United States
Department of
Agriculture

A CASE FOR RURAL **BROADBAND**

Insights on Rural Broadband Infrastructure and Next Generation Precision Agriculture Technologies

APRIL 2019

American Broadband Initiative

Published as part of the American Broadband Initiative

INTRODUCTION AND **PURPOSE**

In January 2018, the *Report to the President of the United States from the Task Force on Agriculture and Rural Prosperity* summarized initial findings on how to promote agriculture, economic development, job growth, infrastructure improvements, technological innovation, energy security, and quality of life in rural America. The Report identified **Achieving e-Connectivity in Rural America** as a central pillar to do so. President Donald Trump led the way by creating the American Broadband Initiative, which reflects the work of his Cabinet to support the private sector's expansion of rural broadband and effectively steward Federal tax dollars in that partnership.

This analysis opens the next chapter in the U.S. Department of Agriculture's (USDA) response to this Call to Action. It is intended to convey high-level and broad concepts about the potential benefits of connected agriculture technologies to policymakers, industry leaders, and all who are affected by the lack of high-speed Internet service in rural areas that is inhibiting greater productivity and profitability for small producers, stifling American innovation, and undermining potential advancements in food security, food safety, and environmental sustainability.

For the purposes of this report, Next Generation Precision Agriculture can be considered an interdisciplinary science leading to breakthroughs and incremental technology advances to improve agricultural productivity, efficiency, and/or sustainability. Enabled by digital tools and connectivity, Next Generation Precision Agriculture is beginning to be applied across the entire food value chain to the benefit of both the producer and consumer. The concept of "precision" in agriculture is not new, and practices called Precision Agriculture have always included in-field processes aimed for more accurate planting, nutrient and pest management, and harvesting. Yet, until recently, Precision Agriculture lacked data collection and analysis that is enabled by 21st century technologies and Internet connectivity. This next generation of technologies will continue to evolve, building innovation and ingenuity into this vital American industry.

Likewise, the definition of broadband continues to evolve, historically by increases in speed of

Internet connections, with a download speed set higher than upload speeds. Currently, the Federal Communications Commission's (FCC) definition of "high-speed Internet" is 25 megabits per second download and 3 megabits per second upload[1]. This places more emphasis on data flowing to the end user rather than from the end user. Today, some Next Generation Precision Agriculture technologies require these speeds, while some do not and instead data can be transmitted intermittently. However, as technology advances and the volumes of data to manage agriculture production grow, higher speeds will likely be necessary, requiring more symmetrical data flows, with a better balance of download and upload speeds and reliability.

For many years, the agricultural industry sector and its institutions, including USDA, have been active in various aspects of researching and supporting usage of Next Generation Precision Agriculture technologies, as well as investing in rural broadband infrastructure. But the interdependency of agriculture technology adoption and broadband infrastructure has not yet been evaluated at a nationwide scale, with a synthesis of the economic impact they both could affect. That is the purpose of this work: exploring the **intersection of broadband Internet infrastructure and the digital Next Generation Precision Agriculture technologies that will depend on improved e-connectivity.** USDA, therefore, has embarked upon this analysis to estimate the possible economic benefits of expanding rural e-connectivity to farms and ranches and explore what's needed to unlock this potential.

TABLE OF CONTENTS

02 • Introduction and Purpose

06 • Background: The e-Connectivity Infrastructure and Adoption Imperative

09 • The Power of e-Connectivity to Transform Industries

12 • Approach to Analysis & Patterns of Business Modernization

17 • How e-Connectivity Will Transform the Business of Agriculture

20 • The Potential Economic Benefits of e-Connectivity for U.S. Agriculture

22 • Table: Connected Technologies in Row Crops & Specialty Crops

23 • Table: Connected Technologies in Livestock & Dairy

24 • Table: Potential Economic Benefits of Next Generation Precision Agriculture and Broadband

33 • Societal Benefits of Next Generation Precision Agriculture

34 • Today's Challenges to Scaling Adoption of Next Generation Precision Agriculture

38 • International Benchmarks for Next Generation Precision Agriculture

39 • Connecting Rural Agriculture: Strategies for Action

42 • What USDA is Committed to Doing

45 • Proposal for Partnerships

47 • Conclusion: Connectivity for the Future

48 • References

"When we are able to deploy broadband ubiquitously, think of all the things we will be able to design, harvest, and develop ... Broadband in rural America will be as transformative in the 21st century as rural electrification was in the last century."

- U.S. Secretary of Agriculture Sonny Perdue

BACKGROUND:
THE E-CONNECTIVITY INFRASTRUCTURE AND ADOPTION IMPERATIVE

High-speed Internet access across America today is characterized by a stark infrastructure gap between rural and urban areas. While urban centers enjoy widespread availability of high-speed Internet service, much of rural America has yet to be connected, and of the 24 million Americans living in households that do not have access to a fixed terrestrial (non-mobile or satellite) broadband provider, 80 percent of them live in rural areas, according to the latest FCC data.[2] In addition, the gap between connectivity "haves" and "have-nots" is at risk of being exacerbated in the coming years: a leading, multinational network hardware and telecommunications equipment technology conglomerate projects that the average global download speed will double from 39 Mbps in 2017 to 75 Mbps by 2022.[3]

Moreover, the increased speed and capacity from forthcoming 5G mobile coverage depends upon network densification, requiring the extension of deep fiber or intensity of infrastructure for similar services to build adequate networks throughout rural America. A recent Deloitte Consulting analysis estimates the United States requires between $130 and $150 billion over the next five to seven years, to adequately support rural coverage and 5G wireless densification.[4]

Such disparities in infrastructure directly impact rural citizens and businesses – including agriculture, which stifles the modernization of food production urban and suburban citizens rely on. Digital technologies in agriculture, including Precision Agriculture, can substantially increase crop and animal yields, improve distribution, and reduce input costs. However, without reliable, affordable high-speed Internet connectivity at both the farmhouse and in the field, many of these technologies cannot realize their full potential. As a result, producers face inconsistent ability to tap into and master new technologies, compromising the higher productivity and greater profitability needed to sustain and grow United States agriculture, meet the dietary needs of a growing global population, and maintain national competitiveness in international markets. Addressing these imperatives is only possible through efficiently and effectively building high-capacity rural Internet infrastructure, both wired and wireless, to deliver reliable, high-speed access and harnessing the emerging generation of Precision Agriculture technologies.

> **"For my [10-year] plan, I need 100 Megabits per second, but there's no way to get it."**
>
> **- Specialty crop producer, West Coast**

Satellite broadband services for supporting Precision Agriculture technologies have historically had both benefits and limitations. According to the FCC's 2018 Broadband Deployment Report[1], access to satellite broadband is much greater than terrestrial broadband in rural areas. However, satellite broadband may not be fully sufficient for Next Generation Precision Agriculture technologies due to the unpredictability of service caused by high latency, capacity limitations, and costs for securing high volumes of data flows, especially when time-sensitive information is required to support on-farm operations and quickly respond to market conditions.

In recent decades, attempts to increase broadband deployment have not replicated the nationwide rural electrification effort of the last century and did not sufficiently incentivize broadband expansion to all rural American homes, businesses, farms, and critical community sites such as healthcare and educational facilities. Low population densities in rural areas and the high cost of installing and operating Internet infrastructure present a non-viable proposition for service providers, disincentivizing large-scale private investment in rural Internet infrastructure.

Telecommunications providers evaluate rural areas like they do urban areas, requiring sustainable business models where revenues can demonstrably cover or exceed costs. This is heavily influenced by a focus on population dynamics like density, but the complexity of connecting remote areas requires new approaches and solutions. Another key factor in supporting a sustainable business model is the predictability of the market, that customers are demanding such products and services. One benefit includes direct-to-consumer sales, as customers seeking fresh produce can more readily find farms that can deliver fresh produce in a timely fashion, minimizing food waste while also meeting consumer demand.

This analysis explores the potential benefits rural Internet infrastructure and emerging on-farm technology can bring to the agriculture industry and all who depend on its success. These Next Generation Precision Agriculture technologies support planning, production, and market coordination in agriculture. The rural broadband challenge is not without precedent as rural electrification faced similar dynamics. While the cost of connecting each rural property to the power grid amounted to, on average, nearly a quarter of annual household income, the long-term benefits of rural electrification accumulated for decades.[6] As America finds itself once again on the verge of economic transformation, it may require similar investments to unlock the economic gains from connectivity for rural businesses and households.

Whereas other studies may focus on the value of individual technologies, this report provides a summary of how technologies can be simultaneously deployed together to impact the United States' top commodity groups: row crops, specialty crops, and livestock (including dairy) products. The following pages explore:

1. How e-Connectivity creates value through digital transformation;
2. What the potential impact of connected agricultural technologies are to the U.S. economy;
3. What producers and the agriculture ecosystem need to unlock this value; and
4. What strategies for action can make this potential a reality.

LIMITATIONS OF FINDINGS

While this report hypothesizes the potential benefits that rural Internet infrastructure and emerging on-farm technology can bring in the future, it does not contemplate or attempt to calculate the cost of implementing these technologies that would be encumbered by producers, telecommunications providers, rural communities, or State and Federal Governments.

Cost estimates are excluded because of the lack of clear, accurate, and publicly available data sources on where broadband infrastructure currently exists, and which connected equipment and other devices are presently in use at which farms and ranches. Also, peer-reviewed research on the required connection speeds is not yet available to indicate the costs to build out such supporting infrastructure and the monthly Internet service costs that would be affiliated for such precision agriculture technologies.

Therefore, the findings reported herein should not be the sole source for decision-making for producers contemplating investing in connected agriculture technologies, but rather can be a tool for policymakers to use when considering the impacts rural broadband infrastructure can have on the agriculture industry and the American economy. As broadband becomes more dependable in rural areas and on-farm technology becomes a reality in the coming years, it is possible Next Generation Precision Agriculture costs may decrease for producers by implementing these technologies. Accordingly, USDA recommends that producers perform their own cost-benefit analysis on whether these emerging technologies would benefit their operations.

THE POWER OF E-CONNECTIVITY TO
TRANSFORM INDUSTRIES

Like many industries today, agriculture is experimenting with the integration of digital technologies that can make the industry more productive. Sectors like finance, logistics, and advanced manufacturing are now almost fully reliant on connected technologies, as are a limited subset of the agriculture industry. Broad adoption of Precision Agriculture technologies has been hit or miss. In the use of autonomous or self-driving vehicles, row crop production is a leader, alongside mining and freight logistics. For instance, guidance systems are used on around 50 percent of planted acres of some row crops in the United States. Other primary segments of the agriculture industry, such as livestock production and specialty crops, have experienced slower adoption and are the least mature industries in terms of overall use of Next Generation Precision Agriculture technologies, due in part to geographic decentralization and cost.[5]

Looking at patterns of digital disruption innovation across industries offers insight into how connectivity's ability to enhance access to information creates value and how digital technologies may impact agriculture today and in the future. Although the agriculture industry is experimenting with innovative technologies such as autonomous tech and self-driving vehicles, we now identify how the collection of technologies can work together to improve agricultural production economics and consumer nutritional and clothing demand, but we do not have the comprehensive tools (digital connectivity) needed to realize this vision. While individual technologies offer direct and discrete value, the greatest impacts will come from the creation of new systems and approaches. In the case of electric power, for example, switching to electricity as a source of power was more efficient than steam and offered direct benefits. However, the rate of return increased dramatically as manufacturers discovered new production practices such as switching from "central drive" to distributed, modular production in manufacturing. The presence of Internet-enabled technology has not yet led to similarly remarkable growth in labor productivity and yet may now be able to achieve the scale and tools needed to truly transform operations the way rural electrification did.[6]

