

S&P Global
Energy

Prepared for:



Fueling agriculture: biofuels as the catalyst

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Fueling agriculture: biofuels as the catalyst analyzes how biofuels provide scalable, market-driven demand that supports productivity gains, reinforces food and feed systems through co-products, and contributes to resilient, sustainable agricultural development. It results from a collaboration of groups across S&P Global.

S&P Global study acknowledgments

S&P Global extends its gratitude to the numerous individuals and organizations whose time, insights, and expertise contributed significantly to this study. Their perspectives proved invaluable in shaping the analysis, confirming assumptions, and anchoring the findings within the realities of the agriculture, energy, and sustainability sectors.

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While these contributors offered valuable insights, the analysis, interpretations, and conclusions contained in this report are solely those of S&P Global and do not necessarily represent the views of the contributors acknowledged above.

Executive summary

Agriculture stands at a crossroads

Technology and innovation have enabled US farmers and ranchers to supply more food and fuel than ever before—a trend that promises to accelerate as artificial intelligence (AI) powers advances in seed technologies, crop protection, regenerative farming practices, and digital agriculture. In 2025, the US experienced another record-breaking harvest, extending the largest-ever surplus of grains and oilseeds. Similar trends are being observed globally. For perspective, world corn yields have increased 1.5% per year over the past decades, helping push global grain, oilseed and fiber stocks to nearly 1 billion metric tons in 2025.

At the same time, global demand has failed to keep pace with rising production. Population growth is decelerating, along with per capita food consumption. For example, global per capita meat consumption growth slowed from around 2.4% since the late 1990s to 0.7% by 2025 and is expected to grow just 0.1% toward 2050, indicating near-saturation in many markets.

Biofuel demand faces similar pressures amid vehicle efficiency gains, changing driving patterns, and increased reliance on electric vehicles. At current blend rates (around 10%), US ethanol demand for on-road transportation fuels could fall nearly 50% (to ~6.6 billion gallons) by 2050.

The imbalance between supply and demand has already emerged as a major long-term challenge for the US farm economy. According to the latest US census data, the farm sector lost 209,000 farms and 58 million acres over 2002-2022. The loss was the greatest from 2017 to 2022, with 20 million acres lost. Absent new sources of feed demand and in a scenario in which the US maintains a 10% ethanol blend rate, US corn growers would cultivate roughly 31% fewer acres by 2050, equivalent to halting production on a land mass the size of North Carolina. Under this scenario, loss of agricultural capacity would expose farmers and consumers to increasingly volatile markets for both food and fuel and would highlight the structural risks associated with stagnant biofuel demand.

In response, stakeholders need to explore new pathways to reignite growth in farm communities, drive innovation, and expand agriculture's capacity to feed and fuel the world using fewer resources. Under a scenario where biofuel demand expands, US agricultural production remains strong and continues to serve as a secure, ample, and reliable long-term supplier of corn, ethanol, and other agricultural products to domestic and international markets. In this context, biofuels stand out as a uniquely powerful catalyst with the potential to:

1. Restore long-term profitability to American farms and drive investment in rural communities
2. Unlock demand for sustainable feedstocks, creating a market that rewards farmers for pioneering modern farm practices
3. Strengthen food, economic and energy security on a global scale

To inform an evidence-based discussion on agriculture's full potential, this S&P Global Energy study combines proprietary datasets, quantitative modeling, and scenario analysis with real world insights from leading participants across the agribusiness and biofuels value chain. In total, more than 25 interviews were conducted with farmers; input and technology providers; grain and oilseed processors; biofuel producers; trade organizations; market experts and academics to validate assumptions and ground the findings in real world conditions.

Within this context, the study challenges outdated assumptions about competition between food and fuel, as traditional demand is no longer sufficient to absorb rising productivity. It also shows how agriculture can meet rising demand for renewable energy through technology-driven advancements.

Based on current and emerging trends, the next wave of agricultural productivity will be driven by stacked technologies. The convergence of biotechnology, AI, and advanced data analytics could lift US corn yields by 1.6% annually through 2050, unlocking nearly 50% more production without expanding acreage - provided farmers have the incentive to invest in new technologies.

Under this optimized scenario, global biofuel output would triple or more by 2050. In addition, biofuel production generates valuable co-products (protein meals and DDGS) that are returned to the food system. Relative to 2025, this scenario delivers 45% higher food and feed supplies—a meaningful increase that could help reduce input costs and strengthen food availability globally. Importantly, these production gains are achieved through improved yields and more intensive use of existing farmland, not broad land expansion, demonstrating that biofuel growth can be realized without deforestation.

At the same time, renewable fuels could supply a growing share of the ~940-billion-gallon liquid fuel market, yielding lower finished fuel costs for consumers. Further, recent periods of elevated oil and gasoline price volatility (e.g., Strait of Hormuz crude oil supply disruption, Russia's invasion of Ukraine) underscored the vulnerability of fuel markets to global supply disruptions and geopolitical risk and reinforced the role and stability that biofuels, as a domestically produced renewable energy source, provide to moderate price volatility and strengthen energy security.

Ultimately, this report illustrates how biofuels can unlock new demand for agricultural commodities while helping meet food, energy, and climate goals - a win-win for rural economic development and the global clean energy transition.



Introduction

Agriculture plays a central role in food and energy security and the economic development of farmers and rural communities. Moreover, agriculture is increasingly relevant to energy security, diversification and decarbonization through its capacity to support scalable low-carbon biofuel feedstocks. Over the past few decades, growth in agricultural food demand has been driven by population expansion and rising incomes, which have supported dietary shifts toward higher per capita food consumption, particularly increased meat consumption in developing economies (especially China). Biofuel demand for agricultural products has also grown steadily, further supporting global agriculture—biofuels accounted for less than 1% of grain and oilseed demand in 2000 and reached near 8% in 2025. Together, these forces have driven a steady increase in food and fuel demand for grains and oilseeds.

Global agriculture is entering a period of structural transition—food demand growth is slowing due to decelerating population growth and moderating per capita meat consumption, while biofuel demand, absent new policy initiatives, is pressured by the decline in gasoline use. At the same time, technological progress is accelerating productivity across agriculture. Record-breaking harvests, such as those seen in the 2025/26 crop year, have pushed global grain, oilseed and fiber stocks above 1 billion metric tons, creating persistent surplus conditions. In this environment, adjustment will occur either through reduced cropland use and lower farmer profitability, or through the creation of new sources of demand.

This imbalance exposes the limited capacity of current markets to absorb surplus production and reflects a structural transformation rather than a short-term cyclical downturn. Without new markets, sustained surpluses are likely to place downward pressure on prices, erode farm incomes, weaken rural economies, and discourage long-term investment and innovation.

Within this context, this S&P Global Energy study explores three core topics. First, it examines structural shifts that signal a change in the “food vs. fuel” narrative, as traditional food demand is no longer sufficient to absorb rising productivity. Second, it highlights the significant potential for global agriculture to increase production by improving multiple levers of farmland productivity and processing efficiency across countries—potential that is not limited to the main agricultural supply countries. Third, it assesses how biofuels can serve as a catalyst for agricultural development by creating scalable demand while generating co-products, such as protein, fiber, and oil, which are reintegrated into the food and feed system.

This study builds on real-world perspectives from across the agribusiness and biofuels value chain, informed by more than 25 interviews with farmers, technology and input providers, processors, biofuel producers, trade organizations, and academics. The analysis shows that while food demand has historically driven agricultural growth, future expansion increasingly depends on the availability of new demand markets. In this context, biofuels are emerging as a key catalyst to support greater production, stability, and long-term profitability in the farm sector.

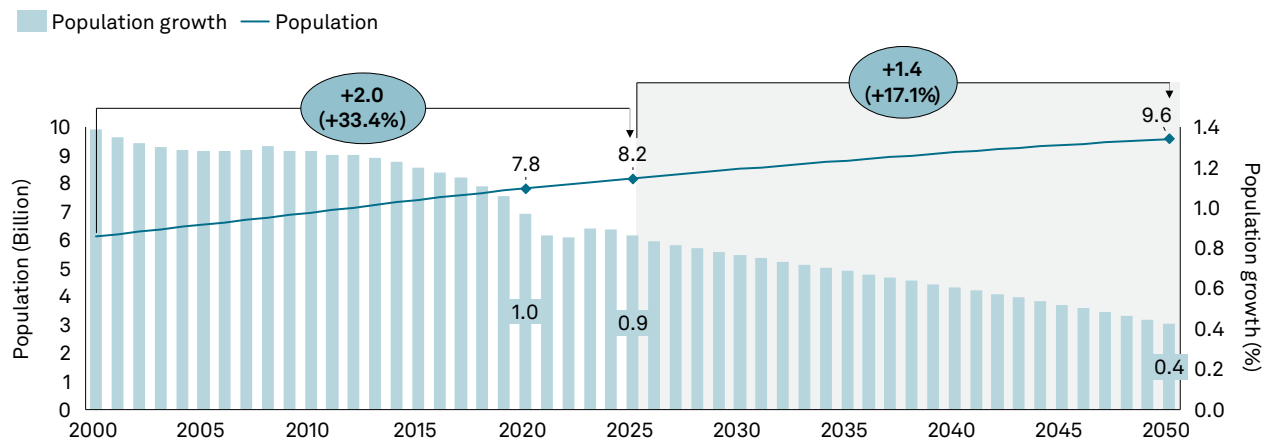


Agriculture stands at a
crossroads as it enters a period
of structural transition

1. Global population growth is decelerating

Population growth has begun to slow, and the annual growth rate is expected to decline to ~0.4% by 2050, driven by a broad-based decline in fertility rates, which are projected to approach the replacement level of about 2.1 births per woman by 2050. Fertility rates in most high-income economies are already below replacement levels (the US is at 1.7 births per woman), and declining populations are becoming a reality in regions such as Japan, China, and the EU, which are projected to lose over 220 million people from their peak by 2050. This shift will reshape regional food demand patterns and trade flows.

Figure 1. Global total population and population growth rate



Source: S&P Global Energy

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2. Food consumption growth is slowing

Global per capita consumption of traditional staple grains shows limited growth potential. Wheat consumption has stabilized at 95-100 kg per person, rice consumption remains broadly flat at 60-65 kg per person, and barley consumption has declined steadily from nearly 35 kg per person in the late-1980s to below 20 kg currently, with further gradual declines projected through 2050.

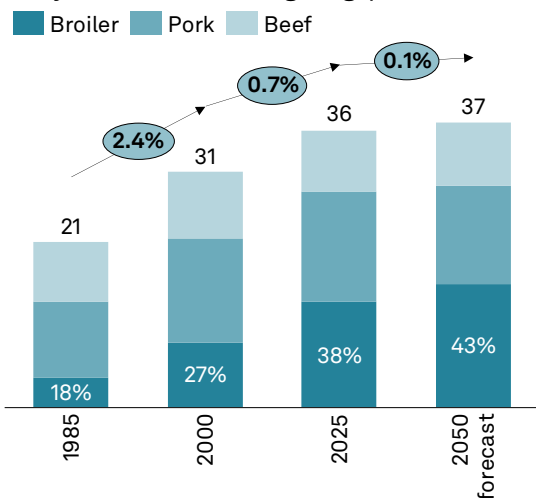
These trends reflect mature consumption dynamics, as dietary diversification and demographic aging reduce incremental food demand per person. As a result, per capita grain consumption is expected to contribute little to future volume growth, reinforcing that demand expansion will increasingly depend on population growth rather than increases in individual intake.

Meat consumption remains critical to agricultural demand because shifts in human diets toward animal protein drive additional grain and oilseed use through the feed-to-meat multiplier.

Per capita meat demand, which has historically supported growth in feed grain and oilseed consumption, has slowed markedly as consumption levels in many regions, including China, approach maturity. Looking ahead, global per capita meat consumption is projected to increase only marginally by 2050. Overall, per capita meat consumption annual growth rate slowed to 0.7% by 2025 from around 2.4% since the late-1990s and is expected to grow just 0.1% toward 2050, indicating near-saturation in many markets.

