Environmental Defense Fund

LANDSCAPE OF AGRICULTURAL INNOVATION

Solutions, investment and policy actions

January 2026

1. EXECUTIVE SUMMARY

These findings are presented in two complementary parts:

Brief for policymakers and private-sector leaders: A high-level summary of emerging innovation areas, with clear actions required from both policymakers and industry to create the market forces and enabling environment needed for ag-tech solutions to mature and scale.

Catalogue of agricultural innovations: A detailed reference that profiles each innovation category, including product examples, assessments of market readiness, geographic considerations and potential climate and environmental benefits and tradeoffs.

Note: All product and company examples are illustrative and have not been researched by EDF for verification of corporate claims of effectiveness.

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Technological advancements are poised to help farmers stay productive in the face of more extreme and variable weather, so that they can maintain good livelihoods and feed a growing population, while reducing the climate impacts of food production. Environmental Defense Fund analyzed nearly 400 companies and innovations in the climate-smart agriculture market to evaluate their climate impacts and benefits, market readiness and environmental co-benefits.

This report illustrates both the strengths and limitations of these technologies. It highlights where effective policy support and investment can accelerate the efficiency gains, emissions reductions and environmental co-benefits needed for building a sustainable and resilient agricultural system. Policymakers must create an enabling environment by funding research, advancing bipartisan legislation and expanding technical support, while the private sector must accelerate investment, partnerships and financing strategies that bring solutions to market. These actions can be the catalyst to unlocking the economic and environmental potential of climate-smart agriculture.

Agriculture accounts for more than 10% of the U.S. greenhouse gas emissions and remains the nation's largest source of methane and nitrous oxide emissions. At the same time, agriculture can play a pivotal role in helping the U.S. achieve economy-wide, net-zero GHG emissions by 2050.

Unlocking the potential of agricultural technology is key to driving a much needed third modern agricultural revolution (Saiz-Rubio & Rovira-Más, 2020). Farmers and society need this revolution now more than ever as climate change makes food production more difficult and population growth means we need more food.

The U.S. has long been a global leader in innovation, from driving the Green Revolution's advances in agricultural science to breakthroughs in biotechnology, aerospace and renewable energy. Today, it stands as the world's leading exporter of software and technology. Building on these strengths, the U.S. can spearhead the next wave of agricultural innovation, enabling American farmers to maintain productivity in the face of a changing climate, while reducing the impact of agriculture on the environment.

The ag-tech sector represents a promising driver of U.S. economic growth, with strong signals of resilience and investor confidence even amid broader downturns in venture capital (RFSI). Regenerative agriculture and climate-smart solutions have proven particularly attractive, drawing steadily increasing private-sector commitments — from just over $2 million in corporate funding in 2018 to more than $10 million in 2023 (EDF, 2024). Globally, agrifood-tech investment reached $16 billion in 2024, with the U.S. capturing 41% ($6.6 billion) (AgFunder, 2024), underscoring America's leadership and the sector's economic potential.

This report highlights five technology fields — **nutrient and fertilizer solutions, smart sensing and precision analytics, agronomic data and measurement platforms, biotech and genetic innovation and automation and machinery**. These valuable tools can boost farm productivity while delivering climate and environmental benefits. This review is focused primarily on field crop applications, with some livestock applications.

TABLE 1

Landscape of high-potential climate-smart agriculture technologies

Innovation area	Technologies	Environmental benefit
Nutrient and fertilizer solutions	Renewables-powered nitrogen fixation and catalytic Ammonia synthesis	Reduced nitrous oxide emissions, lower runoff/ pollution, improved nutrient efficiency, healthier soils
	Biomass-derived fertilizers	
	Enhanced-efficiency fertilizers (EEFs)	
	Biologicals: microbial nitrogen fixation and biostimulants	
	Waste streams to fertilizer	
	Methane to fertilizer	
	Soil amendments	
Smart sensing and precision analytics	Remote sensing for precision agriculture and regenerative agriculture monitoring	Optimized water/fertilizer use, reduced waste, early pest/disease detection, improved yields per input
	In-field farmland sensors and monitoring, precision irrigation	
	Variable rate application and fertigation	
Agronomic data and measurement platforms	Technical assistance for climate-smart agricultural practices	Enhanced soil health, biodiversity support, climate resilience, reduced chemical dependence
	Agronomics and computational agroecology	
	Carbon market facilitators	
Biotech and genetic innovation	Biological pest controls and crop protection	Drought tolerance, pest resistance, reduced chemical inputs, higher productivity on less land
	Seed genome editing, trait discovery and selection	
	Crop microbiome engineering	
	Plant cell culturing	
Automation and machinery	Crop protection weeding robotics and drones	Precision input use, lower labor intensity, reduced fuel/water use, minimized soil disturbance
	Autonomous tractors and farm machinery	

Policymakers and the private sector each have distinct but complementary roles to play in scaling climate-smart agricultural innovations to market and that deliver measurable climate and economic benefits.

Policymaker actions can create the enabling environment for climate-smart agriculture in the following ways:

- Strengthen federal programs — Protect and expand funding for initiatives like AgARDA, Conservation Innovation Grants (CIG) and the Regional Conservation Partnership Program (RCPP) that drive innovation.

- Advance legislation — Pass bipartisan bills such as the Precision Agriculture Loan (PAL) Act, the Innovative FEED Act and the EMIT LESS Act. Additionally, fully appropriating existing federal research programs like AgARDA could encourage further private sector innovation within the agriculture technology space.
- Build partnerships and capacity — Advance public private partnerships through programs like the Conservation Technical Assistance (CTA), provided by USDA's Natural Resources Conservation Service. Support other civil service and private sector partners to ensure farmers have on-the-ground support to adopt new practices and technologies.

Private sector actions can accelerate adoption and scale in the following ways:

- Invest in innovation — Steer capital and leverage technology and research across the five innovation categories to drive impactful solutions within their value chain emissions and across industries.
- Forge partnerships — Food and agriculture companies should collaborate with agtech companies to promote education on supplier-wide adoption of nutrient management programs and precision technologies.
- Innovate financial opportunities — Food and agriculture industry must identify innovative approaches to financing the adoption of climate-smart technologies by adding to the current toolbox of cost-share programs and advancing an array of financial incentives that directly address the barriers faced by farmers (EDF, 2022).
- Ensure scientific integrity — Align on practical, science-based monitoring, reporting and verification (MRV) methods that create a common language for comparing outcomes across supply chains and regulatory districts, with harmonized metrics. Create joint pilots with the public sector to identify synergies and avoid unintended trade-offs to validate outcomes and build confidence for buyers and investors.