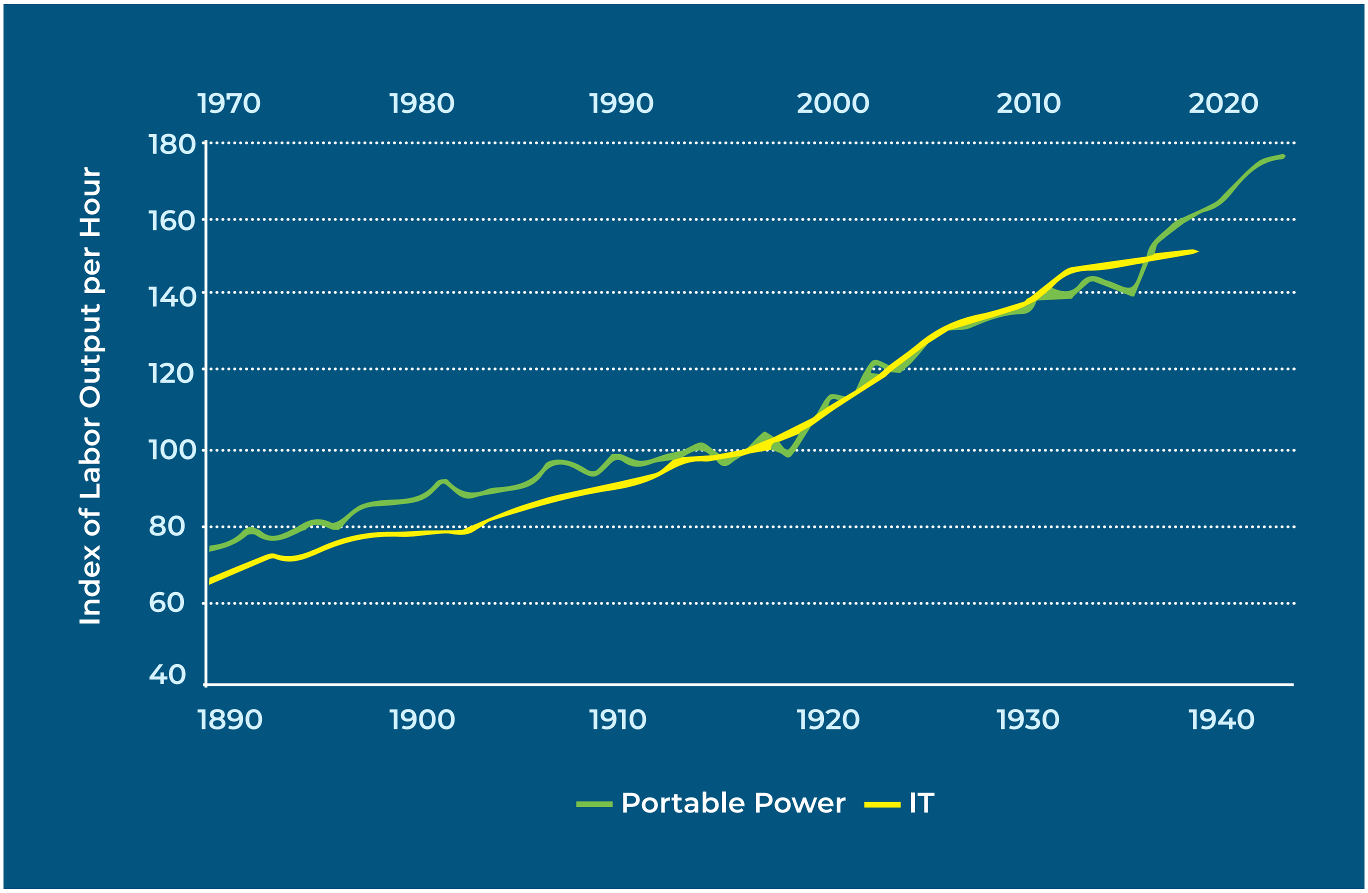
AN ANALOG TO CONSIDER: THE ECONOMIC IMPACT OF ELECTRIFICATION

According to the National Bureau of Economic Research[7], "portable power" (including distributed electric power and the internal combustion engine) initially yielded limited labor productivity gains. It required time and widespread adoption to transform business models. While initial adoption offered direct benefits from 1915 to 1930, productivity grew at a faster rate beginning in 1935, as electricity, along with other inputs in the economy such as the personal automobile, enabled new, more efficient and effective ways of working.

Likewise, electricity-dependent refrigeration fundamentally changed the way America's nutrition supply chain operated. When the Rural Electrification Act passed in 1936, the impacts of refrigeration were not known. For instance, the mass adoption of refrigerators into American homes which started in the mid-1940s spawned new markets in transportation of raw materials, refrigerated storage, and innovative food products[8]. Previously consumers would shop at local markets, but refrigeration enabled access to new types of fresh fruits and vegetables, often on a year-round basis, and less spoilage occurred in their homes[8]. This resulted in an overall decrease in per capita disposable income spent on food, improving overall quality of life, and enabling household expenditures for other purchases[9].

The impact of Internet and information technology today followed a similar trajectory as portable power, and more universal access can continue to unlock the larger-scale, systems-level change that will significantly transform 21st century industries, depending on access to the infrastructure and services that support necessary data flow.

FIGURE 1.
ANALOG OF PORTABLE POWER AND LABOR PRODUCTIVITY[7]



Just as it was not possible to predict electrification's impacts through refrigeration, predictions of the exact effects of Internet access supported by broadband infrastructure are not possible. However, ubiquitous rural broadband infrastructure has immeasurable potential for facilitating innovation and ingenuity by America's producers. Short of access to a full battery of exact data that could be used to calculate future economic benefits of broadband and Next Generation Precision Agriculture, USDA embarked upon an analysis using the following best-available approach.

APPROACH TO ANALYSIS

USDA conducted an in-depth analysis to attempt to understand and capture how the U.S. agriculture industry might be impacted by the 21st century digital technologies impacting other sectors. The analysis included review of academic and industry research as well as validation through site visits with producers and engagement with industry experts. A total of 34 technologies were evaluated, based on their applicability in the field today, as well as published research available to assess for scale for measurable impact. See Table 1 for a summary list of connected Precision Agriculture technologies, categorized by commodity type. Further detail on the calculations and assumptions for each connected technology can be found in the Appendix.

Market sizing baselined potential benefits (gross) by reviewing existing studies on value drivers, extrapolating across commodity groups (row crops, specialty crops, and livestock and dairy products) and to national production levels, determining the available market in the United States, and estimating the contribution of Internet connectivity.

Review of existing studies. USDA cataloged the landscape of digital technologies in agriculture and surveyed academic, government, and industry studies that estimate the value created by each.

Extrapolation. The relative value for similar crops within a commodity group—that is, those that use comparable production methods—were estimated using 2016 cost and production numbers for the studied and targeted commodities and extrapolated to a national scale based on overall production volume. The analysis focused on the highest-volume products in each category (row crop, specialty crop, and livestock and dairy products) which together equate to roughly 75 percent of total U.S. agricultural annual production ($254 billion of $340 billion total)[10]. The direct analysis of the 75 percent subset establishes the low end of the estimate range, while the upper limit is based on an assumption that similar gains can be realized for all production[10].

Determine available market (scale). The national totals were pro-rated to reflect “available” market, an estimate that discounts national totals to reflect anticipated late-or non-adopters and existing users. Late-and non-adopters were factored out based on “diffusion of innovation” theory, which defines standard phases and rates by which a new idea or product has historically spread among users. This model estimates that roughly 16 percent of users are “laggards” who will not adopt new technology in a time period in which the studied gains are meaningful. Therefore, discounts by this rate, and the maximum addressable market is considered 84 percent of U.S. production. Similarly, it is not certain technologies that enjoy less than 16 percent adoption will scale to mass adoption; therefore, the available market was further adjusted to reflect the lower probability of reaching mass market scale. Current rates of adoption were estimated for each technology and incorporated into the analysis. These rates were based on studies like Purdue University’s biannual survey of Precision Agriculture equipment.[11]

Percent of potential value attributable to broadband. Each technology was assigned a standard category for the contribution of Internet connectivity to the overall value, acknowledging that Internet infrastructure combines with sensors,

signals, software, and machines to realize the full value. The classifications were vetted by producers and industry leaders and assigned standard values: technologies classified as having "low" dependence on Internet were estimated at 10 percent contribution; technologies classified as having "medium" dependence were estimated at 30 percent contribution; and technologies classified as having "high" dependence were estimated at 50 percent contribution.

It is important to note that these are rough estimates of the contribution of broadband, relying on general, standard categories rather than precise calculations.

This market analysis has additional limitations that may be addressed in future research. Specifically, the model (1) does not consider input costs that would be required to realize the benefits stated; and (2) is based on a collection of available data and information sources that each have independent assumptions and varying baseline years.

Additionally, this market analysis is not dynamic, because it does not attempt to model interaction, network effects, or iterative impacts. Today, agricultural technologies are often framed as standalone tools, which does not capture the end-to-end use of tech in agriculture. Currently, most producers plan, produce, and organize sales of their goods, using independent, and disassociated technologies. Use of Precision Agriculture will continue to increase as technologies begin working together interdependently, as an agriculture "Internet of Things" to transform the entire business of farming, regardless of which technology or design ultimately creates this value. This may be the most impactful effect of ubiquitous broadband on farms, enabling full and synergistic use of Next Generation Precision Agriculture technologies, yet it is the most difficult to predict and measure, and therefore was not attempted here.

Site visits and industry roundtable. To benchmark the desk research against frontline user perspectives, experience, and results, we conducted research visits to 31 sites in seven agriculture-rich States: California, Illinois, Indiana, Iowa, New York, Pennsylvania, and Texas. To further validate assumptions and hypotheses, USDA's anonymized results were shared with producer association leaders, agriculture technology executives, academic researchers, and telecommunication providers. The insights from these conversations reinforce and illustrate the analysis shared and are highlighted in quotations and case studies throughout this report.

PATTERNS OF BUSINESS MODERNIZATION

Our nation's agricultural producers are seeking to operate just as any other modern business does, with the benefits of technology driving operations, planning, and customer engagement. These broader patterns of digital transformation across other industries can offer insight into what is possible with access to e-connectivity.

Most industries experience a "second wave" of transformation as businesses begin to think digitally and are able to fully leverage real-time, interconnected devices—pointing to not only the types of impact created by today's technologies but also the additional ways in which expanded Internet infrastructure might further drive new ways of working.

By automating activities where possible, resources can be used more effectively and efficiently. Then, increases can be realized in the productivity of personnel who can be freed from more repetitive tasks in favor of new value-added tasks. The time and energy of managers are unleashed to expand business operations, allocate inputs more efficiently, decipher methods to streamline resource allocation, and increase access to more customers.

INTEGRATED DECISION-MAKING – BUSINESS MANAGEMENT

e-Connectivity provides improved quality and higher quantity of information, allowing integration of data to improve business decisions

- Making information more actionable by increasing the quality and quantity of available data, as improved tools for data-centric decision-making can harness the power of a broader scope and larger scale of historical and recently-collected data
- Enabling real-time decision-making by sensing information, organizing it, and providing opportunities to respond in the development and deployment of digital sensor networks allow producers to monitor crop or animal health and environmental conditions that can be used in decision support tools, resulting in better business decisions
- Expanding access to digital educational resources and business data, freeing up workers' time for learning, and expanding the suite of tools available at the push of a button

AUTOMATED PROCESSING AND RESOURCE ALLOCATION – DIGITIZATION

e-Connectivity improves information capture, feeding data to the "Internet of Things," and making it possible to automate activities

- Increasing productivity by eliminating manual rekeying and allowing for automation—particularly where precision and repetition are core needs of business
- Dramatically improving efficiencies and reducing the redundant manual tasks, enhancing capacity to organize and retrieve information and enabling machines to read, manipulate, and act on data

PRODUCTIVITY – LABOR EFFICIENCY

e-Connectivity offers real-time information that helps workers focus on the most pressing tasks and triage issues as they arise

- Technology can support human tasks to increase speed, improve accuracy, and reduce errors – examples are robotics and automation, such as distribution centers' pick-to-light technologies
- Reducing and—in some cases—eliminating the need to be physically present at the site of observation, thereby reducing travel and connecting workers across long distances by powering high-quality audio, video, and file sharing

EXTENDED REACH – GEOGRAPHIC ACCESS

e-Connectivity reduces information asymmetries to make more efficient markets across geographies for both products and people

