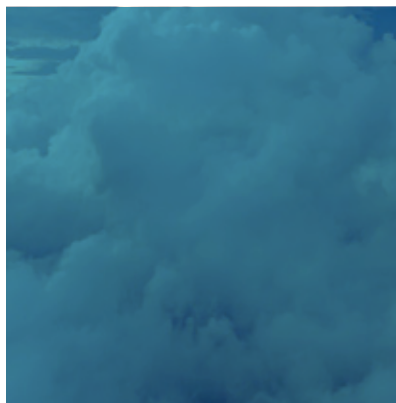
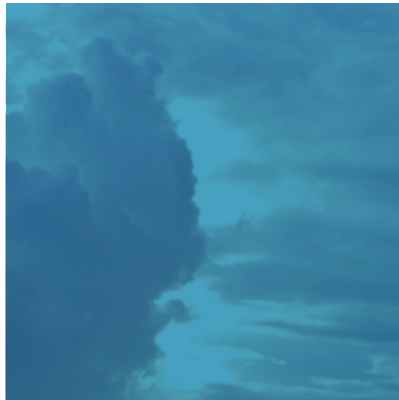




PUBLIC FINANCING FOR AGRICULTURAL DECARBONIZATION AND ABUNDANCE



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EXECUTIVE SUMMARY

In recent years, startups, university researchers, and government laboratories have developed a suite of new technologies capable of revolutionizing agriculture. From electric, autonomous tractors leveraging soil, plant, and satellite data to manufacturing processes that can produce real animal meat grown from a cell and green fertilizers that can increase crop productivity without the need to burn vast amounts of natural gas, innovation underpins the future of agriculture and food. These technologies have the potential to remake our food system for the better by minimizing greenhouse gas emissions, reducing land use, and avoiding animal slaughter, all while continuing to help produce more food.

But these and the many other novel innovations required to decarbonize agriculture are used in only a small fraction of agricultural production today. Bringing these technologies up to scale will require an embrace of public financing and other industrial policies for agriculture.

The Inflation Reduction Act of 2022 (IRA), arguably the most significant piece of climate legislation in U.S. history, appropriated billions of dollars to research, develop, and subsequently fund the deployment of technologies capable of reducing greenhouse gas (GHG) emissions from U.S. and global economic production. But, IRA funding — like much of the climate-focused federal spending in recent years — has centered on energy production, transportation, and infrastructure. While agriculture has received little focus in decarbonization policy, the sector has made strides in improving its environmental footprint.

Over the past half-century, American farmers have increased agricultural yields while reducing the per-unit emissions of many agricultural products. Agricultural productivity growth has made the U.S. the largest agricultural exporter in the world, exporting nearly \$180 billion in agricultural products in 2021 — more than three times the value of U.S. automotive exports in the same year.

But for the United States to achieve decarbonization across its industries, agricultural emissions will need to be diminished further. Agriculture is responsible for 10% of U.S. greenhouse gas emissions and about 25% of the global total. Agriculture is also the single largest user of land in the United States and a major source of air and water pollution. And still, the U.S. has one of the most productive agricultural sectors in the world.

Despite the necessity of new food and agricultural technologies to achieve decarbonization, private sector finance has not been able or willing to fund and build the industries and technologies required to decarbonize the food system. This is not surprising. With some exceptions, private investors are often risk-averse — especially when providing large amounts of funding — and are obligated to seek positive returns. The technologies capable of reducing agricultural emissions while maintaining productivity — electric tractors, alternative proteins, controlled environment agriculture, novel fertilizers, feed additives to reduce methane production in cattle, and much more — all have high potential, but are by no means sure bets.

Ignoring food and farming innovation does not bode well for both decarbonization and the ability of farmers to continue to produce abundant food. During the 2019-2020 fiscal year, food and agricultural technologies received only \$11.9 billion in project-level finance and about \$1 billion in venture capital investments globally, a tiny portion of the estimated need of up to \$218 billion per year to achieve agricultural decarbonization.

This report makes the case for a far more interventionist innovation approach by USDA.

Creating the right policy mixture for the broader challenge of agricultural decarbonization will require understanding the specific problems plaguing firms and technological solutions. Programs aimed at funding the construction of first-of-a-kind facilities, new loan programs designed for agricultural and food technologies and specific tax credits for investments in and production of those technologies are just a few examples of specific solutions to the financing challenges facing emerging industries today.

For agricultural technologies to come to market and provide the climate benefits required to decarbonize agriculture, the federal government will need to invest. Robust funding programs aimed at research, commercial demonstration, and deployment can unlock the crucial technologies needed to accelerate decarbonization and underpin continued agricultural productivity growth.

A person wearing glasses and a light-colored shirt is standing in a field, holding a tablet. They are looking at the tablet. In the background, there is a large, complex structure made of metal beams and cables, possibly a bridge or a large tent. The scene is set in a field with tall grass. The entire image has a teal overlay.

I.

INTRODUCTION

In recent years, startups, university researchers, and government laboratories have developed a suite of new technologies capable of revolutionizing agriculture. From electric, autonomous tractors leveraging soil, plant, and satellite data to manufacturing processes that can produce real animal meat grown from a cell and green fertilizers that can increase crop productivity without the need to burn vast amounts of natural gas, innovation underpins the future of agriculture and food. These technologies have the potential to remake our food system for the better by minimizing greenhouse gas emissions, reducing land use, and avoiding animal slaughter, all while continuing to help produce more food.

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Over the past half-century, American farmers have increased agricultural yields while reducing the per-unit emissions of many agricultural products. Agricultural productivity growth has made the United States the largest agricultural exporter in the world, exporting nearly \$180 billion in agricultural products in 2021 — more than three times the value of U.S. automotive exports in the same year.^{1,2}

But for the United States to achieve decarbonization across its industries, agricultural emissions will need to be diminished further. Agriculture is responsible for 10% of U.S. greenhouse gas emissions and about 25% of the global total.^{3,4} Agriculture is also the single largest user of U.S. land and a major source of air and water pollution. And still, the United States has one of the most productive agricultural sectors in the world.

From novel alternative proteins to improved indoor agriculture and fertilizer alternatives that do not penalize yields to foolproof ways to sequester carbon in agricultural soils, the future of agriculture depends on innovation. While in some cases — like alternative proteins or controlled environment agriculture — the innovative products and processes are on the market or in use, their scale-up is hampered by technological and financial constraints keeping their productivity benefits and decarbonization potential purely theoretical.

The Private Sector Can't Bankroll Agri-Food Decarbonization

Despite the necessity of innovative technologies, private-sector finance has not been able to fund and build the industries and technologies required to decarbonize the food system. During the 2019-2020 fiscal year, agrifood systems received \$28.5 billion of project-level climate finance. Agriculture, specifically, received \$11.9 billion per year in project-level climate finance and about \$2.1 billion per year in venture capital investments globally, a tiny portion of the estimated need of \$30 billion to \$218 billion per year to achieve agricultural decarbonization.⁵ This is not surprising. With some exceptions, private investors are often risk averse — especially when providing large amounts of money — and are obligated to achieve positive returns. Novel food and agricultural technologies, despite their potential for disruption, are by no means sure bets.

To date, agricultural and food technologies have primarily relied on financing from high-risk-tolerant investors willing to wait on returns (Table 1). These seed, angel, and venture capital investors have the capacity to fund early-stage research and development but lack the funds or will to support firms through scale-up of manufacturing activities.

Table 1: Private Sector Financial mechanisms in the Innovation Value Chain

	Innovation Stage(s)	Typical Investment Amount	Expected Time for ROI	Risk Tolerance
Seed Financing	Research; Development	Small	Long-term	High
Angel Investors	Research; Development	Small	Medium to long-term	High
Venture Capital	Development; Demonstration; Deployment	Small; Medium	Short to medium-term	High
Private Equity	Demonstration; Deployment	Any Size	Medium to long-term	Low
Debt Financing	Deployment	Any Size	Medium to long-term	Low
Project Financing	Deployment	Large	Medium to long-term	Low

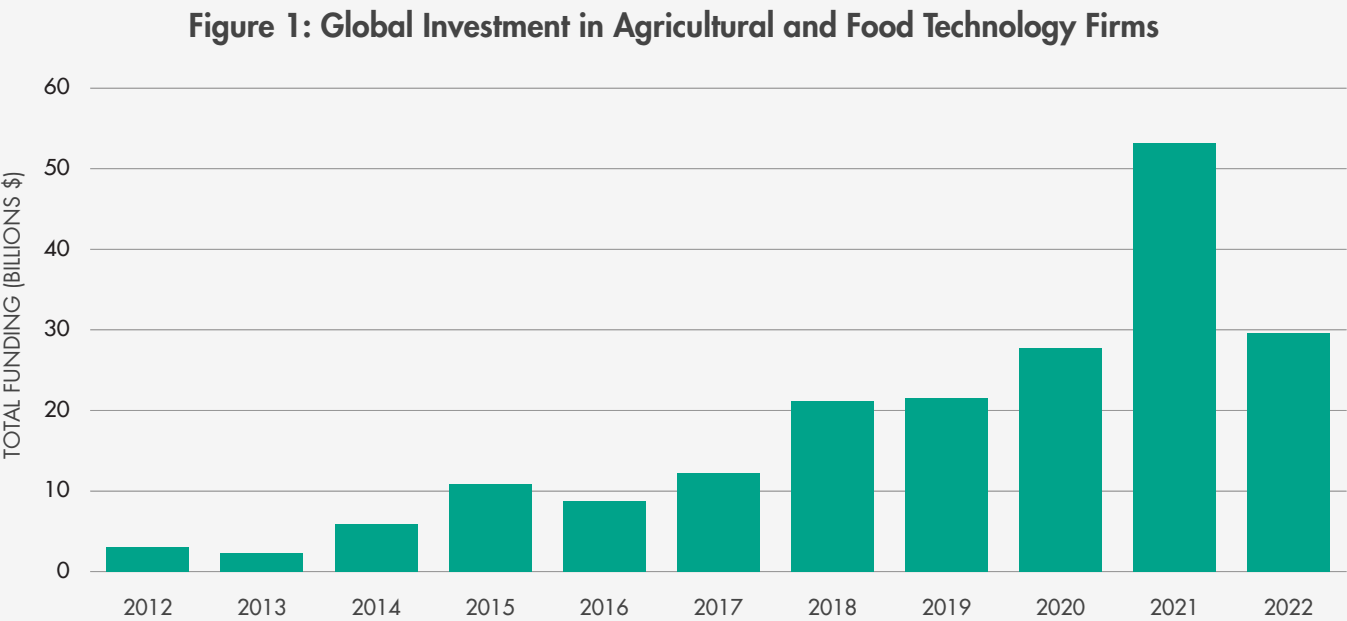
Source: Based on original chart from Jenkins and Mansur, BTI 2011.

While venture capital has been important for agri-food technology developments to date, venture capital firms tend to invest in technologies closer to market readiness rather than those in early stages of development, like green fertilizers. No more than 30% of venture capital investment is directed to early-stage technologies.⁶ Furthermore, these investors typically expect large returns on their investment, in a relatively short time span. Venture capital firms often aim for 10x returns,

meaning that firms heavily dependent on venture capital funds often feel pressure to grow fast, and “exit” — go public or secure a buyout from larger firms — quickly.⁷

For the technologies and industries that have already proven market readiness and have demonstrated some manufacturing capacity — like plant-based meats and electric tractors — venture capitalists and other early-stage investors don’t have the means to fund the high capital expenditures — hundreds of millions of dollars in some cases — to scale manufacturing and get their products into larger markets.

