioeconomy has increased. In 2002, Congress established the BioPreferred program to promote the purchase and use of biobased products across the federal government. (*4*) In 2012, the Obama Administration released the Bioeconomy Blueprint, which laid out strategic objectives to realize the full potential of an American bioeconomy. (*6*) Between 2005-2016, the Department of Energy released multiple reports outlining the modeling, economic analysis, and sustainability benefits of cultivating 1 billion tons of biomass for the United States for use in a biobased economy. (*7–9*) In 2016, the Biomass R&D Board, composed of representatives from several agencies, released a federal activities report on the bioeconomy followed by an implementation framework in 2019. (*10*, *11*) In 2016, the Department of Defense established the Advanced Regenerative Manufacturing Institute to "make practical the large-scale manufacturing of engineered tissues and tissue-related technologies [and] to benefit existing industries and grow new ones." (*12*) In 2020, the Department of Defense established BioMADE, whose mission is to "enable domestic bioindustrial manufacturing at all scales, develop technologies to enhance U.S. bioindustrial competitiveness, de-risk investment in relevant infrastructure, and expand the biomanufacturing workforce to realize the economic promise of industrial biotechnology." (*13*) Among its $250 million annual investment in bioeconomy and biotechnology research, the National Science Foundation has identified biotechnology as an *Industry of the Future* (*14*). The National Institute of Standards and Technology has several initiatives to measure the developing bioeconomy, including reference manuals and standards for measuring the bioeconomy. (*15*) In 2021, the Congressional Research Service published a report, *The Bioeconomy: A Primer* which more extensively covers other relevant proposed bills, congressional and federal activity for the bioeconomy. (*16*)

The Biden Administration has many priorities concordant with bioeconomy development. The American Jobs Plan calls for the country to "revitalize manufacturing, secure U.S. supply chains, invest in R&D, and train Americans for the jobs of the future".

(*17*) They identify biotechnology as a critical technology that should be targeted for investment in research infrastructure, with biofuels and bioproducts mentioned as a targeted breakthrough solution to the climate and sustainability crisis. Additionally, the Infrastructure Investment and Jobs Act includes $550 million for advanced manufacturing and industry of the future research centers (*18*). Lastly, as of the date of this paper, the Senate's Innovation and Competition Act and House's America COMPETES Act aim to catalyze regional development of technological capabilities across the country. (*19*)

Federal Programs to Regionally Build the Bioeconomy in Rural Areas

Agriculture and forest products are necessary to build the bioeconomy; as such, several programs are currently focused on building regional infrastructure in rural areas. The Economic Development Administration already maintains economic develop programs such as Build to Scale, which aims to "further technology-based economic development initiatives that accelerate high-quality job growth, create more economic opportunities, and support the future of the next generation of industry-leading companies" (*20*) and the Small Business Administration seeks to connect regional innovation clusters to small businesses through their Regional Clusters Initiative. (*21*) The Department of Agriculture Rural Business Development grants similarly may be used for technology-based economic development, rural business incubators, and community economic development. (*22*) To note the already rising opportunities in the bioeconomy, 8 of the 60 finalists in the Economic Development Administration's Build Back Better Challenge were proposals primarily focused on biomanufacturing or biotechnology. (*23*)

Diversity, Inclusivity, and Equity as Pillars for Engineering Biology Innovation

There has been an increasing effort to ensure the science, technology, and the innovation enterprise becomes more diverse, culturally inclusive, and provides equitable access and benefits to all people. (*26*) The collective efforts of diversity, equity, and inclusion, commonly grouped under the acronym DEI, have been the focus of recent academic, industry, and government efforts due to a societal recognition that moral imperatives and national workforce cultivation standards have not been met. Herein, DEI will be defined by The Biden-Harris Administration's Executive Order on Diversity, Equity, Inclusion, and Accessibility in the Federal Workforce. (*27*) Diversity refers to the "practice of including the many communities, identities, races, ethnicities, backgrounds, abilities, cultures, and beliefs of the American people, including underserved communities." Equity "means the consistent and systematic fair, just, and impartial treatment of all individuals, including individuals who belong to underserved communities that have been denied such treatment." Inclusion means "the recognition, appreciation, and use of the talents and skills of employees of all backgrounds." It's essential to recognize that actions and investments may affect the separate components of *D*, *E*, and *I* differently. For example, recruiting efforts may work to increase the diversity of a workplace, or cultural wellness seminars may increase inclusivity, but they may not have a substantive impact on equity. The esoteric nature of determining equity can make assessing the *equitable impact* of actions or investments challenging, if not sometimes partisan. One element of equity, market access and opportunity, is incredibly valued across political and ideological boundaries. For example, it is recognized that historically underrepresented communities, defined by their geographic location or their societal demographics, can be given equitable federal research investment. In the case of societal demographics and ethnicities, investment opportunities can be given to underrepresented populations equal to the majority; in the case of geography, investment opportunities can be given to the southeast and midwest equal to that of the coastal cities (see Figure 2). Equitable impact can be tricky to measure or invest in, but there are promising opportunities with the emerging bioeconomy that serve this purpose and further other national objectives.

