INTESA SANPAOLO
INNOVATION CENTER

INDUSTRY TRENDS REPORT
DECARBONISATION
DECARBONISING THE AGRIFOOD SYSTEM

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani
GRINS FOUNDATION

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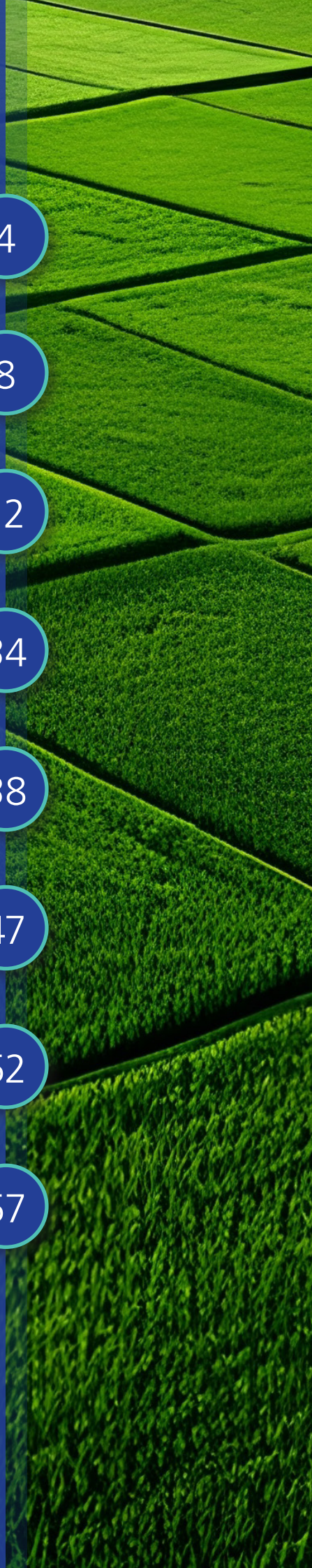


EXECUTIVE SUMMARY

Globally, the food system accounts for 26% of all greenhouse gas emissions. Within this, the main contributors are agricultural production with 82%, processing and packaging with 9% and agricultural equipment and transportation with 6%.

While the need to decarbonize is well established and recognized, there exist a number of key challenges to achieving sustainability, but this is changing as a combination of push and pull factors on the demand and supply side compel market participants to act. Across the value chain, stakeholders are improving land use, reducing waste, adopting renewables and reviewing their approaches to downstream activities.

This report examines how new business models and emerging technologies are allowing the agriculture, food & beverage industry to shrink its carbon footprint.

For agricultural production, precision agriculture forms part of a broader "farming 4.0" ecosystem which also includes sustainable farming. Uptake represents a direct response to climate and environmental changes and is driven by consumer demand and regulatory requirements.

Precision agriculture finds its application across several areas and is expected to allow farmers to anticipate a long-term shift from automation to autonomy. Sustainable farming centers on tracking a farm's performance against SDG indicators. Condition monitoring enables both and allows the real-time monitoring of the condition of crops, livestock and land is expected to be replaced by digital twins. Effective soil management is one of its main benefits that will stem from and shape the further deployment of farming 4.0 methodologies.

More broadly, animal and human nutrition have many common trends and dynamics. Animal nutrition is focused on improved feed efficiency whilst human nutrition is targeting protein diversification.

Farming 4.0 has a role to play in delivering these aims with ADM (USA), BASF (Germany) and Cargill (USA) among the key providers of sustainable solutions. In the future, they and others will increasingly leverage innovations like robotics, 3D printing and cloud to make farming more precise.

Next generation technologies are also impacting the agricultural biologicals sector, in particular in the areas of new product formulation. Agricultural biologicals are segmented into bio-pesticides, stimulants and fertilizers. Overall, the combined bio-stimulants and fertilizers segment is expected to grow most rapidly, expanding from $3.3 m globally in 2021 to $8.7 m by 2030.

Demand will be boosted by increased awareness of their benefits versus conventional chemical crop inputs especially amongst many small-scale farmers. From the supply side, the market for bio-stimulants and fertilizers is highly fragmented with some vendors playing in both of the spaces.

Participants will continue to invest in research & development of novel, environment-friendly biologicals to cater to users' sustainability requirements, which will support the wider use of regenerative farming and other approaches to enabling "greener" agricultural production and animal husbandry.

From a resource perspective, efforts are also focused on reusing water with treated wastewater increasingly feeding emerging sustainable irrigation systems.The fundamental issue driving the sector is water scarcity, but the circularity concept extends to the materials that make up systems with many market players looking to recycle components.

Overall, the global market is valued at $14 b and expected to reach over $31 b by 2030. Within this, and with sustainability in mind, emerging smart and micro irrigation systems are progressively replacing the more conventional mechanical solutions.

The vendor landscape is highly fragmented with more than 500 companies represented. Calsense (US) offers sustainable irrigation systems that leverage generative AI whilst CropX (US) works to serve a broad audience with affordable products.

Moving forwards, the advent of new solar-powered solutions is anticipated to further decarbonize the total irrigation systems market.

Decarbonisation efforts extend beyond inputs to cover outputs with waste management approaches including reducing food waste by tracking and tracing. Upcycling also offers opportunities for companies such as Flock Foods (US) which look to convert agri-food remains into food for humans and animal feed.

More generally, the conventional waste treatment value chain segments into collection, transportation, sorting & separation, reuse & recycling and disposal. Sustainable innovations here include the use of sensors and AI-based robotics across material recovery facilities (MRFs) while interest in advanced chemical recycling will continue to grow, for example in the form of plastic-to-fuel (P2F) methods for hard-to-recycle materials.

For renewable energies, anaerobic digestion represents a key opportunity and presents an alternative way of managing waste emanating from the food system.

Currently there are ~16 thousand biogas plants in Europe and ~1 thousand biomethane in the context of an overall market which is growing at over 7% annually. Their principal feedstock is agricultural surplus with the vast majority stemming from a combination of energy crops and crop residue or manure from livestock.

Growth is driven by the REPowerEU plan with targets for biomethane production but the high capital cost of constructing an AD plant acts as a barrier to deployment. Overall, however, the price of production compares very favorably to natural gas which is boosting its use for electricity, heat and CHP.

Italy is a hotspot for anaerobic digestion with domestic strengths on both the technology & equipment and feedstock & AD gas production sides of the market.

At a European level, supply is characterized by niche players in selected segments of the value chain but also turnkey solution providers like Fluence (Italy). The ability to deliver compact and modular digesters will become important.

In addition to leveraging waste and saving water, improved energy efficiency is vital in the food industry which accounts a quarter of global emissions. All of the major F&B players, including Arla Foods (Denmark/Sweden), Kemin (US) and Glanbia Nutritionals (Ireland) have "green" initiatives in this respect.

One main area of activity is refrigeration technologies with the global farm to fork cold supply chain growing rapidly at 12.6% on a compound average basis. Here, connected devices and automated warehouses are amongst the key innovations that are minimizing the sector's significant environmental footprint, while Ecozen (India) is innovating to bring the cold chain to small scale farmers and, at the same time, reduce the use of fossil fuels as an energy source.

Outside of food and farming, packaging is another segment with scope to decarbonize with products consisting of different materials. In Europe, in particular, sustainability and circularity are key motors for market growth. Here, the market is shifting from single-use plastics to sustainable packaging while lightweighting offers an alternative approach.

Moreover, smart packaging can be used to extend the shelf life of many food products and therefore to reduce waste and/or spoilage. Consumers in both Europe and the Americas are typically more willing to pay more for environmentally friendly packaging than conventional counterparts.

Manufacturers are in turn investing in pushing the adoption of bioplastics, and in expanding recycling infrastructure to secure raw material supply.

Sustainable alternative fuels coming from renewable energies and waste reuse can also be used in the farming equipment themselves.

For transportation, initiatives to improve sustainability stretch to vehicles that are used to distribute food and those that are used to nourish and harvest it.

Diesel is currently the dominant energy carrier for tractors, and it responds very well to farmers' requirements. Nonetheless, powertrain electrification is joined by engine modifications and alternative fuels as a means with which to decarbonize the sector in the future. Additional efforts will be needed to reduce the total cost of ownership, and governments are providing financial instruments to address this. OEMs are responding by developing full electric tractors, like the Sonalika Tiger, or supplying 100% electric powertrains such as that provided by Bosch.

Banks are playing an increasingly important role in supporting the decarbonisation of the agriculture sector, which accounts for a significant portion of global greenhouse gas emissions.

Several major banking institutions have joined forces to support the decarbonisation of agriculture with collaborative initiatives. In 2021, leading banking institutions with total assets of USD $10.1 Trillion joined forces at COP26 to support the decarbonisation of the agriculture and land use sector. The increasing collaboration of Agri-banks is needed to develop climate technical solutions.

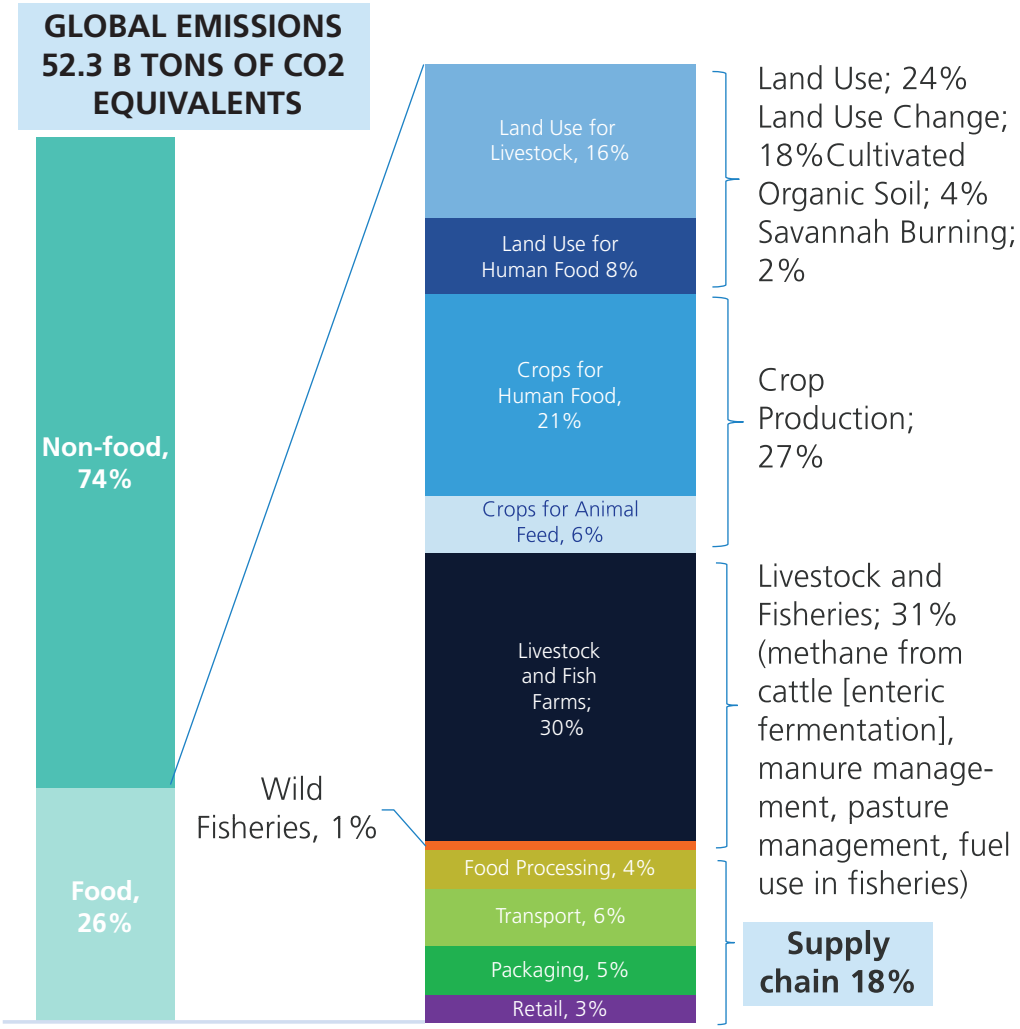
Furthermore, banks are developing innovative financing products and solutions as an opportunity in supporting sustainable agriculture and decarbonizing the food industry. Moreover, banks also create, and scale financial instruments tailored for sustainable agriculture and food production. This also has implications on banks operations to be effective in supporting the food industry's decarbonisation.

Source: Frost & Sullivan

INTRODUCTION

Globally, the food system accounts for 26% of all greenhouse gas emissions

GHG EMISSIONS FROM FOOD PRODUCTION, GLOBAL, 2022



Solving climate change is commonly related to providing clean energy solutions, such as increasing the use of renewable energy sources, enhancing energy efficiency, or shifting to low-carbon transportation. **This is mainly because more than 74% of GHG emissions originate from energy-related activities,** such as electricity production, heating, transport, and industrial processes.

However, as per Joseph Poore and Thomas Nemecek's study published in science in 2018, **the global food systems** (including production and post-farm processes, such as processing and distribution) **contribute to the global GHG emissions footprint and account for over 26%** of total global emissions. Of this, livestock and fisheries are the major contributors.

Source: Frost & Sullivan

In addition to environmental concerns, growing consumer demand for sustainably sourced products and international regulatory obligations, such as the UN SDGs (sustainable development goals) and the Paris climate agreement, is driving value chain participants across regions to adopt sustainable practices to achieve their ESG goals and net-zero targets.

While the importance of reducing the emissions from food systems to tackle the problem of climate change is now recognized globally, the lack of cost-effective technological solutions and limited awareness about tools and technologies, especially in developing regions, are the biggest hurdles in the decarbonisation of agriculture and food value chains. However, this will change as players across the human and animal nutrition value chain focus on reducing the climate and environmental impact of their businesses globally

Within this, the main contributors are agricultural production with 82%, processing and packaging with 9% and agricultural equipment and transportation with 6%

Food requirements for the increasing global population result in the **over-exploitation of environmental resources, leading to GHG emissions, deforestation, and water scarcity.** Moreover, **feed production, processing, and enteric fermentation from livestock are major sources of emissions in this industry.** With environmental concerns rising, **the reduction of GHG emissions has become critical** to the animal farming and nutrition industry.

While the need to decarbonize is well established and recognized, there exist a number of key challenges to achieving sustainability …

Supply Chain Complexity: The nutrition industry has a large and complex value chain that complicates monitoring these emissions and makes it challenging for manufacturers to ensure the implementation of sustainable practices throughout the supply chain.

Price, Availability, Certification, and Verification: Sustainable raw materials can be more expensive and less readily available than conventional ones, challenging companies' balance between sustainability and production cost. Also, achieving sustainability certifications will be time and resource consuming because it necessitates adhering to various standards.

Investment Costs and Consumer Demand Variability: Implementing sustainable manufacturing processes may necessitate substantial capital investment for procuring new equipment and technologies, which may discourage some businesses, especially smaller ones. Moreover, Consumer demand for sustainable products can be inconsistent and unpredictable, making it challenging for manufacturers to maintain production and inventory.

Technological Barriers: Research and advanced technology may be needed to develop sustainable substitutes. For instance, extrusion technologies are required to develop plant-based protein alternatives.

Adopting sustainable manufacturing techniques on a wide scale may be difficult in some cases because they are not always as effective as standard procedures. For instance, in many cases, bio-based chemicals are not as effective as their chemical counterparts.