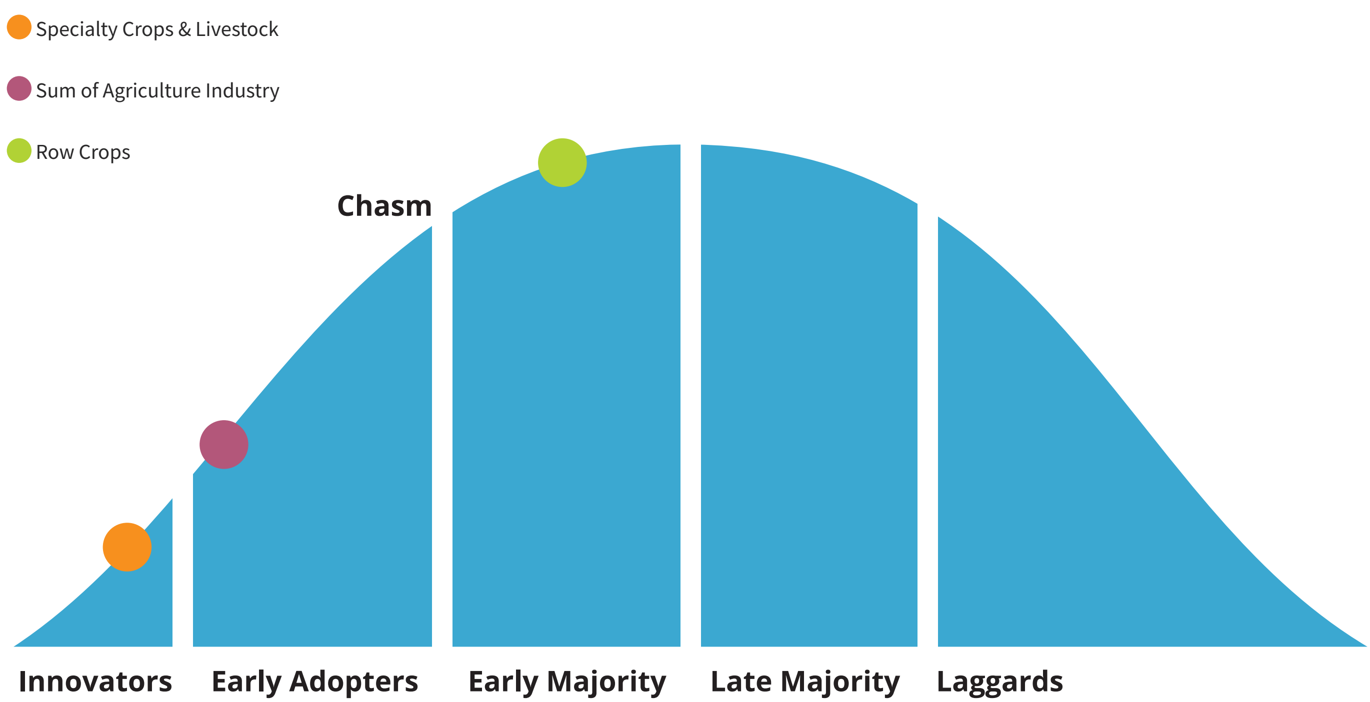
- Expanding communication and market access by enabling companies to enter new markets, better understand their markets, and better meet consumer preferences
- Creating online platforms with a reach not limited by geography
- Mitigating the effects of low unemployment, mismatched skills, or geographic remoteness by providing the option to recruit from other towns, cities, and States

THE ADOPTION CURVE

An adoption curve, based on Rogers' Diffusion of Innovation[12], can model the typical phases/ rates with which a new idea or product spreads among users and gains market traction or scale. Many technologies within agriculture are at early stages of adoption today – suggesting greater potential economic benefits from increased access to connectivity to support these emerging applications. The adoption curve in Figure 2 indicates that on average, the agriculture industry appears to be in the 'early adoption' phase of the diffusion curve, meaning there is potential for a large available market and unrealized future growth.

Increased e-connectivity can harness all the benefits of big data, including reduced costs and the removal of traditional barriers to business growth. New technologies can be adopted and unrealized potential can be unleashed within different types of agricultural production, enabling transformation of agriculture just as e-connectivity has modernized other industries.

FIGURE 2.
ESTIMATION OF AGRICULTURE ON THE TECHNOLOGY ADOPTION CURVE



HOW E-CONNECTIVITY WILL TRANSFORM
THE BUSINESS OF AGRICULTURE

Across the agricultural production cycle, farmers and ranchers can implement digital technologies as other modern businesses are doing, enhancing agriculture by driving decision-making based on integrated data, automating processes to increase operational efficiency, improving productivity with tasks driven by real-time insights, augmenting the role of management in the business of farming, and creating new markets with extended geographic reach.

These patterns of digital transformation create fundamental shifts in agricultural production, developing new ways of working that make the industry more productive, attractive, and financially sustainable for farmers and ranchers. Tech companies which stand to benefit from industry transformation continue to capitalize on these shifts by developing new technologies, which according to one recent study, may help position themselves to capture a portion of an estimated $254 billion to $340 billion in global addressable digital agriculture market.[13]

BUSINESS MANAGEMENT shifts decision-making from instinct to integrated data

Precision Agriculture is transforming the way producers collect, organize, and rely on information to make key decisions. Traditionally, producers' long-term experiences have created a competitive advantage: years of experiments have produced insights and instincts about the land they have farmed and the animals they have raised. **But the volume of data that is possible to collect today can accelerate that learning curve, helping producers learn faster and more rapidly adapt to market shifts—particularly on new fields and with new animals—and creating more nuanced insights, enabling them to act on leading indicators.** This creates a disparity between producers who can utilize high-speed Internet service and those who cannot. Examples include the ability to do the following:

- create decision tools to help farmers and ranchers estimate the potential profit and economic risks associated with growing one particular crop over another
- decide which fertilizer is best for current soil conditions
- apply pesticides in targeted areas of the field, to control pests rather than applying pesticides over the entire field
- use limited water resources more effectively
- respond to findings of sensors that monitor animal health and nutrition

Better choices about what, where, and when to plant, fertilize, and harvest—or breed, feed, and slaughter—can drive above-average returns by removing unrecognized inefficiencies and scaling insights.

DIGITIZATION shifts supply chain management and resource allocation from generic to precise

Precision Agriculture helps make the business of farming more efficient by minimizing inputs—such as raw materials and labor—and maximizing outputs.

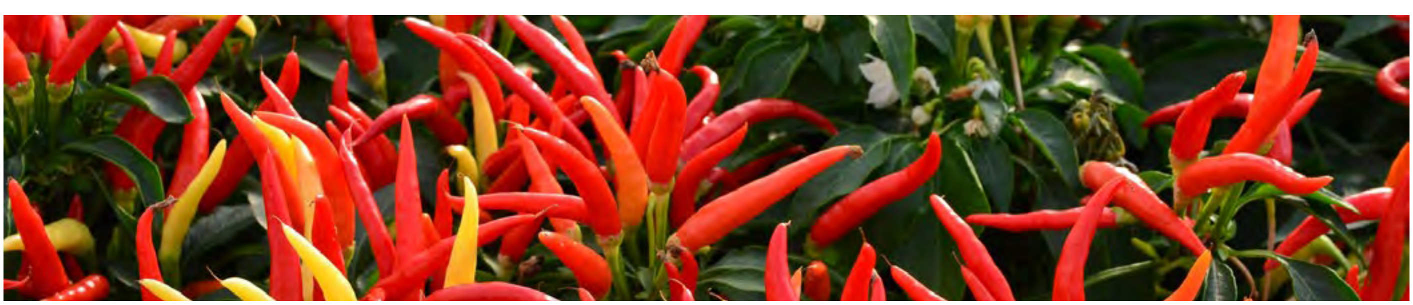
For example, previous research has found that 40 percent of fields are over-fertilized, which not only inflates the cost of inputs but also results in 15 percent–20 percent yield loss suffered from improper fertilizer application.[14] Precise application of inputs, such as fertilizer, herbicides, and pesticides, allows farmers to adjust inputs to location-based characteristics and use exact amounts needed, which saves money and increases sustainability due to more efficient resource stewardship. Improved fertilizer, soil, and water use can significantly improve water quality with less runoff and reduce climate gas emissions, which is important since agriculture accounts for 10-15 percent of worldwide emissions.15 Despite reductions in necessary inputs, Next Generation Precision Agriculture helps maintain or increase yields, leading to significant gains in efficiency[14].

Real-time insights also improve logistics. When growing melons, for instance, real-time data can help farmers overcome challenges in storing and shipping their products. Melons should be stored in an optimal refrigeration environment to minimize spoilage, and real-time precision sensors can reduce spoilage by alerting staff to suboptimal variations in temperature and humidity, allowing the execution of remedies before major losses occur. When refrigerated storage is full or the market price is at a peak, the "Internet of Things" can provide real-time information about where trucks are located and locating customers to market products to help make the sale.

LABOR EFFICIENCY boosts productivity by automating routine processes and enabling real-time response

Connected devices equip farmers with a clear picture of their operations at any moment, making it possible to prioritize tasks more effectively and triage the most pressing issues. While routine inspection and scouting has typically been a regular part of farm management and has increased farm profitability[14], connected technologies can track, sense, and flag where a producer should focus their time and attention that day. Similarly, e-connectivity has allowed rural farms to access new training resources and high-skilled labor that has not been previously available.

Real-time data and automation can radically



improve a producer's peace of mind and performance under time constraints, especially because of reduced physical and mental stress (no longer struggling to keep the machine on a row line between 6 and 10 hours in the field during harvest or planting). On dairy farms, for example, automated devices that milk and feed animals can also track each cow's activity and alert producers to potential problems. Because these tasks are traditionally done by the producer and farm personnel, e-connectivity can substantially reduce the amount of time and effort necessary to run farms. This leads to dramatic increases in flexibility, enabling time and talent to be directed to more advanced tasks. Farmers can use newly found time to re-invest in more high-value tasks like long-term planning and management of the operation. This shift towards farm management opens new possibilities for the way that farms conduct business.

GEOGRAPHIC ACCESS extends the reach of the supply chain and shifts marketing from standard to differentiated

As explained in the previous section, as Precision Agriculture unlocks additional time and resources to explore new ways of doing business farmers are re-investing their time into identifying options to improve inputs, including better-trained labor and more effective types of inputs. New customers and markets can also be explored to increase sales volume and revenues.

THE RISE OF E-COMMERCE

E-commerce provides producers with the ability to access new customer channels, differentiate products, and shape demand.

ACCESS. Online platforms provide access to new customer channels. Web-enabled direct-to-consumer sales, for example, enable producers to shorten their supply chains, develop relationships with customers, and retain more revenue. Through online cattle auctions, cattlemen can save the cost of traveling to live auctions while still participating in transactions across wide geographies.[16] Through MarketMaker, the largest online database connecting buyers, farmers, processors, packers, distributors, restaurants, and others, businesses can find suppliers, form more profitable business alliances, meet new customers, and locate quality products.[17] These examples provide just a small sample of the many ways that e-commerce increases market access.

DIFFERENTIATION. With direct sales, producers can communicate key attributes about their products, helping them charge premium prices. Specifically, traceability technologies can help instill trust in origin and assure buyers that foods exhibit certain characteristics. An innovative technology company operating today, for instance, is combining blockchain technology with barcodes and Quick Response (QR) codes to provide instant information about food origination, nutrition, and quality, empowering the consumer with information to help choose which products to buy.[18] Another company, an Internet-enabled grain marketplace, assures producers they can "get paid for the quality of their grain."[19]

THE POTENTIAL ECONOMIC BENEFITS OF **E-CONNECTIVITY FOR U.S. AGRICULTURE**

Together, new technologies and ways of working combine to improve yields, reduce costs, improve labor efficiency, and increase revenues through greater market access. Business impacts surface across three sets of activities.

Adoption rates for precision technologies have been higher to-date in row crops since they are already highly mechanized. However, because each specialty crop has unique planting, harvesting, and packaging processes, production operations have been difficult to modernize with process automation; market coordination opportunities may have more potential here.

Accordingly, USDA's analysis is reflected in Table 1 below. Though all farming businesses engage in planning, production, and market coordination activities, the application of and benefit from Next Generation Precision Agriculture technologies vary significantly by commodity type. For example, row crops gain more in the planning phase than do specialty crops; since row crops are planted every year, farmers have frequent opportunities to vary their planning decisions, whereas specialty crops, such as crops grown on orchards, are often planted less frequently, limiting the impact of additional data in the planning phase. Because row crops are often considered commodities—that is, products where the price is largely determined by national indices rather than by product quality—row crop farmers seem to have relatively less benefit to gain from market coordination phase technologies than specialty crop farmers. The most consistent gains across all subindustries and stages are found in the production stage, which reflects that farming is, at its core, a manufacturing business where accurate, timely information is invaluable.