There is also a moral imperative to engage in these efforts. The demographics of the United States are rapidly changing. For the first time in 2019, most new hires of prime age workers (ages 25-54) were people of color. (*28*) In 2020, the U.S. population under the age of 18 became "majority-minority", where the collective number of racial and ethnic minorities exceed those of white backgrounds. (*29*) It therefore makes sense that the workforce of tomorrow is predicted to encompass much more racial and ethic minorities and include more female representation. (*30*) The projected growth of multiracial, racial, and ethnic minorities, there remains vast inequities in pay. The 2021 4th Quarter Weekly Earnings of Wage and Salary Workers news release revealed that "median weekly earnings of Blacks ($805) and Hispanics ($799) working full-time jobs were lower than those of Whites

($1,030) and Asians ($1,384)". (*31*) These income disparities increased across life stages, reflecting the cumulative effects of disparities over a lifetime. For engineering biology to best address the needs of a diverse population, its workforce and participants must reflect that diversity. This conviction is reflected in a workshop report from the National Academies of Sciences, Engineering, and Medicine titled "Addressing Diversity, Equity, Inclusion, and Anti-Racism in 21st Century STEM Organizations" which concludes that DEI is needed to build public trust in science institutions, specifically include participants to positions of leadership due to their background, and address health disparities affecting residents of the United States. (*32*) A large portfolio of long-term solutions will be needed to remediate these issues, but we must examine accessible solutions within reach now that promote immediate action while concurrent, longer-form efforts strive towards a more just future.

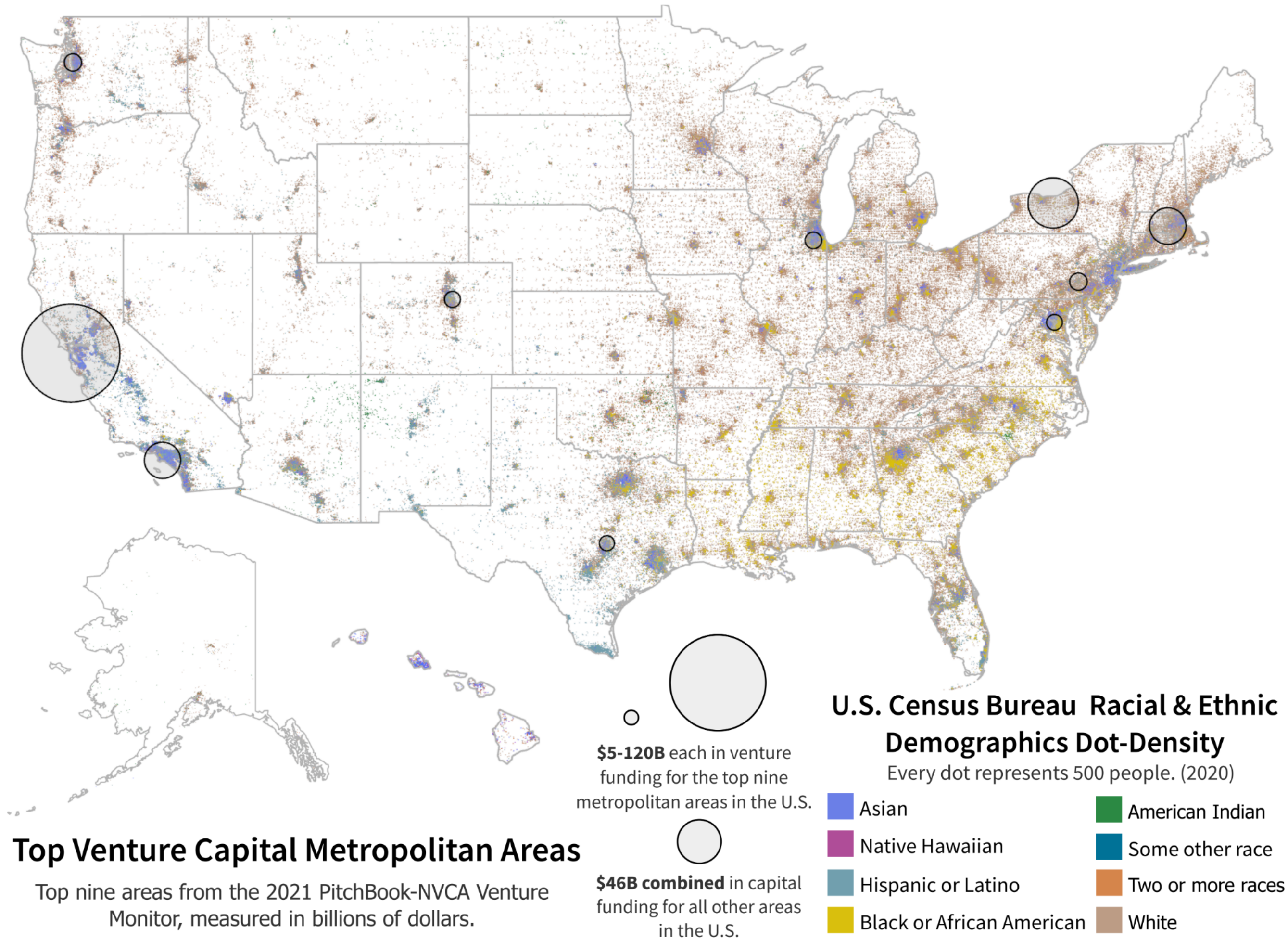

Figure 2. Opportunities for equitable, impactful investment lies within the southeastern and midwestern United States. The image shows a map of U.S. demographics and the top ten metropolitan areas for venture capital funding. Many racially and ethnically diverse areas, as well as the southeast and midwest, have lacked major venture investment relative to coastal cities. The racial and ethnic demographics are represented through a geographic dot density plot with data from the 2020 U.S. Census compiled by Esri. (*24*) Each dot represents 500 people according to the color-designated racial demographic and ethnicity groups. Additionally included in this map are the top ten metropolitan areas for 2021 venture capital investment represented by concentric black circles scaled to the relative proportion of funding they received. The total aggregate of all other metropolitan areas not in the top ten is shown to the right of the map. This data is publically available from the PitchBook-NVCA Venture Monitor.(*25*)

