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Equity Research
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AHEAD OF THE CURVE® SERIES

DEUS EX MACHINA, PART V: ROBOTICS IN AGRICULTURE

JULY 10, 2023

Development and deployment of robotics in agriculture is underpinned by three key megatrends: lack of labor, a rising global middle class, and water scarcity.

We forecast global precision agriculture revenue to grow at a ~13% CAGR during 2023-2030, led by DE.

Our joint survey with MassRobotics suggests positive directional momentum toward deployment, and our private company interviews highlight sector vibrancy.

Private investment in ag tech has grown to $2B+ from <$500MM in 2016. Leaders like DE will likely support the ecosystem through M&A to achieve precision ag revenue commitments.

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In Collaboration With
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- Diversified Industrials: Machinery & Transportation OEMs
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INDUSTRY UPDATE

ROBOTICS IN AGRICULTURE - AHEAD OF THE CURVE SERIES

THE TD COWEN INSIGHT

Part V of a collaborative series examining the global robotics landscape (see I, II, III, and IV). As the world looks to feed a growing population of rising wealth and accompanying tastes in an environment of increasingly scarce resources, robotics will be a key tool utilized to deliver maximum output efficiency. Deployment still early stage, but leaders are committed and tech is expanding.

Our Thesis (Joe Giordano)

We believe investment into ag related robotics and precision ag applications will be born and supported out of necessity based on 3 principle megatrends: **1)** labor shortages for farming related applications; **2)** urbanization / broadening of the global middle class; and **3)** water scarcity. Essentially, we have to figure out how to feed and support a growing population with increasing wealth and more discerning tastes with a declining resource base. There will be multiple strategies deployed to accomplish this, but we believe the application of robotics into the ag world will certainly be one of them - and we are already seeing those signs.

The market is still early stage, but we are seeing a similarity to other next gen robotic success stories like AMR/AGVs, which saw private investment grow more than 50x over 2014-2019 to almost $3.5B as it entered more mainstream discussions in the logistics market. The private landscape is broad and growing, and key large public companies (like Deere) are committed and will likely act as consolidators.

What Is Proprietary

We collaborated with our partners at MassRobotics to survey both robot manufacturers and end users to determine what types of applications are in development, how formalized plans to combat food related issues are today, and key hurdles to overcome. Over 80% of participants are taking some sort of actions to address food scarcity, though only about half have made public commitments. Funding was listed by 2/3 of respondents as a key hurdle, and one we'd view as infinitely solvable as proof points are achieved and consumer awareness increases.

In order to gain further insights into technology development, we held extensive conversations with multiple private companies focusing on different areas within ag tech. In our report we highlight our discussions with advanced.farm (automated harvesting of high value crops - see our recent panel discussion HERE) and Radmantis (sustainable fish farming).

Our Machinery & Transportation OEMs team also developed a model for precision ag revenue growth, which they estimate will grow at a 13% CAGR through 2030.

Financial & Industry Model Implications (Matt Elkott)

We forecast global precision ag revenue to grow at a ~13% CAGR over the 2023-2030 period, led by DE, followed by AGCO, CNHI, and a few other ag technology companies. We see one third of this growth coming from the base ag equipment market that's already equipped with precision, with two thirds driven by machines and services with incremental technology, including autonomy. For DE, we expect at least two thirds of the growth to occur organically. DE has been developing much of its own hardware and software since the 1990s, but the company has not shied away from technology acquisitions when they made sense. We believe DE and its OEM brethren will seek deals that satisfy at least two of four criteria: 1. A strong autonomy or AI offering. 2. New technologies, including new power. 3. Targets that facilitate decarbonization, directly or indirectly. 4. A material percent of revenue from recurring services.

What To Watch (Joe Giordano)

Private company funding continues to accelerate within the precision ag / ag tech space - growing from <$500MM in 2016 to over $2B in 2022. If we look specifically at the robotics and smart field equipment sub vertical (the largest YTD at over $300MM in investment), we note similar (though smaller in magnitude) growth characteristics to mobile robotics (AMR/ AGV) seen over 2014-2018. We'd note that market ultimately grew from <$100MM in 2014 to nearly $3.5B in investment in 2019 as e-commerce penetration accelerated. Covid was the "moment" for logistics tech, as megatrends we explore in this report continue to play out, we look for a similar catalyst for ag tech.

As private companies continue to develop, large companies like DE will likely act as consolidators - and we've already seen activity there. As DE seeks to grow its precision ag business from ~$20B to ~$60B by 2030, up to 1/3 of that growth is expected to be inorganic. We see DE as a discerning buyer of attractive technology and the foundation of a healthy ecosystem of development and exit for private company investors.

Stock Conclusions (Matt Elkott)

DE is a high-quality company on just about every level, and we expect it to continue to lead the rapid-growth precision agriculture field, which it pioneered in the late 1990s. We remain on the sidelines on less-than-compelling current valuation; our view that the broader equipment upcycle will begin to moderate in CY24; our concern that the path to the 10% subscription revenue target, however doable, could be more bumpy and back-end weighted than some investors may hope; and a good deal of external uncertainty, including trade relations that could pressure grain exports and an emerging El Nino event. DE's roughly 4.5-point PE premium to AGCO and CNHI should hold for the foreseeable future throughout the cycle, but an eventual slight narrowing cannot be ruled out as the two smaller OEMs sharpen their focus on precision ag.

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Executive Summary (Joe Giordano and Matt Elkott)

Part V of our robotics series explores how robotics will likely emerge as a necessary tool to feed and sustain a growing population with increasing wealth (and more discerning tastes) with declining physical and human resources. Megatrends such as limited supply of labor, urbanization and a rising global middle class, and water scarcity underpin investment into critical technologies to enable more efficient food production across the chain – from crops to proteins. Behavioral change needs to be a major part of the equation, but robotics/automation will help deliver desired results while minimizing impact to ways of life. Our work seeks to identify technologies that seek to alleviate pain points created by these megatrends and the companies working to develop them.

Precision ag is the first step, and we believe DE is the clear leader and is committed to 10% recurring revenue from these applications by 2030. In this report we provide the foundation for our ~13% precision ag growth estimate through that time period. Consistent M&A is expected to support DE's march towards its target, and the private landscape – though still early stage – is flush with emerging technology. When analyzing funding flows into the sector, there are potential similarities to what we have recently seen with mobile robotics, where funding increased ~50x over a 5-year period.

As part of our work, we collaborated with our partners at MassRobotics to investigate what types of applications are being developed privately and how committed end users are to achieving food related targets. The results of our survey work suggest positive directional momentum at an early stage and supports continued deployment into the sector. In conjunction with our survey, we conducted extensive interviews with private companies in varying niches of ag tech/robotics. Our two case studies, advanced.farm and Radmantis, focus on very different technologies but center on the same core concept – maximizing crop/protein returns per unit of input. We see continued innovation at the private level coupled with leadership and commitment from large enterprises like DE as a compelling backdrop for the sector to move forward.

The risks are clearly high, and the sector appears to be on the precipice of larger scale growth. We go into detail on the key megatrends in our work, but just for scale consider the following: The United Nations projects the world population will grow from 8B people today to nearly 10B people in 2050. This, by some estimates, will require a 50% increase in food production to accommodate not just the greater number of people but their changing diets, as urbanizing populations increase their protein and packaged food consumption. Urbanization will also encroach on arable land, making the reduction in farming input resources and the improvement in yield per acre brought about by precision technology even more important. While the world population is then expected to plateau for two decades before beginning to decline, evolving age demographics will likely present challenges never experienced in human history. The population age pyramid, reflecting – thus far in human history – younger people at the bottom and older people at the top, is expected to invert. A striking way to illustrate this is the "peak-child" concept – an expectation that there will never be more children in the world than there are today. In much of North America, Europe, Australia, New Zealand, and swaths of Asia, the fertility rate is estimated to already be below the 2.1 births per woman threshold required to keep population from declining. This underscores the importance of automation and autonomy.

Deus Ex Machina Series:

Part I – Robotic Arms – LINK
Part II – Mobile / Logistics Robotics - LINK
Part III – Human Collaboration and Augmentation – LINK
Part IV – Robotics As Tools In The Climate Fight - LINK

Key Investment Considerations For PMs:

1. Megatrends limiting available labor, pushing up the global middle class, and a broadening water scarcity provide a durable backdrop for required ag robotic investment. (link)

2. We feel DE is the clear leader in precision ag, a market we expect to grow ~13% annually through 2030. We expect DE to lead both organically and through consistent M&A as it moves towards its goal of 10% related revenue. (link)

3. Our joint survey with MassRobotics suggests a vibrant private landscape of technologies at early stage but with clear momentum. Our private company interviews highlight the economic benefits these technologies can provide, and we explore the competitive landscape. (link)

4. Private funding into ag robotics is early stage but increasing and showing some similarities to other recent robotic success stories like AMR's, which saw a ~50x increase over 5 years to over $3B annually. (link)

Please see our primers on:

Precision Ag (link)
Vertical Farming (link)
Food Statistics (link)

Top Takeaways From Our Work

DE And Precision Ag-Related Takeaways (Matt Elkott)

We Expect Robust Precision Ag Growth: We forecast global precision ag revenue to grow at a ~13% CAGR over the 2023-2030 period, led by DE, followed by AGCO Corp., CNH Industrial (CNHI), and a few other ag technology companies. We see one-third of this growth coming from the base ag equipment market that's already equipped with precision, with two-thirds driven by machines and services with incremental technology, including autonomy. For DE, we expect at least two-thirds of the growth to occur organically. DE has been developing much of its own hardware and software since the 1990s, but the company has not shied away from technology acquisitions when they made sense. Megatrends like a growing world population, urbanization, and water and labor challenges should make investment in precision ag increasingly more compelling.

Acquisition Sweet Spot: We developed a diagram to illustrate our view of the areas ag equipment manufacturers, led by DE, are likely to target for acquisitions. We believe they will seek deals that satisfy at least two of four criteria: 1) A strong autonomy or AI offering; 2) New technologies, including new power; 3) Targets that facilitate decarbonization, directly or indirectly; 4) A material percent of revenue from recurring services.

The Marriage of Autonomy and Precision Ag Could Beget a New Breed of Farmers. Taking a very long-term view, the increasing ubiquity of precision ag coupled with the nascent emergence of full autonomy in large-scale farming could lift much of the burden of running a farm off farmers. This could help address labor and generational issues in family farming, with younger members sometimes reluctant to take over the business. We thought of one scenario where equipment dealers could evolve to become farm operators, especially as equipment technology becomes more complex. This could also enable dealers, for some equipment types, to improve utilization by moving some of the more compact machines that happen to be idle at a given time in a given operation to another. While improved equipment utilization may seem like a demand headwind for OEMs, we are talking about a very long-term horizon in which a significantly higher portion of OEM revenue comes from recurring subscriptions.

The Path to Subscription Could Be Bumpier than Some Might Hope. We think DE's 10% subscription revenue goal is achievable by 2030, and we have devised a hypothetical calculation detailing the fertilizer, herbicide, and labor savings to farmers that should get the subscription model going. But we think it is going to be slower than a typical new product adoption curve.

External Uncertainties: For the broader ag equipment market, intermediate-term uncertainty includes trade relations that could pressure grain exports and an emerging El Niño event. We're exiting La Niña and entering El Niño, and while the last El Niño created some weather challenges and had some overlap with the 2014-2019 equipment down cycle, it is very difficult to gauge what, if any, El Niño's impacts might be this time. While farmers are aware of this weather pattern change, it is not a key factor in their planning.

We Would Remain on the Sidelines, for Now: DE is a high-quality company on just about every level, and we expect it to continue to lead the rapid-growth precision agriculture field, which it pioneered in the late 1990s. We would remain on the sidelines on less-than-compelling current valuation; our view that the broader equipment upcycle will begin to moderate in CY24; our concern that the path to the 10% subscription revenue target, however doable, could be bumpier and back-end weighted than some investors may hope; and a good deal of external uncertainty, including trade relations that could pressure grain exports and an emerging El Niño event. DE's roughly 4.5-point PE premium to AGCO and CNHI should hold for the foreseeable future throughout the cycle, but an eventual slight narrowing cannot be ruled out as the two smaller OEMs sharpen their focus on precision ag.

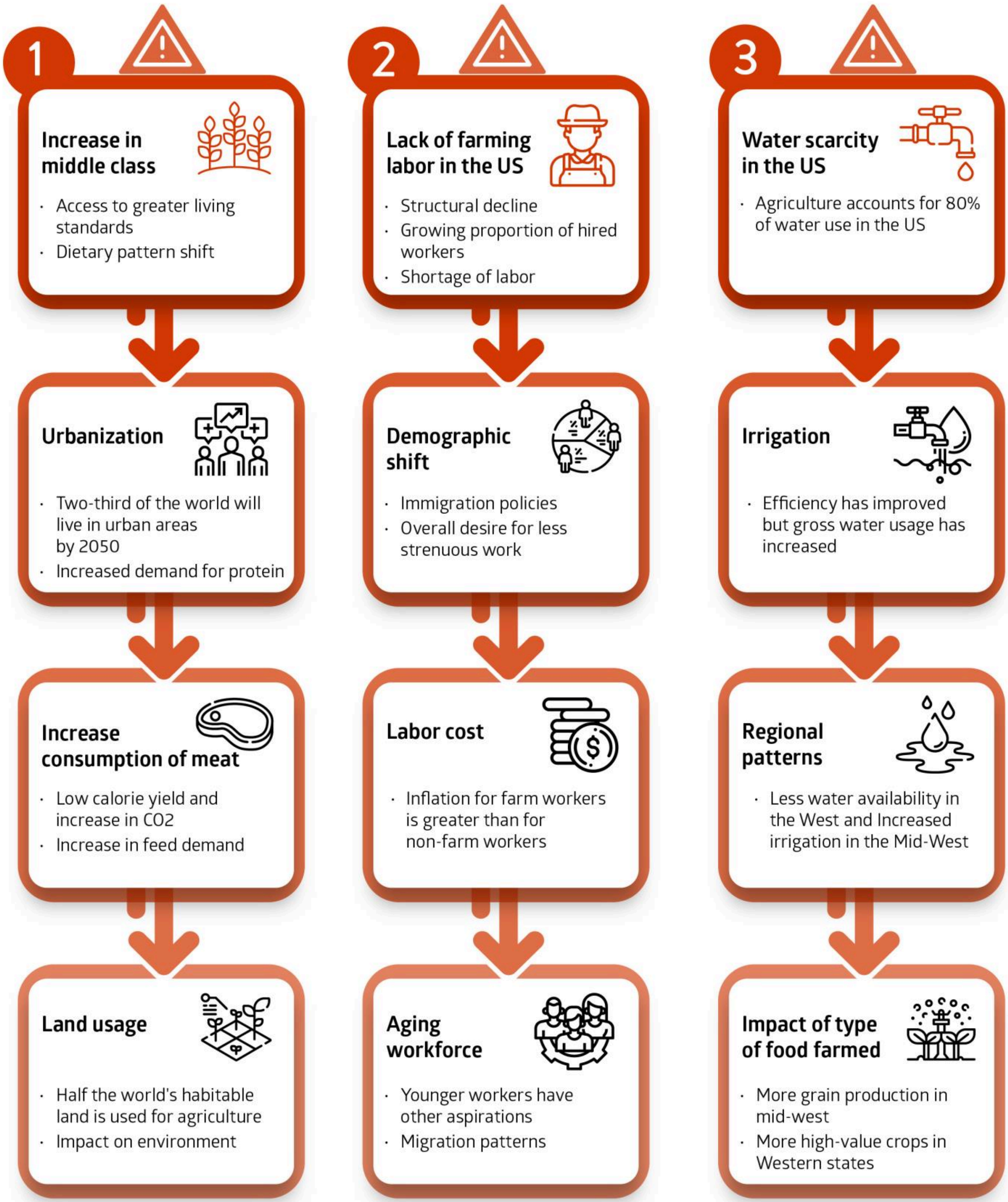
Sector / Technology-Related Takeaways (Joe Giordano)

The Megatrends we Identified are Unlikely to Resolve Naturally: behavioral change will help, but tools like robotics and automation will be necessary to offset impacts of trends that are well entrenched assuming standards of living are maintained.

The Core Technology Required to Meaningfully Deploy Already Exists: ag tech will leverage hardware advanced (mobile robotics, vision, sensing, path planning, etc.) seen over the past several years deployed into markets like logistics/manufacturing and autonomous vehicles. The move into agriculture is iterative, not revolutionary. The primary hurdle is the unstructured nature of the operating environment, which requires robust solutions that can handle diverse weather and physical conditions. In these applications, the relative precision required is less than in a manufacturing environment (which could be down to the micron level in some cases), which should provide flexibility to build solutions to handle the elements.

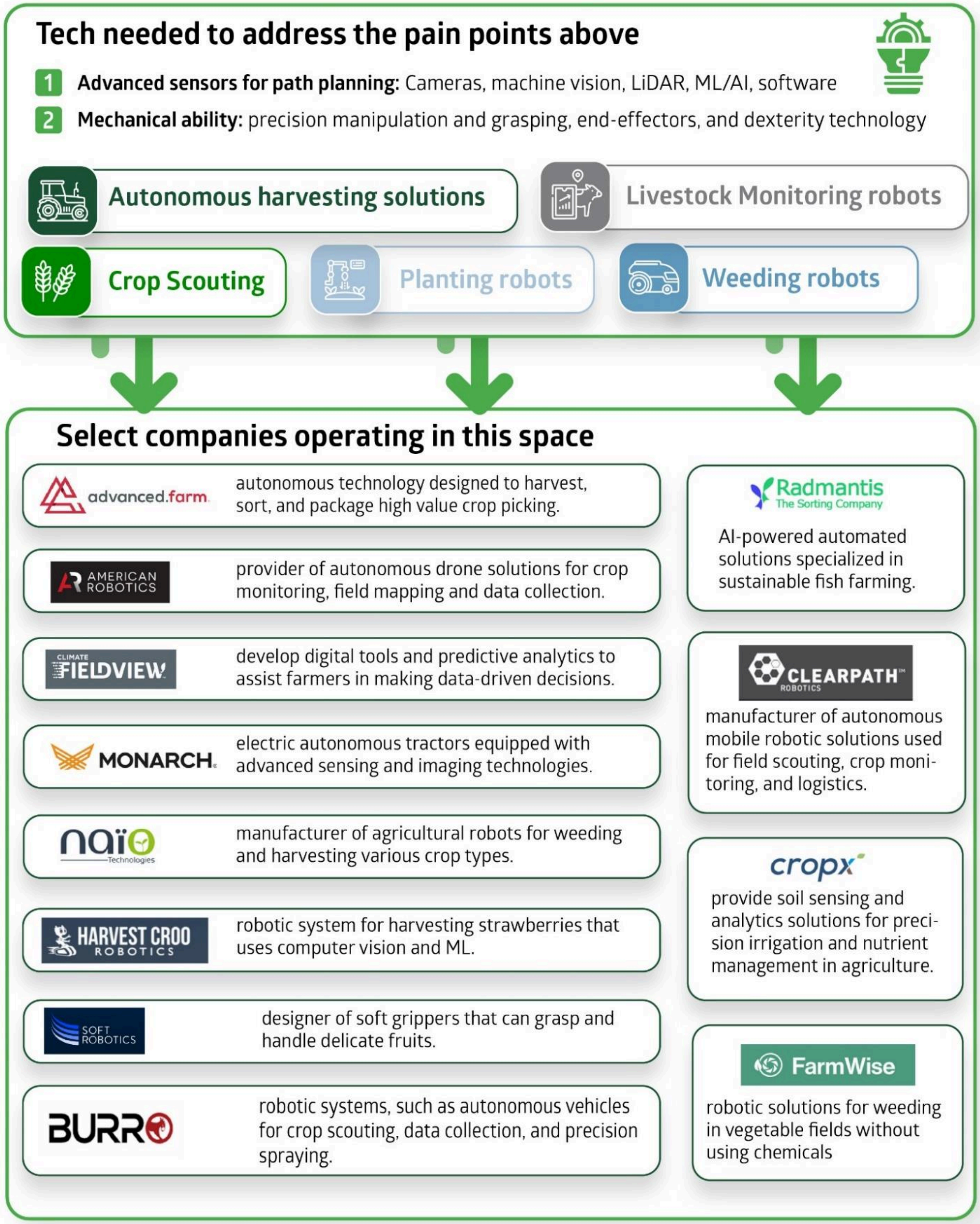
Funding is Accelerating: we've seen private funding into ag tech move from under $500MM in 2016 to over $2B in 2022. Robotics and field equipment specifically is the largest sub-category YTD at over $300MM and we see similar growth patterns that we witnessed several years ago in mobile robotics – a sector which ultimately grew ~50x to nearly $3.5B in annual funding over a roughly 5 year period. The availability of private financing will be crucial, as many companies we have spoken to suggest that although there are government grant programs available, many times the process is too slow / burdensome.

Figure 1 The Three Megatrends We Have Identified As Pain Points



Source: TD Cowen

Figure 2 The Pain Points Above Can All Be Addressed Thanks To Automation



Source: TD Cowen

3 Critical Megatrends Underpinning Robotic Investment In Agriculture

For additional detail / context on the water scarcity topic please see our prior work:

Sustainability Primer (link)
Latest Municipal Survey With Focus On Metering Tech (link)
Water Investing Panel Discussion (link)

Identified megatrends of insufficient labor, rising global middle class, and water scarcity create a landscape where we must learn to feed a growing population with diminishing resources. Below we explore the ramifications of these trends. Water scarcity is a topic we've discussed – please see our prior work listed in the sidebar.

These trends create a variety of pain points that require new tools to address. Robotics will undoubtedly be one of those tools, but application will be iterative. Ultimately, the ag/food sector will need to increase overall productivity (output / acre, maximize protein per unit of input) through a combination of reduction in waste, promotion of sustainable farming techniques, development of alternative food sources, and access to education and new technology.

Megatrend #1 - Labor Concerns In The US

We see four major focus areas within labor:

- Labor shortage: most notably for labor-intensive tasks like crop harvesting and fieldwork can be attributed to factors like demographic shifts, immigration policies, and perception of farming as physically demanding work.
- Labor costs: Wages and associated expenses like healthcare and insurance can significantly impact farm profitability, particularly for labor-intensive crops.
- Age of agricultural workforce: Average worker age is increasing and attracting and retaining a younger workforce is a challenge.
- Working conditions and labor rights: Ensuring safe and fair working conditions for farm laborers is a crucial concern.

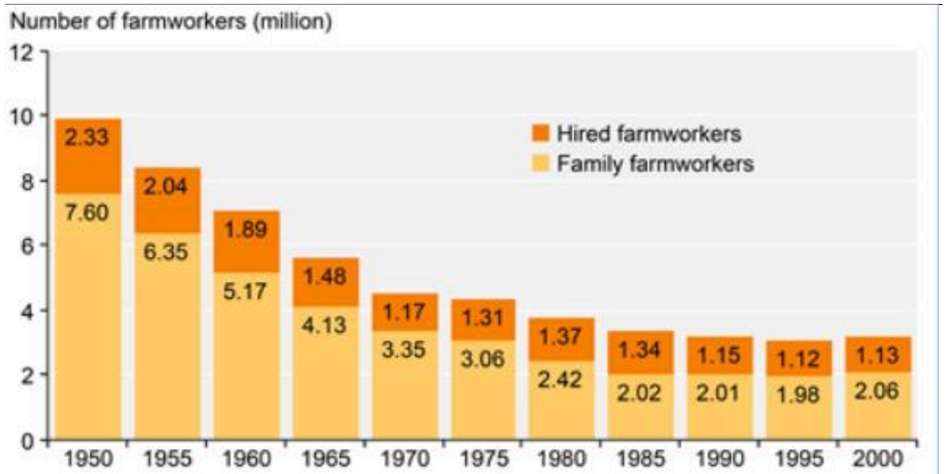
Each of these aspects can be addressed with specifically tailored solutions; however, we see automation as a more universal answer. By automating farm work, the need for labor will decrease. The increase in technology implementation will enhance labor productivity and reduce labor requirements – this should help reduce rising total labor costs. Modern farming practices that include automation and robotics could help attract a younger workforce. By reducing the need for labor and increasing younger new entrants, the industry could shift towards better compliance with labor regulation and improved worker support programs that improve the well-being and job satisfaction of farm workers.

A Look At The Size And Composition Of The US Agricultural Workforce

The US agricultural workforce is composed of two groups: 1) self-employed farm operators and their family members, and 2) the hired workforce. Both groups had been in long-term decline from 1950 to 1990, which was driven by the mechanization that contributed to rising agriculture productivity, which reduced the labor requirement. However, since 1990, employment levels have relatively stabilized.

The proportion of self-employed and hired workers changed drastically over the 1950-1990 period, as family farmworkers declined by 74% vs. only 51% for hired farmworkers. As a result, the proportion of hired workers increased over time.

Figure 3 Proportion Of Family And Hired Farmworkers On US Farms During The 1950-2000 Period



Note: Family farmworkers include self-employed farmers and unpaid family members. Hired farmworkers include direct hires and agricultural service workers employed by farm labor contractors.
Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, Farm Labor Survey (FLS). The FLS stopped estimating the number of family farmworkers beginning in 2001. As of 2012, the survey no longer counts contracted agricultural service workers.

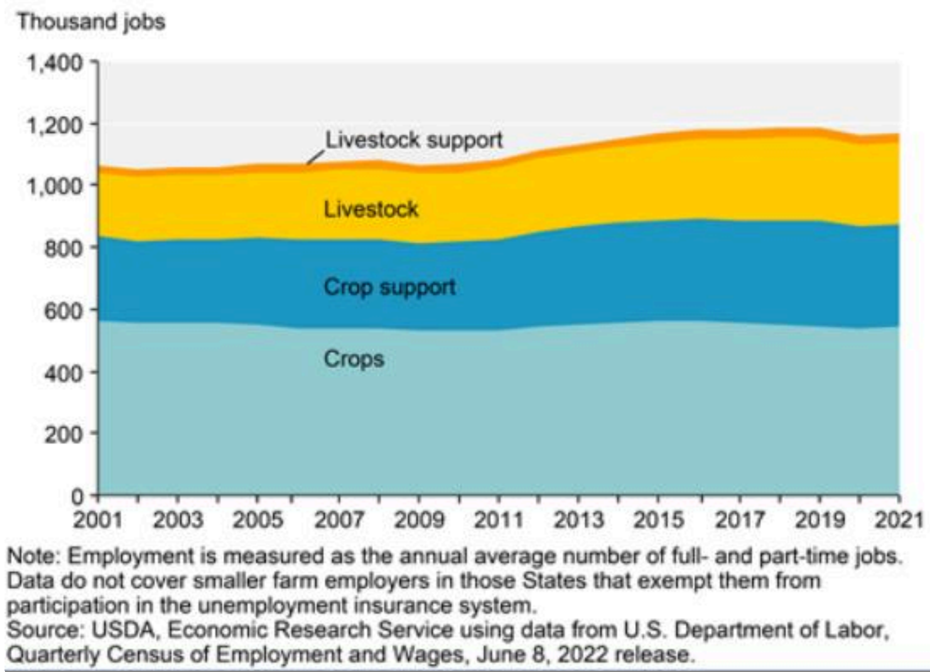
Source: ERS.USDA.GOV

Focus On Hired Farmworkers

Hired farmworkers make up less than 1% of all US wage and salary workers, but their role in US agriculture is vital. Their wages and salaries plus contract labor costs represented only 12% of production expenses for all farms but made up 43% of greenhouse and nursery operations and 39% of fruit and tree nut operations, according to data from the 2017 Census of Agriculture.

Farm employment has risen since the turn of the century, driven mainly by crop support and the livestock sector.

Figure 4 Employment In Agriculture And Support Industries, 2001-2021

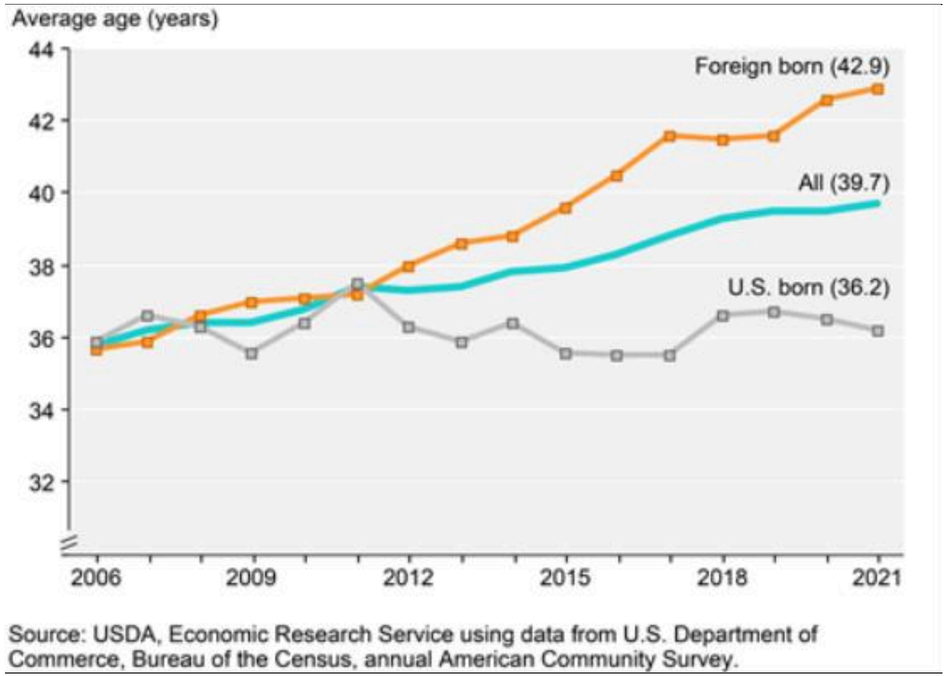


Source: ERS.USDA.GOV

The Existing Hired Workforce Is Aging

There are several factors that are driving fewer young immigrants to enter agriculture. Immigration policies and regulation in the US have become more restrictive over time, making it difficult for younger individuals to enter the country as farmworkers. Younger, foreign-born workers may opt for other employment options that are less physically demanding or offer better prospects, such as non-farm jobs or different industries. There have also been shifts in migration patterns of foreign-born farmworkers who, in the past, came to the US at a younger age and eventually settled or transitioned to other industries. As a result, the average age of foreign-born farmworkers has risen, pulling the average for the farm workforce as a whole higher. Data shows that the average age of immigrant farmworkers rose by seven years between 2006 and 2021, while the average age for US-born farmworkers remained roughly consistent over that same period.

Figure 5 Average Age Of US Farmworkers By Place Of Birth, 2006-2021



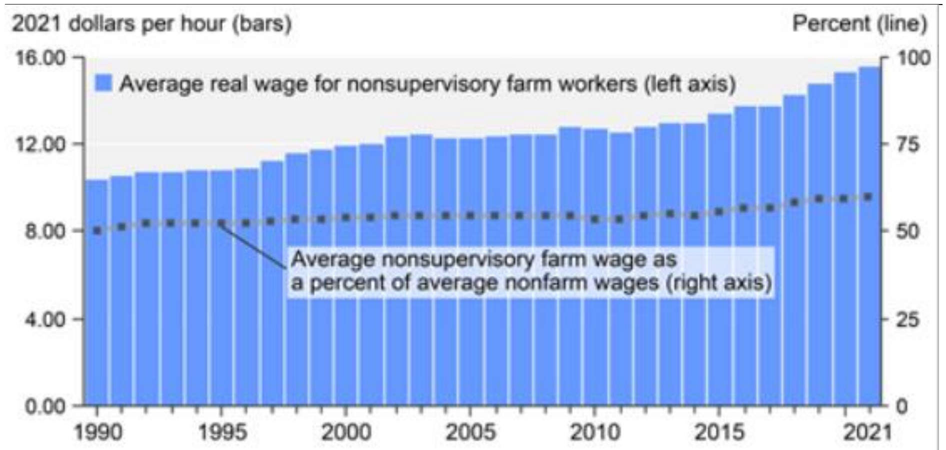
Source: ERS.USDA.GOV

Labor Costs In Farm Work

Wages for hired farmworkers rose 2.5% per year on average for the 5 years prior to 2021. This rate of increase is still relatively modest compared to other areas of the economy; however, when compared to the average annual rate of 1.2% per year between 1990 and 2021, it is substantial and consistent with growers' reports that workers have been harder than usual to find.

Although the average real wage for farm workers as a percentage of nonfarm wages increased by 10 points to 60% over the 1990-2021 period, the gap between the two remains substantial. If the gap continues to close at the same pace it has over the past three decades, it could put significantly more pressure on farm economics.

Figure 6 Real Wage Increase For Farm Workers Has Accelerated In Recent Years, Though Remains Well Below Nonfarm Wages

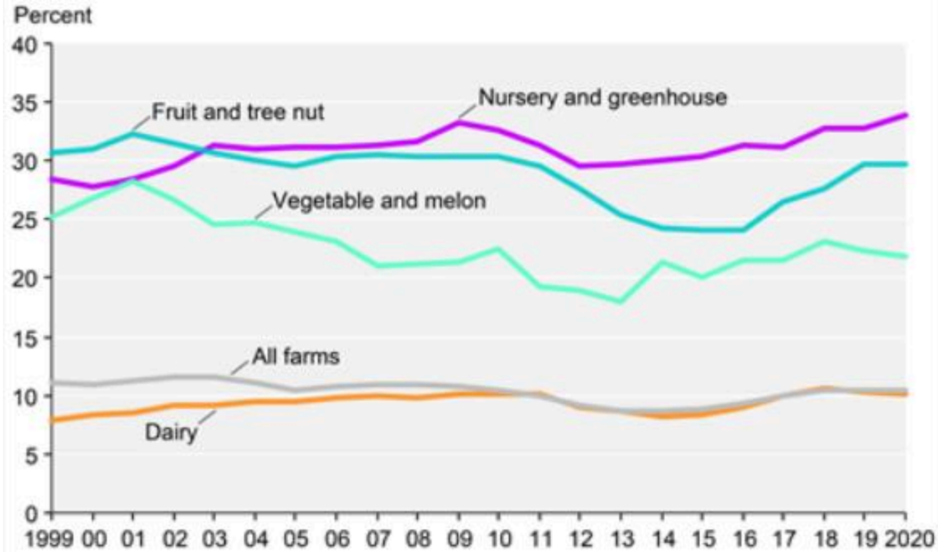


Source: ERS.USDA.GOV

The Real Cost Of Higher Labor

The impact of real wage increases described above has been largely offset by rising productivity and/or output prices. As a result, the whole farming industry's labor cost as a percentage of gross cash income has stayed relatively flat over the past 20 years. However, it is more nuanced under the surface. While labor costs as a share of total gross cash income for vegetables has generally trended down over the past 20 years, the same metric has increased for both fruit and tree nuts and nursery and greenhouse over the past few years. It is worth noting that these last two categories are the most labor-intensive and therefore, continued increases there could put pressure on farming margins.

Figure 7 Labor Costs As A Percentage Of Gross Farm Income For Selected Specializations, 2000-2020



Note: Values for each year are 3-year moving averages to smooth fluctuations because of small sample sizes, e.g., the estimate reported for 2020 is the average over 2018–20.
Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Surveys, selected years.

Source: ERS.USDA.GOV

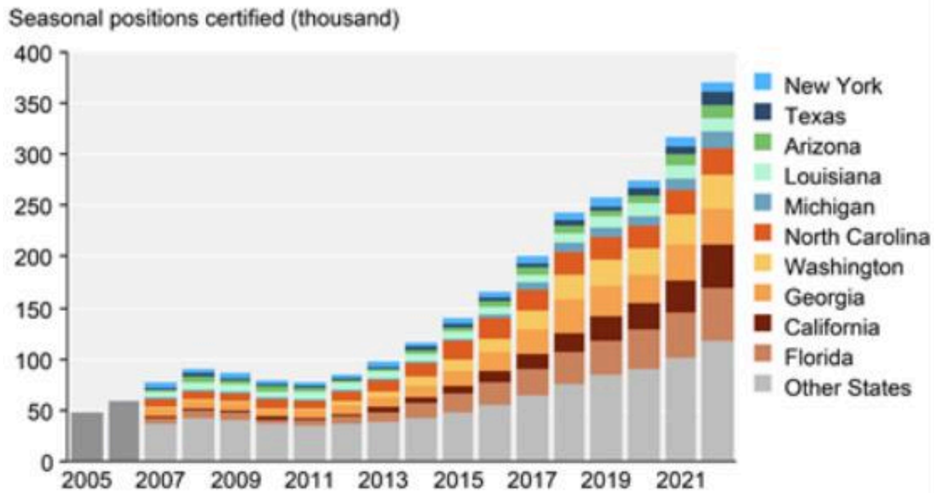
Labor Shortage Confirmation Through The Lens Of H-2A Visas

The H-2A temporary agricultural program is a US visa program that allows agricultural employers to hire foreign workers on a temporary basis (usually for a period of up to 10 months) to fill seasonal or temporary agricultural jobs. The program is designed to address labor shortages in the agricultural sector when there are not enough available US workers to meet demand. The primary goal of the program is to ensure that agricultural employers have access to a legal and reliable workforce to meet their temporary needs. These jobs typically include tasks such as planning, cultivating, harvesting, and processing agricultural products.

Under the H-2A program, agricultural employers can request permission to hire foreign workers to fill their labor needs. They must demonstrate that there are not enough able, wiling, and qualified US workers available for the job. The H-2A program has some built-in worker protection mechanisms. These include guaranteed employment for the duration of the approved labor contract, reimbursement for transportation costs, access to housing meeting certain standards, and payment of wages at or above the prevailing wage rate.

A dramatic and clear indicator of the scarcity of farm labor is the fact that the number of H-2A positions requested over the past 17 years has increased more than sevenfold.

Figure 8 US H-2A Positions Certified By State, Fiscal Years 2005-2022



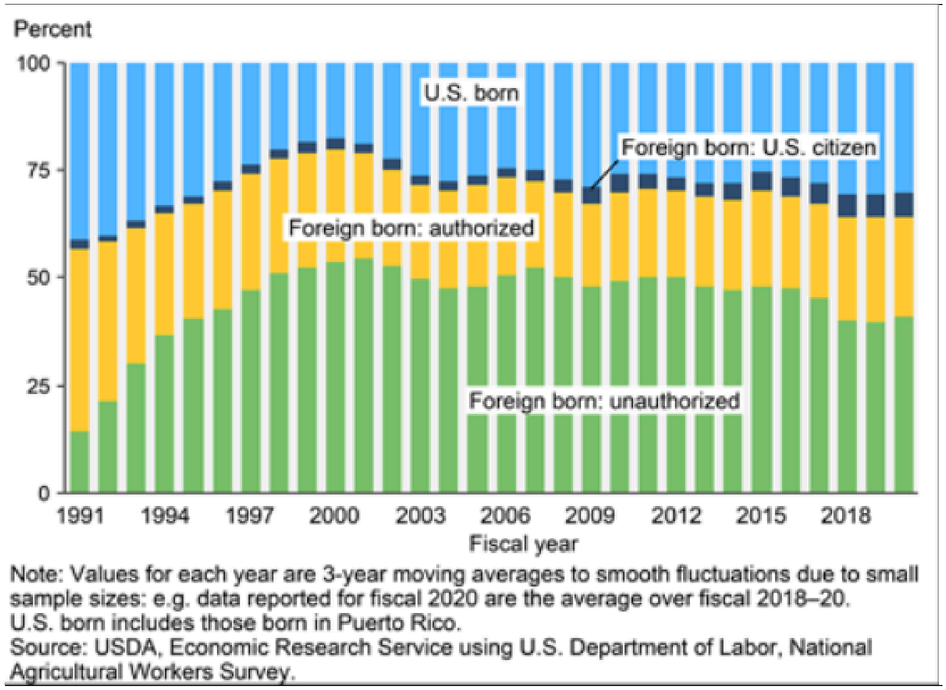
Note: State-level data are not available for fiscal years 2005–06. Individual States identified in the chart were the top 10 in the number of H-2A jobs certified in fiscal 2022. About 80 percent of job certifications result in visas being issued to H-2A workers—some employers do not follow through to hire H-2A workers and some workers fill two certified jobs.
Source: USDA, Economic Research Service using data from U.S. Department of Labor, Office of Foreign Labor Certification.