FIGURE 3.
DIGITAL TECHNOLOGIES APPLIED TO STAGES OF AGRICULTURE MANAGEMENT

Digital Technologies Applied to Stages of Agriculture Management

STAGE 1

PLANNING

Data collection and decision support to make better choices about what, when and where to produce

ACTIVITIES INCLUDE:
Data analytics
Field prescriptions
Fertility planning

STAGE 2

PRODUCTION

Monitoring the growth cycle, managing inputs, and optimizing the product's health and harvest

ACTIVITIES INCLUDE:
Real-time sensing
Algorithmic diagnosis
Automated harvesting

STAGE 3

MARKET COORDINATION

Creating access to new customers and channels, differentiating products, and shaping consumer preferences

ACTIVITIES INCLUDE:
Online sales
Targeted advertising
Optimizing distribution

TABLE 1.
CONNECTED TECHNOLOGIES ANALYZED BY COMMODITY TYPE

(basis for calculations can be found in Appendix)

Connected Technologies in Row Crops and Specialty Crops *(figures are rounded)*					
Commodity Type	Business Function	Technology	Potential Annual Gross Benefit of Next Generation Precision Ag	Potential Attributable to Broadband	Percent Dependent on Broadband
ROW CROPS	PLANNING	MICROCLIMATE MODELING TECHNOLOGY	$1,574,000,000	$787,200,000	50%
ROW CROPS	PLANNING	YIELD MONITORING TECHNOLOGY	$1,771,000,000	$177,100,000	10%
ROW CROPS	PLANNING	PRECISION SEEDING	$810,000,000	$162,000,000	20%
ROW CROPS	PRODUCTION	FIELD SCOUTING	$1,423,000,000	$711,300,000	50%
ROW CROPS	PRODUCTION	VARIABLE RATE APPLICATION	$1,715,000,000	$171,500,000	10%
ROW CROPS	PRODUCTION	CONNECTED EQUIPMENT	$638,000,000	$191,300,000	30%
ROW CROPS	PRODUCTION	MACHINE LEARNING AND VISIONING	$905,000,000	$452,500,000	50%
ROW CROPS	PRODUCTION	REMOTE DIAGNOSTICS & PREDICTIVE MAINTENANCE	$1,981,000,000	$990,400,000	50%
ROW CROPS ROW CROPS	MARKET COORDINATION MARKET COORDINATION	STORAGE MONITORING *or* SMALL PRODUCER COORDINATION	$1,580,000,000 *or* $2,900,000,000	$474,700,000 *or* $1,457,000,000	40%
SPECIALTY CROPS	PLANNING	WEATHER MODELING - TREE	$961,000,000	$288,300,000	30%
SPECIALTY CROPS	PLANNING	WEATHER MODELING - GROUND	$328,400,000	$98,500,000	30%
SPECIALTY CROPS	PRODUCTION	MACHINE LEARNING AND VISIONING - TREE	$414,500,000	$124,360,000	30%
SPECIALTY CROPS	PRODUCTION	PEST PREVENTION AND MONITORING - TREE	$846,700,000	$423,300,000	50%
SPECIALTY CROPS	PRODUCTION	SMART IRRIGATION - TREE	$133,500,000	$66,800,000	50%
SPECIALTY CROPS	PRODUCTION	ROBOTIC HARVESTING - TREE	$586,600,000	$293,300,000	50%
SPECIALTY CROPS	PRODUCTION	INPUT USE AND MANAGEMENT - GROUND	$11,100,000	$5,500,000	50%
SPECIALTY CROPS	PRODUCTION	SMART IRRIGATION - GROUND	$801,900,000	$240,600,000	30%
SPECIALTY CROPS	PRODUCTION	FROST DETECTION - GROUND	$278,500,000	$83,500,000	30%
SPECIALTY CROPS	PRODUCTION	ROBOTIC HARVESTING - GROUND	$403,000,000	$201,500,000	50%
SPECIALTY CROPS	MARKET COORDINATION	FOOD WASTE MANAGEMENT	$901,000,000	$90,100,000	10%
SPECIALTY CROPS	MARKET COORDINATION	DIRECT-TO-CONSUMER SALES - TREE	$642,500,000	$321,240,000	50%
SPECIALTY CROPS	MARKET COORDINATION	DIRECT-TO-CONSUMER SALES - GROUND	$6,400,000,000	$3,200,000,000	50%
SPECIALTY CROPS	MARKET COORDINATION	STORAGE MONITORING - GROUND	$551,000,000	$275,500,000	50%

Connected Technologies in Livestock and Dairy *(figures are rounded)*					
Commodity Type	Business Function	Technology	Potential Annual Gross Benefit of Next Generation Precision Ag	Potential Attributable to Broadband	Percent Dependent on Broadband
LIVESTOCK AND DAIRY	PLANNING	FERTILITY PLANNING	$1,780,000,000	$177,800,000	10%
LIVESTOCK AND DAIRY	PLANNING	INFANTICIDE PREVENTION	$9,800,000	$4,900,000	50%
LIVESTOCK AND DAIRY	PLANNING	LIVESTOCK RECORDS AND MANAGEMENT	$623,100,000	$186,900,000	30%
LIVESTOCK AND DAIRY	PRODUCTION	PRECISION FEEDING	$4,100,000,000	$1,200,000,000	29%
LIVESTOCK AND DAIRY	PRODUCTION	MASTITIS DETECTION	$143,300,000	$14,300,000	10%
LIVESTOCK AND DAIRY	PRODUCTION	AUDIO/VISUAL FACILITY MONITORING	$240,700,000	$120,300,000	50%
LIVESTOCK AND DAIRY	PRODUCTION	UNMANNED HERDING	$470,000,000	$141,000,000	30%
LIVESTOCK AND DAIRY	PRODUCTION	ROBOTIC MILKING	$2,050,000,000	$613,400,000	30%
LIVESTOCK AND DAIRY	PRODUCTION	GENERAL HEALTH MONITORING	$8,800,000,000	$4,400,000,000	50%
LIVESTOCK AND DAIRY	MARKET COORDINATION	AUTOMATED SORTING	$391,200,000	$117,400,000	30%
LIVESTOCK AND DAIRY	MARKET COORDINATION	ONLINE CHANNELS	$1,004,400,000	$502,200,000	50%
LIVESTOCK AND DAIRY	MARKET COORDINATION	TRACING AND MARKETING	$990,000,000	$297,000,000	30%

While digital technologies are already creating value within the agriculture industry today, realizing the full potential of these technologies, according to USDA, could create approximately $47–$65 billion annually in additional gross benefit for the U.S. economy. In other words, if broadband Internet infrastructure, digital technologies at scale, and on-farm capabilities were available at a level that met estimated producer demand, the U.S. could realize econonomic benefits equivalent to nearly 18 percent of total production, based on 2017 levels.[10]

As the following table indicates, USDA estimates that rural broadband connectivity is the driver of more than one-third of the value or $18 billion to $23 billion per year, that digital technologies could create for our nation.

It is important to note that such economic benefits would be realized over a long term and could not manifest during the course of one single year. This is because it will take many years to build all requisite infrastructure for broadband service, deploy all necessary equipment, and train all producers to fully utilize all of these Next Generation Precision Agriculture technologies. Therefore, these figures are being reported here to simply give a general scale of the potential future benefits, in today’s dollars.

TABLE 2.
ANNUAL POTENTIAL GROSS ECONOMIC BENEFITS OF PRECISION AGRICULTURE TECHNOLOGIES DERIVED FROM BROADBAND E-CONNECTIVITY

	Row Crops	Specialty Crops	Livestock	Total	
Annual Value of the U.S. Market Studied *	**$110.6 B**	**$30.1 B**	**$113 B**	**$254 B**	
Precision Ag in Planning	$4.2 B	$1.3 B	$2.4 B	$7.9 B	
Precision Ag in Production	$6.7 B	$3.5 B	$15.8	$25.9 B	
Precision Ag in Market Coordination	$2.2 B	$8.5 B	$2.4	$13.1 B	
Next Generation Precision Ag Potential Gross Economic Benefits Annually, For the Market Studied	$13.1 B	$13.3 B	$20.6	$46.9 B	
Annual Value of Total U.S. Market Production *	**$142.6 B**	**$45.3 B**	**$151.9**	**$340 B**	
Next Generation Precision Ag Potential Gross Economic Benefits Annually, Extrapolated to Total Market	$16.8 B	$19.9 B	$27.7	$64.5 B	
Next Generation Precision Ag Potential Gross Economic Benefits as a Percent of Total U.S. Production	12%	44%	18%	18%	
Average Percent of Next Generation Precision Ag Benefits that Depend on Broadband	35%	43%	38%	36%	
Potential Gross Economic Benefits of Ubiquitous Broadband Infrastructure and Next Generation Precision Agriculture Adoption:	$4.6 *to* $5.9 B *or 4%*	$5.7 B *to* $8.6 B *or 19%*	$7.8 B *to* $10.5 B *or 7%*	$18 B *to* $23 B *or 7%*	***of the total market***

** Source: 2017 Production Values per 2019 reports of USDA National Agricultural Statistics Service and Animal and Plant Health Inspection Service.*

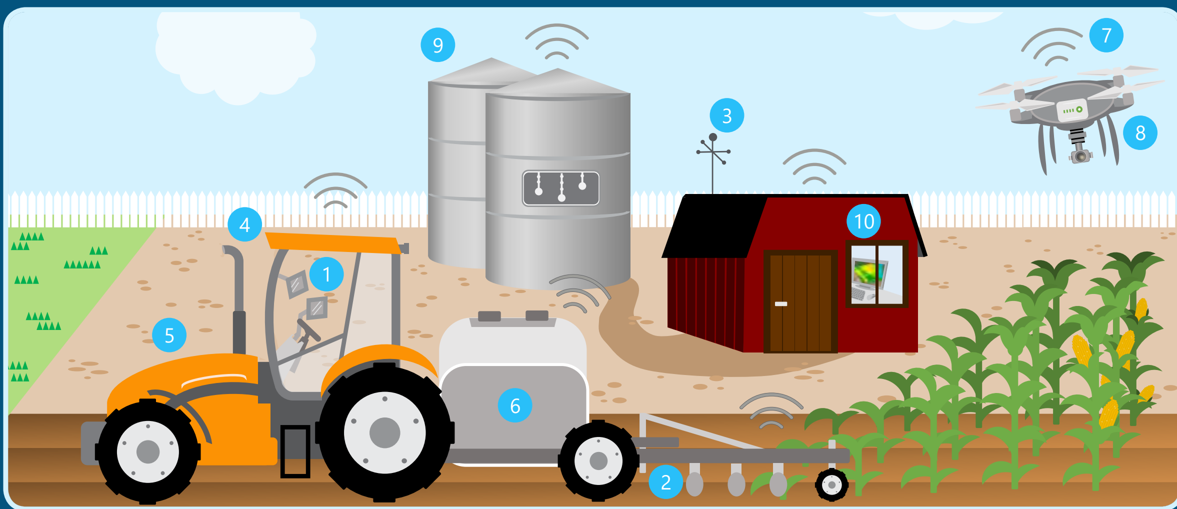
Access to reliable, affordable connectivity is a critical component to powering these technologies and contributes a significant portion of value. In this sense, Internet infrastructure performs a similar function as other types of infrastructure, such as roadway systems. Prior to the construction of the United States' Interstate Highway System that began in 1956, trucks transported inputs to production sites and agricultural commodities to market on at-grade signalized roadways across the nation. However, with a complete system of interconnected high-performance, grade-separated highways, trucks can carry freight across the country exponentially faster and using fewer resources. It has catapulted America's productivity, redefined feasibility of manufacturing and distribution, opened up new markets, and transformed the way our nation's economy runs.

Similar to pre-1956 roadways, some Precision Agriculture technologies in use today may operate with basic functionality on limited Internet access. Only with the efficiencies of ubiquitous, modern high-speed e-connectivity—much like the United States' Interstate Highway System—can producers unlock technology's full potential for their farms and ranches, and for the industry and the nation as a whole.

The following pages explore how these functional differences across sub-industries equate to differences in the utility and application of Next Generation Precision Agriculture technologies and how the suite of technologies varies between commodities. Each section characterizes the landscape of digital technologies today, where they impact the value chain, and what this means for frontline users.

United States Department of Agriculture

CONNECTED TECHNOLOGIES IN ROW CROPS



PLANNING

1 Yield Monitoring: Combine-mounted monitors gather harvest data for business decisions, which can save $25 per acre in input costs for corn farmers.

2 Precision Seeding: Location-tagged field data can be uploaded into planning software to optimize planting decisions and placement, which can save $6.53 per acre on seed expenses.