2. INTRODUCTION

The agrifood sector stands at a moment of extraordinary opportunity. Growing demand for sustainable food, feed and fuel production, emerging technologies ready for scale, and shifting market expectations create a window for the entire agricultural value chain — from brands, retailers, ingredient processors, agribusinesses, agriculture finance institutions and farmers — to profit while driving climate solutions. Yet this opportunity comes against a backdrop of mounting pressures that are reshaping the agricultural landscape. These include climate change, water scarcity, soil degradation and labor shortages. Extreme weather events and volatile political and supply-chain conditions heighten the urgency for action.

EDF analysis of nearly 400 agricultural innovations being deployed within the private sector — from early-stage startups to large scale enterprises — demonstrates that the American agriculture sector can play a transformational role in accelerating the adoption of emissions-reducing practices and technologies. Doing so requires a favorable enabling environment driven by smart policies and impact-aligned investment strategies. These solutions can unlock value by fostering soil health, supporting yields and reducing input costs for producers, while enabling access to sustainability-driven markets and building long-term supply chain resilience — presenting win-wins for farmers, the environment and the American rural economy.

This report maps the highest-potential near-term innovation opportunities available to the agrifood sector and clarifies the role companies and policymakers can play in driving this transformation. Emerging solutions — such as digital tools, automation integration, biological innovations and precision agriculture practices — have the potential to reduce the carbon intensity of crop production, minimize nutrient losses and enhance resilience to climate extremes. Because biological systems and farm operations are diverse, progress requires a portfolio of approaches rather than a single solution; success depends on integrating multiple solutions tailored to geographies, value chains and risk profiles. The analysis examines five categories of solutions — **nutrient and fertilizer solutions, smart sensing and precision analytics, agronomic data and measurement platforms, biotech and genetic innovation, and automation and machinery** — assessing climate impact (mitigation and adaptation), market readiness, value-chain integration and barriers to scale to inform action by business leaders, investors and supply-chain stakeholders.

Stakeholders across the agricultural landscape stand to gain significantly from overcoming adoption barriers. Farmers benefit through cost savings, increased yields, reduced labor demands and improved resilience. Policymakers achieve enhanced food security, economic growth and environmental sustainability. Agribusinesses can strengthen brand reputation, stabilize supply chains and meet growing consumer demands for sustainable products. Investors see long-term financial performance gains, ESG alignment and opportunities for impactful investment.

Realizing these benefits will require forward-looking policies that create an enabling environment for innovation, as well as cross-sector collaboration to accelerate the scaling of climate-smart solutions.

3. LANDSCAPE OF SOLUTIONS

In the last decade, the number of ag-tech start-ups has grown to about 14,600 companies globally, with 47% of these companies residing in the United States (McKinsey 2023, Tracxn 2025). EDF conducted an analysis of nearly 400 venture-funded startups in the climate-smart agriculture market, ranging from early-stage startups to companies facing commercial markets, focusing on emerging technologies with potential for greater environmental and market impact at scale. Companies were selected based on fundraising achieved, with a diverse representation across funding stages, commercialization level and technology pathways.

This section outlines five priority innovation categories identified through EDF's analysis. Each category synthesizes the current state of science, market readiness, climate impact and business relevance, drawing on existing evidence to help companies identify where they can most effectively deploy influence, investment and procurement strategies to accelerate adoption at scale. All product and company examples are illustrative and have not been researched by EDF for verification of corporate claims of effectiveness.

For a full list of available technologies, see EDF's catalogue of agricultural innovations report.

TABLE 2

Landscape of high-potential climate-smart agriculture technologies

Technologies	Market readiness	Adaptation or mitigation	Where benefits occur	Adoption barriers
Innovation area: Nutrient and fertilizer solutions		**Environmental benefit:** Reduced nitrous oxide emissions, lower runoff/pollution, improved nutrient efficiency, healthier soils		
Renewables-powered nitrogen fixation and catalytic ammonia synthesis	Commercial	Mitigation	On-farm energy use & powertrain emissions, non-CO_2 field emissions, up-stream/ downstream supply chain emissions	Upfront cost, technical feasibility, compatibility with existing systems
Biomass-derived fertilizers	Commercial	Mitigation	Soil organic carbon & biomass sequestration, soil nutrient balance, up-stream/downstream supply chain emissions	Technical feasibility, biophysical constraints, market or supply chain access
Enhanced-efficiency fertilizers (EEFs)	Early market	Mitigation	Soil nutrient balance, plant nutrient uptake & use efficiency, non-CO_2 field emissions	Upfront cost, farmer awareness or knowledge, time to realize benefits
Biologicals: microbial nitrogen fixation and biostimulants	Early market	Mitigation	Soil nutrient balance, plant nutrient uptake & use efficiency, yield stability and climate risk buffering	Farmer awareness or knowledge, technical feasibility, time to realize benefits
Waste streams to fertilizer	Early market	Mitigation	Soil nutrient balance, up-stream/downstream supply chain emissions, water quality protections	Technical feasibility, policy or regulatory uncertainty, biophysical constraints