The implementation of equitable investments can also yield powerful effects on building the innovative capacity of the country. While much technological development has been enabled where venture capital resources are immediate (such as the San

Francisco Bay Area and Boston, see Figure 2), investments are beginning to examine how to promote technological growth in parts of the country outside of these traditional hubs. In the United States, the southeast and Midwest have an abundance of biomass that can be used to manufacture biobased products, yet have not seen substantial investment (Figure 3). Several agencies are pursuing equitable economic opportunities in science and technology, including the Department of Commerce's plan to invest in regional industry clusters and the National Science Foundation's Regional Innovation Accelerators. (*14*, *33*) An essential factor in these investments is acknowledging that several parts of the country have been historically excluded from technology and research investments. These areas represent a key opportunity to build technology hubs that promote science and technology competitiveness across the United States and leverage unmet talent in populations where they are. A challenging factor is identifying what strategic resources these regions have and how they can cultivate accessible economic opportunities and growth.

Success in the bioeconomy is already dependent upon a diversity of technical perspectives (e.g. from computer science, biology, engineering, and chemistry). Similarly, an engineering biology workforce composed of diverse individuals that bring their unique talents, ideas, and perspectives to the enterprise will enable the innovation necessary to identify and tackle complex challenges Policymakers and industry leaders are examining strategies to increase diversity, equity, and inclusion in biotechnology and STEM enterprises. In their survey analysis, Biotechnology Innovation Organization found that 71% of organizations stated that they value and/or prioritize diversity and inclusion indicating it is important for better business results and serving a broader customer base. (*34*) In addition, in 2018, the U.S. National Science Council stated that "[a]lthough improved access to STEM education on its own will not create equal representation within STEM fields, equitable access is an essential priority for the Nation." (*35*) Numerous studies have measured the benefits of diversity, equity, and inclusion towards innovation and productivity. These benefits include, but are not limited to, increased innovation in the sciences, greater profitability in industry, and improved business performance by growing knowledge-based perspectives. (*36–38*) These effects can be powerful—a research article determined that a group of diverse problem solvers can outperform groups of high-ability problem solvers. (*39*)

Federal Activity in Creating Equitable Opportunities for Underrepresented Americans

During the 2020 presidential campaign and transition, the (now) Biden Administration's articulated vision for cultivating science and technology for the United States was captured in several places: the campaign's *Build Back Better* principles (*40*); a letter to Dr. Eric Lander (then Science Advisor-designee) with five guiding questions to reinvigorate American science (*41*); and the American Jobs plan (*17*). A central theme emerging from these documents is that the opportunities that arise with science and technology, such as economic prosperity and access to higher education, should be dispersed more equitably with communities across the country. Encompassed in the Build Back Better pillars, there is a focus on creating a "Clean Energy and Sustainability Accelerator that will invest in projects around the country, while delivering 40% of the benefits of investment to disadvantaged communities." (*40*) Of the five guiding questions within the letter to Dr. Lander, two are directly concerned with the equitable impact of science and technology to underrepresented communities: "How can breakthroughs in science and technology create powerful new solutions to address climate change—propelling market-driven change, jump-starting economic growth, improving health, and growing jobs, especially in communities that have been left behind?" as well as "How can we guarantee that the fruits of science and technology are fully shared across America and among all Americans?" (*41*) The American Jobs Plan makes several remarks towards workforce development initiatives designed to improve racial and gender equity with a $100 billion investment in "proven workforce development programs targeted at underserved groups." (*17*) Overall, the Biden Administration has predominantly focused on increasing science and technology access to diverse racial, socioeconomic, and geographic audiences. Its definition of innovation is broadened beyond the *status quo* definition of novelty to incorporate the betterment of society through equitable outcomes. In addition, several initiatives are underway in several federal agencies and interagency working groups to promote a diverse STEM workforce. (*35*, *42–44*) Among some of the top strategies are collaborating with minority-serving institutions to promote STEM workforce development programs and engaging in dialogue with communities generally excluded from funding access. Collectively, these strategies indicate that there is a simultaneous need to expand on successful, past strategies that have created equitable outcomes for underserved populations, while additionally examining new approaches that can deliver meaningful outcomes to underserved groups. Emerging science and technologies, such as those emerging with the bioeconomy, could be a pivotal ground for developing these outcomes.

Equitable Opportunities with Engineering Biology, Biotechnology, and Biomanufacturing