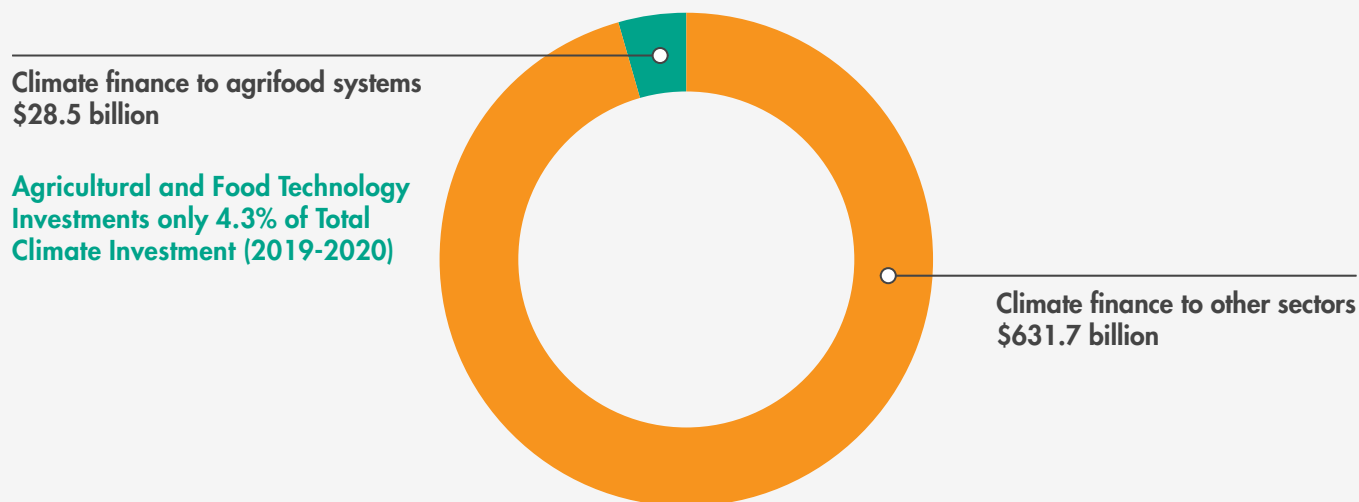
To make matters worse, recent high interest rates have drastically reduced the amount of financing available to firms across industries. High interest rates increase the cost of raising capital, which limits both funders and firms’ growth. This has been proven true for climate-related ventures. In 2023, venture capital investments in climate and clean technologies dropped by 40% from 2022 levels, thanks, in part, to high rates of interest.⁸ A similar drop can be seen for investments in food and beverage start-ups (See Figure 1).⁹



Source: AgFunder, 2023.

Even for climate-focused investors, food and agricultural technologies play second fiddle. In 2022, only 4.3% of total climate finance — which includes both private and public sources — went to food and agriculture (See Figure 2). Similar to U.S. public funding’s focus on energy and transportation, global climate funders have typically ignored the food system.

Figure 2: Climate Finance to Agri-food Systems Compared to Other Sectors



Source: Climate Policy Initiative, 2023

Ignoring food and farming does not bode well for decarbonization goals nor the maintenance of agricultural abundance.

Public Investment Is Needed

The Inflation Reduction Act (IRA) has been touted as the most significant piece of U.S. climate legislation ever but it was also a missed opportunity to include incentives to decarbonize agriculture as part of wider climate policy. While the IRA set aside nearly \$20 billion specifically for agriculture, the funding is primarily for USDA programs aimed at incentivizing the adoption of “climate-smart” conservation practices on farming and ranching operations.

However, investing in conservation programs alone will do little to catalyze innovations capable of making meaningful emission reductions and climate-mitigation without sacrificing an abundant food supply. If the U.S. federal government is serious about decarbonizing agriculture and meeting broader net-zero goals, USDA cannot rely solely on incentivizing producers to implement “climate-smart” conservation practices, like no-till and cover crops, with limited and variable potential to achieve long-term climate mitigation. Instead, USDA must look further upstream and take the lead on funding innovations all the way from early-stage research to commercial deployment.

For example, the DOE Loan Programs Office (LPO) released updated program guidance in May 2023 making food and beverage production eligible under one of its largest financing programs.¹⁰ DOE's Office of Fossil Energy and Carbon Management (FECM) announced a \$35 million Carbon Dioxide Removal (CDR) Purchase Pilot Prize to enable companies to compete for the opportunity to sell carbon dioxide removal credits directly to DOE and includes enhanced weathering and mineralization technologies — which are highly applicable to agricultural lands — as one of only four eligible carbon dioxide removal pathways.¹¹

But making agriculture a sub-priority of DOE programs is not enough. Increasing agricultural research and development funding — which has been diminishing for decades — and investing in the innovations needed to bring about climate-friendly, low land-use, and affordable food abundance will be crucial for the next generation of U.S. food and farming. Fortunately, the Department of Agriculture need not look far to find good examples of how to support the agricultural sector in the 21st-century imperative to decarbonize.

The Department of Energy, in particular, and the many programs funded through the Inflation Reduction Act, in general, exemplify the kinds of pathways available for USDA to strive for the decarbonization of U.S. food and farming. USDA should take cues from the industrial policy measures that have come to define the Biden administration's economic policy, as well as learn from the longer history of U.S. industrial policy supports for the energy, military technology, and transportation sectors.

This report makes the case for USDA to take a far more interventionist innovation approach. For important agricultural technologies to come to market and provide the climate benefits required to decarbonize agriculture, USDA will need to invest. The lack of private-sector ability and willingness to fund crucial agricultural and food technologies necessitates expanded public investment options. Public investment in agricultural technologies can help actualize the potential of these technologies by both providing the necessary funds and knowledge to help solutions reach commercial scale, and by incentivizing more follow-on private sector investment.

In Section II, we provide a background for federal public investment and industrial policy and provide a framework for thinking through the challenges and pathways that innovative firms face. In Section III, we outline the existing programs at USDA and compare them to the Department of Energy's innovation ecosystem. We demonstrate that USDA programs don't go nearly as far to improve upon or scale-up the technologies necessary for agricultural decarbonization. Throughout this section, we present industry case studies on alternative proteins, controlled environment agriculture, and enhanced rock weathering to demonstrate the real-world

needs of firms today. We also provide detailed, technology-neutral federal policy recommendations to increase federal financing for agriculture and food technologies at each stage of innovation. And finally, in Section IV, we summarize a policy framework for building out USDA's innovation ecosystem and setting U.S. agriculture up for long-term decarbonization.



II.

PUBLIC INNOVATION AND THE VALUE CHAIN

The Potential for Industrial Policy to Shape the Future

The U.S. federal government's support for agricultural producers represents one kind of industrial policy. The U.S. farm economy underwrites much of American consumer abundance through the supply of cheap food, and thus agricultural interest groups remain an important political force. In 2021, the Federal Crop Insurance Program insured crops on almost 450 million acres of cropland, with a liability of more than \$150 billion. From 2011 to 2021, the program cost a total of \$90 billion.¹²

But the lack of similar support for innovative technologies and industries tied to food production betrays the myopia of U.S. agricultural policy making. Investing in new agricultural capacities—namely, innovative technologies that can reduce the emissions and land use of the U.S. food system, while increasing productivity — is drastically important.

Industrial policy — long conceived of as the government picking economic winners and losers — has been thoroughly criticized across the U.S. political spectrum for decades. That said, the federal government has consistently supported the development and growth of innovative technologies and industries through what has been dubbed the “hidden developmental state.”¹³

The U.S. military has led the way in terms of government support for innovation, scale-up, and commercialization of novel technologies. The Defense Department's Defense Advanced Research Projects Agency (DARPA) has a history of funding and supporting numerous technological innovations — like the internet, key technologies underpinning the iPhone, and much more.¹⁴ DARPA identified key areas of interest, funded research into those areas, and when technological breakthroughs occurred, effectively underwrote private financial support by purchasing novel technologies and products for military and civil defense applications. For all the decrying of industrial policy by political pundits and politicians in the United States, DARPA has remained politically neutral, and is often cited as the engine of American innovation policy. DARPA's bipartisan support signals the implicit approval of public intervention in technological innovation for politically and strategically important industries.

DARPA's success underscores the opportunity for similar industrial policy programs aimed at technologies and industries that have national strategic importance — including those related to food security and decarbonization. It also provides a clear economic rationale for industrial policy and innovation strategies broadly speaking. The Department of Defense funded basic and applied research, triggering breakthroughs in material science, computer science, and more,

but instead of leaving those new technologies to the market to decide what would or wouldn't get funding, the DOD built out an ecosystem of researchers, investors, and customers that could pull technologies from the laboratory, guide them through commercialization, and scale them up for military or other uses.¹⁵

In effect, the federal government — or state-level agencies — can de-risk technologies and companies, reducing the risk that private investments will fail and thereby helping companies access financing that they would be unable to attain otherwise.

For public investment in innovative technologies to be both effective and equitable, governments need to require companies that benefit from its policies — whether loan guarantees, tax credits, or other types of support — to meet proper labor, climate, and other standards.

At the same time, the newfound risks that the public sector takes on require clear-eyed assessments of necessary policy and technology pathways. Some policy tools work for some kinds of technological or financial burden, some work for others. Put simply, good industrial policy does not provide hammers when screwdrivers are needed.

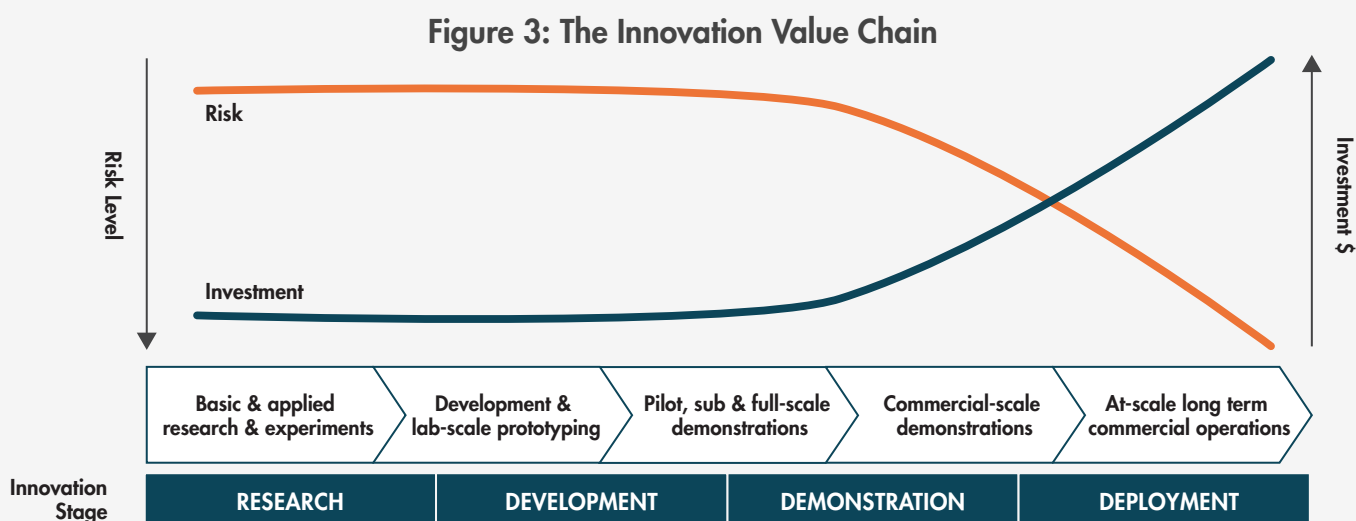
Making sure that industrial policy is cost effective, efficient, and equitable isn't only good governance; it also limits the potential political pushback to important policies. For example, Solyndra's public funding through the DOE's Loan Programs Office (LPO) was heavily scrutinized after the solar firm was shuttered. The scandal led to an unofficial almost decade-long hiatus for LPO, which only provided two loan guarantees between 2011 and 2019. Solyndra remains a thorn in the side of U.S. industrial policymakers, but also a lesson learned. Since its return to the fold, LPO has focused extensively on staffing and processes that give the office increased capacity to make accurately informed decisions and to properly vet the loans it makes.¹⁶

But the failure of Solyndra should not be understood as an outright failure of public financing. The value of public loans — and public financing more broadly — is for the state to invest in higher risk firms and technologies with clear social benefits that might otherwise fail to garner private investment. In effect, failed investments, like Solyndra or Fisker Automotive¹⁷, are encouraging signs of a properly diversified and experimental investment portfolio. In some cases, the technological or economic barriers facing innovative firms and industries will be too large for public investment to help overcome, but balancing those risks with the potentially high rewards of breakthroughs remains the core mission of public financing for innovation.