Figure 2. Global per capita meat consumption

Five-year interval average (kg/person)

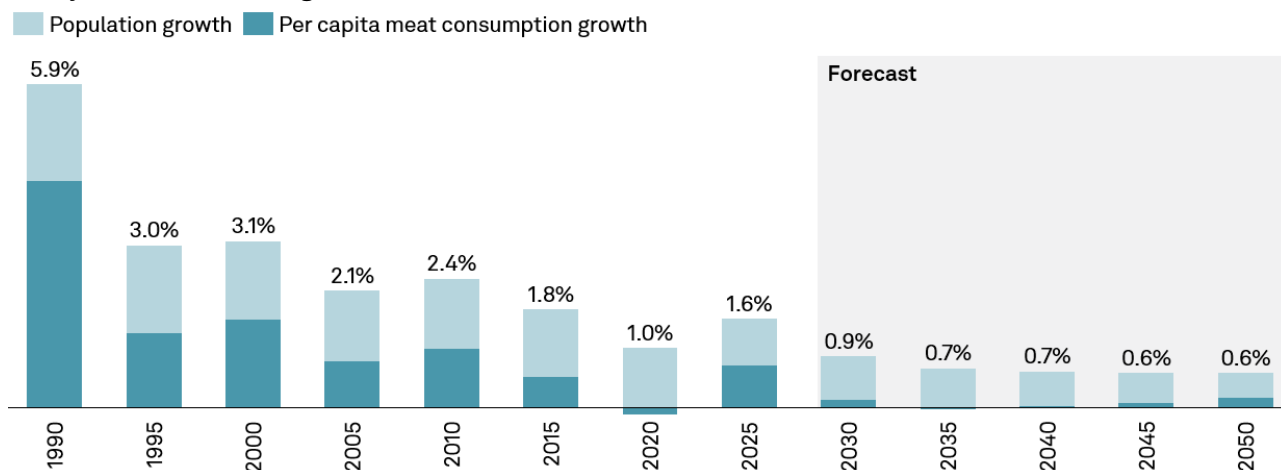


At the same time, meat consumption patterns are shifting toward more feed-efficient proteins. Feed conversion ratios vary by protein, with poultry requiring approximately 1.7 units of feed per unit of output, pork around 3 units, and beef between 4.5 and 7.5 units depending on genetics and production systems. Broilers' share of total global meat consumption increased to 38% in 2025 from 18% in 1985 and is projected to rise further to 43% by 2050, reflecting consumer preferences for affordability and versatility. As poultry's share of global meat consumption rises, the overall feed intensity of meat demand declines, reshaping feed markets and moderating growth in grain and oilseed consumption even as total protein demand

continues to increase.

Figure 3. Global meat consumption growth

Five-year interval average



Source: S&P Global Energy

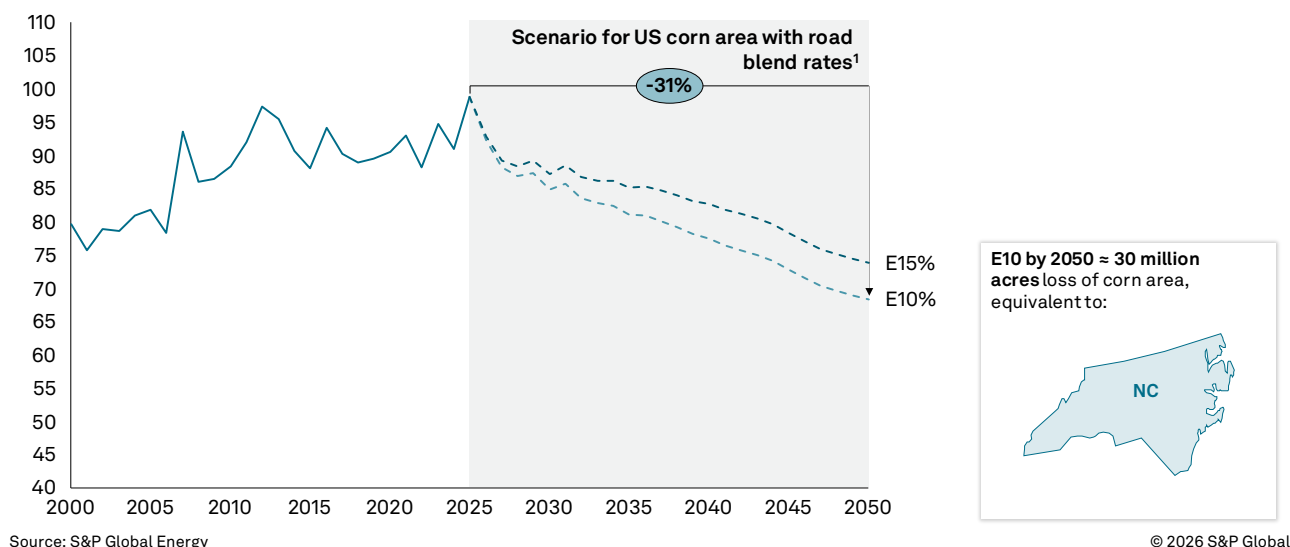
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3. Biofuel demand, particularly ethanol, is under pressure

Liquid road fuel demand, principally gasoline, is expected to decline due to improvements in vehicle efficiency, shifts in driving patterns, demographics and the increasing penetration of electric vehicles. At present, the only binding nationwide policy supporting ethanol use in the US is the Renewable Fuel Standard (RFS), under which ethanol blend rate has been maintained near 10%. At this blend rate, the US would progressively lose ethanol market share as gasoline consumption declines, resulting in a loss of 6.6 billion gallons of ethanol demand by 2050 relative to 2025.

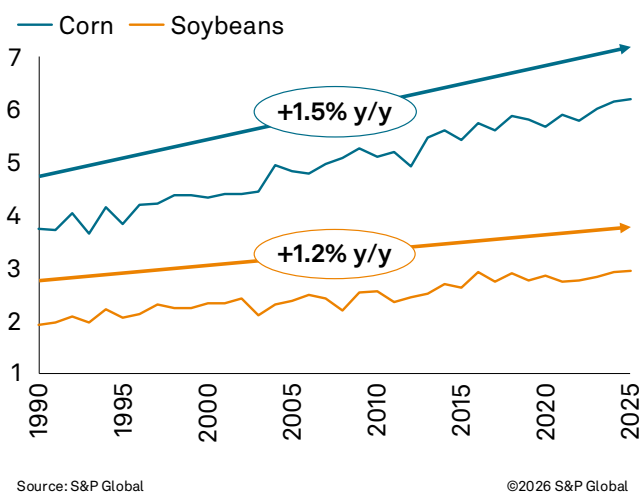
With about 36% of US corn acreage currently tied to ethanol production, weaker ethanol demand would place sustained downward pressure on corn prices, leading to lower farm profitability and ultimately, cropland decline. Absent new sources of feed demand and in a scenario in which the US maintains a 10% ethanol blend rate, US corn growers would cultivate roughly 31% fewer acres by 2050, equivalent to halting production on a land mass the size of North Carolina. The loss of agricultural capacity would expose farmers and consumers to increasingly volatile markets for both food and fuel, and would highlight the structural risks associated with stagnant biofuel demand.

Figure 4. US corn area needed based on road ethanol demand
Million acres



4. Agricultural yields are outpacing food and fuel demand

Figure 5. Global corn and soybean yield
Metric tons per hectare



While absolute food and feed demand will continue to grow due to population momentum, the pace of growth is slowing and is expected to remain below 1% per year. This rate is no longer sufficient to absorb ongoing productivity gains at the farm level. Over the past several decades, yields in major crops, such as corn and soybeans, grew in response to expanding markets and technological advancements. For example, global corn yields increased 1.5% per year over the past 35 years.

That historical alignment between productivity growth and demand expansion is now weakening. As food and fuel consumption growth moderates, continued yield improvements are creating a structural demand gap.

Absent a renewed source of demand, this shift represents a fundamental break from historical patterns and places agriculture at risk of a prolonged downcycle. The combination of slowing demand growth and rising productivity threatens farm profitability, increases price volatility, and heightens the importance of policy, innovation, and new market creation in restoring balance to the agricultural system.

Population growth and per capita consumption of grains and meat are decelerating or, in some cases, declining. As a result, food and feed demand alone is no longer sufficient to absorb ongoing productivity gains—a fundamental break from historical patterns that places agriculture at a crossroads.

The US sits at the epicenter of this imbalance, combining global leadership in the adoption of agricultural technology and yield growth with its position as the world's largest corn exporter and the largest ethanol market. US farmers are already feeling the effects of weakening grain and oilseed export demand alongside flat domestic ethanol demand. These pressures are manifesting in record grain stocks, falling prices, and rising financial stress across rural communities. Corn and soybean prices are at multidecade lows according to the latest US census data; the farm sector lost 209,000 farms and 58 million acres from 2002 to 2022. The loss was the greatest from 2017 to 2022, with 20 million acres lost.

“US farmers continue to produce more each year, even in low-margin environments, because the alternative is worse. Without new demand channels—particularly through biofuels—productivity gains will outpace market demand, and that imbalance is not economically sustainable for farmers or lenders.”

Jacqui Fatka, Farm Supply and Biofuels Lead Economist, CoBank

5. The risk of prolonged agricultural downcycle and spillover effects

Agricultural markets are constantly adjusting supply and demand as prices connect producers and end users. When demand signals are strong, agriculture responds, investment and innovation follow, yields improve and output expands. However, if consumption does not keep pace, the adjustment mechanism is price. As a result, agriculture often experiences transition periods characterized by overproduction and low prices before sufficient production contraction restores market balance. Beyond acreage responses, prolonged price weakness erodes incentives to adopt innovative technologies, delays investment and discourages innovation. These pressures accelerate consolidation, suppress rural economic activity, and can undermine both environmental stewardship and long-term productivity growth.

Analysis of historical cases draws a clear parallel between past periods and the challenges facing agriculture today. While productivity has improved, the underlying economics, along with long-term demographic and consumption trends, point to a structural imbalance rather than short-term market cycle. The agricultural downturn of the 1980s in the US remains a salient example of how insufficient demand growth can create large surpluses and affect farming economics in the US, and globally, including an extended period of declining crop prices, rising debt, widespread bankruptcies, and sharp declines in land asset values. Declining profitability would also weaken incentives for farmers to invest in innovative technologies, such as yield-enhancing and sustainability practices, reinforcing downward pressure on acreage and yields over time and increasing the risk of entering a similar cycle of disinvestment and farm crisis as seen in the 1980s.

“The 1980s taught us what happens when farmers have no markets. Biofuels reversed that story—and we can't afford to go back.”

Kip Tom, Former US Ambassador to the UN Agencies for Food and Agriculture

The effects of an agricultural downcycle would extend beyond crop producers, creating ripple impacts across the agricultural value chain, including input suppliers (i.e., equipment, seed, crop protection, and fertilizer providers), further amplifying the economic consequences.

A prolonged agricultural downcycle in major exporting countries does not remain local; it spills into global markets through surplus production and sustained price pressure. As seen in the 1980s, direct farm subsidies in developed economies enabled continued production and exports—often below the cost of production—depressing global prices. The burden falls most heavily on farmers in developing regions, who lack the financial capacity to absorb extended downturns, undermining agricultural development and rural livelihoods. Over time, this can discourage domestic production and increase reliance on imports, heightening exposure to supply disruptions during periods of geopolitical tension or logistics shocks, and weakening long-term food security.

This dynamic underscores the importance of robust domestic agricultural markets in sustaining a resilient production system, maintaining incentives for innovation, and supporting long-term development, food and energy security, and climate objectives.

This emerging phase reflects a structural transformation rather than a cyclical downturn and biofuels are positioned as a critical response to these structural shifts, as a scalable and capable market to absorb agricultural surpluses, while delivering broader economic, energy, and sustainability benefits.



Unlocking agriculture's potential
for growth

Defining agriculture's potential in this report

Definition framework: The yield optimization concept in this report is not an SPGE forecast. When SPGE projections are used, they are explicitly labeled as the “SPGE reference case”, which is a continuation of historical trend yields under current policies, technological development, and average weather assumptions.