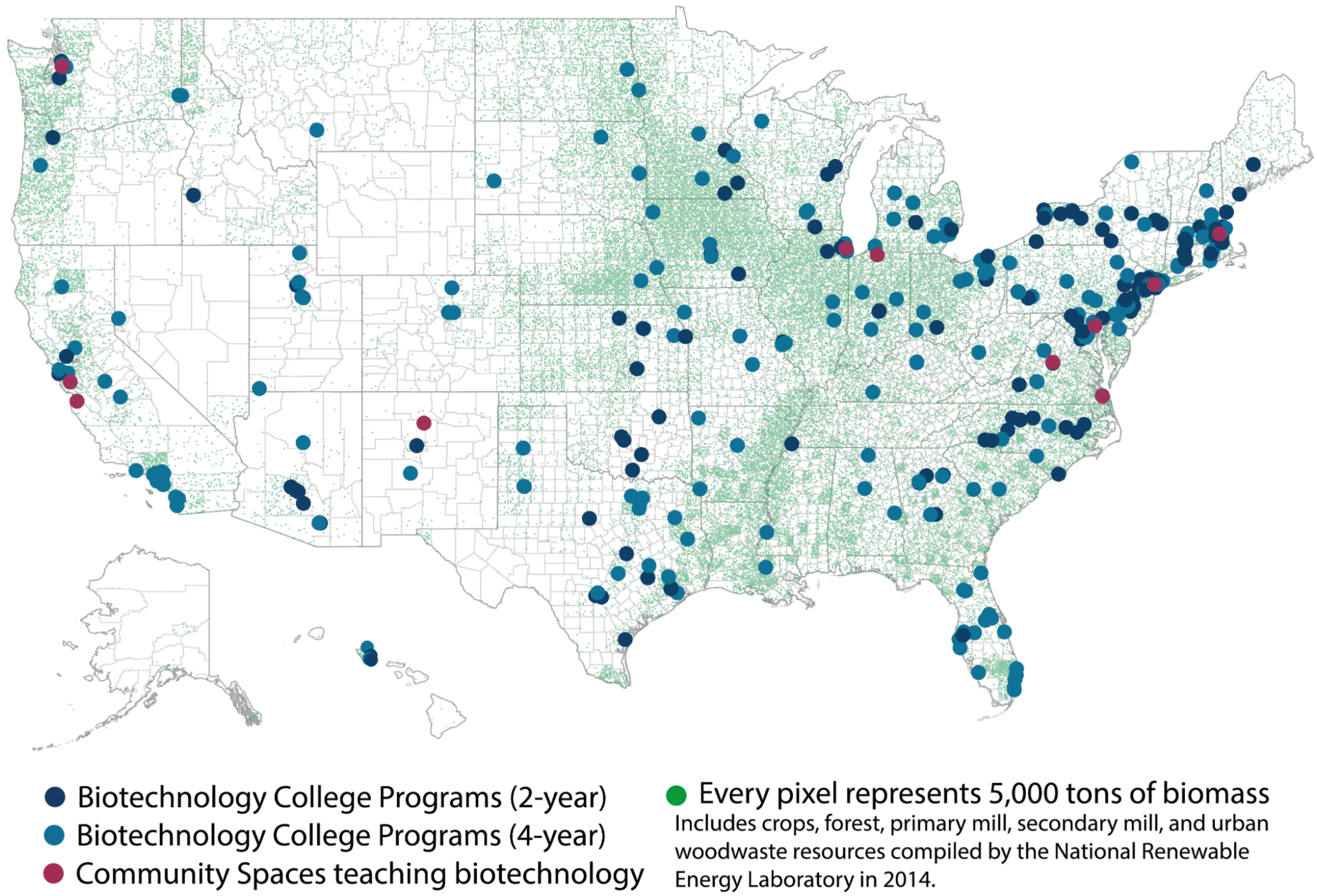

Figure 3. Biotechnology educational infrastructure is poised next to available biomass for bioeconomy development. A map of the United States is shown with several markers showing the available biomass resources (green dots), biotechnology college programs (navy blue and teal circles), and biology community labs (red circles). The map was constructed through ArcGIS. Data is publically available and sourced in regards to biomass from the National Renewable Energy Laboratory (*45*), college programs from the National Center for Education Statistics' College Navigator database (*46*), and community labs from diyBIO (*47*). "College Navigator consists primarily of the latest data from the Integrated Postsecondary Education Data System (IPEDS), the core postsecondary education data collection program for NCES – the National Center for Education Statistics." Biotechnology programs were identified as programs with the search terms Biology/Biotechnology Technology/Technician, Biotechnology, Biological/Biosystems Engineering, and Bioenergy in the program/majors selector.

Although disruptive science and technology in the biological sciences and engineering are often thought to only promote economic opportunities to those with a postgraduate education, engineering biology vastly expands the economic prospects that emerge with biotechnology, including more accessible jobs that only require an associate-level degree or certifications that can be taught at community colleges. The opportunities that engineering biology provides are numerous, though pivotally includes building technology hubs outside of the United States coastal regions through agriculture and forestry resources as feedstocks to create biobased products. Additionally, unique collaborative opportunities, such as community biology labs, represent unique pathways to facilitate everyday involvement within the field and build community entrepreneurship, resilience, and education. Altogether, engineering biology can meet underrepresented or underserved Americans *where they* *are* and welcome them into the ecosystem as full participants (Figure 3).

Inclusive Workforce Development Opportunities

General Educational Attainment	Engineering and Manufacturing	Agriculture, Life, and Physical Sciences	Infrastructure	Operations, Management, and Business	Education, Communication, and Outreach
Advanced	Lead Engineer Senior Fermentation Specialist Senior Computational Scientist	Senior Scientist Senior Natural Resources Engagement Specialist	Design Engineers Architects	Senior Policy Analyst Business Operations Analyst/Manager Lead Attorney	Bioethicist Education Program Manager
Bachelors	Engineer Computer Scientist Chemist	Physical or Life Scientist Forester Nutritionist	Environmental Health and Safety Manager Plant Manager	Business Operations Assistant Economicist Community Partnerships Coordinator	Writer - Editor Public Affairs Specialist Educator Scientific Illustrator
High School or Associates	Computational Technician Winemaker/Fermentor Quality Control Technician	Farmer Physical, Life, or Forestry Sciences Technician Laboratory Assistant	Industrial Equipment Mechanic Safety Technician Plant Operator	Legal Assistant Information Technology Sales Specialist	Educational Aide Graphic Designer

Figure 4. Bioeconomy jobs can promote economic access to technology careers, especially with many jobs only requiring a high school or associate's degree. A table is shown above separating jobs by their general requirements for education. In several of the bachelor degree jobs, career experience may be substituted in lieu of a degree.