The Innovation Value Chain

While every firm, technology, and industry are different, there are some clear consistencies across the various value chains of innovations when it comes to challenges, firm evolution, and structure. Understanding the core principles of the innovation value chain is crucial to designing and putting into practice public policies capable of driving innovation forward.

Theorists have developed different categorizations to help define and elucidate the pathway that firms and technologies take from scientific breakthrough to commercial success. The U.S. Department of Energy — a leading light for systematic thinking regarding innovation — settled on a simple four-part categorization: research, development, demonstration, and deployment (See Figure 3).



While these categories provide useful language to make distinctions about how innovations move from the lab bench to commercial production, in reality, the line between innovation stages can blur as different activities happen in parallel. For example, scientific research can continue even as lab-scale prototyping is developed or as pilot facilities are built. Similarly, while the “research” stage inaugurates the whole process, innovative technological processes and products require constant research as firms move along the value chain.

A CLOSER LOOK AT THE STAGES OF INNOVATION

There are many ways to break up and categorize value chains. For this report, we've chosen to categorize firms and technologies along value chains in four distinct "stages of innovation." None of these stage definitions are hard and fast, and firms may be in multiple stages at once, given different product lines and approaches. The stages, as we define them:

RESEARCH

Research covers the basic science that enables a technological breakthrough, as well as the applied research that focuses on that specific technology. It often occurs in universities and government labs, as well as in companies. Early stage prototyping can also be included in the research stage. Typically, the research and development phases are hard to separate due to the iterative nature of research, prototyping, and early business development.

DEVELOPMENT

The development stage of innovation includes product research, prototype development, early manufacturing demonstration, and more. This stage involves firms working to produce dozens or hundreds of widgets, to clarify pain points in their manufacturing process, and to lay the groundwork for larger-scale demonstration, and ultimately, the commercial deployment of their product.

DEMONSTRATION

In the demonstration phase of innovation firms move from making one-off prototypes to production at close to commercial levels. For some industries, like advanced nuclear manufacturing, that may be demonstrating capacity to make a dozen reactors. For others, like the electric tractor industry, demonstrating production capacity could mean making hundreds or even thousands of products. Firms in the demonstration phase are interested in working through the pain points in their manufacturing and production processes, and growing production capacity to show investors that their product can scale to commercial levels. Firms must be able to work through their technological pain points and, ideally, develop production systems that are capable of achieving economies of scale for commercial production.

DEPLOYMENT

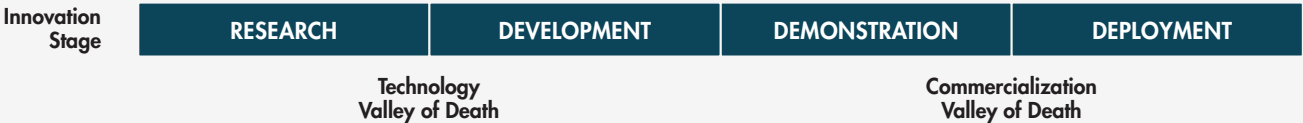
The deployment stage of innovation can be very broad and include a number of different activities. But the primary goal of the deployment stage is for firms to go from demonstrating production capacity to producing their products at commercial scale. Firms in the deployment stage are often looking to expand manufacturing capacity through capital expenditures on facilities and in some cases, manufacturing equipment.

As firms reach different stages along the innovation value chain, the required investment drastically increases. Research, prototyping, and pilot production costs are far smaller than the capital expenditures required to build and operate commercial scale facilities.

At the same time, the riskiness of investment declines once certain stages of the innovation value chain are reached. Early-stage companies in the research or development phases are inherently riskier investments than firms that have proven prototypes or demonstrated production.

The mismatch between perceived risk level and the required investment across the innovation value chain creates barriers for technologies and companies to scale up, typically referred to as the “valleys of death” (See Figure 4).

Figure 4: The Valleys of Death



These “valleys of death” represent points in which firms have a hard time attaining financial capital to further advance their technology. The “technology valley of death” refers to the period of difficulty immediately following a scientific or research breakthrough and represents the challenges associated with making the transitions from the laboratory to prototype to pilot demonstrations. For example, the technology to grow cultivated meat in a laboratory setting was developed in 2013 at Maastricht University, but firms around the world have faced significant difficulty in developing production systems to produce cultivated meat cost effectively at larger scale.

Private investment alone often struggles to carry novel technologies to market due to the inherent riskiness associated with potentially innovative technologies. In some cases, venture capital investors have helped clear this gap, betting on high-risk technologies with the hope of reaping significant returns, even though only a handful of firms might succeed. But venture capital financing is often still not enough for firms to scale up, particularly when technologies require very high capital expenditures for manufacturing facilities. The dearth of private financing available for firms attempting to scale up production and reach economies of scale can be referred to as the “commercialization valley of death.”

Fortunately, governments have proven to be able to bridge these “valleys of death,” supplementing private investment at various stages of development through such programs as direct loans, loan guarantees (loans from private institutions with assurance from the federal government if the loan is not repaid), tax credits, direct subsidies, and more (See Table 2). These programs are often misunderstood as simply providing funds directly to innovative firms. Rather, when designed well, they spur private investment by demonstrating that new technologies function as intended, funding first-of-a-kind facilities, or otherwise reducing the risk of future investment.

Table 2: Public Sector Financing Mechanisms for the Innovation Value Chain

	Innovation Stage(s)	Typical Investment Amount	Risk Tolerance
Research Grants	Research	Low	High
SBIR Grants	Research; Development	Low	High
Demonstration Grants	Demonstration	Medium	Medium
Loan Guarantees	Demonstration; Deployment	Medium to high	Low to medium
Direct Loans	Demonstration; Deployment	High	Low to medium
Government Procurement	Demonstration; Deployment	Medium	N/A
Tax Credits	Development; Demonstration; Deployment	Low to high	N/A
Demand Subsidization	Deployment	Low to medium	N/A

Source: Based on original chart from Jenkins and Mansur, BTI 2011.

These solutions work to mitigate “valleys of death” by dramatically reshaping the informational, regulatory, financial, and market environment, thereby reducing risk and allowing both firms and private investors to have more certainty about future investment. Demonstration programs show investors that a product can be manufactured efficiently and that the technology works as intended. Scale-up funding supports — like loan guarantees or direct loans — do not necessarily guarantee a technology can scale efficiently, but can mitigate the risk associated with private financing. Loan guarantees, for example, give private investors certainty that they can recoup any losses if the project or company they’ve invested in fails. Finally, procurement mechanisms, and other types of demand shaping policies, confirm with signals to private finance that there will, no matter what, be a market for a product if and when it does scale.

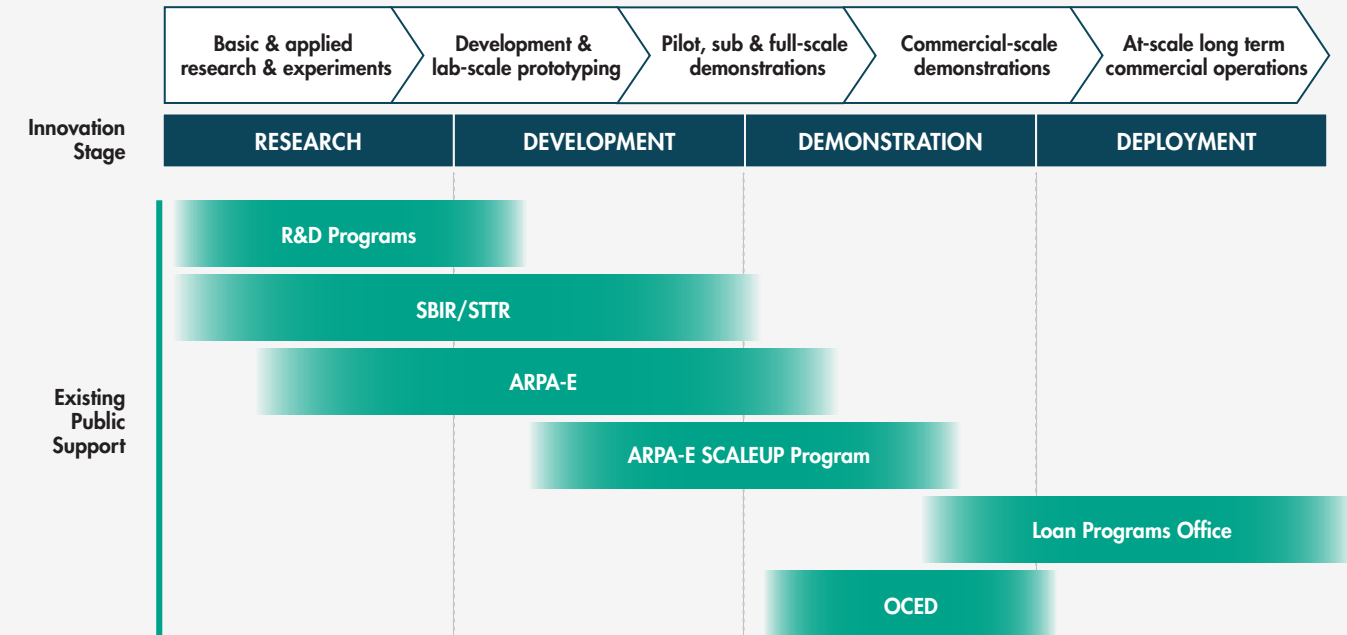


III.

FEDERAL SUPPORT FOR INNOVATION ALONG THE VALUE CHAIN: COMPARING ENERGY AND AGRICULTURE

The Department of Energy’s support for innovative technologies for energy and transportation decarbonization provides a roadmap for how similar policy interventions could apply in the agricultural and food sectors. Current DOE programs and agencies cover all four stages of innovation, and have specific initiatives explicitly targeting the technological and commercialization “valleys of death” (See Figure 5).