Source: ERS.USDA.GOV

Legal Status And Migration Shift Of Crop Farmers In The US

Collecting this data is notoriously difficult because respondents are usually reluctant to answer truthfully, and not many surveys ask the question in the first place. The US Department of Labor's National Agricultural Workers Survey (NAWS) provides some data on farmworkers' legal immigration status and is believed to be of high quality. NAWS data is gathered by trained and trusted census takers who are interviewing workers face-to-face at their job sites with their employers' approval. One of the limitations of the NAWS, however, is that it does not include H-2A workers or livestock workers.

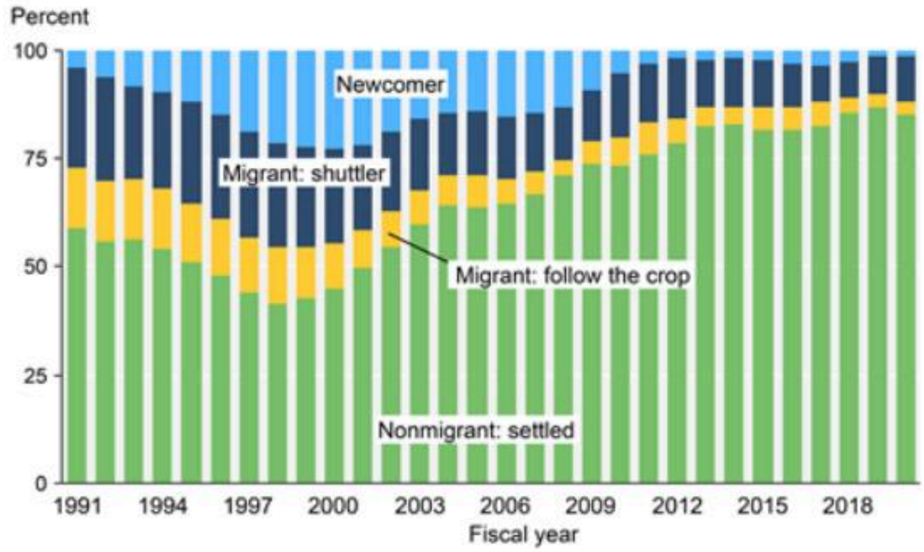
Figure 9 The Share Of Hired Crop Farmworkers That Are Not Legally Authorized To Work In The US Is About 40%, According To NAWS



Source: ERS.USDA.GOV

The migration patterns of farmworkers have changed over time. In the past, many farmworkers came to the US at a younger age and eventually settled or transitioned to other industries. However, in recent years, the migration patterns have shifted, with fewer new and younger individuals entering the agricultural workforce, which is one of the factors impacting the aging workforce. Currently, about 85% of hired crop farmworkers are considered settled, meaning that they work at a single location within 75 miles of their home. Shuttlers, who work at a single location more than 75 miles from their home, make up the majority of the remaining migrant workers, and account for about 10% of hired crop farmworkers. Migrant farmworkers, workers that essentially “follow the crop” used to be relatively common in the past but are now a relative rarity. The final category is newcomers to farming, workers whose migration patterns have not yet been established –make up just 1% of the crop farm workforce. They used to make up 22% of the workforce back in 1998-2000, but the trend is a reflection of the slowdown in net migration from Mexico to the US.

Figure 10 Migration Patterns Of Hired Crop Farmworkers, Fiscal 1991-2020



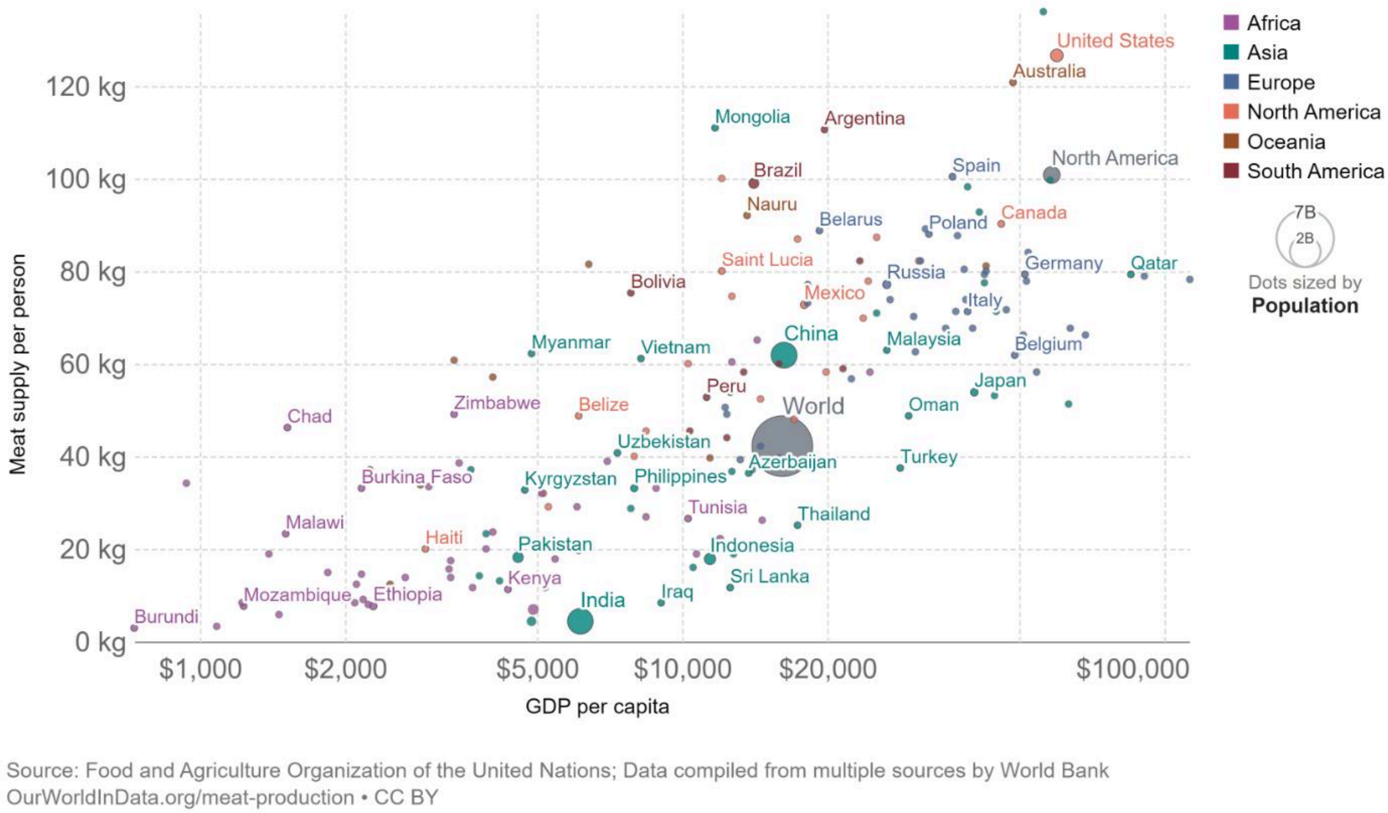
Note: Values for each year are 3-year moving averages to smooth fluctuations due to small sample sizes: e.g. data reported for fiscal 2020 are the average over fiscal 2018–20.
Source: USDA, Economic Research Service using U.S. Department of Labor, National Agricultural Workers Survey.

Source: ERS.USDA.GOV

Megatrend #2 - The Increase Of The Middle Class In Emerging Economies And Its Impacts On Food Preference, Meat Consumption, Urbanization, And Land Use

The increase in the middle class in emerging economies is leading to significant changes in food preferences, particularly in the consumption of meat products. As individuals transition into the middle class, they experience improved living standards and increased purchasing power, allowing them to afford a more diverse and varied diet. This shift towards a higher socio-economic status is often associated with a desire for higher-quality food and a shift towards Westernized dietary patterns. Additionally, meat consumption is often seen as a symbol of social status and affluence, further driving the increase in meat preference. The urbanization of emerging economies, convenience-oriented lifestyles, and a perceived association of meat with improved nutrition also contribute to rising meat consumption among the middle class.

Figure 11 Strong Positive Relationship Between Meat Consumption And National Wealth



Source: OurWorldInData.org

The rise of the middle class in China illustrates these factors. Over a 40 years span (1980-2020), China went from a consumption of 53g of daily protein to almost doubling to 105g of daily protein intake. For reference, the consumption of protein for the US over the same period went from 100g to 117g. This dynamic is even more striking when looking at the consumption of protein from animal sources. Over the same 40 year span, China increased its consumption of protein from 6.5g daily, to 39g, a 6-fold increase. Again, developed nations, like the US, did not experience a large increase in protein from animal sources over the past few decades.

Figure 12 Per Capita Daily Sources of Protein, 1980

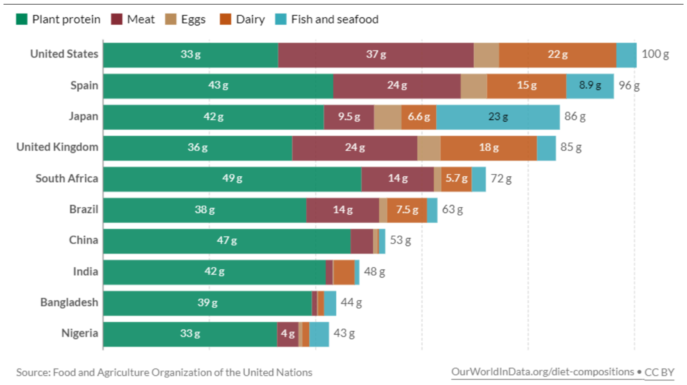
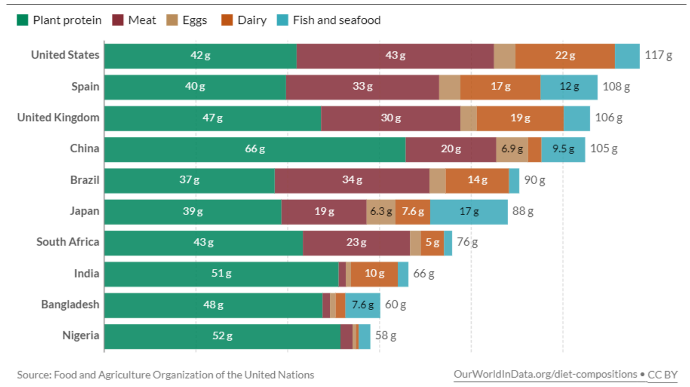


Figure 13 Per Capita Daily Sources of Protein, 2020



Source: OurWorldInData.org

Figure 14 Animal Protein Consumption, 1980. Daily Average Supply Per Capita

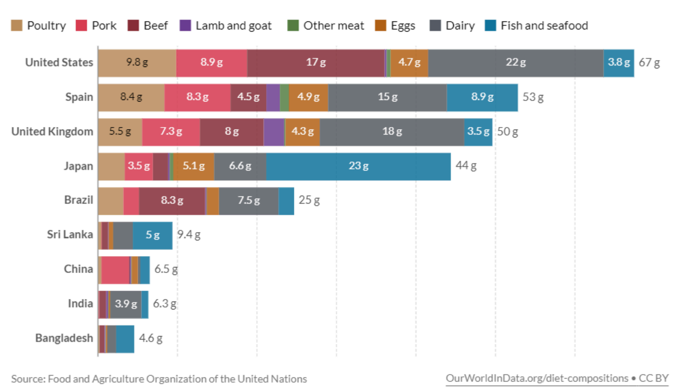
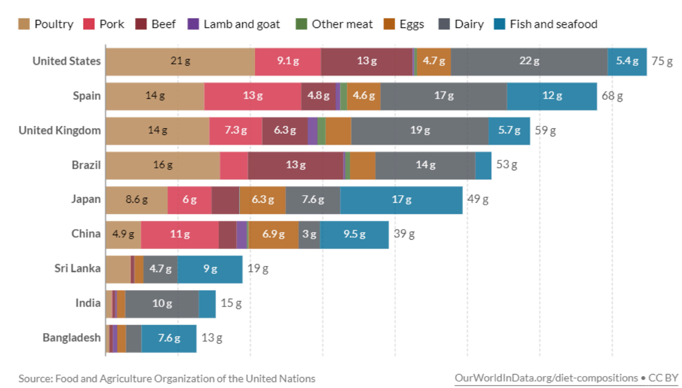


Figure 15 Animal Protein Consumption, 2020. Daily Average Supply Per Capita



Source: OurWorldInData.org

There is an irony that can ultimately develop over time. Gaining national wealth typically drives increased meat consumption. Sustaining wealth for an extended period can lead towards concerns about health, environmental sustainability, animal welfare, and ethical considerations prompting some to seek a rise in alternative dietary choices, including vegetarianism, veganism, and flexitarianism.

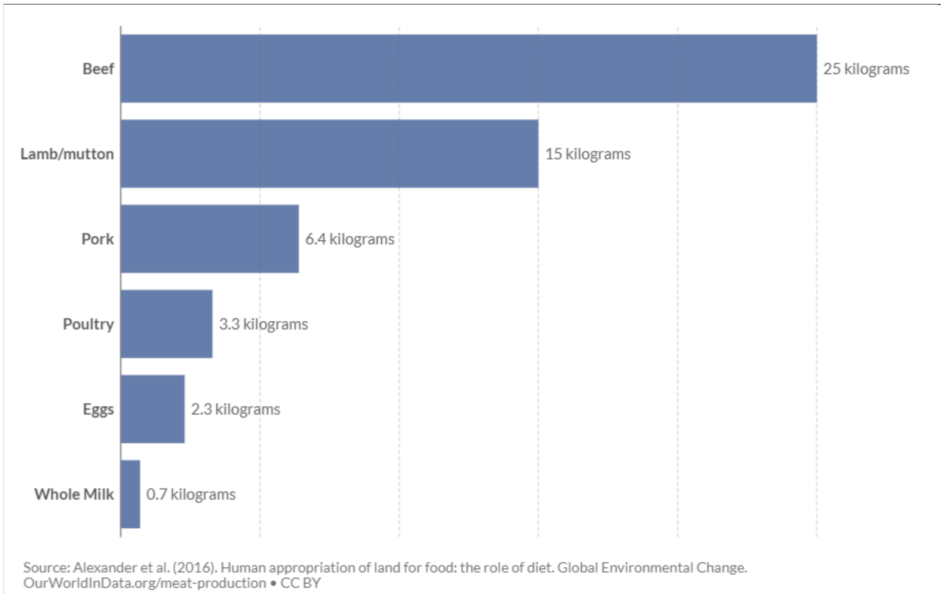
The growth of the middle class is often accompanied by rapid urbanization. Urban lifestyles, with increased work demands and time constraints, lead to a greater reliance on convenience foods and ready-to-eat meals. These convenience-oriented food options often include meat products, contributing to an overall increase in meat consumption. Finally, in some emerging economies, meat consumption is associated with improved nutrition and health outcomes. As consumers become more health-conscious, they may view meat as a valuable source of essential nutrients and protein.

Implications For Agriculture From Increased Meat Consumption

As meat consumption grows, there is a higher demand for animal feed, such as grains and protein-rich cops. Livestock production requires substantial quantities of feed to support the growth and development of animals. This increased demand for animal feed puts pressure on agricultural systems to produce larger quantities of feed crops. The increase in meat consumption can drive changes in agricultural practices. For instance, traditional small-scale farming systems may transition to more intensive and industrialized livestock production methods to meet the growing demand. This shift can have environmental implications, such as increased use of fertilizers, water, and energy, as well as the potential for pollution from animal waste.

In terms of feed required to produce animal protein, beef in particular stands out negatively. Beef requires by far the most feed to produce 1kg of feed relative to other traditional protein sources.

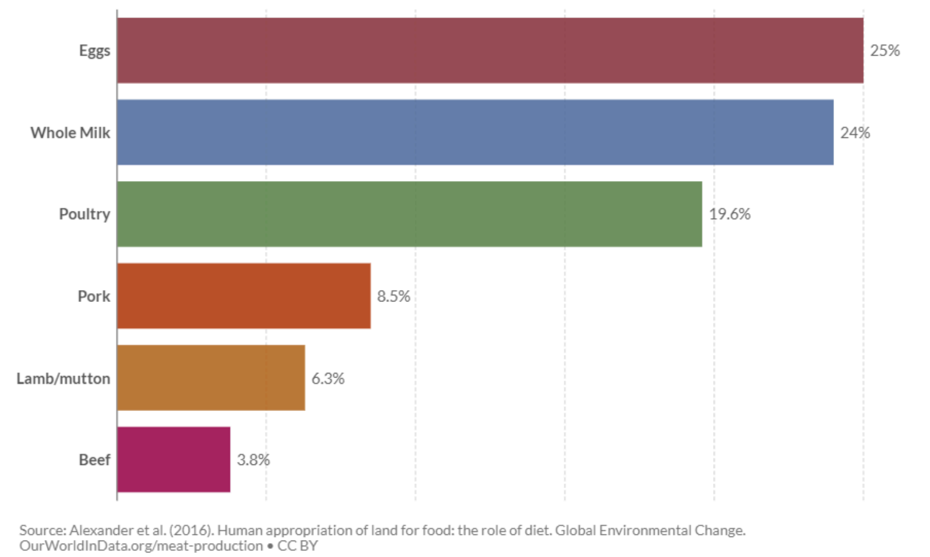
Figure 16 Beef Requires The Most Amount Of Feed To Produce One Kilogram Of Meat



Source: OurWorldInData.org

In addition to the very poor efficiency of producing beef, this specific type of meat has the lowest protein conversion efficiency. In the figure below, an efficiency of 25% means that 25% of protein in animal feed inputs were effectively converted to animal product. The remaining 75% is essentially lost during the conversion.

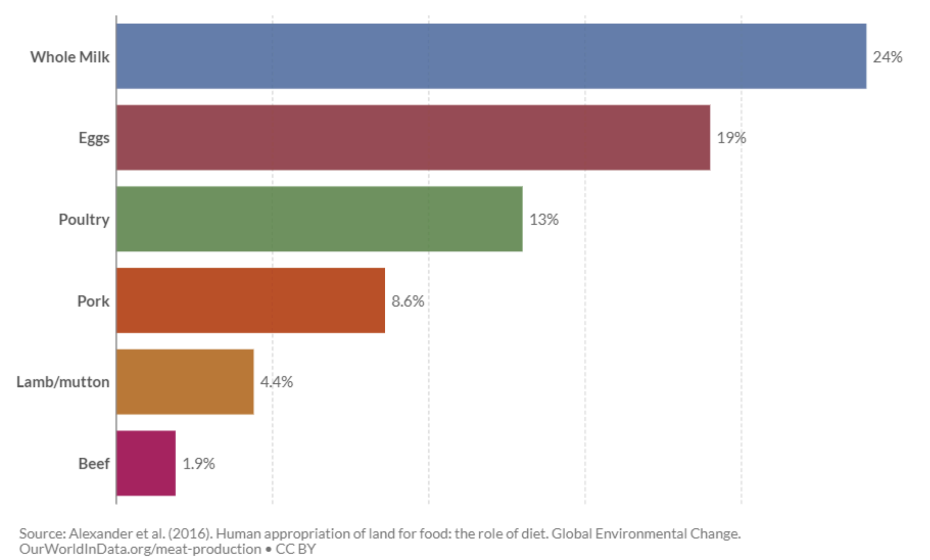
Figure 17 Beef Has Very Poor Protein Conversion Efficiency



Source: OurWorldInData.org

It is also worth noting that beef has a very low energy conversion efficiency. In the figure below, efficiency of 25% means that 25% of calories in animal feed inputs were effectively converted to animal product. The remaining 75% is lost during conversion.

Figure 18 In Addition To Poor Protein Conversion, Beef Is Also Notorious For Low Energy Conversion Efficiency



Source: OurWorldInData.org

Other detrimental aspects of beef production include the emissions, measured in carbon dioxide-equivalents (non-CO2 gases are weighted by the amount of warming they cause over a 10-year timescale), and the relative high amount of water used per kilogram of food product.

Figure 19 Greenhouse Gas Emissions Per Kg Of Food Product

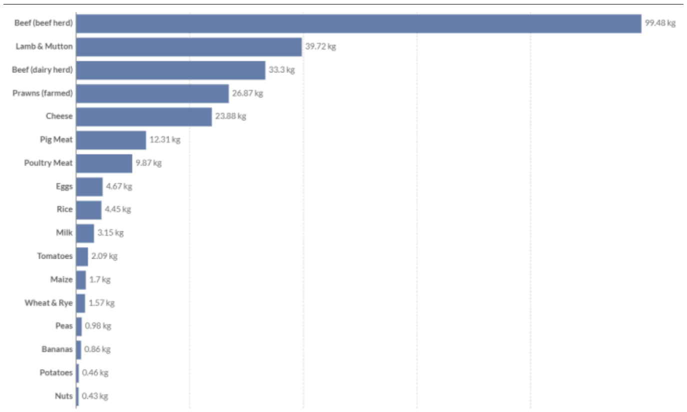
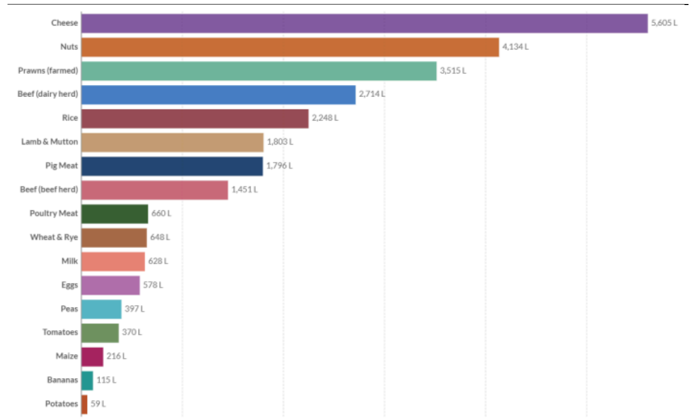


Figure 20 Freshwater Withdrawals Per Kg Of Food Product



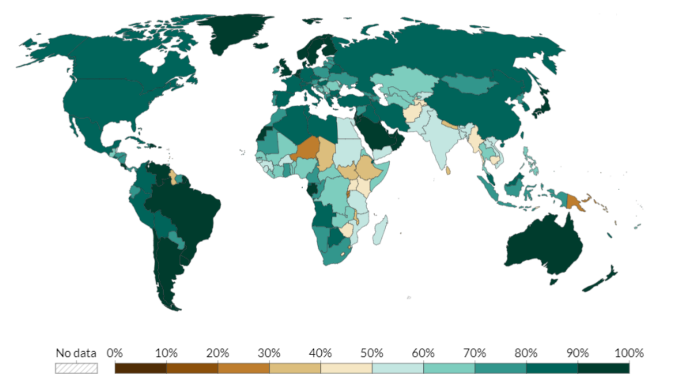
Source: OurWorldInData.org

Urbanization

The UN World Urbanization Prospects estimates that by 2050, more than two-thirds of the world will live in urban areas. These projections assume that by then, nearly all countries will be mostly urban. It is worth noting that India, the most populous country, is projected to have an urban share of only 53% in 2050, which drives the world average down. The UN estimates that by 2050, the world population will reach 9.8 billion people, 7 billion of which are projected to live in urban areas. Urbanization is a byproduct of countries becoming richer. These trends can be complex, however, studies have shown that some of the recognized benefits of urban settings include high-density of economic activity, greater access to amenities and services, utilization of human capital, cultural and social attractions, and the perception of better opportunities and lifestyle.

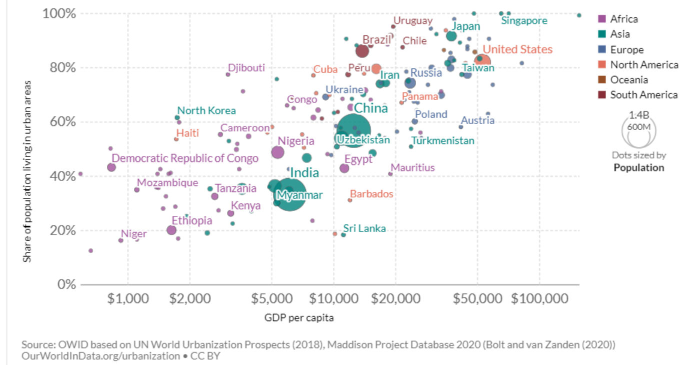
Urban populations tend to have higher living standards, though establishing a clear causal relationship between the two is challenging. Urbanization and living standards are interrelated and mutually reinforcing, making it complex to isolate their specific impacts. Nevertheless, in nearly all countries, electricity access is higher in urban areas than in rural areas. Urban areas also provide better access to improved sanitation, drinking water, and higher proportion of clean fuels for cooking and heating.

Figure 21 Share Of Population Living In Urban Areas, 2050



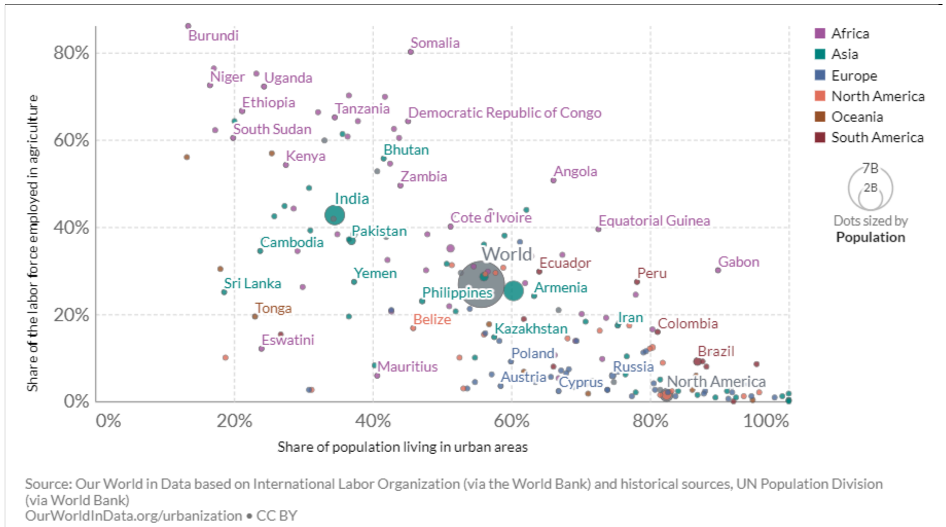
Source: OurWorldInData.org

Figure 22 Urban Population vs. GDP Per Capita, 2016



Rural-urban migration has been empirically linked with the structural employment shift from agriculture towards industry and manufacturing or services. This creates, at least momentarily, labor shortages in agriculture, resulting in challenges for productivity and output. Consequently, this migration also drives technological adoption and innovation in agriculture to compensate for the labor shortage.

Figure 23 Share Of People Employed In Agriculture vs. Urban Population, 2019



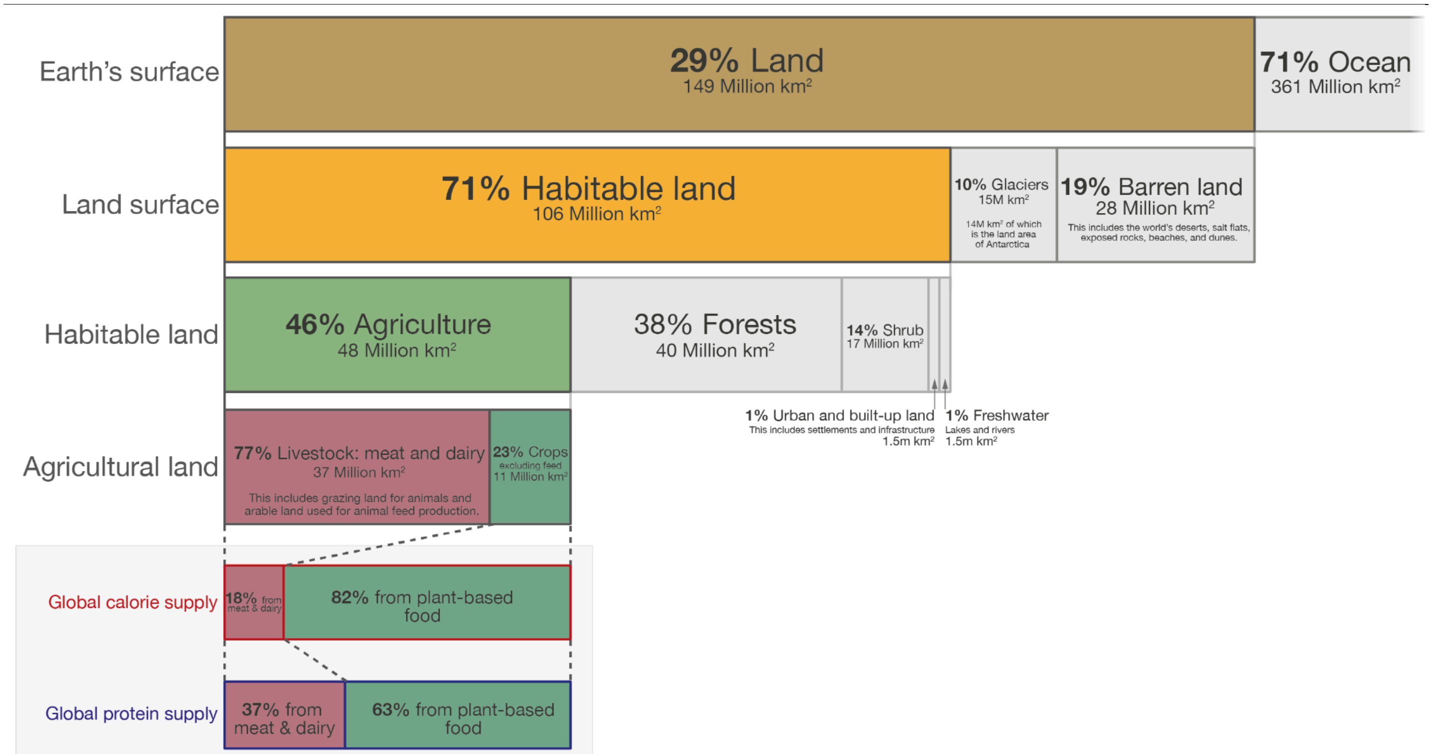
Source: OurWorldInData.org

Aside from the labor shortages in farming activities, urbanization often leads to the conversion of agricultural land into urban infrastructure and housing, reducing the available land for farming. The expansion of cities and towns encroaches on agricultural areas, diminishing the overall agricultural footprint and limiting the potential for agricultural expansion. Urbanization also influences the types of crops grown and farming practices employed. As agriculture adapts to urban markets, there may be a shift towards high-value crops, specialty products, and organic farming to cater to urban consumers' preferences. Intensive and commercial farming methods may become more prevalent, focusing on maximizing yields and profitability. In turn, the need to increase productivity with limited labor resources encourages the implementation of mechanization, precision farming techniques, and other modern technologies. This can enhance efficiency, optimize resource use, and improve overall agricultural productivity.

Half Of The World's Habitable Land Is Used For Agriculture

The UN Food and Agriculture Organization (FAO) estimates that 10% of the world is covered by glaciers, another 19% is barren land – deserts, dry salt flats, beaches, sand dunes, and exposed rocks – which leaves what is referred as "habitable land". Half of all habitable land is used for agriculture.

Figure 24

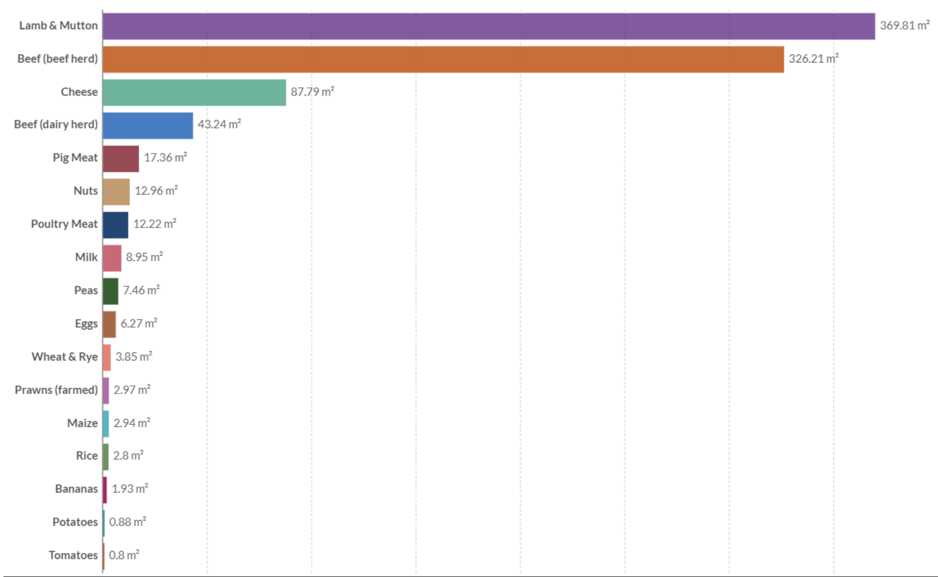


Source: OurWorldInData.org

Interestingly, over three-quarters of the agriculture land is used for livestock, which includes grazing land for animals and arable land for animal feed production. Despite taking a large majority of the land, meat and dairy production only accounts for about 18% of the world's calorie supply. Perhaps more surprisingly, the same land only accounts for 37% of the global protein supply.

We addressed some of the environmental impact form beef production above. In addition to the low protein conversion and energy consumption, beef production also requires a lot of land. As shown below, each kilogram of beef produced requires over 300 square meters of land. To put this in perspective, an American football field of land yields only 36 pounds of beef.

Figure 25 Lamb And Beef Require The Most Land Area Per Kilogram Of Food Product



Source: OurWorldInData.org

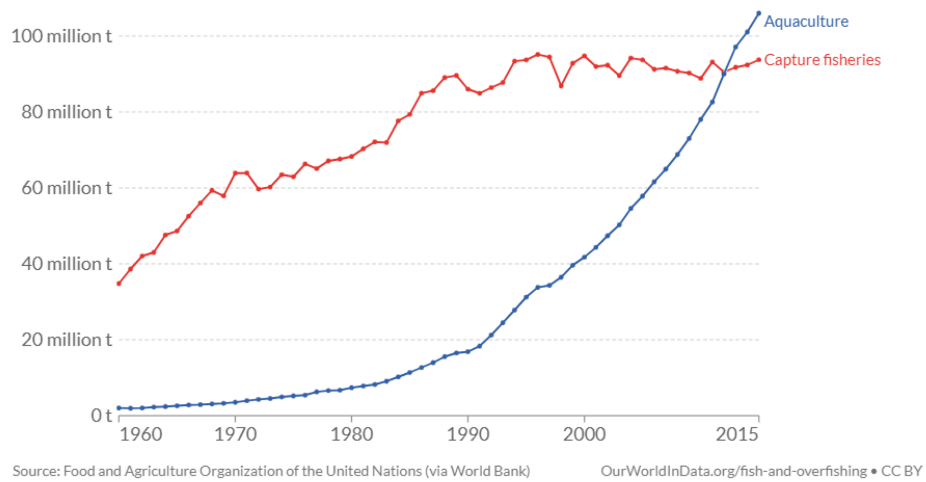
The Need For Protein – Fish Farming Provides A Cheaper, Healthier, And More Sustainable Way To Feed The Growing Middle Class

See highlights from our conversation with Radmantis on this topic HERE

The global production of fish and seafood has quadrupled over the past 50 years. We note that the world's population more than doubled over that period, but the average person now eats almost twice as much seafood than half a century ago. Demand for fish products shares similar factors with meat – rising income leads to changing dietary preferences. Furthermore, fish is also considered a healthy protein source and its consumption has been encouraged by nutritional guidelines and awareness. Unfortunately, this increase in consumption has driven overexploitation and current levels of wild fish catch are unsustainable.

One innovation which has helped alleviate some of the pressure on wild fish catch is aquaculture. Humans have been raising land-based animals on farms for thousands of years. Fish farming, on the other hand, is just over 50 years old. Aquaculture, also known as fish farming, is the practice of cultivating fish and other aquatic organisms in controlled environments for commercial purposes. Fish farming can be carried out in various settings, including freshwater, brackish water, and marine environments, and encompasses a wide range of species, including freshwater fish like tilapia and catfish, as well as marine fish like salmon, trout, and sea bass, In addition to fish, aquaculture also involves the faming of other aquatic organisms such as shrimp, oysters, mussels, and seaweed.

Figure 26 The Amount Of Wild Fish Catch Has Remained Relatively Even Over The Past 30 Years, While Fish Farming Has Exploded



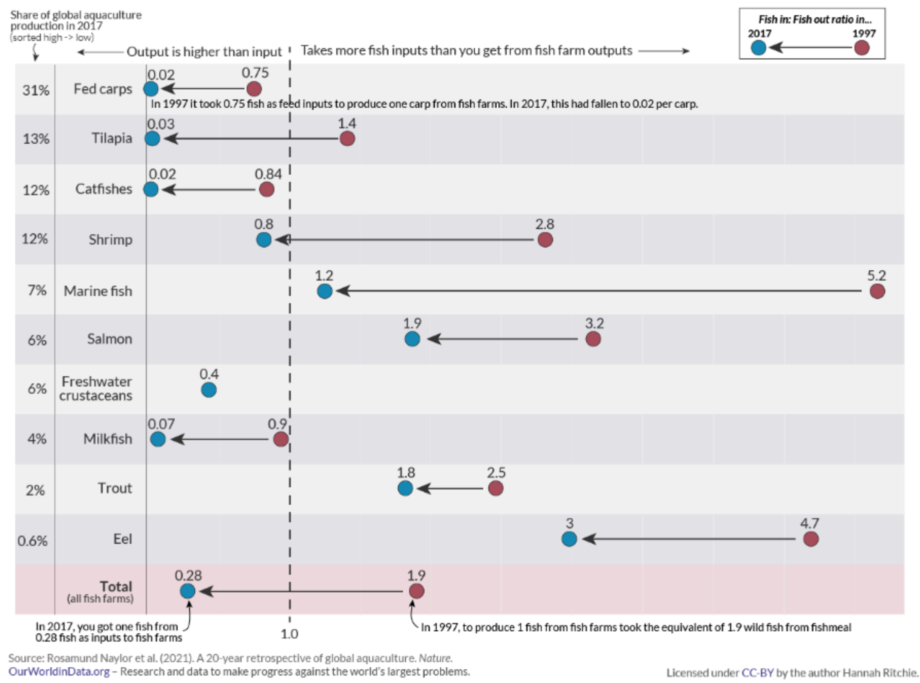
Source: OurWorldInData.org

Aquaculture often relies on wild fish catch as a key component of feed, specifically fishmeal and fish oils. Fishmeal is a high-protein feed ingredient made from wild-caught fish, while fish oils are rich in omega-3 fatty acids and are also derived from wild fish. This practice has raised concerns about its sustainability and the impact on wild fish stocks. The demand for fishmeal and fish oils puts significant pressure on wild fish populations and can contribute to overfishing and depletion of fish stocks. This has ecological consequences and affects the overall health of marine ecosystems. There are alternatives that include plant-based protein, though some of these feeds lack the specific nutritional requirements that are more efficiently met by fishmeal and fish oils. The aquaculture industry is striving to strike a balance between sustainable feed sourcing and meeting the nutritional needs of farmed fish. This involves continually improving feed formulations, exploring new feed ingredients, and optimizing feed conversion rates. The aim is to reduce the reliance on wild fish catch for aquaculture feed while ensuring the sustainability and long-term viability of the industry. Today, around 11% of fish catch is used as feed for aquaculture. The good news is that this ratio has declined over the past several years. Even though aquaculture increased by 250% between 2000 and 2015, fish catch used for feed actually declined.