Technologies	Market readiness	Adaptation or mitigation	Where benefits occur	Adoption barriers
Methane to fertilizer	Early market	Mitigation	Soil nutrient balance, nutrient uptake and use efficiency, non-CO_2 field emissions	Technical feasibility, farmer awareness or knowledge, data infrastructure or digital literacy
Soil amendments	Early market	Mitigation	Soil organic carbon and biomass sequestration, non-CO_2 field emissions, soil nutrient balance, yield stability and climate risk buffering	Technical feasibility, farmer awareness or knowledge, upfront cost, policy or regulatory uncertainty
Innovation area: Smart sensing and precision analytics		**Environmental benefit:** Optimized water/fertilizer use, reduced waste, early pest/disease detection, improved yields per input		
Remote sensing for precision agriculture and regenerative agriculture monitoring	Market scale	Mitigation	Field operations efficiency, soil nutrient balance, yield stability and climate risk buffering	Data infrastructure or digital literacy, upfront cost, farmer awareness or knowledge
In-field farmland sensors and monitoring, precision irrigation	Market scale	Mitigation	Irrigation water-use efficiency, soil nutrient balance, yield stability and climate risk buffering	Upfront cost, data infrastructure or digital literacy, farmer awareness or knowledge, technical feasibility
Variable rate application and fertigation	Market scale	Hybrid	Soil nutrient balance, plant nutrient uptake and use efficiency, irrigation water-use efficiency	Upfront cost, technical feasibility, farmer awareness or knowledge
Innovation area: Agronomic data and measurement platforms		**Environmental benefit:** Enhanced soil health, biodiversity support, climate resilience, reduced chemical dependence		
Technical assistance for climate-smart agricultural practices	Early market	Hybrid	Soil nutrient balance, non-CO_2 field emissions, yield stability and climate risk buffering	Farmer awareness or knowledge, policy or regulatory uncertainty, time to realize benefits
Agronomics and computational agroecology	Early market	Hybrid	Soil nutrient balance, field operations efficiency, yield stability and climate risk buffering, chemical-use intensity	Data infrastructure or digital literacy, technical feasibility, policy or regulatory uncertainty
Carbon market facilitators	Early market	Mitigation	Soil organic carbon and biomass sequestration, non-CO_2 field emissions, upstream/downstream supply chain emissions, soil nutrient balance	Policy or regulatory uncertainty, upfront cost, technical feasibility
Innovation area: Biotech and genetic innovation		**Environmental benefit**: Drought tolerance, pest resistance, reduced chemical inputs, higher productivity on less land		
Biological pest controls and crop protection	Market scale	Adaptation	Chemical-use intensity, soil nutrient balance, yield stability and climate risk buffering	Technical feasibility, farmer awareness or knowledge, market or supply chain access

Technologies	Market readiness	Adaptation or mitigation	Where benefits occur	Adoption barriers
Seed genome editing, trait discovery and selection	Early market	Adaptation	Plant nutrient uptake and use efficiency, non-CO_2 field emissions, yield stability and climate risk buffering	Policy or regulatory uncertainty, farmer awareness or knowledge
Crop microbiome engineering	Commercial	Adaptation	Soil nutrient balance, plant nutrient uptake and use efficiency, yield stability and climate risk buffering	Technical feasibility, farmer awareness or knowledge, time to realize benefits
Plant cell culturing	Commercial	Mitigation	Upstream/downstream supply chain emissions, non-CO_2 field emissions, yield stability and climate risk buffering	Upfront cost, technical feasibility, market or supply chain access
Innovation area: Automation and machinery		**Environmental benefit:** Precision input use, lower labor intensity, reduced fuel/water use, minimized soil disturbance		
Crop protection weeding robotics and drones	Early market	Mitigation	Chemical-use intensity, field operations efficiency, on-farm energy use and powertrain emissions	Upfront cost, technical feasibility, compatibility with existing systems
Autonomous tractors and farm machinery	Early market	Mitigation	On-farm energy use and powertrain emissions, field operations efficiency, chemical-use intensity	Upfront cost, technical feasibility, compatibility with existing systems

Table 2: Key	
Market readiness	A marker of "relative maturity," based on the sum of fundraising rounds for each company in that category, as well as the extent to which the product is being deployed commercially. • Pilot: Small-scale testing with early adopters or trial partner • Early market: Limited release, often targeting niche or visionary customers • Commercial: Broad release with a viable business model and revenue generation • Market scale: Rapid growth, infrastructure investment and mainstream adoption • Mature market: Saturation, stable demand and slower growth; high competition
Adaptation or mitigation	Adaptation — in human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. Mitigation (of climate change) — a human intervention to reduce emissions or enhance the sinks of greenhouse gases.
Where benefits occur	Part of agricultural production process where climate or adaptation benefits are realized: soil nutrient balance, nutrient uptake and use efficiency, water use efficiency, on-farm energy use, field operations efficiency, chemical-use intensity, soil carbon sequestration, non-CO_2 field emissions, water quality protection, upstream/downstream emissions, yield stability and climate-risk buffering
Adoption barriers	Starting point of general barriers to scaling the technology, including upfront cost, technical feasibility, farmer awareness, labor disruption, compatibility with existing systems, policy misalignment, biophysical constraints, market access, data infrastructure or digital literacy, time to realize benefits

3.1 Nutrient and fertilizer solutions — early market to commercial scale

Fertilizer innovations are designed to reduce the carbon intensity and environmental footprint of nutrient inputs while sustaining or improving yields. Synthetic nitrogen fertilizers account for an estimated 1-2% of global GHG emissions (IFA. 2022), making them a priority target for climate-smart interventions. Opportunities include low-carbon production methods, enhanced efficiency fertilizers and biological alternatives, all of which can cut emissions from both manufacturing and application.

These solutions deliver multiple value levers: lower N_2O and upstream emissions, improved nitrogen use efficiency, reduced input costs, and enhanced soil and water quality. Near-term, enhanced efficiency fertilizers offer market-ready returns through input savings. Medium- to long-term opportunities are emerging, with scalability dependent on policy, infrastructure and buyer demand — examples include low-carbon ammonia production and renewable-powered nitrogen fixation.

Adoption potential spans global crop production, particularly in commodity grain systems with high fertilizer intensity. Co-benefits include soil health gains, reduced nitrate leaching and improved water quality, though transitions may require farmer education and equipment adjustments. Performance variability by crop and geography underscores the need for technical support, competitive pricing and procurement incentives.

Recent fertilizer and crop nutrient innovations include: renewable-powered nitrogen fixation and green ammonia synthesis that reduce reliance on fossil fuels in manufacturing; microbial inoculants and biostimulants that improve nutrient uptake and boost resilience; soil amendments such as biochar and ground silicate or limestone rock that enable enhanced weathering; and circular nutrient approaches — like composts, digestates, and improved manure management — that close nutrient loops and cut emissions.

INNOVATOR SPOTLIGHT

Indogulf BioAg

Indogulf BioAg is a biofertilizer developer specializing in organic and nanofertilizers, biological inoculants that stimulate plant physiological processes and improve nutrient uptake and targeted nutrient solutions. The company's technology leverages beneficial soil microbes and nanotechnology to facilitate natural nutrient cycling, enhancing plant growth while replenishing organic matter in soils to strengthen long term ecological resilience in farming systems. Indogulf BioAg exports products to 25 countries with worldwide recognition and certification, serving the organic agriculture industry with nanofertilizer solutions in a sector growing at a compound annual rate of 14.3 percent.