Optimized yield concept: Optimized yield stands for an outcome, conditional on sustained innovation and technology adoption incentives which was informed by the research and interview process. This also assumes a demand structure in place to drive yield expansion. Optimized yield is far under the biological or technical upper-bound.

Technology-based construction: Estimates are grounded in technologies currently available to farmers, with adoption rates determined by economic viability, farmer incentives, and expected capital allocation.

Framework levers: Optimized yield is determined by the interaction of Genotype, Environment, and Management (GEM), encompassing seed innovation (breeding, hybrids, GMOs, NGTs), fertilizers, crop protection, and precision farm management.

Dynamic innovation path: Yield gains reflect both improved realization of existing biological potential and a rising genetic ceiling, expected to accelerate through AI-enabled breeding and biotechnology. The framework incorporates anticipated technological progress within the study horizon, while recognizing that unknown innovations have historically continued to lift yields beyond trend.

Market and policy driver: The optimized crop yield concept assumes that there is incentive in the form of a market demand and policy frameworks to drive agricultural demand and crop yield expansion.

Land-use: Land expansion is constrained and restricted by environmentally sensitive areas; production increases are, therefore, driven primarily by intensification (closing yield gaps) rather than area expansion.

Food, feed, and biofuel allocation logic: Food and feed requirements are prioritized, accounting for population growth and dietary needs. After food and feed deficits are met regionally, remaining surplus production is considered available for biofuel and bio-based industrial uses.

Climate-change context: Climate change is assumed to have a measurable impact throughout the study horizon, with material effects intensifying after 2050. Within the period of this analysis, technological progress is expected to partially offset climate pressures through improved resilience to drought, heat, pests, and disease, limiting near-term constraints on yield potential.

Crops and countries where biofuels can be a catalyst for agricultural growth

The analysis focuses on a defined set of crops and countries with potential for agricultural expansion. The selected ethanol feedstocks include corn, wheat, sorghum, rice, sugarcane, and cassava, while renewable diesel and biodiesel are assessed based on soybean and canola/rapeseed.

Countries included: Brazil, Canada, China, EU, Ghana, India, Kenya, Nigeria, Tanzania, Thailand, Uganda, and the US

Biofuel feedstock potential includes:

- **Corn:** US, Brazil, India, EU, China, Nigeria, Kenya, Ghana, Uganda, and Tanzania
- **Wheat:** US, Canada, and EU
- **Sugarcane:** Brazil, India, and Thailand
- **Cassava:** Nigeria, Ghana, Uganda, Tanzania, and Thailand
- **Rice:** Brazil
- **Sorghum:** US, Brazil, and Nigeria
- **Soybean:** US and Brazil
- **Rapeseed/canola:** Canada, China, and EU

Altogether, the selected countries accounted for approximately 93% of global ethanol production in 2025, 78% of soybean oil and canola supply relevant for HEFA biofuels, 56% of global grain production, 64% of sugarcane production, and 37% of cassava production. Where global totals are referenced for optimized yields or production, aggregate values are extrapolated from this country coverage using the same proportional shares.

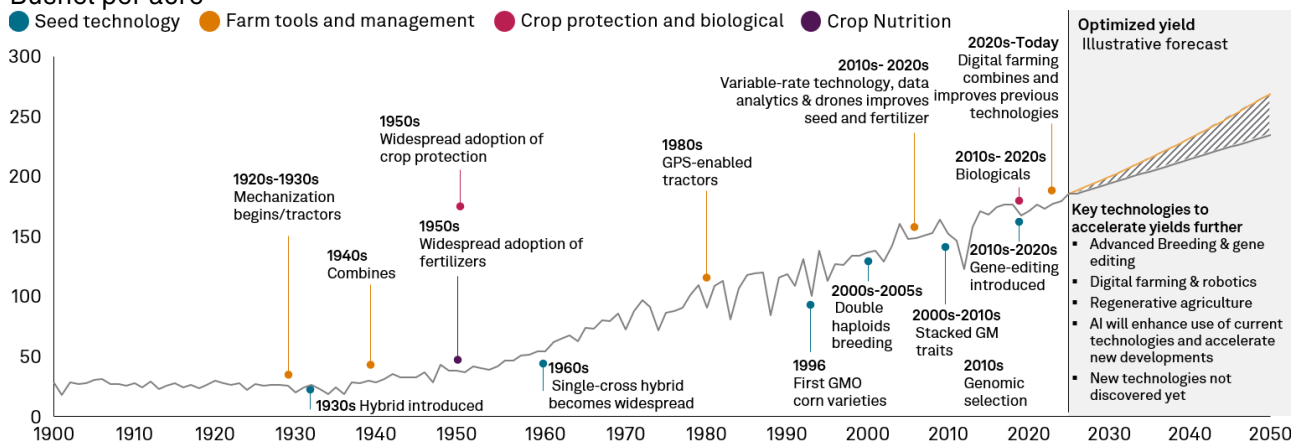
1. Technology at the center of unlocking agriculture's potential

During the early 20th century, crop yields remained largely stagnant, reflecting limited technological adoption and weak incentives to invest. This trajectory shifted beginning in the 1940s and 1950s with the widespread adoption of agricultural machinery, fertilizers and crop protection products, which marked the start of a sustained upward trend in productivity. Subsequent waves of innovation added cumulative layers of yield improvement, including the introduction of seed technologies, such as widespread adoption of hybrids after the 1960s and genetically modified crop varieties in the 1990s, followed by stacked traits, improved hybrids, and GPS-enabled machinery in the 2000s. Each technological wave reinforced the gains of the previous one, embedding productivity growth more deeply into the agricultural system.

In more recent decades, the pace of yield improvement was driven by digital farming technologies, variable-rate application, remote sensing, biological inputs and other innovations. These tools have improved the precision and efficiency of crop management, reduced input intensity while raising output.

Figure 6. US corn yield as an example of technology as a growth driver

Bushel per acre



Source: S&P Global Energy

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While crop yields have increased since the early 1900s, realized yields remain well below their agronomic potential. For example, US corn yields rose from approximately 100 bushels per acre in the early 1980s to more than 120 bushels per acre by 1990, reaching a national average of about 186 bushels per acre in 2025. However, yields in leading Corn Belt states such as Iowa already exceeded 210 bushels per acre in the same year, underscoring the gap between average performance and what is currently achievable under improved conditions. Evidence of untapped potential comes from the annual yield contest conducted by the US National Corn Growers Association, where adoption of existing technologies and precision management practices has enabled yields exceeding three times the current US average.

2. Future frontier: Expanding biological potential

Historically, agricultural innovation focused on protecting the biological potential already embedded or enhanced by traditional breeding techniques. The emphasis was on minimizing plant stress rather than expanding the genetic ceiling. This approach relied heavily on defensive hybrids and traits from pests and diseases, chemical crop protection, and nutrient programs to preserve yield under variable conditions.

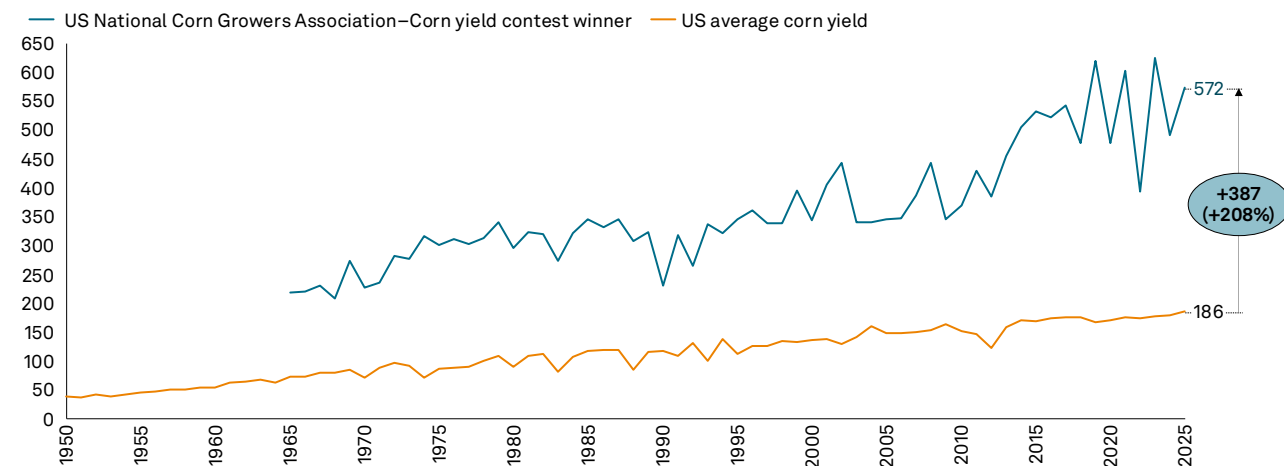
“Technologies and capabilities like biotech traits, breeding and gene editing have to be combined in a comprehensive research engine that produces stress-resilient seeds in the fastest possible way, allowing farmers to continue to benefit from yield improvements.”

Elzandi Oosthuizen, Bayer's Head of Corn Strategy

Today, a new frontier is emerging. The annual US corn yield contest demonstrates that corn yield potential is neither fixed nor capped. Notably, elite yields have accelerated since 2010, underscoring the substantial impact of recent and ongoing innovation. The convergence of biotechnology, AI, and advanced data analytics is not only uncovering new ways to optimize existing potential but also actively expanding biological potential.

Figure 7. US average yield vs. yield contest winners

Bushels per acre



Source: NCGA/S&P Global Energy

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The new frontier in agricultural biotechnology research includes tools such as AI-enabled digital twins. These virtual crop models test how plants grow, allocate nutrients, and respond to environmental stress before deployment in the field, enabling evaluation across different soils, climates, and management practices. This capability allows scientists to predict and optimize yields and tailor crop outcomes for specific end uses, such as increasing starch or oil content, improving resilience to climate stress, or optimizing performance under specific farming systems, while reducing trial and error, lowering development risk and cost.

In seed development, AI-enabled breeding, gene editing, and predictive modeling allow researchers to simulate optimal trait combinations and growing conditions before undertaking costly and time-consuming field trials. This approach shortens development timelines, reduces research costs, and expands the biological frontier by unlocking gains in photosynthetic efficiency, root architecture, and stress tolerance, effectively raising the yield ceiling rather than simply protecting existing performance.

“From prediction to design: For most of the history of crop breeding, we’ve been predicting what we might get from a cross. With gene editing and AI, we’re starting to design traits, while still working within native plant biology.”

Aaron Hummel, SVP of R&D PairWise

Future increases in yield are expected to come from innovations in breeding, digital agriculture, regenerative techniques, robotics, and AI-powered optimization. For example, gene-editing research, which began in the 2010s, has yet to be commercialized and, therefore, has not influenced yield trends. AI is also expected to amplify the impact of existing and emerging technologies by optimizing decisions, integrating complex data streams, and accelerating innovation cycles. Together, these developments suggest an agricultural system increasingly characterized by the convergence of biology, computation, and automation, with future breakthroughs—some still emerging or yet to be discovered—reinforcing long-term productivity through successive and compounding waves of innovation.

“Future corn yield potential will come primarily from micro-level optimization through more precise field- and plant-level management, deeper understanding of biology, targeted nutrient timing, and the use of data-driven tools such as advanced analytics and AI.”

Jed Bower, President of the National Corn Growers Association (NCGA)

The compounding waves of innovation is at the center of the optimized yield concept in this report, illustrating how seeds, agronomy, equipment, data tools, and farm management reinforce one another, multiplying their impact. When these layers are adopted together and applied consistently, yield potential increases far beyond what each technology could deliver on its own.