Figure 5: Department of Energy Support Across Stages of Innovation



Source: Adapted from ARPA-E and OCED.

The Department of Agriculture, on the other hand, offers incomplete support for firms along the innovation value chain. In this section, we compare the policies and programs at the Department of Energy and the Department of Agriculture to highlight the gaps in public support for emerging agricultural technologies. We find that existing policies and programs specific to other sectors, like energy, can offer lessons about how to expand industrial policy for agricultural technologies and ensure these policies address the specific and varied financing barriers experienced by firms today.

Research and Development

Research and development investments are crucial for advancing scientific understanding and providing the underpinnings for important breakthroughs — both for novel technologies and for the continued advancement of existing technologies. In this section, we outline why federal R&D programs remain especially important for agricultural abundance and detail what existing programs support R&D activities for emerging agricultural technologies.

Companies conducting agricultural R&D tend to focus on areas that have high expected profits, limiting their scope. Their R&D often focuses on techniques to better process crops and other agricultural products, and on developing products with potential for commercial success in established markets.^{18,19}

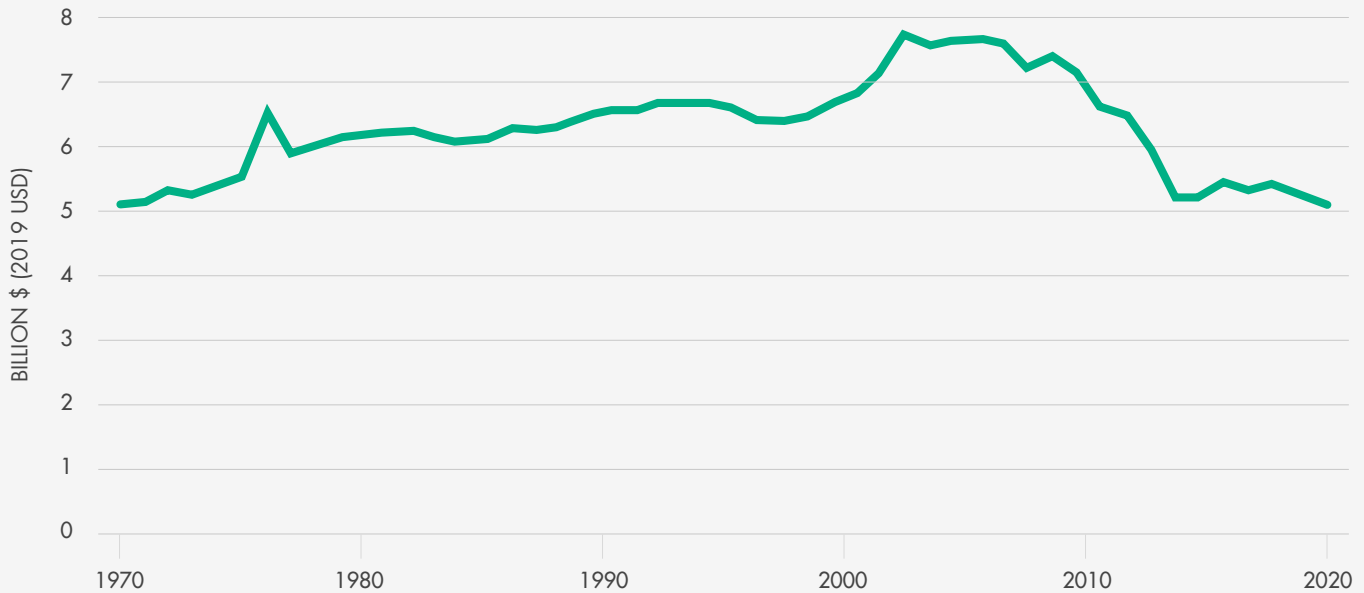
Public agricultural research provides an important complement to private R&D, supporting scientific and technological innovations that go beyond the private sector's scope.²⁰ By funding applied research in areas the private sector lacks sufficient incentive to support, public agricultural research fills critical gaps and often generates scientific findings that form the basis for future private-sector R&D.

At USDA, two agencies fund much of the research needed to develop low-carbon agricultural and food technologies: the National Institute of Food and Agriculture (NIFA) and the Agricultural Research Service (ARS). NIFA provides grants to researchers at universities, other public agencies, and private firms. ARS, through a network similar to the Department of Energy's network of national laboratories, conducts research led by more than 2,000 scientists at federally operated facilities across the country.²¹

Through ARS and NIFA programs, USDA administers more than half (55%) of the public agricultural R&D funding in the United States. Other federally funded agencies and programs — like the Foundation for Food and Agriculture Research (FFAR) — complement USDA's research agenda, while state-financed programs provide approximately 20% of U.S. public agricultural research funding.²²

These public investments generate significant benefits for the U.S. economy on the order of a \$20 return for every \$1 of spending.²³ Despite these returns, U.S. investment in public agricultural R&D lags major trade competitors, having declined by a third since peaking more than two decades ago (See Figure 6).²⁴

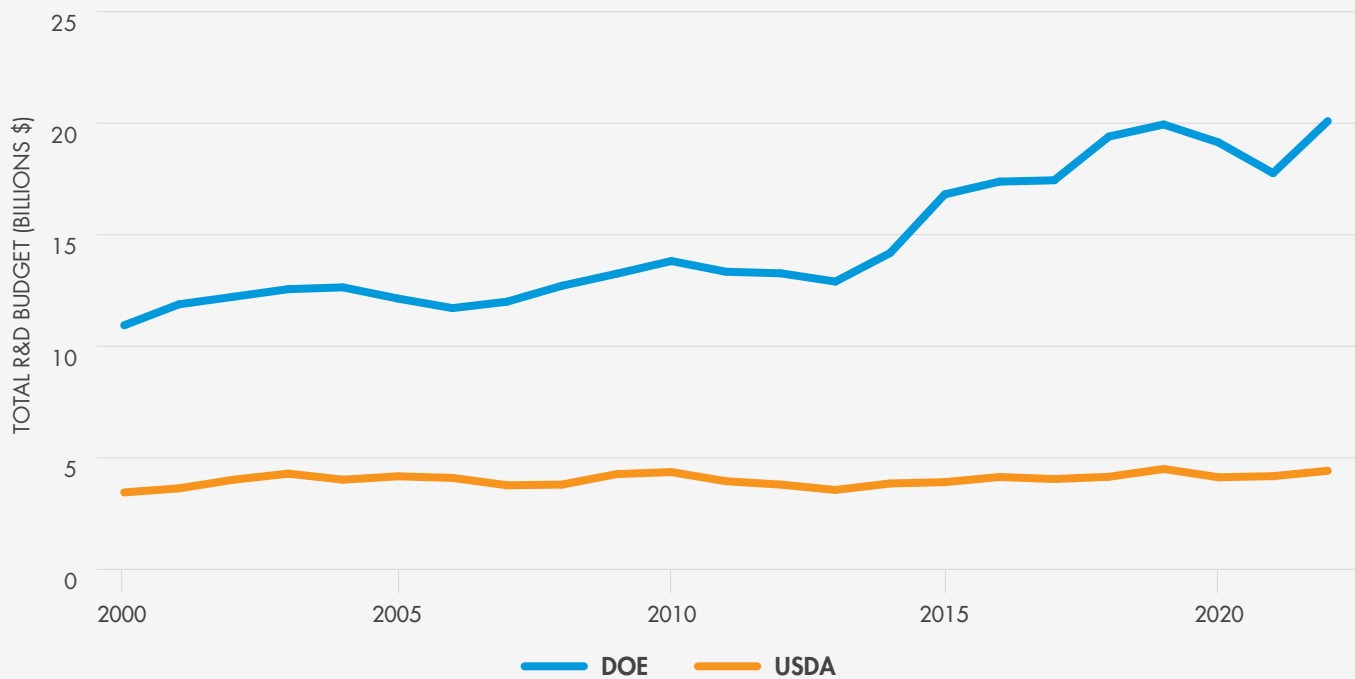
Figure 6: U.S. Public Spending on Agricultural R&D Has Fallen by One-Third Since 2002



Source: Nelson and Fuglie, USDA Economic Research Service, 2022

Other economic sectors, like energy, have benefitted from more consistent congressional support to grow their R&D budgets (See Figure 7). For example, the Department of Energy's Advanced Research Projects Agency (ARPA-E) has provided approximately \$3.27 billion in funding to more than 1,415 projects since its inception in 2009.²⁵ Its annual appropriations grew from approximately \$180 million²⁶ in 2011 to \$470 million in 2023.²⁷ In comparison, the Department of Agriculture's Advanced Research Authority (AgARDA) was established in the 2018 Farm Bill and has yet to receive more than \$1 million per year in annual appropriations.²⁸

Figure 7: DOE R&D Budget Growth Has Outpaced USDA Since 2000



Note: USDA R&D budget does not encompass all public R&D for agriculture, such as funds from other federal agencies or state governments focused on agricultural innovation. Dollar values are in constant 2022 dollars.

Source: American Association for the Advancement of Science, Historical Trends in Federal R&D, 2022

This comparison is especially stark when looking at federal funding for climate-related R&D. In 2020, the U.S. government spent about \$8.4 billion on clean energy innovation which is at least 35 times more than R&D agencies spent on climate mitigation in agriculture.²⁹ In the same year, the energy sector (e.g., electricity, transportation, heating, and cooling) accounted for only eight times more GHG emissions than agriculture.³⁰

ENERGY AND AGRICULTURE R&D COLLIDE

ARPA-E has funded several projects with technological implications for agriculture. The agency's ROOTS (Rhizosphere Observations Optimizing Terrestrial Sequestration),³¹ SMARTFARM (Systems for Monitoring and Analytics for Renewable Transportation Fuels from Agricultural Resources and Management),³² TERRA (Transportation Energy Resources from Renewable Agriculture),³³ and MARINER (Macroalgae Research Inspiring Novel Energy Resources)³⁴ programs focus on improving the sustainability of biofuel supply chains.

The MARINER program, for example, supports projects to advance the domestication of macroalgae and new farming technologies. The program's explicit goal is to develop the tools needed to achieve the scale, efficiency and production costs necessary to support a seaweed-to-fuels industry, enabling the United States to become a world leader in marine biomass production for biofuels. The technology developed by Umarm Foods (formerly Trophic) with a grant under the MARINER program aims to help grow seaweed farming but is also spurring innovation in food products.³⁵ Umarm Foods is developing a process to extract proteins from seaweed for human consumption and has rolled out a product using red seaweed to make a plant-based alternative to bacon.³⁶

Despite these examples, ARPA-E's patchwork support for agricultural-adjacent projects is limited to those with a bioenergy tie-in thanks to the agency's energy mandate. For this reason, among others, interdisciplinary research programs at other federal agencies should not be relied on to sufficiently fill in gaps in advanced research for agricultural innovation gone unaddressed by USDA.