Regulatory Compliance and Policy Gaps: It can be challenging for manufacturers to comply with various sustainability and environmental rules across regions, such as wastewater treatment standards or emissions limitations, because they differ from region to region. Furthermore, Inconsistent sustainability rules can hamper the adoption of sustainable practices. For instance, the criteria for organic certification vary across regions, making it difficult for companies to adopt uniform organic standards.

Risk of Greenwashing: Some suppliers may claim to follow sustainable practices without taking meaningful action, making it challenging to determine genuine sustainable sourcing from greenwashing.

… but this is changing as a combination of push and pull factors on the demand and supply side compel market participants to act

The main factors contributing to this are climate and environmental changes, ***consumer demand and regulatory requirements*** with a high impact on the adoption of sustainability practices. Furthermore, other factors are also parts of this dynamic, such as ***technological advancements, business incentives, brand image and reputation***, which also have a significant impact on this.

Across the value chain, stakeholders are improving land use, reducing *waste*, adopting r*enewable energy practices*, and reviewing their approaches to downstream activities

Many initiatives are adopted by various value chain participants to address climate and environmental change including the following:

Optimizing Supply Chains: Carbon emissions from transportation are a major concern and lead to Scope 1 and Scope 2 emissions. Companies gradually shift toward vehicles powered by biofuels or electric vehicles to tackle transportation-related emissions. In addition, companies adopt digital technologies to make supply chains leaner and smarter.

Water Usage Reduction and Withdrawal: Companies install wastewater treatment systems to reuse water and minimize wastage. Systems for optimized water usage are also in use.

Waste Reduction and Safe Disposal: Companies invest in safe disposal processes and adopt technologies to improve products' shelf life—either by using smart packaging technologies or specialty additives—and reduce food wastage.

Improving Land Use: Land use for food production accounts for more than 24% of GHG emissions. Companies collaborate with local communities to reduce deforestation, improve soil health, and motivate farmers to use sustainable and regenerative agricultural practices.

Adopting Renewable Energy Practices: Companies adopt renewable or clean energy sources, such as solar electricity and hydroelectricity, to power their manufacturing processes, thus, reducing their Scope 2 emissions.

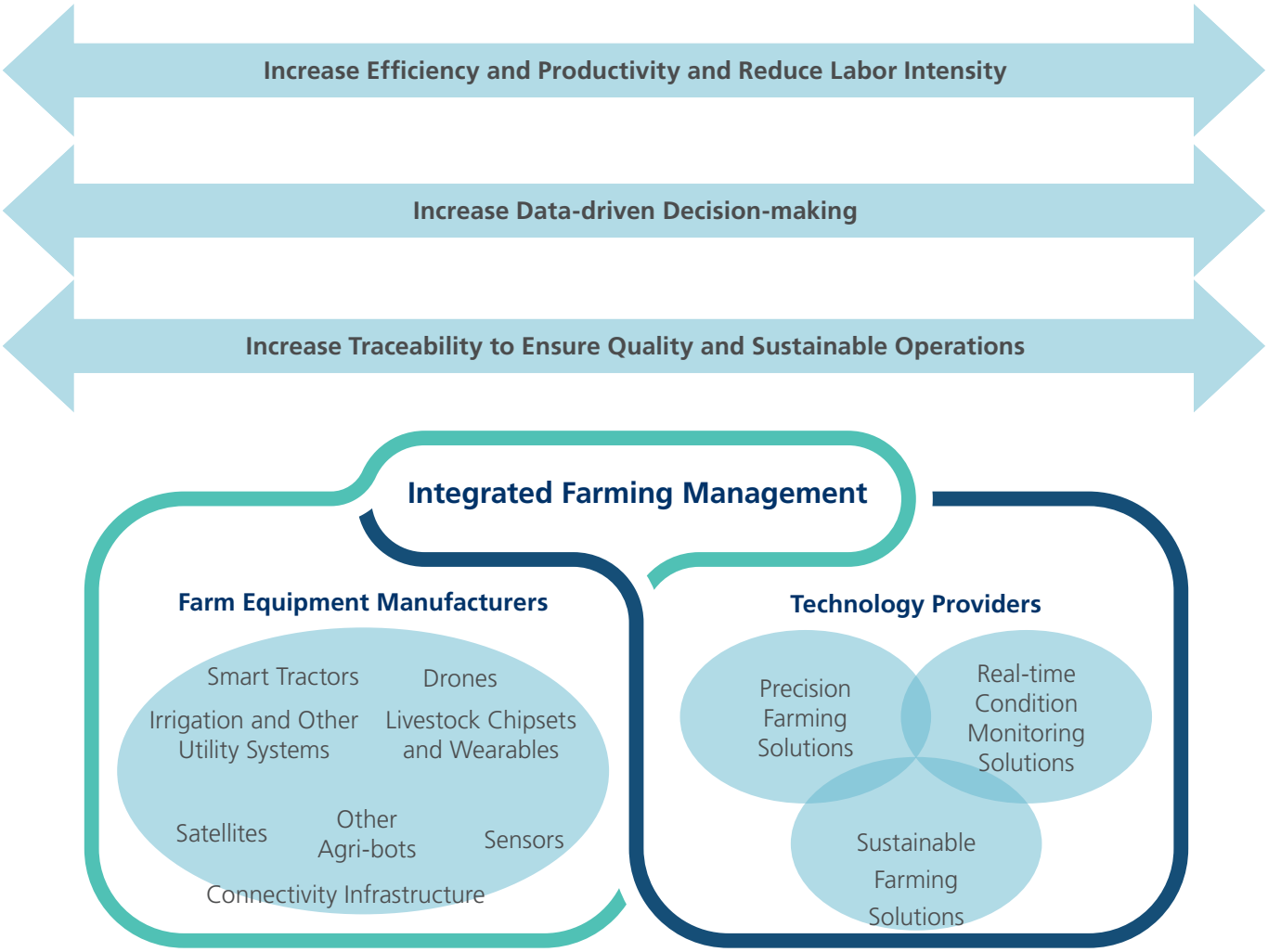
Community Engagement to Reduce Climate Impact: Companies collaborate with local communities to raise awareness about sustainability. They undertake social initiatives, such as planting trees and providing food and clean water.

This report examines how new business models and emerging technologies are allowing the agriculture, food & beverage industry to shrink its carbon footprint

AGRICULTURAL **PRODUCTION**

PRECISION AGRICULTURE AND SOIL MANAGEMENT

FOR AGRICULTURAL PRODUCTION, PRECISION AGRICULTURE FORMS PART OF A BROADER "FARMING 4.0" ECOSYSTEM WHICH ALSO INCLUDES SUSTAINABLE FARMING



Uptake represents a direct response to climate and environmental changes and is driven by consumer demand and regulatory requirements

The first factor contributing to the adoption of sustainable practices is ***climate and environmental changes. Within food-related GHG emission,*** agricultural ***activities*** **use the most land and water** and account for the majority of the total emissions. As the global population expands, food security challenges drive the adoption of more intensive agricultural and food production practices, impacting climate and the environment. Another key factor contributing to the adoption of sustainable practices **is a growing awareness of the impact of food systems on climate and the environment** which is driving value chain participants to adopt sustainable practices.

Source: Frost & Sullivan

Consumer demand as increasing consumer awareness and preferences for sustainable and environmentally friendly products drive nutrition companies to adopt sustainable practices to meet these expectations and remain competitive. Manufacturers will invest in R&D to innovate nutrition products that can be sustainable alternatives. For instance, alternative proteins would align with changing consumer requirements.

Regulatory requirements as international organizations and governments impose sustainability standards and reporting requirements, pushing companies to comply with environmental and social responsibility policies. For instance, UN SDGs and other such standards encourage industry participants to practice sustainability in their processes.

Technological advancements in digital tools and technologies will enable industry participants to adopt sustainability measures across their supply chain. For instance, precision farming technologies can improve yield and reduce GHG emissions and wastage, and ***supply chain digitalization*** can reduce a company's overall environmental footprint.

Many investors, banks, and shareholders emphasize ESG factors when investing in companies. Start-ups or established corporations with strong sustainability records may find it easier to attract investment and support.

Business incentives and brand image and reputation, as adopting sustainability practices and demonstrating commitment to ethical, responsible, and sustainable business practices can **enhance the brand image and reputation of a nutrition company**. This may **attract consumers who prioritize such values** and enhance the company's image and visibility, helping it gain a competitive edge.

Precision agriculture finds its application across several areas and is expected to allow farmers to anticipate a long-term shift from automation to autonomy

Though still in the early adoption stages, the most widespread precision systems expected to see the highest growth rates in the next 5 years are precision irrigation, seeding, feeding, and phytosanitary and fertilizer applications systems.

Precise Irrigation Systems presents an innovative approach to water management by integrating sensor data to optimize irrigation processes, enhance water efficiency, reduce resource wastage, and contribute to delivering water precisely when and where it is needed.

Precise Fertilizer and Phytosanitary Applications Systems, this methodology guarantees customized fertilizer, pesticide, and herbicide applications. It ensures optimum variable rate application based on soil conditions and pest or weed presence, prevents overlapping, and ensures optimum applications when and where needed.

Precision Planting Systems, this methodology guarantees customized seed placement. It promotes a data-driven approach to optimize seed selection, improve spacing, minimize land and seed wastage, regulate downforce pressure, and meticulously manage seed depth to achieve the highest planting efficiency.

Precision Feeding Systems, these systems promote a data-driven approach to delivering individualized and customized feed rations for each animal's needs and conditions. They aim to optimize feed intake, enhance nutrient utilization, and improve overall animal health and performance while minimizing food and water waste and environmental impact.

Many precision agriculture technologies are being developed by companies and startups, aiming at improving crop yields and impacting positively the environment

Blue River Technology (US) has developed **See & Spray technology** and LettuceBot. Using computer vision and machine learning, **See & Spray** identifies the plant's condition and only sprays chemicals on weed-affected plants, eliminating bulk spraying of chemicals. The company's **LettuceBot** is a solution for precision agriculture that removes the lettuce seeds from the field by carefully identifying them, which used to be a time-consuming and expensive process. For the accuracy level of this technology, the robotic **LettuceBot** can take images of about **5,000 plants per minute** to within a

quarter inch of their actual location. A single machine can treat 1**6.19 hectare per day**. these devices use computer vision and artificial intelligence technologies that help detect and identify every plant and make insightful decisions regarding the plants to save **1.13 billion kg** of herbicides through its services till now. **Blue River Technology** reported an annual revenue of $147 million in 2023, which will increase because of the growing demand for agricultural robots. These robots are better alternatives to cost-intensive agricultural practices.

FMC corporation (US) is also offering many innovative precision agriculture solutions. **FMC's 3RIVE 3D® application technology** at plant crop protection delivery system helps growers efficiently cover **more ground in less time with fewer refills** - saving water, fuel, labor and time. Designed with convenience in mind, the **3RIVE 3D®** combines the right amount of product and water, eliminating the need for mixing, measuring and tank agitation. One fill protects up to **194 hectares**, while using **90% less water** than traditional liquid systems and carrying **50% less weight** than granular systems. Fewer refills and less weight translate to consistent high-speed coverage and less risk of compaction.

Another innovative precision agriculture platform launched by the same company is **Arc™ farm intelligence** which aims for sustainable agriculture by monitoring and predicting pest pressures up to a week in advance up to **90% in accuracy. FMC** deploys in field sensors, drones or aerial imagery for monitoring in fields which saves time and labour. Then the data is gathered from in-field sensors, drones or aerial imagery. FMC utilizes data science to optimize and forecast insect management. Real-time data and insights help the users to make informed decisions on where, when and how to apply control tactics, making proactive pest management simple, fast and clean.

Precision AI (Canada) has developed **advanced drones and AI-based algorithms for drone operations** to offer agriculture drone services in herbicide spraying operations. SolveTM Intelligence drones detect weeds with high accuracy because of the vision sensor's superior **0.5 mm pixel resolution**, enabling precise application while achieving up **to 95% savings in herbicide usage**. Furthermore, the drones can achieve high speeds (above 80.47 km/h) for any size of operation, making the system **highly time efficient**.

To enhance water management on vast crops, the agritech company **TSE (France)** constructed a **2.9 MW agrivoltaic power plant with a smart irrigation system.**

In Brouchy, Hauts-de-France, the system covering three hectares is anticipated to **save water by about thirty percent**. The technology can improve irrigation by supplying the right amount of water and only watering when necessary thanks to sensors mounted on the canopy.

Source: Frost & Sullivan

The five-meter-tall solar panels are rotatably oriented from east to west by use of trackers. This equipment generates partial and rotating shading on the plot throughout the day, effectively mitigating thermal and water stress, as reported by **TSE**.

In Italy, the vertical farming start-up **LocalGreen** plans to expand to the retail and food service industries in Italy. This startup aims to be a leading company in the **precision agriculture sector** by developing a new concept of growing crops vertically in a controlled environment that aims to optimize plant growth through soil-free cultivation techniques based on maximizing yield. Furthermore, **Spain-**based **Terraview** and **Indian** precision agriculture company **Fyllo** have partnered to expand precision agriculture in Italy and Europe.

Precision agriculture technologies have a significant positive impact on reducing **CO_2 emissions** and **other greenhouse gases** in agriculture. Either by reducing input use (fertilizers, herbicide, pesticide and water), improved fuel efficiency, carbon sequestration or enhanced productivity (crop production and higher yields).

Sustainable farming centers on tracking a farm's performance against SDG (Sustainable Development Goals) indicators

Although **SDG tracking indicators** are constantly expanding toward new areas such as biodiversity levels, animal welfare, and greenhouse gas (GHG) emissions, **the novelty of SDG tracking systems** in farming lies not in the indicators themselves, but **in the integrated and data-driven approach these systems offer for tracking, managing, and optimizing the achievement of SDG goals.**

While farmers have been implementing various practices to address sustainability concerns, such as **ensuring better labour conditions, improving soil health, and minimizing water consumption**, these efforts have often been **fragmented and lacked a comprehensive framework for measurement and optimization**. The ability to transform sustainability from a vague concept into a **measurable and actionable framework** that directly incorporates the industry's requirements around certifications and regulations will drive the future of SDG tracking systems.

Condition monitoring enables both and allows the real-time monitoring of the condition of crops, livestock and land, and is expected to be replaced by digital twins

For crop condition monitoring, these systems utilize data from drones, satellites, robots, and advanced sensors, coupled with AI algorithms, to forecast harvest yields and optimize crop selection. By considering factors like crop health, growth stages, environmental conditions, and possible pest presence, farmers can make better-informed decisions and mitigate risks in advance.

For land condition monitoring, data sources like sensors and satellite images fuel powerful data analytics to verify soil parameters, such as moisture levels and nutrient content. Land condition monitoring systems allow farmers to accurately target actions to ensure they execute soil improvement strategies when and where needed.

For livestock condition monitoring, farmers can place smart wearables or chipsets on the animals for livestock monitoring. Other data sources like smart sensors, cameras, and drones can fuel these systems to enable real-time monitoring of herds or individual animals. Applications of this type of technology include counting, selecting, and classifying livestock as well as early identification of health issues due to abnormal animal behaviour.

In the future horizon, there is an anticipating rise of digital twins in the coming decade.

Digital twins act as a centralized source of data collection, allowing **a more comprehensive farm management approach**. They connect isolated systems to avoid data silos and ensure that stakeholders take all farm areas into account during decision-making. Furthermore, digital twins leverage **enhanced visualizations to represent complex data clearly and intuitively**. Real-time data analytics provide valuable insights into the current state of operations, and digital twins can make analytics go a step into the future. In addition, digital twins enable **predictive and prescriptive models to simulate "what-if" scenarios and predict possible outcomes.** This allows farmers to make proactive decisions based on anticipated conditions rather than simply reacting to past events.