If a goal of technology infrastructure investment is to create inclusive economic opportunities, then investments should incorporate accessible workforce opportunities in biotechnology, biomanufacturing, and engineering biology.

Building accessible opportunities for the pre-baccalaureate workforce

Although engineering biology and biomanufacturing careers are frequently viewed as needing a graduate degree level of training for workforce entry, joining the biotechnology workforce is actually very accessible to many demographics. As reported in the 2021 Life Sciences Workforce Trends Report, "the [life sciences] industry employs one-third of its workforce in jobs typically requiring more training or education beyond a high school diploma but less than a bachelor's degree—the important middle-skills workforce." (*48*) The biomanufacturing industry, beyond scientists and engineers, needs technicians, office and administrative support, production teams, information technology, communication, construction, policy, and transportation support - all of which professional certification may require little beyond a high school level diploma (Figure 4). For example, the Mid-America Regional Council conducted a 2017 labor analysis of the Kansas City life sciences industry and reported that 9/10 of the fastest-growing life science manufacturing jobs (including plant operators, supervisors, inspectors, testers, and technicians) required only a high school diploma (*49*). Organizations such as the nonprofit BioBuilder Educational Foundation have demonstrated that synthetic biology curricula for high school students, high school apprenticeship programs, and outreach is not only possible, but incredibly practical for providing hands-on training and lessons to promote biomanufacturing workforce entry (*50*).

There has been much promising development on accessible workforce development pipelines, including community college, certification, or high-school targeted programs. Still, there are opportunities to expand the presence of these programs to underserved parts of the country and scale up existing efforts.

Many community colleges have begun to form accessible biomanufacturing and biotechnology workforce training programs. For example, the InnovATEBIO National Center for Biotechnology Education, which provides leadership in biotechnology technical education, serves 129 biomanufacturing and biotechnology college programs across 39 states. (*46*) These programs play pivotal roles in their local communities by providing educational access to skill development. Hundreds of biotechnology companies (particularly in the biopharmaceutical industry) are recognized as hiring community college graduates of these biomanufacturing programs, including large employers like Gilead, GlaxoSmithKline, and Genentech, suggesting a high demand for the talent generated from these programs. (*51*) There is a committed effort of high school educators dedicated to promoting biotechnology workforce development. Currently, eighty-seven K-12 schools partner with InnovATE*BIO* that participate in biotechnology credentials, internship opportunities, course sequences on biomanufacturing, and college credit courses. (*52*) Although this number is phenomenal, there is much room for growth.

Some community colleges collaborate with local biotechnology companies to identify and teach the skills needed locally. Partnering companies often hire directly from the affiliated program. For example, Solano Community College Industrial Biotechnology track includes laboratory practice, regulatory and business affairs, and biotechnology instrumentation. (*53*) Solano Community College specifically cites industry partners who often hire from their program, including Genentech, Jannsen Pharmaceuticals, and BioMarin. (*54*) In addition to their bachelor's degree, this program also creates different certification standards where local community members can take streamlined or abbreviated courses to gain entry into the workforce. (*53*) Among its degree-granting programs, these certificates serve as accessible academic credentials that individuals from different backgrounds with all types of life experiences can acquire. Other examples of certification programs include the City College of San Francisco BRIDGES program. This 8-unit semester-long program prepares students of all backgrounds for a bioscience career. (*55*) Several biomanufacturing programs and training centers, such as the North Carolina Biotechnology Center, have additionally established targeted efforts on transitioning military veterans, service members, and military spouses to biomanufacturing opportunities. (*56*) Overall, investing in community college biotechnology education gives a powerful opportunity to build a diverse, locally-represented workforce accessible to many American families. New programs can seek advice and mentorship from BioBuilder, Solano Community College, and InnovATEBIO as role models for building quality educational experiences.

Enabling accessible workforce opportunities requires the intentional design of services and support for families and individuals in need. Many community colleges and technical programs are examining ways they can increase access in biotechnology or biomanufacturing education. Several biomanufacturing training programs, such as those at Worcester Polytechnic Institute Biomanufacturing Education and Training Center, are creating remote training opportunities to create flexible schedules for individuals with families or jobs. (*57*) Solano Community College offers an "Industrial Biotechnology Intensive Summer Boot Camp," which provides a credential suitable for entry-level laboratory technician programs that can be accomplished in only ten weeks. (*58*) Critically, it's important that these opportunities are low cost, or there are scholarships allotted to prevent financial burden from being a barrier. Alongside more accessible education platforms, services that provide resources for families in need, such as childcare, food and nutrition assistance, and unemployment assistance, can greatly promote impactful opportunities to people who need it most.

Building accessible opportunities for the post-baccalaureate workforce

Engineering biology and biomanufacturing pivotally provide many opportunities for workforce entry without a graduate degree. Alongside developing and shaping these workforce development opportunities, impactful investments can also shape efforts to provide fundamental research opportunities to diverse undergraduate and graduate populations at four-year institutions and community colleges. Several programs, networks, and conferences have been established that provide a solid foundation to further build efforts.