Alongside direct research funding, U.S. federal research agencies often also provide funding for prototyping and early-stage scale-up that can be categorized as part of the "development" stage of innovation. One relatively small federal program — the Small Business Innovation Research (SBIR) program — has been particularly impactful at stimulating technological innovation and increasing private-sector commercialization since its inception in the 1980s. This is especially due to the program's focus on early-stage technologies. SBIR funds have historically been distributed to a large number of firms and are more consistently directed to early-stage technologies, compared to other funding sources. For example, when comparing the number of awards made, SBIR has been found to support five to seven times as many early-stage technology projects than venture capital.³⁷

The SBIR program awards grants on a competitive basis to companies to develop innovative concepts and prototypes. It is administered by several federal agencies, which are required to commit a percentage of their extramural R&D budgets to the program, 3.2% since 2017.³⁸ SBIR provides grants in multiple phases. Phase I grants are small — generally up to \$150,000 — and

support experimental or theoretical work that assesses the feasibility of new technologies or products.³⁹ Phase II grants are substantially larger — generally up to \$1 million — and support continued R&D that exhibits potential for commercial application. Some agencies continue to support SBIR recipients on the path to commercialization as they transition technologies to market. USDA, along with DOE and others, provides Technical and Business Assistance (TABAs) funds to connect SBIR awardees with commercialization assistance from a third party to generate revenue, scale their manufacturing operations, develop commercialization plans, and more.⁴⁰

USDA awarded \$21 million in SBIR Phase I and II grants in fiscal year 2019.⁴¹ In recent years, the agency has tied its SBIR program to USDA's Strategic Goals for FY 2022-2026.⁴² The strategic plan includes several objectives that will require commercialization and deployment of agricultural innovations that build resiliency and move the sector toward decarbonization.

To this end, USDA has made SBIR awards to firms developing new technology to lower the energy costs and environmental impacts associated with nitrate production for fertilizer,⁴³ exploring how to use certain cover crops as new sources of plant-based protein,⁴⁴ and designing more precise equipment to reduce pesticide spray drift during aerial application.⁴⁵

SBIR grants often build upon federally funded research, helping it lead to commercial technologies and products. For example, past grant recipients under USDA's Sustainable Agriculture Research and Education (SARE) program have gone on to leverage the SBIR program to bring their SARE project findings closer to real-world application.⁴⁶

SBIR's funding helps the private sector understand which technologies and companies are suitable for investment. Due to private-sector trust in SBIR's analysis, each award effectively serves as a certificate of the awardee's legitimacy and growth potential. This serves to generate follow-on investment enabling continued development. Over a 15-year period, 20% of venture capital investments made in life sciences were made to firms that had previously received at least one SBIR award.⁴⁷ Likewise, SBIR funding preceded at least 10% of venture capital investments in energy and industrial firms.⁴⁸ In short, SBIR's modest spending on development has an outsized impact, helping new technologies and companies scale more quickly.

Policy Recommendations

As U.S. public spending on agriculture lags behind major trade competitors abroad, federal spending on agricultural R&D for climate mitigation agriculture also trails domestic R&D spending on other hard-to-decarbonize sectors. For the U.S. agriculture sector to stand a chance of meeting net-zero goals, recent downward trends in public agricultural R&D spending must be reversed. This should start with robust investments in federal agricultural R&D programs and agencies on an annual basis.

Ongoing public-sector research is needed to ensure U.S. agriculture has the tools, data, and technologies needed to face growing challenges facing the sector. The following recommendations aim to reaffirm U.S. leadership in public agricultural R&D and accelerate research into new low-carbon agriculture technologies and food products:

1. **Double Federal Research and Development Funding:** Given the large environmental and economic benefits of agricultural R&D, Congress should double the funding for major agricultural R&D agencies and programs, including NIFA and ARS. Maintaining a robust ecosystem of publicly supported agricultural R&D remains essential to developing and advancing new low-carbon agricultural technologies and products that are not explored through private R&D.⁴⁹ Furthermore, doubling or otherwise increasing R&D funding, including for competitive grant programs, would in turn also increase SBIR funding available through USDA.
2. **Fully Establish AgARDA to Support Research and Enable Scale-Up:** Standing up the Agriculture Advanced Research and Development Authority (AgARDA) would fill a critical research niche for the development of innovative technologies at USDA. AgARDA was authorized as a pilot initiative by the 2018 Farm Bill with \$50 million per year in funding but has received only \$2 million in funding to date.⁵⁰ With sufficient funding and staff, AgARDA would have the capacity to carry high-impact innovations over the technology valley of death by funding prototyping of these technologies. When standing up AgARDA, USDA should apply the lessons of ARPA-E directly to its efforts to support advanced agricultural research and explore opportunities to help technologies scale. As an example, ARPA-E has successfully supported technological innovations in bridging the commercialization valley of death by connecting researchers with business leaders, loan opportunities, and corporate development as part of its SCALEUP program.

Demonstration

Federal R&D grants are the seeds of agricultural innovation, generating promising ideas for new products and technologies. But many of these novel ideas never grow to see the light of day. Even the most successful researchers often struggle to secure funding to test and validate their technologies. Just as they reach the point where their prototypes are ready for real-world testing — often an expensive step — they no longer qualify for the research grants they relied on earlier.

Federal initiatives can play a pivotal role in bridging this gap. They can support the practical demonstration of innovative technologies, bringing them out of the lab and into the field. In fact, public programs have provided over half of the funding for first-of-a-kind demonstration projects in wind power, biofuels, and concentrated solar power.⁵¹

Compared to many sectors with robust late-stage financing, there is a large need in agriculture for publicly supported demonstration projects and testbeds. Testbeds are real-world environments, like field areas or farms or food manufacturing plants, where new technologies and practices can be evaluated. These allow researchers, farmers, and technology developers to collect data and measure results to demonstrate effectiveness and assess potential benefits and drawbacks in real-world conditions before widespread adoption. Testbeds are particularly important to assess crop varieties, novel fertilizers, and other technologies that will be applied on farming operations.

Testbeds also offer the opportunity to gather real-world data across temporal and spatial distributions. While time consuming, it is imperative that new tools, practices, or technologies poised for use on agricultural lands undergo efficacy demonstrations across soil types, climate zones, crops, and other variable conditions.

The idea of establishing federally funded testbeds for agriculture is not new. Although few and far between, testbeds have been established at USDA's Agricultural Research Service sites, including for soil moisture technologies⁵² and rural broadband.⁵³ Similarly, research farms at public land-grant universities have long served as testing sites, often adapting crop varieties and other technologies developed elsewhere for the local environment.

In recent years, NIFA has also funded several “farm of the future” testbeds and demonstration sites through its Regional Innovation and Demonstration of Climate-smart Agriculture for Future Farms (CAFF) program. The first award was made to Cornell University in 2022 with \$4 million in funding.⁵⁴ Working across one crop research farm and two dairy farms at Cornell, the multidisciplinary research team will develop, evaluate and demonstrate data-driven precision

agriculture, smart automation, and data connectivity technologies and management practices.⁵⁵ The effort plans to refine and test existing and in-the-pipeline technologies in a commercial-like setting. The following year, NIFA awarded \$4 million to the University of Georgia to establish a Digital and Data-Driven Demonstration Farm⁵⁶ and Virginia Tech to establish a testbed dedicated to minimizing emissions from indoor agriculture systems by leveraging advanced AI and sensor technologies.⁵⁷ Additional testbeds are needed to evaluate other emerging agricultural technologies and practices, including enteric methane-reducing products for livestock, enhanced rock weathering applications, and soil carbon sequestration practices.

In addition to using testbeds, firms might also need to build pilot plants in the demonstration phase before commercialization. This is especially true for new agricultural technologies or food products that require first-of-a-kind manufacturing processes or production facilities. Pilot testing can help to validate technical feasibility on a smaller scale and identify problems to minimize expensive mistakes during larger scale deployment. Successful demonstrations in pilot facilities can build confidence in the technology, lowering risk for investors and stakeholders. Pilot performance metrics can inform and optimize the design and engineering of a commercial-scale production system. Depending on technology complexity, operational scale, location, and other factors, building pilot facilities requires financing to cover capital and operating expenditures. Here, again, the Department of Energy has outpaced USDA.

In 2019, DOE launched a new program, SCALEUP, to help innovators move their proof-of-concept technologies toward a commercially scalable stage. Operated by DOE's advanced research agency, ARPA-E, the program provides funds for pre-commercial scaling projects.⁵⁸ SCALEUP has enabled awardees to build pilot production facilities⁵⁹ and to validate manufacturability and commercial scalability.⁶⁰

DOE's Office of Clean Energy Demonstration (OCED) also plays a role in bridging the gap from R&D to market adoption. Established in 2021 with \$20 billion from the Bipartisan Infrastructure Law, OCED offers grants, cooperative agreements, and market expertise to facilitate large-scale demonstrations of clean energy technologies, focusing on those with significant barriers to scale. Unfortunately, there is no comparable agency or program within USDA.

Agricultural and food technology firms looking to the federal government for support for demonstration projects must rely on broader programs. These provide much-needed finance, but are insufficient to address many of the challenges that agricultural companies face. The Department of Commerce's Build to Scale program, for example, has funded organizations to support local agri-food startups and entrepreneurship. Organizations received between \$300,000

and \$2 million in funding depending on their maturity and capacity to develop an effective ecosystem.⁶¹

In 2020, the Department of Commerce awarded \$600,000 to an ag-tech incubator program at the University of Nebraska focused on moving agricultural innovation from proof of concept to initial commercialization.⁶² Similarly, in 2022, a \$1.5 million grant was awarded to AgLaunch, a Memphis, Tennessee-based ag-tech accelerator aiming to incubate, grow, and accelerate farm trials for agricultural innovations related to autonomous farm equipment, biological pesticides, and climate mitigation among other topics.⁶³

And yet, examples like those above are few and far between. Agriculture is only one of the many sectors supported by scale-up programs administered by the Departments of Commerce, no USDA program dedicated to establishing agricultural testbeds exists, nor does any USDA program provide comparable support to OCED for large demonstration projects for agricultural technologies.

CASE STUDY: ENHANCED ROCK WEATHERING

Enhanced rock weathering (ERW) is a promising technology that removes carbon dioxide from the atmosphere by accelerating the natural process of rock weathering. ERW involves pulverizing silicate-rich rocks, like basalt, and spreading the rock dust on land, including cropland. As the crushed rocks erode, they convert carbon dioxide into stable forms, resulting in highly durable carbon removal.

The emerging ERW industry can build on already established distribution networks used for liming and other soil treatments to distribute its products to farmers. Notably, the practice can also be applied using existing fertilizer or lime spreading equipment, making it easy for farmers to integrate the practice with other climate-smart practices already in place in their operations. Estimates have shown that, if implemented on one-half of U.S. cropland, enhanced rock weathering could sequester around 0.4 billion tonnes of CO₂ per year.⁶⁴ Rock weathering also has the potential to reduce soil acidity, improve soil nutrient content, reduce the need for fertilizer application, and boost crop yields.

Nevertheless, the ERW industry faces significant barriers when it comes to scaling up production to make ERW widely available to those farmers. Several ERW companies, like Eion⁶⁵ and Lithos,⁶⁶ have benefited from funding agreements to accelerate their operations and begin deployment. Fueling additional excitement in the space, DOE announced it would purchase \$35 million in carbon dioxide removal credits from firms using such technologies as ERW.⁶⁷

To meet the initial demand for ERW, firms will need to finance the construction of first-of-a-kind silicate rock processing facilities and deploy ERW on a growing number of acres across the United States. However, first-of-a-kind facility projects can struggle to attract investment from commercial project finance lenders due to technology risk, variable unit economics, or deal sizes that are too small to justify transaction costs.