Effective soil management is one of its main benefits that will stem from and shape the further deployment of farming 4.0 methodologies

Indeed, ***increasing data-driven decision making*** is one of the trends that will shape the future of **farming 4.0. Soil and crop condition monitoring systems,** satellite imagery analytics, and smart chipsets for livestock health management are a few examples of a vast number of real-time data systems that fuel farming analytics. The convergence of real-time data analytics and AI empowers farmers to proactively anticipate pest infestations, mitigate diseases, effectively respond to unexpected climate changes, and optimize the management of farming input resources.

Furthermore, ***increasing traceability to ensure quality and sustainable operations*** is also a significant future trend of **farming 4.0.** The increasing demand for traceability in farming 4.0 is a response to the rising pressure to ensure food quality and sustainability. Food traceability involves digitally recording and verifying every production stage of the farming value chain. Thus, **the industry must adhere to stringent quality standards to meet increasing food safety regulations and address the evolving consumer demands for organic, local, and fresh crops.** Moreover, **digital tools** play a crucial role in the urgent need to **combat soil degradation caused by the rise in pesticide-resistant species or the overuse of chemicals.** Integrated farming systems enable traceability, bridge the gap between consumer demands and farmers, and meet government regulations.

More broadly, animal, and human nutrition have many common trends and dynamics

Human nutrition's main trends include increasing the visibility on food sustainability, the shift to sustainable agricultural practices, policies to ensure food security and protein diversification causing dietary changes, upcycled food/ingredients market growth, and plastic footprint reduction efforts and eco-friendly packaging implementation

Animal nutrition's main trends are related to sustainable and traceable sourcing, alternative protein sources, improved feed efficiency and gut health, and precision nutrition and digitalization

Animal nutrition is focused on improved feed efficiency …

Sustainable and Traceable Sourcing: As consumers look for higher traceability and transparency, livestock farmers select ingredients that **reduce their environmental footprint and are ethically sourced.** Many animal nutrition companies, such as dsm-firmenich (Netherlands), ADM (US), Kemin Industries (US), and Cargill (US), are collaborating with customers, providing them with insights on raw material sourcing through

digital platforms and helping them make informed decisions using data analytics. Some examples of such platforms include KEMINCONNECT (Kemin Industries), Sustell (dsm-firmenich), and iQuatic (Cargill).

Precision Nutrition and Digitalization: Precision nutrition is used to customize animal feed based on the specific nutrition requirements of the species. It ensures improved animal productivity by offering curated and consistent nutrient delivery. It also helps **reduce feed costs and prevents wastage,** thus, supporting sustainability. Furthermore, Companies use real-time data and digital platforms to analyse animal needs and decide the feed composition for better results. For instance, **the Cargill (US) Nutrition System provides real-time nutrient analysis** of feed and allows **accurate feed formulations** based on species, geography, climate, nutrient requirements, local ingredient costs, and business goals.

Alternative Protein Sources: They have garnered significant interest and hold strong potential as a sustainable alternative to conventional feed sources, such as soy, fishmeal, bone meal, or meat. Furthermore, proteins offer sustainable options to formulate animal diets while meeting adequate nutritional requirements necessary to support animal health. In addition, **Insect protein** has been gaining traction in the animal feed industry thanks to its **favourable digestibility and high protein content.** Other alternative sources used in animal feed include microbial protein and plant protein. Although alternative protein sources are high-growth opportunities, **regulatory reforms will be necessary to drive their adoption.** Companies must achieve economies of scale to compete with conventional sources like soy and fishmeal.

Improved Feed Efficiency and Gut Health: Increasing feed efficiency entails **better ingredients and techniques.** Livestock farmers seek additives that **improve the feed conversion ratio the most.** Additives that play a key role in improving animal gut health and ensuring higher performance will garner higher traction. Improved gut health promotes growth and better digestion, which also results in reduced GHG emissions. Companies offer novel feed additives that result in higher-quality animal production while ensuring lower methane and nitrogen emissions.

… whilst human nutrition is targeting protein diversification

Increasing the Visibility of Food Sustainability: Sustainability in the food industry is gaining visibility globally thanks to rising awareness about the industry's contribution to GHG emissions.

Governments and companies recognize the importance of developing resilient food systems for reducing carbon emissions and addressing climate challenges.

In November 2023, several countries signed the **COP28** Declaration on Sustainable Agriculture, Resilient Food Systems, and Climate Action, in which they pledged, for the first time, to focus on reforming policies and finances to transform the agriculture and food systems to drive the future responses to climate change.

Shift to Sustainable Agricultural Practices: The management of soil, land, crops, and natural resources, such as water and energy, forms the basis for sustainable agricultural practices.

Regenerative agriculture that emphasizes improving soil health has emerged as a prominent route to sustainable farming.

Public-private partnerships increase the adoption of regenerative agricultural practices to reduce the environmental impact of agriculture. For instance, **ADM (US)** partnered with **the Cool Farm Alliance** to help farmers detect on-farm emissions.

Additionally, the adoption of precision agriculture technologies, such as artificial intelligence (AI), data analytics, cloud computing, and robotics, will revolutionize the agriculture production models globally and drive farm profitability and efficiencies by ensuring a sustainable use of resources.

Policies to Ensure Food Security and Protein Diversification Causing Dietary Changes:

Food security has long been a global challenge, and it has become a cause of concern for many countries.

The **UN's SDG 2 (Zero Hunger)** compels countries to ensure food security and end hunger by improving nutrition and promoting sustainable agriculture practices.

Many governments are now considering protein diversification to be a viable option to enable more sustainable food systems that are less reliant on animal farming.

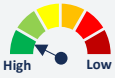
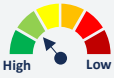
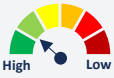
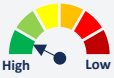
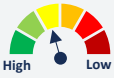
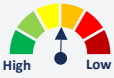
As per the **Good Food Institute (GFI),** in July 2023, the European Union and national governments announced half a billion euros in funding to develop innovative and sustainable proteins.

Plant-based and cultivated meat are potential ways of reducing GHG emissions. Denmark and the Netherlands broke global records when they announced €168 million and €60 million in funding to support the plant-based sector and commercialize cultivated meat and precision fermentation, respectively.

In October 2023, the European parliament voted in favor of plant-based protein production and consumption to decrease the dependency on animal feed imports and tackle climate issues. In the same month, EIT Food, an EU-funded think tank, launched a policy guidance on Accelerating Protein Diversification for Europe to enable Europe to transition to more sustainable proteins for food security.

Source: Frost & Sullivan

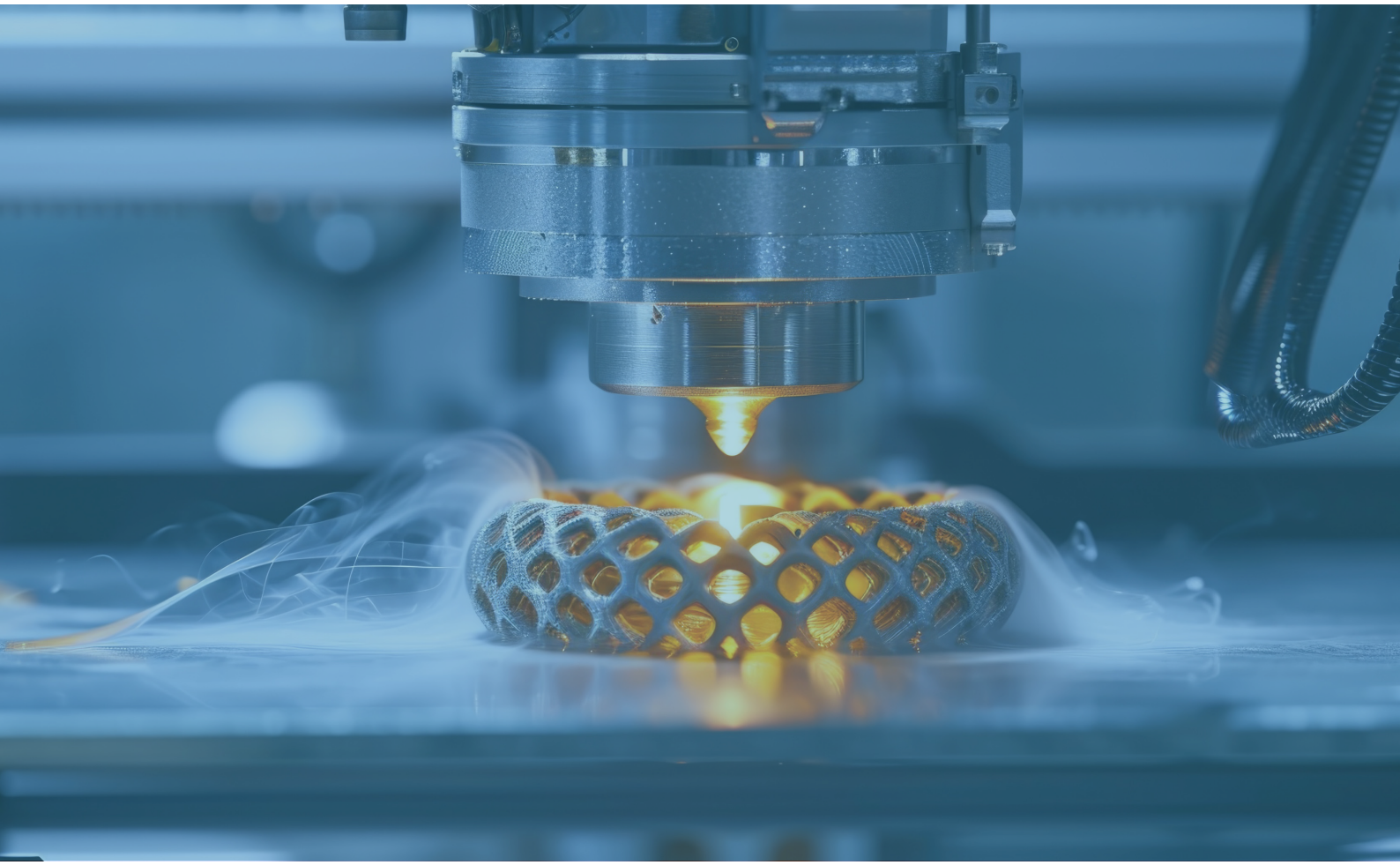
Farming 4.0 has a role to play in delivering these aims with ADM (USA), BASF (Germany) and Cargill (US) among the key providers of sustainable solutions

Sustainable Products/ Solutions		ADM	BASF	Cargill	dsm-firmenich	IFF	Ingredion	BASF
Sustainable Solutions for Human Nutrition	Sustainable Alternatives	X	X	X	X	X	X	X
	Sustainable Alternatives	X		X	X	X	X	X
	Biotechnology/ Bioprocessing	X	X	X	X	X	X	X
	Clean Label Products and Ingredients	X	X	X	X	X	X	X
	Personalized/ Precision Nutrition	X	X		X	X		X
Sustainable Solutions for Animal Nutrition	Sustainable Alternatives	X	X	X	X	X		X
	Managing GHG Emissions		X	X	X			
	Precision Farming	X	X	X	X			
	Managing Health Challenges	X	X	X	X	X		X
	Improving Feed Efficiency	X	X	X	X	X		X
Company Rating								

In the future, they and others will increasingly leverage innovations like robotics, 3D printing and cloud to make farming more precise

For ***digital technologies for improving production efficiency (industry 4.0),*** technology is critical to optimizing sustainable production processes. Nutrition companies adopt **industry 4.0 technologies, such as robotics, data analytics, AI, Internet of Things (IoT), cloud computing, and 3D printing,** to enhance production and processing efficiency. Companies drive precision farming technologies adoption across their farmer networks to enable sustainability. For instance, **livestock farmers** use **data analytics** to understand **animal health, detect diseases, and improve feed efficiency to get better produce. AI** is being considered as a tool that automates feeding systems to enable precision nutrition and reduce feed waste.

For the digitalization of supply chain, by leveraging technology and innovations, nutrition companies can **reduce wastage and create leaner supply chains, build efficient logistics and transportation systems to reduce fuel costs and consumption, lower carbon emissions, and enhance sustainability.** Furthermore, implemented nutrition supply chain technologies include blockchain technology (for improved product transparency and traceability), predictive analytics (for optimized logistics and distribution), and IoT, sensor, and data analytics (for real-time inventory management and demand planning). In addition, companies **digitalize supply chains** by launching **software-as-a-service (SaaS)-based interactive platforms or tools** to enable easier communication and coordination among stakeholders, reduce turnaround time, promote and track sustainable practices across the value chain, and **improve overall efficiency.**



Source: Frost & Sullivan

AGRICULTURAL BIOLOGICALS AND REGENERATIVE AGRICULTURE

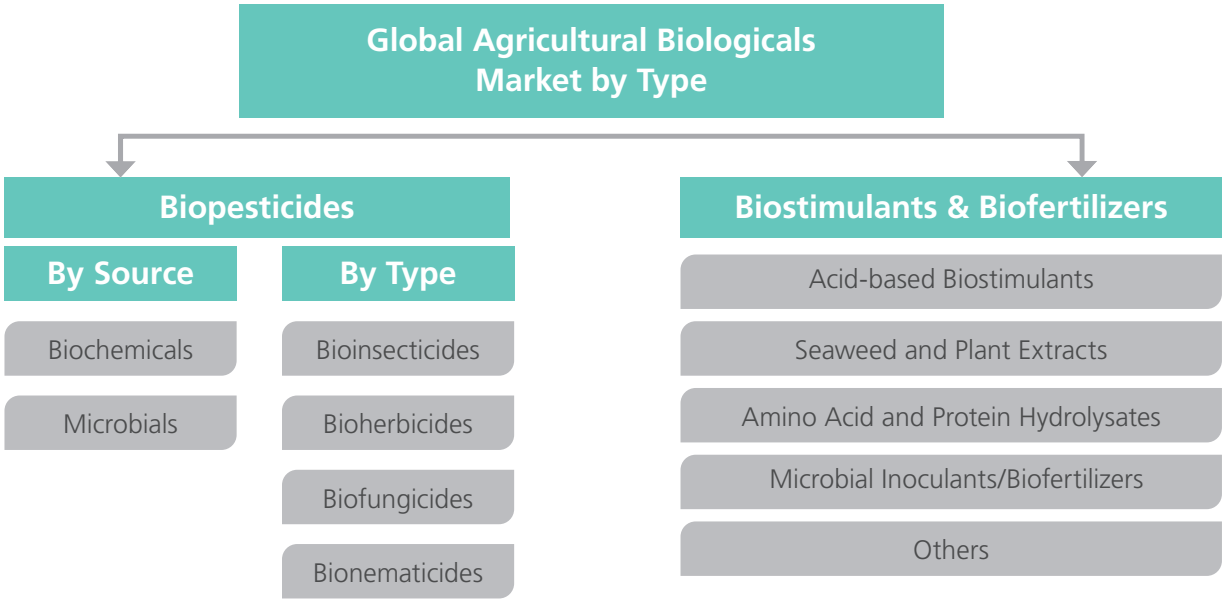
NEXT GENERATION TECHNOLOGIES ARE ALSO IMPACTING THE AGRICULTURAL BIOLOGICALS SECTOR, IN PARTICULAR IN THE AREAS OF NEW PRODUCT FORMULATION

The adoption of **precision farming technologies** is expanding globally, and 2024 will continue to see the penetration of **next-generation tools and technologies** to make agriculture more efficient and climate resilient. **Generative AI, advanced cloud solutions to manage data, advanced data analytics, and technologies such as digital twins, AI-powered drones, and fully autonomous farm equipment** are set to revolutionize agricultural models globally. In 2024, increased focus on regenerative farming practices from farmers, food companies, and investors will continue. **Next-generation AI and data analytics tools and technologies** will enable farmers to expand the adoption of **regenerative farming practices** that benefit the environment and enhance productivity. Controlled environment agriculture will continue to offer strong growth opportunities, provided **companies can reduce the cost of production.**

Nutrition and food companies will continue to invest in and drive the adoption of regenerative and sustainable farming practices to meet changing consumer requirements, and this will drive opportunities for Agtech players to offer tools and technologies that are tailored to farmers' requirements. Technologies that can **improve yield and profits while reducing carbon emissions and ensure compliance with the ever-evolving regulatory landscape** will witness higher adoption. New business models such as carbon farming will gain higher traction. The start-up ecosystem will remain competitive and investments in the sector will remain strong. With a focus on sustainable and precision farming, innovation in biological formulations will remain a key growth and development area for agrochemical players. Also, there are adjacent growth opportunities for agrochemical players. For instance, at the Crop Science Innovation Summit 2023, **Bayer** (Germany) identified carbon farming, biologicals, precision application services, and digital platforms as key adjacent growth markets that it will target.