3.2 Smart sensing and precision analytics — market scale to mature market

Monitoring and sensing technologies collect and analyze field-level data to enable precision management of inputs, improve operational efficiency and provide verifiable metrics for sustainability reporting. These tools include remote sensing satellites, UAVs (drones), in-field internet enabled smart-devices and AI-driven analytics platforms.

From a climate perspective, monitoring and sensing enable farmers and companies to track crop health, soil moisture, nutrient status and pest pressure in near real-time. This facilitates targeted interventions which can decrease GHG emissions and nutrient losses: reducing excess fertilizer application, optimizing irrigation and lowering chemical use. The resulting data also supports Scope 3 emissions accounting, regulatory compliance and access to sustainability-linked markets.

Market readiness is high for many sensing solutions, particularly in high-value crops and large-scale commodity systems where ROI from input optimization can be realized quickly. However, adoption can be limited by equipment costs, connectivity challenges in rural areas, and the need for technical expertise to interpret and act on data.

Examples of technologies within this category include satellite-based vegetation indices for early stress detection, drone-mounted multispectral imaging for precision input application and soil sensor networks for real-time nutrient monitoring. Partnerships between ag-tech firms, cooperatives and downstream buyers can accelerate adoption by integrating these tools into existing farm management workflows and tying procurement incentives to verified data.

3.3 Agronomic data and measurement platforms — early market to market scale

Integrated agri-management solutions combine multiple practices and technologies into cohesive systems tailored to local agroecological and market conditions. By pairing practices like conservation tillage, diversified crop rotations, cover cropping, integrated pest management and precision irrigation with robust monitoring and verification, farmers can track and refine how inputs are applied and managed. Data on fertilizer use, irrigation schedules and pest control not only improve day-to-day efficiency but also provide a basis for quantifying best management practices and agricultural greenhouse gas emissions. In this way, integrated systems not only optimize inputs and enhance biodiversity but also strengthen resilience while contributing to broader climate change and mitigation efforts.

By stacking practices, integrated systems can deliver cumulative benefits that exceed those of individual interventions — improving soil organic carbon, reducing erosion, enhancing water retention and lowering input use. Climate impacts include both mitigation, through reduced emissions and increased sequestration, and adaptation, by buffering farms against climate variability.

Market readiness varies, with many practices already widely adopted in certain geographies, while others require further demonstration and technical support. The business case often hinges on aligning agronomic benefits with market incentives, such as sustainability-linked procurement contracts or access to carbon markets.

According to a survey of farmers on their ag-tech adoption, “farm management software” is the most common agriculture technology currently being used by farmers in North America, with 47% of farmers either already using or planning to use it in the next two years (McKinsey, 2022).

Representative business models are emerging to support integrated agri-management at scale. For example:

- Farm data management and MRV platforms (e.g., Regrow Ag, CIBO Technologies) that integrate agronomic, satellite and supply-chain data to help farmers optimize practices while generating climate-ready measurement and verification; revenue models are typically subscription-based or tied to carbon credit transactions.

- Market linkage platforms (e.g., Indigo Ag, Nori) that connect growers directly to carbon markets or sustainability-linked buyers, monetizing by taking a share of credit or premium payments.

- Farmer networks and input disruptors (e.g., Farmers Business Network, Pivot Bio) that combine peer-to-peer data, digital agronomy and novel biological inputs, often pairing product sales with services that target enhancing soil health and reducing emissions.

- Precision technology innovators (e.g., Arable, Taranis) offering in-field sensors, drone-based scouting and AI analytics to reduce input use and improve resilience; revenue models blend hardware sales with ongoing analytics subscriptions.

Together, these models illustrate how a new generation of ag-tech companies are moving beyond individual practices toward integrated systems that create value through both improved farm performance and climate outcomes.

INNOVATOR SPOTLIGHT

CIBO Technologies

CIBO Technologies is a leader in regenerative agriculture monitoring and data reporting. It uses advanced agricultural modeling technology to understand agricultural systems at any scale and was recently selected as the technology partner for a groundbreaking Virginia Tech-led $80M USDA farm conservation program grant. CIBO harnesses the power of farm system data to support the implementation and monitoring of regenerative agriculture across farms of all sizes and unites remote sensing and drone data collection with high-quality quantification and reporting, creating trackable visualizations and metrics for farmers, businesses and the public sector. CIBO demonstrates, through robust research, institutional partnerships and private sector engagement, a vision for the large-scale distribution and dissemination of agricultural innovations through strategic, cross-disciplinary collaboration.

3.4 Biotech and genetic innovation — early market to market scale

Biotechnology and genetic innovations are designed to reduce reliance on synthetic inputs, improve nutrient cycling and enhance crop resilience while sustaining or increasing yields. These solutions encompass biological inputs such as microbial inoculants, biostimulants and biocontrol agents, which leverage naturally occurring organisms or compounds to improve nutrient uptake, plant health and stress tolerance, while reducing chemical pesticide use. Advanced genetic tools — including (Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) and precision breeding — enable targeted development of traits such as drought tolerance, nitrogen use efficiency and pest resistance (Upadhayay et al., 2023; Singh et al., 2020).

These types of innovations deliver multiple value levers: improved input efficiency, reduced greenhouse gas emissions from fertilizer application, enhanced resilience to climate stressors and potential reductions in production costs. Near-term opportunities include commercialized microbial products with proven yield and resilience benefits, while medium- to long-term opportunities — advanced trait development and microbiome engineering — are emerging and depend on clear regulatory pathways, robust field validation and buyer demand.

Adoption potential spans diverse crop systems, from high-value horticulture to broadacre commodities, with co-benefits including improved soil health, reduced pesticide use and increased yield stability. Barriers include performance variability by crop and geography, longer R&D cycles for genetic innovations and farmer hesitancy toward novel technologies without clear ROI.

Illustrative examples include microbial inoculants enhancing root-zone nutrient uptake, CRISPR-edited crops with improved nitrogen use efficiency, and microbiome engineering approaches to increase plant disease resistance while reducing synthetic input needs.