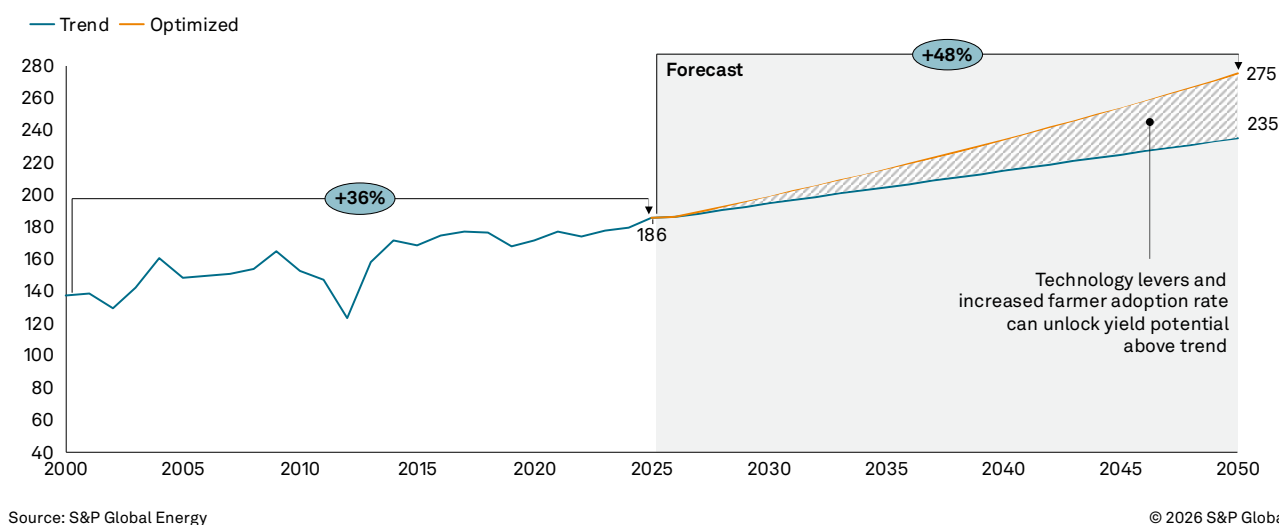
The widening gap between average farm yields and contest-level yields highlights that productivity is heavily constrained by farmer adoption rates, influenced by economic incentives and market signals. The 2025 Purdue University Precision Agriculture Dealership Survey indicates that many advanced, yield-critical technologies remain widely underutilized in the US. Adoption of grid or zone soil sampling remains below 50% adoption, variable-rate fertilizer application has been adopted by only 40-45% of producers, satellite or aerial imagery usage is roughly 30%, and cloud-based farm data platforms and analytics services remain limited to just 20-30% of farms.

“History shows that farmers can scale production, and continued technological innovation allows them to do so more efficiently—producing more with fewer inputs. If demand signals return, we’re confident even more technology will be adopted and supply will follow.”

Josh Garetson, John Deere Renewable Fuels & Corporate Strategy Director

The message is clear: technology expands the yield ceiling, but market incentives determine whether farmers can reach it. Even in the US, the widespread under-adoption of precision and digital tools shows that further yield gains are achievable, provided that strong demand signals, such as biofuels and exports, continue to support investment and innovation.

Strong and durable markets create the demand structure needed to sustain innovation and incentivize farmers to adopt advanced technologies. Under these high-growth conditions, US corn yields could grow at a compound annual growth rate of ~1.6% through 2050, surpassing the historical long-term trend of approximately ~1.2%.

Figure 8. US corn yield SPGE reference case and optimized scenario

This accelerated yield growth would be driven by the combined and reinforcing adoption of multiple technologies:

Advanced seed technologies: Continued innovation in seeds could deliver significant yield gains, improving stress tolerance and disease resistance.

Crop nutrition: Smart nutrient management using digital tools and variable-rate application optimizes fertilizer use, boosting yields while reducing environmental impact and input costs.

Enhanced crop protection: Integrated pest management and next-generation crop protection and biologicals can safeguard yield potential.

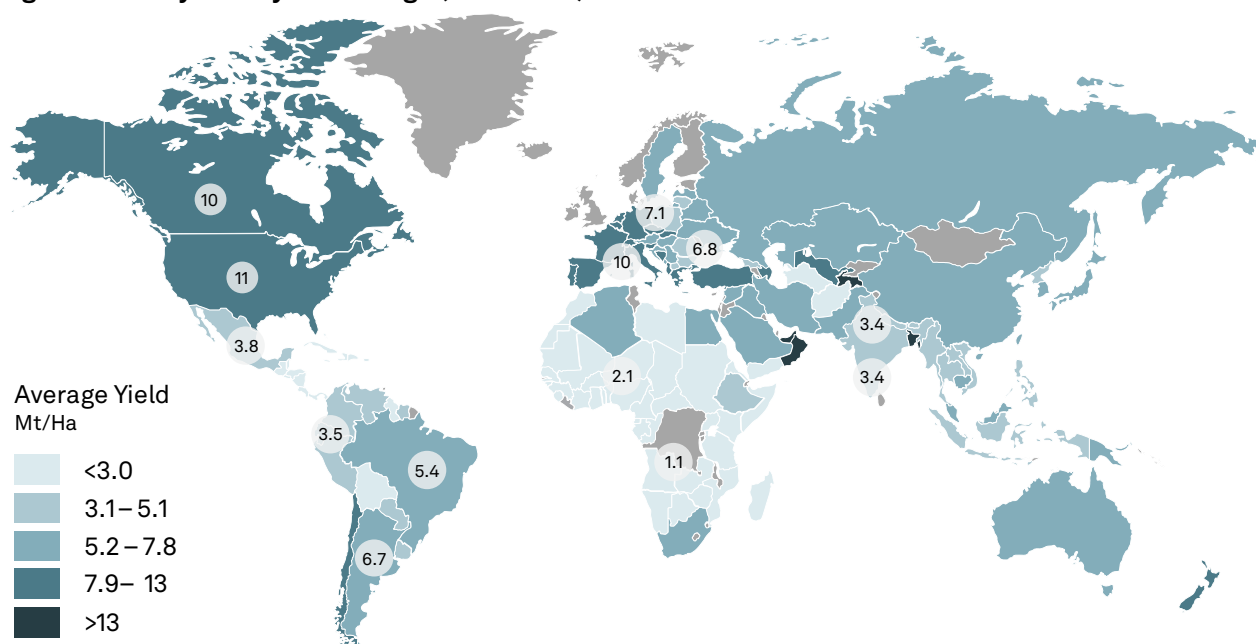
Farm tools and management: Adoption of digital, AI-driven analytics, and regenerative practices improves soil health, water efficiency, and overall productivity.

Technology interaction: Total yield optimization depends on the combined adoption of these technologies; stacked innovations amplify gains beyond individual contributions.

Farmer adoption rates: Rapid adoption of new technologies has been a key factor behind sustained US yield growth and plays a central role in driving further yield improvements across US production systems.

3. Closing crop yield gaps: Not a technical, but an economic challenge

Wide differences in performance across countries and crops emerge because farmers adopt different layers of yield-enhancing technologies at different speeds. In areas where demand, incentives, and access to innovation are strong, yields rise quickly. Conversely, where these conditions are weaker, yields remain far below their potential.

Figure 9. Corn yield 5-year average (2021-2025)¹

Note: 1. For Brazil, the yield reflects the national average of double-cropped corn specifically.

Source: S&P Global Energy

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A significant gap exists between actual and potential crop yields worldwide. Corn is a clear example: while the US consistently yields over 11 metric tons per hectare, many countries produce less than 2 metric tons per hectare. On average, it takes five hectares of land in Africa to match the output of one hectare in the US. Large areas of low-productivity and degraded land, particularly in Africa, offer opportunities for rehabilitation through modern agricultural practices. High-yield agriculture delivers important environmental benefits, including reduced pressure for land conversion and the rehabilitation of soils through lower erosion and degradation, increased soil organic matter, and associated carbon sequestration, particularly on previously degraded fields. This allows agriculture to meet rising demand while sparing land and aligning productivity gains with long-term environmental outcomes.

“Africa already possesses the technologies needed to transform maize productivity. With supportive government policies, improved farmer access to finance, stronger last-mile delivery of inputs and extension services, and expanding market demand, maize yields in high-potential regions such as the Southern Highlands of Tanzania could rise rapidly from 2 Mt/ha to 4 Mt/ha, with the potential to approach 8 Mt/ha by 2050.”

David Priest, CEO FIPS Africa

¹ Brazil corn yield refers to second-crop corn.

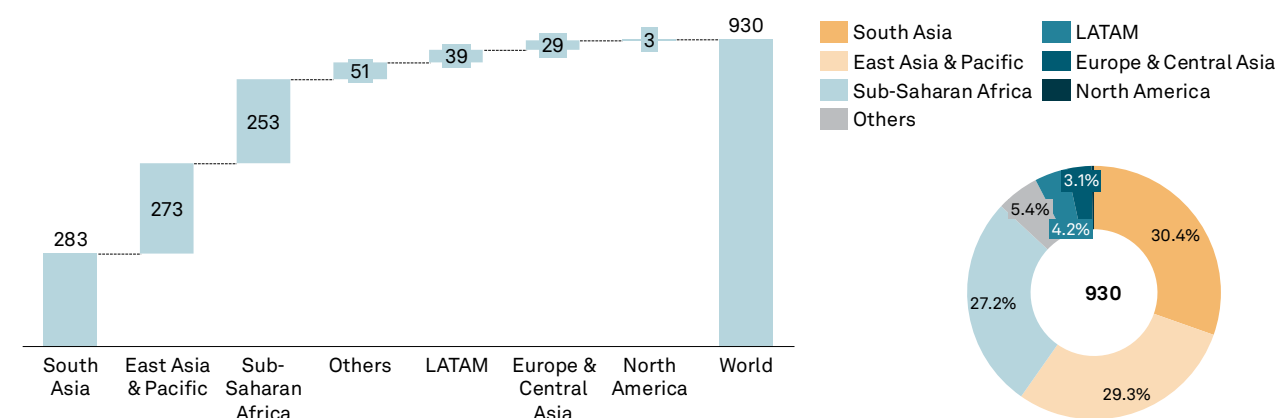
Technology adoption is often cited as the primary explanation for this disparity, and it is certainly part of the story. However, the deeper and more decisive factor is demand. Closing yield gaps requires technology adoption, improved management, and supportive policies, all of which depend heavily on market confidence and investment incentives. These, in turn, are undermined when prices are controlled or global prices remain structurally depressed.

4. Empowering 1 billion farmers globally

Agriculture remains a critical source of employment globally, with over 930 million people directly dependent on the sector for their income, and many more relying on it for food through subsistence production. Agri-food systems account for approximately 40% of global employment². Dependence on agriculture is highly uneven across regions: in Asia and Africa, the sector accounts for close to 50% of total employment. The stability of the agricultural sector is a matter of global strategic importance, with direct implications for food security, rural livelihoods, macroeconomic stability, and social cohesion.

Figure 10. People employed in agriculture in 2024

Millions of people over the age of 15



Source: S&P Global Energy

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For decades, agriculture in countries such as the US and Brazil has benefited from growing food and biofuel demand that created the confidence needed to invest in innovative technologies and increase adoption by farmers. The cumulative effect of these technologies, deployed consistently over time, is what pushes yields and production higher. Another significant aspect of domestic biofuel production is its impact across the value chain and broader economy, stimulating job creation and development.

“Improving productivity is a long-term effort that involves trust-building and access to frameworks like the 4R. In organized systems like Brazil, progress is faster, while Africa's dispersed producers need cooperative organization. Despite accessible technology, guidance on fertilizer use remains a crucial challenge.”

Yoursa Ben Bouker, Senior Lead of Climate Action Program at OCP Group

² FAOSTAT, share of AFS employment in total employment.

While the US and Brazil offer the most developed case studies, agricultural systems in many regions continue to be constrained by weak demand signals and limited access to technology. In the absence of reliable markets, farmers have limited incentives to invest in yield-enhancing practices, perpetuating productivity gaps, rural poverty, and land and biodiversity degradation.

Africa illustrates how weak incentives and market distortions can suppress domestic production even in resource-rich regions. In many areas, adopting basic agronomic practices, such as correcting soil acidity, improving fertilizer use, and building soil organic matter, could substantially boost yields, increase farm incomes, and strengthen resilience. Despite this potential, more than 300 million people in Africa were undernourished in 2024. Further, the continent imports nearly \$200 billion in food annually, leaving many countries vulnerable to food security risks. While identifying past shortcomings is not the objective of this report, a persistent gap in development efforts has been the lack of reliable markets beyond subsistence consumption that can support farm income, innovation, and technology adoption.