3 Microclimate Monitoring: Satellites or on-site weather stations can forecast local weather more accurately, avoid potential pest problems, and reduce crop loss by up to 80%.

PRODUCTION

4 Connected Equipment Guidance: Vehicles, including autonomous vehicles, use GPS to determine field boundaries for precise tending and save an estimated $15 per acre on corn farms.

5 Remote Diagnostics and Predictive Maintenance: Connected hardware and software diagnose—and even anticipate—needs for repair, saving $5 to $15 in costs per acre.

6 Variable Rate Application: Technologies apply precise, optimal levels of raw inputs, saving $22 per acre for corn farms and increasing operating profit by 1.1%.

7 Field Scouting: Drone imagery and software can collect nutritional and growth data used to calculate optimal inputs, saving $12 per acre on corn farms.

8 Machine Learning and Visioning: Connected cameras and software can identify weeds, detect disease with 90% to 99% accuracy, and locate pests, facilitating treatment and reducing crop loss by 30%.

MARKET COORDINATION

9 Storage Monitoring: Temperature and moisture sensors can detect storage quality for harvested products, reducing crop loss and increasing sale price by $1 per hundredweight for grain sorghum.

10 Small Producer Coordination: Web platforms connect farmers directly to buyers, allowing them to earn premiums for meeting specific quality standards and bringing between $0.35 to $0.51 more per bushel for corn, soy, wheat, and rice.

BENEFITS OF NEXT GENERATION PRECISION AGRICULTURE

ROW CROP FARMERS

After implementing precision agriculture technologies enabled by internet connectivity, row crop farmers can enjoy benefits to their **business management** and **quality of life**.

- **Faster learning curve** for new fields or crops
- **Better, real-time records** help triage problems faster and improve decision making over time
- **Physical health and peace of mind** through reduced hours and stress
- **More time** to learn new skills, research and plan, multitask, or manage
- **Peer learning** over digital channels

CONNECTED TECHNOLOGIES IN

ROW CROPS

Producer Narrative: Row Crops

Today is "fly day" for Jane, a Midwestern corn and potato grower. She heads outside and fires up her drone to do a pass over the fields she operates north of the office. She has her workers check on the fields throughout the week, of course, but they only check a fraction of what the drone's camera does. While the drone is out flying, she checks her connected irrigation system on her phone; it takes 3 or 4 minutes to load, but then she adjusts the rate for each pivot based on the data as it streams in from thermal images and soil water sensors.

The drone is mostly a scouting tool now, but she heard at last week's Next Ag Leaders event that one company is developing some with 10-foot sprayers. That seems too small, but the manufacturer pointed out that "swarms" of 10 drones could fly down a field and spray almost as much as a 120-foot boom. Even at $12,000 per drone with a spraying attachment, the total would still be half the cost of a new, quarter-million-dollar sprayer. Plus, there would not be any compaction or crop damage.

Speaking of sprayers, it looks like she needs to apply more fertilizer in the new field she picked up this year. Without past years' yield maps, she couldn't set a prescription formula to program her variable-rate fertilizer application. She could probably approximate something based on her drone imagery, but the drone and larger machinery are from different manufacturers with proprietary software, so she can't integrate and overlay the data. Drone imagery takes so much bandwidth that she has made it a habit to leave her laptop open overnight to upload and stitch images, once the rest of her staff has left, since her office WiFi isn't fast enough while others use it.

Jane pulls out the tractor and heads out to spray. Tractors mostly drive themselves these days, thanks to autosteer, allowing Jane to multitask from the driver's seat. She does a little research into a few purchases she is considering, including connected scales for the grain loading dock.

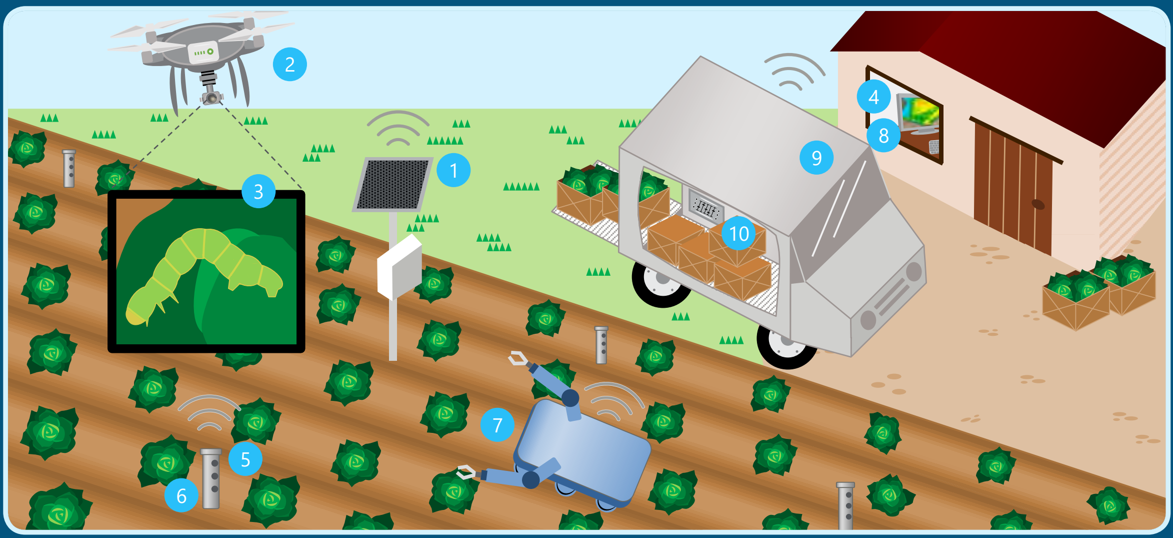
In reviewing last years' haul data, the drivers had entered almost a third of it incorrectly! This kind of recordkeeping software is a game-changer. In fact, as she pulls out of the field, she saves a record of the pesticide treatment applied, and shares a copy with the landowner. The cab is a lot less cluttered these days; it used to be jam-packed with coffee-stained notes trying to keep track of how much had been put on and where. Plus, Jane's shoulders hurt a lot less at the end of the day than with her old tractor, and the extra time gives her more energy to focus on her business.

Back at the office, Jane kicks aside a box of soil sensors under her desk; they had required constant "fixes" and tech support from the manufacturer. Still, they weren't the most costly example of failed equipment: when a $2 sensor on her combine failed last year, she lost half a day of harvest time and incurred $1,500 in repair costs.

From her computer, Jane skims through message threads on the online discussion forum AgBlog. Jane is always searching for new practices and tech, but she's extremely reluctant to share her own. Crops like corn and potatoes are—for the most part—commodities, and so her peers are also her competitors. Speaking of which, she flips over to check her marketing app to see where prices are today. With the price jump, it has reached the "sell" target she set this spring, so she commits 20 percent of her anticipated harvest at that value. In past years, she might gamble that the price will keep rising, but the data has given her the discipline to stick with pre-planned targets.

She flips back to the forum and reads a post about a farm with a new side business offering Precision Agriculture services. Diversifying into other businesses seems like a good way to reduce risk. She still doesn't have quite enough time to build up the skills she'll need, but maybe one day she can become a full-time Precision Agriculture services provider. Maybe.

CONNECTED TECHNOLOGIES IN SPECIALTY CROPS



PLANNING

1 Weather Modeling: On-site stations can forecast and detect local problems, saving users $19,500 per year in spray costs and preventing $264,000 per year in crop loss.

PRODUCTION

2 Machine Learning: Software and field imagery can identify overgrown or foreign plants and inform fungicide application, reducing labor costs by 20% to 25%.

3 Pest Prevention and Monitoring: Connected drones and software can prevent or identify pest problems, reducing spray loss on the ground by 68% to 93%.

4 Input Use and Management: Decision support software can enable data-driven decision making to maximize yield while reducing inputs, like fungicide use by 50%.

5 Smart Irrigation: Soil-based plant sensors can help control irrigation systems to improve water efficiency by 20% to 25%, increase yields by 17.5%, and cause 10-20% less tip burn, increasing profitability by $500-$4,000 per acre.

6 Frost Detection: Wireless sensors can help identify frost patterns and alert producers, improving forecasts by 50% and increasing relative crop value by an average of 18%.

7 Robotic Harvesting: Autonomous pickers using vacuums or pincers for harvesting and picking can reduce overall harvest costs to 35% to 45% of total production costs.

MARKET COORDINATION

8 Food Waste Management: Online platforms can help sell perishable food that might otherwise go to waste, increasing market access and creating $10,651 in additional revenue per producer.

9 Direct-to-Consumer Sales: Digital platforms can shorten the supply chain and increase producer revenue by 50% per unit of apples, 649% per unit of salad mix, and 183% per unit of blueberries.

10 Storage Monitoring: Remote sensor systems can manage containers and send alerts, to avoid temperatures and pressures causing perishable good prices to drop 10% per hour.

BENEFITS OF NEXT GENERATION PRECISION AGRICULTURE

SPECIALTY CROP GROWERS

After implementing precision agriculture technologies enabled by internet connectivity, specialty crop farmers can enjoy benefits to their **business management** and **quality of life**.

- **Remote work** facilitating recruitment of top-tier talent
- **Resource sustainability** as a result of reducing raw inputs like water
- **Decreased reliance on labor** through automation, addressing shortages and premiums on labor
- **Improved food safety** and compliance with federal requirements
- **Experimentation** to test new tech and customize based on farm-specific needs

CONNECTED TECHNOLOGIES IN
SPECIALTY CROPS

Producer Narrative: Specialty Crops

As the CTO for a 2,000-acre specialty crop farm, José keeps a constant pulse on his crops. From a couple of digital dashboards on his iPad, he checks the final numbers on yesterday's broccoli and lettuce yields and double-checks the settings of the remote-controlled refrigeration lockers, which help minimize spoilage before crops are shipped out. On his drive to the next site, he listens to a podcast from a regional innovation center explaining some of the new ag tech projects they're incubating. He's consistently been an innovator in this area, building many of his own technologies for specialized production of each crop. He now hosts his own peer groups to share what he has learned and show off his latest tech.

His drive is interrupted by a call from Tom, who's been experimenting with irrigation systems on iceberg lettuce fields, as part of an effort to reduce water usage due to rising water prices. A few years ago, Tom had pitched and implemented a variable-rate irrigation system to replace the farm's flood irrigation system and reduce overwatering. Estimates were that precision irrigation could reduce inputs by up to 20 percent while maintaining—or improving—yield per acre, and the results have more than delivered. José asks about the new autonomous irrigation pilot that Tom has been running. During the lettuce harvest, they'll record conclusive results, Tom says, but so far, it appears that the water sprayers are automatically adjusting based on continuous water and soil sampling.

José hangs up and pulls up to the broccoli field to check on his favorite project: a custom-built broccoli harvester. Automated harvesters are commonplace for row crops like corn, but specialty crops are usually picked by hand, since they're too delicate or inconsistently shaped for machines to handle. Due to rising wages, the owners had asked José to think about ways to reduce dependence on seasonal labor. José had seen a similar machine at a trade show in Spain, and the big U.S. manufacturers didn't seem focused on specialty crops, so he decided to engineer the first broccoli harvester in the country. He actually outsourced production to Canada, in order to keep American competitors from swiping his design. José pulls up to the harvester and walks around it a couple of times, admiring his work.