INNOVATOR SPOTLIGHT

Provivi

Provivi is a California-based biotechnology company specializing in the development of biopesticides and safer insect control. The company is creating a new foundation for affordable and sustainable crop protection to improve the lives of farmers globally. Originating from biocatalyst technology developed at CalTech, Provivi secured $85M in Series C funding in 2019. Since then, it has demonstrated leadership grounded in its mission to advance not only biological pest control in the United States but also worldwide, spreading a vision for accessible and effective solutions in global markets. Born from university-backed development, Provivi highlights the importance of continuous scientific research in agricultural innovation and maintaining the strength of the United States as a global leader in agricultural science and technology.

3.5 Automation and machinery — early market

Automation and mechanization innovations integrate AI, GPS and precision application systems to improve labor efficiency, reduce chemical use and optimize resource allocation while maintaining or improving yields. These solutions include autonomous tractors, drones and robotic weeders, often paired with monitoring and sensing technologies to enable site-specific management that minimizes inputs and emissions.

These technologies deliver multiple value levers: labor cost savings, reduced fuel consumption, lower herbicide and fertilizer use, improved operational timing, and resilience against labor shortages. Near-term opportunities include commercially available autonomous machinery and robotic weeders delivering immediate ROI in certain cropping systems. Medium- to long-term opportunities involve further integration of AI and robotics to automate complex field operations.

Adoption potential is strong in large-scale commodity systems and high-value crops where labor or chemical costs are significant. Co-benefits include reduced soil compaction through optimized traffic patterns, lower risk of chemical drift and enhanced worker safety. Barriers include high upfront costs, rural connectivity gaps and the need for operator training and equipment maintenance capacity.

Illustrative examples include robotic weeders achieving over 90% weed removal rates with minimal crop damage (Jiang et al., 2023; Upadhyay et al., 2024), drone-based precision spraying reducing chemical use by up to 85%, and autonomous tractors performing planting and tillage with high precision to reduce fuel use and soil disturbance.

INNOVATOR SPOTLIGHT

Monarch Tractor and Carbon Robotics

Monarch Tractor, maker of fully electric, driver-optional smart tractors, and Carbon Robotics, developer of AI-powered weed control systems, led two of the largest ag-tech funding rounds in 2024. Monarch Tractor secured $133 million in Series C — the largest raise to date in agricultural robotics — while Carbon Robotics closed $70 million in Series D, bringing its total funding to $157 million. Both rounds underscore strong venture capital momentum in autonomous and AI-driven farm technologies (iGrow News 2024)

3.6 Integrity-led innovation and guardrails

As the technologies profiled in this report demonstrate, innovations — ranging from advanced sensors to engineered microbes — represent a promising future for climate-smart agricultural systems. Translating these innovations into scalable solutions requires careful consideration of their systemic impacts and limitations. Agricultural systems are biologically complex and have high geographic variability.

Investments in these technologies by the finance sector, food companies and the farmers who use them will often involve environmental incentives such as green financing mechanisms, impact investing, insetting, carbon markets and more.

A robust, science-backed understanding of the environmental impact of new practices is fundamental to market integrity. Doing so is dependent on effectively determining baseline emissions levels and accurately measuring, monitoring, reporting and verifying (MMRV) avoided and reduced emissions beyond the business-as-usual scenario. The reputation of, and confidence in, any new agriculture technology rests largely on ensuring there is an understanding of the full impact of implementing technologies in complex systems. Without proper scientific testing and appropriate guardrails, even the most promising solutions risk being dismissed as greenwashing or resulting in unintended environmental consequences. Integrity is not a barrier to growth — it's the guardrail that makes innovation investable, verifiable and enduring.

Where investment and cross-sector collaboration is needed to ensure scientific integrity:

- Large-scale trials — Multi-year pilots for promising technologies across diverse regions to validate results and reduce uncertainty for buyers and investors.
- Harmonized metrics — Practical, science-based MRV methods that create a common language for comparing outcomes across supply chains and regulatory districts.
- Socioeconomic insights — Understanding farmer behaviors, cultural norms and financing constraints to design solutions that work in the real world.
- System interactions — Testing bundles of practices together to identify synergies and avoid unintended trade-offs.

With concerted investment in data, guardrails and transparency, businesses can move from bold commitments to credible outcomes. Closing these gaps is not about slowing adoption — it is about ensuring that climate-smart agriculture delivers real value for farmers, markets and the planet.

4. MARKET CONTEXT

While the public and private sector are increasing recent investments into climate-smart agriculture, a growing body of research indicates that the magnitude of the funding and financing gap to support widespread global adoption is massive.

Globally, agrifood-tech investment reached $16B in 2024 (-4% YoY), with the U.S. capturing approximately 41%, equivalent to ~$6.6 billion (AgFunder, 2024). The U.S. was the only major developed market to post double-digit growth and one of a handful of markets — including India, the Netherlands, Finland and Japan — to buck the global slowdown (AFN, 2025). This performance reaffirms the United States' central role as a hub for innovation development, even amidst shifting ag-tech investment landscapes.

According to AgFunder in 2025, U.S. ag-tech investment in 2024 was concentrated in categories forming the foundation of a sustainable and resilient agriculture system.

- Ag biotechnology — $976M: Reflects sustained interest in microbial products, genetic engineering (RNA, CRISPR), precision breeding and microbiome-based technologies for crop and animal agriculture. These tools improve input efficiency and climate resilience, and reduce reliance on synthetic chemicals.
- Bioenergy and biomaterials — $643M: Focused on non-food value chains, including biomass conversion into fuel, feedstock innovation and sustainable materials, supporting circularity and diversifying revenue streams.
- Farm robotics, mechanization and equipment — $345M: Automation technologies enhancing labor efficiency, reducing chemical use and enabling ultra-precise input application. Drones, autonomous machinery and AI-guided equipment are central to this category.

INVESTOR SPOTLIGHT

AgRogue Growth Partners

Land O'Lakes, Inc., together with a coalition of local agricultural retailers, has launched AgRogue Growth Partners, a new investment platform designed to accelerate the development and adoption of ag-tech. Managed by venture firm Radicle Growth, the initiative aims to invest up to $7 million each in 10 to 15 ag-tech companies, focusing on innovations in crop inputs, ag data, supply chain systems, business models and more. Retail partners in the initiative include Keystone Cooperative (Indiana), Central Valley Ag and Farmers Cooperative-Dorchester (Nebraska), Farmward Cooperative (Minnesota), and both Alabama Farmers Cooperative and GreenPoint Ag (Alabama). This approach highlights a multi-stakeholder, private-sector–led model for investing in agricultural innovation — one that combines capital, technical vetting and market access to drive adoption. As such, it serves as a potential blueprint that other cooperatives or private groups could replicate to support ag-tech at scale.