Aquaculture is a net producer of seafood by a factor of three. However, there is a high degree of variation between the types of fish. Overall, we note that aquaculture has made meaningful improvement in efficiency over the past quarter century.

The figure below illustrates the improvement in the fish in : fish out (FIFO) ratio for different types of fish. The FIFO ratio tells us how much fish is needed to feed aquaculture species to get one fish back in return. A ratio of 2 means that we need two fish equivalents of fishmeal and oil to be able to produce one fish in return. A ratio of 0.5, on the other hand, means that we get 2 fish back from every fish put in.

Figure 27 The Aquaculture Industry Has Become Significantly More Efficient Over The Last 25 Years



Source: OurWorldInData.org

Megatrend #3 - Water Scarcity And Implications On Food Production

Agriculture accounts for about 80% of the water consumed in the United States, while the remaining 20% is attributed to municipal, industrial, and other purposes. Irrigated agriculture is the largest consumer of water in the US. It encompasses the artificial application of water to crops through various methods such as sprinkler systems, drip irrigation, and surface irrigation, Irrigation helps supplement natural rainfall, particularly in arid and semi-arid regions. Irrigation efficiency – the amount of applied water that effectively reaches the plant roots and contributes to crop growth – can vary depending on factors such as irrigation method, infrastructure, soil type, and management practices. On average, irrigation efficiency ranges from 60% to 80%, meaning that some portion of applied water may be lost due to evaporation, runoff, or deep percolation. Surface water and groundwater are the primary sources of irrigation water in the US. Surface water includes rivers, lakes, reservoirs, and canals, while groundwater refers to water stored underground in aquifers. The availability and reliability of these water sources can vary across regions and can impact the sustainability or irrigation practices. Water management practices play a crucial role in improving water use efficiency in agriculture. These practices include:

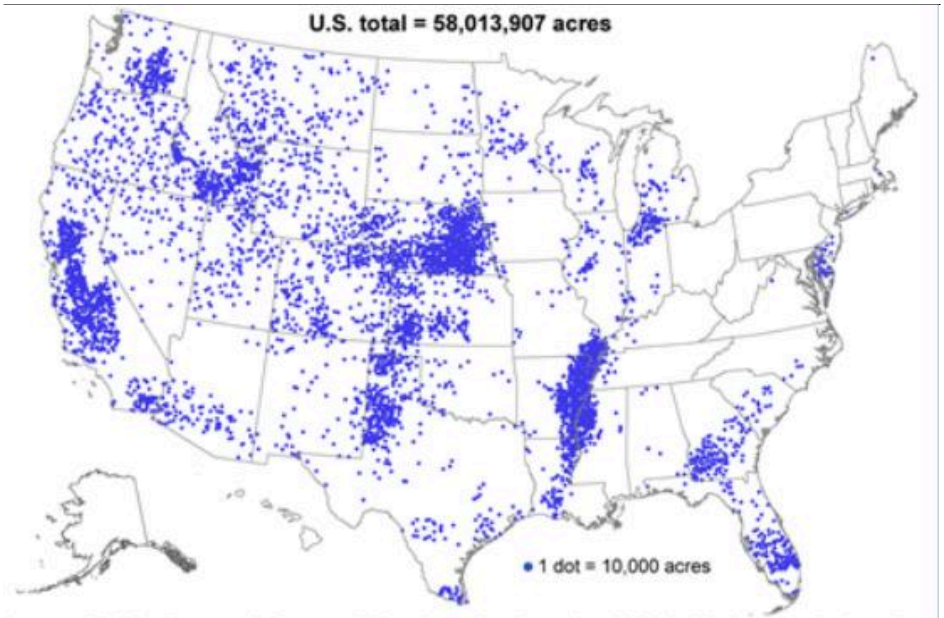
- Precision irrigation technologies: Technologies such as soil moisture sensors, weather-based irrigation controllers, and variable-rate irrigation systems help optimize water application based on crop water requirements and minimize losses.

- Regulated deficit irrigation (RDI): RDI involve intentionally applying less water than the crop's full water requirement during specific growth stages to induce mild water stress, which can improve water use efficiency without significant yield losses.

- Conservation practices: Cover cropping, mulching, and conservation tillage techniques help reduce evaporation, conserve soil moisture, and improve water infiltration, thus maximizing water utilization by crops.

- Water recycling and reuse: On-farm practices such as capturing and reusing runoff and tailwater, as well as implementing drainage water management systems, can reduce water waste and enhance overall efficiency.

Figure 28 US Acres Of Irrigated Land By County, 2017



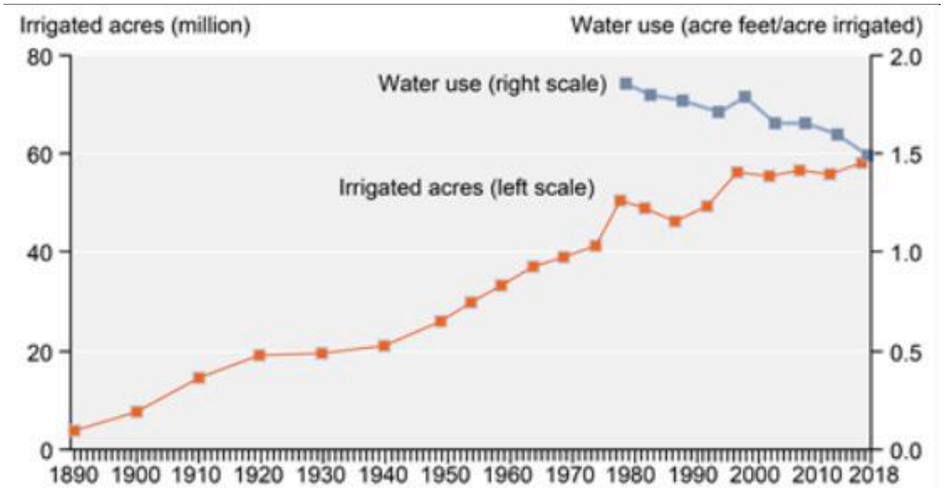
Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, 2017 Census of Agriculture.

Source: ERS.USDA.GOV

Irrigation in the US dates to the early days of European settlement, with practices influenced by Native American techniques. Initially, irrigation was mainly practiced in arid regions of the West, where scarcity was a significant challenge. The use of irrigation accelerated in the late 19th and early 20th centuries with the development of infrastructure, such as canals, ditches, and reservoirs. Large-scale projects, such as the Central Valley Project in California, brought water from distant sources to support agricultural production. With the advent of mechanization, especially in the mid-20th century, irrigation techniques evolved. Sprinkler systems, center pivots, and later drip irrigation gained popularity, allowing for more efficient water application and reduced evaporation losses. Irrigation expanded beyond the traditional western states to include regions in the Midwest, South, and Southeast, This expansion was driven by the need to support diverse crop production and ensure stable food supplies. Over time, advancements in water management practices have aimed to improve efficiency and conserve water resources. These include the adoption of precision irrigation technologies, computerized control systems, soil moisture sensors, and remote monitoring, enabling farmers to better manage water application based on crop needs.

Over the past 4 decades, the intensity of irrigation (measured as the nationwide average of water use per acre irrigated) has declined in part to improved efficiency in water application technologies, but also due to changing cropping patterns, and regional shifts in area irrigated.

Figure 29 US Irrigated Acreage And Water Use Per Acre Irrigated, 1890-2018

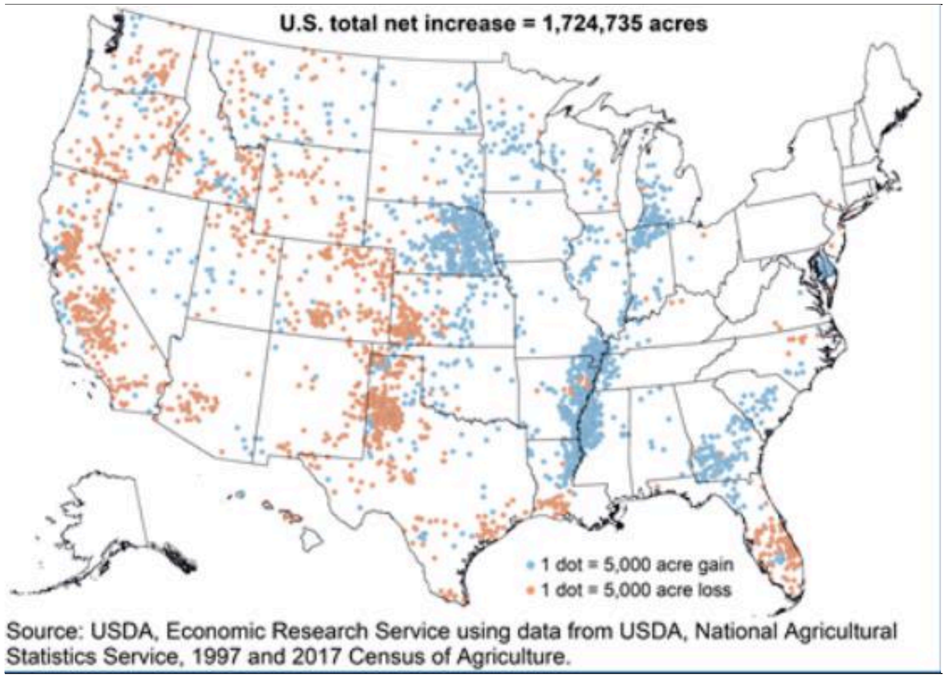


Note: An acre foot of water equals about 326,000 gallons, or enough water to cover an acre of land 1-foot deep.
Sources: Irrigated acreage data are from USDA, National Agricultural Statistics Service and predecessors, Census of Agriculture (1890-2017). Water use data are from USDA, National Agricultural Statistics Service, Census of Irrigation and Drainage on Farms (1969, 1974), Farm and Ranch Irrigagion Survey (1979-2013), and the Irrigation and Water Management Survey (2018).

Source: ERS.USDA.GOV

Water usage efficiency has continually improved over the past decades, but the number of irrigated acres is up 50% from the mid-1970s, largely offsetting much of the efficiency gain when viewed on a gross water usage basis. There are some important shifts taking place at the inter-regional level. For example, between 1997 and 2017, total irrigated agriculture land in California saw a decline from 8.8 to 7.8 million acres, while irrigated land in Nebraska increased from 7 to 8.6 million acres. These regional trends highlight how changing water availability - due to competing demand, drought impact, and groundwater depletion – has influenced the distribution of irrigated production. The map in the figure below, emphasizes the shift in total irrigation – mostly a loss to the western part of the US and a net gain for the mid-west and east of the country.

Figure 30 Change In US Acres Of Irrigated Agricultural Land By County, 1997-2017



Source: ERS.USDA.GOV

Pioneering Precision Ag – The Deere Story (Matt Elkott)

Deere is nearly two centuries old but has not ceased reinventing itself. The company is a pioneer of precision ag, which can be traced back to the late 1990s/early 2000s, when GPS technology paved the way for yield mapping, AutoTrack and Selection Control—base features in today's equipment. The 2010s saw the evolution to connectivity and cloud-based computing and the John Deere Operations Center, an open online farm management system that allows farmers to access and input data.

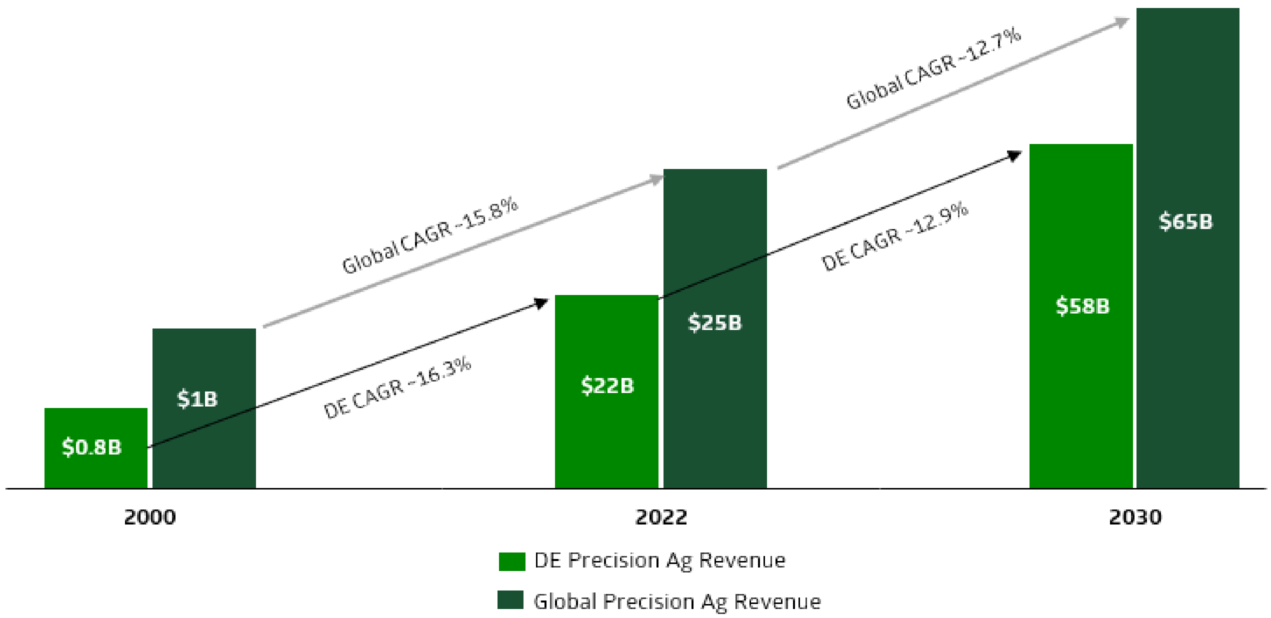
There is not a purely scientific and unequivocal definition of precision ag. And as new technologies evolve and replace prior ones, the rolling effect of the historical timeline means that one must continuously reevaluate what can be considered the origin and hence the origin story. We believe it is reasonable to mark the year 2000 as the starting point of commercial application. In absence of concrete reported metrics during that time and based on our industry checks and examination of the technology, we have assumed that the global precision ag market size in the broadest sense was roughly $1Bn in 2000, with 80% of it being pioneered by DE. We estimate that the global market has grown at a 15.8% CAGR from 2000 to 2022, with DE, which is most of it, having grown at a 16.3% CAGR. Our estimate bakes in most of DE's Production and Precision Ag revenue, even though, if one chooses a starting point later than 2000, not all of it would qualify. We also factor in revenue from AGCO, which we see as DE's distant second; CNHI; TRMB; Claas; Lovol; and others. It is important to note that some of the revenue is components and services, but the majority OE. In Figure 1 and 2, which should be looked at together, we depict our estimated historical and future precision ag market.

Today, DE, which is the clear leader and far ahead of everyone else, has over 397MM engaged acres, with a goal of reaching 500MM by 2026. Engaged Acres is one of the foundational measures of customers' use of the John Deere Operations Center. It reflects the number of unique acres with at least one operation pass documented in the Operations Center in the preceding 12 months. Of the 500MM engaged acres targeted for 2026, the company envisions 50% being highly engaged acres, which is defined as the number of unique acres with documentation of multiple production steps and the use of digital tools to complete multiple value-creating activities in the preceding 12 months. The company also aims to ensure that 75% of engaged acres are sustainably engaged by 2030. Sustainable engaged acres are defined as the number of unique acres farmed with two or more sustainable John Deere technology solutions or sustainable practices over the preceding 12 months.

Addressing farmers with existing fleets comprising older John Deere models and mixed fleets, the company has developed the '4640 Universal Display' within its precision ag product line, offering its customers solutions for realistic scenarios. Further adapting its technology to fit mixed fleets gives DE an opportunity to reach a broader consumer base to market other emerging technologies within this space.

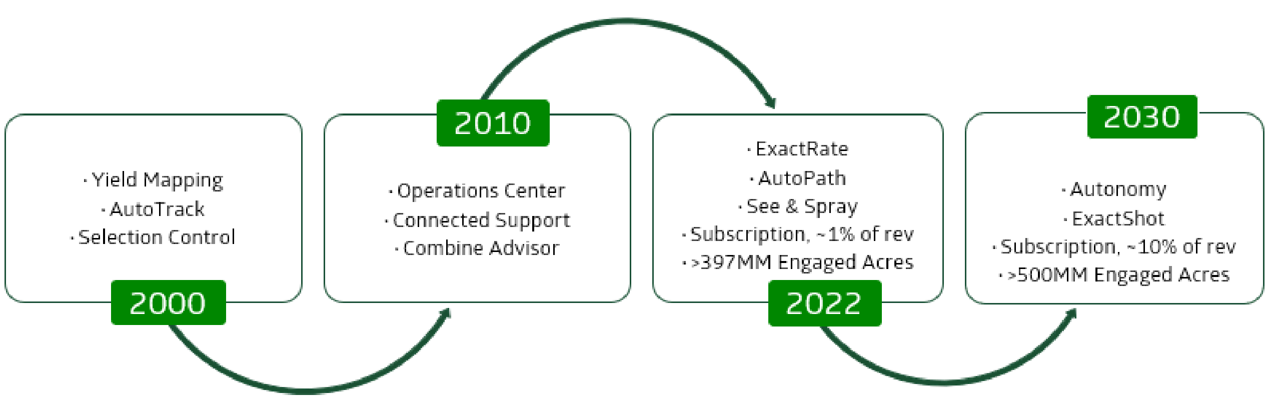
Earlier this year, DE showcased ExactShot, a starter fertilizer application designed to succeed ExactRate. ExactShot's primary benefit is the variable rate of starter fertilizer application, as opposed to continuous application. In testing, DE has seen north of 60% fertilizer volume savings at 10mph. For US corn, this could translate to savings of over 90MM gallons of starter fertilizer and over $600MM in savings for farmers annually. Initial ExactShot testing is this year, with commercial use likely in the next few years. Existing planters could be retrofitted possibly going back to 2015 models. While ExactRate is all upfront, ExactShot could have a recurring revenue component in addition to the equipment cost.

Figure 31 Estimated Historical & Future Precision Ag Revenue



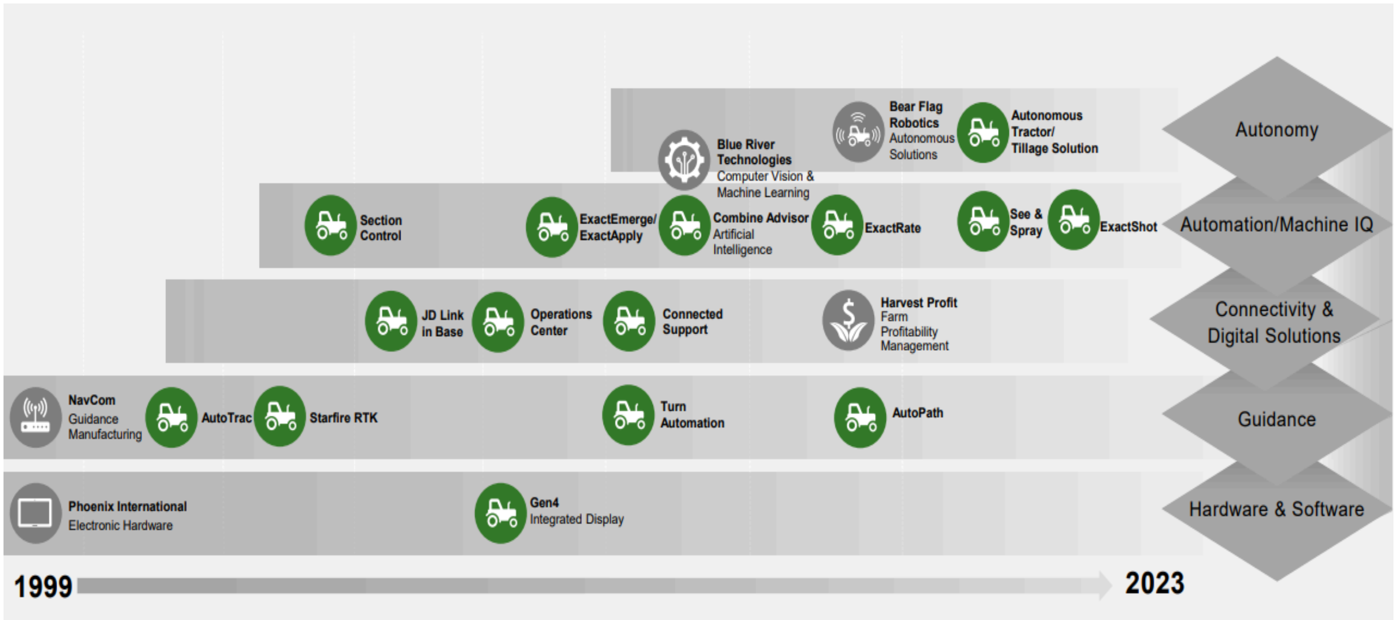
Source: TD Cowen Estimates

Figure 32 DE's Precision Ag Technologies Timeline



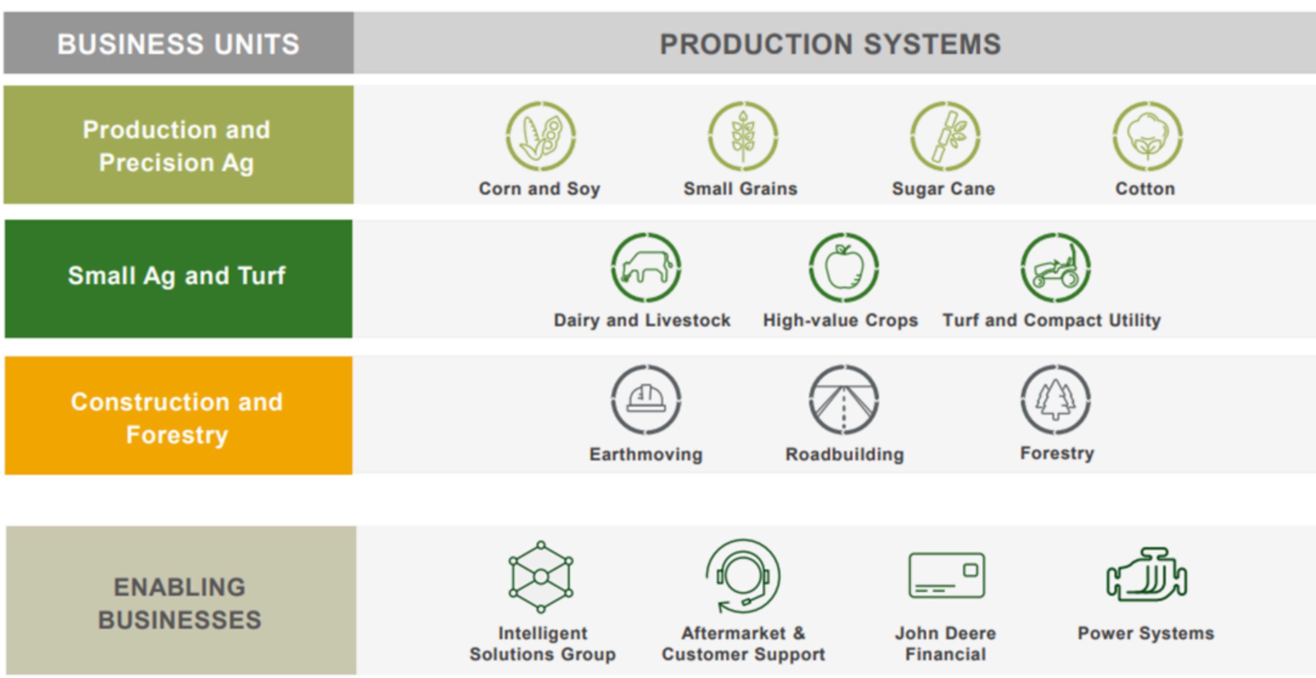
Source: TD Cowen, DE

DE's Precision Ag Historical Timeline



Source: DE

DE Equipment by the End Markets Served



Source: DE

The Subscription Model Could be a Tough Sell Right Now, But Robust Precision Ag Growth Should Continue Without It

The precision ag subscription model, birthed by Deere, is still in its infancy. The company has a goal of reaching 10% recurring revenue by 2030, in large part through the introduction of the subscription model. But the march toward 10% may be more back-end weighted than some investors may think. We believe the company may not show much reportable progress on this front over the next 12-24 months. Currently, roughly 1% of revenue is recurring, and one way DE is going to change that is by offering equipment as a service, essentially a structural change in the sale process from point-of-sale to subscription based.

We do think the 10% goal is achievable by 2030, and we have devised a hypothetical calculation detailing the fertilizer, herbicide, and labor savings to farmers that should get the subscription model going. But we think this is going to be slower than a typical new product adoption curve. We did find some indications that new product adoption by farmers is not that dissimilar from the generic consumer adoption curve. But this is not just the introduction of a new model tractor. This is reconditioning the customer base into a new way of acquiring products and services. And because of the sometimes-brutal uncertainty inherent in farming, it may prove challenging at first to get buyers to commit to a subscription model. We think the contract structure could undergo many fine tunings before it reaches a sweet spot that is appealing to end users and makes sense for Deere.

Some might say that if the company is still around 1% recurring revenue into FY24, it would not be a big deal. True, that may not be disappointing in itself, but it would probably make more investors want to know where DE is going to be by the end of that year; and if things appear to be going slowly, that could be a headwind to the stock. As far as other ag equipment manufacturers, we encountered mixed views on the subscription model, with AGCO, for example, a bit more enthusiastic than CNHI.

If DE does achieve meaningful traction with the subscription model, more investors may begin to view the company as the AAPL of agriculture. With already a 60% market share in NA large ag, DE could make it even more compelling for farmers to stick to its products with a subscription model. It would not be too dissimilar to how a consumer using an iPhone and iOS may be more likely to purchase a MacBook than a non-Apple computer.

Line of Sight to Recurring Revenue Growth but Bumps Along the Way

We devised an example to gauge the recurring revenue potential from new precision ag technologies introduced this year and ones likely to be introduced in the coming years. Our example (see below) yielded an incremental recurring revenue opportunity from new precision technologies used in U.S. corn alone for DE of $2.8Bn. We estimate that the U.S. soybean opportunity could be close to $2.0Bn, for a total of $4.8Bn from U.S. corn and soybean alone. Assuming a similar amount from all other U.S. crops and the total opportunity outside the U.S., we get to $9.6Bn. These results give us confidence in the company's ability to achieve its 2030 goal of 10% recurring revenue.

Assuming this is heavily back-end weighted (more so than many investors might think), and assuming a high-teens margin, we see a potential path for DE to get to $38 of EPS in 2026, representing a ~14% CAGR over four years, concurrent with a low double-digit CAGR in engaged acres. Our sense is that Street expectations are at least just as optimistic and assume smoother growth than we do. We are modeling for a period of moderating growth in 2024/25, as we are starting to see initial signs of cost-related demand moderation. We also want to account for a host of variables that could pose what seem to be underappreciated risks in the coming two years.

Figure 33 Precision Ag Incremental Recurring Revenue Potential

Hypothetical Example Illustrating Incremental Precision Ag Recurring Revenue Potential for DE from New Equipment for US Corn				
	Based on current equipment technology	**Based on using See & Spray Ultimate for herbicides**	**Sense & Act for Fertilizer**	**Autonomy**
	In service today	*Introduced early 2022*	*Likely in coming years*	*Likely in coming years*
A farmer's total fertilizer cost as a percent of the farmer's per-acre crop revenue	25%	25%	15%	15%
A farmer's total herbicide cost as a percent of the farmer's per-acre crop revenue	6%	2%	2%	2%
A farmer's labor cost as a percent of the farmer's crop revenue	4%	4%	4%	2%
Recurring precision ag fees paid to OEM by the farmer	0%	1%	3%	4%
Total of the above selected costs to the farmer as a percent of the farmer's per-acre crop revenue	35%	32%	24%	22%
$ amount per acre of total selected costs	400	365	274	251
$ amount of savings per acre				148
Hypothetical acres (MM)				90
Savings from upcoming precision ag technologies ($MM)				$13,361
Portion of savings maintained by farmers				$8,818.52
Portion of savings to equipment manufacturers				$4,542.88
Portion of savings to DE at 62% of US market*				$2,816.58

* Assumes market share gain of ~200bps

Source: TD Cowen estimates, USDA, SEC filings, DE

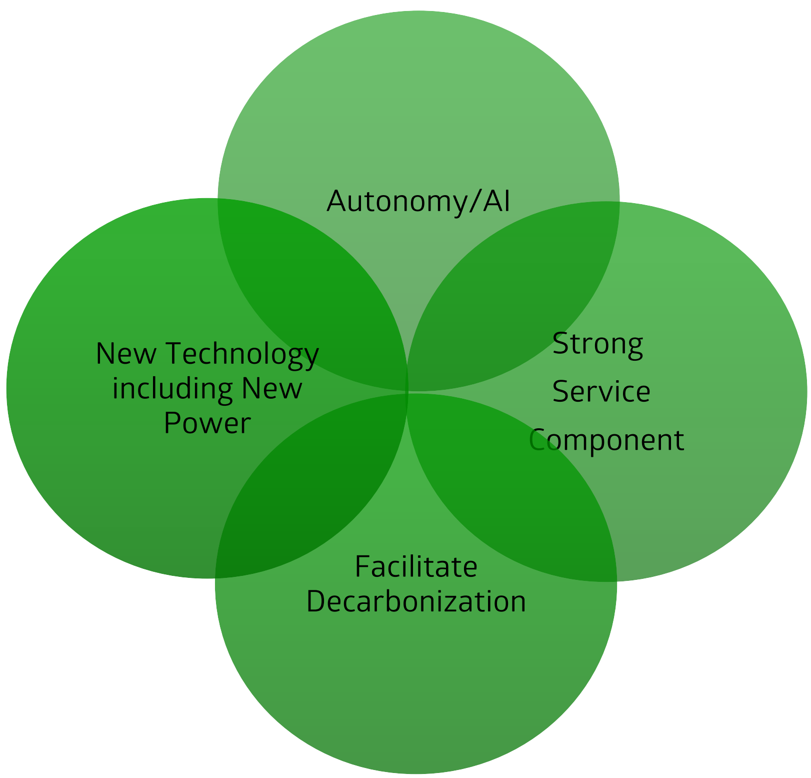
External Growth Should Continue to Be Part of the Story – Identifying the Acquisition "Sweet Spot"

As we worked to construct a view on future acquisitions, we sifted through filings, earnings calls, and industry presentations, among other things. Then, with our industry checks and secular trends in mind, we developed the diagram below to illustrate our view of the areas ag equipment manufacturers, led by DE, are likely to target for acquisitions. We believe they will seek deals that satisfy at least two of four criteria: 1) A strong autonomy or AI offering; 2) New technologies, including new power; 3) Targets that facilitate decarbonization, directly or indirectly; 4) A material percent of revenue from recurring services. These criteria are associated with positive environmental attributes, strong pricing, and secular growth trends that could help offset the seasonality and cyclicality of the business through multiyear replacement and/or retrofitting.

It is not hard to envision a scenario in which the culprits behind a potential financial market pullback are consumer related and not quite as detrimental to the machinery sector, which is set to benefit from future government infrastructure spending, growth of autonomous technology, and energy transition forces. Depressed valuations could help to widen the M&A target pool. Alternatively, lower valuations could make the precision ag companies themselves attractive to mega investment conglomerates. AGCO Corp., for example, has long been viewed as a potential acquisition target for several companies, including CAT. We see a takeout by the construction equipment giant as unlikely because it already has more than ten end markets and sub-markets, and an entry into ag equipment (CAT's current ag exposure is mostly post-harvest) would add another layer of complexity to the CAT story. Instead, we have published about the possibility of CAT selling the transportation segment or some of its assets.

One of the most recent major transactions in precision ag was CNHI's $2Bn purchase of Raven in 2021. Another important one was Deere's $250MM acquisition of Bear Flag Robotics, also in 2021. Other potential acquisition targets could include Claas and TRMB.

Figure 34 TD Cowen's Acquisition "Sweet Spot" Diagram for Potential Deals by DE



Source: TD Cowen

Figure 35 Precision Ag Transactions & Potential Acquisitions

Key Precision Ag Transactions			
Acquirer	**Target**	**Close Date**	**Price**
CNHI	Raven Industires	Dec-21	$2.1Bn in cash, representing ~44x trailing EV/EBITDA
AGCO	Faromatics	Sep-21	Undisclosed
DE	Bear Flag Robotics	Aug-21	$250MM
DE	Harvest Profit	Nov-20	Undisclosed
DE	Blue River Technology	Sep-17	$305MM

Potential Precision Ag Acquisition Targets	
Potential Target	
CLAAS	Sensor technology and autonomy
AGCO	Sensor technology, tracking and controlling, autonomy
CNHI	Software and autonomy
TRMB	Guidance systems, correction services, electronic control units
Lovol	Air/mechanical precision seeder
DE	Precision ag pioneer

Source: SEC Filings TD Cowen

Could This Remaining Low-Hanging Fruit Pique the Appetite of Large OEMs?

The primary focus of this report is precision technology in row-crop farming, but the large OEMs have also pursued automation in certain aspects of specialty crops, although full robotic harvesting of specialty crops such as apples and strawberries is one of the remaining low-hanging fruit yet to capture the full attention of the large OEMs. It cannot be completely ruled out that Deere or its smaller OEM brethren would work up an appetite for specialty-crop robotic harvesting companies with viable technologies. While Deere has been developing much of its own hardware and software since the 1990s, the company has not shied away from technology acquisitions when they made sense (Bear Flag Robotics, Harvest Profit, Blue River Technology). AGCO and CNHI have also pursued external growth.

Could the Marriage of Autonomy and Precision Ag Beget a New Breed of Farmers?

DE's precision ag and new progress on autonomy compelled us earlier this year to revisit our contemplation of the farming business model. Taking a very long-term view, the increasing ubiquity of precision ag coupled with the nascent emergence of full autonomy in large-scale farming could lift much of the burden of running a farm off farmers. This could help address labor and generational issues in family farming, with younger members sometimes reluctant to take over the business. We thought of one scenario where equipment dealers could evolve to become farm operators, especially as equipment technology becomes more complex. This could also enable dealers, for some equipment types, to improve utilization by moving some of the more compact machines that happen to be idle at a given time in a given operation to another. While improved equipment utilization may seem like a demand headwind for OEMs, we are talking about a very long-term horizon in which a significantly higher portion of OEM revenue comes from recurring subscriptions. Could other types of equipment operators emerge? Again, it seems unlikely in the foreseeable future, but it is something we will continue to examine.

DE continues to make progress toward its 2030 fully autonomous row crop system. Our recent checks on ongoing tillage campaigns with customers suggest promising results. But our work also shows that farmers who have not tested the autonomous tillage tractor remain skeptical. We see this as unsurprising and note that farmers tend to be science and economics oriented, and if the OEMs can demonstrate the benefit, adoption should follow. Currently, DE has autonomy on over 20K acres (all in North America), which management describes as a small down payment on what's to come. Farm sizes in SA put it next on the list for autonomous testing, followed by Europe.

Tech Anxiety a Minor Transitory Risk

As precision ag technology becomes increasingly complex, and as the prospect of autonomy in commercial use looms, it is important to note that the journey is unlikely to be without bumps. The right-to-repair discussion is likely to continue for the foreseeable future. The following example may be a good illustration of tech anxiety on the part of smaller, less sophisticated farming operations. On the heels of the recent agreement between Deere and The American Farm Bureau Federation boosting farmers' ability to repair their own equipment, Big Equipment Co and Rome Industries announced they will build the first new Big Bud tractor since 1991. When describing the new Big Bud, Big Equipment Co owner Ron Harmon said "[the tractor] is going to have a CAT engine, CAT transmission, CAT axle, and we are going to use the heaviest axles used in the farm industry ever, including heavier than the 747." We note that CAT's current exposure to agriculture is only ~3%, mostly in post-harvest. The new Big Bud is much less computerized than most modern equipment and specifically designed to be easier for farmers to repair without restrictions. Although we believe it is unlikely that precision ag and digitally connected machine adoption could be slowed meaningfully by a potential revival of less computerized equipment (precision ag's input cost reductions and yield optimization are too compelling), it may be a minor transitory risk worth keeping an eye on, especially during cycles of low input costs (particularly if crop prices are also low) when precision ag advantages may be reduced and farmers are more sensitive to the high upfront costs of precision equipment.

No Shortage of Demand Drivers in the Current Cycle, but They're Well Documented

A robust replacement cycle has been underway for much of the last three years, driven by 1) Aging equipment, 2) New technology, 3) Low inventories for much of the last three years, 4) Solid farmer P&Ls, and 5) A favorable equipment CapEx outlook. However, much of this has been well documented.

Figure 36 Our Ag Equipment Revenue Outlook vs Consensus

Ag Equipment Historical Revenues and TD Cowen Estimates ($MM)								
	2018	**2019**	**2020**	**2021**	**2022**	**2023e**	**2024e**	**2025e**
Production & precision ag	13,086	13,364	12,962	16,509	22,003	26,757	29,166	30,916
Small ag & turf	10,105	10,302	9,362	11,861	13,380	14,204	15,056	15,809
Total ag and turf equipment	23,191	23,666	22,324	28,370	35,383	40,962	44,222	46,725
Growth								
Production & precision ag		2%	-3%	27%	33%	22%	9%	6%
Small ag & turf		2%	-9%	27%	13%	6%	6%	5%
Total ag and turf equipment		2%	-6%	27%	25%	16%	8%	6%

Ag Equipment Historical Revenues and Consensus Estimates ($MM)								
	2018	**2019**	**2020**	**2021**	**2022**	**2023e**	**2024e**	**2025e**
Production & precision ag	13,086	13,364	12,962	16,509	22,003	26,484	26,574	27,393
Small ag & turf	10,105	10,302	9,362	11,861	13,380	13,903	13,312	14,621
Total ag and turf equipment	23,191	23,666	22,324	28,370	35,383	40,387	39,886	42,014
Growth								
Production & precision ag		2%	-3%	27%	33%	20%	0%	3%
Small ag & turf		2%	-9%	27%	13%	4%	-4%	10%
Total ag and turf equipment		2%	-6%	27%	25%	14%	-1%	5%

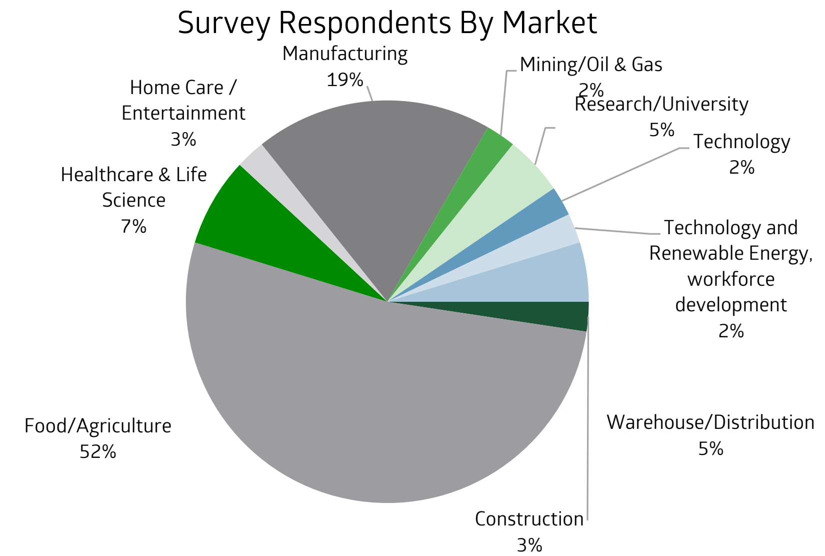
Source: TD Cowen estimates, SEC filings, Eikon

MassRobotics and TD Cowen 2023 Ag Tech Manufacturer And User Survey Results (Joe Giordano)

In conjunction with MassRobotics, we surveyed 42 companies to better understand how robotics is used to tackle the issue of food scarcity at large by focusing on sustainable food production, automation, and energy efficiency. These companies are either robot manufacturers or the technology end-user.