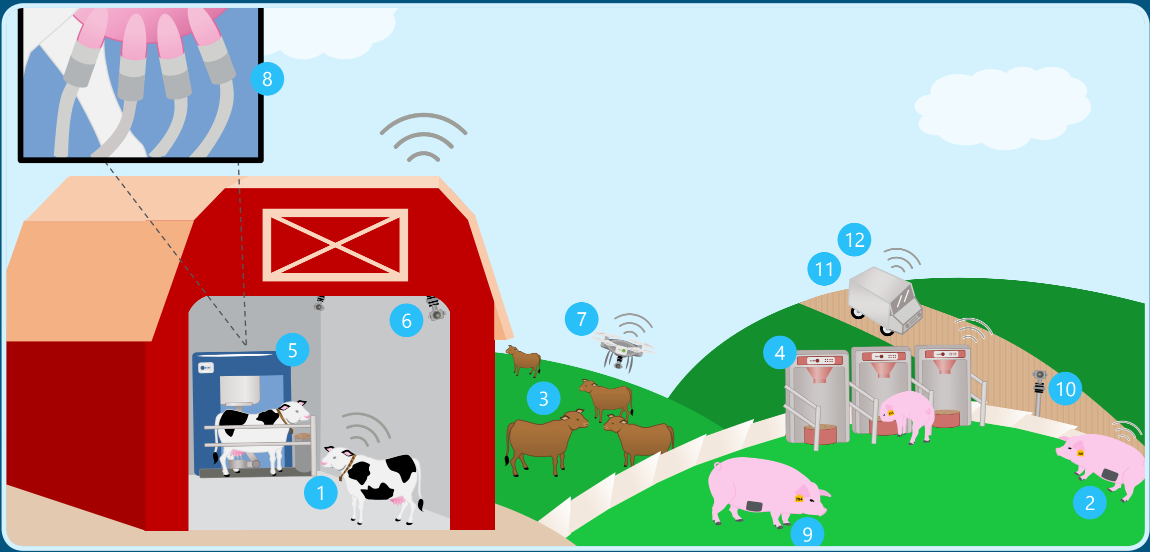
A few yards away, a field crew packs romaine into bags. José helped implement barcode scanners and in-field label printers, although spotty service constantly interrupts the data stream, and he has to cross-check against shipping records. Last week the cell service was so bad, José had to manually input half the barcodes. The tracking increases traceability and insulates the operation a little from outbreaks and scares. José suspects consumers will continue wanting to know more about where their food comes from and how it's grown, so he invested early.

As he returns to the office for a chat with the Deputy CTO, José glances at his phone and scans an email from the aerial imagery service he hired. Three times a week, for a reasonable fee, they fly over his fields in their special drone, equipped with an expensive multispectral camera, to generate maps of chlorophyll levels, temperature, and water density in the soil. The maps they send take so much bandwidth to download, José usually needs to drive to his equipment dealer's office to view them. He archives the email for later.

When hiring for the Deputy CTO job last year, José struggled to find good applicants who were in—or willing to relocate to—the area. Rather than lowering his standards, he hired Jenny, who lives in San Francisco. She lives close enough to visit the farm every week or two while doing most of her work on the systems remotely. José is very pleased with her work and feels proud to have hired top-tier talent. It gives him even more time to plan for future investments; he's looking forward to reading the latest Fresh Produce Growers newsletter on his iPad, where he'd seen a teaser for an article about next generation autonomous harvesters.

USDA
United States Department of Agriculture

CONNECTED TECHNOLOGIES IN LIVESTOCK & DAIRY PRODUCTS



PLANNING

1 Fertility Planning: Biosensors can track ovulation cycles and detect estrus with a 95% to 97% success rate, helping to boost pregnancy rates.

2 Infanticide Prevention: Sensors can listen for sounds of distress and stimulate sows to re-position, reducing these preventable animal deaths by 75%.

3 Livestock Records and Management: Software can keep records and make decisions based on real-time herd data to reduce costs by $6 per 20kg of production.

PRODUCTION

4 Precision Feeding: Sensors can calibrate and distribute optimal amounts of feed, decreasing costs by $0.12 per day per cow.

5 Mastitis Detection: Automated monitoring systems can detect early signs of mastitis and help avoid $316 in indirect costs per infected cow per year.

6 Audio/Video Facility Monitoring: Cameras and AI can help avoid or track lost animals, reducing labor time by 2.27 labor hours per 1000 pounds and two hours per broiler house per day.

7 Unmanned Herding: Unmanned Aerial Vehicles can monitor and herd, reducing by 20% the cost of searching for lost cattle.

8 Robotic Milking: Robots can sanitize and stimulate teats, self-attach to utters, and catch milk, increasing the frequency of milkings and increasing production by 8%.

9 General Health Monitoring: Bluetooth-enabled animal wearables can monitor activity and detect anomalies, reducing medication by 15% per animal and shortening the cattle finishing process by 4 to 6 weeks.

MARKET COORDINATION

10 Automated Sorting: Visual inspection, weighing, and quality sorting can optimize product pricing and return an additional $27 per day or $10,000 per year for a farm.

11 Online Channels: Channels like online cattle auctions can return 65% more revenue per unit of beef, compared to mainstream supply chains.

12 Tracing and Marketing: Technology can communicate key product attributes so consumers make informed purchases and, for farmers, unlock 15% premiums compared to retail prices of commodity beef.

BENEFITS OF NEXT GENERATION PRECISION AGRICULTURE

LIVESTOCK & DAIRY PRODUCERS

After implementing precision agriculture technologies enabled by internet connectivity, livestock and dairy farmers can enjoy benefits to their **business management** and **quality of life**.

- **Early detection** of illness, fertility cycle, and digestive issues in animals
- **Eroding advantages of scale** with diversifying business models a new selling channels
- **Physical health and peace of mind** by reducing manual labor and allowing for flexible scheduling of daily activities
- **Data-driven decisions** over gut instinct results in quicker, more accurate business management
- **Meeting consumer demands** through direct marketing channels and transparency

CONNECTED TECHNOLOGIES IN
LIVESTOCK & DAIRY PRODUCTS

Producer Narrative: Livestock & Dairy Products

Dave's alarm goes off at 6:00 a.m., two hours later than it used to. Out of habit, he swings by the barn before breakfast and checks on the dairy cows lining up to get into the robotic milking stalls. All 180 will be milked 2 to 3 times today, compared to before the robots when three people milked twice daily.

When his four kids still lived at home, the family could easily get by with a parallel milking system, but as the kids moved out, he realized that they needed to make a change to stay in business. His son, Will, is pretty tech-savvy and had begged him to consider automating the operation with the robotic milkers he'd read about. Dave was skeptical at first, but after penciling out the cost of hiring 3 new laborers versus outfitting the barn with robotic milkers, the financial cost-benefits were pretty similar. Plus, with this new tech, he has scaled from 60 dairy cows to 180 in 3 years, without new hiring. This automated system has made his cost structure more similar to much larger operations; as Will puts it, "less time milking, more time managing."

Dave walks to the small office attached to the side of the barn, from which he runs much of the operation, and checks the system dashboard from his computer. As each cow enters the stall, its RFID tag pulls up its record from the livestock management software, flashing its recent stats across the screen (including feed, medications, milk yield, and fertility cycle). This data is used to set cows' feeding regimen in the stall, and the software increasingly enables personalized precision feeding, varying the type and amount of feed based on yields and other factors. He suspects these records will one day make it easier to meet food safety and traceability regulations, and he's heard some producers are experimenting with using blockchain applications to share stats with customers who want more information about their food.

The herd-level dashboard loads pretty quickly, but pulling up an individual cow's trends means sitting for 15 to 20 seconds each time. Because the metal barn blocks cell signals, Dave has 14 different cellular plans for full coverage, costing about $1900 per month.

Dave's smartphone chimes with a mobile alert. Cow #138 is eating and drinking less, a classic early warning sign of mastitis. He walks back to the barn to inspect, making a mental note to check the data from the activity tracking collars, too. They're like "fit bits" for cows, in that they record each animal's movements and digestive habits (although, annoyingly, they operate with a separate software from the robotic milking system). It took Dave a while to trust the data; he grew up around cows and jokes that he has a sixth sense for when they're in heat or getting sick. But the data reports have been alerting Dave to health issues 12 to 24 hours earlier than his gut was telling him and improving his breeding practices too. He's heard that swine and poultry facilities have started using artificial intelligence in cameras and audio recorders to flag signs of illness based on animal breathing or signs of duress. He wonders if similar tech exists for cows. The real value, of course, would be in streaming all this data to his vet, offloading some health management duties and getting recommendations faster and more consistently.

He checks his schedule for the day as he heads back to the house for lunch. He has a call set up with his contact at a meal kit startup, one of the direct-to-consumer marketing channels he's trying. With more time on his hands, he's been testing the idea of a dual-purpose herd, instead of selling his bulls to someone else. Before, he lacked the volume to make it economical, but this startup likes small, nontraditional suppliers. Plus, they provide recipes to buyers, shaping consumer tastes. He is able to sell more of each animal, which reduces waste to increase profitability.

Dave is looking forward to this evening when the whole family is coming over for dinner at 5 p.m., since the young grandkids have an early bedtime. For most of his life, Dave couldn't attend many family events because of his hours. Not anymore, and not tonight.

USDA
United States Department of Agriculture

SOCIETAL BENEFITS OF PRECISION AGRICULTURE

SECURITY

7.5% fewer people at risk of hunger in developing countries[20]

HEALTH

2 seconds to trace food products' journey, using blockchain-enabled records[21]

SUSTAINABILITY

40% less fuel burned, due to VRT technologies[22]

20–50%+ lower water usage[22,23]

up to 80% reduction in chemical application[24]

OTHER BENEFITS OF E-CONNECTIVITY FOR RURAL DEVELOPMENT

Next Generation Precision Agriculture technologies have the potential to generate a "killer application"[25] that leads to a demand for more or quicker expansion of rural broadband infrastructure and services. Such expansion of broadband throughout America's rural areas, would also enable Internet service access for other uses. Rural based industries like mining and forestry will find effieciencies and quality of life measures can increase access to health care and improved education facilities for rural citizens. A similar analysis can be done in these industries and quality of life measures.

FORESTRY. The forest products industry is among the top ten manufacturing sectors in the continental United States, by population employed, and generates billions of dollars in annual sales.[26] The largest gains can be found in monitoring forest growth through smart pest management, drone planting, and connected fire prevention technologies. Real-time information provides significant value where delayed information transmission or imprecision in the early stages of planting can result in long-term and consequential loss.

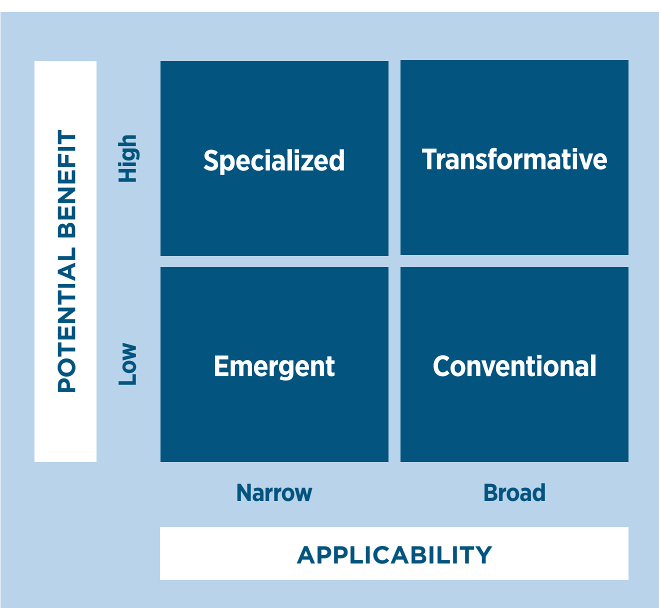
TELEMEDICINE. Demographic, environmental, economic, and social factors put rural residents at higher risk of preventable death from conditions like cancer, heart disease, unintentional injuries, and stroke.[27] Mental health issues, including opioid dependency, have become a focus for rural health interventions.[28] Connected technologies enable constant information streaming that can improve care quality, resource use, and diagnosis, reducing missed cases and medical waste.
Non-emergency treatment technologies can improve the management of chronic conditions, ensuring adherence of medication and preventing costly, unnecessary interventions. Telemedicine applications often require higher speeds, reliability and capacity, and if available could expand treatment access to rural residents who may be too remote for needed access to providers and could enable local hospitals to continue financially-sustainable operations.[29]

DISTANCE LEARNING. Connected technologies can benefit student retention, including increasing education accessibility for disabled students. Technologies enable tailored learning directed to the individual student or for teacher support. Digital learning, such as coding skills for post-graduates, expands educational access for adults.

TODAY'S CHALLENGES TO SCALING ADOPTION OF NEXT GENERATION PRECISION AGRICULTURE

If Next Generation Precision Agriculture adoption fueled by a strong rural Internet infrastructure is so transformative, then why are we not yet causing wide-scale change?

Farmers currently face challenges in adoption and deployment of advanced technologies in the field, limiting the extent to which the U.S. agriculture industry can realize the potential economic impact. A 2017 Purdue University survey, for example, found that one-third of Precision Agriculture technology dealers believed that interpreting and making decisions with Precision Agriculture information took too much of their customers' time. These dealers also expressed that producers might be shying away from use of Precision Agriculture tech because of affordability (65 percent), soil type (23 percent), a lack of confidence in data (23 percent), topography (21 percent), and limited time to interpret data (21 percent).[11] Broadly speaking, these trends are classic industry challenges to adoption for any new practice, product, or service and are not unique to the digitization of agriculture.