“Improving nutrient efficiency has long been a priority, but adoption ultimately depends on clear economic value for growers. When farmers can see the benefits, and are compensated for the outcomes, they’re more likely to stay engaged over time. Scaling lower-carbon feedstocks will require systems that recognize the value of on-farm data, management practices, and measurable results. Sustainability is most effective when it supports the grower’s long-term profitability.”

Dr. Sally Flis, Nutrien Ag Solutions - Director, Sustainable Ag Programs

Strengthening agriculture represents the most effective and scalable pathway to improving food and energy security, sustainability, and advancing economic development in lower-income regions of the world. Within this context, biofuels can play a stabilizing role by creating additional and more predictable demand for agricultural outputs. When backed by appropriate policies and sustainability safeguards, biofuels can function as an income-stabilization and rural development instrument, reinforcing the resilience of agricultural systems while contributing to energy diversification and long-term food security objectives.

“Technology opportunities are there but require investments to make them happen. To succeed, we need win-win cases that build markets and strengthen local farming ecosystems. As markets consolidate, the incentives for higher yields can naturally support broader agricultural productivity, contributing to improved food supply. Solutions must be designed for what truly works locally.”

David Priest, CEO FIPS Africa



The path forward with biofuels as a catalyst for agricultural growth

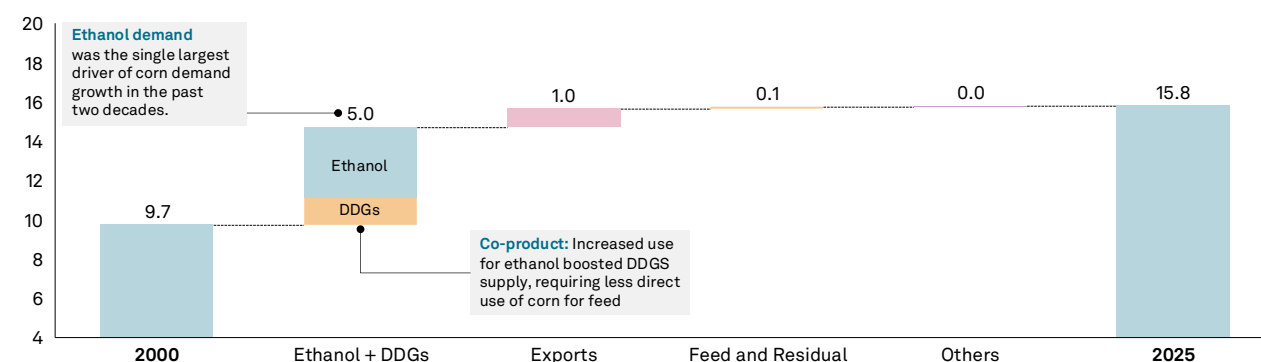
1. The US case: Biofuels driving agricultural growth and market resilience

In the US, the RFS was implemented in 2005 and expanded in 2007, in the wake of higher energy prices. It aimed to improve energy security by reducing dependence on foreign petroleum. Following this clear policy signal, US corn production expanded rapidly to address the new opportunity, and biofuels emerged as a significant market for agricultural products.

Today's environment of heightened energy price volatility reinforces the original energy-security rationale of the RFS. Domestic biofuel production continues to provide a strategic buffer against petroleum market disruptions, supporting price stability while reducing reliance on imported energy sources.

As shown in the chart below, ~83% of the net increase in corn demand since 2000 has been attributable to ethanol expansion. This demand growth coincided with sustained yield improvements, ~1.2% annually during this period, which enabled total US corn production to increase roughly 70% since 2000. Currently, US corn ethanol represents ~10% of US gasoline consumption (the largest fuel market globally).

Figure 11. Change in corn use by segment in the US
Billion bushels



Source: S&P Global Energy

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The US is a global leader in soybean and soybean oil production. Rising RFS Renewable Volume Obligations (RVOs) for biomass-based diesel has driven significant investment in domestic soybean crush capacity which increased by 480 million bushels (i.e., 20% increase) since 2022 in response to increased demand for soybean oil. Increased demand for soybean oil and soybeans supported the US soybeans during a period of weaker exports (e.g., China shifted part of its US soybean import to South America).

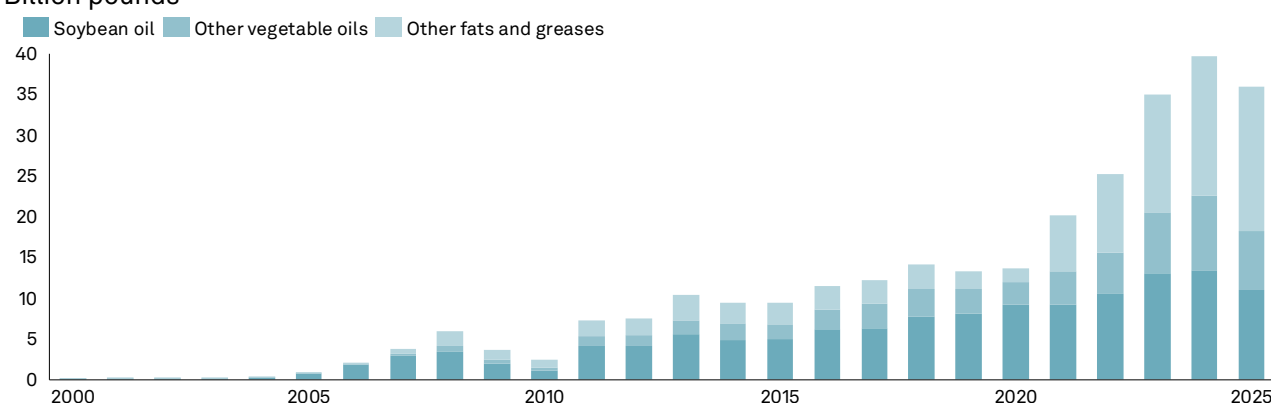
Furthermore, EPA's March 2026 RVOs set out a significant demand increase for biomass-based diesel from 5.42 billion gallons for 2025 to 8.95 billion gallons by 2027. Clearly the new RVOs signal continued support for US farmers, the soybean supply chain and biofuel use expansion. Additionally, EPA has signaled its intent to potentially favor US-origin feedstocks. More broadly, biofuels have become a critical driver of oilseed and vegetable oil demand in the US and globally.

“Now that we have biodiesel and renewable diesel, about half of the value of soybeans comes from the oil—once something we barely paid attention to due to limited demand.”

Tim Ostrem, Director, United Soybean Board (USB)

Although imported feedstocks accounted for 27-28% of renewable diesel feedstock supply over the past two years, soybean oil is expected to remain a core US feedstock. Continued demand growth and policy incentives supporting US-origin biofuels and feedstocks should underpin soybean demand and support the broader farm sector.

Figure 12. Use of biomass-based diesel feedstock in the US
Billion pounds



Source: S&P Global Energy

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In parallel, biofuel production utilizes starch and oil from the corn kernel, as well as oil from oilseeds. Corn oil, produced as a co-product of ethanol production, can be used for biofuel production or as a livestock feed ingredient. The remaining protein and fiber are returned to the supply chain, typically as livestock feed. The process expands the supply of co-products such as DDGS and protein meal (i.e., soybean meal), reinforcing the multi-market role of crops in serving food, feed, and fuel simultaneously.

Biofuels demand has strengthened agriculture and rural America by balancing exports versus domestic consumption, reducing price risk, and creating stability to support long-term investments while increasing domestic food and feed supply. It has expanded the agriculture export value by almost 50% since the early 2000s (i.e., by adding DDGS and biofuels to the export mix).

US biofuel growth is also exemplary of the impact on rural economies. The expansion of biofuel in the early 2000s coincided with rising farm profitability that in turn supported farmland prices. Of course, biofuels, coupled with ongoing food demand, provided the demand signal that justified long-term investments on technology development and adoption. For perspective, farmland prices have increased 300% since 2000 (nominal terms), providing prosperity to rural economies as well as support for investment and innovation in the agriculture supply chain (i.e., equipment, seed, fertilizer, crop protection, storage, merchandising/trading, and feed and food processing). A similar pattern of expansion in farmer incomes and farmland appreciation is observed in other geographies as well.

The historical record shows that periods of strong demand coincided with accelerated adoption of yield-enhancing technologies, from advanced seed traits to precision agriculture. These investments, in turn, reinforced yield and supply growth.

What would happen without biofuels in the US?

Domestic demand for corn and soybean would be significantly lower. At the same time, continued yield improvements would increase the risk of structural grain oversupply, placing sustained downward pressure on prices. In this environment, the US would export surplus grain at low prices, reinforcing global agricultural stagnation and increasing reliance on government support, with higher fiscal costs for taxpayers.

Domestically, such conditions would lead to acreage contraction, reduced investment, slower technological progress, and a sharp deterioration in US farm incomes, along with heightened bankruptcy risk in rural communities.

Beyond price effects, the removal of biofuels would disrupt interconnected food, feed, and energy markets by reducing the supply of protein co-products, increasing reliance on fossil fuels and amplifying global food, feed and energy markets volatility.

Historical experience underscores these risks. The agricultural downturn of the 1980s, driven by excess grain supply, resulted in widespread farm bankruptcies and long-lasting damage to rural economies, with global consequences. The lesson is clear: Agriculture does not adjust smoothly to declining demand. Instead, it undergoes prolonged periods of low prices, financial stress, and underinvestment.

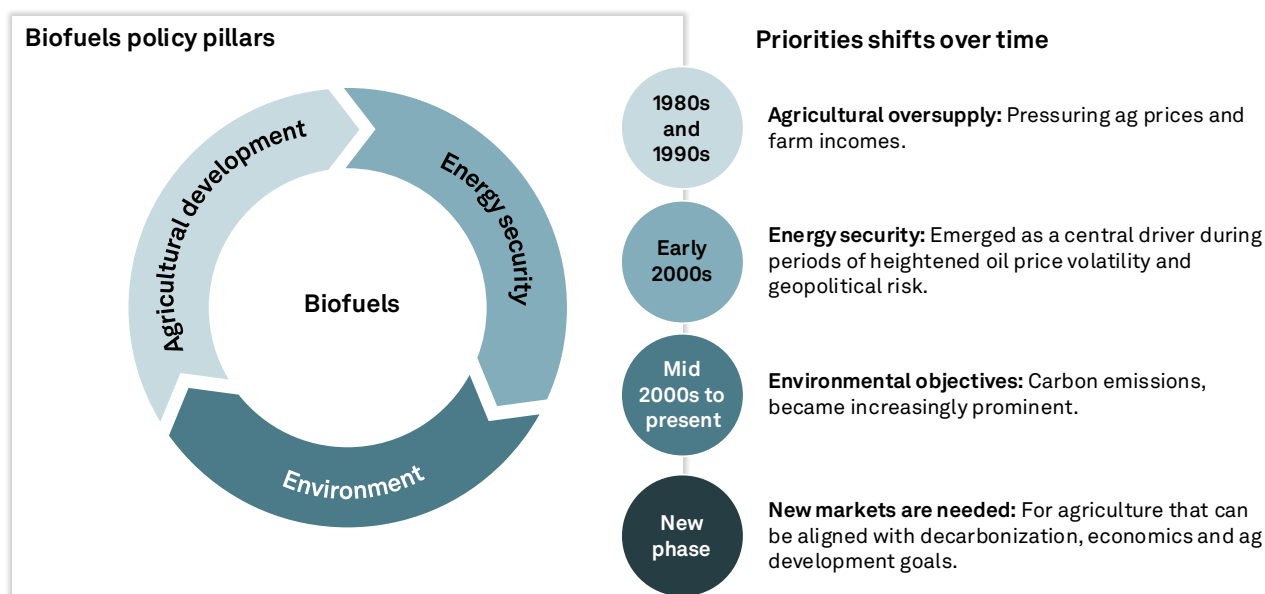
Biofuels helped reverse this dynamic in the early 2000s by providing a structural source of demand that enabled agriculture to operate closer to its productive potential. In this context, biofuels have served as a tool for preserving farm viability, supporting food security, and lowering fuel costs for consumers, while also offering a pathway toward zero-emission fuels.