Over 50% of the respondents defined themselves as being part of the food/agriculture industry. Manufacturing was the second largest share at 19% and could encompass robot manufacturers that provide technology for various industries. The primary focus of our respondents is some form of automation – whether it is automated equipment, mobile robots, or guided vehicles. This category represents nearly 50% of the companies surveyed. We note that the second largest share is made up of companies focusing on AI/ML applications with 12% of responses.

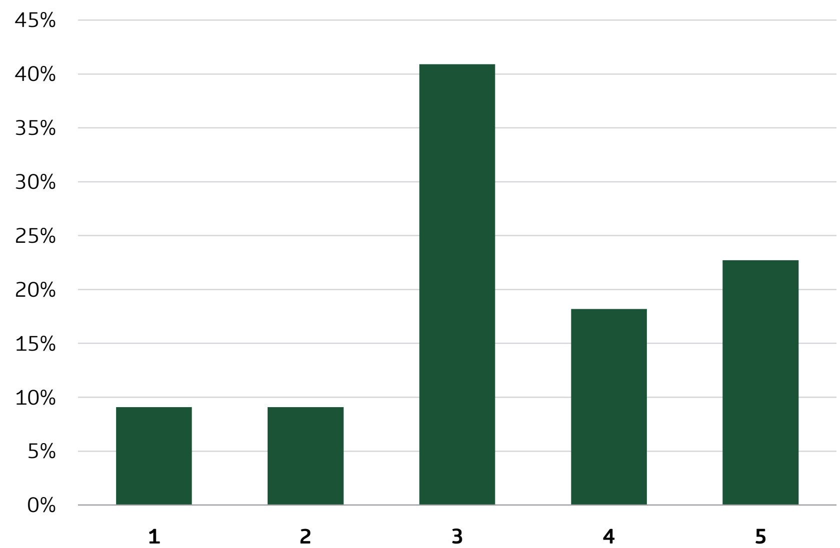
Respondents Largely In Food/Ag Field But Broad Overall Coverage



Source: MassRobotics || TD Cowen Ag Tech Survey 2023, n=42

83% of the respondents are taking some actions to address food scarcity. Most often, the business model of these companies incorporates some aspect of food scarcity by providing innovations aimed directly at this issue. However, the number of companies were split when asked directly if they had publicly committed to objectives to fight food scarcity. For the companies who have committed to objectives to fight food scarcity, their plan of action is relatively well-formalized. On a scale of 1-5, 5 being the best, over 80% of respondents mentioned having a score of 3 or better. This suggests that those that have committed to objectives are making concrete plans to achieve them – certainly a good sign.

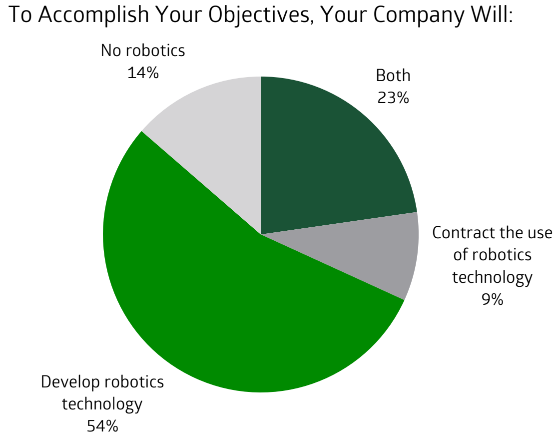
Figure 37 For Companies That Do Have A Plan Of Action, Their Plan Is Relatively Well-Formalized (5 = Most Formalized)



Source: MassRobotics || TD Cowen Ag Tech Survey 2023, n=42

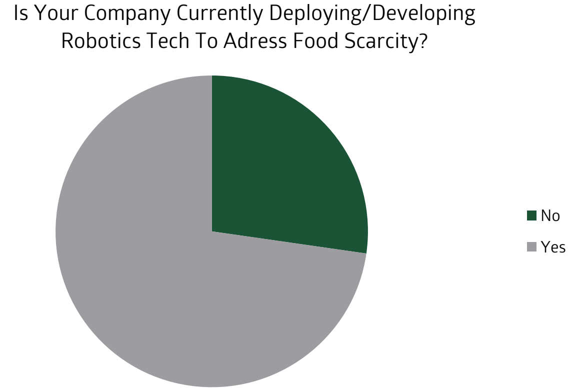
To achieve their objectives, our respondents are more likely to develop robotic technology themselves rather than contract the use of technology. In-house development allows for customization and full control over the design and functionality of the technology (likely protected through patents), allowing the user to tailor it specifically to its needs and preferences. The disadvantages of this approach is the cost, time requirement, and the risk of failure. However, for a market as nascent as ag tech, everyone seems to be on an equal footing in terms of specific expertise. Three-quarters of our respondents noted that they are currently deploying and developing robotics technology to mitigate food scarcity. Most of these technologies revolve around increasing agricultural productivity.

Figure 38 Most Companies Plan To Develop Solutions In-House



Source: MassRobotics || TD Cowen Ag Tech Survey 2023, n=42

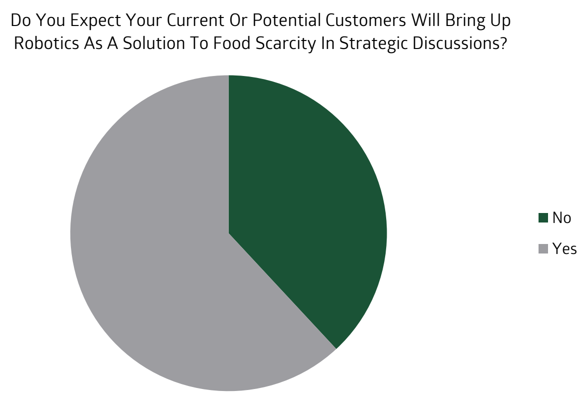
Figure 39 Nearly 75% Of Our Respondents Are Currently Deploying Or Developing Tech



<u>By far the most common barrier to deployment – listed by nearly 2/3 of respondents – was funding. To us, this was the best possible answer, as we view this as an infinitely solvable issue. Either through private venture funding or publicly available resources (grants from organizations like the USDA) – both of which we explore later in this report – we believe good ideas will find appropriate capital.</u>

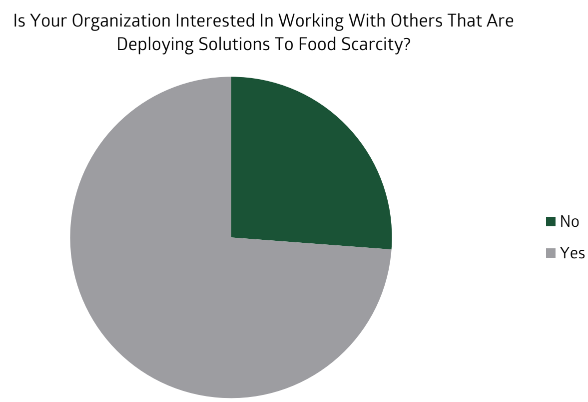
Our respondents widely agree that their current or potential customers will use robotics as a solution to food scarcity. They are also very much in favor of working with organizations that are deploying solutions to food scarcity.

Figure 40 Respondents Believe That Customers Will Use Robotics To Help Solve Food Scarcity



Source: MassRobotics || TD Cowen Ag Tech Survey 2023, n=42

Figure 41 Respondents Are Very Much Interested In Working With Organizations That Focus On Food Scarcity



However, the companies we surveyed were split when asked if their current sales pitch includes the topic of food insecurity or similar topics. Only 12% of our respondents mentioned having seen robotics manufacturers including topics of food scarcity aspects in their pitches.

Figure 42 Companies Are Split In Their Decision To Include Food Scarcity In Their Sales Pitch

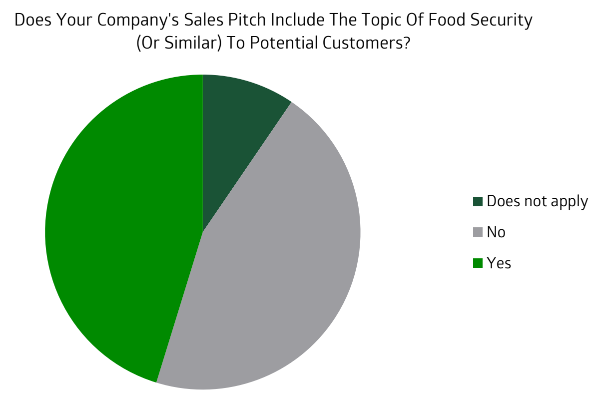
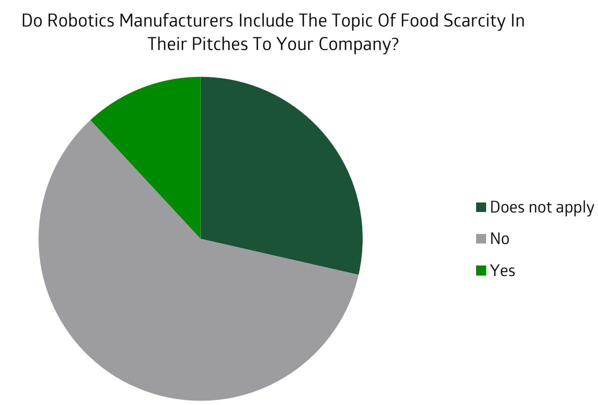


Figure 43 The Vast Majority Of Robotics Companies Do Not Mention Food Scarcity In Their Pitch Deck



Source: MassRobotics || TD Cowen Ag Tech Survey 2023, n=42

Overall, our respondents are confident that their company will create tools to help mitigate food scarcity with over 40% self-scoring a 5 on a 1-5 scale. On the same 1-5 scale, 5 being the best, companies surveyed believe robotics will likely be essential to solving key food scarcity challenges. Finally, >75% of our respondents mentioned being assured that their organizations' efforts in food scarcity mitigation will have a positive impact on food insecurity.

Figure 44 Our Respondents Widely Believe That Food Scarcity Challenges Have To Be Solved Through Robotics

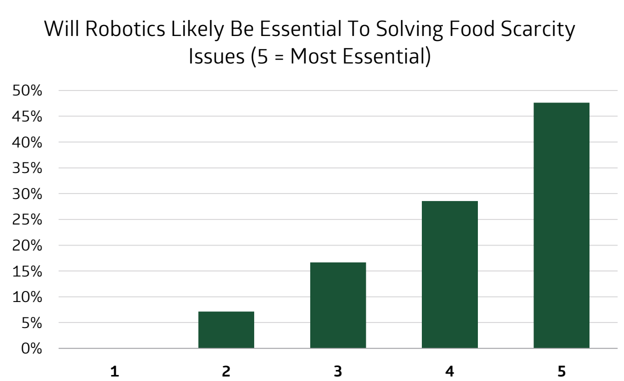


Figure 45 Each Organization's Self-Belief That Their Efforts In Food Scarcity Mitigation Will Have A Positive Impact On Food Insecurity

Source: MassRobotics || TD Cowen Ag Tech Survey 2023, n=42

Ag Tech Capital Investment Has Increased Dramatically – Venture Capital And Acquisitions By Strategics Remain At the Forefront

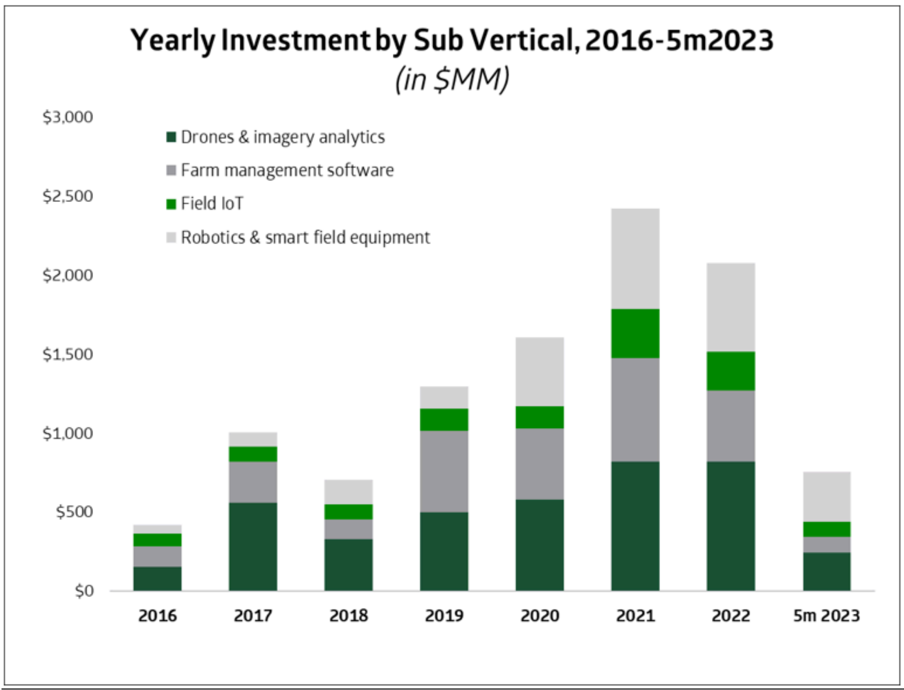
Venture Capital investment into the Precision Ag sector has accelerated – annual investment dollars expanded from <$500MM in 2016 to >$2B in 2022 (with robotics & smart field equipment the largest subsector YTD June 2023). The majority of spend has been directed toward the following areas: Drones & Imagery Analytics ($4.2B, ~40% of spend), Farm Management Software ($2.7B, ~26% of spend), Field IoT ($1.3B, 12% of spend), and Robotics & Smart Field Equipment ($2.5B, ~23% of spend).

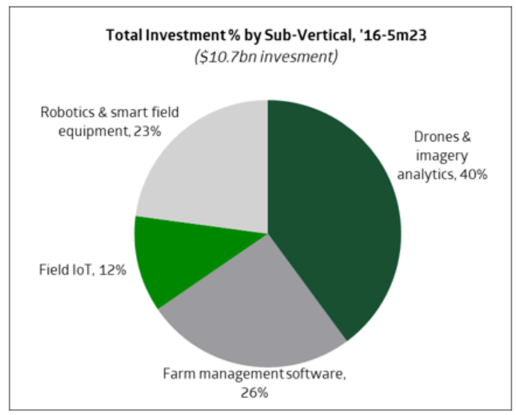
North America-based companies accounted for 65% of total investments during 2016-5m2023 (through May). Asia accounted for 13%, Europe 13%, and ROW 9%.

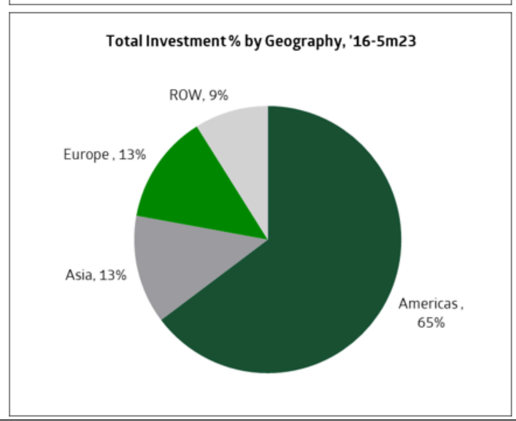
Significant Venture Investment Growth In Precision Ag Over The Last 8 Years – Robotics & Smart Field Equipment Becoming A Larger Share Of Total VC Capital Allocations (From ~13% in 2016 to over 42% YTD)

Yearly Investment By Sub Vertical, 2016 - 5m2023

(in $MM)	2016	2017	2018	2019	2020	2021	2022	5m 2023
Drones & imagery analytics	$154	$557	$327	$500	$579	$821	$819	$243
Farm management software	$127	$259	$124	$515	$447	$655	$450	$99
Field IoT	$79	$99	$97	$137	$144	$309	$245	$98
Robotics & smart field equipment	$55	$87	$156	$144	$432	$634	$561	$314
Total Investment	**$416**	**$1,002**	**$705**	**$1,296**	**$1,602**	**$2,419**	**$2,075**	**$754**







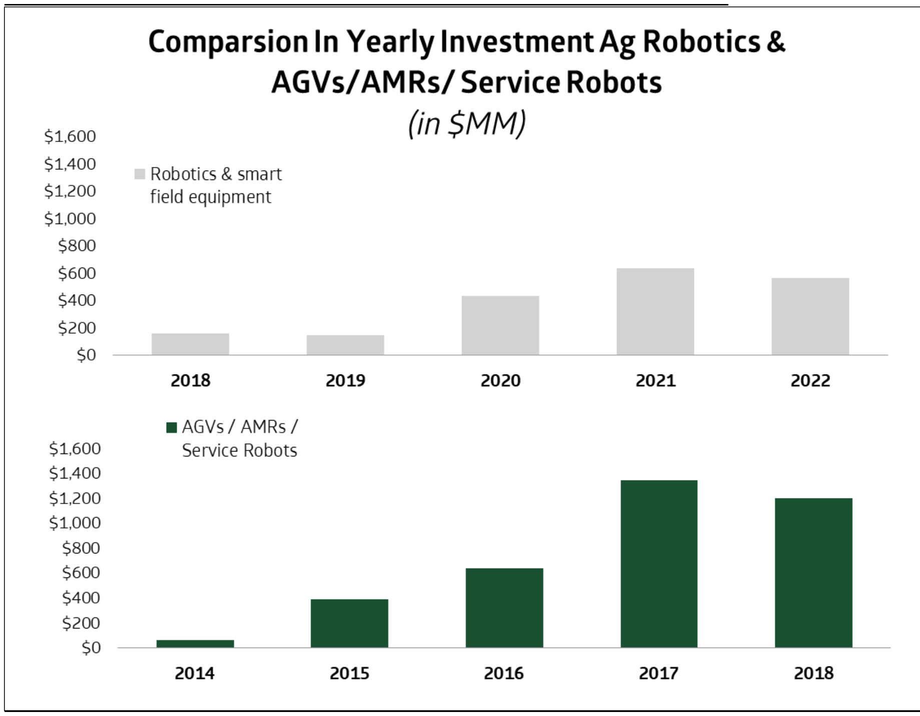
Source: Pitchbook, TD Cowen

We hosted a panel discussion on investment within the ag space – see takeaways HERE.

Over the past 4 years, Robotics & Smart Field Equipment venture capital related raises have followed a similar shape as the highly successful mobile robotics space (AMR/AGV) experienced over the 2015-2018 period – both off low starting points. The magnitude of the increase has been less pronounced (and we note that in 2019 AMR/AGV investment spiked notably to nearly $3.5B as e-commerce acceleration took hold) but notable. Covid ultimately acted as the "moment" for logistics-related investment into robotics – as megatrends we've discussed continue to play out, we will look for a similar coalescing of conditions for ag-related robotics.

Ag Robotics & Smart Field Equipment VC Investment Trends Have Mirrored Autonomous Mobile Robots (AMRs)

Type	4y CAGR	3y CAGR	2y CAGR
Robotics & smart field equipment	37.7%	57.5%	13.9%
AGVs / AMRs / Service Robots	110.4%	45.4%	37.7%



Source: Pitchbook, TD Cowen

We also examined potential exit opportunities for private companies within the Precision Ag arena. Since 2016, the primary liquidity event has come from a sale to a strategic – 54 deals were completed (35% with valuations over $100MM). Notable assets include ($valuation | Acquirer): Wirtgen ($5.1B | Deere), Bayer Digital Farming ($2.1B | BASF), Great Plains Manufacturing ($430MM | Kubota), Granular Business (>$300MM | Traction), Blue River Technology ($305MM | Deere), Bear Flag Robotics ($250MM | Deere).

To date, there haven't been any material initial public offerings of precision agriculture technology, likely as the largest players are already scaled public companies or smaller venture-backed companies.

Our Private Company Interviews Support Survey Takeaways And Suggest Broad Innovation Across Various Applications

We held extensive conversations with advanced.farm, which has developed autonomous technology for high value crop picking (strawberries, apples, etc.), and Radmantis, specializing in sustainable fish farming. Both companies have developed technologies to attack pain points discussed in this report. Radmantis' tech is geared towards sustainable fish farming, an area of increasing importance given the protein efficiency of fish vs. beef (far less feed required to grow a pound of protein), and advanced.farm's autonomous picking technology is utilized in the most physically demanding and time consuming applications where harvest cost/acre are extremely high.

Our Conversation With Radmantis

Radmantis is an innovative technology company that specializes in the development of automated solutions for natural resource management, smart fisheries, population monitoring, improved seafood production and robotic aquaculture. We had the opportunity to interview Robert Hubert, PhD, Senior Researcher and Co-Founder of Radmantis.

Radmantis has developed modular devices, which when coupled with machine learning, is able to classify fish with specific criteria like species, size, sex, and health. Based on the nutritional status or disease incidence, Radmantis systems are able to perform a range of functions, such as selective harvesting and removing individual fish in a timely fashion. The company is currently operating its control functions for a Recirculation Aquaculture Systems (RAS) in Northern Ohio and is working with industry partners to seek collaborations on expanding its technology into coastal marine netpen operations.

RAS is a type of aquaculture production system that enables the intensive rearing of fish or other aquatic organisms in a controlled environment. Unlike traditional aquaculture systems, RAS operates by continuously filtering and recirculating water within the system, reducing the need for large volumes of fresh water and minimizing the environmental impact.

Radmantis aimed to solve a common problem in RAS, where the handling of fish is done manually. As a result, the mortality rates are high. A typical plant will employ 15 people. What separates the company from a competitive standpoint is its ability to act on the patterns they detect. Others may be able to detect a sick fish but not be able to do anything about it. Radmantis' tech can identify, and equally importantly, isolate and remove sick fish before they are allowed to contaminate the rest of the population and do so without human intervention. The specific design of the apparatus enables this outcome, and the company estimates it can increase operational efficiency by 15-20%.

Dr. Huber highlighted that over 90% of seafood consumed in the US is imported and of the 9% domestic supply, most is wild – implying significant opportunity for effective and sustainable farming. He expects much of the production to move towards land-based facilities, which can be controlled at a much higher level and can keep out disease, contaminants, microplastics, etc.

Figure 46 Radmantis Offers Modular Systems That Can Channel Fish

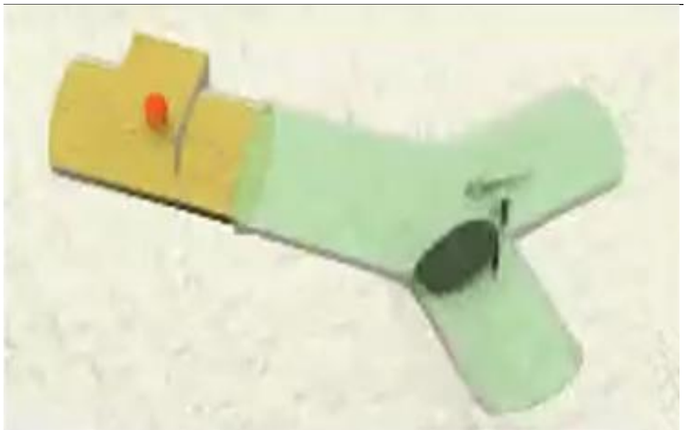


Figure 47 These Systems Are Equipped With Ai-Enhanced Image Classification

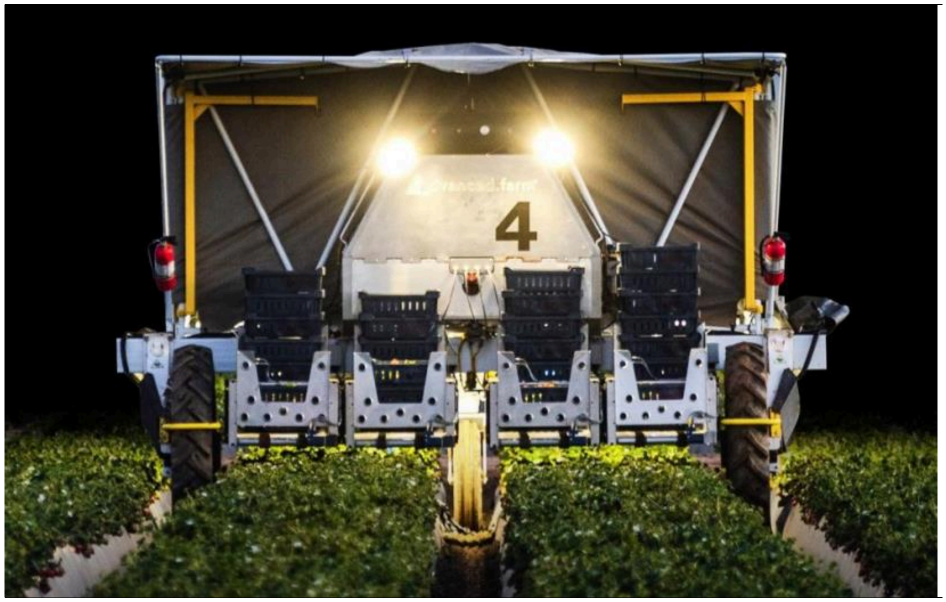
Source: Radmantis

See Takeaways From Our Ag Tech Discussion Panel (Including advanced.farm's Co-Founder) HERE

Our Conversation With advanced.farm

advanced.farm is a pioneering agriculture technology company that focuses on developing innovative solutions to enhance productivity and sustainability in farming practices. With a deep understanding of the industry's challenges, advanced.farm leverages cutting-edge technologies, including artificial intelligence, robotics, and automation, to create intelligent farming systems particularly well suited for precision harvesting of high value crops. Their solutions encompass a range of applications, such as precision planting, crop monitoring, harvesting, and data analytics, enabling farmers to optimize their operations and make data-driven decisions. By integrating advanced technology with traditional farming methods, advanced.farm aims to improve efficiency, reduce resource waste, and minimize environmental impact. They are at the forefront of the agriculture tech sector, working towards shaping the future of farming by combining the power of tech and agriculture to meet the growing demands of a sustainable and productive agriculture industry.

Figure 48 The advanced.farm BetterPick Strawberry Harvester



Source: advanced.farm

The company, based in Davis, California, has engineered and manufactured a harvester dedicated for the picking of several berries and tree / stone fruit. The system is currently used to pick strawberries, a notoriously challenging berry to harvest that requires significant manual labor. Strawberries require selective rather than destructive harvesting (like cutting down wheat, for example) and the plants flow continuously. This means that farmers must harvest the same plants multiple times as product ripens, a process that can take 6-9 months, which leads to harvesting costs / acre upwards of $50k vs. $20 for corn.

Advanced.farm's autonomous solution doesn't require a large tractor apparatus and is much more scaled down in size. Machine vision is used to identify ripe fruit and proprietary gripping and arm technology is used to pick. A single vehicle can harvest about the same amount as a human in a day (about 100lbs per hour per machine), but 1 human can control 5 vehicles, and the vehicles can run 24 hours a day. Sorting and packaging solutions are a logical extension of the company's core product offering.

The company sees an industry at an inflection, and farmers are finally ready for more meaningful adoption of automation. From a regulatory standpoint, it is becoming harder to import seasonal labor. This is coupled with minimum wage laws changing in states like California. The economics of automation, particularly service models like advanced.farm utilizes, begin to make more sense in this environment.

Advanced.farm believes the ag tech sector is still settling in. Farming is new for a lot of entrepreneurs and investors, but there is growing interest from OEMs, PE funds, and family offices. The company also mentioned that while government grants like the ones given by the USDA are helpful for the industry, often times the process is overly cumbersome and slow.

A Glance At The Technology And The Competitive Landscape

A key point in understanding the technology required to deploy into ag applications is that much of it already exists. What makes ag particularly challenging is the outdoor, unstructured environment, which is harder to account and plan for and requires significantly more robust solutions vs. indoor, predictable ones. In this way, we can view ag robotics as a logical evolution of technology already in place in areas like manufacturing and logistics that already employ advanced camera/vision suites combined with path planning algorithms.

Successful ventures will likely combine elements of existing technology with adapted in-house variations. In certain applications, existing machine vision and sensing will be appropriate and sufficient, but a new robot arm or gripping apparatus would be required. In other cases the exact opposite will be true. Regardless, core elements of sensing, machine learning, AI, mechanics, and gripping will be leveraged into ag applications. Cloud compute will likely be utilized as well to leverage the vast quantities of data collected and transform it into usable predictive models.

Examples Of Ag Robots

Autonomous tractors: these are self-driving vehicles that can be programmed to perform tasks such as planting, plowing, and harvesting. They can be equipped with a variety of sensors, including GPS, cameras, and LiDAR, to navigate fields and avoid obstacles.

Crop scouting robots: these are designed to collect data on crop health and soil conditions. They can be equipped with sensors that measure factors such as moisture levels, nutrient content, and temperature, and use this data to provide farmers with insights into crop health and growth.

Harvesting robots: these are designed to pick and sort crops such as fruit, vegetables, and berries. They can be equipped with vision systems and robotic arms that enable them to identify and pick ripe produce and deposit it into collection bins.

Weeding robots: these are designed to identify and remove weeds from fields. They can use a variety of techniques, including mechanical weeding, thermal weeding, and chemical spraying to eliminate weeds without damaging crops.

Planting robots: these are used to plant seeds in precise locations and depths, which can help optimize crop growth and yield. They can be equipped with GPS, vision systems, and robotic arms that enable them to plant seeds with precision and accuracy.

Livestock monitoring robots: these are used to monitor the health and behavior of livestock, including cows, pigs, and chickens. They can use sensors to measure factors such as temperature, humidity, and movement, and provide farmers with insights into the health and well-being of their animals.

Hurdles To Overcome To Spur Deployment

Cost: developing and deploying farming robotics can be expensive depending on the model utilized, which can be a significant barrier to adoption for many farmers. While the long-term benefits of these technologies can be significant, the upfront investment required likely remains a challenge. Service models can be an attractive alternative.

Complexity: farming robotics can be complex to develop, deploy, and maintain. Farmers may require specialized training and support to operate and maintain these systems, which can be a barrier to adoption.

Compatibility: some farming robotics technologies may not be compatible with existing farm equipment and infrastructure. This could require farmers to make significant changes to their operations to adopt new technologies.

Regulation: agricultural technologies may be subject to regulatory approval, which can slow down the adoption process. Farmers may also face regulatory barriers when deploying new tech, such as restrictions on the use of drones for crop monitoring.

Reliability: farming robotics technologies may be less reliable than human labor in some situations. For example, robots may struggle to navigate uneven terrain or work effectively in inclement weather conditions.

The USDA And Its Funding Mechanisms

Given farmer economics, it is often challenging for the industry to invest in new technology. However, the USDA has funded several research projects and programs related to the development and implementation of robotics and automation technologies in agriculture. These projects and programs aim to increase farming productivity, reduce labor costs, and improve sustainability in agriculture.

- The USDA's National Institute of Food and Agriculture (NIFA) has funded several grants to support research on agricultural robotics and automation. For example, in 2021, NIFA awarded a grant to the University of California, Davis to develop a robotic weed control system for organic vegetable farms. NIFA has also supported the development of robotic systems for livestock farming. This includes projects such as automated milking, feeding, and cleaning in dairy farms, as well as robotic systems for monitoring and managing animal health.

- The USDA's Agricultural Research Service (ARS) has also funded research on agricultural robotics. For instance, the ARS has developed a robotics system for automated fruit tree pruning and has tested a robotic system for identifying and removing weeds in cotton fields.

- The USDA has also established a program called the Agriculture Advanced Research and Development Authority (AGARDA), which aims to accelerate the development and commercialization of advanced agricultural technologies, including robotics.

- The USDA's National Robotics Initiative (NRI) has provided funding to support research on robotic systems for precision agriculture. This includes projects such as the development of robotic systems for plant and soil sensing, robotic seeders and planters, and robotic systems for crop monitoring and disease detection.

- The USDA's Small Business Innovation Research (SBIR) program has also provided funding for robotics projects in agriculture. For instance, the SBIR program has supported the development of a robotic system for harvesting apples, as well as a robotic system for automated fruit tree pruning.

- The USDA's Natural Resources Conservation Service (NRCS) has funded research on robotics and automation technologies for sustainable agriculture. This includes projects such as the development of automated systems for soil management and irrigation, as well as robotics systems for precision livestock farming.

- The USDA's Agricultural Marketing Service (AMS) has funded research on robotics and automation technologies for improving the efficiency of the produce supply chain. This includes projects such as the development of robotic systems for grading and sorting produce, as well as automated systems for packaging and labeling.

NIFA Economics

The National Institute of Food and Agriculture's (NIFA) vision is to catalyze transformative research, education, and extension to address the country's most pressing societal challenges. The budget for Agriculture and Food Research Initiative (AFRI) in 2022 totaled $700M. This compares to the 2021 budget of $435M. AFRI is a large part of NIFA's budget – in 2022, NIFA's total, discretionary, farm bill mandatory, and endowment funding was just shy of $2.2B.

$455M of AFRI's spending is directed to Foundational and Applied Science, which seeks to:

- Mitigate, adapt, and drive resiliency of agricultural systems to climate change.

- Serve disadvantaged and underserved communities.

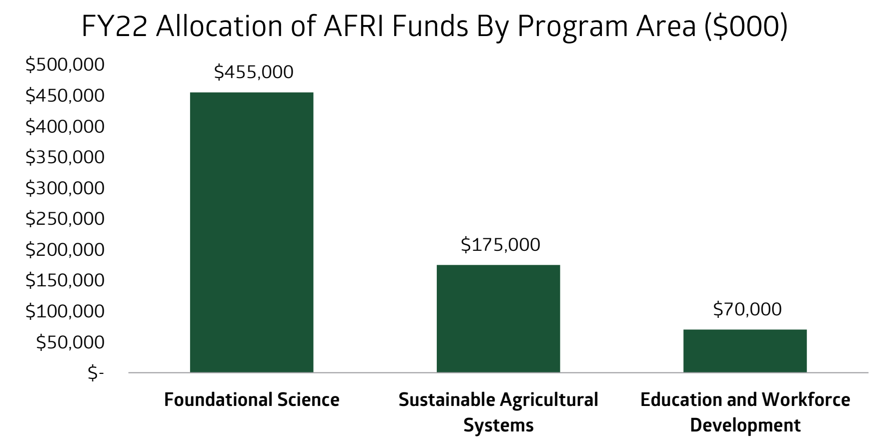
- Support the next generation of scientists and educators.

- Enhance focus on new technologies, such as gene editing, robotics, unmanned aerial systems, cyberphysical systems, machine learning, and the application of big data.

- Foster research on agricultural biosecurity.

- Increase award size commensurate with the scope of foundational work required.

Figure 49 AFRI's Budget Was Up 60% In FY22 Compared To FY21



Source: TD Cowen, nifa.usda.gov

Companies That Received USDA Funding

- **Blue River Technology** (acquired by John Deere in 2017): developed a robotic system for precision weed control in row crops. Funding:
  - $225k from the USDA's SBIR program in 2012
  - Another $100k in 2012 from the USDA's SBIR program in 2012
  - $500k from SBIR in 2014
- **Harvest CROO Robotics**: developed a robotic system for harvesting strawberries that utilizes computer vision and machine learning to identify and pick rope berries. Funding:
  - $1m from the USDA's SBIR program in 2016
- **Abundant Robotics**: designed a robotic apple picker that uses machine vision and robotics arms to identify and harvest ripe apples. Funding:
  - $500k from the USDA's SBIR program in 2016
- **Soft Robotics**: developed a soft robotics gripper that can grasp and handle delicate fruits and vegetables without causing damage. Funding:
  - $600k from the USDA's SBIR program in 2019
- **Energid Technologies**: developed a robotic system for automated fruit tree pruning that uses 3D sensing and motion planning algorithms to navigate and prune fruit trees. Funding:
  - $500k from the USDA's SBIR program in 2017

- **Agribotix**: develops drone-based systems for agriculture data collection and analysis. Its systems use advanced imaging technologies to provide farmers with detailed insights into their crops and fields, allowing them to make data-driven decisions about irrigation, fertilization, and other key factors that can affect crop yields. Funding:
  - $250k form the USDA's SBIR program in 2015
- **Carbon Robotics**: The company's LaserWeeder uses high-power lasers to eradicate weeds using thermal energy without disturbing the soil. The technology is a safer and more effective way to improve yields when compared to traditional methods like the use of herbicides. The autonomous system, which is equipped with 30 150W lasers and tracking cameras, can kill up to 200k weeds per hour. Funding:
  - $200k from the USDA's SBIR program in 2020
- **FarmWise**: manufacturer of autonomous robotic systems for agriculture. Its flagship product is the autonomous weeder, a robotic platform that uses computer vision and machine learning to identify and remove weeds from crop fields. The company also offers other robotic solutions for tasks such as seeding, transplanting, and harvesting. Funding:
  - The USDA's National Institute of Food and Agriculture was among a variety of investors that invested $14.5m in 2020
- **Iron Ox**: develops fully automated indoor farming systems. Its systems use robotics and machine learning to monitor and optimize growing conditions, allowing for highly efficient and sustainable production of fresh produce. Funding:
  - Received $20m in funding from a variety of investors, including the USDA
- **Root AI**: develops intelligent harvesting robots for indoor farms. Its Virgo robot uses advanced sensors and algorithms to identify and harvest ripe produce with precision and care, minimizing waste and increasing yields. Funding:
  - $2.3m from the USDA in 2020
- **Smart Ag**: develops autonomous farm machinery, including tractors and other equipment. Its AutoCart system allows farmers to remotely control their tractors and coordinate harvesting and transportation operations. Funding:
  - Received $5.7m in funding from a variety of investors, including the USDA
- **EcoRobotix**: develops autonomous weed control robots for agriculture. Its robots use advanced sensors and algorithms to identify and target weeds with precision, reducing the need for herbicides and other chemicals. Funding:
  - Received $10.7m in funding from variety of investors, including the Swiss government and the USDA

- **TerrAvion**: provides drone-based imaging and data analytics services for agriculture. Its systems allow farmers to monitor their crops and fields with high-resolution imagery, helping them make data-driven decisions about planting, irrigation, and other key factors. Funding:
    - Received $10m in funding from a variety of investors, including the USDA.

Other Ag-Tech Companies

American Robotics: provider of autonomous drone solutions for crop monitoring, field mapping and data collection. The drones are equipped with AI and computer vision capabilities, allowing the company to identify and analyze crop health, irrigation needs, and pest detection.

Guardian Agriculture: focuses on precision farming solutions, offering precision planting systems, automated irrigation solutions, and crop monitoring tools. Their technologies utilize sensors, satellite imagery, and data analytics to optimize crop production, reduce inputs, and enhance sustainability.

FFR Robotics: specializes in robotics and automation solutions for agriculture, including harvesting, pruning, and sorting tasks. Their robots are designed to increase efficiency, reduce labor costs, and improve productivity in agriculture operations.

Augean Robotics (Burro): offers robotic systems for outdoor agriculture, such as autonomous vehicles for crop scouting, data collection, and precision spraying.

Octinion: develops robots for fruit picking and harvesting, utilizing computer vision, machine learnings, and robotic arms for gentle and efficient handling of delicate fruits.

Robotnik: provides mobile robotics platforms for agriculture, enabling autonomous navigation, monitoring, and data collection in fields and greenhouses.