Several initiatives encourage diversity and representation of underserved communities in the post-graduate education field. Critical to having a successful career in science and technology is navigating the complex academic culture that surrounds university laboratories, identifying impactful mentors who have the pedagogical capacity to address mentee needs, and discovering communities of like-minded individuals who serve as collaborators and counselors. These characteristics are not inherently present in every graduate training program. Students from historically underrepresented backgrounds may face additional barriers stemming from their unique circumstances, ultimately creating a high barrier to entry into the field even past the graduate student stage. Several science agency programs, such as the National Institutes of Health Initiative to Maximize Student Development (IMSD) and Post-Baccalaureate Research Education Program, create community-centered cohorts of students in intensive research universities to help facilitate technical training for underrepresented students, especially if their previous training may originate from an academic institution that lacks extensive research facilities. (*59*, *60*)Programs such as the National Science Foundation's Research Experiences for Undergraduates allow undergraduate students to perform research over the summer outside of their home institution, providing valuable hands-on training to cultivate research skills. (*61*) Lastly, large organizations and conferences dedicated to promoting access to STEM opportunities such as the Society for the Advancement of Chicanos and Native Americans in Science (SACNAS), Annual Biomedical Research Conference for Minority Students (ABRCMS), and the AfroBiotech Conference. (*62–64*) These opportunities provide students the ability to connect with mentors, engage with graduate school opportunities, and create professional networks in their research fields. Although many opportunities exist, they do not have the capacity to serve all qualified, interested students and thus need more funding and expansion.

Transforming Rural Resources to Biobased Products

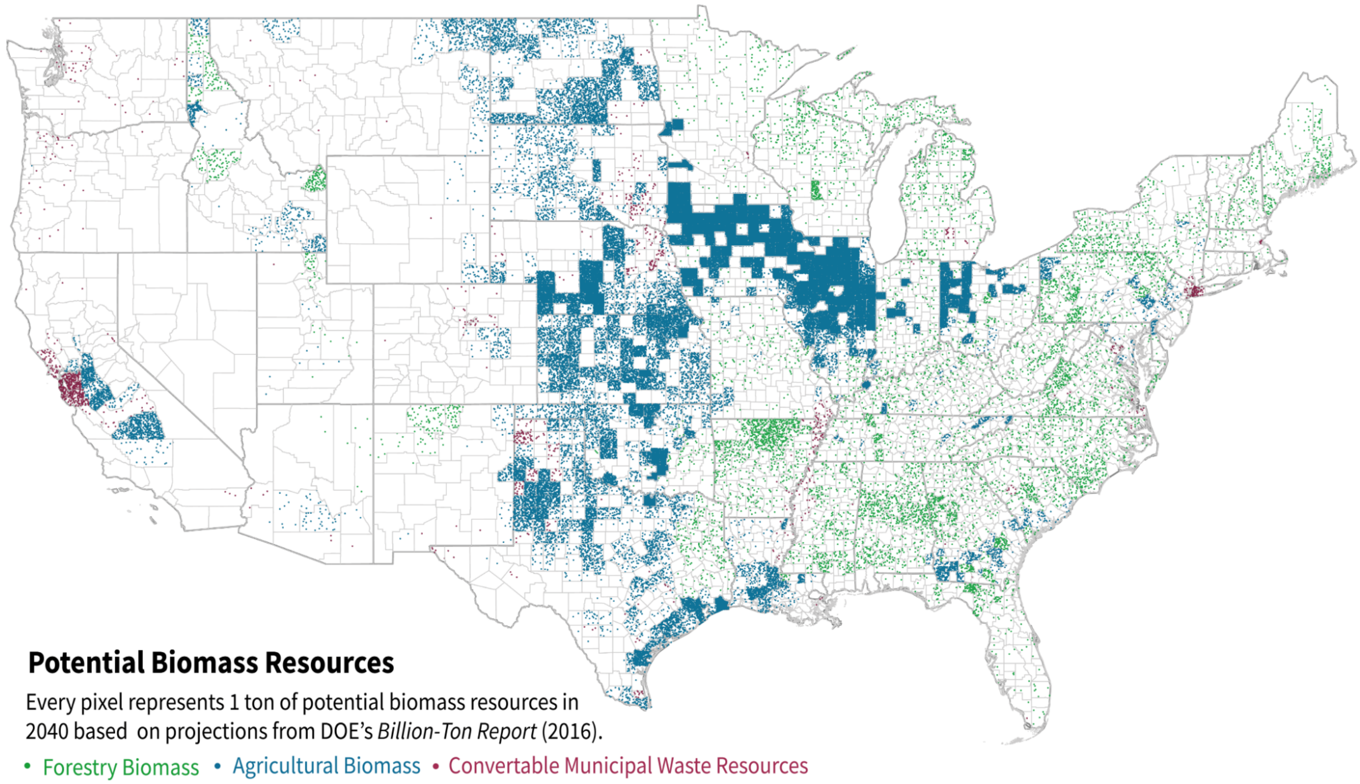

Figure 5. The American southeast and midwest can contain strategic agriculture and forestry resources that can generate opportunities for biobased production. In the map above, county-level potential biomass resources projected for the year 2040 are illustrated using a dot density map, using teal dots for potential agricultural resources, green dots for potential forestry resources, and red dots for potential waste resources. The U.S. Department of Energy published the *2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy* that "evaluates the most recent estimates of potential biomass that could be available for new industrial uses in the future." (*8*) The report projected the amount of potential biomass resources and feedstocks that could be cultivated for use in 2040 by several baseline factors, The scenario shown above assumes biomass supplies available at $60 per dry ton per year or less, forestry will only be impacted by moderate housing and low energy demand, agriculture at a 1% yield increase, and all wastes recorded in the report. Hawaii and Alaska were not included in this dataset, and were therefore omitted from this figure.