Source: Frost & Sullivan

Agricultural biologicals **are segmented into bio-pesticides, stimulants, and fertilizers**



Biostimulants and biofertilizers are considered under the same umbrella by certain regional authorities; however, they fall into different segments by a few other regulatory authorities.

Others include combination ***biostimulant products*** such as **combination of extracts and acids; vitamins; inorganic trace minerals and chitosan.**

Overall, the combined bio-stimulants and fertilizers segment is expected to grow most rapidly, expanding from $3.3 b globally in 2021 to $8.7 b by 2030

METAL ROOFING GROWTH METRICS, GLOBAL, 2022–2030

Life Cycle Stage	Revenue in 2021	Revenue in 2030
Growth	$3,278.8 M (2021)	$8,733.6 M (2030)

Base Year Growth Rate	Compound Annual Growth Rate	Number of Competitors	Degree of Technical Change
12.7% (2021)	11.5% (2021–2030)	100+ (active competitors in 2021)	9 (scale:1 [low] to 10 [high])

Source: Frost & Sullivan

Demand will be boosted by increased awareness of their benefits versus conventional chemical crop inputs especially amongst many small-scale farmers

Growth in adoption of sustainable farming practices will drive adoption of biological crop inputs: With sustainability being the key theme for value chain participants, a definite **rise is occurring in the adoption of sustainable farming practices,** such as organic farming.

Countries are already focusing on expanding their share of organic farming. For example, as part of its Green Deal, the EU plans to expand land designated for organic farming by **25%** by **2030.**

Also, the global rise in adoption of integrated pest management techniques will drive the **penetration of biological crop** inputs further during the forecast period.

The environmental impact of chemical inputs and increased focus on setting up frameworks for achieving SDGs in the wake of challenging climatic conditions will provide impetus to adopt environment-friendly solutions.

Rise in Demand for Biologicals from Conventional Production Systems Results from Growing Awareness and Government Initiatives: In addition to organic farming systems, demand for ***biologicals*** from conventional production systems has risen significantly due to growing awareness and government initiatives.

For example, the Indian government has been promoting the use of ***biofertilizers*** since the launch of its 7th Five Year Plan by offering subsidies to farmers and financial support to expand local production of biofertilizers. Similarly, subsidies and packages the UE offers to promote integrated pest management and sustainable use of pesticides have shifted farmers' focus on biological alternatives.

Also, demand is increasing for biologicals across different agricultural crops including **cash crops like sugarcane.** Previously, use was limited to high value organically produced fruits and vegetables.

Increasing awareness about the benefits biologicals offer over chemical crop inputs, especially amongst small-scale Farmers, will Drive Adoption: Awareness of biologicals is expanding. rise in government, public, and private initiatives targeted specifically to create awareness among small-holder farmers will drive adoption.

For example, UPL will use its vast network of retail stores and distributors to reach millions of Indian farmers and create awareness about its brand, and in general about the benefits of using biologicals. Such initiatives are being adopted across all emerging countries where share of small-holder farmers is large.

As ***biostimulants*** are a less known concept when compared to ***biopesticides*** or ***biofertilizers,*** especially among small-holder farmers, companies need to invest more, and authorities need to harmonize regulatory frameworks to prevent confusion and drive adoption.

Value chain participants are investing in creating awareness about the science behind their products to drive adoption of biologicals: Companies are trying to effectively communicate the mechanism of action and the science behind their products to make merit-based sales. For example, companies are investing considerably in training distributors and sales teams to effectively communicate their products' benefits to farmers.

Adoption of innovative go-to-market strategies will drive product penetration during the forecast period. For example, most of the players are no longer selling a single product but instead are bundling solutions that can help farmers throughout the crop life cycle. This is particularly true with ***biostimulants,*** which are generally used in combination with other products and conventional crop inputs.

From the supply side, the market for bio-stimulants and fertilizers is highly fragmented with some vendors playing in both spaces

The key competitors in biopesticides and biostimulants & biofertilizers include:

BIOPESTICIDES	BIOSTIMULANTS & BIOFERTILIZERS
• Bayer CropScience • Syngeta • BASF • Corteva Agriscience • Nufarm (NuBio) • FMC Corp • Koppert Biological Systems • UPL • BioWorks Inc. • Valent BioSciences Corporation (Parent Sumitomo) • Gowan Company (incl. Isagro S.P.A) • Certis Biologicals • Marrone Bio Innovations (announced merger with Bioceres) • AMVAC Chemical Corporation (includes Agrinos) • Rovensa Group (incl. TradeCorp, Idai Nature and Oro Agri) • ADAMA • Andermatt Biocontrol • SIPCAM OXON S.p.A.	• Syngenta (incl. Valagro) • Gowan Company (incl. Isagro S.P.A) • Marrone Bio Innovations • UPL • Novozymes • Biolchim CIFO • Bioceres (incl. Rizobacter) • Fertinagro Biotech • Bioiberica (SARIA group) • HELLO NATURE • Rovensa Group (incl. TradeCorp, Idai Nature and Oro Agri) • SICIT group • Atlantica Agricola • AMVAC Chemical Corporation (includes Agrinos) • Koppert Biological Systems • Haifa Group • Algaenergy • Agrauxine • Tecnobell SRL • Intermag • Interagro • Bioconsortia • SEIPASA S.A. • Omnia Holdings • Agronutrition

Furthermore, the start-up ecosystem is very strong. Many companies are developing novel biostimulants and inoculants for improving crop health. In the biofertilizer space, start-ups are focused on recycling waste products and novel microbes

Source: Frost & Sullivan

The main identified startups in the **biofertilizers** area are the following:

- ***Fertoz Ltd,*** a **Canadian** start-up developing phosphate-based fertilizers, has also developed live microbes coated with phosphate fertilizers.
- ***Earnest Earth,*** **US-based** start-up that offers vermicompost biofertilizers by converting local farmers' waste and using machine learning to develop an optimum mixture and rejuvenate the soil.
- ***Kula Bio (US),*** maker of a proprietary nitrogen-agnostic biofertilizer based on active microbe.
- ***Toopi Organics,*** a **French** start-up with a patented technology that converts human urine into fertilizer using a microbiological process.

For **biostimulants,** there are also many startups operating in this field such as:

- ***NewLeaf Symbiotics (US),*** which develops proprietary prescriptive biologics based on Pink Pigmented Fa cultative Methylotrophs (PPFMs) or "M-trophs".
- ***Sound Agriculture (US),*** creator of Crop Solution SOURCE, a foliar spray that increases nutrient efficiency by fixing nitrogen and unlocking phosphate.
- ***ONIT Sciences (US).*** developed proprietary nano-surfactant additive, ONIT Grow™, non-GMO, all-organic formulation that stimulates nutrient and water uptake.
- ***Groundwork BioAg (Israel),*** developed Rootella, mycorrhizal fungi-based inoculants, to improve crop yield, improve stress resistance, and reduce fertilizers.
- ***Micropep Technologies (France),*** developing natural peptide-based plant stimulation and protection solutions.
- ***South Agro (Italy),*** develops seaweed-based biostimulants based on its proprietary extraction technology.
- ***FYTEKO (Neetherlands),*** maker of proprietary plant-based molecules, such as hydroxycinnamic acid derivative oligomers.

Furthermore, there are startups that have overlapping focus for both **biofertilizers and biostimulants** such as;

- ***Ficosterra (Spain),*** which developed the **Biological Crop Booster technology** that uses blue-green algae and microbes to restore soil fertility; offers both fertilizers and bio-stimulants)
- ***Aminocore (Netherlands),*** maker of amino acid-based biofertilizers and biostimulants.

Participants will continue to invest in research & development of novel, environment-friendly biologicals to cater to users' sustainability requirements …

Indeed, Companies need to invest in the R&D of novel, environment-friendly biologicals to cater to sustainability requirements. In general, **biostimulants** contribute to climate-smart agriculture. There lies significant opportunity to develop novel biostimulants and **specialized fertilizers** from waste byproducts to support the circular economy concept. However, government and regulatory support are critical to the commercialization of such products.

For instance, opportunities exist to explore the use of industrial and agro-food byproducts to produce **biostimulants and biofertilizers.** Start-ups like ***Toopi Organics*** (France) and ***Earnest Earth (US)*** are already working on similar concepts.

Furthermore, identification of novel microbial inoculants that can optimize soil microbiome and sequester carbon offer significant growth opportunity. For instance, **Groundwork BioAg**'s product **Rootella**, which is based on the company's mycorrhizal inoculant platform, reported sequestration of approximately 200 kilotons of carbon in 2021

… which will support the wider use of regenerative farming and other approaches to enabling "greener" agricultural production and animal husbandry

The fact that companies are actively reducing their environmental footprint will drive opportunities for adjacent value chain participants, such as companies/ labs offering **carbon footprint analysis services**, to achieve the required certifications. Also, this would drive demand for analytics tools, equipment, and software that enables companies to test, track, and manage their environmental footprint. There lies a robust growth opportunity for packaging companies to offer innovative and environment-friendly solutions that can extend the shelf-life of products to address the pressing issue of food wastage.

From an ingredients standpoint, upcycling/recycling agro-industrial side streams to develop novel ingredients for the personal care, nutrition, and animal feed industries will offer significant opportunities. In 2024, more products will feature ingredients from ***regenerative farms***. In terms of processes, ***precision fermentation*** is garnering much attention as an alternative to plant and animal-derived ingredients, and value chain participants are already expanding their fermentation capacity to lower production costs. Also, the use of ***synthetic biology*** will further push the development of sustainable ingredients in the coming years. However, identification of alternative feedstocks, and the development of stable, safe microbial strains remains central to wider adoption.

Source: Frost & Sullivan

The Triple Win of Regenerative Agriculture: A Path to Profitability, Biodiversity, and Climate Resilience

Many leading companies in the agri-food and retail sectors are setting ambitious climate and biodiversity targets, participating in initiatives like Race to Zero and rethinking their product portfolios to align with these commitments. However, achieving such goals will require more than simply sourcing sustainable ingredients. Currently, four crops provide 60% of global calories, while many locally sustainable ingredients that could replace higher-impact ones are still underutilized. To develop a nature-positive food system, a more diverse mix of plants and livestock is essential, along with a deeper understanding of local contexts. **Circular design for food**, which combines food design with circular economy principles, offers a framework to redesign product portfolios with nature-positive goals.

A key component of this shift is the use of **regeneratively produced ingredients**. Companies are increasingly recognizing the environmental benefits of regenerative agriculture, which can lead to higher yields and greater profitability for farmers. Regenerative practices vary according to context and need to be reviewed over time, but evidence indicates they can increase food production, improve farmer income, and provide significant benefits for the climate and biodiversity, such as healthier soils, greater local biodiversity, and improved air and water quality.

Regenerative agriculture is a holistic and location-specific approach rooted in traditional agricultural practices. While there is no universal definition, regenerative practices generally aim to restore nutrient cycles, closing the cycles of essential mineral elements like nitrogen and potassium, which are often disrupted by modern agriculture. By prioritizing soil health and integrating local conditions and communities, regenerative agriculture has the potential to **restore ecosystems** while providing **social** and **economic benefits** to local communities.

The key practices of regenerative agriculture are adapted to **local contexts**. For example, intercropping (growing different plants together) and agroforestry (integrating trees and plants) promote biodiversity by attracting pollinators, deterring pests, and supporting local wildlife. This biodiversity-focused approach can restore ecosystems and enhance the resilience of agricultural systems.

Soil quality improvement also plays a fundamental role in combating **climate change**. Jacqueline McGlade, former Chief Scientist at the United Nations Environment Programme, has highlighted that increasing soil carbon by 1% across half of global agricultural land could capture around 31 gigatons of CO_2 annually, nearly enough to meet the 1.5°C climate target. Studies by the Rodale Institute support these findings, suggesting that regenerative organic agriculture could sequester over 100% of current annual CO_2 emissions, potentially reversing global warming effects.

"Carbon farming," a component of regenerative agriculture, provides an additional financial incentive by allowing farmers to sell **carbon credits** for sequestered CO_2. This "triple benefit" could favor the planet, farmers, and companies aiming to offset their emissions through high-quality carbon credits. However, questions remain about the long-term stability of carbon stored in soil, which requires thorough verification.

The global potential of regenerative agriculture is significant, with partnerships between farmers, policymakers, companies, scientists, and financiers essential for its effective spread. The World Economic Forum estimates that regenerative agriculture could unlock $1.14 trillion in **business opportunities** by 2030.

However, regenerative agriculture is not a definitive solution and presents various challenges, including the lack of globally agreed impact metrics. In the absence of standardized definitions, there is a risk of "greenwashing" as some companies may make unverified claims about their regenerative practices. Additionally, regenerative agriculture requires new skills, technologies, and equipment, which can be costly and challenging for farmers to adopt. Studies indicate that **financial and technical support** is among the main obstacles to the transition to regenerative practices, a gap that banks could help fill.

IRRIGATION SYSTEMS

FROM A RESOURCE PERSPECTIVE, EFFORTS ARE ALSO FOCUSED ON REUSING WATER WITH TREATED WASTEWATER INCREASINGLY FEEDING EMERGING SUSTAINABLE IRRIGATION SYSTEMS

The untapped potential of treated wastewater presents a huge opportunity for the ***irrigation industry***. Promoting the reuse of treated wastewater can reduce water consumption for agricultural purposes, irrigating up to **40 million hectares** with this alternative source.

Several **wastewater treatment technologies** remove pathogens and pollutants that can contaminate and impact crop health and yield while **preserving nutrients**, which, in turn, reduces the need for fertilizers. Depending on crop and land requirements, a combination of sedimentation, filtration, and disinfection using ClO2, O3, UV, or TiO2 are the ideal technologies for water treatment for irrigation.