Clearpath Robotics: develops autonomous mobile robotic solutions for various industries, including agriculture. Their platforms and software tools enable autonomous navigation, data collection, and mapping, supporting tasks such as field scouting, crop monitoring, and logistics in agricultural operations.

Autonomous Tractor Corporation: manufactures autonomous tractors for agricultural applications. Their tractors utilize advanced guidance systems, GPS technology, and artificial intelligence to operate autonomously, aiming to provide labor-saving solutions and increased precision in tasks like plowing, seeding, and cultivation.

FarmBot: offers precision farming systems that combine robotics, automation, and open-source software. Their FarmBot Genesis is a small-scale robotic farming device that allows users to design, manage, and automate customized planting and watering sequences, enabling precise control over plant spacing, watering, and soil monitoring.

The Climate Corporation: develops digital tools and predictive analytics to assist farmers in making data-driven decisions about planting, fertilizing, and managing risks related to weather and climate.

Taranis: utilizes aerial imagery, machine learning, and AI to provide farmers with real-time insights into crop health, enabling targeted interventions and optimized farm management.

CropX: provides soil sensing and analytics solutions for precision irrigation and nutrient management in agriculture. Their soil sensors and cloud-based platform enable data-driven decision-making to optimize water and fertilizer usage, resulting in improved crop yields and sustainable farming practices.

Monarch Tractor: develops electric autonomous tractors that incorporate advanced sensing and imaging technologies. Their tractors offer automated implement control, precision navigation, and data collection capabilities, aiming to provide sustainable and efficient farming solutions.

BrightFarms: constructs and operates indoor hydroponic farms close to urban areas, supplying locally grown produce while minimizing transportation and water usage.

Plenty: focuses on vertical farming and produces a wide range of crops using controlled indoor environments, optimized lighting, and automated systems for efficient and sustainable production.

Bowery Farming: specializes in vertical farming using AI, robotics, and data analytics to grow a variety of leafy greens in controlled indoor environments, minimizing resources use and maximizing yield.

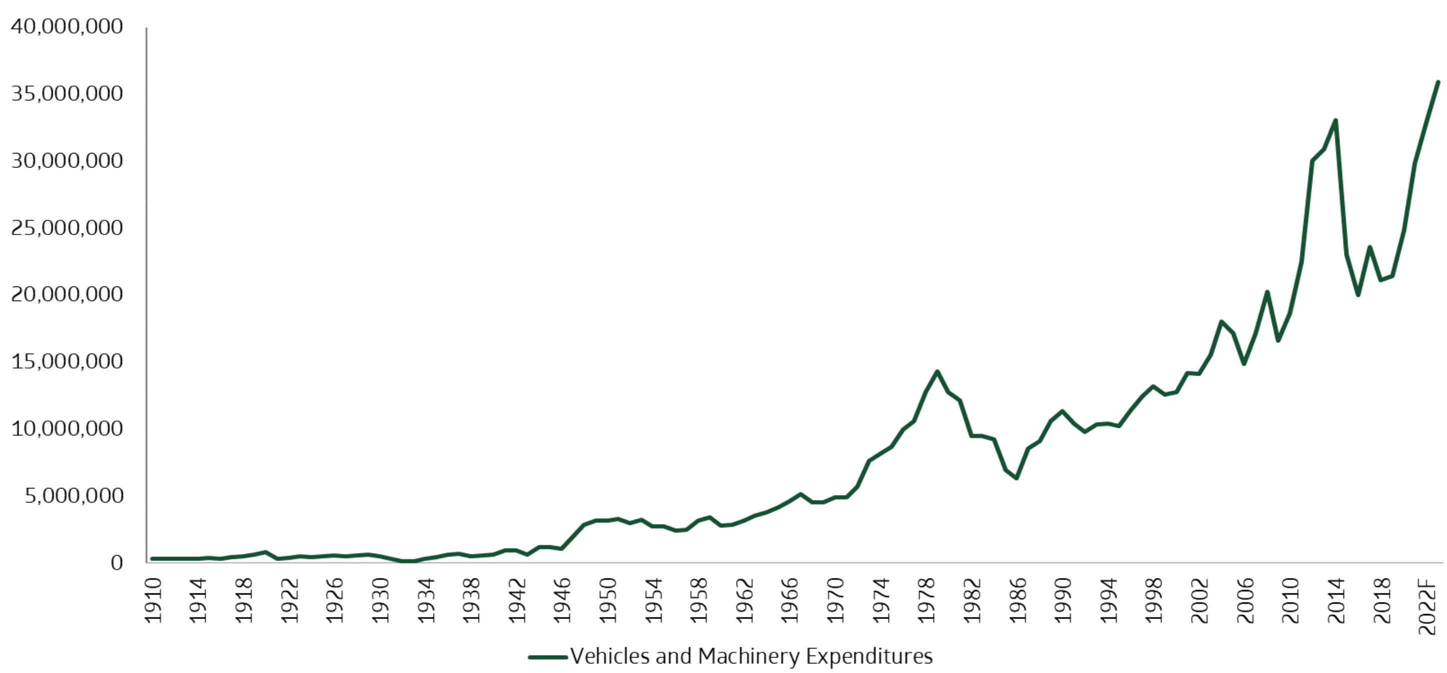
Naio Technologies: provides agricultural robots for weeding, hoeing, and harvesting in various crop types, promoting chemical-free and sustainable farming practices.

Primer: The Ag Equipment Cycle – Past, Present, and Future

The 2007-2013 period was for the most part an expansion marked by higher purchases of capital items by farmers, driven partly by ethanol. The 2014-2020 period saw suppressed replacement of large ag equipment, exacerbated by trade tensions with China that pressured export grain, weather issues, an El Niño event, and Covid-19. After the early phase of the pandemic, the second-half of 2020 marked the beginning of a robust recovery in equipment production that is likely to continue through CY23 and into CY24. This is as supply chain disruptions have thus far imposed a ceiling on the production level warranted by underlying demand, effectively smoothing out the cycle somewhat. This expansion has been driven by the rally in crop prices following the pandemic, something that boosted farmer income in 2021 and 2022. While 2023 is a down year for farmers so far, it's off a very high level, and farm fundamentals remain strong. That said, barring the emergence of new favorable dynamics for farmers in 2024, that year could see stabilization, if not moderation, in equipment replacement following a solid four years.

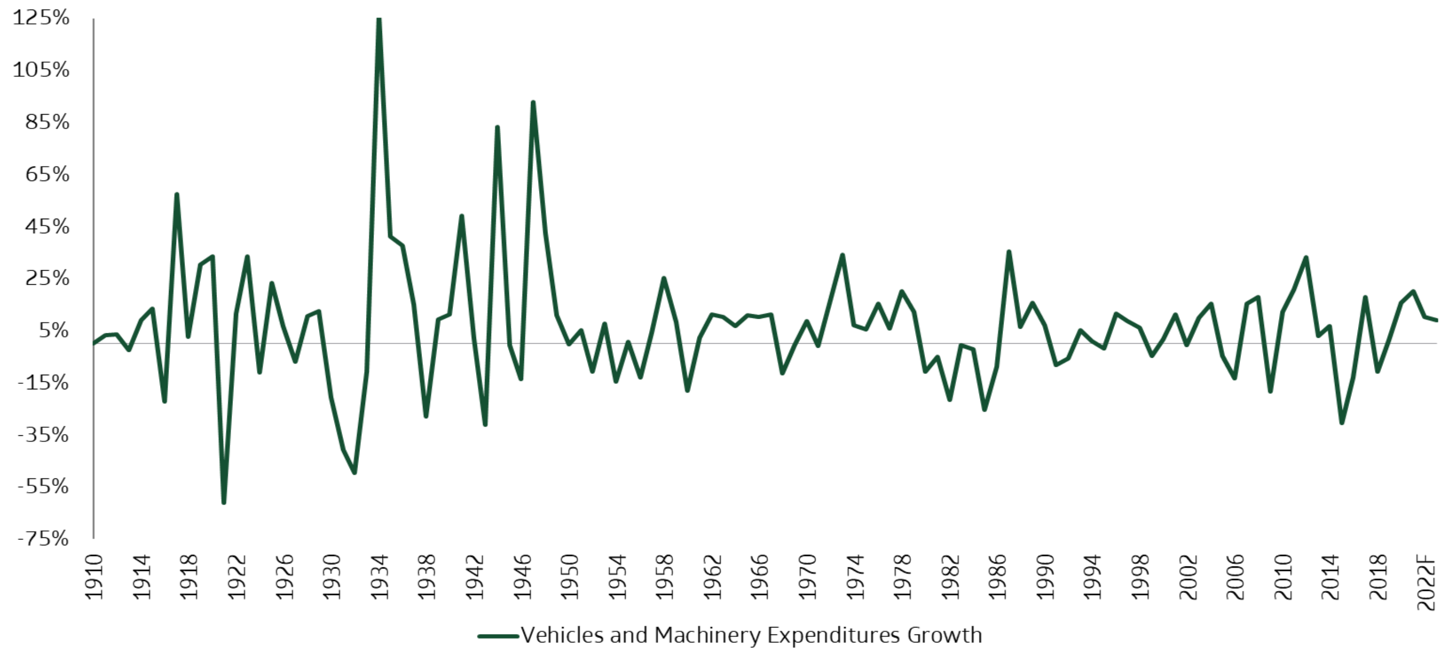
Looking beyond CY24, whether there is a down cycle or a mere stabilization will be a function of several variables, not the least of which is weather. We are about to enter an El Niño event and five years of warmer-than-average temperatures following a few years of La Niña. The last El Niño had some overlap with the last equipment down cycle. Election uncertainty should begin to loom larger in the coming months. Trade tensions intensified under the previous administration and pressured ag exports. Higher interest rates and a shaky macro environment have also tempered farmer sentiment. All that being said, any incremental strength in grain prices could override most other challenges.

Figure 50 U.S. Farm Equipment Expenditures ($)



Source: USDA/ERS and TD Cowen

Figure 51 U.S. Farm Equipment Expenditure Growth



Source: USDA/ERS and TD Cowen

Mexico's Proposed GMO Corn Ban

If this unlikely scenario materializes, U.S. producers would be able to accommodate, although that would require a switch that would incur additional costs that would be at least partly offset by a higher crop price.

The Broader Agricultural Equipment Market

In the broadest sense, TD Cowen estimates the global market size of agricultural equipment to be $150Bn, growing at a CAGR of 4-5%, but the market that is more relevant to DE, AGCO, and CNHI is closer to $100Bn, with DE having a ~35% share. In North American large ag (where much of the precision ag is), DE has ~60% share, followed by CNHI at ~30% and AGCO at 10%. DE derives its agricultural equipment sales through its production and precision agriculture and small agriculture and turf business segments, which totaled over $35Bn in FY22.

DE is the global leader in agricultural equipment. Other players include AGCO, CLAAS, CNH Industrial, Kubota Tractor Corporation, Lovol, among others, and smaller regional competitors. The only other major domestic OEM competitor is AGCO, which manufactures and sells tractors, combines, hay tools, among other farming equipment.

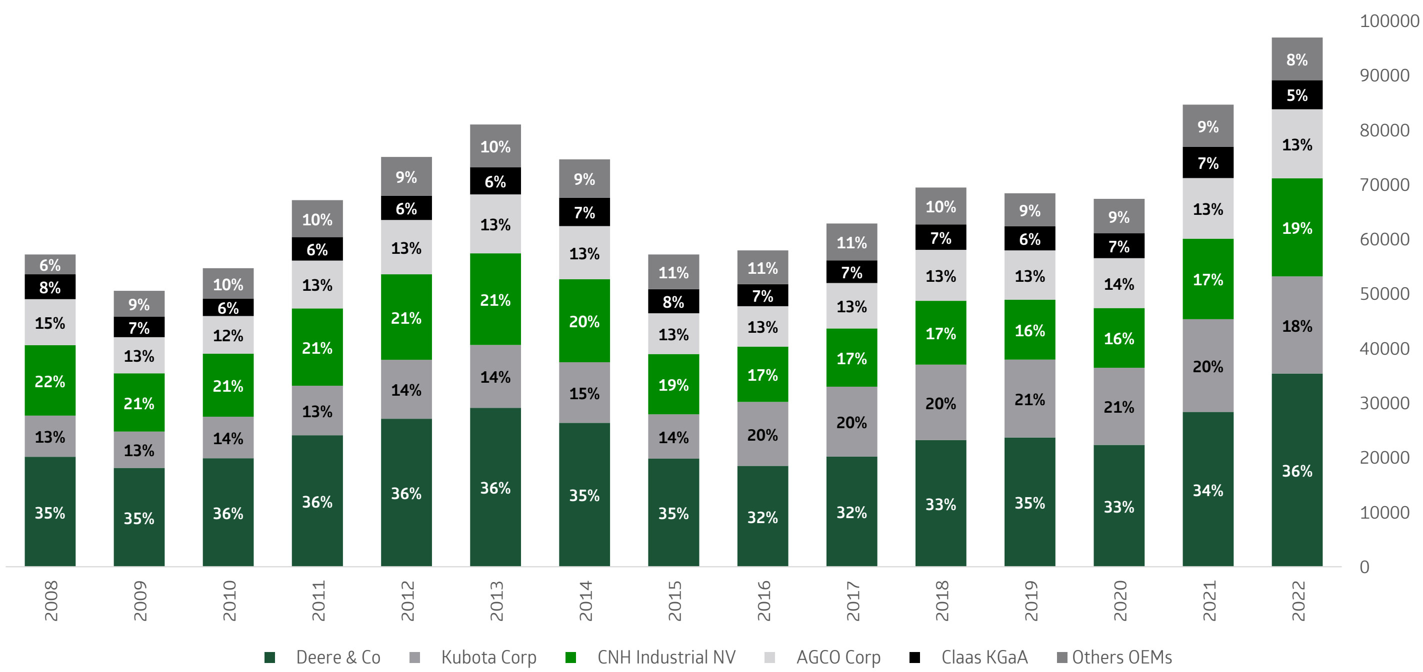
Mirroring the success DE has had with its Precision Ag segment of the business, competitors have been ramping up their investments in new precision ag technology to better facilitate their own product line. More specifically in the industry, AGCO has tweaked its strategy in recent quarters towards its precision ag products by acquiring five technology companies over the past two years specializing in height sensors, tracking and controlling devices, software development, and smart solutions for operator productivity and improved animal welfare. In addition, AGCO has emphasized that its precision ag products are compatible with mixed fleets.

Global Precision Agricultural Technology Market

Company	Precision Ag Product Focus	Product Example
John Deere	Automation/Machine IQ, Autonomy, Connectivity & Digital Solutions, and Guidance	**AutoPath** Use: Accurate secondary operations such as planting, spraying, and harvest Capability: Uses data from first pass to automatically create full-field guidance lines Solutions: Faster setup time and reductions in crop damage
AGCO	Sensor Technology, Tracking and Controlling, Autonomy	**Precision Planting** YieldSense Use: Easy calibration and spatial accuracy throughout harvest Capability: Differentiates different hybrids and varieties yielded Solutions: Time-saving accurate yield data for harvesting decisions
CNH Industrial	Software and Autonomy	**Agxtend** SoilXplorer Use: Contactless ISOBUS compatible soil sensor Capability: Autonomous soil conductivity measurement Solutions: Automatic soil mapping process with different parameters
CLAAS	Sensor Technology & Autonomy	**Telematics** Use: Inform, analyze, optimize, and document Capability: View fuel consumption, work status, remote service Solutions: Work times and processes, diesel consumption, agronomic data (crop yield, application rate, etc.)
LOVOL	Air/ Mechanical Precision Seeder	**Air Precision Seeder** Model 2BMQF-4A Use: Planting Crops (corn, beans, sunflower, sorghum, beet, etc.) Seed Tank Capacity: 40x4 L Fertilizer Tank Capacity: 160x2 L

Source: Deere, AGCO, CNH Industrial, CLAAS, Lovol

Global Agricultural Equipment Market ($MM)

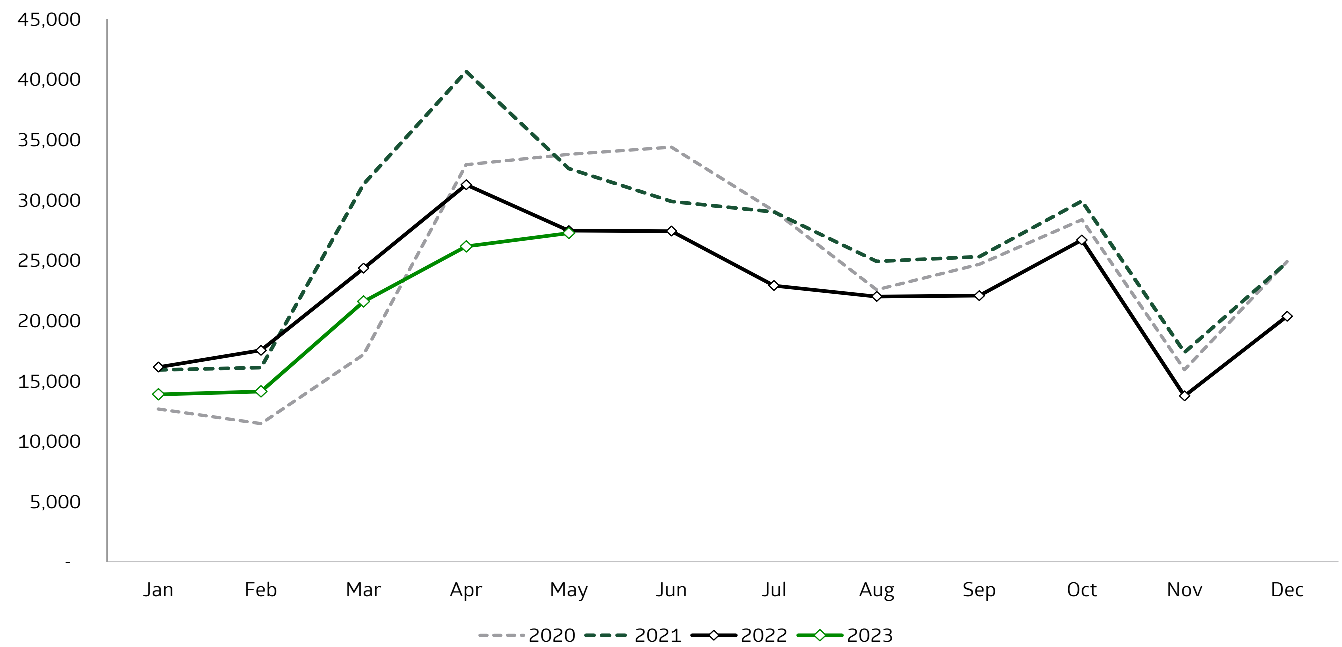


Source: TD Cowen, Bloomberg, Eikon, SEC filings

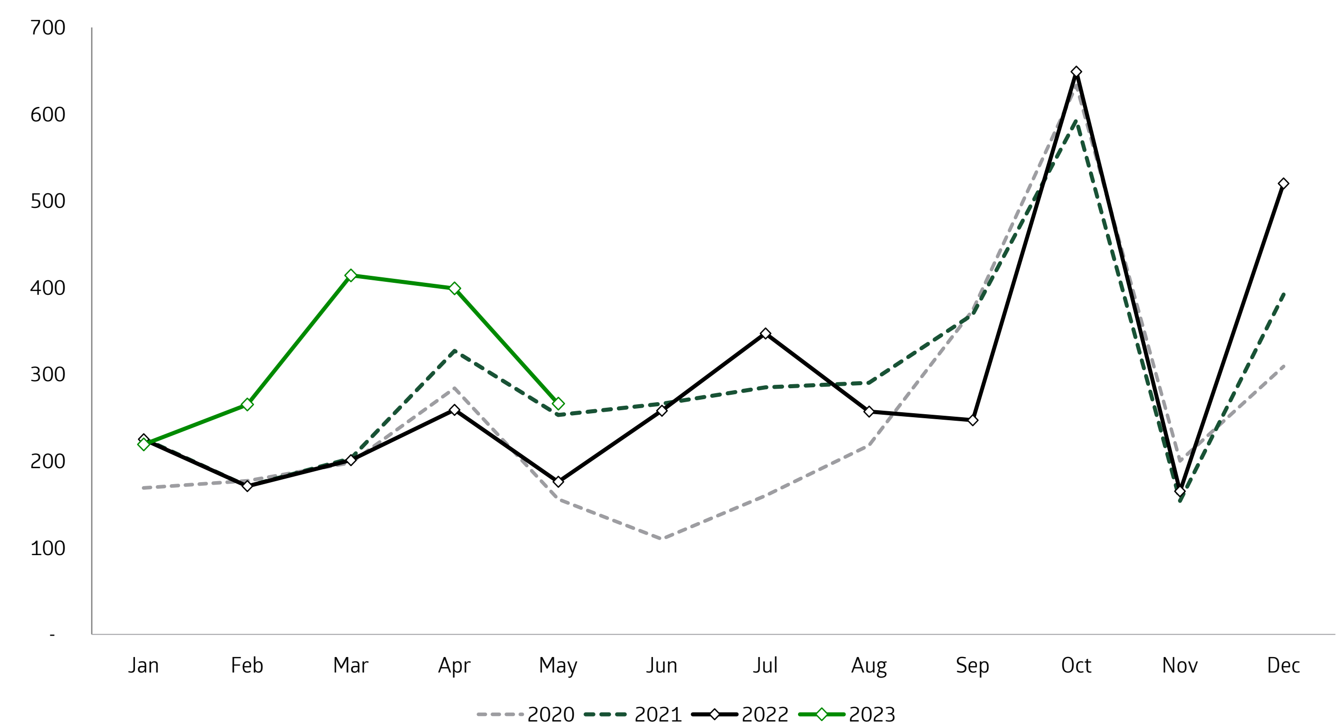
Seasonality and Cycle

Retail sales by dealers to farmers largely follow seasonal patterns and are a function of planting and harvesting seasons. The seasonality of the business results in significant variations in product volume sales through the year. This leads equipment manufacturers to make large demand estimates as manufacturing must be based on anticipation before the peak season. OEMs offer early order programs that allow customers to place and lock in orders, which helps the OEMs with early indication of demand schedule. Some OEMs award customers (costs of sales via waives of certain charges, financing) who take delivery during non-peak seasons, and many customers (Australia, Canada, U.S.) do equipment trade-ins when purchasing new equipment. Below are the total industry retail sales by month for total farm wheel tractors and combines in the U.S.

Total Farm Wheel Tractors Retail Units, U.S. (Industry)

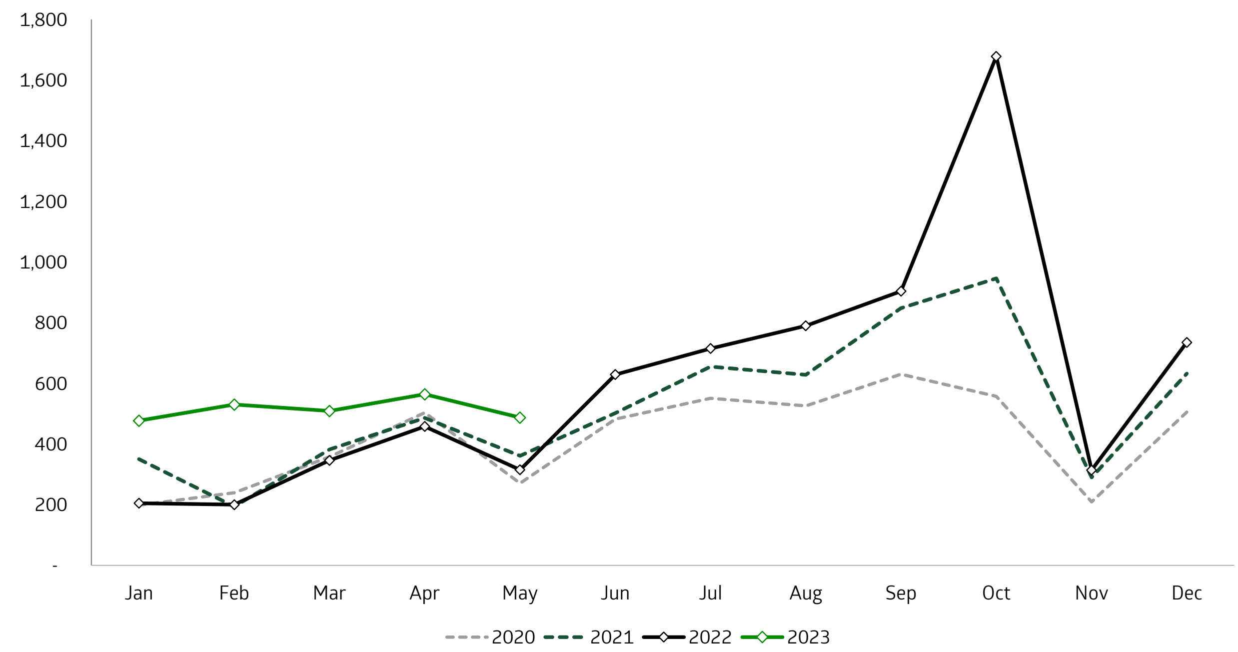


4WD Retail Units, U.S. (Industry)



Source: AEM and TD Cowen

Combine Retail Units, U.S. (Industry)

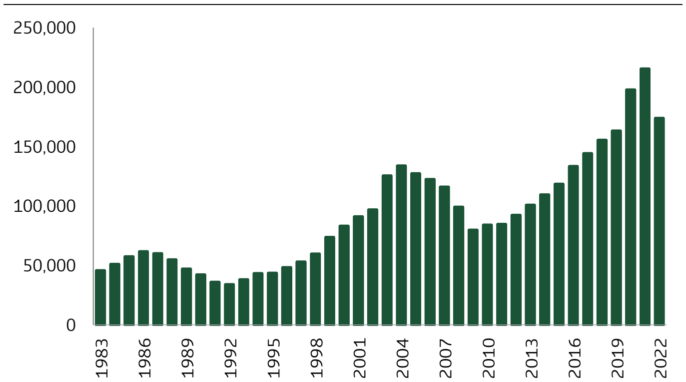


Source: AEM and TD Cowen

Equipment Trends

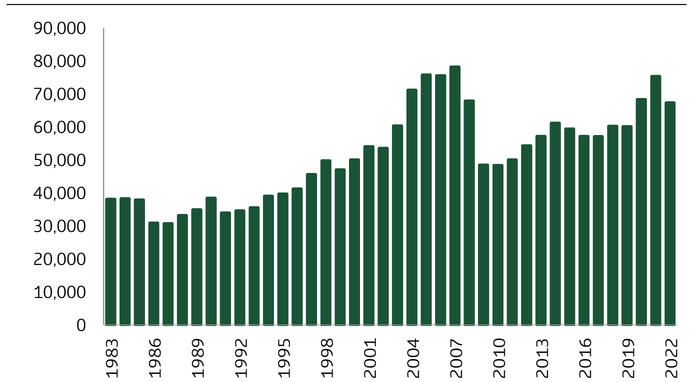
AEM is an organization in North America that gathers industry data across equipment manufacturing. Sourced from AEM, the data offers insights into U.S. agricultural equipment, leveraging data from over 500 agricultural partners.

Tractors Under 40HP (Retail Sales, Units)



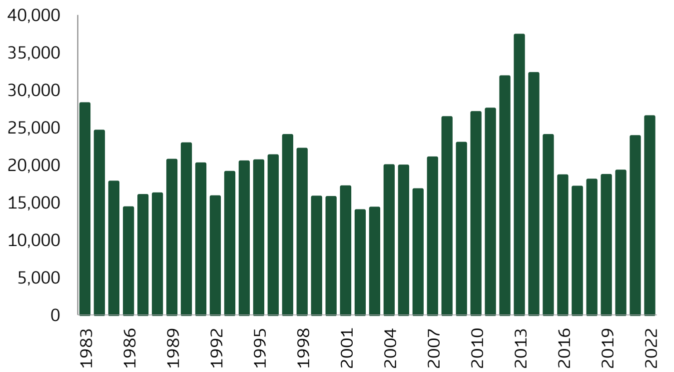
Source: AEM, TD Cowen

Tractors Under 100HP (Retail Sales, Units)



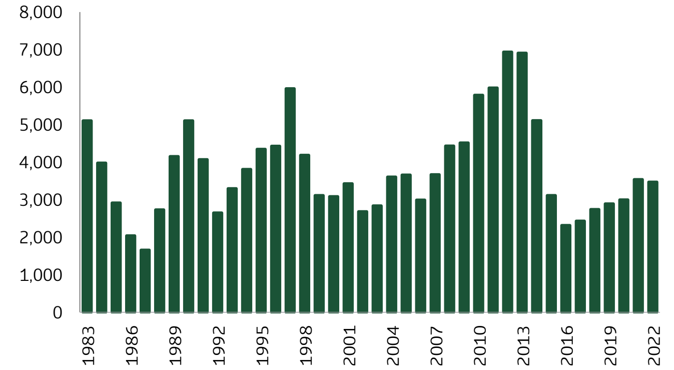
Source: AEM, TD Cowen

2WD Tractors 100HP & Over (Retail Sales, Units)



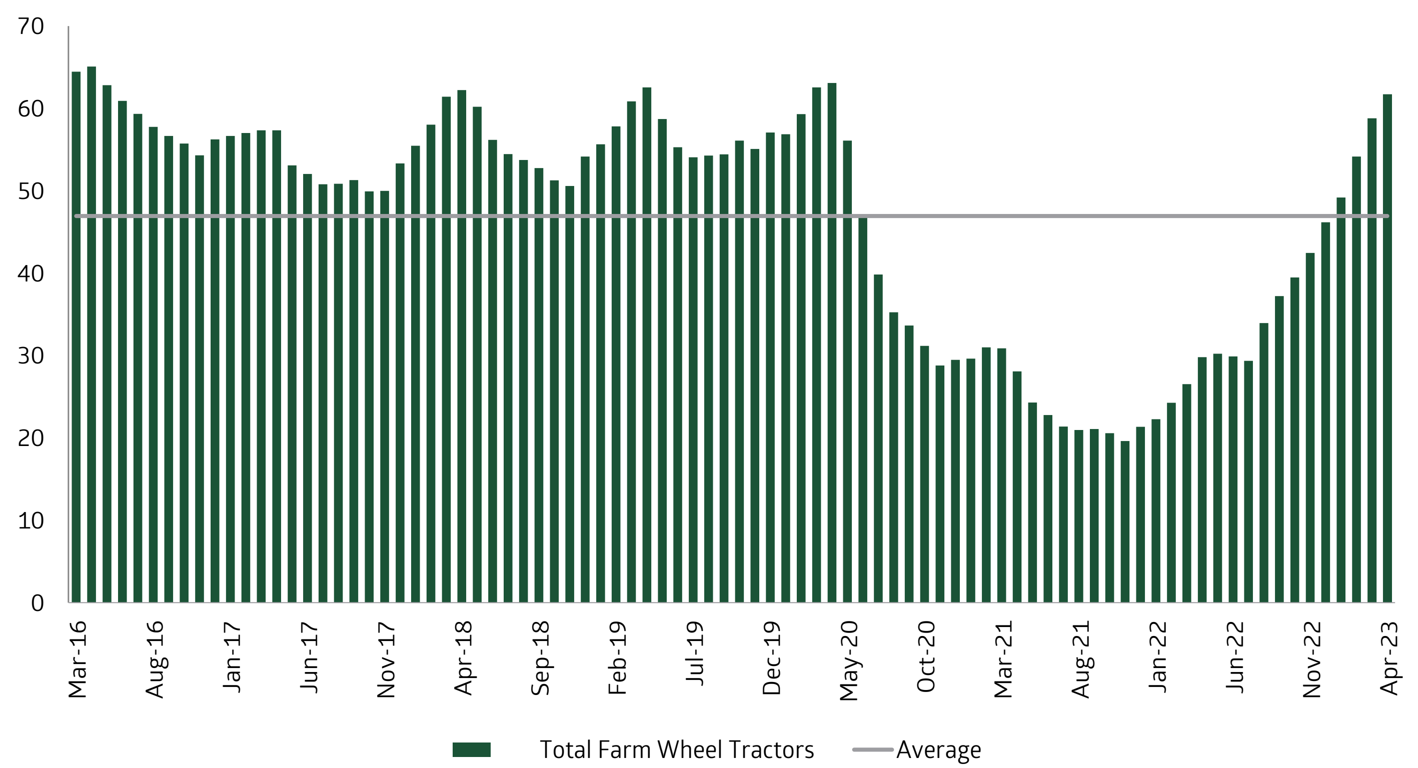
Source: AEM, TD Cowen

4WD Tractors (Retail Sales, Units)



Source: AEM, TD Cowen

Inventory to Sales, Total Farm Wheel Tractors (US)



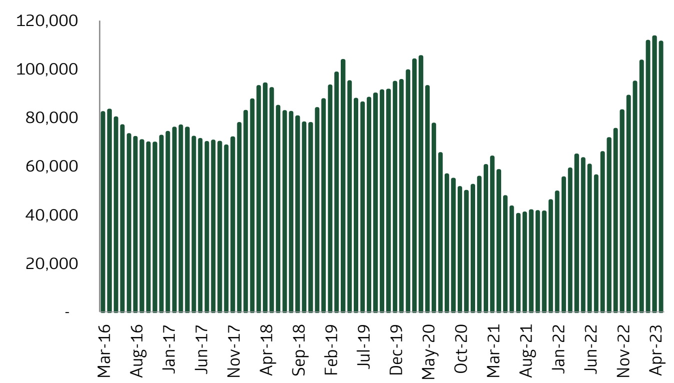
Source: AEM, Bloomberg, TD Cowen

Inventory to TTM sales data has been growing, driven primarily by smaller equipment. Retail sales have been weaker in smaller the equipment, which is correlated with housing and the broader economy. The growing inventory number keeps the cycle peak concerns alive.

On DE's earnings call in May 2023, management stated that in the U.S. and Canada, industry sales within large ag equipment are expected to be up ~10%, with demand continuing to outpace supply, and with supply-based delays expected to continue to restrain shipments. Management stated, "elevated demand to continue for the back half of the year, as evidenced by an order bank that extends into fiscal year 2024."

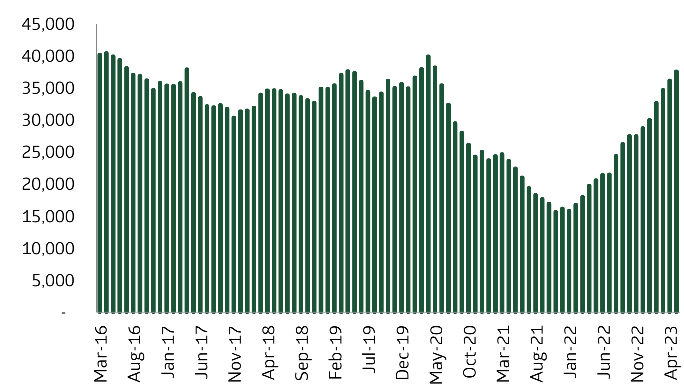
Within small ag and turf, industry sales are expected decrease ~5% in both the U.S. and Canada as strength for midsized equipment is offset by weakness in more consumer-oriented products. Demand for compact tractors has declined year-over-year, resulting in inventory levels rising to pre-COVID levels. Meanwhile, the hay and forage segments remain strong, driving demand for products like our 100 to 180 horsepower tractors, windrowers, and round balers.

Tractors Under 40HP (Inventory Data, Units)



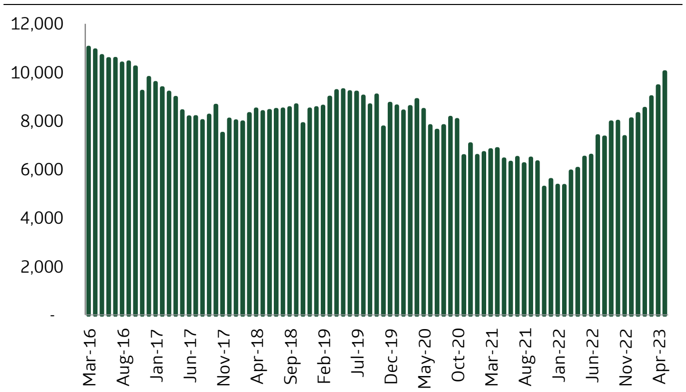
Source: AEM, TD Cowen

Tractors Under 100HP (Inventory Data, Units)



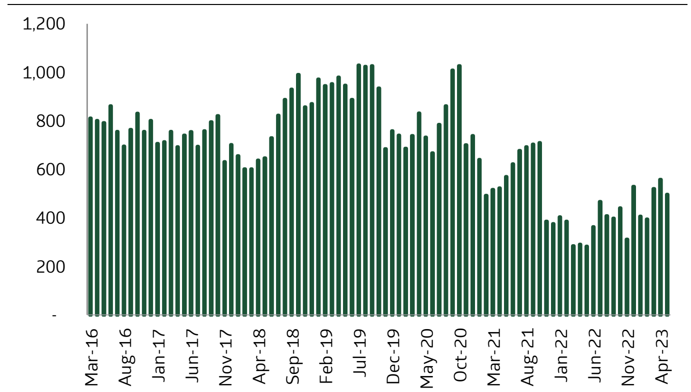
Source: AEM, TD Cowen

2WD Tractors 100HP & Over (Inventory Data, Units)



Source: AEM, TD Cowen

4WD Tractors (Inventory Data, Units)



Source: AEM, TD Cowen

Agricultural Rail Traffic – A Closer Look At The Class Is

With the Class Is all reporting their first quarter of 2023 in April, some of the rails offered an updated look into 2023 outlook, particularly on the volume front, which has been struggling to return to pre-pandemic levels. For the 2021/2022 crop year, grain in

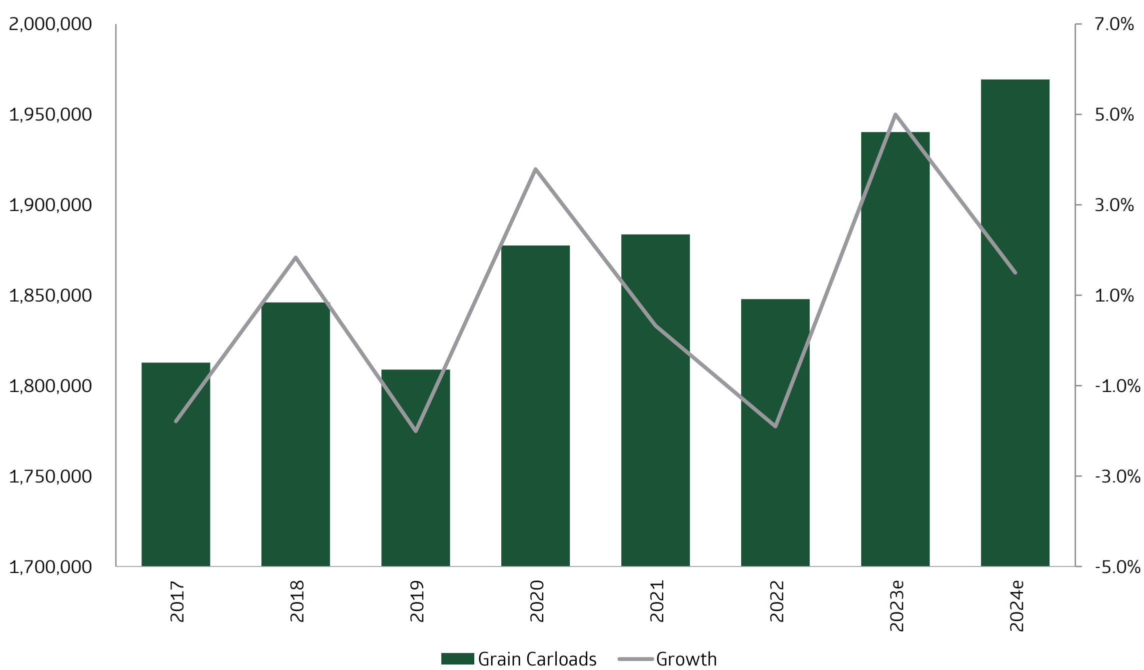
Canada was below its three-year average, while in the U.S., it was in line with its three-year average.