INDUSTRY EXAMPLE: EION

Eion was founded in 2020 and focuses on ERW as a carbon dioxide removal solution. Since its founding, the company established an MOU with Sibelco, which operates its olivine quarry, and secured a patent for its measurement methodology to verify carbon removal. Eion continues to explore best practices for using olivine with other agronomic practices and aims to reach a supply of 10 million tons of carbon removal annually starting in 2030.

Recently, Eion was the first ERW company to successfully complete a partial delivery of a carbon removal purchase to Stripe.⁶⁸ However, as the company grows, it will look to develop a first-of-a-kind facility. The facility would fund olivine purchase, ocean transport, material handling, and last-mile logistics associated with delivering CDR. As Eion's technology risk lowers and its unit economics become well established, Eion expects to build larger projects with capital needs that could be addressed with commercial project finance.

Policy Recommendations

As innovative food and agriculture companies seek to further develop and demonstrate their readiness for commercialization, they will need to overcome financing gaps to engage in robust demonstration trials and, in some cases, build first-of-a-kind production facilities.

The federal government can play a role in filling this gap. The following recommendations would help to fund demonstration projects, validate manufacturability, and build first-of-a-kind pilot facilities:

1. **Fund Agricultural Testbeds Through ARS and NIFA:** There is a growing need for agricultural testbeds that can support the demonstration of novel technologies and evaluate novel carbon removal methodologies. New testbed and demonstration sites should be established within the existing network of ARS sites as well as at research farms at public land-grant universities with the help of NIFA grants. By funding these sites, the federal government can accelerate the evaluation of innovative agricultural technologies and practices, including enteric methane-reducing products for livestock, ERW approaches, and soil carbon sequestration practices.
2. **Establish an Office of Food and Agriculture Technology Demonstration at USDA:** Similar to the Department of Energy's Office of Clean Energy Demonstration (OCED), USDA should establish an office to extend grants and cooperative agreements to facilitate large-scale demonstrations of agricultural technologies, particularly those that exhibit climate mitigation potential and are facing barriers to scale. By following a similar path in structuring cost-share agreements as public-private partnerships, USDA should work closely with the private sector to ensure follow-on investment from non-public sources of capital accelerates deployment.

Deployment

The scale-up stage for innovative firms and technologies is expensive. Moving from a demonstration or prototype production facility to a larger-scale plant, with several magnitudes more capacity, typically requires far more capital than any previous activity. Though demonstration projects can help firms attract financing, the sheer size of capital expenditure required for commercial-scale production can send firms hurtling down the “commercialization valley of death.”

Direct loans and loan guarantees, grant programs for commercial expansion, and tax credits are just a few examples of policies that can help companies bridge the funding gap. Several agricultural grant and loan programs exist to expand or diversify domestic production within existing agricultural industries. For example, in 2022, the Biden administration announced plans to put \$1 billion into an expansion of independent meat and poultry processing capacity.⁶⁹ The administration's latest tranche of awards includes \$38 million in grants to processors through the Meat and Poultry Processing Expansion Program and \$77 million to intermediary lenders to finance the start-up, expansion, or operation of independent processing facilities under the Meat and Poultry Intermediary Lending Program.⁷⁰

USDA has done something similar to spur domestic fertilizer production. The Fertilizer Production Expansion Program provides grants to help increase or expand the manufacturing and processing of fertilizer by supporting activities like building new facilities, purchasing or modernizing equipment, or providing working capital to increase output.⁷¹

USDA programs like these are often industry- or technology-specific and largely focus on commercial expansion of an already dominant industry, limiting the agency's flexibility to extend grants or loans to novel products or innovative technologies. federal programs that help to expand production, encourage competition, and spur innovation within existing industries remain crucial. However, financing gaps also exist for industries and technologies that are far less mature than the conventional meat-processing or fertilizer industries.

In this section, we focus on industries entering or in the early processes of commercialization. We outline the existing programs at USDA that provide capital to agricultural firms and producers, compare those programs to DOE's support for technological deployment, and argue that USDA is, once again, lacking a diverse portfolio of financing mechanisms to support innovation.

Direct Loans and Loan Guarantees

A straightforward policy measure to support technology deployment and incentivize follow-on private investment is for the government to provide direct loans and loan guarantees to firms looking to scale up. Loan guarantee programs allow government agencies to make agreements with qualified financial institutions to ensure a certain percentage of the loan will be repaid if the borrower defaults. By minimizing the lender's financial risk, guarantees can enable borrowers to secure more favorable loan terms, like lower interest rates or larger loan amounts, compared to conventional loans.

USDA offers billions of dollars in loans and loan guarantees each year for agricultural producers, small businesses, and rural industries. USDA's Farm Service Agency (FSA) and Rural Development Agency (RD) administer USDA's most popular loan and loan-guarantee programs, aimed at ensuring the economic viability of agricultural production and increasing economic development in rural communities, respectively.

RD has guaranteed thousands of loans Business & Industry Loan Guarantee Program (B&I), obligating an average of \$1.7 billion per year.⁷² The program offers guarantees to qualified lenders that extend loans to rural businesses to expand or modernize operations; purchase equipment and machinery; or purchase land, buildings, or facilities. B&I loans typically fall between \$200,000 and \$5 million, averaging around \$3 million.⁷³

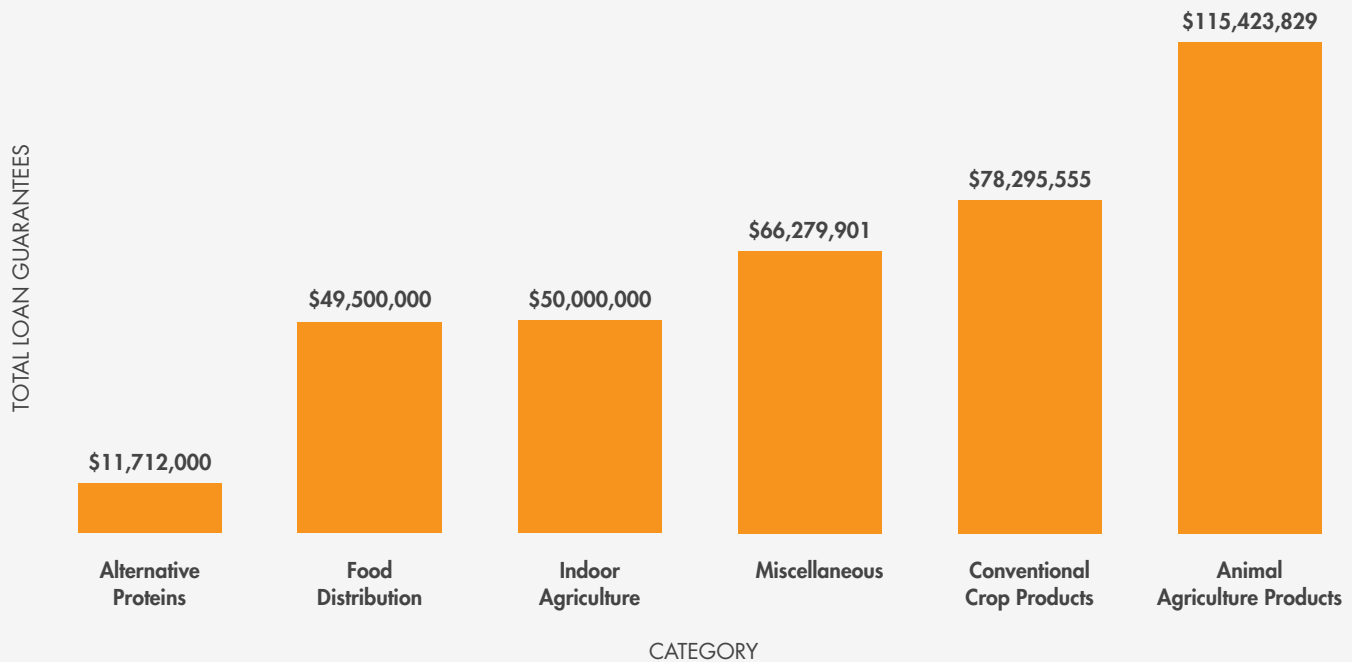
While B&I loans can help some agricultural manufacturing or processing firms secure capital, the program provides support only to projects in rural areas. In addition, given the program's focus is rural economic development, only a portion of its funding goes to the food and agriculture sectors. As of late 2021, only 6.6% of B&I funds made available through the CARES Act went to agricultural producers and businesses.⁷⁴

Amid the dozens of other RD loan programs, only one recent program explicitly targeted the middle of the food supply chain. From 2021 to 2023, the Food Supply Chain Guaranteed Loan Program (FSCGLP) provided loan guarantees for qualified lenders to finance food system projects, specifically for the start-up or expansion of activities related to the aggregation, processing, manufacturing, storing, transporting, wholesaling, or distribution of food. With \$100 million from the American Rescue Plan Act, USDA aimed to guarantee nearly \$1 billion in private loans.

FSCGLP had a focus on improving the resilience and productivity of the U.S. food system and funded projects across a range of food industries and commodities. Over its tenure, the program primarily supported conventional commodity crops and conventional agriculture facilities, including cold storage facilities and dairy processing equipment (See Figure 8). The program guaranteed loans of up to \$40 million, with recipients receiving an average of \$15.7 million.

The program did provide some limited support to scaling up innovative, low-carbon food products and technologies. For instance, the program supported PlantBased Innovations LLC, a plant-based yogurt company, enabling them to acquire a plant and equipment in Fredericksburg, Iowa.

Figure 8: Majority of Food Supply Chain Guaranteed Loans go to Conventional Agricultural Products



Note: Miscellaneous includes investment in various firms, for example agricultural inputs and bottled water production.

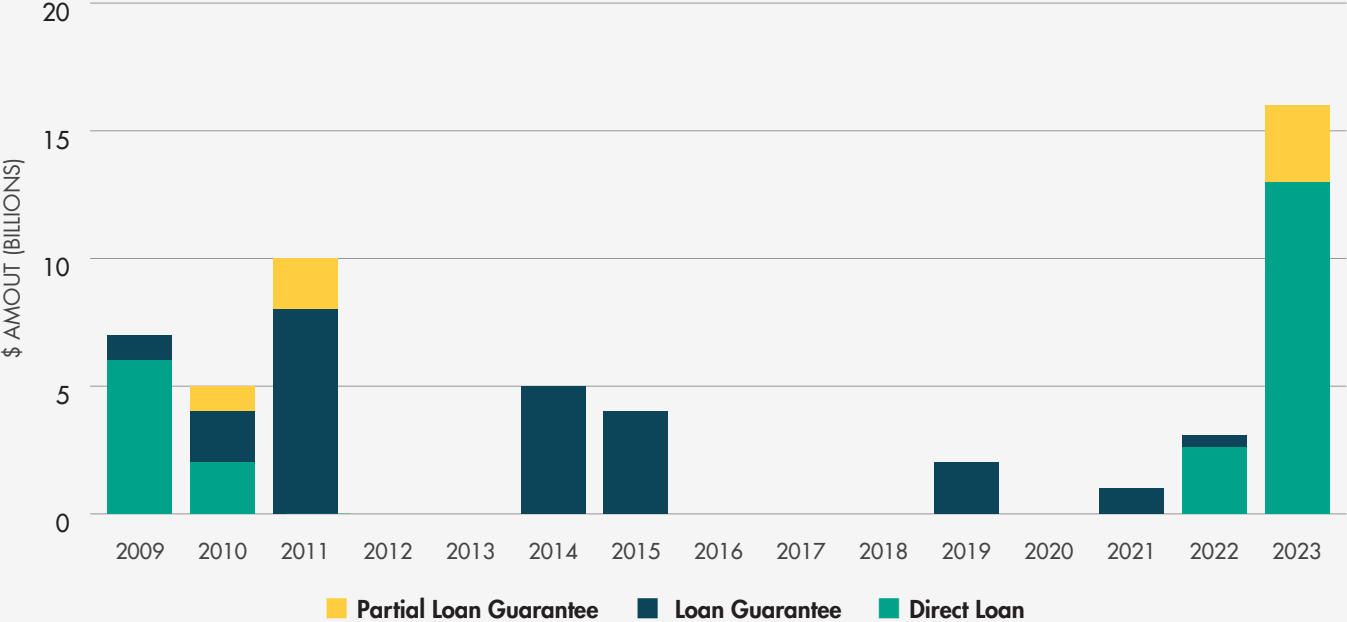
Source: FSCGLP Portfolio Data, June 2023.