If a goal of technology investment is to build economically resilient communities, investments should focus on building up the capability of these regions to cultivate and transform their biomass resources into biobased products.

Biomanufacturing has the potential to transform rural communities by potentially converting agricultural, forestry, or other resources into biobased products. (*3*) Some of these products are essential for U.S. manufacturing and needs, such as life-saving medicines, chemicals, biofuels, and advanced materials. Inputs can vary from fibers, crop residues, or animal waste products and are not necessarily extractive (Figure 5). Biomanufacturing initiatives can support the development and strength of agricultural communities even as the number of farms across the U.S. is falling while contributing to climate and sustainability goals and bringing forward rural America to respond to national needs. Biotechnology-focused educational infrastructure can help secure community interest, buy-in, and workforce. For example, BioBuilder's synthetic biology curriculum has been adopted and adapted in rural Tennessee high schools. (*65*)

A significant economic argument for establishing biomanufacturing in rural communities is the presence of major agricultural, forestry, and land resources that can be used for biobased production. (*9*) Given the potential high transportation costs to move large quantities of biomass to different parts of the United States (*66*), it makes strategic sense to cultivate biomanufacturing hubs close to their biomass feedstocks. Local production of bioenergy could alleviate the cost burden of energy transport to rural America. (*67*) Over the long term, self-sufficient bioenergy can provide numerous advantages to rural areas over urban centers due to local transportation using self-produced biofuel sources. Furthermore, opportunities exist to sustainably incorporate rural waste resources, such as crop residues, forest residues, animal manure, and chicken litter into biomass processing. Economic analyses have illustrated that it's more feasible to convert these waste products into energy than food into energy sources. (*67*–*74*) Additionally, numerous other benefits of noncoastal areas, such as less expensive real estate, tax credits, and cheaper-to-build infrastructure, are cited as key factors that favor biotechnology development throughout the United States. (*75*)

Many in these communities are eager to engage with policymakers and funders, especially towards bioeconomy development, but are often not included in the portfolio of key stakeholders that funders counsel before proceeding with an investment. Funders must engage in meaningful conversations with these communities and make meaningful connections when building the bioeconomy enterprise, especially when resources such as agricultural biomass and land use play an important role. Identifying regional coalitions that incorporate individuals representing the totality of the individual cultures in an area should be considered a heavy priority for funders to identify critical wants, needs, and strategic assets that regional areas can offer. Examples of positive collaborations can be seen between the bioscience network, BioKansas, and the social organization, KC Rising, in promoting inclusive biotechnology careers in the Kansas City metropolitan area. (*76*, *77*)

Enhancing Community Resilience through Local Spaces that Teach Biology

If technology infrastructure investment aims to promote technology access and entrepreneurship, then impactful investment should encourage the development of community-based biology laboratory spaces.

Academic research often requires rigorous training, access to expensive scientific equipment, and specialized technical knowledge to develop the technologies that advance societal interests. Although these components are necessary for society's technological advances, they result in unintentional barriers of access between scientists and the public, who often fund the research with their tax dollars. For engineering biology to best address national and community needs, mechanisms should encourage public participation in research. This participation can lead to identifying the most pressing issues, refining research or a product to serve societal needs best, and providing multiple perspectives that act as input to the scientific process and regulatory issues.

Table 1. Select Examples of Community Laboratory Spaces Focused On Synthetic Biology

Laboratory	*Location*	*Examples of Recent Activities*
Baltimore Underground Science Space	Baltimore, MD	● Active lectures, classes, coursework, private and public projects for the public to investigate the life sciences. Also heavily proactive on biosafety and risk education. ● Active projects in studying yeast, barcoding the harbor, open insulin, efficiently expressing cellulose in bacteria, and characterizing bacteria.
GenSpace	New York, NY	● Provides STEAM education programs for all ages, cultural and outreach events, and contributes to the community lab biosafety handbook. ● Numerous nonprofit, corporate, and academic partnerships to cultivate life science education, public trust, and entrepreneurship.
ChiTownBio	Chicago, IL	● Aims to equip Chicagoans to explore the living world and use it to benefit their community, acquiring physical space. ● Hosts virtual seminars, outdoor nature talks, virtual book clubs to discuss science and technology.
Counter Culture Labs	Oakland, CA	● Aims to democratize synthetic biology, science, and technology to be in the public's hands; additionally efforts in biohacking. ● Active community projects with open insulin, making vegan cheese, kombucha, rice transformation, and BioArt.
BioCurious	Santa Clara, CA	● Organizes meetings, coursework, community, and personal projects and lends space for startups and early-stage biotech companies. ● Active community projects with open insulin, making vegan cheese, kombucha, bioprinting, and studying the dwarf cuttlefish.
Xinampa	Salinas, CA	● Aims to be a catalyst for local talent to nucleate, engage the local economy and innovate the industry. ● Conducts workshops and presentations at community events

Other labs include Biodidact in Los Alamos, NM; Biologik in Norfolk, VA; Biotech Without Borders in Brooklyn, NY; BOSlab in Boston, MA; Open Bio Labs in Charlottesville, VA; HiveBio in Seattle, WA; Scihouse in South Bend, IN; and SoundBio Lab in Seattle, WA.