As demonstrated by the following figure, Next Generation Precision Agriculture incorporates technologies of varying maturities, with some of the most transformative technologies still nascent or requiring new capabilities for full deployment across the industry. Technologies that can integrate with existing machines in highly-mechanized production, like GPS guidance in combines, for example, are a popular technology that is widely used but may not have capacity to significantly modernize business beyond current practice. On the other hand, technologies like image and video recognition may dramatically change detection and diagnosis of issues in livestock facilities or produce fields, requiring large datasets to train machines and causing significant changes in business.

Between these two factors, user characteristics and technology maturity, Next Generation Precision Agriculture brings several new or more nuanced challenges to adoption that may necessitate new roles within the industry ecosystem and new strategies for action.

A lack of ubiquitous, reliable broadband service undermines potential benefits.

E-connectivity is the backbone of digital technology and drives much of the value by making it possible to aggregate, analyze, and act on the data collected. When the Internet isn't reliable enough to support connected devices, the benefits derived from precision technologies are substantially diminished. Some farmers, therefore, dedicate significant time and effort to find workarounds to insufficient Internet service, which takes time away from managing their businesses and serving their customers. Some of the more innovative and risk-tolerant rural telecommunications providers and co-ops are deploying nontraditional, creative methods to help local farmers gain internet connectivity, highlighting an untapped customer base for larger-scale providers willing to understand and tailor their services to rural communities' needs.

Some Next Generation Precision Agriculture technologies function with basic Internet connections, so even slow speeds are better than no connections at all. But many require a more reliable and high-speed Internet connection as a minimum requirement. Additionally, without access to online learning and peer sharing platforms, farmers are less likely to succeed with technology implementation, having wasted money, time, and effort without realizing complete benefits.

Farms may not be able to access the full value of the technologies they are purchasing.

New, high-tech features can drive more equipment sales and higher usage, but purchases can be expensive for producers, and obtaining the greatest value from devices requires overcoming a steep learning curve by farmers.

A grain farmer, for example, might use the basic functionality of a yield monitor but may not realize its full potential by analyzing year-over-year patterns. Similarly, many livestock operations use livestock management systems to record daily activity but rely on analog clipboards for real-time recordkeeping, due to clunky interfaces that differ from their actual protocols.

> **"90 percent of people do nothing with the data they collect. They don't know what to do with it."**
>
> **- Row crop producer, Midwest**

The complexity of managing and interpreting large datasets requires advanced technical skills and overwhelming amounts of information that can make it hard to, in practice, integrate insights into daily operations. For early adopters, these problems are complicated by a relative lack of educational resources about new technologies, and they are left shouldering a heavy burden of exploration. Farmers who do maximize the use of their investments are learning how to do so through self-education or peer learning, which are both time-intensive and inefficient to scale naturally. Broadband use could help expand the reach of these specialist staff members and justify higher pay.

Crowd-sourced, cloud-based data sharing and aggregation services are emerging, yet remain limited when considering the full scale and scope of American agriculture. Such services are not readily available to all producers, especially to those in the specialty crops and livestock and dairy industry, who might be able to benefit more from market coordination and production than row crop applications. USDA has taken significant steps to improve its data analytics capabilities but still primarily relies upon traditional data collection methods, which limit the types of analyses that can be performed to support farm program administration and to improve small producers' profitability and sustainability. Enhanced technical assistance and modernized Extension Services are only possible with more ubiquitous deployment of broadband to farms and ranches along with expanded use of Precision Ag technologies.

Values in the data economy, such as openness and sharing, can seem contrary to traditional farming culture that is grounded in proprietary practices.

Farmers are often hesitant to share data because of competition, privacy, and ownership concerns. But the ability to tailor services, benchmark performance, and discover new connections relies on exchanging information with providers and peers. Attitudes toward peer data sharing run the full spectrum from (a) farmers who believe in full transparency to (b) those who are open to sharing transactionally or with people they know to (c) still others who, as a rule, decline to share their data.

Many farmers acknowledge discomfort with sharing data with suppliers but are willing to make a tradeoff to realize the benefits of technology. This points to the importance of informed consent on the ways in which farmers' data may be used and to what extent they wish to participate in various data-sharing activities.

The value of many connected technologies comes from interoperability, but the industry lacks standards to drive compatibility between Precision Agriculture technologies.

Different technology systems create a need for interoperability and a "common language" for agriculture tech devices, but data integration has so far been disappointing: "many companies claim they can do it until [you] sit down and discuss the … data sources and system requirements."[13] A tech-sophisticated farmer, for example, might wish to predict year-end water usage by connecting data from GPS field maps, drone images, variable-rate irrigation systems, and farm management software; however, these technologies might not be compatible with each other. Technology

> **"It's a major victory in my career to establish a WiFi connection on this farm."**
>
> **- Hog producer, Midwest**

by different companies often cannot interface, sometimes resulting in manufacturer-dependent purchasing decisions.

Without interoperable software, farmers have a difficult time getting a top-level view of their operations, limiting their ability to use devices to their full potential. Manufacturers often do not use open standards, and some farmers are improvising solutions or even "hacking" their equipment to generate more automation or deeper, real-time insights. Innovations that are possible in batch processing, interpreting, and archiving data on-farm or near-farm are constrained because of the lack of data standards.

Taken together, siloed products reinforce a view of new ag technologies as standalone tools, making it hard to get a full picture of on-farm data, generate the new insights that are possible, and unlock the full potential of digital production systems.

New and beginning farmers often seek or advocate for technological innovation, but fewer people are returning to farms.

According to research by USDA's Economic Research Service, 65 percent of beginning farmers are under 54 years old, including 17 percent under 35 years old, and these new farmers are more likely to be digital natives, who have comfort and experience using technologies.[30] They tend to have a passion and interest in tech jobs or using digital skills in their work. These individuals who are interested in agriculture are attracted to the ways that technology can bring value to the industry and often take it upon themselves to make the case for ag tech investment. Today, however, the reality is that many people are less attracted to careers in production agriculture and are more interested in jobs with less manual labor or with higher pay.

This may, in part, explain the net outmigration of people from some rural areas, with annual population losses recorded between 2010 and 2016.[31] Engaging digital natives is critical to accelerating adoption of ag tech; in fact, by expanding broadband e-connectivity to farmland and ranchland, this would improve the ability of technology growth in technology applications on farms to slow the outflow of tech-savvy people from rural areas.

INTERNATIONAL BENCHMARKS FOR

NEXT GENERATION PRECISION AGRICULTURE

Many countries are embracing new agriculture technologies, including Precision Agriculture, with partnerships, policies, and targeted investment strategies designed to transform farms, businesses, and local economies. These developments promise to improve agricultural sustainability and the world's capacity to meet demand but also raise questions about the United States' ability to remain internationally competitive with other leaders in ag tech.

Here's a brief snapshot of how Next Generation Precision Agriculture is driving productivity and profitability internationally—as well as what adoption looks like around the world.

AUSTRALIA

Rural communities in Australia—much like those in the United States—often lack Internet connectivity, due to the challenges of an expansive land mass.[32] To help spur innovation and technological adoption, the government created a AU$60 million ($43.3 million USD) grant program for individuals and organizations interested in testing and implementing sustainable land management practices.[33] Grant recipients at research centers and connected farms are now validating innovative technologies such as virtual fencing, drones that muster (corral) sheep, remote solar pump monitoring,[34] and sensors.[35] Due in part to the rise of Next Generation Precision Agriculture, production in Australia is expected to increase by AU$20.3 billion ($14.9 billion USD) in gross value by 2030, up 25 percent from 2015 levels.[36]

CHINA

China has begun to embrace the use of Next Generation Precision Agriculture as one solution to its constantly expanding population's demand for food and shrinking amount of arable land, due to degradation from pollution. The government has launched a pilot program to test autonomous technologies in Jiangsu Province,[37] and companies are developing technologies such as artificial intelligence (AI),[38] wearables,[39] and blockchain[21] to track livestock and monitor their health. Gains from the technology have been seen at the microeconomic level, such as a 25 percent increase in milk yield due to livestock wearables,[39] but have not yet been significant country-wide due to the small size of most farms. Productivity can be expected to increase with continued consolidation and modernization of Chinese farms.[40]

THE NETHERLANDS

Despite its small size, the Netherlands invests heavily in innovative and sustainable agricultural practices to help farmers and technology companies remain competitive.[41] Its adoption of Next Generation Precision Agriculture has led to notable successes in agriculture leadership through the use of pioneering technologies: drones that measure soil chemistry, water content, and nutrients of individual plants; high-tech broilers; and LED-lit, climate-controlled greenhouse complexes. The Netherlands produces the largest tomato, chili, and cucumber yield globally, has reduced its water dependence by almost 90 percent for key crops, and has reduced antibiotic use in poultry and livestock by 60 percent. The Netherlands is the world's number two exporter of food, in terms of value, behind only the United States, despite being 270 times smaller in landmass.[42]

CONNECTING RURAL AGRICULTURE: STRATEGIES FOR ACTION

Connected technologies can improve profitability for producers, prosperity for agricultural communities, and boost national competitiveness for the industry, especially for small producers and those in specialty crops and livestock who could benefit most from understanding and utilizing all the data their farms and ranches generate. This will take dedicated efforts to unlock the potential value for stakeholders. Harnessing the promise of e-connectivity, digital technologies, and data will require new ways of working, new skills, and new tools, and additional action can accelerate their development, at USDA, in land-grant universities, and within industry.

As explained in the following call-out, greater access to e-connectivity is at the core of this opportunity and opens up additional opportunities within healthcare, forestry, distance learning, and other rural industries. Discussions on e-connectivity that focus primarily on equity and quality of life—while accurate—continue to focus on dynamics of population, such as density, and may miss new technologies to deploy the speed and scale required by the agriculture industry to reap the potential economic and societal benefits.

Realizing these results, therefore, will require coordinated action focused on six key priorities:

1. Tailor deployment of Internet infrastructure to communities

One of the most basic challenges is the variability between communities—the differences in the challenges each face and the unique assets to address them. In many cases community-based groups may be best positioned to aggregate demand for connectivity and realize substantial benefit from deployment. Local utility co-ops, for example, are able to tap into existing customer bases, while local business and industry groups could potentially serve as intermediaries or resellers who cover a greater portion of the cost of deployment. Aggregating local voices and developing applicable strategies to connect supply with demand can create sustainable strategies for deploying Internet infrastructure.

2. Incentivize development of innovative technologies and solutions, both for scaling connectivity and improving agricultural production

There is a revolution underway in how farmers interact with off-farm service providers, suppliers, and customers, offering the opportunity to bring United States leadership in innovation and digital technology to bear on the challenges of agriculture and rural connectivity. Both the agricultural and telecommunications industries are complex and specialized, and it is not always easy to identify which solutions might provide the most effective and long-term success, but identifying innovative ideas, providing seed funding for promising ventures, and supporting technologies through proof of concept can accelerate advancements from single-operation "tinkering" to mass market research and development. Tapping into a farm's digital assets is a huge opportunity for equipment retailers, agronomic consultants, or input dealers that in turn feed the continuing development of digital tools for agricultural production.

3. Create the conditions that allow, encourage, and reward innovation, including identifying the statutory or regulatory obstacles that hinder new, innovative providers

Where laws are inconsistent across jurisdictions, policymakers can help align requirements at various levels of government and ease the path to growth and profitability. The Federal Government, under the leadership of President Trump and his Cabinet, has set forth on a concerted effort through the American Broadband Initiative, to reduce barriers in Federal processes to access Government assets for broadband deployment and coordinating public programs, with the goal of filling broadband connectivity gaps in America. More information can be found in the American Broadband Initiative's Milestone Report, published in February 2019, at https://www.whitehouse.gov/articles/high-speed-broadband-unlocks-opportunities-americans.

Moreover, issues around use of spectrum frequencies and interoperability limit the effectiveness of new technologies and keep them from working together everywhere, and the agriculture industry could benefit from shared agreement and standards. Without them, new providers will remain with suboptimal access to key resources needed to create greater value. In order that the nationwide spectrum strategy can best address the future needs of the Federal Government as well as those of the private sector, President Trump issued a Presidential Memorandum on October 25, 2018, directing the Executive Branch to evaluate current and future spectrum needs to devise a national strategy, including reporting on "emerging technologies and their expected impact on non-Federal spectrum demand"[43]. These activities are currently underway, including USDA's review of the comments received through the Notice of Inquiry issued in the Federal Register in March 2019.