Biofuels address three core objectives simultaneously: They function as an agricultural support mechanism without imposing a direct tax burden on US taxpayers, serve as a cost-effective fuel blending component, and provide a scalable pathway for future decarbonization.

2. Policy frameworks supporting biofuel deployment and agricultural resilience

Biofuels have scaled globally through policy frameworks that align market incentives with agricultural, energy, and climate objectives. When well-designed, these policies create durable demand signals that reward efficiency, drive innovation, and support rural economies. Agricultural policy and rural development remain central drivers in Asia, the US, and Latin America, while energy security, though less prominent, continues to underpin demand in Asia and Latin America. In contrast, environmental and decarbonization objectives have recently become dominant policy drivers in the EU and North America. The diversity of regional approaches (i.e., US, Brazil, EU, and Asia) confirms that while policy design may differ, its relevance is universal. Biofuels have been a policy-enabled response to structural challenges in energy, agriculture, and climate.

Figure 13. Evolution of biofuel policy priorities



Source: S&P Global Energy

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In the US, state-level policies are emerging to complement the federal RFS program. California's LCFS has raised soybean demand by rewarding low-CI feedstocks with a premium, while ethanol mandates such as Iowa's E15 Access Standard require retailers to offer E15.

Brazil also offers an integrated biofuel model that links agricultural development with energy security. Biofuels are supported by mandatory blending requirements—currently, up to 30% ethanol is blended into gasoline and 15% biodiesel is blended into fossil diesel—alongside high penetration of flex-fuel vehicles, which allow consumers to increase ethanol use beyond the mandate when ethanol prices are favorable. In 2025, ethanol accounted for more than 50% of Brazil's light-duty vehicle fuel pool, reflecting the blending requirement and discretionary consumer choice. This framework is reinforced by the RenovaBio carbon credit system, which rewards biofuels based on lifecycle greenhouse gas (GHG) emissions reductions.

In this context, policy relevance becomes even more pronounced when examining fuel segments. In road transport, blending mandates and low-carbon fuel standards have directly translated into higher volumes and rising blend rates. In aviation, sustainable aviation fuel (SAF) pathways illustrate how policy incentives are essential to unlock demand. For marine fuels, emerging international regulations and carbon pricing discussions create an opening for renewable and low-carbon biofuels.

Most importantly, the most robust biofuel policies are typically those that align all three, supporting farmers and rural economies, improving energy resilience, and delivering measurable climate benefits.

EU biofuel policy: without the farm development pillar

The biofuel crop cap: Under the EU Renewable Energy Directive, first-generation (crop-based) biofuels are capped for biofuel use at the member state level.

Constraining agriculture: While intended to protect food supplies, strict regulation of crops linked to biofuel feedstocks kept yields and production well below potential, contributing to crop area decline across the EU.

Crop area decline: From 2010 to 2025, Europe's harvested rapeseed area—a major EU crop supplying vegetable oil for food use and feedstock for biofuels—declined about 12%, to 6.3 million hectares from 7.0 million hectares, while wheat area fell 8% to around 24 million hectares.

Rising imports: Despite mature per capita food consumption, rapeseed and rapeseed product imports rose ~120% (from ~2.8 to 6.3 million metric ton), while corn imports surged ~160% (from ~7.4 to 19.5 million metric ton).

Unintended consequences: European farmers lose market opportunities and domestic production is replaced by foreign supply. Growing dependence on imported grain and oilseeds undermines regional food security, energy security and rural development.

The historical perspective reinforces the central theme of this report. Market-driven demand and innovation function as catalysts for agricultural development. When end markets strengthen, investment follows, enabling rural economies to grow. Where demand signals are weak or uncertain, investment slows, adoption lags, and productivity gaps persist, limiting food security gains and broader economic development.

“Policy is the spark that ignites innovation. Without strong biofuel policy, the engine of US agricultural progress stalls, and the next generation of farmers will not stay in an industry that survives on subsidies. They need markets, not handouts.”

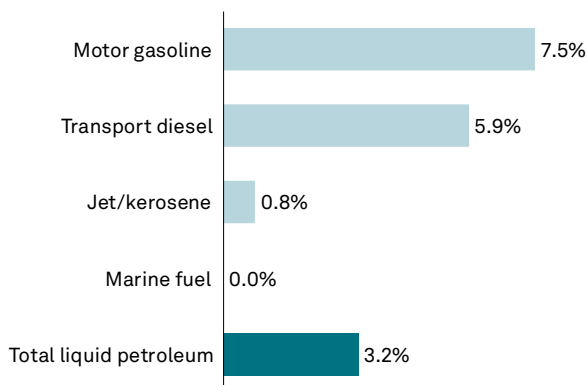
Kip Tom, Former US Ambassador to the UN Agencies for Food and Agriculture

3. Biofuel blend rates suggest significant market potential for agriculture

The transportation and industrial sectors remain heavily reliant on fossil fuels, especially in aviation, shipping, and long-haul freight where low-carbon alternatives are limited. Biofuels have emerged as crucial substitutes in these hard-to-decarbonize segments. For example, SAF made from bio-based feedstocks is one of the few options to reduce aviation emissions, while ethanol is an affordable option to decarbonize heavy fuel oil in marine shipping.

Figure 14. World biofuel blend rate by refined liquid petroleum product (2025)

%



Source: S&P Global

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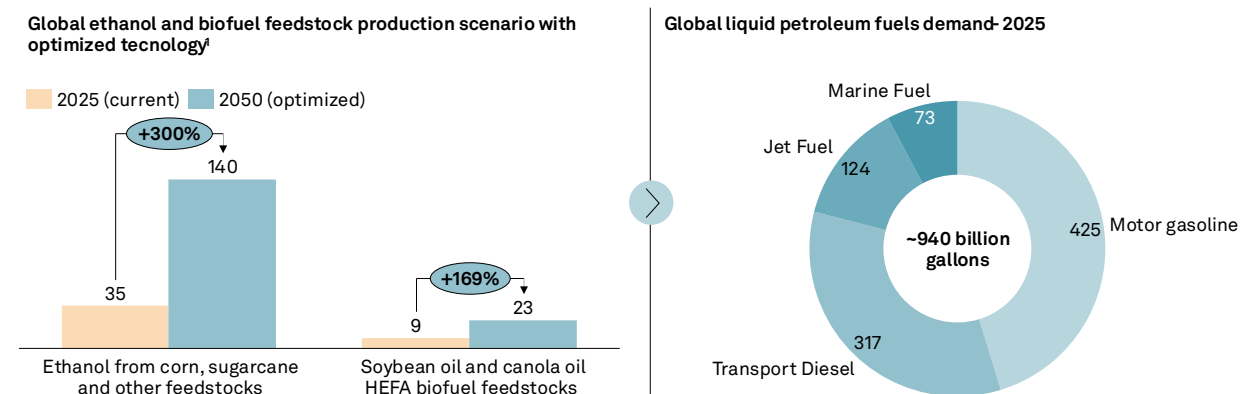
Across the global liquid fuels pool, biofuels represent just 3.2% of liquid petroleum demand, highlighting the scale of potential growth, if blending expands beyond the current levels.

Even in road transport, where blending is most established, global biofuel blend rates are only 7.5% for gasoline and close to 6% for diesel. Aviation and marine fuels are future opportunities. Moreover, penetration in other markets, including marine fuels, SAF, and bio-based materials—remains limited.

Under an optimized scenario, global ethanol output from major feedstocks such as corn and sugarcane could increase 300%, while oil-based biofuels, such as biodiesel, derived from soybeans and canola, could grow about 170%. This expansion would allow biofuels to supply a much larger share of the ~940-billion-gallon global liquid fuel market, extending beyond road transport into SAF, marine applications, and even household energy use in developing regions.

Figure 15. Biofuels can expand significantly by 2050, if market conditions are in place

Billion gallons



Note: 1. 2050 biofuel potential based on technological advances beyond trend yields. Volume is based on selected countries (the US, Brazil, India, the EU, Nigeria, Kenya, Tanzania, Ghana, Uganda and China) account for about 93% of 2025 ethanol production and 78% of soybean oil and canola production for HEFA biofuel feedstocks in 2025 and extrapolated for global production

Source: S&P Global Energy

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From an agricultural perspective, incremental blending across multiple end-use segments could materially expand demand while remaining aligned with energy-transition and climate objectives. This includes higher ethanol blends in on-road vehicles—such as E15 and above—which represent a scalable, near-term opportunity to increase domestic biofuel demand within existing fuel systems. Marine and aviation fuels, along with emerging bio-based materials, represent large, growing and largely untapped markets where even modest blend mandates or voluntary adoption could generate meaningful new demand for agricultural feedstocks. As policy frameworks evolve and conversion technologies mature, these applications offer durable, long-term growth optionality beyond traditional gasoline and diesel blending.

“Profitability ultimately drives technology adoption and long-term success. To remain competitive, US farmers must build strong and reliable demand in domestic and export markets. Ethanol, marine fuels, and other low carbon-intensity markets are essential for sustaining value and supporting long-term growth.”

Jed Bower, President of the National Corn Growers Association (NCGA)

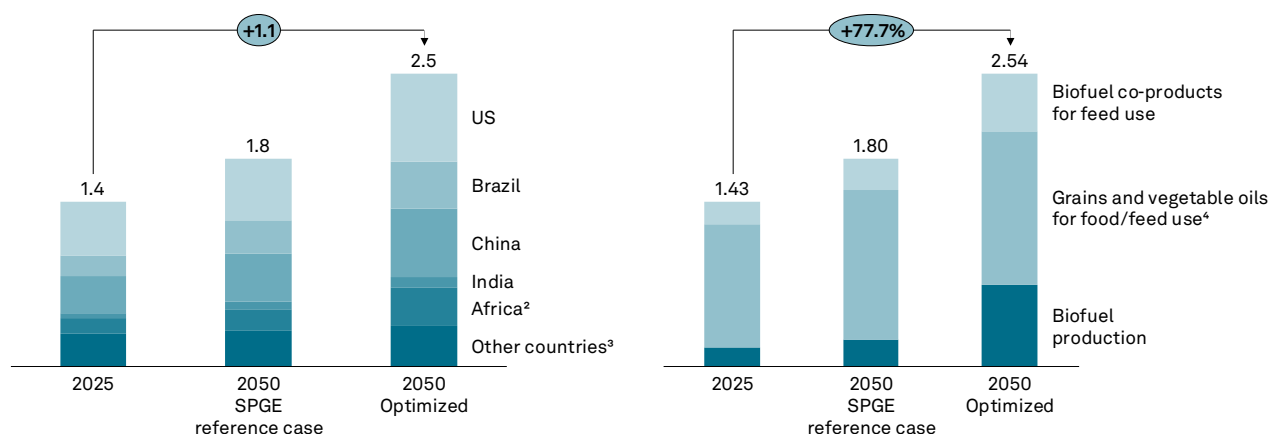
4. Unlocking new opportunities in biofuel, food and feed supply

Under the optimized production scenario, projected grain and oilseed supplies across selected countries suitable for biofuel feedstock production could nearly double by 2050 compared with 2025 levels.

This growth is primarily expected to be driven by productivity gains rather than land expansion, with approximately 82% of additional output coming from higher yields. Net cropland expansion would remain limited, with incremental area increases concentrated in efficiency-enhancing practices such as double cropping (for example, second-crop corn following soybeans) and crop switching from alternative uses, such as barley to corn in the EU. In addition, biofuel feedstock growth is expected to complement rather than compete with food and feed markets. In fact, total production under this scenario is projected to deliver 18% more food and feed supplies by 2050 than the S&P Global Energy reference case, potentially reducing costs and strengthening food affordability globally.