Consequently, considerable opportunities exist for applying **water treatment solutions for agricultural purposes** globally, across most climates but especially in arid areas most vulnerable to water stress. Furthermore, businesses must develop cost-effective and scalable solutions that facilitate the wide adoption of these systems, even among small-scale farmers that might be subject to cost constraints.

Public-private partnerships and the development of policy frameworks and promotion projects from all levels of government are imperative, encouraging adoption through subsidies or sanctions. Investment in discharge strategies and treatment technologies with low environmental impacts and associated emissions is important.

In addition, the development of technologies that can ensure the quality of **treated wastewater and the removal of contaminants** needs to be at the forefront of market demands and government policies, given that crops can have a direct impact on human health. Governments should establish standards for reuse, as the EU is currently doing with the EU Regulation 2020/741 on minimum requirements for water reuse.

The fundamental issue driving the sector is water scarcity …

The overreaching and increasingly heightened water crisis that affects all continents has been driving advances and development in various industries, striving to reduce water waste and pollution by making technologies and operations more efficient and sustainable.

Source: Frost & Sullivan

The pressing need to protect and safeguard water as a limited and scarce resource can be illustrated by the fact that the World Bank estimates that **60% of the world population** will be affected to some degree by water scarcity by 2030. Accordingly, irrigation technologies are progressively focused on maximizing water use and preventing evaporation and runoff.

Regarding **policies and regulations,** governments have long taken on the task of protecting water as a limited resource. Given the close relationship between irrigation and agriculture, with the European Union (EU) reporting that farming activities account for almost 70% of global water withdrawals, the rural sector has been a key target for water regulations. For instance, as part of the EU's commitment toward sustainable development, the Common Agricultural Policy aims to control the environmental impact of farming, thus maximizing water use efficiency.

The regulatory landscape includes promotional initiatives to facilitate sustainable irrigation (replacing manual, surface, or rainfall watering) through loans and subsidies, tackling the issue of high costs and the lack of investments. The Mexican government's policy of subsidizing electricity consumption for groundwater pumping for irrigation is a key example.

This concern for sustainable farming and water use represents the growing public awareness regarding the environmental impact of food production and the appalling amounts of water wasted yearly, with the general population taking notice of these issues and incorporating these considerations into their consumption patterns and decisions.

… but the circularity concept extends to the materials that make up systems with many market players looking to recycle components

The materials used in most irrigation systems are polyvinyl chloride (PVC), low-density polyethylene (LDPE), high-density polyethylene (HDPE), and aluminium. All these materials can be recycled to reduce the environmental impact of the industry and the associated GHG emissions.

Irrigation systems consist of several parts and tools, including pipes and tapes, which can amount to massive amounts of waste if they are not recycled properly.

Plastics used for irrigation have a lifespan of between 1 and 3 years. After that, most plastics end up in landfills or burned if not properly recycled, resulting in elevated GHG emissions.

Replacing the materials used in these systems remains challenging, given their benefits in preserving leaks and ensuring efficiency. Until alternative materials with lower environmental impacts can be widely used (because of material and cost restrictions), the safest option remains to recycle them.

After recycling these materials, the recycled pellets can be used to produce more tapes and pipes, reducing plastic waste, and reinforcing the circularity of the irrigation industry.

Therefore, national, and subnational governments must compel companies to incorporate recycling into their value propositions and business strategies by establishing policy frameworks and sanctions.

A lack of knowledge and accessibility often hinders widespread recycling because businesses and farmers end up seeing these practices as a burden instead of an opportunity for creating additional revenue streams by selling their used products as feedstock or reducing costs by accessing recycled parts and pieces. Accordingly, governments should campaign and spread information, and specialized companies need to demonstrate the profitability of these practices.

Overall, the global market is valued at $14 b and expected to reach over $31 b by 2030

The market is in its growth stage, the base year growth rate was 8% in 2023 and the compound annual growth rate between 2023-2030 is expected to reach 12.2%.

Within this, and with sustainability in mind, emerging smart and micro irrigation systems are progressively replacing the more conventional mechanical solutions

Smart irrigation systems are expected to dominate the market until the end of the study period, with demand fostered by both governments and businesses and their focus on efficiency and sustainability. Growing investment in key areas, such as the Americas and the Middle East, will likely respond to these novel market demands.

Mechanical irrigation is expected to be displaced by other technologies because of its high CAPEX. Nevertheless, given that it is less labor intensive than other techniques and remains an efficient method for large-scale farms, this irrigation method will still grow in the current decade.

The United States Geological Survey (USGS) reports that over 30% of the world's freshwater sources are underground, which explains the continued importance of irrigation pumps in the market. While the use of surface water sources and treated wastewater will likely transform this segment, its growth will remain stable, with new developments employing renewable energy sources.

The micro-irrigation segment will grow just behind the smart irrigation industry and will continue its global expansion because of its higher efficiency and yield potential, with APAC, particularly China, dominating the market.

Market revenue growth is expected to be determined by the rising demand for agricultural products, which FAO expects to increase by 15% in the current decade, pressing for the development and installation of efficient irrigation systems to maximize yield given its higher productivity levels, countering the prevalence of rainfed agriculture. The impact of climate change, intense weather events, urbanization trends, and population growth will likely deepen water stress and strain crop production, demanding an expansion of agricultural production of over 70% by 2050.

The vendor landscape is highly fragmented with more than 500 companies represented

Irrigation systems companies are segmented into 3 main categories: ***Tier 1*** generating in total ***$7 b*** and representing 50% of top participants, ***tier 2*** generation in total ***$4.9 b*** representing 15% of top participants in the market. In addition, the remaining 35% of the top participants represent ***tier 3*** which generates **$2.1 b** in terms of revenues.

The main tier 1 companies are: Netafim (Israel), Jain irrigation systems (India), Rivulis (Israel), Valmont Industries (US) and The Tori Company (UK). For the Tier 2 segment, the main market players are Nelson Irrigation (Headquarter), Hunter Industries Lindsay (US), Xylem (US), Rain Bird (US), NEC (Japan), Irritec (Italy) , Reinke Irrigation (Netherlands) , Andritz AG (Austria), Grundfos (Danemark).

Calsense (US) offers sustainable irrigation systems that leverage generative AI …

Capitalizing on technological advancements such as **generative AI**, Calsense augments its smart irrigation systems portfolio with data-based decision support that combines hardware and software products for more efficient management, resource consumption, and reliable operations. Water-saving measures are at the core of the company's focus on conservation and sustainability, influencing the development of its user-friendly, cost-efficient, and climate-responsive irrigation solutions and services. These priorities have translated into effective sales and marketing strategies through active media and online presence, technical support to distributors, and continuous social media interactions with customers.

Calsense's comprehensive product portfolio caters to different geographical and segment needs. The **AI-driven Irrigation Assistant** Cal launch reflects its focus on sustainable, user-friendly, and technology-driven irrigation solutions. This assistant is part of the Calsense Connect platform, which users can employ for decision support, troubleshooting, and real-time control and surveillance of irrigation practices leveraging sensor data.

Calsense adapts its irrigation management as a service solution to clients' demands and priorities. The annual subscription program for continuous monitoring and support brings together its product and service portfolio for tailored, turnkey approach. The technology was recognized with the Silver Award in the irrigation association's 2022 new product contest. Its "FLOWSENSE" flow monitoring technology eliminates the need for central management of irrigation controllers, enabling decentralized control and monitoring of the entire irrigation system. ***Calsense*** CS3000 controller monitors water and labour usage for resource management, providing accessibility to this data through any internet-connected device for maximum flexibility. These products have been integrated into the Land F/X landscape design specification software in 2024, facilitating widespread access and use.

Furthermore, ***Calsense*** develops **sustainable irrigation systems technologies** that guarantee adequate water and labour management, resource conservation, and cost reductions, underscoring its vision that water is the world's most precious resource. With a strong presence in the smart irrigation segment, the company's data-based solutions aim to meet various client requirements and scale, including irrigation designers, installers, landscape maintainers, and water managers.

Calsense's broad-based, customer-centric approach contributes to its stable revenue growth by addressing evolving industry demands and challenges, reinforcing its technological leadership. The company has considerable growth prospects as it seeks opportunities to expand its businesses via product launches, updates, and robust marketing and sales strategies. Calsense has research partnerships with educational institutions such as California state university to support the development of advanced irrigation systems solutions, build an internet brand, create multiple customer channels, and develop user-friendly interfaces. These priorities are integral to its corporate strategy and growth.

… whilst CropX (US) works to serve a broad audience with affordable products

CropX delivers affordable irrigation solutions that ensure ease of use for growers of different scales and backgrounds. The company's sensor technology facilitates easy installation, automatic calibration, and connectivity to its proprietary data platform without requiring additional telemetry devices. This translates into lower costs and maximizes efficiency and effectiveness.

It has 6 registered patents for its technologies, employed across its comprehensive solutions portfolio that supports over 70 crop types in 70 countries and about 20,000 sensors currently deployed.

Some of CropX's latest innovations include the ***Reinke Direct ET*** by Crop, launched in february 2024 in collaboration with **Reinke Irrigation**, to provide a cost-effective solution for enhanced water management by gathering actual evapotranspiration (ETa) measurements from a ***CropX*** sensor mounted in a Reinke center pivot irrigation system; and a new mobile app, introduced in February 2023, to improve user experience by facilitating communication with the data sensors, guaranteeing better reliability and efficient access to information.

The ***CropX*** product portfolio covers various irrigation enhancement products and services backed by data gathered by its novel sensor technology. Its agronomic farm management system provides solutions for data management to facilitate monitoring of fields and crops; as well as for irrigation planning by optimizing timing and quantity to reduce plant stress and water consumption; disease control with precise insights on when, where, and how to tackle disease; nutrition monitoring and managing salinity and nitrogen concentrations for yield maximization; and tracking, compiling, and generating reports using data from multiple sources on its platform.

Moving forwards, the advent of new solar-powered solutions is anticipated to further decarbonize the total irrigation systems market

The irrigation industry relies heavily on groundwater sources, accounting for about **35% of total water use**, which presents a significant opportunity for the use of solar pumps. However, collaboration is needed across all sectors of society to ensure the viability of solar-powered irrigation.

Governments should encourage adoption by facilitating access to this costly alternative through subsidies and data gathering. Spreading awareness about best practices and standards can be especially helpful in areas where there is a lack of information and knowledge regarding novel advances in the irrigation industry.

Businesses should focus their development on reducing costs and ensuring widespread access because sustained high initial investments will hinder adoption among small-scale and middle- and low-income farmers. Furthermore, alternative business models that can cater to less-advantaged farmers by providing pay-as-you-use or instalments are crucial. For instance, SunCulture's AgroSolar Irrigation Kit aims to reduce the cost of solar pumping and drip irrigation for small-scale farmers, facilitating adoption.

NGOs and international organizations can contribute by adopting and promoting the use of renewable energy-powered irrigation systems through financial assistance or social projects. For instance, the Consultative Group on International Agricultural Research NEXUS Gains program works to encourage and support low-income farmers in South Asia and Sub-Saharan Africa.

Source: Frost & Sullivan

WASTE **MANAGEMENT**

FOOD WASTE AND WASTE TREATMENT

Decarbonisation efforts extend beyond inputs to cover outputs with waste management approaches including reducing food waste by tracking and tracing

As per the United Nations and World Economic Forum (WEF), more than 17% of global food production may be wasted, leading to a **global annual loss of $936 billion and approximately 8% of global GHG emissions.**

Food loss or waste equates to the loss of resources used in its production, i.e., water, energy, land, labour, and capital. Additionally, food waste disposal creates a burden on waste management systems, leading to landfills and GHG emissions and contributing to climate change. It will also negatively impact food safety and security, thus, increasing the cost of food. Food wastage and loss is a critical issue that needs to be addressed, and its reduction throughout the value chain could have significant economic, environmental, and social benefits. Therefore, food waste reduction solutions offer a great opportunity to determine sustainability goals in the nutrition industry.

Thus, to ensure food waste reduction and promote sustainability, companies should opt for solutions that will increase efficiency at different stages of the value chain stages. Consumer education, innovative packaging solutions, and governments enforcing strict wastage policies will help address environmental issues due to food loss/wastage.

An important improvement could come from investing in technological innovations to support the **tracking and tracing of food products.** Additionally, major manufacturers should collaborate with start-ups to upcycle food waste, which will help achieve a circular economy.

Companies should be encouraged to explore the possibility of **converting food waste into compost or bioenergy.** In that same vein, there have been studies for food waste valorisation to create protein ingredients, which companies may consider as an alternative.

Upcycling also offers opportunities for companies such as Flock Foods (US) which look to convert agri-food remains into food for humans and animal feed

Food loss/wastage can happen at various stages of the value chain, such as during food production, processing, and consumption. Value chain participants continuously look for ways to reduce losses, and **upcycling** has emerged as a popular choice. In contrast to recycling, **upcycling** converts waste and low-value products into high-value ones.

Source: Frost & Sullivan

Upcycling agro-food and agro-industrial waste streams offers strong growth opportunities in the human and animal nutrition supply chains.

According to the US-based upcycled food association, as of 2022, there were a total of 324 products and ingredients that have received the upcycled certification. An estimated 726 million kg of food were used in upcycling, thus, preventing food waste.

Some companies offering upcycled food products and ingredients include **Upcycled Foods Inc. (US)** (ReGrained SuperGrain+), **Flock Foods (US)** (Flock Chicken Crisps), **NutriLeads (Netherlands)** BeniCaros), and **Harmless Harvest (US)** (dairy-free yogurt alternative).

More generally, the conventional waste treatment value chain segments into collection, transportation, sorting & separation, reuse & recycling and disposal

The collection part contains primary storage (waste containers and smart bins), fill-level sensors, radio-frequency identification (RFID) bin tags, in situ selective collection (separation at source), drop-off points, deposit return schemes (DRSs) and consumer interface operations.

The transportation part contains waste collection and transportation fleet, route planning and logistics solutions, smart fleet management and business activity monitoring.

The sorting & separation part contains preparation for processing with mechanical sorting and separation, magnetic sorting, automated sensor-based sorting and AI-based robotic sorting.

The reuse and recycling part contains digital material passports, digital material banks•, blockchain records, track and trace solutions, mechanical recycling based on material type/grade, chemical recycling for hard-to-recycle materials and organic waste composting.

The landfill disposal part contains residual management, biological stabilization/neutralization before landfilling, methane emission management and landfill gas recovery.