Canadian Pacific (CP) noted that grain volumes were up 26% in 1Q23. The company saw another strong quarter in Canadian grain, posting its second largest February on record and breaking its January record of 2.3 MM metric tons. The strength in Canadian grain was partially offset by softer demand for U.S. grain corn exports, as well as challenging compares from last year.

For Union Pacific Corp (UNP, covered by Jason Seidl), grain and grain products were down 1% in volume in 1Q23, driven by weaker export grain shipments as world demand for U.S. grain has softened, coupled with drought impacts affecting supply in UP's SAAR region. Fertilizer carloads were flat in the quarter. UNP noted that it expects grain to be challenged near term as export demand softens and supply tightens throughout 2023.

Below is the average Class I volume growth. We estimate grain volume growth across North America will be 5% in 2023 and ~1.5% in 2024.

Historical & Projected Grain Volume on Rail



Source: Company filings, TD Cowen

What Is Precision Ag and Its Technology?

Precision agriculture is a modern farming approach that utilizes technology and data to increase the efficiency and productivity of farms. It involves the application of various technologies, including Global Positioning Systems (GPS), Geographic Information Systems (GIS), remote sensing, sensors, and machine learning algorithms, with the goal of optimizing crop production, reducing resource usage, and improving overall yield.

According to USDA, One of the main advantages of precision agriculture is its ability to help farmers make the most effective use of resources like water and fertilizer. By analyzing data on soil moisture and nutrient content, farmers can apply fertilizers and irrigation in a more precise manner, minimizing waste and enhancing crop yields. Additionally, using sensors and drones to monitor fields and detect early signs of diseases or infestations, precision agriculture proves to be effective in managing pests and diseases. This allows farmers to take timely precautions to prevent the spread of problems and protect their crops. In addition to these practical benefits, precision agriculture also holds the potential to reduce the environmental impact of farming. By optimizing resource utilization and minimizing waste, farmers can contribute to sustainability efforts and reduce their carbon footprint.

The technologies involved in precision agriculture include GPS, which helps determine accurate field locations and boundaries. This information can be used to create digital maps of the fields, enabling farmers to identify specific areas that require special attention. For example, GPS technology can be used to precisely locate nutrient deficiencies in the soil, allowing farmers to apply fertilizers only where they are needed instead of broadcasting them across the entire field.

Another key technology used in precision agriculture is GIS, which allows farmers to analyze spatial data to identify patterns and trends in their fields. By creating maps that display soil composition, crop yields, and other relevant data, farmers can make informed decisions about crop management, such as determining the optimal time for planting or harvesting.

Remote sensing technology, on the other hand, involves the use of sensors and cameras to capture data from a distance. This data can be used to identify struggling areas in the field, such as regions with lower vegetation density. Farmers can then make targeted interventions by applying fertilizer or irrigation only to those specific areas. Sensors play a critical role in precision agriculture by monitoring moisture levels and nutrient content in the soil. This information helps farmers determine the right timing for watering and fertilizing their crops. Additionally, sensors can monitor weather patterns and provide predictions for adverse weather events like storms or droughts.

Machine learning algorithms are increasingly being utilized in precision agriculture. These algorithms analyze large amounts of data to identify patterns and make predictions about crop yields and disease outbreaks. They can also optimize crop rotations, determine the ideal planting density, and predict the best time to harvest crops. Lastly, precision agriculture involves the use of precision equipment such as planters and harvesters. These machines utilize GPS technology to ensure accurate seed planting depths, spacing, and precise crop harvesting timings.

Benefits of Precision Ag

Precision agriculture offers several benefits to farmers, the environment, and society. Here are some of the key benefits of precision agriculture:

- **Increased crop yields:** Precision agriculture enables farmers to optimize crop production by identifying specific areas within a field that require attention. By providing targeted interventions like fertilization, irrigation, and pest control, farmers can enhance crop yields, effectively meeting the rising demand for food.

- **Reduced input usage:** Implementing precision agriculture techniques allows farmers to minimize their consumption of water, fertilizers, and pesticides. This not only reduces costs for farmers but also helps mitigate the environmental impact of agriculture by minimizing the application of chemicals on crops.

- **Improved soil health:** Precision agriculture practices, such as variable rate fertilization and tillage, contribute to enhancing soil health. These techniques reduce erosion and soil compaction, increase organic matter content, and improve nutrient availability in the soil.

- **Decreased environmental footprint:** Precision agriculture plays a vital role in reducing the environmental impact of farming. By minimizing the application of chemicals, controlling runoff and erosion, and curbing greenhouse gas emissions from agricultural activities, precision agriculture promotes sustainable farming practices.

- **Enhanced efficiency:** Precision agriculture empowers farmers to maximize their resource utilization, including labor, fuel, and equipment. By leveraging precision equipment like advanced planters and harvesters, farmers can optimize their operations, reduce waste, and improve overall efficiency.

- **Informed decision-making:** Precision agriculture provides farmers with valuable data and insights, enabling them to make informed decisions regarding crop and livestock management. Tools like Geographic Information Systems (GIS) and remote sensing allow farmers to analyze data, identify patterns, and make strategic choices regarding planting schedules, fertilization practices, and crop harvesting.

Current Applications of Precision Ag

- **Soil and crop mapping:** Precision agriculture technologies such as remote sensing, GIS, and machine learning can be used to create detailed maps of soil types, soil properties, and crop growth patterns. These maps can be used to generate prescription maps that guide variable rate application of inputs such as fertilizers, pesticides, and water.

- **Variable Rate Technologies (VRT):** Precision agriculture technologies such as soil sensors, spectral reflectance sensors, and GPS-guided equipment can be used to apply inputs at variable rates based on the needs of different areas of a field. Algorithms and machine learning models can be used to process data and generate prescription maps that guide the application of inputs.

- **Drones, Aircraft, or Satellites:** Precision agriculture technologies such as drones, satellites, and ground-based sensors can be used to monitor crop growth and health by collecting and analyzing data on factors such as plant height, chlorophyll content, and canopy temperature. This data can be used to detect and diagnose crop stress, pests, and diseases, and to generate prescription maps for targeted intervention.

- **Yield Maps:** Precision agriculture technologies such as yield monitors, GPS receivers, and GIS can be used to create yield maps that show the yield of different areas of a field. This data can be used to identify spatial variability in crop yields, to analyze yield trends over time, and to generate prescription maps for variable rate application.

- **Livestock management:** Precision agriculture technologies such as wearable sensors, RFID tags, and data analytics can be used to monitor and manage livestock. This data can be used to optimize feeding and watering schedules, to detect and diagnose health issues, and to generate recommendations for management decisions.

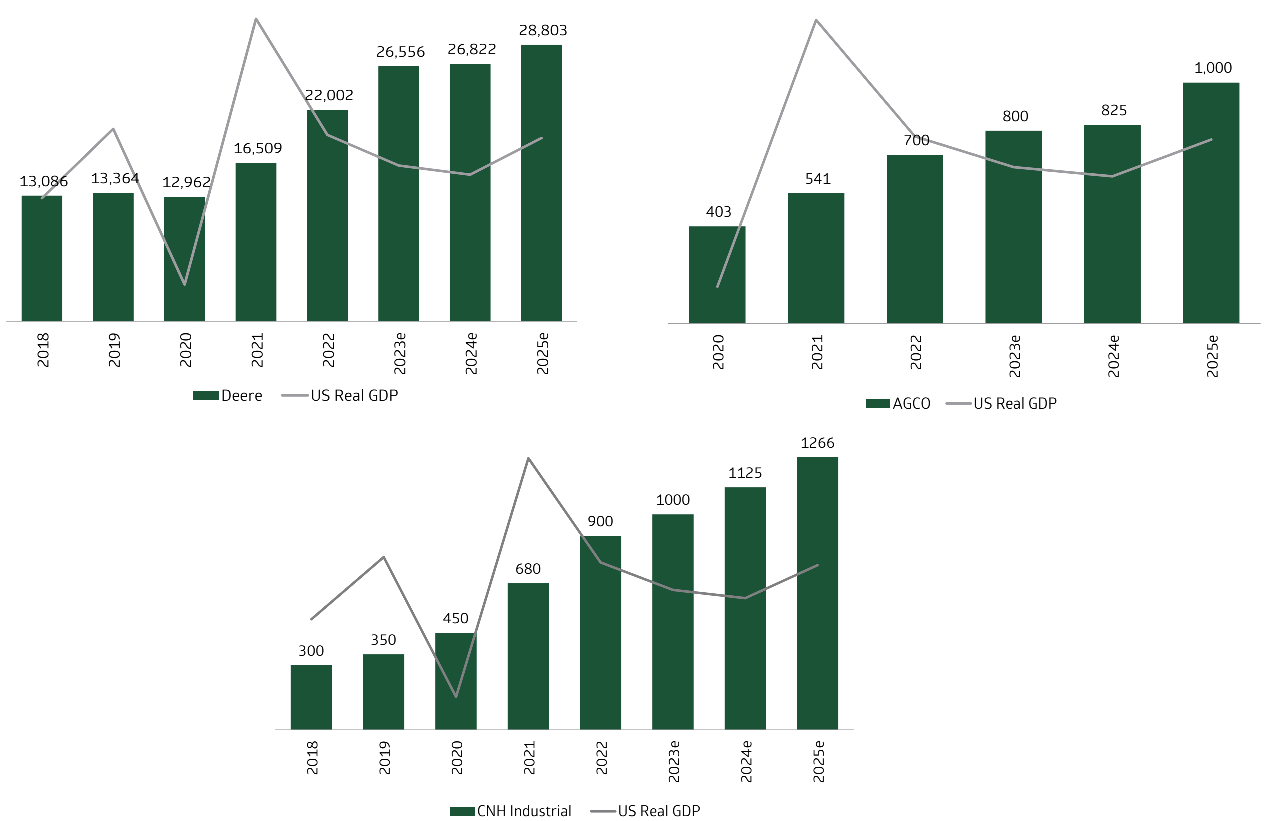
- **Autonomous equipment:** Precision agriculture technologies such as GPS, machine vision, and robotics can be used to develop autonomous equipment such as tractors, harvesters, and drones. These devices can perform tasks such as planting, harvesting, and spraying with high precision and accuracy, reducing labor costs, and improving efficiency.

Global Precision Ag Players

Although Precision Ag has been around since the early 2000s, it has really come to the forefront in the past decade. Global Ag Equipment players have not only spent R&D and acquisition dollars in the space but also set revenue targets in some instances. The three major players DE, CNH and AGCO have meaningful sales and have acquired multiple companies in the past few years.

CNH saw $900MM revenue from Precision Tech components in 2022 and expect that number to continue to grow at about 10% to 15% annually, and in the near-term expect to deliver more than $1 bn in 2023. In 2022, AGCO's precision ag sales grew to approximately $700 MM, which was a 29% increase over the prior year. They had recently increased their precision ag sales target to $1bn by 2025.

Figure 52 Precision Ag Revenue – DE, CNH & AGCO



Source: Eikon, Company filings, TD Cowen

Yield Map Adoption

Yield Maps were first seen in 1990s when producers first used them to calculate and characterize within-field production variability. They help analyze variable factors to factor inputs such as fertilizers and pesticides. A long yield history is fundamental to try not to misjudge data created from yield maps. Utilizing yield monitors with high resolution offers a potential solution to this misinterpretation.

Farmers are increasing yield map adoption: According to the ARMS surveys, Soybean-planted acreage adoption rates increased from 5.3% in 1996 to 43.8% in 2018; In 2016, adoption rates on all corn-planted acres reached 43.7 percent, up from 7.7 percent in 1997. Sorghum's adoption rate in 2003 was 1.5%, increasing to 22.7 percent in 2019; winter wheat increased from 0.7% in 1997 to 21.4% in 2017; furthermore, from 0.7 percent in 2000 for cotton to 15.2 percent in 2019.

Figure 53 Yield Map Adoption - Percent Of Crop-Planted Acres

Source: USDA/ERS, TD Cowen

Soil Maps Adoption

Soil Maps are used to identify soil types and their properties such as pH levels, depth of the soil, texture etc. They are used as decision tools to understand soil attributes as well as the ability of different types of soil.

Adoption rates have flattened: Soil maps adoption has been lagging compared to other precision ag technologies, as it remains consistently below 25% of planted acreage across surveyed crops, according to ARMS surveys. Only 21.5% of corn-planted acres were managed with soil maps in 2016, 14.3% of soybean-planted acres were managed with soil maps in 2018, 6.2% of sorghum-planted acres were managed with soil maps in 2019, and 5.6% of winter wheat-planted acres were managed with soil maps in 2017.

Figure 54 Soil Map Adoption - Percent Of Crop-Planted Acres

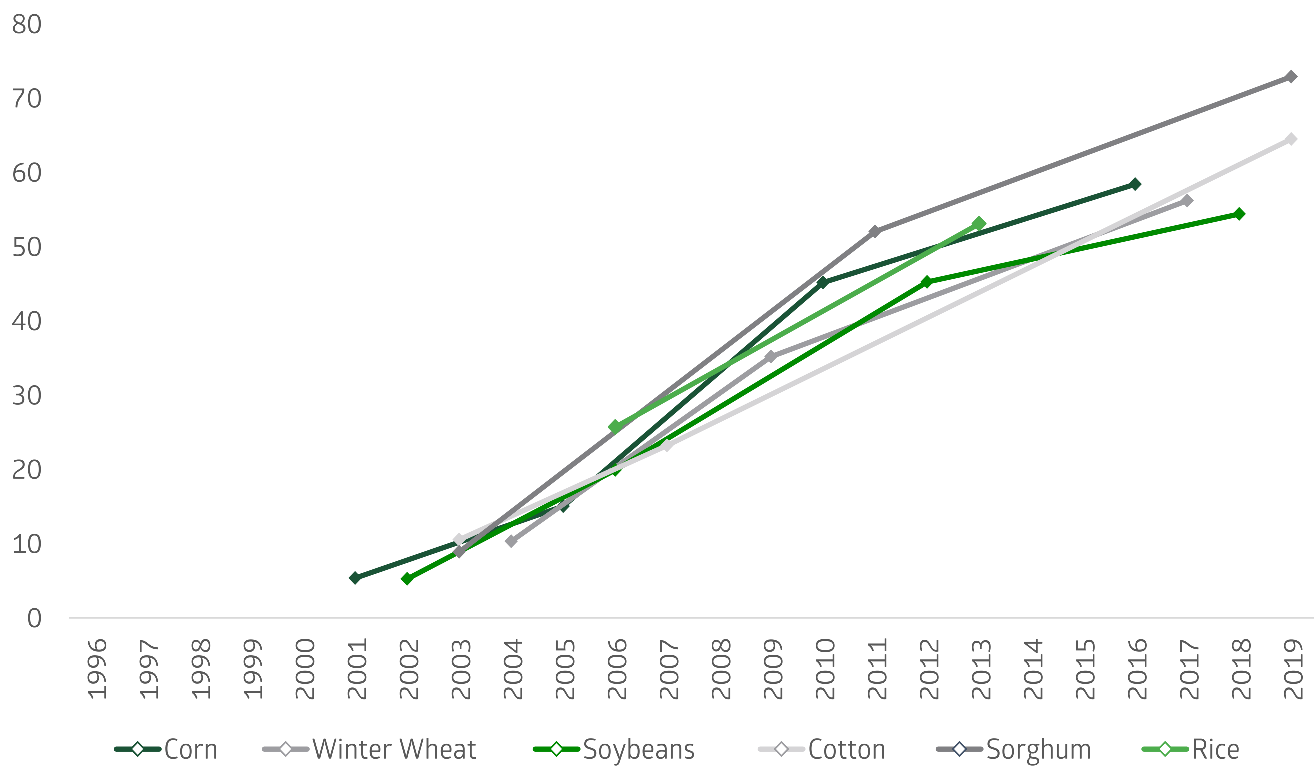
Source: USDA/ERS, TD Cowen

Guidance Systems Adoption

Guidance systems were one of the first precision ag technologies and are now present in a large portion of U.S. farms. It helps visualize the position of the equipment in the field to reduce skips and overlaps. Adoption rates have expanded as these systems not only help reduce input costs for farmers, but also free up their time with newer automated steering in tractors.

More than half of U.S. cropland managed with guidance systems: Adoption rates for guidance systems have increased significantly from mid-teens in the 2000s to over 50 percent for all row crops, according to ARMS surveys. Adoption rates ranged from 54.4 and 58.4 percent of planted soybean and corn acres in 2016 and 2018, respectively, to 64.5 and 72.9 percent of cotton- and sorghum-planted acres, respectively, in 2019.

Figure 55 Guidance Systems Adoption - Percent Of Crop-Planted Acres



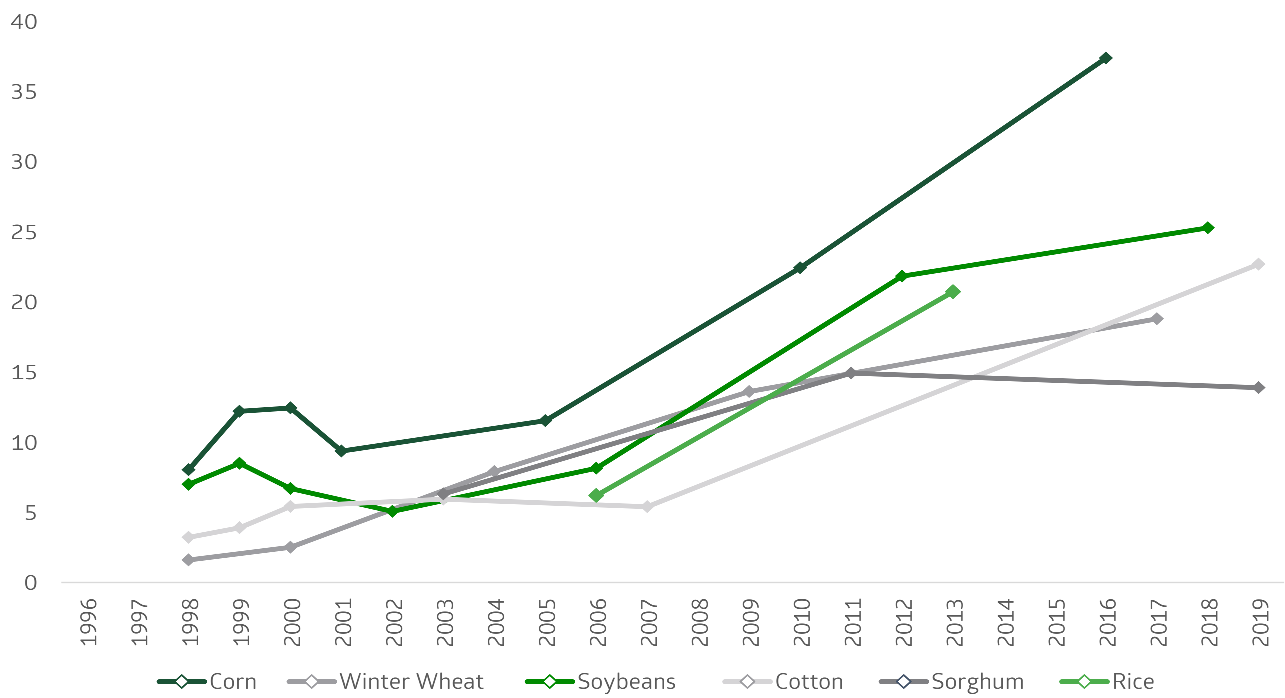
Source: USDA/ERS, TD Cowen

VRT Adoption And Use Case

VRT are used for various seeding and applications tasks on the farms. The most crucial benefit of VRT is being able to control variable inputs that lead to lower input costs. VRT is mostly used for application of pesticides, seeds, and fertilizers. It also helps commodity production in a sustainable and efficient manner.

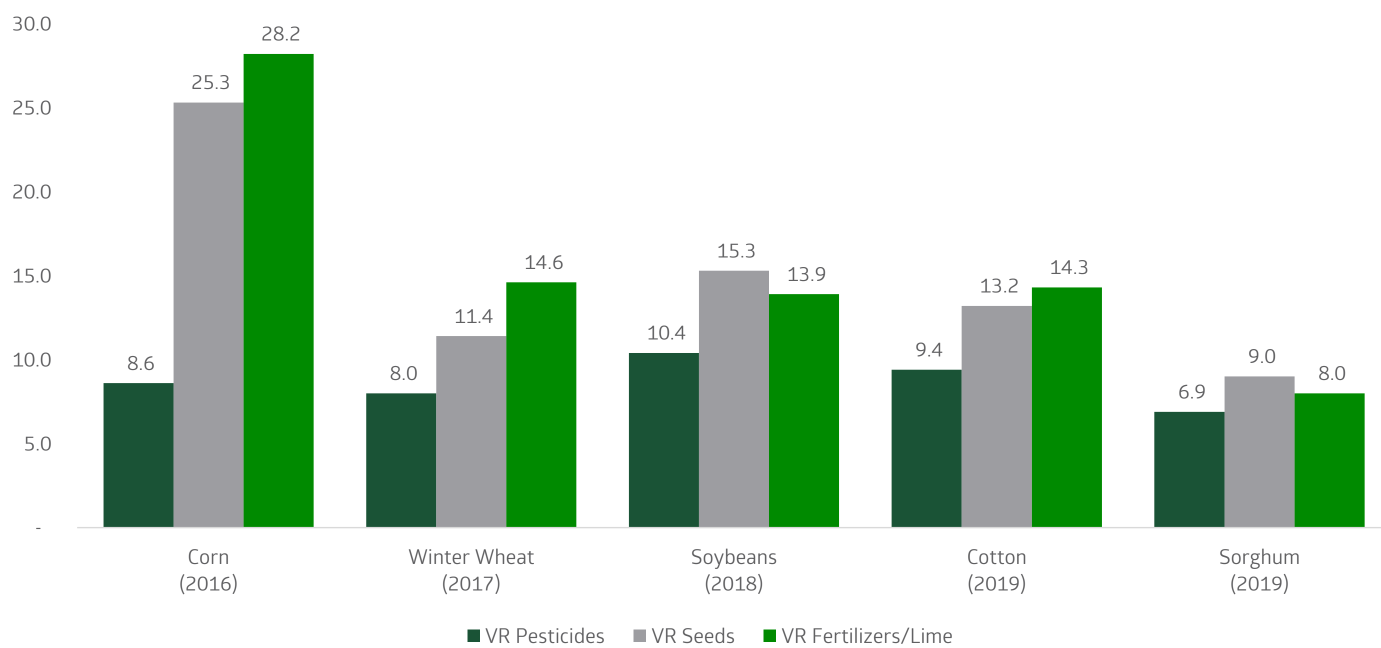
According to the ARMS surveys, VRT adoption rates reached 37.4 percent on corn-planted acres and 25.3 percent for soybean-planted acres in 2016 and 2018, respectively. VRT adoption rates for winter wheat reached 18.8 percent of planted acres in 2017, 13.9 percent for sorghum in 2019, and 22.7 percent for cotton in 2019.

Figure 56 VRT Adoption - Percent Of Crop-Planted Acres



Source: USDA/ERS, TD Cowen

Figure 57 VRT Use Case - Percent Of Crop-Planted Acres



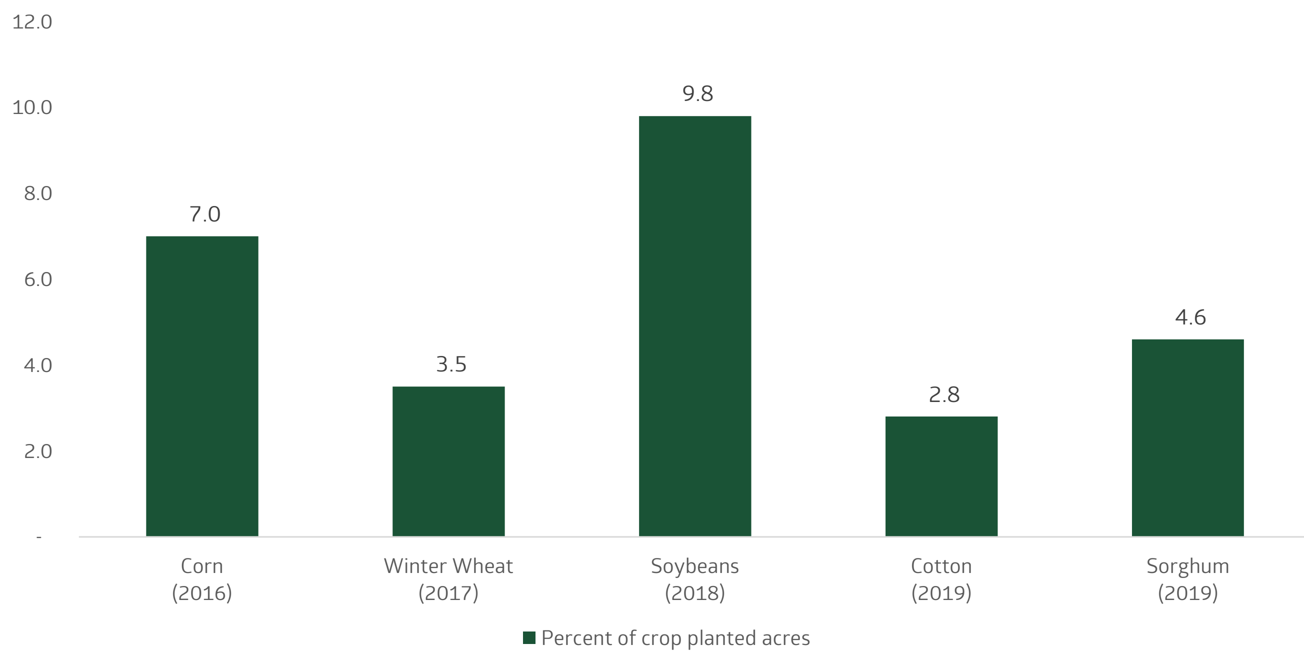
Source: USDA/ERS, TD Cowen

DAS Adoption

Traditionally, farms have used aircrafts for various operations. The use of drones that are equipped with satellite tracking are newer technologies that farmers are using to optimize their farm operations. There are various use cases such as crop mapping, livestock monitoring, land surveying, crop spraying, and crop dusting.

Given the technological complexities and expenses, adoption of these technologies remains limited. Adoption rates remained at 7.0 percent for corn in 2016 to 9.8 percent for soybeans in 2018. Meanwhile, the adoption rate on winter wheat-planted acreage in 2017 was 3.5 percent, with similar adoption in 2019 on cotton acres at 2.8 percent and sorghum at 4.6 percent.

Figure 58 DAS Adoption - Percent Of Crop-Planted Acres

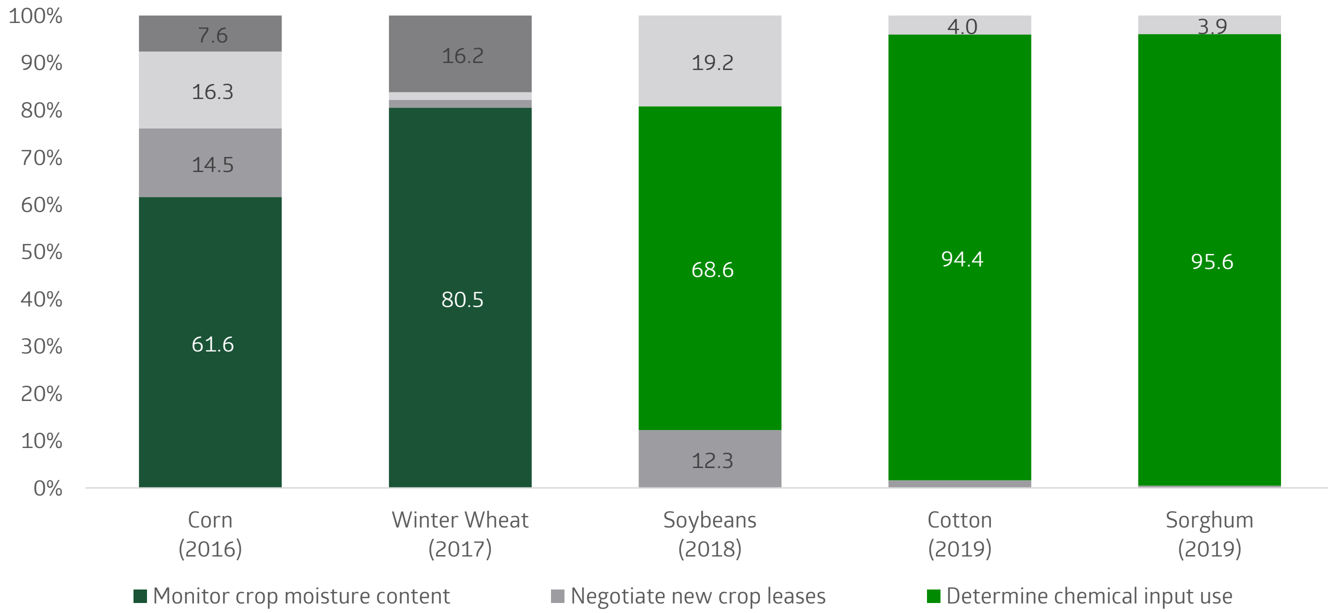


Source: USDA/ERS, TD Cowen

Yield Monitors – Use Case

Yield Monitors comprise 3 components: a mass flow sensor, a moisture sensor, and a GPS receiver. According to the USDA's ARMS survey, 61.6 percent of corn-planted acres in 2016 and 80.5 percent of winter wheat acres in 2017 used yield monitors to monitor crop moisture content. Meanwhile, of the farms adopting yield monitors – 95.6 percent, 94.4 percent, and 68.6 percent of sorghum (2019), cotton (2019), and soybean (2018) planted acres, respectively – were managed with yield monitors to help determine chemical input use. Farmers can use information generated by yield monitors to add or improve tile drainage and/or other water-related technologies.

Figure 59 Yield Monitors Use Case - Percent Of Crop-Planted Acres



Source: USDA/ERS, TD Cowen

Technology Combination

Producers use combinations of technologies for various reasons. Sometimes it may be due to productivity as equipment from the same OEM work better together and sometimes it may be due to cost-related reasons. It may also be due to marketing practices such as bundling.

Although a vast majority of national acreage for corn (2016), winter wheat (2017), soybeans (2018), and cotton (2019) are managed with use of only one precision technology, many technology combination are commonly used.

Figure 60 Percent of Planted Acreage Managed with Technology Combinations, 2016-2019

Technology combination	Survey and year			
	Corn % (2016)	Winter wheat % (2017)	Soybeans % (2018)	Cotton % (2019)
Maps only	2.32	1.81	4.97	0.8
Drones, aircraft, or satellites (DAS) only	0.49	0.61	0.02	0.04
Variable rate technologies (VRT) only	2	1.55	2.53	1.98
Guidance only	11.12	38.93	14.92	36.47
(Maps + VRT)	1.97	0.61	1.94	0.11
(Maps + guidance)	12.4	12.47	15.36	7.47
(VRT + guidance)	5.56	7.78	2.5	12.13
(Maps + DAS + guidance)	1.36	0.21	3.66	0.87
(Maps + VRT + guidance)	22.85	7.33	13.07	5.94
(Maps + DAS + VRT + guidance)	4.52	2.05	4.26	1.52

Source: USDA/ERS, TD Cowen

Costs & Fees

According to the ARMS surveys of soybean and cotton fields in 2018 and 2019, information on equipment replacement costs, annual fees, and premiums paid for different types of equipment is the table below. Premium paid for VRT is assumed for the entire farm operation, whereas annual fees are typically subscription fees.

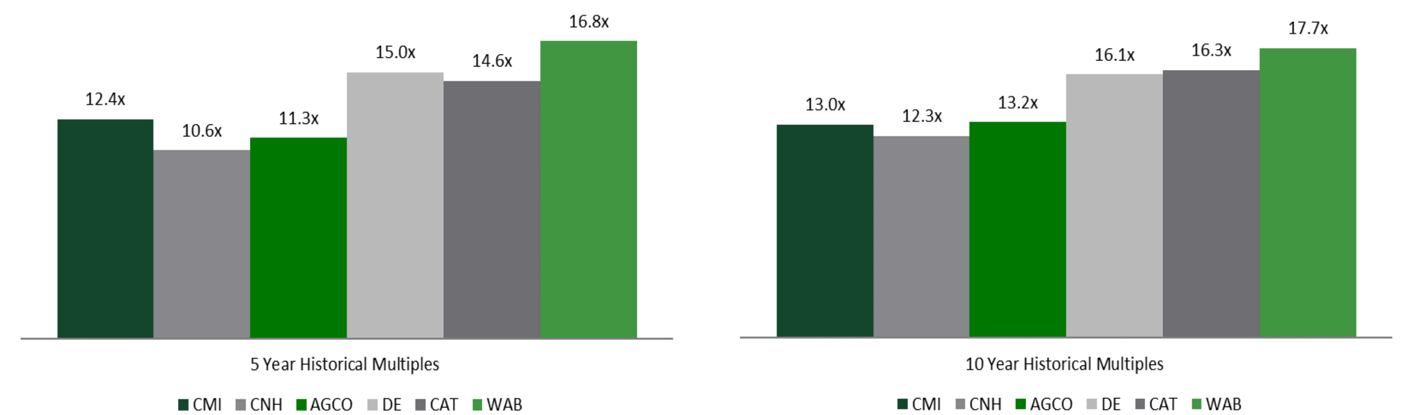
Notably, equipment manufacturers have different pricing and fees structures. The costs are not specific to any manufacturer, some are high-cost providers, whereas some have lower costs.

Figure 61 Replacement Costs, Annual Fees, Or Premiums Associated With Precision Technologies

Technology	Cost, fee, or premium	Soybeans (2018)	Cotton (2019)
Yield Monitor	Equipment replacement	$8,051	$13,775
		($350)	($1,293)
	Annual fee	$1,041	$1,772
		($76)	($482)
Variable rate technologies	Premium paid for equipment	$5,630	$10,319
		($1,320)	($3,546)
Guidance	Equipment replacement	$20,165	$25,168
		($5,019)	($2,836)
	Annual fee	$1,154	-
		($76)	-
Drones, aircraft, or satellites	Equipment replacement	$2,610	-
		($630)	-

Source: USDA/ERS, TD Cowen

Figure 62 Historical P/E Multiples



Source: TD Cowen estimates, Thomson Eikon, Bloomberg, SEC filings

Figure 63 Comparative Analysis

	Company	Ticker	Rating	Price 7/7/2023	Target Price	Market Cap (millions)	Dividend Yield	Implied Upside	2023e EPS	2024e EPS	23 EPS Growth	24 EPS Growth	23 P/E	24 P/E	Enterprise Value	EBITDA 2023	EBITDA 2024	EV/23 EBITDA	EV/24 EBITDA	52 Week Low	52 Week High	Change from 52 Low	from 52
Railcars	Freightcar America	RAIL	Market Perform	$2.98	$5.00	$52	NM	68%	($0.27)	$0.30	NA	NA	-11.0	9.9	152	18	29	8.4	5.2	$3	$5	13%	-45%
	Greenbrier *	GBX	Outperform	$43.01	$51.00	$1,317	2.5%	21%	$3.88	$4.39	246%	13%	11.1	9.8	2,798	339	395	8.3	7.1	$24	$45	81%	-4%
	Trinity Industries	TRN	Outperform	$25.45	$36.00	$2,034	3.6%	45%	$1.68	$2.10	77%	25%	15.1	12.1	7,916	754	843	10.5	9.4	$20	$32	27%	-20%
Truck Equip.	Paccar	PCAR	Market Perform	$82.80	$84.00	$42,757	4.3%	6%	$7.00	$5.60	22%	-20%	11.8	14.8	50,263	4,410	3,434	11.4	14.6	$51	$85	61%	-3%
	Cummins	CMI	Outperform	$244.65	$267.00	$34,286	2.1%	11%	$19.78	$20.88	21%	6%	12.4	11.7	40,857	4,866	5,028	8.4	8.1	$192	$262	28%	-7%
	Allison Transmission	ALSN	Not Rated	$56.70	NA	$5,098	1.5%	NA	$6.57	$6.90	25%	5%	8.6	8.2	7,260	1,054	1,054	6.9	6.9	$33	$57	74%	-1%
Selected Industrials	Caterpillar Inc.	CAT	Outperform	$245.01	$287.00	$123,984	1.9%	19%	$17.40	$18.40	25%	6%	14.1	13.3	154,254	13,433	14,775	11.5	10.4	$161	$266	53%	-8%
	Deere & Company	DE	Market Perform	$403.58	$438.00	$117,620	1.1%	10%	$31.15	$31.25	38%	0%	13.0	12.9	170,558	15,322	15,570	11.1	11.0	$288	$448	40%	-10%
	Agco Corporation	AGCO	Not Rated	$130.93	NA	$9,678	0.7%	NA	$14.55	$14.54	23%	0%	9.0	9.0	11,107	1,825	1,825	6.1	6.1	$85	$140	54%	-6%
	CNH Industrial NV	CNHI	Not Rated	$14.26	NA	$19,025	2.7%	NA	$1.73	$1.78	18%	3%	8.2	8.0	37,887	3,193	3,193	11.9	11.9	$11	$18	34%	-21%
	Terex Corporation	TEX	Not Rated	$58.35	NA	$3,894	0.9%	NA	$6.02	$6.07	46%	1%	9.7	9.6	4,417	631	631	7.0	7.0	$27	$61	115%	-4%
	Wabash National	WNC	Not Rated	$23.72	NA	$1,115	1.3%	NA	$4.13	$3.42	92%	-17%	5.7	6.9	1,444	342	342	4.2	4.2	$14	$30	74%	-21%
	Knorr-Bremse	KBX.DE	Not Rated	$69.79	NA	$10,902	2.2%	NA	$3.80	$4.27	8%	12%	18.4	16.3	12,701	1,286	1,286	9.9	9.9	$46	$77	52%	-9%
	Wabtec	WAB	Outperform	$109.38	$114.00	$19,469	0.5%	5%	$5.55	$6.05	14%	9%	19.7	18.1	23,265	1,751	1,842	13.3	12.6	$78	$111	40%	-1%
Lessors	GATX Corp	GATX	Outperform	$126.86	$135.00	$4,455	1.6%	8%	$6.90	$6.80	14%	-1%	18.4	18.7	10,658	744	756	14.3	14.1	$85	$130	49%	-3%
	Brambles	BXBLY.PK	Not Rated	$18.71	NA	$12,969	NM	NA	$0.49	$0.54	19%	11%	38.3	34.5	12,969	2,057	2,057	6.3	6.3	$14	$20	36%	-5%
	Ryder System	R	Not Rated	$84.37	NA	$3,877	2.8%	NA	$11.64	$11.59	-27%	0%	7.2	7.3	9,964	2,855	2,855	3.5	3.5	$66	$102	28%	-18%
	Triton International	TRTN	Not Rated	$84.25	NA	$4,603	3.1%	NA	$9.45	$9.79	-16%	4%	8.9	8.6	13,147	1,464	1,464	9.0	9.0	$52	$84	61%	1%
	Textainer Group	TGH	Not Rated	$39.55	NA	$1,653	2.5%	NA	$4.83	$5.30	-22%	10%	8.2	7.5	7,023	663	663	10.6	10.6	$26	$41	52%	-3%
Int'l	Alstom SA	ALSO.PA	Not Rated	$27.62	NA	$10,308	1.0%	NA	$1.46	$1.71	28%	18%	19.0	16.1	13,549	1,272	1,272	10.7	10.7	$17	$31	58%	-11%
	Thales SA	TCFP.PA	Not Rated	$144.03	NA	$30,029	2.2%	NA	$8.56	$9.59	13%	12%	16.8	15.0	30,431	3,159	3,159	9.6	9.6	$118	$157	22%	-8%
	Total Average					$21,863	2.0%															50%	-10%
	Railcar Average					$1,134	3.1%															40%	-23%
	Truck Equipment					$27,381	2.6%															54%	-3%
	Selected Industrials Average					$38,211	1.4%															58%	-10%
	Leasing Average					$5,511	2.5%															45%	-6%
	International Components					$20,169	1.6%															40%	-9%

* Estimated calendar year metrics

Source: TD Cowen estimates, Thomson Eikon consensus estimates, SEC filings

DE Company Overview

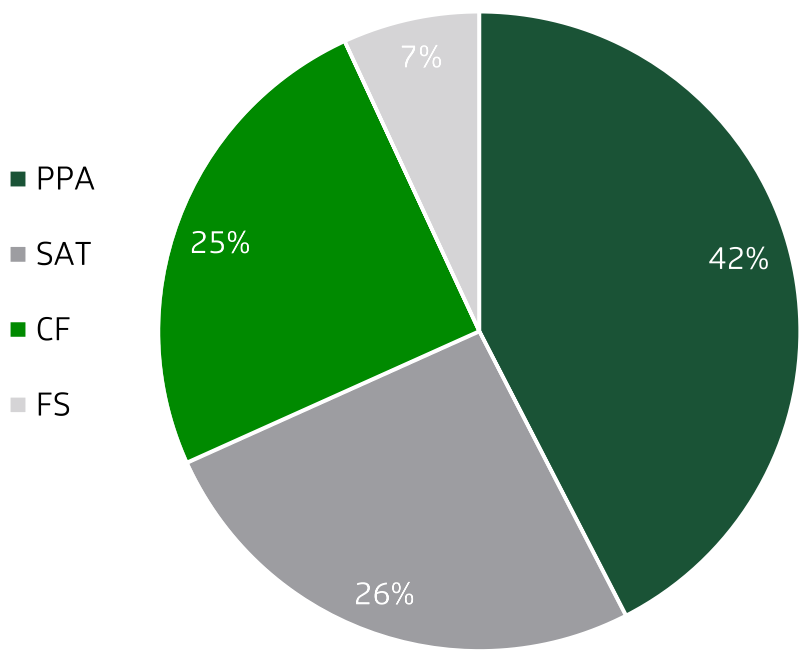
Profile

Founded in 1837 with headquarters in Moline, IL, Deere & Company (DE) is a global manufacturer and distributor of equipment used in agriculture, turf, construction, and forestry. The company operates four different primary segments, which include production and precision agriculture (PPA), small agriculture and turf (SAT), construction & forestry (CF), and financial services (FS). In the U.S. and Canada, Deere owns and operates 21 factory locations and leases and operates another two locations. Outside of these regions, Deere owns/operates 44 factories for equipment manufacturing across the globe. Deere has an October 31 fiscal year-end.