- Farm management software, sensing and IoT — $302M: Tools that collect, integrate and analyze field-level data to support nutrient optimization, emissions quantification, risk assessment and financial reporting — critical for Scope 3 tracking.
- Innovative foods — $574M: Includes cultured meats, alternative proteins and plant-based foods. While not all are tied directly to primary production, these align with trends in sustainable consumption and supply chain decarbonization.

Government agencies are also important investors in agricultural innovation, specifically in conducting agricultural R&D and translating that work into new technologies that are introduced to the marketplace. A study published in the Proceedings of the National Academy of Sciences (PNAS), finds that "public agricultural R&D expenditures underwent a steady rise throughout most of the 20th century, but slowed starting in 1970, stagnated around 2000, and then declined in the last decade" (A. Ortiz-Bobea, 2025). Maintaining and expanding government investment in R&D is critical to the innovation ecosystem.

The agrifood innovation landscape remains dynamic but the investment environment is becoming more selective. Venture capital firms increasingly prioritize near-term ROI, clear regulatory pathways and capital-efficient models. Startups face pressure to show both measurable climate and productivity impacts and a credible path to profitability. While this cautious investing climate can limit investment in long-horizon, systems-level innovation, momentum persists for technologies able to deliver quantifiable benefits within shorter timeframes, acting as stepping stones toward broader transformation.

Companies have a critical opportunity to invest in innovative solutions to provide the tools needed to mitigate agricultural emissions and build more resilient landscapes. By leveraging existing technology and research capabilities, companies can drive innovation and invest in impactful solutions within their value chain emissions and across industries. The current investment climate favors solutions with fast, measurable returns and clear market fit. Agrifood companies should prioritize partnerships and procurement strategies that align with these conditions, leveraging near-term wins to build capacity for scaling more transformative, longer-term innovations.

5. FEDERAL POLICY LANDSCAPE

Transformative innovations rarely scale on technical merit alone. Rather, their success hinges on enabling policy environments that address the scientific, financial and social barriers that influence farmers' adoption of novel practices and technology. Climate-smart agriculture is no exception. From early-stage research and development to market deployment and on-farm adoption, government policy plays a pivotal role in aligning public and private action toward climate solution outcomes. The governance landscape shapes both the pace and equity of innovation diffusion, with program design and funding mechanisms determining who adopts CSA practices, when, and at what cost. This section reviews the current U.S. policy environment, with a focus on federal and state-level programs and proposals that enable more sustainable, productive, and climate-resilient farming systems.

5.1 Existing federal programs supporting CSA innovation

Federal policy has long set the tone for national priorities in agricultural innovation by directing where and how innovation is developed, supported and adopted — from foundational research through the USDA National Institute of Food and Agriculture defining key R&D agendas, to the USDA Natural Resources Conservation Service Conservation Technical Assistance program guiding on-farm practice changes, and USDA Risk Management Agency setting the tone of financial incentive structures for farmers.

In the context of climate-smart agriculture, recent years have seen increased, but not unchallenged, emphasis on supporting practices and technologies that reduce emissions, improve soil health and enhance system resilience. While political shifts have tested the durability of these priorities, key agencies such as USDA, DOE and EPA continue to shape the tools and funding streams that influence how producers, agribusinesses and researchers engage with agricultural innovation. This section outlines the major federal policies and proposals influencing CSA innovation, highlighting both established programs and emerging opportunities for reform.

Protecting and expanding access to public-private partnerships, competitive grants and demonstration projects can accelerate the commercialization of promising solutions and make them more accessible to farms of all sizes. By focusing on practical measures that improve resilience, cutting costs for producers and reducing environmental impacts, federal policy can ensure U.S. agriculture remains competitive globally while delivering shared economic and environmental benefits.

- AgARDA: The Agriculture Advanced Research and Development Authority was established in the 2018 Farm Bill to invest in high-risk, long-term research that can lead to “disruptive” scientific discoveries that could solve agriculture's most complex problems. Modeled after similar federal research programs such as the Department of Defense’s Defense Advanced Research Projects Agency (DARPA) and the Department of Energy’s Advanced Research Projects Agency (ARPA-E), the program is authorized to receive up to $50 million annually but has historically received much less through annual appropriations, most recently only $1 million in fiscal years 2022-2025. This lack of funding has prevented the program from ever moving past the conceptual phase and advocates continue to encourage Congress to fully fund the program during the annual appropriations process.

- Conservation Innovation Grants (CIG): a subprogram of the Environmental Quality Incentives Program (EQIP), CIG offers competitive grants to spur innovative new practices on farms and help scale their adoption. The program’s On-Farm Trial grants have recently supported climate-smart agriculture projects to reduce enteric methane emissions from livestock, improve irrigation efficiency and bolster MMRV methodologies that can better quantify GHG reductions from agriculture. In 2022, the program received a significant but temporary funding boost from the Inflation Reduction Act, which was then made permanent in the recent One Big Beautiful Bill Act.

- Regional Conservation Partnership Program (RCPP): a public-private partnership program administered by the Natural Resources Conservation Service (NRCS) that allows partner organizations to apply for cost-sharing and technical assistance in delivering conservation services to farmers. One of the four ranking criteria for proposals is ‘innovation,’ giving applicants who seek to develop innovative new techniques to conserve natural resources more consideration in the application process. RCPP also received a funding boost in the IRA, which was enshrined permanently in the OBBB.

- Conservation Technical Assistance (CTA): provided by USDA’s Natural Resources Conservation Service and other civil service and private sector partners, is critical to helping farmers understand how new technologies, practices and equipment can help them increase productivity and reduce inefficiency. These boots-on-the-ground advisors help identify innovations and drive cultural adoption of new practices that improve farm resilience in increasingly difficult growing conditions.

5.2 Policy proposals and legislative opportunities

Federal policymakers can strengthen U.S. agriculture by advancing bipartisan legislation that supports both innovation and sustainability. The bills listed below represent realistic, market-driven approaches that can enhance farm profitability, strengthen rural economies and deliver measurable environmental benefits. EDF supports the following legislation:

- Precision Agriculture Loan (PAL) Act: would create a program within USDA to provide loan financing to farmers and ranchers interested in purchasing precision agriculture equipment.