Figure 16. Projected grains supply and use for selected countries¹

Billion Mt



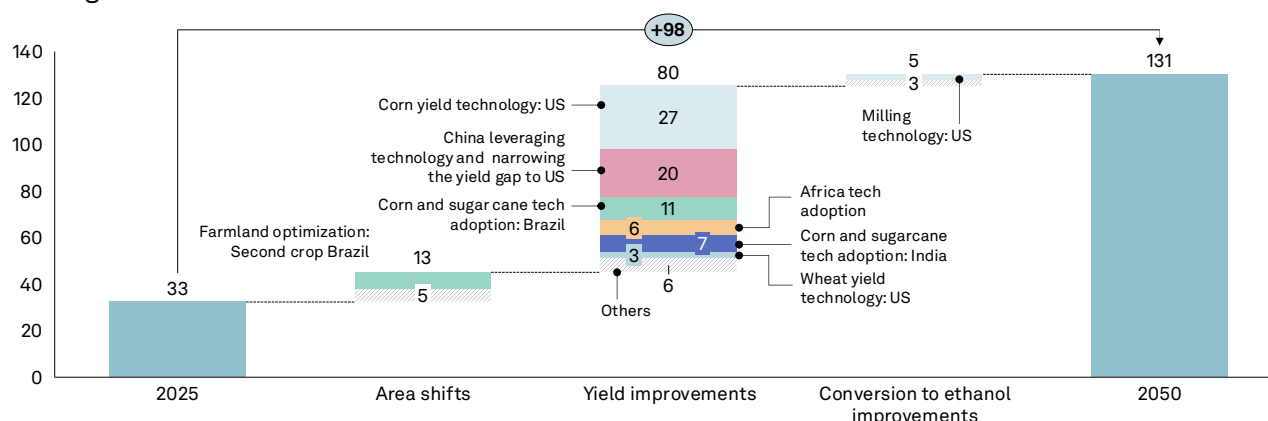
Notes: 1. Countries with strong ethanol feedstock potential include the US, Brazil, India, the EU, China, Canada, Nigeria, Kenya, Uganda, Tanzania, Ghana and Thailand. They account for approximately 56% of global grain production, 64% of sugarcane production and 37% of cassava production. Sugarcane was not included in this assessment. 2. Nigeria, Tanzania, Kenya, Uganda and Ghana. 3. EU, Thailand and Canada. 4. Include both direct and industrial food use.

Source: FAO, USDA and S&P Global Energy

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Under an optimized production scenario, biofuels are positioned for a major expansion by 2050, driven by technological progress in agriculture, improved feedstock productivity, and higher extraction rates. If the surplus agricultural production is used for biofuel, global biofuel production could triple or more by 2050.

Figure 17. Optimized ethanol production growth in selected countries¹ by type of technology lever
Billion gallons



Note: 1. Countries with strong ethanol feedstock potential include the US, Brazil, India, the EU, Nigeria, Kenya, Tanzania, Ghana, Uganda and China. Selected countries accounted for approximately 93% of global ethanol production in 2025, 78% of soybean oil and canola supply relevant for HEFA biofuels.

Source: S&P Global Energy

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Corn ethanol is expected to remain the dominant biofuel pathway through 2050, driven by its scalability, production efficiency, and compatibility with existing fuel and agricultural infrastructure. The US and Brazil already operate mature ethanol industries that can expand materially as corn yields continue to improve. Under sustained innovation and technology adoption incentives (e.g., advanced seed technologies, improved agronomy, better farm management), global corn production could increase by more than 80% between 2025 and 2050.

Across regions, environmental outcomes (e.g., limits on deforestation or land use) associated with agriculture and biofuel expansion depend on a well-designed policy framework. The outcomes of the scenarios assessed emphasize yield improvements and the use of existing agricultural land, rather than land expansion, as the primary pathway for scaling production globally.

This growth is expected to be driven mostly by productivity gains rather than land expansion. In the US alone, yield technology adoption would contribute more than 200 million metric tons of additional corn supply, with no cropland change. These changes reflect economic and agronomic optimization rather than widespread land conversion.

Other crops are also expected to play important, region-specific roles in future biofuel supply, reflecting climatic and agronomic comparative advantages. Sugarcane ethanol production is expected to continue expanding in Brazil, India and Thailand, supported by yield improvements and higher ethanol conversion efficiency.

A broader set of feedstocks can contribute to incremental supply growth. Wheat surplus presents potential in Canada and the EU. While wheat acreage is unlikely to expand materially, yield improvements and advances in conversion technology could increase output. In regions where food demand growth is slowing and productivity continues to rise, particularly in the EU, the traditional ‘food vs. fuel’ debate is no longer the binding constraint on land use. The core challenge is how to preserve crop acreage and farm viability amid structural surplus risk.

Cassava and sorghum highlight how biofuel development can support agricultural growth in developing regions. Cassava shows significant upside in Africa, where productivity gains can support both food and fuel demand, while sorghum’s drought tolerance makes it well-suited to more arid regions.

The expansion of alternative feedstocks is expected to strengthen the resilience of the global biofuel system by diversifying supply, reducing exposure to climatic risks, and allowing countries to scale production based on local agri-ecological advantages. Leveraging this diversity can help stabilize output, reduce volatility, and align biofuel growth with rural development and energy transition objectives.

5. Biofuels as a catalyst to preserve crop acreage

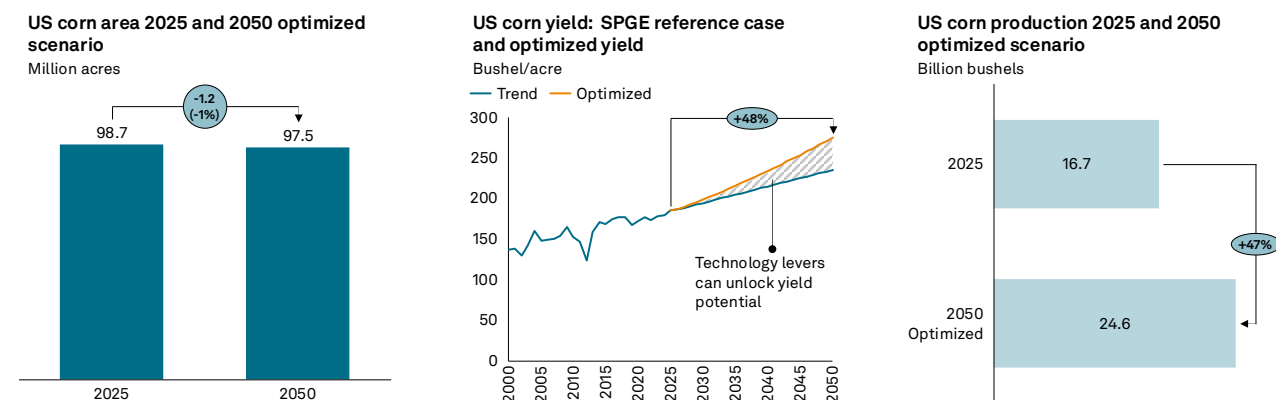
The energy and agricultural sectors are converging at a pivotal moment. Productive capacity of agriculture continues to expand, yet traditional demand from food and feed is plateauing. This structural shift presents both a challenge and an opportunity. Agriculture urgently needs new markets to absorb surplus output, while the energy sector seeks scalable, low-carbon alternatives. Biofuels sit at this intersection.

Two contrasting trajectories define the future of biofuels. In a no-action path, marked by policy inertia and limited investment, biofuels are projected to remain a niche contributor (e.g., US ethanol blend rates remaining at around 10%). In contrast, an optimized scenario—driven by policy signals, technological adoption, and market incentives—positions biofuels as a mainstream energy source and decarbonization solution.

The US is at the epicenter of these structural changes, and biofuels can help maintain current cropland by supporting demand for corn and soybeans, at a time when traditional drivers are weakening. Introducing additional demand incentives through ethanol and other biofuels could reverse this trend, stabilizing corn acreage. The extent of preservation will depend on relative economic incentives and agronomic constraints, including crop rotation limits.

The optimized yield scenario shows how emerging technologies could lift yields through 2050 if adoption remains strong. US corn output could increase nearly 50% by 2050, resulting in substantially more crop supply while maintaining a stable land footprint. While higher corn yields are technically achievable, realizing this outcome requires strong market signals and sufficient farmer incentives to access and adopt yield-enhancing technologies.

Figure 18. US corn production potential under optimized



Source: S&P Global Energy

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6. High biofuel growth would deliver measurable benefits

A) Advancing sustainability and decarbonization goals

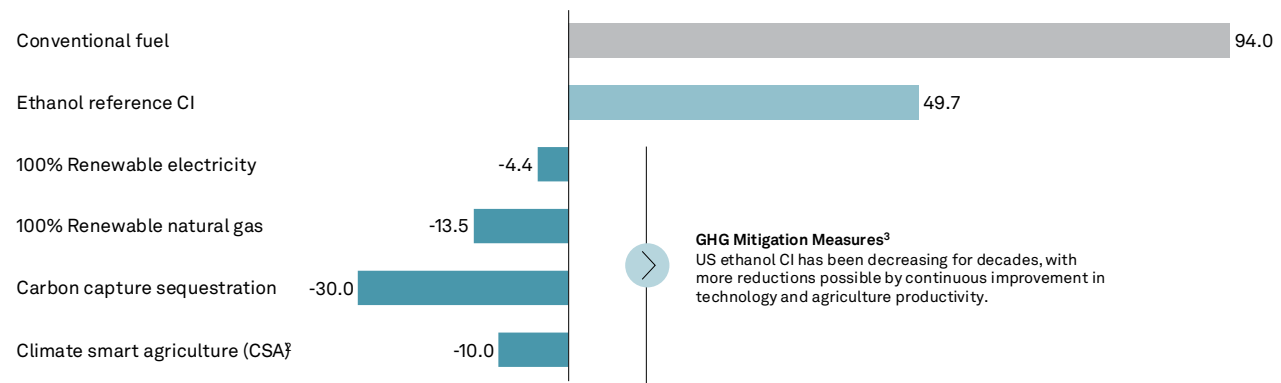
Biofuels deliver environmental benefits by reducing greenhouse gas (GHG) emissions through the displacement of higher-carbon fossil fuels, with outcomes improving as agricultural productivity rises and sustainability practices are applied across the value chain. Beyond conventional blending for road transport, biofuels are increasingly relevant for hard-to-abate sectors such as aviation and marine fuels, where scale and low-carbon intensity create new demand outlets that can help stabilize agricultural markets.

“The global market is demanding low carbon fuels, and American ethanol is uniquely positioned to deliver. With continuous innovation—from the farm to the biorefinery—we can supply billions of gallons of cost-competitive, low-carbon energy to meet domestic and international markets.”

Emily Skor, CEO of Growth Energy

While emissions vary by feedstock and farming practice, biofuels consistently achieve materially lower lifecycle emissions than fossil alternatives. In the US, ethanol-related GHG savings increased from about 8 MMt CO₂e in 2005 to roughly 61 MMt CO₂e by 2015, reflecting gains in crop productivity, process efficiency, and fuel production technologies. There is significant additional emission-reduction potential through climate-smart agriculture, renewable energy use at refineries and carbon capture, further strengthening ethanol’s role as a low-carbon liquid fuel.

Figure 19. Opportunity of further reducing ethanol carbon intensity (CI)¹
g CO₂e / MJ



1.CI reduction¹ results are indicative. Actual results of specific GHG mitigation may vary by plant, equipment and settings. 2. CI reduction from CSA is indicative and based on Notice 2024-37, jointly released by the US Department of Treasury and IRS in 2024 for 40B SAF credit eligibility. The USDA's interim rule (Notice USDA-2024-0003) for CSA biofuel feedstock was released in January 2025 but was not finalized at the time of this analysis and, therefore, was not used. 3. CI can be below zero only for manure-derived fuel.
Source: S&P Global Energy analysis of Argonne National Lab 45ZCF-GREET Model

Traditional volume-based blending mandates have supported agricultural demand and farm returns but do not differentiate sustainability performance. In contrast, emerging CI-driven frameworks, including initiatives such as the IRA's Clean Fuel Production Credit (Section 45Z), are beginning to directly reward lower-GHG fuels and recognize farmers' contributions to emission reduction, soil health, and water conservation. By linking incentives to CI outcomes, these policies better align economic and sustainability objectives, creating new income streams for climate-smart practices such as no-till, cover crops, and enhanced-efficiency fertilizers.