Segments

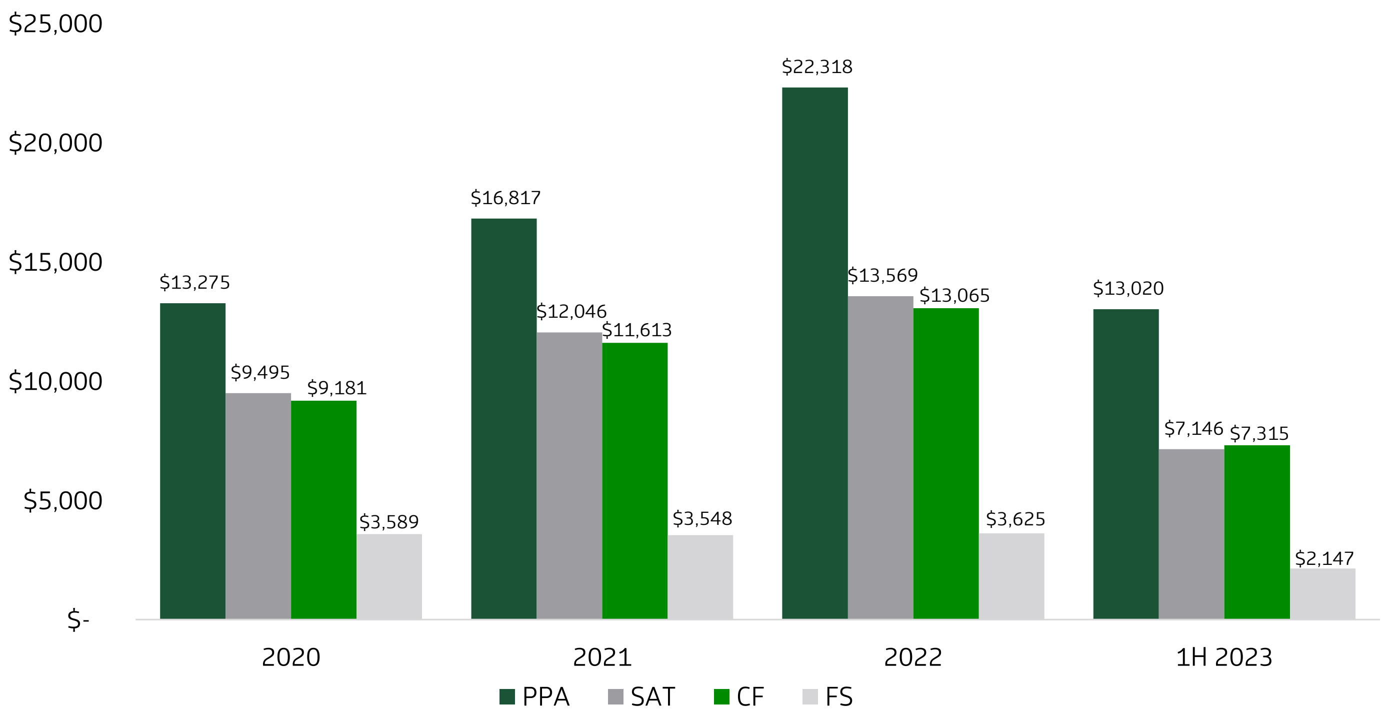
In fiscal 2021, Deere changed its reporting structure, breaking out its previous agriculture and turf segment into two new segments, production and precision agriculture, and small agriculture and turf. Its two other segments, construction and forestry and financial services, remain unchanged.

Figure 64 Revenues by Segment, Fiscal 2022



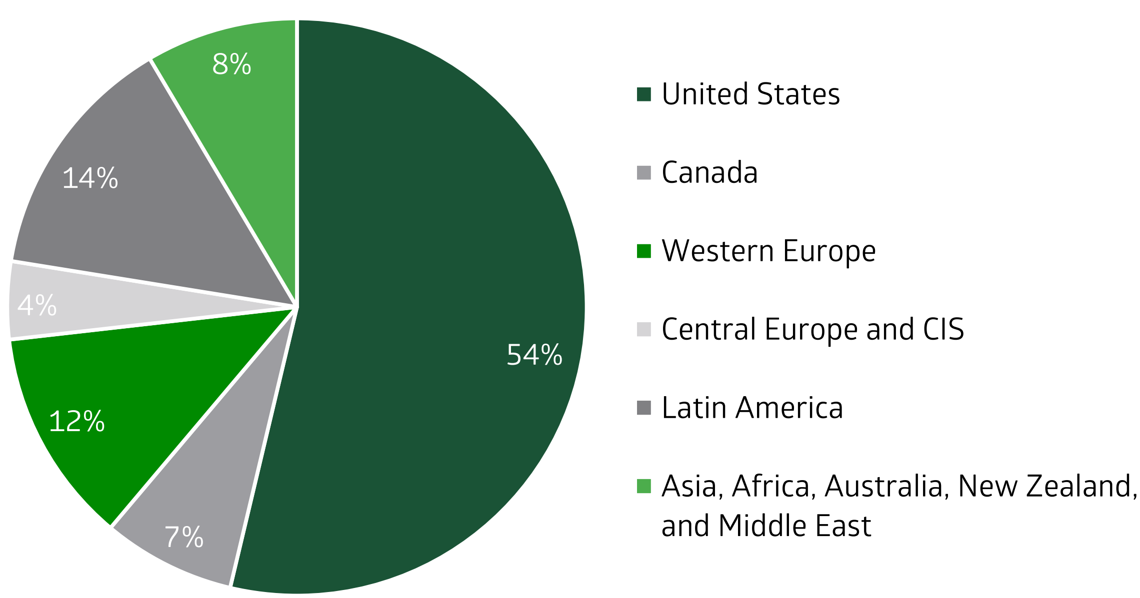
Source: Eikon, SEC filings, TD Cowen

Figure 65 Revenues by Segment, Fiscal 2020-2022 and 1H 2023 ($MM)



Source: Eikon, SEC filings, TD Cowen

Figure 66 Geographic Revenue, Fiscal 2022



Source: Eikon, SEC filings, TD Cowen

Production and Precision Agriculture

Production and precision agriculture develops and manufactures global equipment and technology for large and small grains, cotton, and sugar. This equipment includes large and mid-size tractors, combines, cotton pickers, cotton strippers, sugarcane harvesters, loaders, scrapers, and other harvesting equipment. On the technology and solutions side, this segment offers precision technology to improve customer profitability, productivity, and sustainability. These encompass a wide range of solutions including sensors, software, digital tools, and other analytics. This segment also manufactures and sells other equipment (sprayers, planters, seeders) under different brand names, including Hagie and Mazzotti, PLA, and King Agro.

Small Agriculture and Turf

Under this segment, DE defines small agriculture and turf as equipment and technology for dairy and livestock producers, high value crop producers, and turf and utility customers. Equipment manufactured and distributed under this segment includes small and mid-size tractors, loaders, turf and utility equipment, riding lawn equipment, commercial mowing equipment, golf course equipment, utility vehicles, tilling, snow, sports, and other outdoor products, among others. DE also purchases products for resale in this category. Additionally, DE sells other equipment and other attachments under names including Frontier, Kemper, and Green Systems. Aftermarket parts for a variety of products are sold under the names Vapormatic, A&I, and Sunbelt. This business segment sells primarily to independent dealer networks, as well as mass retailers including The Home Depot and Lowe's.

Fluctuations in this segment are affected by total farm cash receipts, which include commodity pricing, crop yields, and government subsidies. Macro trends also affect this segment such as agricultural trends, land prices, labor costs, tax policies, exchange and interest rates, and other input costs. Sales are driven primarily by weather conditions, consumer spending, and general economic conditions. Its retail segment is subject to significant seasonality, with most of its sales higher in the second and third fiscal quarters.

Construction & Forestry

Deere's Construction & Forestry segment makes equipment including backhoe loaders, crawler dozers and loaders, graders, dump trucks, milling machines, paves, compactors, rollers, crushers, among others. This segment provides a broad line of construction and forest equipment that comes with a high level of competition among many global players. Some of its machines are not distributed under the John Deere brand name, including, Wirtgen Group products (Wirtgen Vogele, Hamm, Benninghoven, and Ciber), and forestry products under the brand name Waratah. Additionally, Deere purchases certain products from manufacturers for resale. This segment also provides connectivity and telematics to offer customers improved worksite management, productivity, and efficiency. Fluctuations in this segment are driven by economic trends, investments in infrastructure, forestry conditions, interest rates, and commodity prices.

Deere also offers products in the rental market for construction, earthmoving, roadbuilding, material handling, and other equipment, which are designed by rental programs for John Deere dealers and other international partners. The company has numerous licensing and joint venture partners to assist the manufacturing and distribution of certain products in countries outside of North America.

Financial Services

The company's Financial Services segment relates to the financing and leasing by John Deere dealers of new and used equipment across its product portfolio. Deere also provides wholesale financing to dealers of equipment, financing retail revolving charge accounts, and equipment warranties. John Deere Capital Corporation, a U.S. financial services subsidiary, is responsible for purchasing retail installment sales and loan contracts. Deere runs a Canadian equivalent; both also provide wholesale financing for inventories for equipment across its portfolio owned by dealers of those products. This segment generates income but is also designed to enhance sales for Deere products.

To provide a security interest in the equipment financed, the segment has guidelines for minimum down payments, which vary by type of equipment (generally 0-20% of purchase price). The financial services operation generally receives income from the sales companies at roughly market interest rates for periods of financing during which finance charges are waived or reduced on the notes/leases (which typically occur in the off season).

Competition

Equipment operations and services are a highly competitive global and regional market. The primary competitive factors are performance, quality, innovating, distribution, price, and customer service.

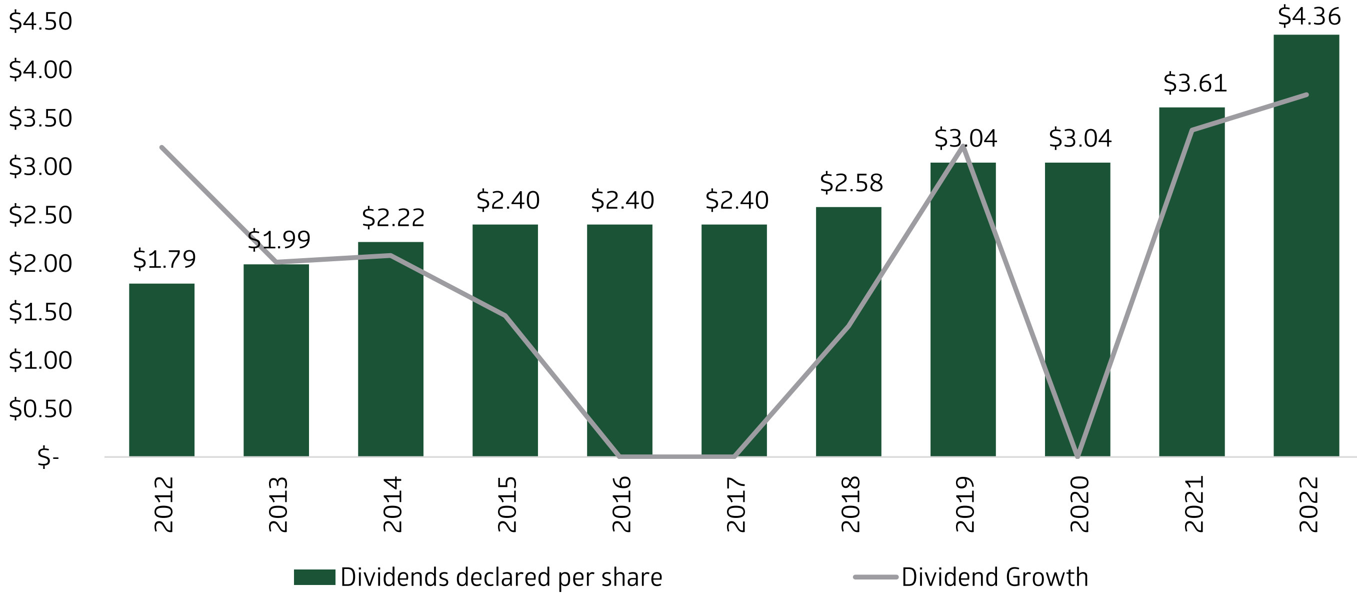
Within its agriculture segment, global competitors include AGCO Corporation, CLAAS KGaA, CNH Industrial, Kubota Tractor, Mahindra, and The Toro Company. Regional competitors focus on more specialized products catered to a specific region, specialty manufacturing, unique marketing methods. As technology continues to grow and integrate with equipment, non-traditional companies are entering the competitive environment including tech-focused startups and ventures. While Deere remains competitive in North America and Western European markets, the company is pushing into expanding markets such as Brazil and India.

Within its construction and forestry segment, global competitors include Caterpillar, CNH, Doosan Infracore, Doosan Bobcat, Fayat, Komatsu, Kubota, Ponsse, SANY, Terex, Tigercat Industries, Volvo, and XCMG. Deere remains competitive in North and South America, as well as other markets such as China and Russia. The company manufactures over 90% of the types of construction equipment used in the U.S. and Canada, which includes construction, forestry, earthmoving, roadbuilding, and material handling equipment.

Dividend and Share Repurchase History

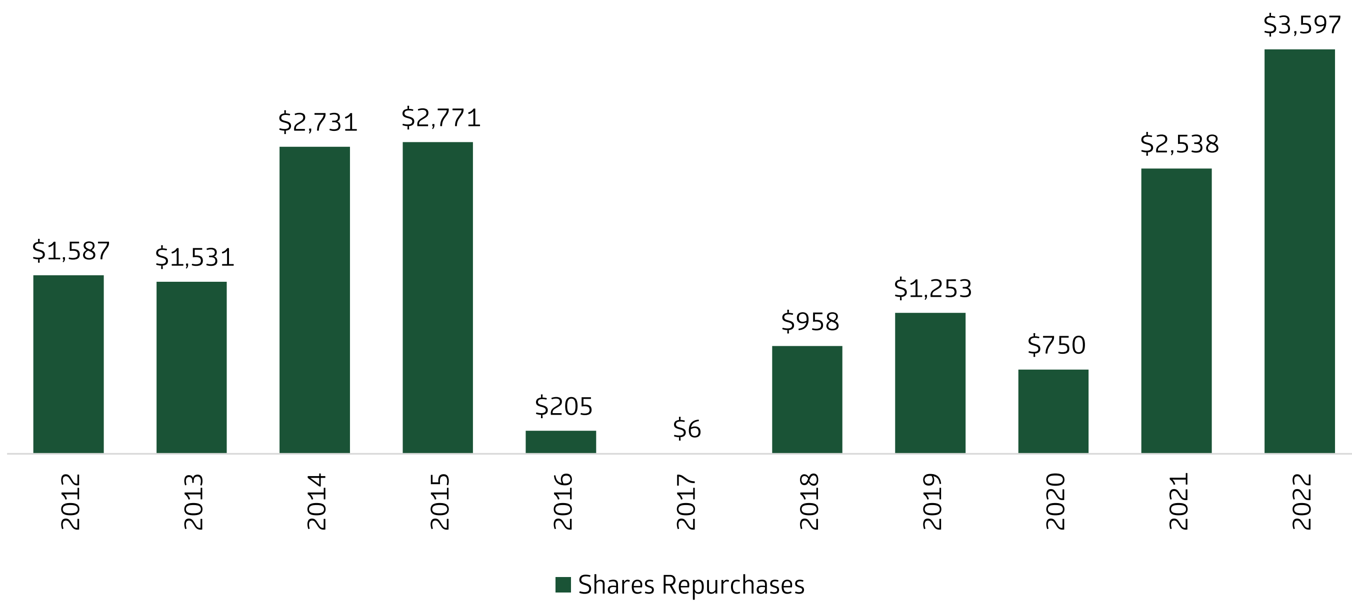
In fiscal 2022, Deere returned $4.9Bn to investors via dividends ($1,313MM) and share repurchases ($3,597MM). In fiscal 2022, the company increased its dividend to $4.36 per share, up 8% from 2021 In December 2022, the board authorized the repurchase of up to $18,000 MM of additional common stock. This repurchase program will supplement the existing $8,000 MM share repurchase program, which had $2,228 MM remaining on October 30, 2022. On December 7, 2022, a quarterly dividend of $1.20 per share was declared at the board of directors meeting, payable on February 8, 2023, to stockholders of record on December 30, 2022.

Figure 67 Dividend History (2012-2022)



Source: Eikon, SEC filings, TD Cowen

Figure 68 Share repurchases ($MM, 2012-2022)



Source: Eikon, SEC filings, TD Cowen

ESG Initiatives

The current Truvalue Labs ESG score for DE is 59. A score of 50 represents a neutral impact. Scores above 50 indicate more positive performance, and scores below reflect more negative performance.

In 2021, DE completed its inaugural sustainability materiality assessment to identify, assess, and prioritize the sustainability topics most significant to its business and stakeholders. According to the company's 2022 sustainability report:

- In 2021, Deere exceeded its 15 percent absolute Scope 1 and 2 GHG reduction goal one year early, achieving nearly 20 percent reduction. As the company closes out its 2022 goals, it achieved a total reduction in operational GHG emissions of nearly 29 percent between 2017 and 2022. They validated Science Based Targets to reduce its Scope 1 and 2 GHG emissions by an additional 50 percent by 2030, with fiscal year 2021 serving as the baseline.

- The company has created initiatives around diversity to be achieved by 2025, such as spend $500 million with minority-owned businesses, spend $1 billion with woman-owned businesses, and grow relationships with disadvantaged business enterprises owned by veterans, members of the LGBTQ community, individuals with disabilities, small businesses, and businesses in underutilized business zones.

- DE has a Center for Global Business Conduct, which provides continuous training, communications, and best practices throughout Deere's operation to sustain a strong ethical culture and ensure compliance with laws and regulations.

Figure 69 Historical Timeline

1837	John Deere founded with commercial steel plow
1868	John Deere's business was incorporated under Deere & Company
1918	John Deere enters the tractor business with two models (Waterloo Boy & John Deere Tractor)
1935	Introduces first industrial-use tractor (DI)
1956	Acquires German truck manufacturer Heinrich Lanz making its first European manufacturing site
1963	Enters the market with lawn and garden tractors
1992	Introduces Gator Utility Vehicle
1996	Introduces fully-integrated mapping package (Greenstar system)
1973	Introduces "Sound Idea" tractors
1999	Introduces Single-Tine Separation System to improve handling with new technology
2017	Acquires Wirtgen, manufacturer of roadbuilding equipment
2017	Acquires Blue River Technology to further AI stack with next gen. technology
2019	John May assumes role of CEO
2021	Acquires Bear Flag Robotics
2021	Acquires majority ownership in Kreisel Electric

Source: Eikon, SEC filings, TD Cowen

CNH Industrial Company Overview

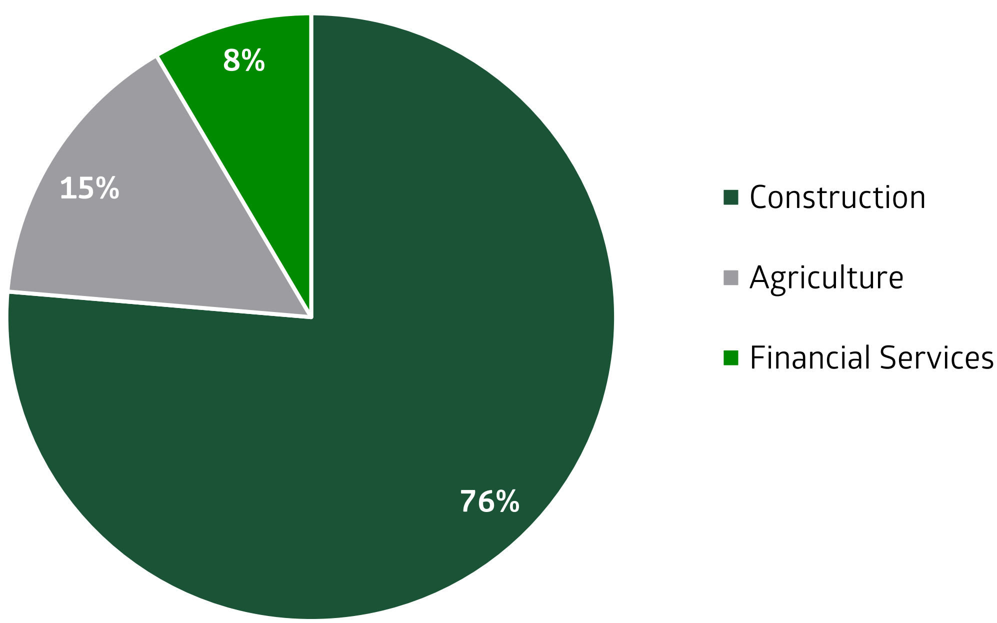
Profile

CNH Industrial is a global equipment and services company engaged in the design, production, marketing, sale, and financing of agricultural and construction equipment. It has industrial and financial services companies located in 32 countries and a commercial presence in approximately 170 countries.

History and Development

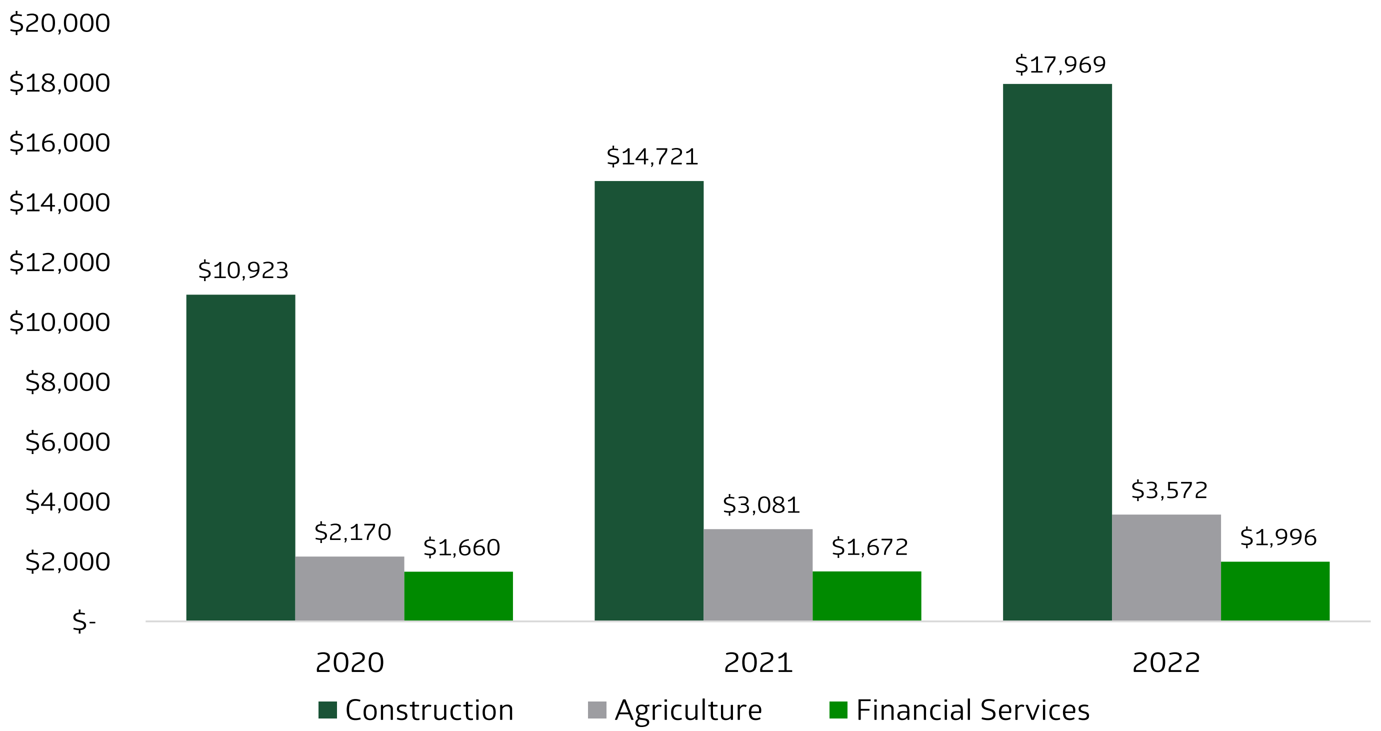
CNH Industrial is the company initially formed by the business combination transaction, completed on September 29, 2013, between Fiat Industrial S.p.A. and its subsidiary CNH Global N.V. Until December 31, 2021, CNH Industrial N.V. owned and controlled the Commercial and Specialty Vehicles business, the Powertrain business, and the related Financial Services business (together the "Iveco Group Business" or the "On-Highway Business"), as well. Effective January 1, 2022, the Iveco Group Business was separated from CNH Industrial N.V. by way of a demerger to Iveco Group N.V. (the "Iveco Group"), and the Iveco Group became a public listed company independent from CNH Industrial with its common shares trading on the Euronext Milan.

Figure 70 Revenues by Segment, Fiscal 2022



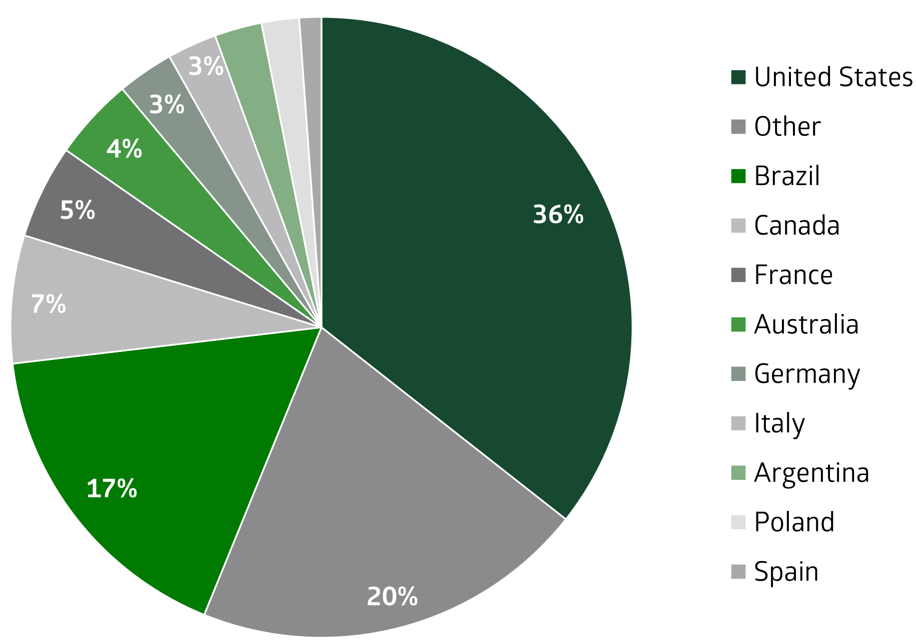
Source: Eikon, SEC filings, TD Cowen

Figure 71 Revenues by Segment, Fiscal 2020-2022 ($MM)



Source: Eikon, SEC filings, TD Cowen

Figure 72 Geographic Revenue, Fiscal 2022



Source: Eikon, SEC filings, TD Cowen

Agriculture

The company offers a full line of agricultural machinery and equipment, including 2WD and 4WD tractors, crawler tractors, combines, grape and sugar cane harvesters, hay and forage equipment, planting and seeding equipment, soil preparation and cultivation implements, and material handling equipment. Agricultural equipment is sold under the New Holland Agriculture and Case IH brands. Regionally focused brands include: STEYR, for agricultural tractors; Flexi-Coil specializing in tillage and seeding systems; Miller manufacturing application equipment; Kongskilde providing tillage, seeding and hay & forage implements. Further, starting in December 2021, Raven was included in the agriculture segment bringing a leader in digital agriculture, precision technology and the development of autonomous systems to CNH Industrial.

Construction

Construction designs, manufactures and distributes a full line of construction equipment including excavators, crawler dozers, graders, wheel loaders, backhoe loaders, skid steer loaders, and compact track loaders. Construction equipment is sold under the CASE Construction Equipment, New Holland Construction and Eurocomach brands.

Financial Services

Financial Services offers retail note and lease financing to end-use customers for the purchase of new and used agricultural and construction equipment and components sold through CNH Industrial brands' dealer network, as well as revolving charge account financing and other financial services. Financial Services also provides wholesale financing to CNH Industrial brand dealers and distributors.

AGCO Corporation Company Overview

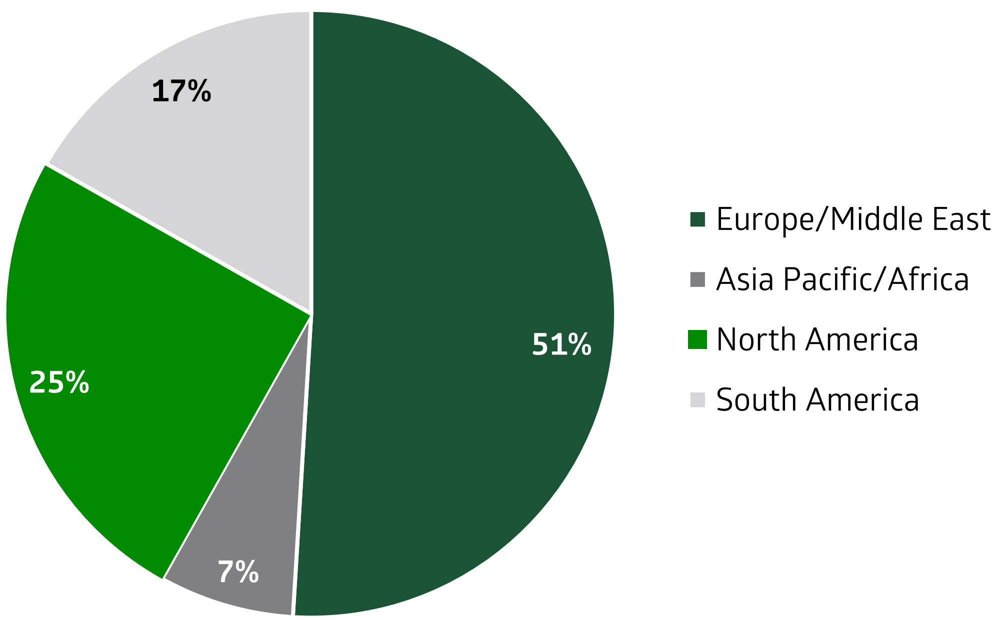
Profile

Incorporated in 1991 in Delaware, AGCO Corporation (AGCO) is a global manufacturer and distributor of agricultural equipment and related replacement parts. It sells a full range of agricultural equipment, including tractors, combines, self-propelled sprayers, hay tools, forage equipment, seeding and tillage equipment, implements, and grain storage and protein production systems marketed under brands such as Fendt, GSI, Massey Ferguson, Precision Planting and Valtra. It distributes most of its products through approximately 3,100 independent dealers and distributors in approximately 140 countries.

Segments

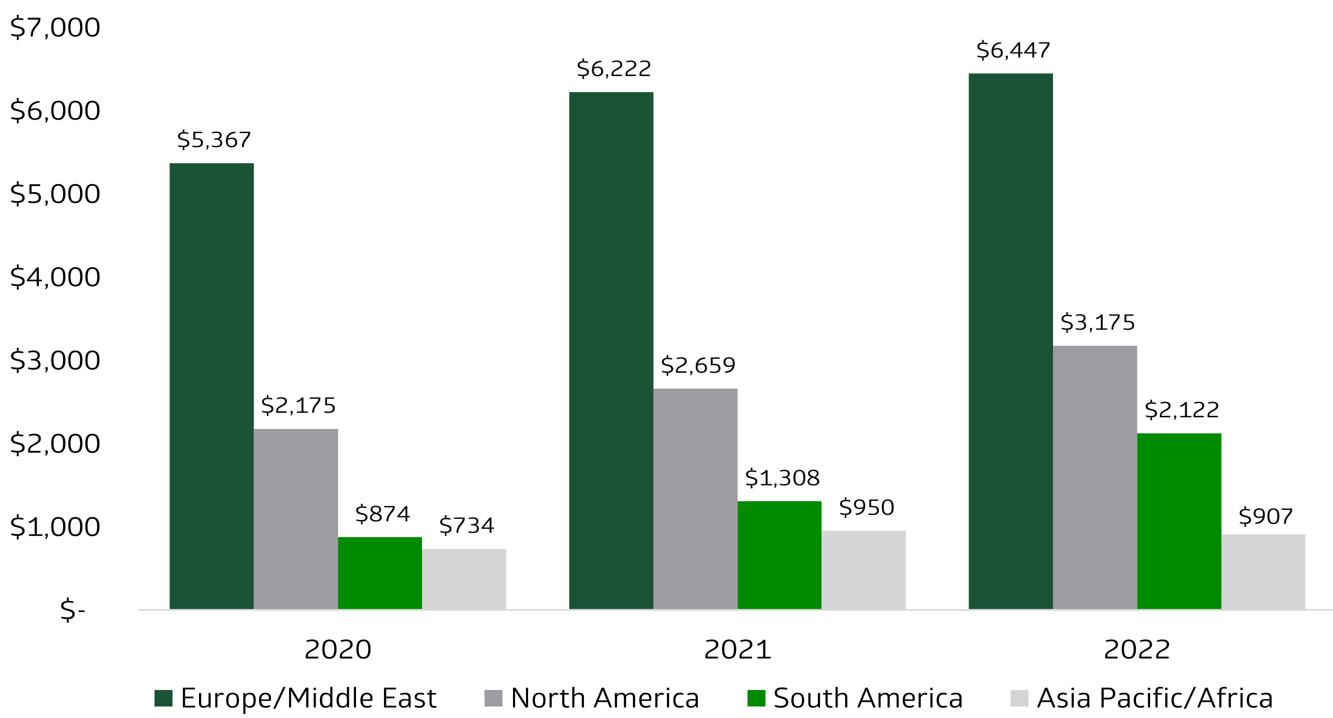
AGCO reports revenue by both regionally and by product line. There are four major segments in each of these breakdowns. Regional – North America, South America, Europe/Middle East/Africa, and Asia/Pacific. Product Line – Tractors, Replacement Parts, Grain Storage and Protein Production Systems, and Other.

Figure 73 Revenues by Region, Fiscal 2022



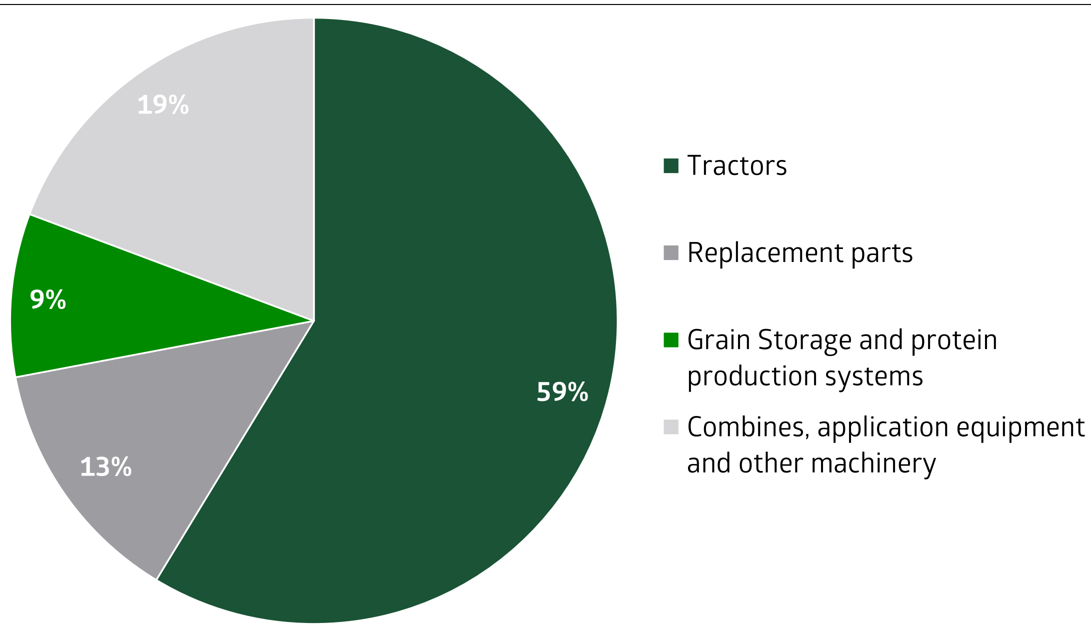
Source: Eikon, SEC filings, TD Cowen

Figure 74 Revenues by Region, Fiscal 2020-2022 ($MM)



Source: Eikon, SEC filings, TD Cowen

Figure 75 Revenue by Product Line, Fiscal 2022



Source: Eikon, SEC filings, TD Cowen

Regional Business

Although AGCO is a U.S.-based company, the largest share of their revenues comes from sales in Europe/Middle East, contributing 51% in FY22. North America is second on AGCO's revenue list at 25%, with South America and Asia/Pacific rounding out at 17% and 7%, respectively. Over the same timeframe, North America has held steady in the lower- to mid-20s and Asia/Pacific remains at similar levels, where South America has more than doubled its share from 7% in 2020 to 17% in 2022.