Sustainable innovations here include the use of sensors and AI-based robotics across material recovery facilities (MRFs) …

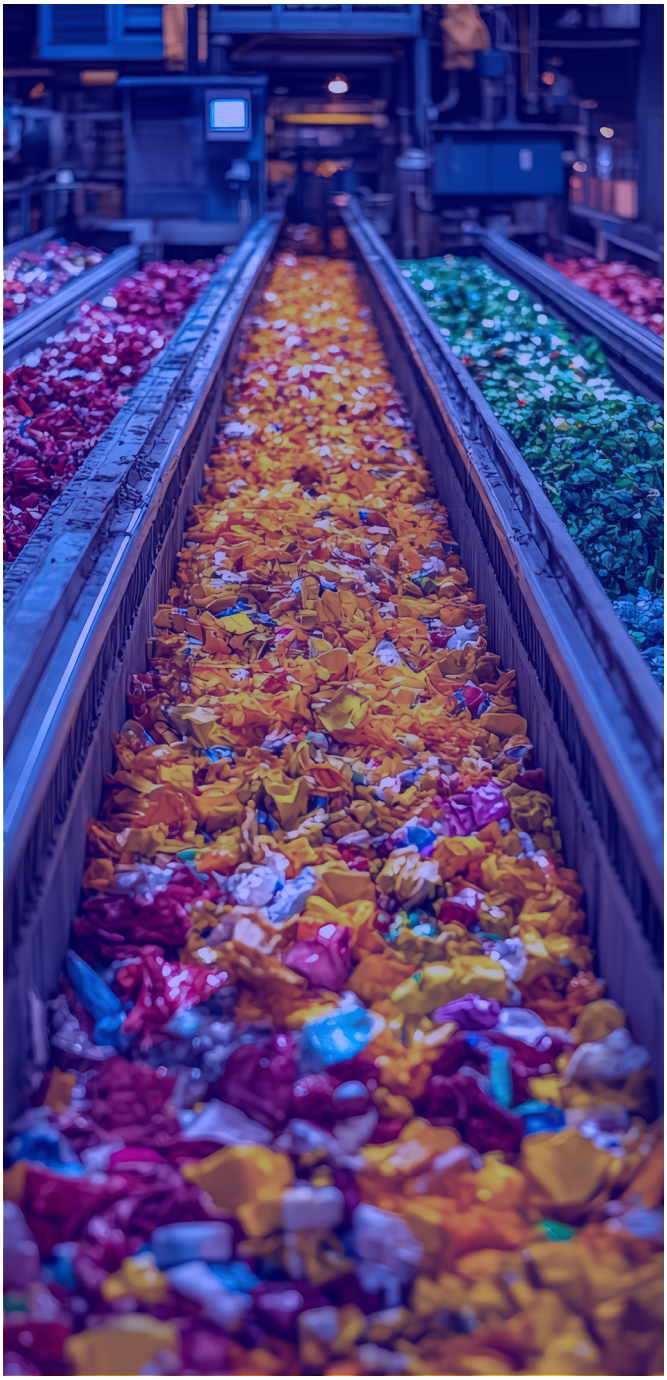
Material recovery facilities (MRFs) are progressively deploying non-contact, sensor-based, and optical systems to enhance waste sorting and material classification, and advanced robotics and AI to perform complex tasks, boost productivity, and provide valuable insights on materials and sorting performance. Higher performance, accuracy, and detection speed during waste separation will enhance mechanical recycling processes by increasing profitability, minimizing loss of valuable materials, improving material purity and recovery rates, and optimizing both time and the extraction of multidimensional information about the processed materials. Enhanced processing visibility and transparency will enable MRFs to make intelligent, data-driven decisions at the plant level and beyond. These solutions offer a bigger picture of the circular economy approach to improve understanding, transparency, and mapping of the material recovery potential.

AI-based sorting and robotics will improve material recovery efficiency, the ability to sort difficult-to-separate materials (e.g., black plastics), and material-specific sorting (e.g., separating out food-grade plastics) to boost material output quality and increase resale value. Connecting optical sorting with data-driven process optimization and deep learning for image and material recognition will increase sorting efficiency and optimize existing technologies at recycling facilities to address current and future material sorting and processing challenges. Technology integrators will likely benefit from combining AI with laser scanning, sensors, and optical sorters to create a digital copy of objects for data-driven decision-making. This approach will enable 3D object recognition and enhanced materials classification to provide high-accuracy sorting in numerous applications. Furthermore, demand for data-based operations—using solutions such as waste data management and material flow analysers—will result in higher measurements, efficiency, and informed decision-making.

… while interest in advanced chemical recycling will continue to grow, for example in the form of plastic-to-fuel (P2F) methods for hard-to-recycle materials

The plastic recycling sector is continually developing, driven by EPR with more than 80 consumer packaged goods companies committed to at least 15%—and up to 50%—recycled content in their packaging by 2050. Ongoing integration of advanced sorting and processing technologies dedicated to complex packaging waste results in the separation of new materials that require new processing (e.g., plastic films, multilayer foils, flexible plastics) and chemical recycling that will complement mechanical recycling and close the loop on hard-to-recycle plastics. Industry experts agree that chemical recycling will support the plastic packaging recycling rate, which should reach a global average of about 45% by 2030 with contributions from both mechanical and chemical recycling solutions. Frost & Sullivan estimates that the global mechanical recycling of plastic packaging waste sector reached $11.91 billion in 2022 and will record a 13.7% CAGR from 2022 to 2030. The chemical recycling sector is still emerging but shows major potential that will likely result in growth of 43.5% from 2022 to 2030.

Globally, demand is high to reduce infrastructure gaps between developed and developing regions and urban and less-urban areas in well-established areas. The aim is to limit disproportionate distribution and increase access to well-functioning end-to-end recycling infrastructure. Improvements are ongoing in material processing technologies to achieve recycled plastics for direct use with food or cosmetics. Development of advanced chemical recycling will continue in the form of **plastic-to-fuel (P2F)** methods for treating hard-to-recycle plastics and avoid landfilling or incineration. The growth opportunity is the refinement and use of plastic waste as a fuel to replace traditional fossil fuels or as feedstock to produce other chemicals. The emerging chemical recycling opportunity is food-grade **plastic-to-plastic (P2P)** recycling to enable material flow without quality or value loss wherein plastic packaging resources become feedstock for new plastics production and mitigate dependence on virgin fossil resources. Progressive development of the chemical recycling sector creates growth and innovation opportunities for well-established mechanical recycling specialists in supplying machinery for material recovery facilities.



Source: Frost & Sullivan

RENEWABLE **ENERGIES**

ANAEROBIC DIGESTION

For renewable energies, anaerobic digestion represents a key opportunity and presents an alternative way of managing waste emanating from the food system

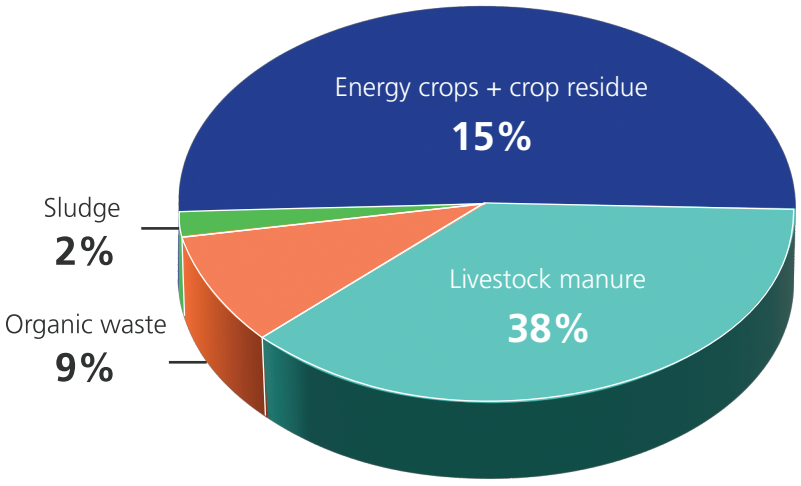
Currently there are ~16 thousand biogas plants in Europe and ~1 thousand biomethane in the context of an overall market which is growing at over 7% annually

In 2022, Germany had the biggest number of biogas plants with nearly 10000 plants which represents **63% of the total number of biogas plants in Europe.** Followed by **Italy** in the second place with **1661 plants** and France with nearly **1000 plants.**

As far as biomethane plants are concerned in Europe, in 2022, **France** held the first position with **365 plants**, followed by **Germany** with **232 plants**, and **UK** with nearly **100 plants**. Between 2019 and 2022, the number of biomethane plants oin France has grown by 30%. Favorable incentives, feedstock availability, and growing demand are the key drivers to this growth.

urrently there are ~16 thousand biogas plants in Europe and ~1 thousand biomethane in the context of an overall market which is growing at over 7% annually

TONNAGE OF FEEDSTOCK USED IN OPERATIONAL AD PLANTS, EUROPE, 2022



Feedstock used in operational AD = ~ 233 million tons

In Germany and the United Kingdom, energy crops are a primary feedstock, while France, Italy, Benelux, and Denmark primarily depend on agricultural waste, including livestock manure. Austria and Sweden have a relatively higher share of sewage sludge as feedstock.

Source: Frost & Sullivan

Growth is driven by the REPowerEU plan with targets for biomethane production …

The **REPowerEU** plan targets the production of 35 bcm of biomethane by 2030, which will drive European countries to leverage various types of feedstocks to produce biogas through AD.

Furthermore, gas imports have doubled during the last decade, especially due to the gradually decreasing dependence on coal. The Russo-Ukrainian War has highlighted Europe's vulnerabilities as it significantly depends on gas imports from Russia (which, in turn, has disrupted gas prices). Biogas is the best-fit alternative to mitigate volatility and reduce dependence.

Most countries have an abundance of feedstock, **mainly in the form of organic waste** (MSW biowaste, industrial waste), livestock manure, and crop residue. Biogas producers can increase their revenue through the tipping fee (for waste disposed at their facility). Increased source separation by urban local bodies (ULBs) will also unlock new revenue potential.

The transportation sector has become a key target for GHG reduction and is rapidly **adopting biomethane**. Vertical market opportunity from biomethane production is carbon sequestration and green hydrogen production. New policies are being implemented to further investments in green gas retailing infrastructure for use in mobility/transportation.

… but the high capital cost of constructing an AD (Anaerobic Digestion) plant acts as a barrier to deployment

AD and biogas production involves a high CAPEX; hence, project developers are reliant on incentives and subsidies to remain economically sustainable.

Furthermore, the electricity produced from biogas is costlier than other renewable sources, such as wind and solar, thereby accounting for a significant portion of green investments and lacking financial backing for rapid expansion. Moreover, the need for extensive permits to set up an AD plant (in comparison to other renewable energy sources) restrains market growth. In addition to that, the high logistics costs involved in the transportation of feedstock to AD plants and the disposal of the digestate add to overall operating costs.

Overall, however, the price of production compares very favorably to natural gas which is boosting its use for electricity, heat and CHP (combined heat and power)

According to **ICE ENDEX (Intercontinental Exchange)** estimates, NG price will gradually decrease to pre-2021 levels after 2026. Biomethane production will cost between $53.3/MWh (€50/MWh) and $106.6/MWh (€100/MWh), depending on plant size and feedstock, with most countries offering an average feed-in tariff (FIT) and/or premiums of up to $133.2/MWh (€125/MWh).

The existing biogas production facilities are expected to install biogas upgradation technology to meet **REPowerEU** targets. Frost & Sullivan estimated total biogas and biomethane production capacity to grow from **20 bcm** in **2020** to **55 bcm** in **2030**. During the forecast period (2023-2030).

During the period (2023-2030), most greenfield plants and up to 60% of brownfield plants will install biogas upgrading systems or be connected to centralized biogas upgrading facilities, which will result in significant absorption of biogas to produce biomethane, resulting in more biomethane plants over pure biogas plants. 80% of the end use of Biogas and Biomethane produced in Europe is for heat and power.

Italy is a hotspot for anaerobic digestion with domestic strengths on both the technology & equipment and feedstock & AD gas production sides of the market

The **biogas** produced in the country is predominantly used for **electricity production;** however, the focus is now shifting to biomethane production to supplement gas demand and to be used as fuel for gas-based vehicles. Italy is also a leader in leveraging **organic waste** (source-segregated biowaste of MSW), **industrial waste**, and **sludge** to produce **biogas**. The country aims to further leverage its agriculture waste and energy crop potential, with the Northern region holding more potential. Over the past 10 years, FIT (Feed-in tariffs) and FIP (Feed-in Premiums) schemes have predominantly incentivized the growth of AD plants with feedstock of agricultural byproducts and biowaste, respectively. The Italian NECP for 2030

will assist the conversion of existing biogas plants into **biomethane production facilities**, especially those nearing the end of the incentive period. The transportation sector is also seeing increased demand for biomethane, further driving demand for AD plants.

During the forecast period, Italy will witness the growth of **large-size cogeneration AD facilities**. Approximately $2 billion is expected to be invested as part of the NRRP implemented in 2021 to specifically produce biomethane from organic waste.

XRHealth (US), for example, has developed a Digital Therapeutic XR Platform, which aims to improve patients' range of motion

The market is highly fragmented with multiple niche companies across the technology/equipment value chain.

Design & Engineering	Technology & construction		
	Anaerobic Digestion & Gas Collection	Gas Filtration & Upgradation	Energy Production
• Veolia • Suez • AB Energy SpA • I.G.W. Srl • Landwärme kIEFER TEK Ltd • Scandinavian Biogas • IES Biogas • Weltec Biopower • Anaergia • Fluence • Biogest • Ultrawaves • Envitec biogas • PlanET biogas • Schmack Biogas • BTS Biogas • BTA International	• Anaergia • Veolia • LIPP • IES Biogas • Biogest • Envitec biogas • PlanET biogas • Schmack Biogas • BTS Biogas • BTA International • Weltec Biopower • Biovoima • Nature Energy **For THP Process:** • Cambi • Eliquo (Lysotherm)	• Greenlane biogas • Desotec • Evonik • FWE • GM-Green Methane • Wartsila • Carbotech • DMT • AB Energy SpA • ETW Energietechnik • Agraferm • Pentair • Airliqude • Malmberg • Atlas copco	• APROVIS Energy Systems • ETW Energietechnik • GE gas Power • Clarke Energy • METCO Engineering • Wartsila • Siemens-energy • Man • MWM • MTU (Rolls Royce) • 2G Energy

Source: Frost & Sullivan

Process Control & Automation	Chemical/ Nutrient Aids	Biomethane Off Takers
• Pentair Haffmans • Bioprocess Control Sweden AB • Xylem Water Solutions • Hach • ABB • Awite Bioenergie GmbH • Geotech • Endress & Hauser • Kohne	• Yara International • Schmack • DSM • Kemira • DuPont • Schaumann BioEnergy	• Engie • GRDF • Shell • Total Energies • ORLEN group • PGNiG • Gasunie • GRT gaz • Terega • Energinet • Fluxys • Nordion • Ontras • DESFA • Snam

Most turnkey companies own and operate their own plants apart from offering end-to-end solutions (that is, delivered as a regular EPC contract).

The ability to deliver compact and modular digesters will become important

Agricultural waste, livestock manure, and food waste will become the feedstock seeing the highest demand, mainly due to ready availability and the economic value-generation potential in leveraging the biogas yield of these types of feedstocks. However, to keep logistics costs at a minimum and moisture content at the appropriate levels, the AD plant must be within 25-50 kms from the source of the feedstock. Thus, **compact and modular digestors** are the most viable option.

Therefore, AD plant solution providers should **develop modular/compact solutions** that cater to end-customers' needs, specifically in the agricultural sector. Furthermore, Customers prefer **modular plug-and-play AD units (with minimum 20 KW and scalable up to 500 KW)**.

In addition, **modular AD units** should also have co-digestion capacity for various types of agricultural waste and manure, which will ensure high growth penetration.

At present, **France, Germany, Benelux, and Denmark** are hotspots for modular AD plants in the European region. In the medium-to-long term (3-5 years), Spain, Italy, Poland, Greece, the Alpine countries, and the Nordic countries will also contribute to the growth in demand for modular AD plants.

Source: Frost & Sullivan

ENERGY EFFICIENCY AND REFRIGERATION TECHNOLOGIES

In addition to leveraging waste and saving water, improved energy efficiency is vital in the food industry which accounts a quarter of global emissions

Food requirements for the increasing global population result in the over-exploitation of environmental resources, leading to GHG emissions, deforestation, and water scarcity. Moreover, feed production, processing, and enteric fermentation from livestock are major sources of emissions in this industry. With environmental concerns rising, the reduction of GHG emissions has become critical to the animal farming and nutrition industry.