“Historically, US farmers have only benefited from biofuel policy indirectly, through higher crop prices. IRA Section 45Z marks the first time federal policy explicitly links farm level carbon performance to direct financial value, creating a pathway for farmers to benefit from producing lower-carbon feedstocks.”

Jessica Monserrate - Head of Sustainability North America, BASF

B) Ethanol: A cost-effective blend component enhancing price stability

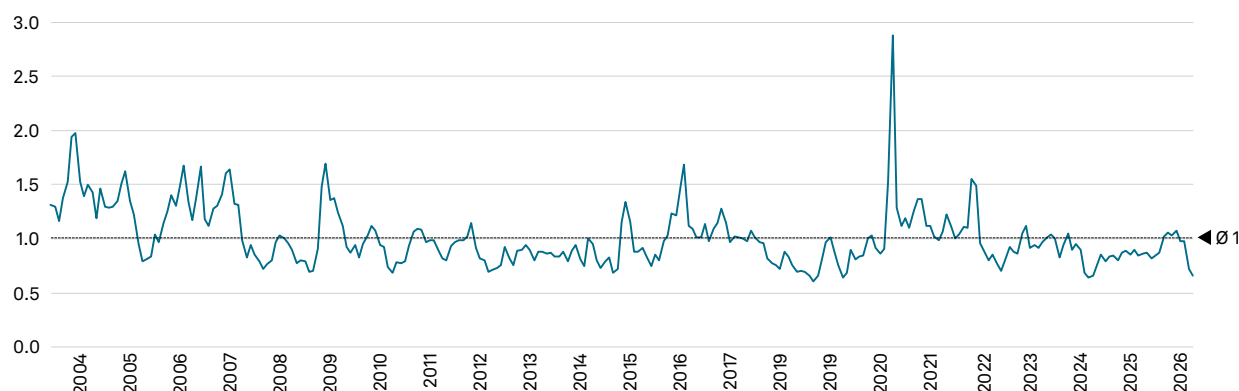
Biofuels also provide measurable economic benefits for downstream fuel markets and consumers. Historical price relationships show ethanol has frequently traded at a discount to gasoline, supporting blending economics and lowering the cost of finished motor fuel. Ethanol's blending value is driven by two mechanisms. First, its naturally high-octane content reduces the need for more expensive refinery-produced octane components. Second, as a diluent blend component, ethanol's price competes with gasoline on an energy-adjusted basis, helping reduce the cost of the blended fuel pool.

The ethanol-to-gasoline price ratio illustrates that ethanol can function as a cost-effective blend component, enabling blenders to use it to substitute a portion of petroleum-based fuel while maintaining fuel performance. Since the RFS was implemented in 2005, the Chicago ethanol-to-gasoline price ratio has been below 1 about 63% of the time and has declined over time, indicating improved competitiveness as rising corn productivity has lowered ethanol production costs.

Because it is domestically produced, ethanol helps moderate fuel price volatility, providing cost relief at the pump and reinforcing national energy security.

Figure 20. Ethanol price vs. gasoline price (Chicago)¹

Ethanol/gasoline price ratio (%)



Note: 1. The analysis is based on the price relationship between wholesale Ethanol Chicago Pipe and Gasoline CBOB Chicago Pipe.
Source: S&P Global Energy

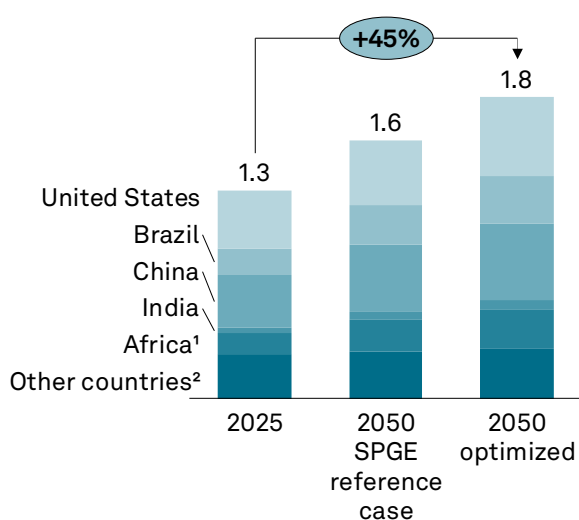
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In addition, US ethanol output per acre is expected to continue rising, driven by both stronger corn yields and ongoing improvements in ethanol conversion efficiency. Advances in technology are supporting higher yields and may increase corn starch content over time, further boosting ethanol production per acre. At the same time, gains in industrial processing, particularly improvements in corn extraction rates and advances in enzymes, yeast, and AI-enabled biological research, continue to lift conversion efficiency. Together, rising corn yields and improving conversion efficiencies are expected to enhance ethanol's value relative to gasoline, reinforcing both consumer value and market stability.

Assuming all corn produced on an acre is converted to ethanol, US corn ethanol productivity has increased from ~350 gallons per acre in the early 2000s to ~550 gallons in 2025 and could reach ~900 gallons by 2050 under an optimized technology scenario.

C) Increased supply of animal feed products

Figure 21. Selected crops supply for feed (including by-products)¹ and food use for selected countries²
Billion metric tons



1. Corn, wheat, rice, sorghum, soybean, canola/rapeseed and cassava, and meals (DDGS and oilseed meals). 2. Countries with strong ethanol feedstock potential include US, Brazil, India, the EU, Nigeria, Kenya, Tanzania, Ghana, Uganda and China. Selected countries account for approximately 56% of global grain production. Sugarcane was not included. 3. Nigeria, Tanzania, Kenya, Uganda and Ghana. 4. EU, Thailand and Canada “

Source: S&P Global

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Biofuel production generates valuable co-products (protein meals and DDGS) that are returned to the food system.

In an optimized production scenario, grain and protein meal supplies in selected countries are projected to increase substantially by 2050 compared with 2025 levels, highlighting the role of technology levers, improved agronomic practices, and yield optimization in meeting rising demand.

In such scenario, these co-products substitute traditional feed ingredients, lowering feed costs for livestock producers and helping make meat and dairy more affordable. The resulting productivity gains would enable countries to increase food and feed supply while simultaneously supporting a much larger biofuel industry.

Relative to 2025, this scenario would deliver 45% higher food and feed supplies, a scale of increase that could help reduce input costs and strengthen food affordability globally, while simultaneously supporting biofuel demand.

In practical terms, this implies a future in which farmers produce both food and surplus biomass for biofuel on the same land, creating a win-win: expanded energy supply, lower emissions, strong agricultural markets, and stable food availability. The broader spillovers are significant. Rural economies benefit from higher farm incomes and new biorefinery jobs. Consumers may see more stable or lower fuel prices as domestically produced biofuel buffers oil price volatility. And the energy sector gains access to a cleaner, renewable fuel source that helps meet climate targets.



Conclusion

Global agriculture is entering a period of structural transformation. Food demand growth is slowing because of decelerating population growth and moderating or declining per capita consumption of grains/starches, sugar, oilseeds and meat. Biofuel demand, absent new policy initiatives, is stagnating and is further pressured by a decline in gasoline use. Meanwhile, rapid modernization has enabled farmers to supply more food and fuel than ever before. This trend is expected to continue and potentially accelerate, leading to an outcome in which agricultural productivity outpaces both food and fuel demand.

The imbalance between supply and demand has emerged as a major long-term challenge for the US farm economy. Without new demand markets, US corn acreage could fall 31% by 2050, a loss of nearly 30 million acres—equivalent to the size of North Carolina. As these structural shifts unfold, the core challenge facing agriculture will move away from how to meet future food demand and toward how farmers and rural economies can be sustained. New and expanded markets for agricultural commodities are essential to sustain farm incomes, preserve farmland, and support rural economies.

While the potential for higher food consumption growth is limited, biofuels are a scalable catalyst that can unlock access to markets seeking viable low-carbon solutions. In fact, biofuels are a demand source large enough not only to change the trajectory of agriculture and restore profitability, but also to unlock the potential to accelerate innovation, and productivity growth, deliver emission reductions and foster sustainable development. Biofuels could become a meaningful player in global energy markets, participating in the world's current 940-billion-gallon liquid fuel market.

Advances in seed genetics, gene editing, crop protection, regenerative farming practices, digital agriculture and AI are enabling further yield gains, not only in traditionally agricultural countries, but across a broader set of countries positioned to benefit from the next wave of productivity. Under optimized agricultural productivity conditions (i.e., sustained innovation and technology adoption incentives, but well below a crop's biological and technical potential), US corn output would rise 50% by 2050 without change in land use. Global corn production could increase more than 80% by 2050, mostly by closing yield gaps using current technology rather than land expansion. In this scenario, ethanol would potentially represent nearly 50% of global road motor gasoline demand by 2050, up from roughly 7% in 2025, or extend well beyond road transport into aviation, marine, and the largely untapped biomaterials market, which is also actively seeking scalable renewable solutions.

This finding indicates that expanding agricultural production does not inherently require deforestation or extensive land-use change. Rather, improvements in productivity on existing farmland, alongside environmental safeguards, can support increased agricultural and biofuel supply while enhancing long-term agricultural resilience.

The path forward also demonstrates that agriculture does not face a choice between food and fuel, but between stagnation and adaptation. This report shows that the solution lies not in expanding farmland, but in unlocking the full potential of existing land through technology. As agriculture is hurting and stands at this pivotal crossroads, tapping into new demand markets is essential for farmers. Biofuel markets present a strategic, scalable and market-driven option for absorbing agricultural surpluses, an essential role that food demand alone can no longer fulfill.

Appendix A. Glossary

4R	Fertilizer nutrient stewardship
AI	Artificial Intelligence
Bu	Bushel
CI	Carbon Intensity
DDGS	Distillers dried grains with solubles
EPA	Environmental Protection Agency
EPAct05	Energy Policy Act of 2005
FAO	Food and Agriculture Organization
GEM	Genotype × Environment × Management
GHG	Greenhouse Gas
GMO	Genetically Modified Organism
HEFA	Hydroprocessed Esters and Fatty Acids
LCFS	Low Carbon Fuel Standard
MMt	Million metric tons
Mt	Metric ton
Mt/ha	Metric tons per hectare
N	Nitrogen
NGT	New genomic techniques
NPK	Nitrogen–phosphorus–potassium
OCP	Office Chérifien des Phosphates
P	Phosphorus
RFS	Renewable Fuel Standard
RNAi	Ribonucleic acid interference
SAF	Sustainable aviation fuel
SPGE	S&P Global Energy
USD/bu	US dollars per bushel
USDA	United States Department of Agriculture
VEETC	Volumetric Ethanol Excise Tax Credit

Conversion units

1 Hectare	2.47 Acres
1 Mt	2,204.62 lbs.
1 Mt of Corn	39.37 Bushels
1 Mt of Soybeans	36.74 Bushels
1 Mt of Ethanol	334 Gallons

S&P Global Energy project team

Project Director

Juan Sacoto
Global Head of Agribusiness Consulting

Advisors

Kevin Lindemer
Head of Downstream Americas Consulting

Cristopher Berg
Head of Biofuel Value Chain Service

Ryland Maltsbarger
Head of Crop Long-Term Research

Joe Sommers
Director, Agribusiness Consulting

Project Manager

Emerson Wohlenberg
Director, Agribusiness Consulting

Project Consultants

Daniela Flores
Principal Consultant, Agribusiness

Dienice Bini
Principal Consultant, Agribusiness

Maria Eduarda Erthal
Consultant, Agribusiness

Tom Philip
Senior Consultant, Agribusiness

Laura Krishfield
Senior Consultant, Agribusiness

Swati Mathur
Associate Director, Agribusiness

Guolin Yao
Senior Consultant, Agribusiness

Report Design

Fernanda Capetillo
Designer

For more information on this report, please contact

Juan Sacoto

Global Head of Agri Consulting

juan.sacoto@spglobal.com

Emerson Wohlenberg

Consulting Director - Agribusiness

emerson.wohlenberg@spglobal.com

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