Despite robust demand for loan guarantees from companies spanning the food and agriculture sector, the program stopped accepting applications when Congress rescinded its remaining funds in the Fiscal Responsibility Act of 2023 — passed to raise the nation's debt ceiling before default. Renewing the program would unlock more private investment in food supply chain innovation and infrastructure. Should FSCGLP be revived, it should continue to direct funds to plant-based products. The program could also prioritize support for cell-cultured meat products, as well as other products or ingredients with potential to diversify the U.S. food supply and reduce emissions.

In contrast to USDA's limited loan initiatives, the Department of Energy's Loan Programs Office (LPO), provides significant support for the deployment of a wide range of clean energy technologies. Through direct loans and loan guarantees for firms that demonstrate technical readiness, DOE LPO fills critical gaps in private funding, particularly for high-risk, high-reward ventures that private lenders often overlook. This public financing steers market forces toward companies and industries with substantial social value. Since its creation in 2005, DOE LPO has provided

\$30 billion in financing and loan guarantees, which have led to significant emission reductions in the energy sector as well as job creation (See Figure 9). For example, the LPO's Advanced Technology Vehicles Manufacturing Loan Program is estimated to have cut 25 million metric tons of CO₂ to date. As of 2021, LPO-financed projects created 37,000 permanent jobs.

Figure 9: DOE LPO Has Provided Over \$54 Billion in Financing Since 2009



Note: 2022 and 2023 data includes conditional commitments from DOE LPO.

Source: DOE LPO Portfolio.

While DOE LPO primarily focuses on clean energy and advanced vehicle projects, its Title 17 Clean Energy Financing Program supports a wider array of technologies. LPO released updated program guidance in May 2023, including a change to include food and beverage production as an eligible industrial decarbonization technology.⁷⁵ Title 17 loans are typically on the order of \$100 million to \$1 billion, often a transformative amount for recipients.

That said, DOE LPO's authority to tackle decarbonization across food and agriculture industries remains limited. Industrial decarbonization technology is one of the 13 technologies eligible for Title 17 support. Given the breadth of LPO's scope, the number of loans to food and agriculture are likely to remain few and far between.

CASE STUDY: ALTERNATIVE PROTEINS

The alternative protein sector is dedicated to developing and producing protein sources that do not rely on animal agriculture, like meat or milk alternatives. It encompasses a diverse range of technologies and products, which can be divided into three primary categories: plant-based, fermentation-based, and cultivated. Plant-based proteins are made from plants like legumes, grains, and nuts. Fermentation-based proteins are either composed of or produced by microorganisms, like fungi. Finally, cultivated alternative proteins — more colloquially called “lab-grown” — are dairy and meat products that are cellularly identical to traditional animal-based products, but are grown in factory-like facilities directly from meat and dairy cells, and without the slaughter of animals.

While alternative protein companies face varied challenges in the R&D stage as they attempt to create unique products, many firms share similar difficulties when it comes to scaling production. In some cases, plant-based products — like those produced by Impossible Foods, Oatly, and Beyond Meat — have successfully scaled up to meet rising demand. Despite this growth, prices remain high, in part because many firms are too small to take advantage of economies of scale. For cultivated meat firms, scaling up from laboratory to production facility — often through first-of-its-kind facility construction — represents the signal challenge. Despite some cultivated meat production in Singapore and the United States, the industry still needs to demonstrate that large-scale, low-cost production is feasible.

If alternative proteins can scale up, the environmental, climate, and land-use benefits could be immense. Meta-analyses of life-cycle assessments for plant-based meats have found that plant-based meats have several-fold lower carbon emissions per unit than beef, and less than most pork and chicken, and require less land than all three. By one estimate, alternative proteins can produce the same total calories as traditional proteins but using 640 million fewer hectares.⁷⁶

The need for public financing is especially clear for this industry, which has seen high year-to-year variance in private investments and has reached a stage where public investments could significantly de-risk the expansion of production. Estimates show that it will cost between \$10 billion and \$18 billion to build new or retrofitted facilities capable of producing 10 million metric tons of plant-based meat products, approximately four times global plant-based meat production capacity in 2022.⁷⁷ Capital cost estimates for a commercial scale facility capable of producing 10,000 metric tons of cultivated meat reach as high as \$450 million.⁷⁸

INDUSTRY EXAMPLE: FINLESS FOODS

Finless Foods was founded in 2017 in Alameda, California, and seeks to fill an ever-widening gap between seafood availability and consumer demand by creating alternative seafood products. Their plant-based tuna launched in early 2022 and their cultivated bluefin tuna is made from wild-caught, high-quality bluefin tuna cells. Finless’ cultivated product is in the demonstration phase and approaching commercialization.

Finless leveraged seed funding for its initial research and has relied solely on private venture capital funding to develop and prototype its cultivated seafood product and build a pilot plant.⁷⁹ With its plant-based tuna already on the market, Finless shifted its attention to the commercialization of its cultivated tuna. Finless will need to continue to raise venture funds as it seeks regulatory approvals, optimize production efficiencies, and build a roadmap for widespread commercialization. Finless will also need to build out a physical commercial-scale facility equipped with bioreactors to scale and deploy their product, but private financing can be hard to come by for such a nascent product with high risk.

Tax Credits

The tax code is one of the largest ways the federal government catalyzes the deployment of innovative technologies and industries. Tax credits can be categorized into supply-side incentives — namely tax credits to invest in new infrastructure — and demand-side incentives, which effectively subsidize consumer adoption of a given technology.

Few tax credits are available for innovative agricultural technologies or food products, aside from a number related to energy production. Producers of several types of biofuel, including biodiesel and sustainable aviation fuel, are eligible for tax credits, like the Biodiesel Producer Credit. Thanks to the IRA, companies that produce machinery, like manure digesters — to trap and then sell the biomethane byproduct of livestock operations for electricity or heating systems — are eligible for a tax credit.⁸⁰ Farmers interested in purchasing digesters can also receive financial support through the Rural Energy for America Program or the Environmental Quality Incentive Program, both of which also received additional funding through the IRA.⁸¹ Notably, none of these tax credits aim to support emerging agri-food technologies.

In contrast, a suite of tax credits exist to spur clean energy, carbon capture, and clean hydrogen production. Congress has established both production tax credits and investment tax credits for clean energy, illustrating the tremendous potential to expand tax credits to spur agriculture innovation.⁸²

PRODUCTION TAX CREDITS

Production tax credits (PTCs) allow businesses to claim a tax credit for each unit they produce. The federal government provides PTCs for a number of decarbonization-related industries, like carbon capture and storage, clean hydrogen, and clean energy, to name a few. For clean energy, the federal government provides PTCs for every unit of clean electricity produced and sold for 10 years after a facility is constructed. Prior to the IRA, only wind and biomass energy developers were able to take advantage of PTCs, but since the IRA's passage, PTCs have been expanded to include other forms of clean energy.

PTCs change the calculus of investing in a clean-energy project by reducing the costs of clean-energy production. Reducing the financial risk involved with new projects incentivizes both larger projects and increased private investment. Prior to the IRA, many developers established tax equity investment partnerships that allow them to trade their PTCs to firms, investors, or individuals with high tax burdens in exchange for more liquid capital. Under IRA, some firms

receiving PTCs can elect to receive their credits as direct payments from the federal government until 2028. For example, the Clean Hydrogen Production Credit, established by the IRA, allows firms producing clean hydrogen to receive a tax refund equal in value to their PTC for the first five years of their operation.⁸³

INVESTMENT TAX CREDITS

Investment tax credits (ITCs) are one-time tax write-offs given to firms for their initial investment in a facility. ITCs have spurred production of clean energy, semiconductors, and a range of other technologies. Since the IRA, clean energy firms have been eligible for a base credit worth 30% of their total investment, though they must choose to receive either an ITC or PTC, not both. Firms can receive bonus tax credits if they meet a set of criteria established by the IRA, like locating facilities in fossil-fuel-dependent areas or meeting domestic content thresholds. For smaller installations, additional tax credits are available if the project is in a low-income community, on tribal lands, part of a low-income housing project, or part of a low-income economic benefit project.⁸⁴

ITCs reduce the cost of initial investment and funding needed for clean energy installations, helping firms attract private investors. Unlike PTCs, which have per-unit payouts, one-time payments with ITCs incentivize larger investments up front due to the correlation between size of investment and the size of the write-off.

Like PTCs, ITCs are often less helpful for smaller or newer companies that do not have high tax liability. This means that firms often trade their ITCs, as others do their PTCs, to attain more flexible financing and capital in the short term. Future tax credit expansion could also include direct payment for ITCs — something IRA included for nontaxpayers like non-profits and government entities⁸⁵ — which would provide full tax refunds for anyone eligible to access credits, meaning that firms would not necessarily need to trade their tax credits to garner the benefits.

Creating ITCs and PTCs for low-carbon agriculture and food technologies could help expand and accelerate deployment.

CASE STUDY: CONTROLLED ENVIRONMENT AGRICULTURE

Controlled environment agriculture (CEA) — indoor production systems that grow crops and plants in a controlled and protected environment, including in greenhouses or vertical farms — often employs advanced technologies, like active climate control and hydroponics. These farming production systems could boost U.S. food production sustainably if operations are powered by renewable energy, rely on less land and water inputs, and if built close to markets, dramatically shortening supply chains and thus driving down food transport emissions. New York-based vertical farming start-up Bowery Farming has the largest vertical farming operations in the United States and claims its farms are 100 times more productive than field-grown operations.⁸⁶

CEA is not a new production method. In the United States, greenhouse-grown tomatoes represent 75% of all fresh tomatoes sold in retail stores.⁸⁷ Their market share has grown steadily since the early 1990s in North America.

Increasingly, CEA producers are producing a wider range of fresh fruits and vegetables. Leading vertical farming companies, like AeroFarms, Bowery Farming, and Plenty, are tackling indoor production of leafy greens. Many of these firms have benefited from early venture capital investments. Bowery Farming, for example, has a \$2.3 billion valuation and has raised more than \$647 million in equity and debt capital.⁸⁸

However, the industry is struggling to operate profitably without relying on venture capital. Challenges include securing financing to construct new farms and addressing high capital costs associated with innovative technologies including robotics, automation, and artificial intelligence systems. Scaling up commercial production profitably has proved a challenge for many vertical farming start-ups in recent years. AeroFarms filed for bankruptcy in June 2023 soon after building a new 140,000 square-foot indoor farming facility in Danville, Virginia.⁸⁹ After going public in a special purpose acquisition company (SPAC) in the 2021 boom, AppHarvest saw a 99% drop in share value before filing for bankruptcy in July 2023.^{90,91}

As CEA companies look to expand operations, produce a wider variety of crops, and accelerate food production to meet growing demand in innovative ways, many find they are ineligible for federal farm programs that are primarily focused on outdoor agriculture. For example, USDA's farm operation and B&I loan programs set strict eligibility limits based on geography. This leaves vertical farms operating in urban areas with limited options to take advantage of federal funds.