All of the major F&B players, including Arla Food Ingredients (Denmark/Sweden), Kemin (US) and Glanbia Nutritionals (Ireland) have "green" initiatives in this respect

Arla Food Ingredients (Denmark/Sweden) is adopting renewable energy practices. The company aims to use 100% renewable electricity across its European production sites by 2025 and has made investments in solar and wind projects. It is also investing in energy-efficient systems to reduce energy consumption across its farms by electrifying boilers and heat pumps and generally optimizing electrically powered equipment.

Glanbia Nutritionals (Ireland) is doing water usage reduction and withdrawal, the company has committed to reducing its water use 10% annually by 2025 from a 500-million-liter baseline in 2021. Furthermore, the company is also working on waste reduction and safe disposal, the company recycles 70% of food waste into animal feed. Kemin (US), on the other hand is also investing in renewable energy practices the company is investing $1.5 million in an on-site solar energy plant.

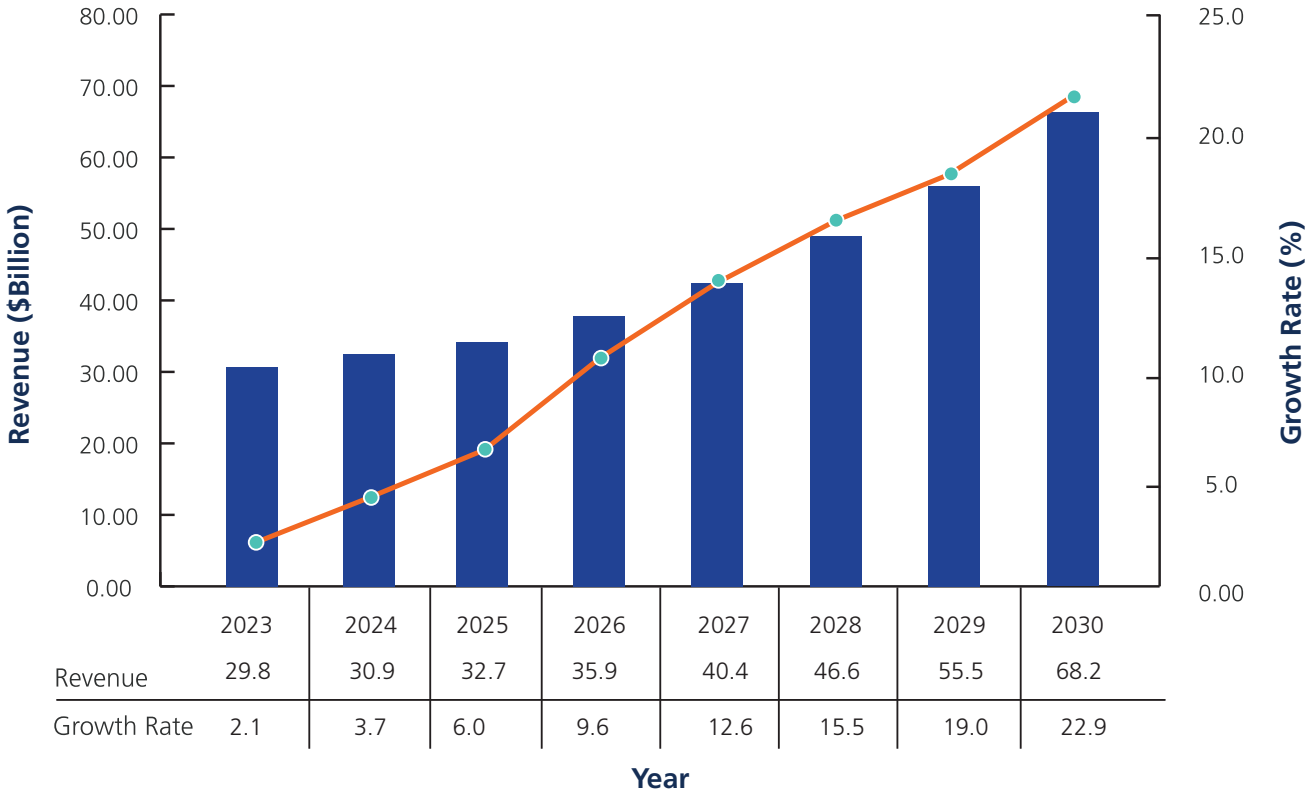
Adisseo (France) is shifting towards clean energy, in 2022, the company partnered with Air Liquide to create an underground pressure hydrogen pipeline to supply its Saint Clair du Rhône site. **For water usage reduction and withdrawal**, the company invests heavily in solutions to reduce the impact of its activities on the environment. For instance, Adisseo commissioned a new wastewater treatment plant at its site in France with an investment of €20 million. This new setup has helped reduce effluent discharges drastically, supporting the company's efforts toward sustainability.

For **FrieslandCampina (Netherlands)**, the company has achieved 100% green electricity through solar at its Netherlands and Philippines sites. The company is also working on **improving land use, FrieslandCampina** renewed its planet sustainability program, Focus, increasing rewards for member farmers for CO reduction. The company has also initiated a pilot project with dsm-firmenich's feed additive "**Bovaer**" at its dairy farms to lower the methane emitted by cattle.

Source: Frost & Sullivan

One main area of activity is refrigeration technologies with the global farm to fork cold supply chain growing rapidly at 12.6% on a compound average basis

IT IS WITHIN THERAPEUTICS THAT THE METAVERSE IS HAVING THE GREATEST IMPACT



	2023	2024	2025	2026	2027	2028	2029	2030
Revenue	29.8	30.9	32.7	35.9	40.4	46.6	55.5	68.2
Growth Rate	2.1	3.7	6.0	9.6	12.6	15.5	19.0	22.9

Year

Note: All figures are rounded. The base year is 2023. Source: Frost & Sullivan

Here, connected devices and automated warehouses are amongst the key innovations that are minimizing the sector's significant environmental footprint …

As far as the digital transformation is concerned in this area, the main growth driver here are the rise of Internet of Things (IoT)-enabled devices, eCommerce, direct-to-consumer (DTC) channels, blockchain, and AI-driven analytics, which are revolutionizing food safety, production, and distribution processes. Connected devices and automated refrigeration warehouses are improving cold solutions' efficiency, which could translate to lower risk for investing in the cold supply chain industry. This digital transformation is most prevalent in NALA (North America & Latin America), followed by EMEA (Europe Middle East and Africa) and APAC (Asia-Pacific)

… while Ecozen (India) is innovating to bring the cold chain to small scale farmers and, at the same time, reduce the use of fossil fuels as an energy source

Ecozen is a company based in Pune, India, has designed solar cold storage rooms for **small scale storage needs**. The solution aims at increasing the shelf life of farm produce and to allow more sustainable storage of perishables at source for small and medium-sized farms or farming communities. The cold storage room is **Internet of Things (IoT)** enabled and allows users to remotely monitor and control key functions along with providing **predictive maintenance** with the help of **artificial intelligence (AI), and data analytics**.

The situation is that in a country such as India, where distances are vast and multiple mid-level vendors are involved between the harvesting and final sale of produce, the chances of wastage are very high. In addition, remote rural areas often face infrastructural issues such as lack of electricity and sporadic availability of means of transportation, further complicating the issue.

EcoFrost, the cold storage room solution by ***Ecozen***, is equipped with **solar panels** that can change the system completely in 5-6 hours. The system is designed to be easy to maintain, with minimal maintenance cost owing to the absence of chemical battery or diesel and uses thermal plates to provide more than 30 hours of battery backup.

At present, ***Ecozen's*** products are present in over 20 000 farms and the company is planning to develop a new cold chain enabled product for the perishable value chain. The company is also working on development of tech-enabled platform for sourcing pre-cooled perishables directly from the farmers, scale up the irrigation business, and diversify into new turfs.

Furthermore, in developing countries such as India, a large amount of agricultural and dairy produce comes from small farms, owners of which do not have the financial capability to access advanced technologies. Therefore, technologies such as ***Ecozen's*** smart cold-storage solution can be owned and operated on a community level and can help reduce the wastage of produce. ***Ecozen*** has achieved noteworthy success in the Indian markets and has managed to reach hard to reach customers across rural markets. The company can leverage its wide reach to grow through cross selling.

PROCESSING
AND PACKAGING

SUSTAINABLE AND SMART PACKAGING TECHNOLOGIES

Outside of food and farming, packaging is another segment with scope to decarbonize with products consisting of different materials

The **food packaging industry** operates in an extended value chain. The use of various **mono- and multi-materials** for packaging and the increasing implementation of circularity components increases the role of stakeholders operating in the industry.

Packaging manufacturers establish long-term agreements with upstream suppliers to ensure a steady supply of raw materials and minimize the impact of price fluctuations owing to packaging materials' high commoditization.

The industry requires the following raw materials: ***plastics*** (including virgin and PCR resins and preforms), ***paper & paperboard*** (pulp, biomass, and waste/recycled and packaging paper), glass (sand, soda ash, limestone, and glass cullet), ***metal & alloys*** (aluminium, stainless steel, tin/copper); and ***multi-material packaging*** (thin layers of paper, plastic, and aluminium).

Food packaging supply is a highly fragmented tier consisting of several **large, medium-sized, and small-scale producers** specializing in specific product areas in particular regions according to their technological expertise. Few companies operate globally to cater to the increasing number of multinational F&B suppliers.

With limited product differentiation in the market and the increasing demand for F&Bs, companies mainly compete in packaging product prices, creating lucrative opportunities for small-scale manufacturers to target emerging downstream food processors by offering cost-efficient, sustainable packaging solutions.

The growing **demand for sustainability** has forced companies operating in each tier of the value chain to **implement optimal circularity** according to respective regulatory requirements. Packaging manufacturers are making substantial efforts to **minimize product wastage** and revert defective products/batches upstream for integration with recycled feedstock.

In Europe, in particular, sustainability and circularity are key motors for market growth

As Stakeholders operating in Europe are focusing on sustainability and circularity. The European Union has set targets for recycling packaging waste at 65% by 2025, 70% by 2030, and a commitment to ensure that 100% of packaging is recyclable by 2030. According to a European Consumer Packaging Perceptions survey, nearly two-thirds of respondents switched brands because of packaging concerns. Although sustainable packaging alternatives are more expensive than their conventional counterparts, they will experience healthy growth in the region during the forecast period.

Here, the market is shifting from single-use plastics to sustainable packaging …

The packaging industry's focus on sustainability is forcing businesses to monitor their operations and evaluate their environmental impact, especially the use of single-use plastics as major contributors to the global solid waste problem.

Food packaging products based on single-use (disposable) plastics include films, mineral water bottles, disposable cups, straws, and takeaway trays. Although sustainable alternatives have penetrated all application areas of single-use plastics, more cost-effective traditional packaging solutions limit their adoption.

The growing popularity of takeaway food and food delivery has significantly increased single-use plastic consumption. Food takeaway packaging accounts for a sizeable proportion of municipal waste in cities. For instance, according to the Association of Municipal Companies, takeaway packaging in Germany accounts for nearly 40% of public waste.

Because food residues cause contamination, recycling single-use plastic containers from the takeaway food sector is unviable, and these containers mostly end up in landfills.

Therefore, several packaging manufacturers, food processors, and regulatory authorities are encouraging stakeholders to seek sustainable alternatives to single-use plastics by using recycled/recyclable plastics or eliminating plastics altogether and adopting other packaging solutions, such as paper-based materials.

Furthermore, consumers are becoming increasingly aware of the harmful environmental impact of single-use plastics and demanding sustainable alternatives. The higher costs of these alternatives compared to conventional plastics contribute to revenue growth in the market.

… while lightweighting offers an alternative approach

As numerous F&B (Food and beverage) manufacturers adopt sustainable packaging because of regulatory mandates or to market green packaging, one solution is to reduce its overall weight. **Lightweight packaging** offers logistical benefits by lowering unit mass, thereby reducing costs throughout the supply chain. For example, 20 grams (g) to 40 g of food typically requires 1 g of plastic. Glass packaging is less efficient, requiring 1 g glass for 1.5 g to 2 g of food. Some companies are decreasing their reliance on plastic and increasing packaging efficiency by using paper in certain applications.

F&B players achieve **lightweighting** in the following 2 ways:

- Replacing the Packaging Material with **Lightweight Alternatives**: For instance, A Glass of, an Australian wine delivery service, packages and delivers wine in pouches that are 73% more energy-efficient to manufacture and emit 82% less carbon than conventional glass bottles.
- Reducing the Quantity of Material in Packaging: Nestle S.A. reduced the weight of its plastic-based packaged water bottles by 22% by adopting a novel blow molder control system.

In 2019, the average weight of glass bottles decreased by 30% compared to the previous decade. For instance, *Accolade*, one of the largest winemakers in the United Kingdom, reduced the proportion of bottles weighing more than 500 g bottles from 17% in 2017 to 3% in 2020 and increased the proportion of bottles weighing less than 390 g bottles from 24% to 42% during the same period.

All things considered, **lightweighting** is more sustainable. *AB InBev*, a global brewer, reduced carbon emissions per bottle by 17% by decreasing the weight of its standard longneck beer bottle from 180 g to 150 g. Although **lightweighting** offers multiple advantages, its widespread adoption can decrease packaging volumes and limit market growth. This restraint is expected to have a high impact during the short- and medium-term forecast period and a moderate impact over the long-term forecast.

Source: Frost & Sullivan

Moreover, smart packaging can be used to extend the shelf life of many food products and therefore to reduce waste and/or spoilage

An extended shelf life provides end consumers with fresh F&Bs and prevents food wastage owing to premature spoilage. For instance, the global meat supply chain loses or wastes **nearly 20% of meat production by volume**, with half of this loss occurring during distribution and retail and consumer use.

A **prolonged shelf life** benefits all stakeholders in the supply chain. Food processors can penetrate new regional markets, retailers can increase their inventory size and reduce frequent restocking and end consumers can easily maintain a well-stocked pantry.

Packaging can considerably affect the product's shelf life and is sometimes based on food processing. The direct link between packaging and shelf-life forces food processors to focus on their packaging operations. For example, processed UHT milk in sterilized multilayer packaging, such as **paper-aluminium-PE *(TetraPak)*** cartons, has a **90-day shelf life** at room temperature, while refrigerated pasteurized milk in **high-density PE jars** has a maximum shelf life of **only 2 weeks**.

As consumers become more aware of the disadvantages of preservatives in processed foods, manufacturers are exploring packaging alternatives that offer a similar longer shelf life.

Active packaging, which acts as a barrier to protect food from adulteration/spoilage owing to moisture, oxygen, or other microorganisms, is gaining prominence among packaging technologies. This type of packaging includes oxygen scavengers, moisture absorbers, and CO emitters/absorbers.

These technologies result in higher packaging costs than traditional alternatives and drive food packaging revenue growth. This factor will have a moderate impact on the market during the short-term forecast period and a high impact in the medium and long term.

Consumers in both Europe and the Americas are typically more willing to pay more for environmentally friendly packaging than conventional counterparts

Plastics are the preferred packaging material because of their lightweight advantages and cost-effectiveness. In addition, consumer perception of glass as a premium packaging material and higher energy costs will significantly increase the price of glass.

Although metals are lighter and more sustainable, frequent shortages are forcing manufacturers to switch to alternate materials, limiting the potential increase in metal prices.