- Innovative FEED Act: bipartisan legislation that would establish a pathway at the U.S. Food and Drug Administration (FDA) for novel feed additives and increase livestock efficiency and production.

- EMIT LESS Act: Enteric Methane Innovation Tools for Lower Emissions and Sustainable Stock Act aims to address enteric methane and create opportunities for producers by empowering the USDA to quantify the environmental benefits of products and practices that reduce enteric methane emissions. It creates voluntary incentives through conservation programs to ease their adoption by producers.

5.3 Interplay between state and federal policy

Although all U.S. states operate under the same federal framework for climate-smart agriculture, each state brings its own budgetary constraints, political dynamics and priority incentives to the table. Varying frameworks exist to incentivize agricultural innovation and sustainable farming practices. These include grant-based cost-share programs, regulatory relief or tax incentives and procurement mandates or co-governance networks. States typically operate with smaller budgets and more flexible political environments, whereas federal programs must navigate complex interagency coordination, broader stakeholder interests and stricter fiscal scrutiny. State policies can serve as a testing ground for federal initiatives, allowing policymakers to test approaches, measure impacts and refine program design before scaling solutions nationwide.

Ideally, state and federal policy can work hand-in-hand by aligning incentives. Federal programs can provide broad frameworks, funding streams and regulatory clarity, while states can adapt implementation to reflect regional crops, climates and market dynamics. For example, federal cost-share or loan programs could be paired with state-level technical assistance or demonstration trials to ensure farmers see benefits in their own fields. Coordinated action allows for both scale and flexibility by leveraging federal resources while empowering states to pilot, adapt and accelerate innovation in ways that are locally aligned.

5.4 Smart policy to enable private sector progress

Protecting and expanding access to public-private partnerships, competitive grants and demonstration projects can accelerate the commercialization of promising solutions and make them more accessible to farms of all sizes. By focusing on practical measures that improve resilience, cut costs for producers and reduce environmental impacts, federal policy can ensure U.S. agriculture remains competitive globally while delivering shared economic and environmental benefits.

Stable, science-based regulatory pathways for emerging technologies like biologicals and feed additives can give innovators and producers confidence to invest. Advancing the policies mentioned above can help create an enabling environment that de-risks innovation and gives the private sector confidence to make long-term investments in R&D.

6. BARRIERS AND ENABLERS TO SCALING WITH INTEGRITY

While the technologies outlined in this report represent some of the most promising agricultural innovations, scaling them requires overcoming persistent and often intertwined adoption challenges. These challenges operate at two levels — the farm level, where decisions and capacities are made field-by-field, and the system level, where policy, finance, infrastructure and markets set the rules of the game. Addressing both dimensions in parallel is essential in moving innovation from pilot plots to sector-wide transformation.

TABLE 3

Farm-level barriers and enablers

Barriers	Enablers
Variable ROI and performance uncertainty. Even the most promising technologies can perform differently across crops, soil types and climate zones. For example, a microbial inoculant that boosts maize yields in the Midwest may underperform in the Southeast due to soil pH differences or pest pressures. Without locally relevant evidence, farmers face the risk of sunk costs with uncertain returns, making early adoption a gamble.	Invest in large-scale, multi-year trials and harmonized MRV systems to generate locally relevant evidence in key regions and locales, reduce performance uncertainty and give farmers and investor confidence in ROI and benefits.
Upfront costs. Capital-intensive solutions such as autonomous machinery, precision irrigation systems or low-carbon fertilizer production equipment require significant CAPEX and sometimes higher OPEX before benefits materialize. Small and mid-sized farms — which often operate on tight margins — may be priced out of adoption unless financing is tailored to their cash flow.	By matching financial and technical support to farmers' needs for a given transition, companies can provide more holistic solutions to farmers and enable greater adoption of the right practices. A combination of financial mechanisms, such as cost-sharing, crop warranties and premiums, crop insurance and government subsidy programs offer a powerful toolbox to create a more flexible and secure system for farmers. A fusion of corporate and government support remains an important catalyst for scaling these efforts and offers the potential to bring in other critical partners such as agronomists and financial institutions. More pre-competitive collaboration is needed to support farmers in overcoming the financial barriers they face in decarbonizing agriculture, moving beyond cost-share incentives to de-risk the transition (EDF+Business).
Technical capacity and agronomy support. Innovations rarely succeed without hands-on guidance. Farmers need training to integrate tools into existing systems, troubleshoot issues and adapt settings for local conditions. Without trusted advisors or embedded agronomic support, adoption can stall.	Strategic public-private partnerships between supply chain actors, USDA, land-grant universities, extension services and ag-tech startups represent the most effective mechanism for scaling farmer training on emerging innovations, with government and extension partners uniquely positioned to provide the neutral, science-based credibility that ensures producer trust and accelerates adoption.

Barriers	Enablers
Equipment and infrastructure readiness. Some solutions depend on compatible hardware or connectivity. A farmer may be willing to invest in soil-moisture sensors, but if rural broadband is unreliable, the data pipeline breaks down.	Expand rural infrastructure such as broadband and equipment-sharing networks through public-private investment, ensuring farmers can reliably adopt and benefit from new technologies. Sponsor on-farm demonstration trials and farmer-to-farmer learning exchanges that validate results under local conditions, making performance data tangible and credible.

TABLE 4

System-level barriers and enablers

Barriers	Enablers
Data gaps and verification challenges. Without standardized measurement, reporting and verification protocols, companies and regulators struggle to quantify and reward climate benefits. This slows eligibility for carbon markets or sustainability-linked procurement programs.	Develop clear, science-based MRV protocols aligned to both corporate Scope 3 reporting and public policy frameworks.
Digital divide. Precision agriculture's promise hinges on connectivity, yet broadband coverage and digital literacy lag in many agricultural regions. The result: farmers can't fully leverage monitoring tools or real-time decision platforms.	Invest in rural broadband, IoT infrastructure and farmer-focused digital literacy programs to unlock precision agriculture at scale.
Regulatory uncertainty. The evolving rules for biologicals, carbon credits and nutrient management can create "wait and see" hesitancy among investors and adopters. Without predictable pathways, innovation pipelines slow.	Establish stable regulatory frameworks for emerging inputs and market mechanisms including explicit timelines for review and approval.
Short corporate ROI horizons. Biological and environmental benefits may take multiple seasons to materialize, while corporate decision-making often demands payback in 12–24 months. This mismatch can cause promising solutions to be overlooked.	Align procurement contracts with verified environmental outcomes, using long-term sourcing commitments to reward producers who deliver on sustainability metrics.
Fragmented data sharing. Knowledge generated in pilots or private R&D often remains siloed, preventing the cross-learning needed to de-risk innovation at scale.	Build pre-competitive data-sharing platforms and coalitions that pool anonymized results to accelerate collective learning.