Policy Recommendations

Several policy levers could benefit emerging agri-food companies as they deploy new, low-carbon or market disrupting technologies and products. By including innovative technologies and production methods under existing and new government-backed loan guarantee programs, companies could better access capital to scale commercial production facilities, catalyze job creation, and help improve the resilience and productivity of the U.S. food supply chain.

Investment and production tax credits can also help incentivize producers or companies to invest in innovative technologies or production systems — especially those with high upfront costs.

The following policy recommendations aim to accelerate the adoption of innovative agri-food technologies and expand farming systems that can bolster food system resilience and sustainability, taking cues from federal loan programs and tax credits that aimed to decarbonize the energy sector:

- 1. Re-establish the Food Supply Chain Guaranteed Loan Program:** The FSCGLP could ensure that an ongoing, reliable source of government-backed loans are available to innovative food and agriculture companies, including those working on alternative proteins. Congress should codify the program, provide it with sustained annual funding, and increase the program's loan caps. Should FSCGLP be revived, the program will stand out in USDA's Rural Development portfolio as one capable of scaling production of a broad array of novel food products alongside middle-of-the-supply-chain support for conventional commodities. These loans can support investment in physical infrastructure and help companies purchase or lease processing equipment or manufacturing facilities. To better evaluate the eligibility of innovative food products or agricultural products made with emerging technologies, USDA should consider creating a dedicated "innovation" pathway under FSCGLP for loan applications falling outside of the conventional commodity products categories.
- 2. Expand Eligibility Under Other USDA Loan Programs:** USDA's Business & Industry Loan Guarantee Program (B&I) should expand its support for companies engaged in agricultural manufacturing and processing, especially those building facilities for alternative protein products or other lower-carbon food products. Additionally, USDA should consider to what extent rural eligibility requirements for B&I and other RD loan programs exclude emerging agriculture and food industries.

3. **Establish a Loan Programs Office at USDA:** USDA should take a cue from the Department of Energy's Loan Programs Office (LPO) and explore ways to provide larger loans that help commercialize low-carbon innovations. A new loan programs office focused on food and agriculture should apply lessons learned from LPO. These include but are not limited to, ensuring the office is equipped with sufficient staffing and expertise to be able to conduct accurate emission-life-cycle assessments for innovative products compared to conventional products, prioritizing direct loans and loan guarantees for firms demonstrating their technologies are ready to be deployed, and managing proactive relationships with industry players. A new loan program office would fill a glaring gap in USDA's loan program portfolio for innovative low-carbon technologies that prove capable of helping the agriculture sector reach net zero.
4. **Establish a Sustainable Agriculture Investment Tax Credit:** By establishing an ITC to support sustainable agriculture technologies and systems, the federal government could strengthen domestic production of lower-carbon or innovative food products. The ITC should be structured to include qualified investments in technologies and systems that improve domestic food security, strengthen supply chains, and minimize the environmental footprint of the global food system. This could apply to a range of food and agriculture industries. In 2022, the National Association of State Departments of Agriculture unanimously endorsed investment tax credits as one way to help scale indoor farming, given its high upfront capital expenditures.⁹²

IV.

CONCLUSION: CREATING AN ECOSYSTEM OF INNOVATION AT USDA

For many climate activists, decarbonization provides a unique opportunity to rebuild aspects of society intentionally. A green transition, in this logic, can also be a transition to more, or completely, equitable economic models. While decarbonization will likely be difficult enough already without a social reformation or revolution attached to it, the core idea that decarbonization can and should be done with intention — not haphazardly through market forces — is fundamental to an industrial policy-driven vision for decarbonization.

But for the state to lead on decarbonization, it must be able to target specific problems with specific policy solutions. Letting loose a firehose of public investment for food and agricultural innovations may not have the desired effect of reducing carbon emissions from agriculture while maintaining food abundance.

Creating the right policy mixture for the broader challenge of agricultural decarbonization will require a nuanced understanding of the specific problems plaguing firms and slowing technological progress. Programs aimed at funding the technical demonstration of production capacity, new loan programs designed for agricultural and food technologies, and specific tax credits for investments in and production of those technologies are just a few examples of specific solutions to a number of challenges (See Table 3).

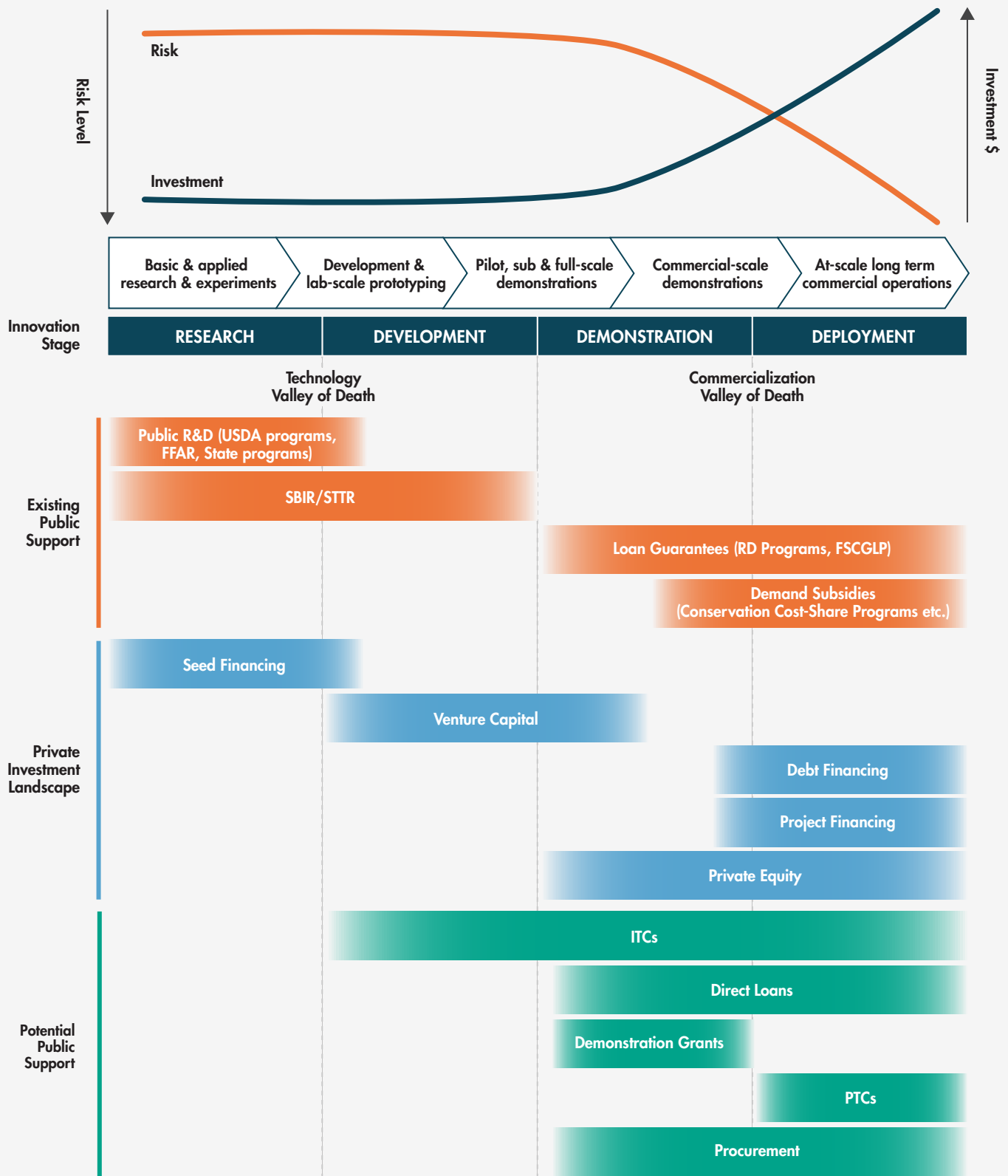
Building out USDA's capacity to support novel agricultural and food technologies will be a decades-long process. The Department of Energy and Department of Defense, after all, have more than a half-century of experience funding innovative technology research and carrying those technologies from lab bench to commercial production.

In the long term, a public innovation ecosystem for agricultural and food technologies will require far more than we have proposed here. For example, additional industrial policy measures such as procurement policies, workforce development, and production tax credits, to name a few, would further incentivize private investment and spur agricultural decarbonization. Together with existing programs, and our recommendations, these policies could further incentivize and shape private investment in food and agricultural technologies to the benefit of both society and climate (See Figure 10).

Table 3: Summary of Policy Recommendations

Research & Development	<ol style="list-style-type: none"> 1. Double federal research funding for major agricultural R&D agencies and programs — including NIFA and ARS — to reverse recent downward trends in public R&D spending and ensure continued U.S. leadership in developing new agricultural technologies and products. 2. Fully establish AgARDA with sufficient funding and staffing to fill a critical research niche for the development of innovative technologies at USDA.
Demonstration	<ol style="list-style-type: none"> 1. Fund testbeds through ARS and NIFA to evaluate and measure GHG emissions and environmental impacts of an increasing number of agricultural technologies and practices. 2. Establish an Office of Food and Agriculture Technology Demonstration at USDA to focus on bridging the gap from R&D to market adoption for emerging food and agricultural technologies and products with decarbonization potential.
Deployment	<ol style="list-style-type: none"> 1. Support and prioritize innovation under USDA direct and guaranteed loan programs—like the Food Supply Chain Guaranteed Loan Program and the Business & Industry Loan Guarantee Program—to enable the expansion of commercial scale production of lower-carbon food products and technologies. Programs should also consider to what extent rural eligibility requirements exclude emerging agriculture and food industries or innovative production methods that offer lower-carbon alternatives to conventional products. 2. Establish a Loan Programs Office at USDA to explore ways to provide larger loans to catalyze innovations with decarbonization potential for the food and agriculture sector. 3. Establish a sustainable agriculture investment tax credit to encourage investments in sustainable agriculture technologies and systems, especially those with high upfront costs.

Figure 10: The Innovation Value Chain for Agricultural and Food Technologies



Source: Adapted from ARPA-E and OCED.

A legitimate and thriving public innovation ecosystem will require coordinating the efforts of USDA and other federal and state agencies working on agricultural technologies and food systems. For example, ensuring DOE efforts to mitigate emissions through agricultural systems complement existing USDA programs, and any new programs, will be crucial to maximizing the benefits of federal public investment.

Ultimately, coordinating an innovation ecosystem for food and agriculture across federal and state agencies and offices will be difficult, but opens the possibility for significant advances toward agricultural decarbonization. Ensuring synergistic relationships between public and private sector investment in agricultural and food technology can expedite the pathway from scientific breakthroughs to fully-scaled solutions, bringing U.S. agriculture and the American food system firmly into the 21st century.

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