A unique model from the synthetic and engineering biology community is community laboratories - where individuals can take biotechnology courses or engage in research outside a traditional academic or industry environment. (*78*) Some models of community labs focus on serving as incubation spaces to spur entrepreneurship in the local community; others are focused on developing biology solutions to local issues. Some community lab spaces, such as New York's GenSpace, develop accessible teaching curricula that give practical, hands-on experience conducting biotechnology experiments. (*79*) Some, like ChiTown Bio, focus on allowing community members to have hands-on access to equipment or reagents at a reduced cost to stimulate community members' involvement with the sciences. (*80*) Finally, a number of these community laboratories focus on how their capabilities can address local community issues, such as Salinas Xinampa's focus on how to provide COVID-19 protective equipment to agriculture workers in their community. (*81*) Another promising example is seen with the Open Insulin Project, which defines itself as a "collection of researchers and advocates working to develop an open source protocol for producing insulin that is affordable, has transparent pricing, and is community-owned." (*82*) These several community lab models can cater to communities' unique needs and identities within the United States. One of these community laboratories' most critical features is building public trust and relationships between underrepresented communities and life sciences.

The individual needs and willingness to engage with external organizations can significantly vary between several of these community laboratories; however, needs for philanthropic support, physical space, teachers/volunteers/contributors, and supplies are generally considered desirable. Much of the needed funding would include start-up costs, monthly rent, utilities, and supplies. Funding professionals to develop community-based biology laboratories' organizing body and collective ecosystem is also a need. The activities funded include collaborative and individual research projects, public lectures and workshops, and courses. These spaces also allow an environment where professionals in the biosecurity space can communicate with citizen scientists and understand the current landscape of the growing do-it-yourself biotechnology field. Biosecurity, in its definition of measures that aim to prevent the introduction and/or spread of harmful organisms, is essential to ensure public trust in the engineering biology ecosystem. It's important to note that established community laboratories typically incorporate foundation bylaws or documents that prescribe several safety measures to govern the community. Ensuring that these community spaces have funding for biosecurity professionals, or engagement with biosecurity communities, will be critical for ensuring public trust with biotechnology.

Many corporate social responsibility activities or opportunities in academic outreach can strengthen community resilience through education and community investment. A typical and admirable example is the outreach associated with computational and coding skill development, such as Girls Who Code. (*83*) These activities teach essential job skills to the community, allow young adults to learn about the various careers associated with the technical field, and provide a space for entrepreneurship and growth. These outreach efforts can easily be modeled through private-nonprofit partnerships. For example, Ginkgo Bioworks currently powers a BioBuilder learning lab for synthetic biology workforce development training (*84*), thus allowing the biotechnology company to engage with potential future employees and promote a local workforce.

Discovering means to introduce the excitement, imagination, and wonder of engineering biology to K-12 audiences will be critical for establishing a long-term, sustainable workforce. Although an initial reaction may be to expand the standardized curriculum to more broadly teach biotechnology, it's important to recognize that K-12 teachers are undergoing a massive workforce shortage and are experiencing an overburdened load of job duties, especially in light of the COVID-19 pandemic. In their 2021 State of the U.S. Teacher Survey, the RAND Corporation identified that "[n]early one in four teachers said that they were likely to leave their jobs by the end of the 2020–2021 school year, compared with one in six teachers who were likely to leave, on average, prior to the pandemic." (*85*) The National Education Association espoused some of the reasons for this increased stress, namely shifting workload demands, increased hours, lack of childcare, and lack of teacher input into workload decisions. (*86*) Efforts to introduce biotechnology curricula into K-12 education, minimally, must be done with input from teachers; more preferably, it must be done without adding to their workload. With these major caveats in mind, there are several resources available for biotechnology education. Notably several curricula for biotechnology education, including those with hands-on experiments, have been developed for middle school classrooms. (*87–89*) Activities in science museums and centers, such as those at San Jose's The Tech Interactive, allow tinkering with biology to create sustainable materials - providing a valuable hands-on opportunity that is minimally invasive on teacher workloads. (*90*) Additionally, organizations such as the Engineering Biology Research Consortium and InnovATEBIO maintain a database full of biotechnology instruction resources, outreach activities, and lesson plans. (*91*, *92*)

A Final Thought

The next industrial revolution is poised to be engineered and driven by biology - scientists and engineers can use their imagination and conscience to create biotechnological solutions to address national and global issues. Critically, the bioeconomy can provide inclusive workforce development opportunities accessible to all Americans, provide economic prosperity opportunities for rural towns to grow a circular economy, and promote community resilience through community laboratory spaces. In building a bioeconomy that is competitive and sustainable for the next century, we have the chance to craft an inclusive, resilient, and equitable ecosystem where all workers are welcomed as total participants.

On the creation of this white paper:

This white paper was created through a combination of landscape analyses, literature reviews, and off-the-record interviews with key stakeholders involved with various levels of the bioeconomy. These informational interviews included policymakers, underrepresented communities affected by bioeconomy development, academic professors, biotechnology coalition leaders, and economists. Albert Hinman is a Postdoctoral Fellow at EBRC and may be contacted at awh@ebrc.org. Douglas Friedman is President of EBRC and may be reached at dcf@ebrc.org.

About the Engineering Biology Research Consortium

The Engineering Biology Research Consortium (EBRC) is a non-profit, public-private partnership dedicated to bringing together an inclusive community committed to advancing engineering biology to address national and global needs. We showcase cutting-edge research in engineering biology, identify pressing challenges and opportunities in research and application, articulate compelling research roadmaps and programs to address them, and provide timely access to other key developments in engineering biology.

Funding Acknowledgement

This work was supported by the National Science Foundation under Award Nos. 1818248 and 2116166. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Recommended Citation

Albert W. Hinman and Douglas C. Friedman. Actions to Enable an Equitable and Innovative U.S. Bioeconomy. *Engineering Biology Research Consortium*. 2022. https://doi.org/10.5072/FK2K64KS62

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