RECOMMENDATIONS

The barriers and enablers above underscore the importance of designing policies that lower adoption risks, improve market certainty and ensure equitable access to innovation. By focusing on practical measures that improve resilience, cut costs for producers and reduce environmental impacts, federal policy can ensure U.S. agriculture remains competitive globally while delivering shared economic and environmental benefits.

With the right enabling environment, companies can leverage existing technology and research capabilities to drive innovation and invest in impactful solutions within their value chain emissions and across industries. Companies across the supply chain — from early-stage startups to grain elevators and consumer brands — can play a critical role in scaling ag-tech by investing in R&D, prioritizing and partnering to advance scientific integrity and working directly with farmers to implement solutions on the ground, including co-creating financial tools that lower barriers to adoption.

Recommendations for policymakers

Good policy creates an enabling environment that de-risks innovation and gives the private sector confidence to make long-term investments in R&D and practice changes. We need effective regulatory approval processes to enable faster market entry for novel products, particularly in biological and genetic innovations. Additionally, the insufficiency of consistent technical assistance and cost-share programs means that farmers — especially those operating small and mid-sized farms — lack both the knowledge and financial resources needed to de-risk the adoption of new practices.

A bipartisan path forward includes investing in research and development, financial tools and incentives for farmers. It also requires advisory services to help scale new technologies — such as precision agriculture, climate-resilient crops and soil health monitoring tools — that help farmers boost productivity while reducing inputs. Policymakers can do this by:

Protecting and fully appropriating access to existing federal programs

- Programs such as The Agriculture Advanced Research and Development Authority (AgARDA), Conservation Innovation Grants (CIG) and Regional Conservation Partnership Program (RCPP) are all essential to driving U.S. agricultural innovation.

Advancing bipartisan legislation that supports both innovation and sustainability

Policymakers should advance bills that represent realistic, market-driven approaches that can enhance farm profitability, strengthen rural economies and deliver measurable environmental benefits.

- Measures like the Precision Agriculture Loan (PAL) Act and the PRECISE Act would give farmers and ranchers practical financial tools to adopt precision agriculture technologies, helping them increase efficiency, reduce costs and conserve natural resources.
- The Innovative FEED Act would establish clear pathways for safe, science-based feed additives that improve livestock productivity while lowering environmental impacts.
- The EMIT LESS Act builds on this momentum by empowering USDA to measure and incentivize solutions that reduce methane emissions from livestock, creating new opportunities for producers to benefit from climate-smart practices.

Protecting and expanding access to public–private partnerships to accelerate the commercialization of promising solutions

- Programs like the Conservation Technical Assistance (CTA), provided by USDA's Natural Resources Conservation Service and other civil service and private sector partners, is critical to helping farmers understand how new technologies, practices and equipment can help them increase productivity and reduce inefficiency.

- Funding collaborative data-sharing initiatives and on-farm demonstration networks, federal and state leaders can de-risk innovation across diverse geographies.

Helping set transparent MRV standards that align public programs with private-sector reporting needs, reducing duplication and speeding recognition of verified climate benefits

- Policymakers can improve and standardize data collection used for measuring, monitoring, reporting and verifying of climate outcomes through various federal programs, such as the Long-Term Agroecosystem Research Network (LTAR) and Agriculture and Food Research Initiative (AFRI), as described in the Agriculture Resilience Act (ARA).

Recommendations for the private sector

Barriers are not simply roadblocks; they are market signals highlighting where corporate influence, strategic investment and coalition-building can make the greatest impact. Companies can address the above barriers by:

Investing in innovative solutions to provide the tools needed to mitigate agricultural emissions

Integrating enablers into sourcing, investment and R&D strategies not only accelerates climate impact but also builds durable supply chain resilience and competitive advantage.

Prioritizing scientific integrity through robust GHG measurement and accounting and collaborating across sectors to test solutions

- Measure and prioritize impact to meet targets. Commit to robust measurement and prioritize investments that can be tracked against corporate climate goals and verified emissions reductions.

- Ensure that any efforts to increase soil organic carbon (SOC) complements emissions reductions in nitrous oxide (N_2O) and carbon dioxide (CO_2) as well as accounting for upstream (e.g., fertilizer production) or downstream (e.g., land-use change) emissions (EDF, 2024).

- Address performance variability by partnering across sectors to test interventions in real supply-chain contexts, learn from pilots, then scale the approaches that show strong, locally relevant ROI and emissions benefits. Even proven technologies can work inconsistently depending on soils, climates, and farm practices.

Co-creating and scaling the financial tools needed to enable on-farm adoption of agricultural innovations within the value chain.

- Co-fund or design risk-management tools, cost-share programs, and technical assistance that make adoption of precision and nutrient-management practices economically feasible for farmers.
- Partner with ag-tech companies to promote education on supplier-wide adoption of nutrient management programs and precision technologies.

7. CONCLUSION

The breadth of evidence, analysis and practical guidance in this report reinforces that agriculture innovation is not a single technology or tactic, but a systems-level transformational opportunity requiring alignment across supply chains, markets, farmer priorities and policy frameworks. The innovation categories outlined — nutrient and fertilizer solutions, smart sensing and precision analytics, agronomic data and measurement platforms, biotech and genetic innovation, and automation and machinery — represent actionable entry points that can deliver measurable benefits when deployed strategically and in combination.

The market context shows both opportunity and urgency: investment flows, policy signals and shifting buyer expectations are converging to reward less carbon intensive, more resource-efficient production. Yet realizing this potential requires coordinated action to overcome systemic barriers, create strong demand signals for lower Carbon Intensity (CI) scores, and ensure that farmers have the technical, financial and market support to adopt innovations with confidence.

If the agrifood sector can align around shared goals, integrate innovation adoption into core business strategy and commit to continuous improvement backed by robust MRV, it can simultaneously advance climate mitigation, climate adaptation and market resilience — unlocking value for producers, companies and society at large.

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