Product Line Business

Similar to the Regional breakdown, there is a one major contributor in their Product line: Tractors. For 2022, tractors made up ~59% of AGCO's revenue, more than tripling any of the other segments. Combines, Application Equipment & other machinery was next with ~19%, with replacement parts just after at ~13% and grain storage and protein production systems at ~9%.

Primer: Vertical Farming

Vertical farming is a method of cultivating crops in vertically stacked layers using combination of artificial lighting, temperature control, and hydroponic or aeroponic growing systems. The practice has gained popularity in recent years as a potential solution to the challenges of traditional agriculture, such as limited land availability, unpredictable weather conditions, and resource-intensive farming practices.

It is worth noting that not all crops are well-suited for vertical farming. Leafy greens, herbs, and some fruits such as strawberries are among the most commonly grown crops in vertical farms due to their relatively low height and quick growth cycle. Root crops such as potatoes and carrots, and crops that require extensive branching such as tomatoes and corn, are typically better suited to traditional farming methods.

Pros:

- **Efficient footprint:** vertical farming allows for high-density cultivation in a relatively small space, making it ideal for urban environments.

- **Year-round production:** with the use of artificial lighting and climate control systems, vertical farms can produce crops year-round, regardless of seasonal changes or weather conditions.

- **Efficient resource usage:** vertical farms typically use significantly less water and fertilizers than traditional farms and can also reduce the need for pesticides and herbicides.

- **Reduced transportation costs:** by growing crops in urban areas, vertical farms can reduce the distance that produce needs to travel to reach consumers, lowering transportation costs and reducing emissions.

Cons:

- **High startup costs:** vertical farming requires significant upfront investment in equipment, infrastructure, and technology, which can be a barrier to entry for many farmers.

- **Energy-intensive:** the use of artificial lighting, climate control systems, and other technologies can make vertical farming energy-intensive, leading to higher operating costs and potential environmental impacts.

- **Limited crop variety:** some crops are better suited for vertical farming than others, and the technology is still evolving to make it possible to grow a wider variety of crops in a cost-effective manner.

- **Complexity:** vertical farming involves complex systems and technologies, requiring specialized knowledge and skills to operate effectively.

Economics And Yield Of Vertical Farms Vs. Traditional Farms Is Compelling – What Studies Have Shown

Multiple studies all show similar conclusions: vertical farming has higher output efficiency and better water conservation, but energy costs are elevated vs. traditional methods per unit of output.

Cornell University found that indoor vertical farms could achieve a profit margin of 15-20% on leafy greens such as lettuce and spinach, while outdoor conventional farms typically have profit margins of around 2-3% on these crops.

The University of Arizona found that indoor vertical farms can produce up to 10 times as much lettuce per unit of land compared to outdoor farms, while using 70% less water. However, the study found that the energy costs of indoor farming were higher than traditional farming, resulting in higher production costs per unit of output.

The University of California, Davis compared the production costs of strawberries grown in a vertical farm to those from in a traditional field. The study found that the cost of production per kilogram of strawberries was slightly higher in the vertical farm ($3.32/kg) compared to the field ($2.87/kg). However, the vertical farm was able to produce strawberries year-round, while the field could only produce them during the summer season.

A study by the University of Nottingham found that a vertical farm growing lettuce could produce up to 1,200 times more lettuce per square meter per year than a traditional field, while using up to 70% less water. The study also found that the energy costs of vertical farming were higher than traditional farming, but that the higher yield could offset these costs.

Automation Equipment Required In A Vertical Farm

Pumps: required to circulate water and nutrients through the growing system.

Valves: used to control the flow of water and nutrients through the growing system.

Temperature and humidity sensors: used by the grower to adjust environmental conditions to optimize plant growth.

CO2 sensors: used to monitor the level of carbon dioxide in the growing area, an important metric to track for plant growth.

pH sensors: used to measure the acidity or alkalinity of the nutrient solution in the hydroponic system, allowing the grower to adjust nutrient levels for optimal plant growth.

EC/TDS sensors: used to measure the electrical conductivity (EC) or total dissolved solids (TDS) of the nutrient solution, providing information on the nutrient concentration and allowing the grower to adjust nutrient levels as needed.

Light sensors: used to measure the amount of and intensity of light in the growing area, allowing the grower to optimize lighting conditions for plant growth.

Nutrient dosing systems: used to automatically add nutrients to the hydroponic system based on the readings form the pH and EC/TDS sensors.

Climate controllers: these controllers use the data from the sensors to adjust the temperature, humidity, and CO2 levels in the growing area.

Irrigation controllers: these controllers automate the watering and nutrient delivery system, ensuring that plants receive the right amount of water and nutrients.

Monitoring software: allows the grower to monitor the growing environment remotely and receive alerts if any environmental conditions fall outside of preset parameters.

Hydroponic Vs. Aeroponic Growing Systems

Both are soilless methods of growing plants, but they differ in how the plants receive water and nutrients.

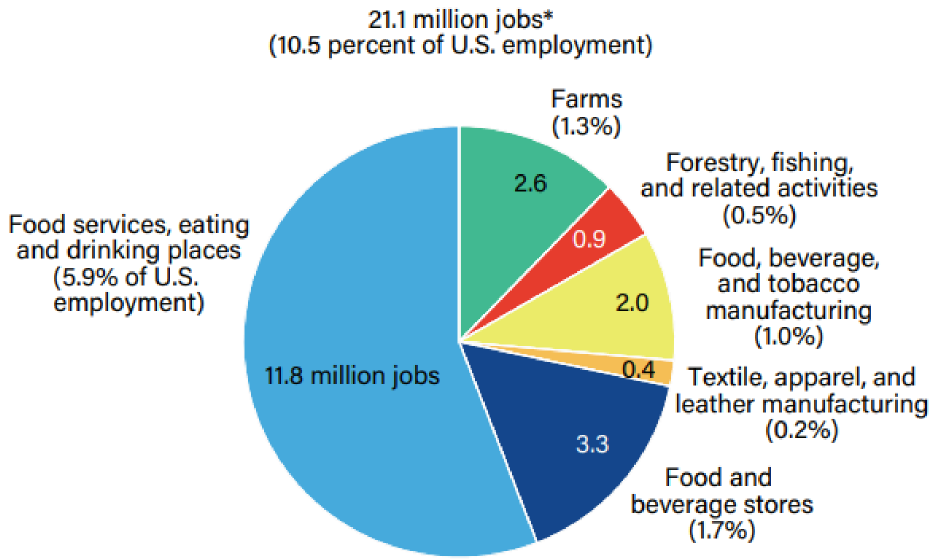
Hydroponic systems involve growing plants in a nutrient-rich water solution without the use of soil. The plant roots are directly submerged in the nutrient solution, which is constantly recirculated to ensure that the plants receive a consistent supply of water and nutrients. Hydroponic systems can use a variety of growing media, such as perlite, rockwool, or coconut coir to support the plant roots and help maintain the proper moisture levels.

Aeroponic systems involve growing plants in an air or mist environment without the use of soil or water. The plant roots are suspended in the air, and a nutrient-rich mist is sprayed onto the roots at regular intervals. This method allows the roots to absorb more oxygen, which can lead to faster growth rates and higher yields. However, it requires precise control over the moisture levels and nutrient delivery and can be more complex to set up than hydroponic systems.

Primer: Ag and Food Statistics

The farming industry employed 2.6 million people in the U.S. in 2021. We note that these include full-time and part-time jobs but not seasonal workers.

Figure 76 Employment In Ag, Food, And Related Industries In 2021

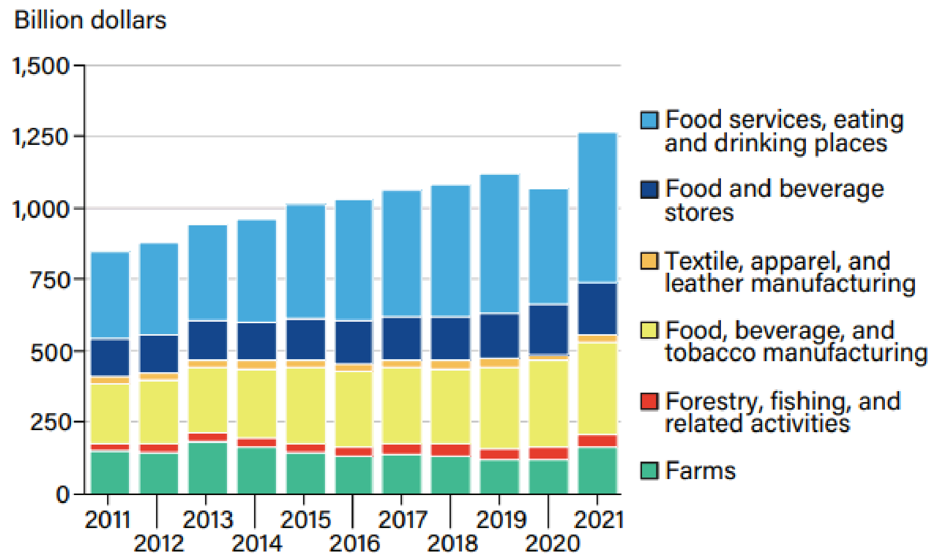


Source: ERS.USDA.GOV

* Employment in Ag, Food, And Related Industries in 2021

The farming industry in the U.S. had been declining almost every year for the past decade before rebounding in 2021.

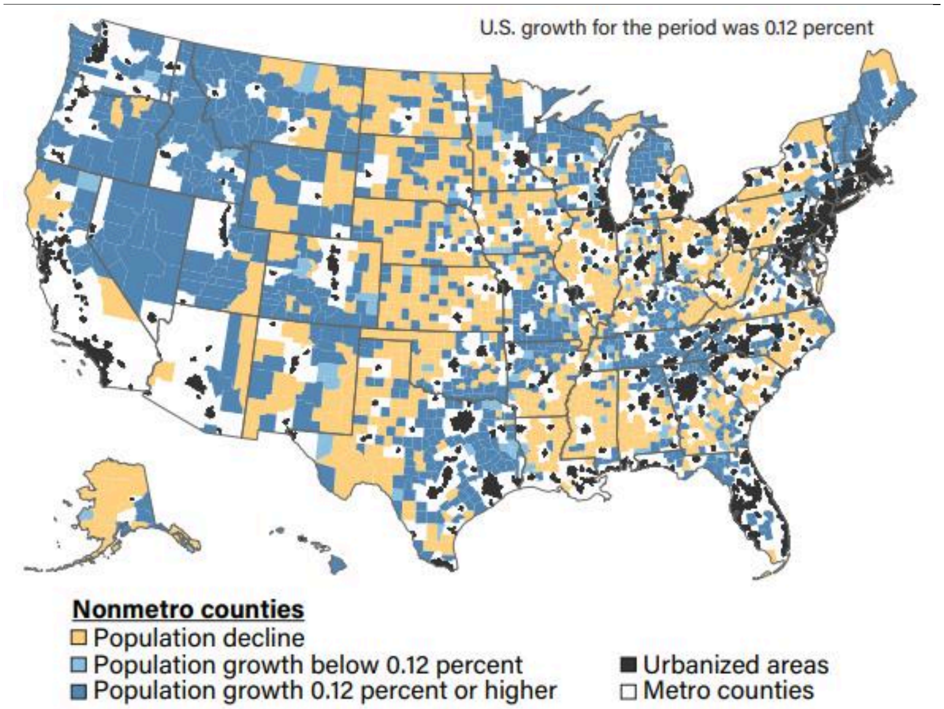
Figure 77 Value Added To U.S. GDP By Agriculture And Related Industries, 2011-21



Source: ERS.USDA.GOV

Urbanization trends: Rural population has been in structural decline vs. urban population over the past few decades, but this varied across the U.S. more recently.

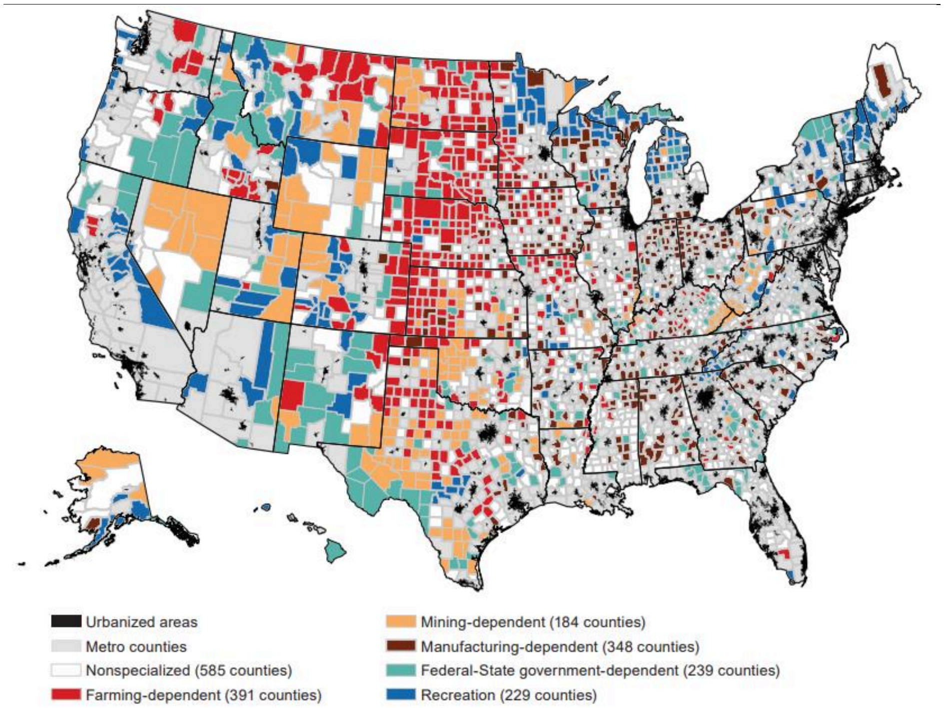
Figure 78 U.S. Non-metro County Population Change, 2020-21



Source: ERS.USDA.GOV

When layering the economic typology of the U.S. on top of the map above, it suggests that population decline has been more pronounced recently in counties that are more farming-dependent.

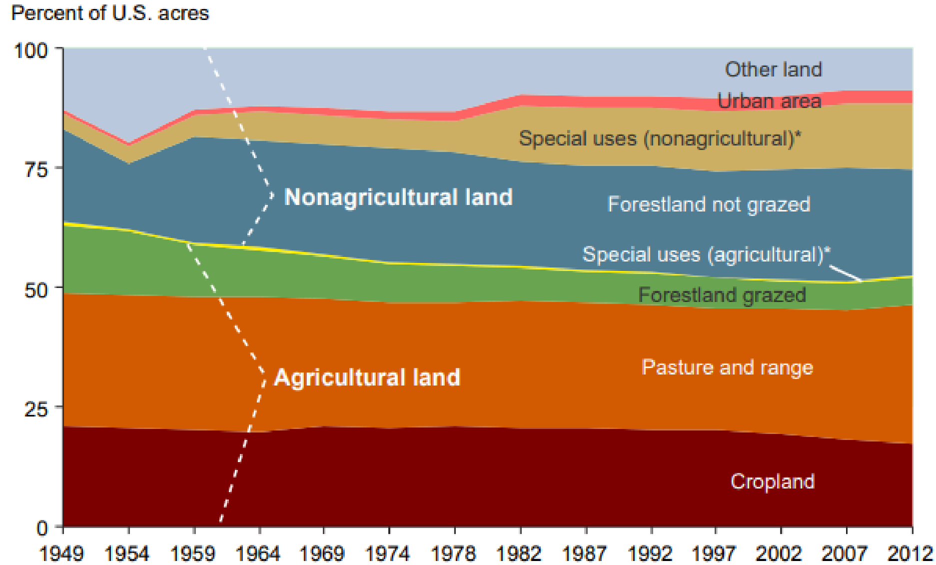
Figure 79 Rural Areas Vary In The Industries That Underpin Their Economies



Source: ERS.USDA.GOV

In the U.S., agricultural production is a major use of land, accounting for over 50% of the U.S. land base.

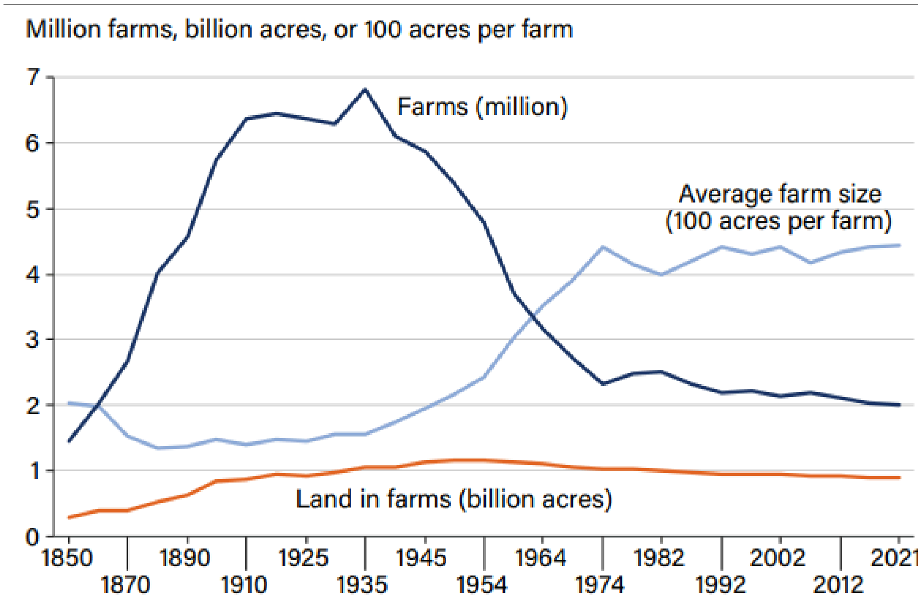
Figure 80 Major Land Uses In The U.S., 1949-2012



Source: ERS.USDA.GOV

The farming landscape has greatly evolved over the past century in the U.S. At the start of the 20th century, agriculture labor was very intensive covering many small, diversified farms. Today, agriculture production is done on large, specialized farms. Will we see another leg lower in the number of farms as a new wave of automation is introduced?

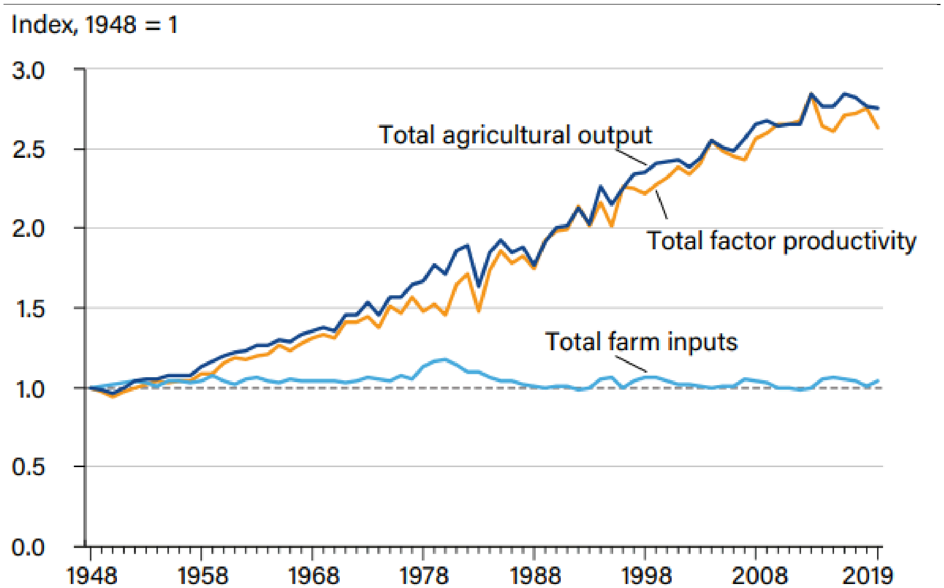
Figure 81 Farms, Land In Farms, And Average Acres Per Farm, 1850-2021



Source: ERS.USDA.GOV

What is interesting in the chart above is the fact that the number of acres used to feed the population a hundred years ago is similar to what is used today. This is of course due to the increase in factor productivity.

Figure 82 U.S. Agriculture Output, Inputs, And Total Factor Productivity, 1948-2019

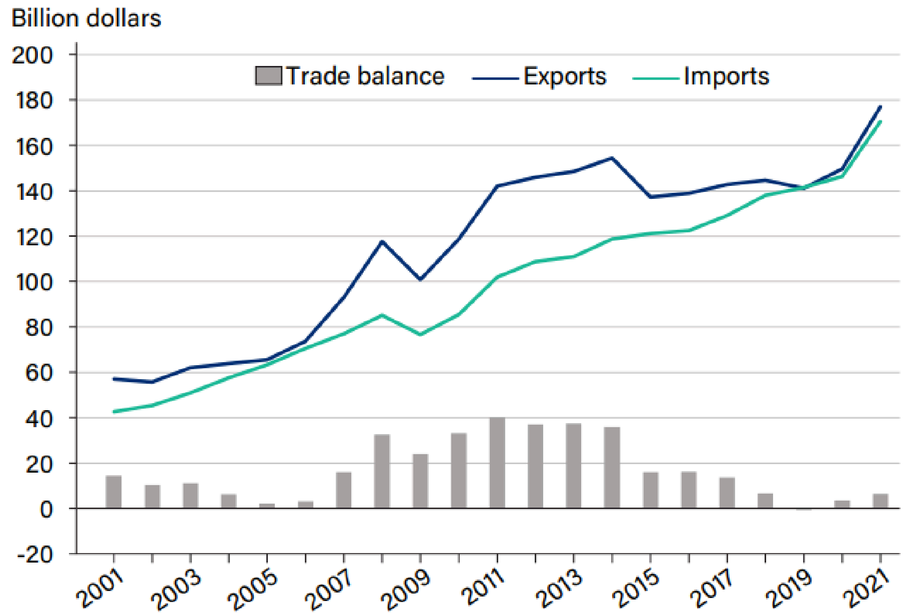


Source: ERS.USDA.GOV

Agricultural Trade

The U.S. has typically exported more agricultural goods by value than it has imported. However, the trade balance has shrunk over the past few years as the value of imports has risen faster than the value of exports.

Figure 83 U.S. Agricultural Trade, 2001-2021

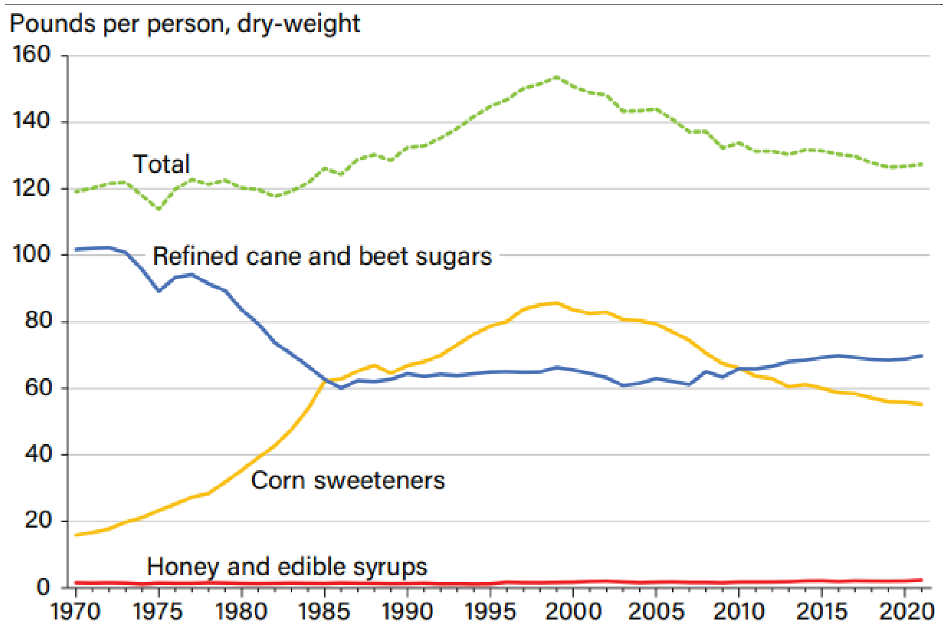


Source: ERS.USDA.GOV

Food Consumption And Availability In The U.S.

The per capita caloric sweetener availability in the U.S. has trended down over the few decades primarily due to changing dietary preference, health concerns, and increased awareness about the potential negative impact of excessive sugar consumption.

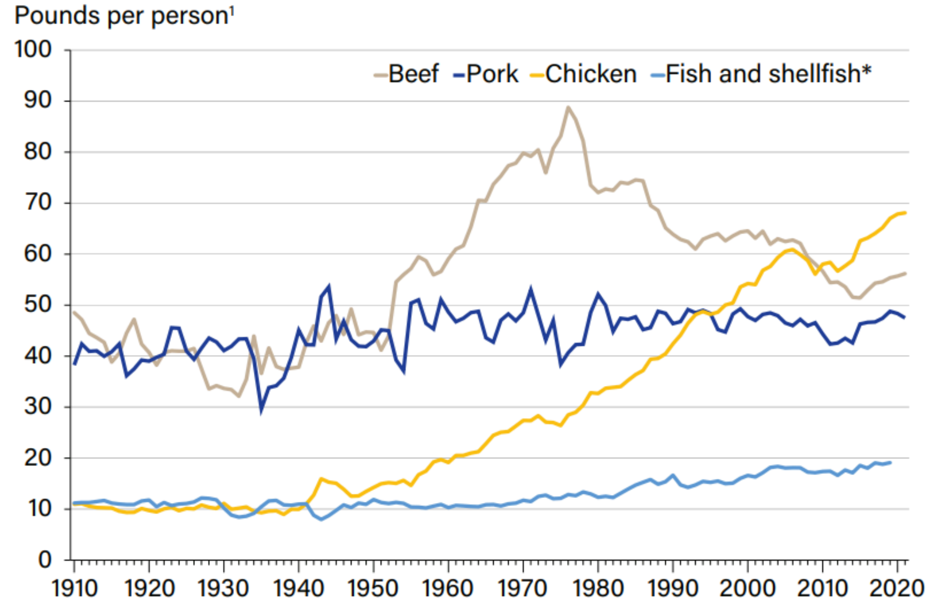
Figure 84 U.S. Per Capita Caloric Sweetener Availability, 1970-2021



Source: ERS.USDA.GOV

The per capita availability of red meat, poultry, and seafood has varied over time. Consumer preferences play a role. For example, beef has been a popular meat of choice in the U.S., but this has shifted over time in favor of poultry due to factors such as taste preference, perceived health benefits, and affordability. Other factors impacting the type of protein consumed include production practices and efficiency, economic factors, dietary recommendations and health concerns, and trade and imports.

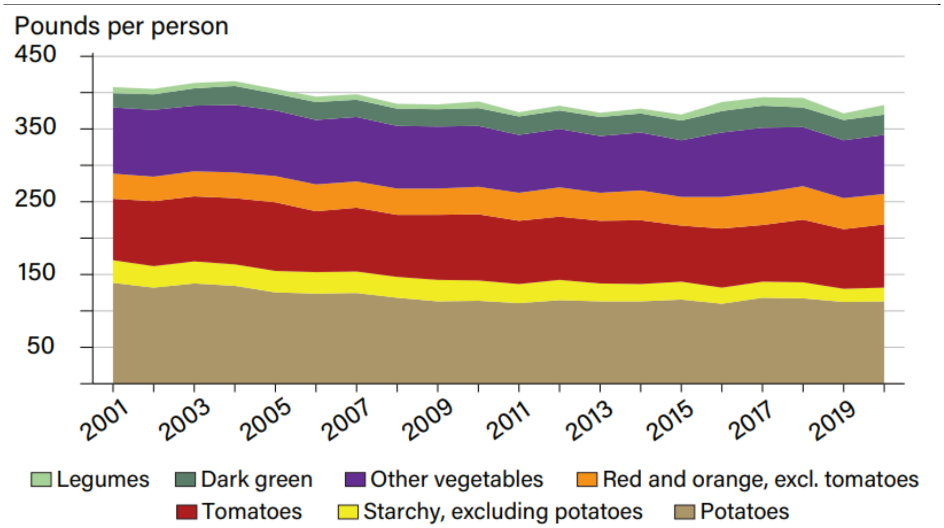
Figure 85 U.S. Per Capita Availability Of Beef, Pork, Chicken, And Fish/Shellfish, 1910-2021



Source: ERS.USDA.GOV

The variety of vegetables available for consumption has remained proportionally equal over the past two decades in the U.S.; however, the number of pounds per capita has generally trended downward.

Figure 86 U.S. Per Capita Vegetable Availability, 2001-2020



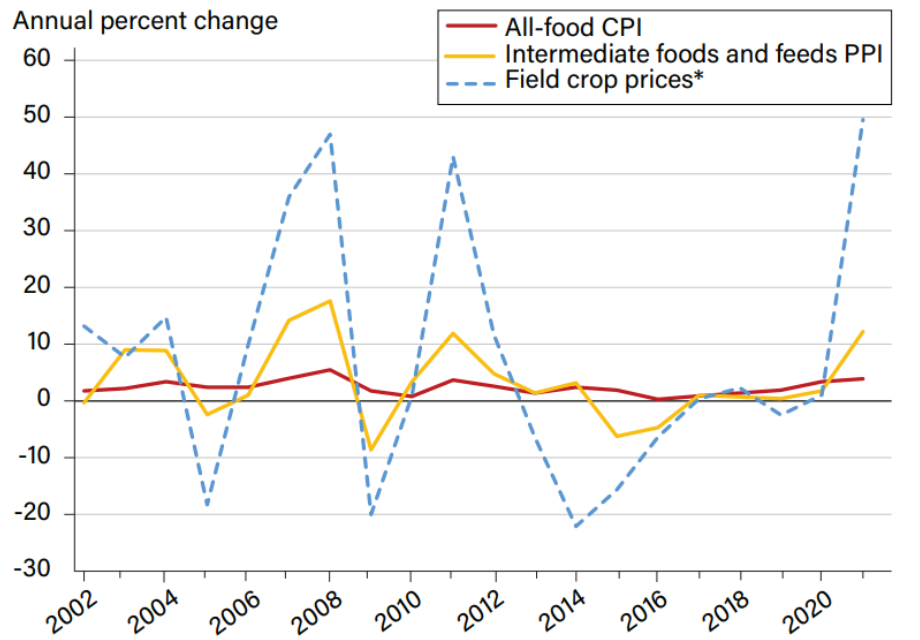
Source: ERS.USDA.GOV

Economics Of Producing Food In The U.S.

The price that the consumer pays at retail locations for food reflects farm-level commodity prices; however, packaging, processing, transportation, and other marketing costs play a greater role in determining prices on supermarket shelves and restaurant menus.

Field crop prices, which are reflected by commodity prices, can experience large swings, though only result in modest changes in food prices.

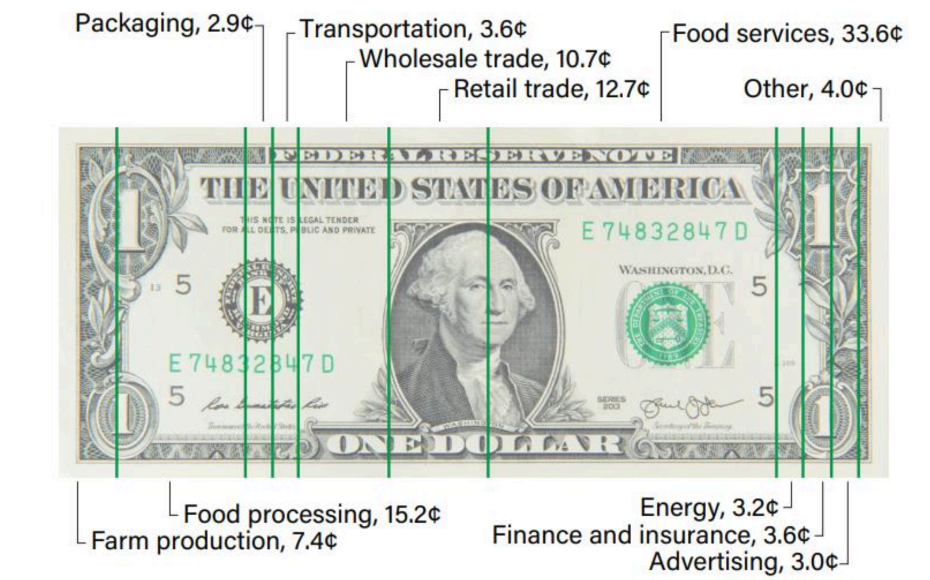
Figure 87 Change In All-Food CPI, Intermediate Goods And Feeds PPI, And Field Crop Prices, 2002-2021



Source: ERS.USDA.GOV

The U.S. consumer pays almost as much for food service as it does for food production, processing, and retailing, combined.

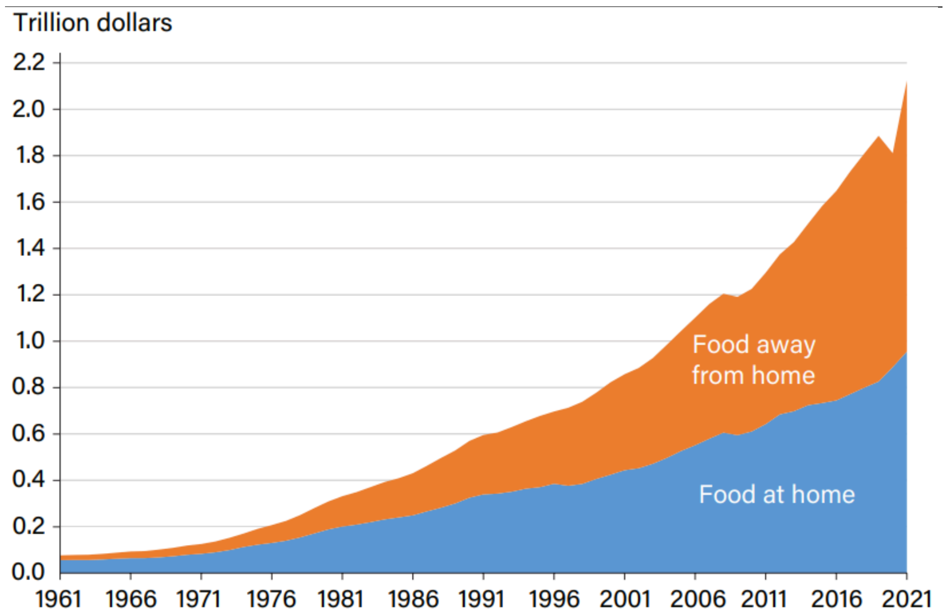
Figure 88 2021 Nominal Food Dollar By Industry Group



Source: ERS.USDA.GOV

Food spending is a $2.1T industry in the US and food-away-from home has been outpacing food-at-home spending for the last six decades.

Figure 89 Food-At-Home Vs. Food-Away-From Home Expenditure In The U.S., 1961-2021



Source: ERS.USDA.GOV

Ticker	Rating	Price*	Price Target	Ticker	Rating	Price*	Price Target
ABBN.SW	Outperform	CHF33.57	CHF39.00	**ABBNY**	Outperform	$37.74	$44.00
CAT	Outperform	$245.18	$287.00	**DE**	Market Perform	$405.28	$438.00
AME	Outperform	$157.08	$165.00	**APH**	Market Perform	$83.62	$70.00
CGNX	Market Perform	$54.23	$48.00	**IEX**	Outperform	$209.98	$235.00
PH	Underperform	$384.17	$300.00	**ROK**	Underperform	$325.38	$220.00
ST	Outperform	$44.41	$63.00	**SYM**	Outperform	$41.17	$33.00
TEL	Market Perform	$139.82	$115.00	**TDY**	Outperform	$409.97	$500.00
ZBRA	Outperform	$295.22	$350.00				

**As of 07/07/2023*

VALUATION METHODOLOGY AND RISKS

Valuation Methodology

Diversified Industrials, Automation & Robotics:

We utilize multiple analysis and discounted cash flow (DCF) analysis to value companies under coverage. We employ both EV/EBITDA and P/E multiple analysis and look at historical valuation multiples (typically 5- and 10-year averages) as well as current and historical multiples for competitor or representative companies. We evaluate the subject company independently and in terms of its comp group. In certain instances, we may look at current/recent transaction multiples to evaluate the subject company. When utilizing DCF analysis, we include a sensitivity table to both discount and terminal growth rates.

We make investment recommendations on certain early stage, pre-revenue companies based upon an assessment of their business model, technology, probability of market success, and the potential market opportunity, balanced by an assessment of applicable risks. Such companies may not be assigned a price target.

Machinery & Transportation OEM:

We generally use one-year forward PE multiples to value covered companies in the transportation OEM sector. We support our valuation with EV/EBITDA and Price-to-book analyses.

We make investment recommendations on certain early stage, pre-revenue companies based upon an assessment of their business model, technology, probability of market success, and the potential market opportunity, balanced by an assessment of applicable risks. Such companies may not be assigned a price target.

Investment Risks

Diversified Industrials, Automation & Robotics:

A general decline in the industrial production index, coupled with a global decrease in automation spending as a percentage of total capex could negatively impact the sector and the implied industry growth rate as well as leading to additional project delays.

Sustained pressure in emerging markets (especially countries with lower labor wages) could cause delays in automation implementation in several sectors, including general industrial, automotive, logistics, medical, and aerospace as factory upgrades are delayed.

Significant, lasting changes in the prices of key commodities, such as oil and natural gas could have material impact on upstream, midstream, and downstream applications. For example, a sharp increase in domestic natural gas projects could make LNG export facilities in the US less attractive and cause delays or cancellations of planned domestic chemical facilities. Sharp declines in oil and gas prices could lead to reduced production activity and therefore reduce demand for midstream logistics and downstream processing applications.

Machinery & Transportation OEM Risks:

- The transportation OEM industry is highly cyclical; the timing of the cyclicality may be difficult to predict; and down cycles could weigh on the top and bottom lines of companies in the sector.
- The industry is highly dependent on the North American and global economies. Economic downturns could pose a threat to the companies' earnings power.
- Fluctuations in the price of steel and other materials used in the manufacture of equipment could be unfavorable at times.
- Currency fluctuations could negatively impact production costs and demand for finished products.
- Potentially unfavorable shifts in freight among transportation modes, such as between rail and trucking, could impact demand for certain types of transportation equipment.
- Relatively high capital expenditure requirements.
- Relatively high fixed cost structure.
- Regulatory risk.
- Litigation risk.

ADDENDUM

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Assumption: The expected total return calculation includes anticipated dividend yield

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Distribution of Ratings/Investment Banking Services (IB) as of 06/30/23

Rating	Count	Ratings Distribution	Count	IB Services/Past 12 Months
Buy (a)	614	68.60%	162	26.38%
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Sell (c)	4	0.45%	1	25.00%

(a) Corresponds to "Outperform" rated stocks as defined in Cowen and Company, LLC's equity research rating definitions. (b) Corresponds to "Market Perform" as defined in Cowen and Company, LLC's equity research ratings definitions. (c) Corresponds to "Underperform" as defined in Cowen and Company, LLC's equity research ratings definitions. Cowen and Company Equity Research Rating Distribution Table does not include any company for which the equity research rating is currently suspended or any debt security followed by TD Cowen Cross-Asset Research.

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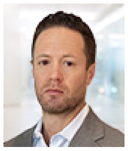

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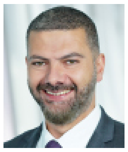

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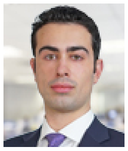

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