Source: Frost & Sullivan

Manufacturers are in turn investing in pushing the adoption of bioplastics …

Amid these industry changes, **bioplastics** can gain significant momentum as food producers seek green alternatives to plastic packaging products to reduce their carbon footprint. Although demand will remain the main driver of the shift to alternate materials, including bioplastics, supply-side stakeholders can integrate these materials into their product portfolios to establish a stronger presence in the wider marketplace. This can also help packaging manufacturers secure a first-mover advantage in the industry.

A demand-side **shift from conventional materials to bioplastics** can potentially provide a **lucrative opportunity** for companies to develop sustainable materials that fulfil packaging requirements.

Indeed, although bioplastics globally have a lower production volume than regular plastics, many companies are exploring food packaging products based on bioplastics, such as **PLA, polyhydroxyalkanoate, and bio-PET**. Hence, manufacturers involved in the production of such packaging materials will likely benefit from this increasing demand.

Furthermore, **PLA** is a commonly used bioplastic in food packaging applications, and companies developing alternative biomaterials will see high demand from the market.

… and in expanding recycling infrastructure to secure raw material supply

Suppliers can develop sustainable packaging in numerous ways, from producing materials to increasing consumer awareness about optimal waste disposal. Replacing conventional packaging with recyclable counterparts is the first step to eliminating material-related challenges in food packaging recycling. Almost all packaging suppliers are revamping their portfolios to include recyclable products, including reducing the use of single-use packaging by promoting reusable solutions.

Packaging suppliers can partner with upstream resin manufacturers to procure chemically recycled resins and develop an **entirely circular packaging product**. For example, in December 2022, *Amcor* signed a five-year procurement agreement with *ExxonMobil* to purchase its certified **circular PE**. Furthermore, investing in recycling infrastructure is another lucrative option for suppliers to secure a reliable supply of recycled raw materials. In September 2022, Greiner Packaging acquired a Serbian PET flakes producer, ALWAG, to maximize the recycled material in its products.

Source: Frost & Sullivan

AGRICULTURAL EQUIPMENT **AND TRANSPORTATION**

Sustainable alternative fuels coming from renewable energies and waste reuse can also be used in the farming equipment themselves

Alternative fuels use non-petroleum feedstocks, such as tallow oil, corn, soyabean oil, rapeseed oil, used cooking oil (UCO), fatty acidmethyl esters, hydro processed esters and fatty acids (HEFAs), and HVOs in the case of biofuels; organic waste, animal waste, and wood in the case of biogas; and water, electricity, and biogenic or direct air capture CO⊠ in the case of eFuels.

These fuels are substitutes for more carbon-intensive energy sources, such as diesel, gasoline, and jet fuel in the transportation sector, contributing to the broader decarbonization and net-zero targets of COP 29.

The alternative fuels are segmented into 3 main segments: **Biofuels** (Biodiesel, Biomethanol, Bioethanol, Renewable Diesel, SAF, and Biobutanol), **Gases** (Biogas, Biomethane, R-CNG, and Bio-LNG), and **eFuels** (eMethane, eMethanol, eSAF, eDiesel, eGasoline, eAmmonia, and eHydrogen).

In terms of production and availability, **eFuel** have the biggest growth rate within the three segments of alternative fuels. The production volume is expected to grow from 3.9 MTPA in 2024 to 135.6 MTPA in 2030 with a very high CAGR. **Gases segment** of alternative fuels will also grow in the coming years as the production will increase from 47.3 MTPA in 2024 to 81.2 MTPA in 2030. **Biofuel** production is also forecasted to increase from 197.8 MTPA in 2024 to 287.6 in 2030.

For transportation, initiatives to improve sustainability stretch to vehicles that are used to distribute food and those that are used to nourish and harvest it

Diesel is currently the dominant energy carrier for tractors, and it responds very well to farmers' requirements

Diesel fuels are the dominant energy carrier for nonroad equipment, followed by **gasoline** and **liquid petroleum gas (LPG)**. The energy density, as well as the ease of transporting and handling these fuels, have long satisfied the equipment users' energy requirements.

One of the main criteria for market requirements is ***time sensitivity of work***. Indeed, companies look to avoid delays as much as possible. Delays can lead to cascading interruptions on the jobsite, ballooning costs, project schedule slip, monetary losses, and potential public safety concerns. Equipment manufacturers attempt to mitigate delays by maximizing onboard energy storage capacity while minimizing recharge and refuelling time for their products.

Major examples of this customer needs:

- Crop planting and harvesting: Due to the unpredictable nature of the growing season, farmers have limited windows to both plant and harvest crops from their fields. Inoperable equipment, or equipment that requires long refuelling times, can jeopardize the profitability of an entire farm.
- Livestock feeding: Livestock require consistent and continuous care from the farm owners. Equipment must remain operational to ensure the farm needs are met.

Another significant factor for market requirement in this area is ***duty cycle***. The energy demands of tractors vary broadly depending on the job. **High load factor** applications are characterized by frequent **high-power demands, near continuous use**, or a **combination of the two**.

The resulting power requirements lead to **significant energy consumption** throughout the workday, such as in field tillage or crop planting and harvesting.

The ***location factor*** is also very important. Oftentimes, tractors operate in remote locations, distant from readily available energy supplies. These sites often operate over longer time periods, sometimes as long as several months or years. Other projects may require a piece of equipment to move to several locations over a given day, or gradually migrate long distances while performing continuous work, all without returning to an established energy resupply base.

Source: Frost & Sullivan

Nonetheless, powertrain electrification is joined by engine modifications and alternative fuels as a means with which to decarbonize the sector in the future

Engine modifications is one of the main trends in decarbonisation and innovation related to this industry as engines require stricter norms. Particulate emissions and filter systems will improve. Diesel oxidation catalytic converter (DOC), diesel particulate filter (DPF), and selective catalytic reduction (SCR) exhaust gas aftertreatment systems will likely be utilized to adhere to emission norms. Furthermore, retrofitting existing tractors involves upgrading the engine to reduce emissions.

Alternative fuels are also a major trend. Instead of diesel fuel, farmers will have the option to switch to alternative fuels such as biodiesel or renewable diesel. These fuels are made from renewable sources, and they emit fewer greenhouse gases than traditional diesel fuel.

Furthermore, **the electrification of power trains** will evolve. Electro-mechanical power split, stepless gearbox, auto transmission, and fully electric tractors in a small power range are some innovations in this space.

Innovation in implements is another trend, as implements are the actual working tools of a tractor, innovations such as no-till technology, variable rate applications, and controlled traffic farming are underway and will increase both yield and productivity.

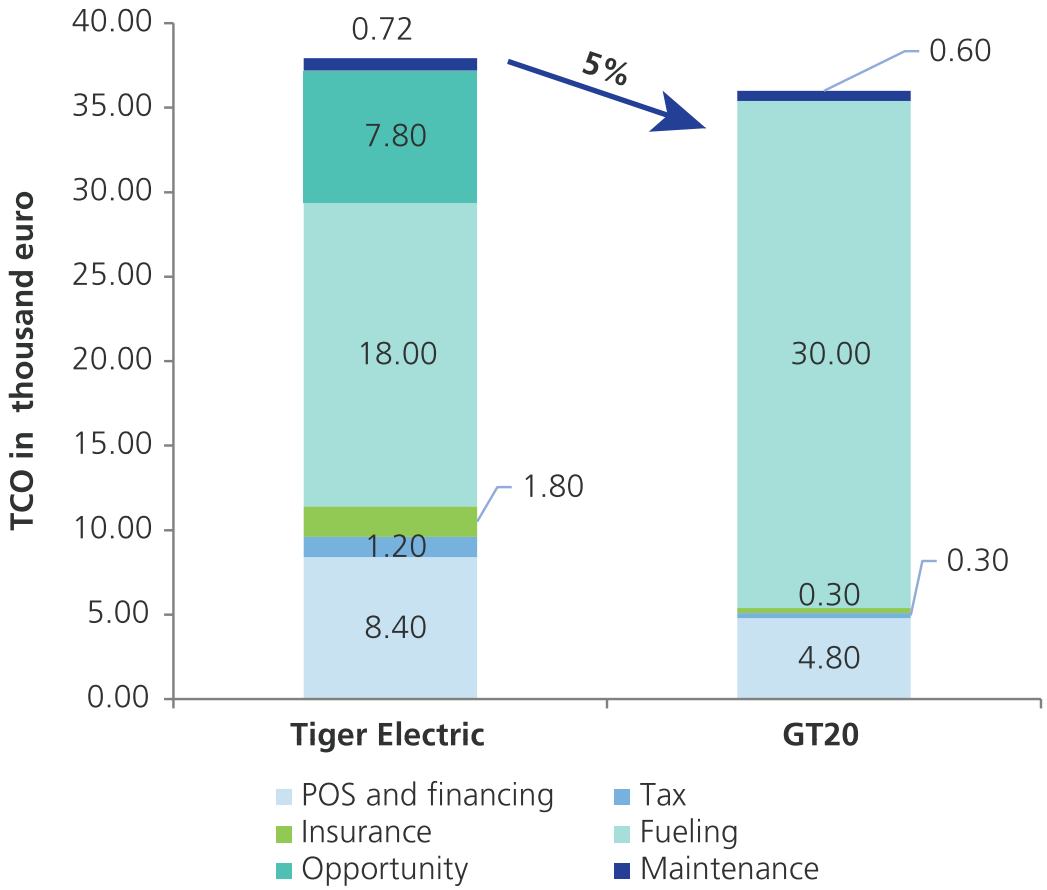
The industry's requirements will continue to influence the adoption of new technologies and energy carriers used in nonroad equipment. Ideally, future energy carrier technologies will reduce both pollutants and greenhouse gas emissions.

Additional efforts will be needed to reduce the TCO (total cost of ownership) …

The TCO is calculated for a 10-year period, procured in 2022 and owned up to 2031, which includes POS (Point of sale) cost, insurance, financing and operating cost, tax, and fees.

After comparing the TCO between the electric and the diesel model, although electric tractors do not provide significant fiscal benefits on the face of the analysis, a few considerations could change the inference:

- Incentives could boost the overall TCO for electric tractors.
- As BEV tractors become the norm, economies of scale will reduce TOC.
- Electricity prices could change the overall TCO to positive operationally for BEV.
- With better charging infrastructure, opportunity cost could drop for BEVs.



The two models compared are **Sonalika – Tiger electric (BEV)** and **GT 20 (diesel)** with similar transmission and lift capacity. The electric tractor comes with a 25.5 kWh battery, which can run 8 hours with a 2-ton trolley on a single charge. Opportunity cost includes the waiting time for charging and driving distance time to charge is ignored.

… and governments are providing financial instruments to address this

In the USA, the **electrification program** rebates support farmers in r**eplacing fossil fuel-powered tractors with electric or alternate fuel equipment**. The farmers are usually eligible for incentives from 70 to 100% of total project cost, up to $30,000. Examples include *Clean Coast Committee, Central Coast Community Energy, and Clean Diesel Program.*

Many other initiatives exist in this area such as:

- The **Diesel Emissions Reductions Act (DERA)** for instance provides grants for replacing engines emitting high CO⊠ and NOx.
- **Core** is a funding program that provides POS discounts for purchasing zero-emission equipment in California.
- **The Funding Agricultural Replacement Measures for Emission Reductions (FARMER)** Program provides funding through local authorities for ag tractors and other equipment.
- Sustainable Northwest, in partnership with Forth, Wy'East RC&D, and Bonneville Environment Foundation, is a leading program in Oregon helping small and medium-scale farmers test and gain a feel for electric tractors by operating them for extended periods of time.

Source: Frost & Sullivan

The US government wants to move closer to the vision of net zero, yet agriculture is a minor contributor compared to other sources of emissions in transportation and in total.

OEMs are responding by developing full electric tractors, like the Sonalika Tiger, or supplying 100% electric powertrains such as that provided by Bosch

Sonalika (India) developed ***Tiger Electric*** a field-ready **electric tractor**, featuring a German design eTRAC motor that offers high energy efficiency with optimized power density and top speed of 24.9 kmph, fully charged in 10 hours. This model is compact and has 8 speed transmission.

Kubota (Japan) also developed **LXe-261**, an **electric tractor** with rental offerings in Europe. This model has a large capacity electric battery installed with 1-hour quick charge and 3-4 hours of continuous operations. It also has the **same compactness level as diesel counterparts**.

Bosch Rexroth (Germany), on the other hand, is also developing a **100% electric powertrain**, with **eLION electrification platform** including modular systems for electrification of machinery, a single-phase onboard charger and BODAS capabilities of IO, software, and electric hardware.

Source: Frost & Sullivan

PRINCIPAL **ABBREVIATIONS**

AI	*Artificial intelligence*
AD	*Anaerobic Digestion*
B	*Billion*
bcm	*Billion Cubic Metres*
BES	*Battery energy storage*
BEV	*Battery Electric Vehicle*
Bio-LNG	*Liquefied biomethane*
C	*Celsius*
CAES	*Compressed air energy storage*
CAGR	*Compound Annual Growth Rate*
CAPEX	*Capital Expenditure*
CHP	*Combined heat and power*
ClO2	*Chlorine dioxide*
CO_2	*Carbon dioxide*
COP28	*28th United Nations Climate Change Conference*
COP29	*29th United Nations Climate Change Conference*
DCF	*Deforestation and Conversion Free*
DERA	*Diesel Emissions Reductions Act*
DOC	*Diesel oxidation catalytic converter*
DPF	*Diesel particulate filter*
DRSs	*Deposit return schemes*
EU	*European Union*
EUDR	*EU Deforestation Regulation*
g	*Gram*
GES	*Gravity energy storage*
GHG	*Greenhouse gas*
GW	*Gigawatt*
H2	*Hydrogen*
ha	*Hectare*
KG	*Kilogram*
km/h	*kilometre per hour*
kWh	*Kilowatt-hour*
LPG	*Liquid petroleum gas*

m^2	*Square metre*
m^3	*Cubic metre*
MES	*Mechanical energy storage*
Mm	*Millimetre*
MRF	*Material recovery facilities*
MSW	*Municipal solid waste*
MTPA	*Million tonnes per annum*
MW	*Megawatt*
MWh	*Megawatt hour*
MWh	*Megawatt-hour*
NG	*Natural gas*
NOx	*Nitrogen oxides*
O3	*Ozone*
P2F	*Plastic-to-fuel*
PCR	*Post-Consumer Recycled material*
PE	*Polyethylene*
PLA	*Polylactic Acid*
POS	*Point of sale*
R&D	*Research & Development*
R-CNG	*Renewable compressed natural gas*
RFID	*Radio-frequency identification*
SaaS	*Software-as-a-Service*
SCR	*Selective catalytic reduction*
SDG	*Sustainable development goals*
TCO	*Total cost of ownership*
TES	*Thermal energy storage*
TiO2	*Titanium dioxide*
UCO	*Used Cooking Oil*
UK	*United Kingdom*
ULBs	*Urban local bodies*
US	*United States*
UV	*Ultraviolet*
W	*Watts*

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Published: October 2024

GRINS FOUNDATION

This study was funded by the European Union - NextGenerationEU, Mission 4, Component 2, in the framework of the GRINS -Growing Resilient, INclusive and Sustainable project (GRINS PE00000018 – CUP B13D21011870004). The views and opinions expressed are solely those of the authors and do not necessarily reflect those of the European Union, nor can the European Union be held responsible for them.