4. Coordinate across public programs to effectively use taxpayer funds and develop new partnerships

Access to capital can support commercialization and help new solutions scale to all communities, offsetting high up-front costs through direct funding, coordination of existing sources of public plus new private funds, and development of partnerships to share the cost of deploying new solutions. In some cases, equipment manufacturers or telecommunications co-ops may partner to offset the costs of infrastructure investments, since they realize added benefits in a specific community. Similarly, agricultural producers may be able to more quickly adopt new production technologies with the help of cost-sharing programs—particularly in cases where the technologies not only increase profitability but drive greater societal benefits.

5. Build capability to scale adoption and realize value

An additional priority is building the capability to take advantage of these assets, increasing awareness of new developments, insight into the expected return on investment, and access to the skills needed to generate this value. To harness this revolution, farmers need opportunities for knowledge transfer to develop new skills, utilize relevant services, and receive training on digital assets. In some cases, these services may be coordinated and shared, driven by local production cooperatives. Borrowing from the co-op model, in fact, one Texas-based data cooperative offers access to benefits such as data analysis tools and aggregated insights.[44] Local universities and colleges may also provide test sites, demonstrations, courses, and certifications in new, high-value technologies. Ideally, farmers and ranchers would be able to invest in technology-neutral technologies that run on WiFi, 600MHz, or multiple bands of spectrum, enabling the producer and the farm's data to move freely between satellite coverage to a mesh WiFi network (or vice versa).

Each of these priorities needs key players to own them and will require a broad set of partners to achieve these outcomes: **advocates** who can mobilize support, **policymakers** who create the right conditions, **incubators** to accelerate innovation and new solutions, **planners** to help communities adapt it to their context, **funders and financers** who address resource gaps, and **researchers and educators** who help build the awareness and capability to get the most from those resources. The combination is beyond the resources of any one organization or actor and will require shared commitment over years to realize the benefits to country, communities, and citizens.

6. Clarify and emphasize the importance of rural connectivity to all consumers of agriculture commodities

E-connectivity is not simply a rural issue; Internet expansion, economic productivity, and food security contribute to each citizen's quality of life, regardless of where they live. The benefits of broadband e-connectivity accrue not only to the producers using Next Generation Precision Agriculture technologies, but also to consumers throughout America and the world who value a safe and efficient food supply. Plus, more universal access to e-connectivity opens up economic opportunity to more Americans through improvements in quality of life, including education, health, and leisure activities. However, citizens of urban and suburban areas may not have awareness of the importance of e-connectivity for rural areas and the paucity of Internet services available there. Therefore, it is important to continue educating and energizing the public and policy makers to grow the basis of support for deploying broadband infrastructure in farmland and ranchland, as well as enhancing knowledge of agriculture technology's potential for the nation's entire economy and prosperity.

WHAT USDA IS COMMITTED TO DOING

Broadband and Next Generation Precision Agriculture are critical components to creating a rural America with access to world-class resources, tools, and opportunity, and USDA is committed to tackling the challenges that limit full realization of this potential.

In many cases, the strategies outlined above can be utilized by industry associations, community groups, private companies, or other coalitions, and USDA's best role will often be as a convener and integrator.

USDA is taking early action to see where incisive government support can accelerate impact. USDA has launched an internal working group of relevant Mission Areas to analyze opportunities across programs and support coordination and action for the specific initiatives:

POLICY

USDA will work with other Federal agencies to remove barriers to broadband deployment and precision technology adoption and advocate for standards that facilitate scale.

- ***Documenting Spectrum Requirements for Precision Agriculture.*** On October 25, 2018, the White House issued a Presidential Memorandum on Sustainable Spectrum Strategy, which will inventory spectrum needs for U.S. industries. USDA will support this process through industry engagement and policy analysis on agricultural spectrum requirements and engage with stakeholders to advise other Federal offices as spectrum strategy is developed.
- ***Standards for Data Sharing and Access.*** USDA will support industry discussions on equipment interoperability and data communication standards, making it easier for producers to aggregate and use the data they collect.
- ***Reducing Barriers to Ag Tech Innovation.*** USDA continues to help streamline Federal permitting processes as part of the American Broadband Initiative and will similarly coordinate across federal agencies to reduce regulatory burden and barriers to use of digital technologies in agriculture.

FUNDING AND FINANCING

USDA will continue to play its traditional role in improving access to capital where private markets are unable to do so at sustainable rates or levels. USDA is coordinating with, and providing technical assistance to, other Federal agencies making investments in rural broadband. In particular, USDA plans to launch already appropriated infrastructure funding and will adjust existing programs, to the extent allowed by law, to recognize and encourage Precision Agriculture adoption.

- ***ReConnect Broadband Funding Pilot Program.*** Beginning in 2019, an innovative funding program for rural broadband will expand communities' and providers' eligibility for Federal funding, increase access to capital, and incentivize public-private funding and partnerships. For the first time ever, USDA will be encouraging Internet service providers to connect farms and ranches with modern Internet infrastructure.
- ***Farm Production Financing***. USDA's conservation mission offers opportunity to incentivize tech trials through cost-sharing options, and the Natural Resources Conservation Service (NRCS) will explore opportunities to finance digital technologies that improve water and soil management, starting with a pilot for water control measures. Similarly, the Farm Service Agency (FSA) will evaluate opportunities to incorporate Next Generation Precision Agriculture into existing FSA farm program funding or loans, such as those for storage facilities.

INCUBATING

USDA will look for opportunities to test and scale the use of precision technologies where they can improve delivery of existing mission areas.

- ***Agriculture Data Strategy.*** USDA will support accelerated innovation through open data and/or research insights from aggregate data. The increased volume of data creates new questions about data use and protection as well as new opportunities to improve services and outcomes for producers. USDA will explore how anonymized data sets might offer new agronomic insights or impact measurement for conservation or other programs.

- ***Blockchain for Major Retailers and Organics.*** USDA will perform short-term demonstration projects to test the applications of traceability within the Agricultural Marketing Service (AMS), helping to potentially certify specialized production practices such as organics.
- ***Integrated Reporting***. Seek opportunities to ease the burden for producers interacting with USDA by offering integration with precision technologies (like yield monitors) and allowing digital reporting. In particular, the recently launched Acreage Crop Reporting Streamlining Initiative offers a first test case for this potential.

PLANNING

USDA will help local communities understand how specific resources and strategies fit their context, identifying patterns and models that can help accelerate deployment and adoption.

- ***The e-Connectivity Resource Handbook.*** This document outlines all USDA programs that support broadband deployment and adoption of e-connectivity technologies in the agriculture industry. This new tool will support communities seeking to deploy high-speed, reliable broadband.
- ***The Rural Economic Development Initiative (REDI)***. Under this initiative, Rural Development has offered technical assistance to communities for strategic asset-based planning, including assessment of and strategies for e-connectivity infrastructure.

RESEARCHING & EDUCATING

USDA will engage producers and other constituents to provide access to resources and local support at USDA offices and assets.

- ***Assess Standards and Options for Production Models***. USDA's Agriculture Research Service (ARS) will be on the forefront of conducting fundamental Next Generation Precision Agricultural research, developing standards, evaluating new technologies, creating production models that can be used in decision support tools, and developing a publicly available dataset that will be used in Next Generation Precision Agriculture applications.
- ***Examine Constraints to Adoption.*** Conduct research to uncover barriers to producers' adoption that are impeding more broad utilization of Next Generation Precision Agriculture applications.
- ***Evaluate Options for Federal Investment Priorities.*** Collect and analyze data on USDA's program performance and further quantify the societal and financial impacts of Next Generation Precision Agriculture to improve the effectiveness of Federal funds.
- ***Extension Offices.*** USDA will develop methods and protocols within Extension Services, creating capabilities to promote or scale Precision Agriculture use by advising producers on relevant technologies and potential financial benefits once applied.
- ***New and Beginning Farmers.*** USDA's Office of Public Partnerships and Engagement (OPPE) will include Precision Agriculture elements in its New and Beginning Farmer programs.

PROPOSAL FOR PARTNERSHIPS

The call to action extends well beyond USDA, and both public and private actors have roles to play. Expanding rural broadband Internet infrastructure and spreading Next Generation Precision Agriculture to farms across America are herculean tasks that will require sustained engagement from influential entities, innovators, partners, investors, and more.

All hands are needed to help lead the nation towards digital transformation and greater economic prosperity.

Sitting at the intersection of infrastructure and adoption, catalyzing this economic revolution will depend on agriculture technology companies, Internet service providers, community leaders, producers, as well as the associations that represent these interests. Each stakeholder group can fill multiple roles to realize the benefits of digital transformation.

ADVOCATING

Making infrastructure and adoption a national priority is a job for all involved stakeholders and beneficiaries, by building exposure to the challenges and awareness of the importance of solving them. Researchers can measure and communicate the impact of broadband and Next Generation Precision Agriculture expansion as well as evaluate methods to tackle challenges to deployment. Technology companies, Internet service providers, and rural electric cooperatives can highlight and prioritize the challenges of rural communities and producers for talented technologists to solve. Additionally, best practices should be promoted to address cybersecurity and privacy concerns in coordination with other Federal agencies and external stakeholders.

FUNDING AND FINANCING

Public funding can play a role to address the scale of the challenge for broadband infrastructure and Next Generation Precision Agriculture technology deployment, because the nation needs public-private partnerships to share costs and risks. Agribusiness companies and manufacturers could consider offsetting high initial costs of infrastructure with the opportunity to gain users and long-term revenue streams. New cross-industry partnerships with other companies that have business interests in expanding rural connectivity, such as transportation or shipping, could also offer a regional corridor play.

INCUBATING

Innovation will be at the core of efforts to break through the tradeoffs inherent in scaling infrastructure as well as developing compelling tools that are practical and profitable for producers to put to use. Associations can help provide a platform with easy access to frontline users (producers) for rapid testing of new technologies. Similarly, universities and/or USDA's ARS can create hubs of talent and expertise focused on these challenges, bringing together multiple disciplines to solve tough challenges. Technology companies can help encourage and support innovation not only from their research and development pipeline, but also from small players embedded in rural communities, providing channels to scale success.

PLANNING

Communities can draw on their strengths and assets to both attract infrastructure providers and support technology deployment. Local co-ops, including telecom, electric, and agriculture, can help aggregate demand for connectivity and figure out how to invest to meet the demand. Producers and farming associations can crowdsource more accurate connectivity maps by canvassing and sending surveys to local producers. They can also clarify the local community's business case for broadband implementation using local connectivity knowledge and peer groups. Internet Service Providers can collaborate with community leaders to set expectations and explicitly lay out requirements needed to deploy broadband to specific communities in response to their unique needs. In technology adoption, community organizations can identify methods to pool high-demand support services, similar to some local cotton gins that have experimented with offering data services.

RESEARCHING AND EDUCATING

The economic return of U.S. Federal investment in agricultural research is estimated at 45 percent, with widespread benefits to society that are realized for generations.[45] Communities need access to the best knowledge resources and tools to support deployment and adoption, spreading insight around what is possible, efficacy, and expected return on investment. Producers' associations, as well as agribusiness companies and manufacturers, can leverage their access to producers to encourage knowledge sharing through peer learning groups and/or regional networks. Today, USDA extension specialists conduct symposia and field days where technologies are demonstrated and the management "how to" and scenarios are shown. Researchers and extension specialists can establish courses and accelerators to help translate knowledge into action or conduct return-on-investment studies and testbeds to ease the burden of analysis for producers. Agriculture technology companies can broaden their support and package all the components for the end user, just as one cloud-based artificial intelligence company has started to deploy WiFi networking kits that provide the backbone for data aggregation and cloud access.

"We can make America great again with broadband e-connectivity accessible to all Americans"

- U.S. Secretary of Agriculture Sonny Perdue

CONCLUSION

CONNECTIVITY FOR THE FUTURE

Rural broadband has become a national priority to address the e-connectivity gap and deliver increased economic and societal benefits. The American economy stands to capture substantial gains from e-connectivity through adoption of Next Generation Precision Agriculture. USDA's analysis estimates that connected technologies are poised to transform agricultural production and create a potential $47-$65 billion in annual gross benefit for the United States.

If Internet infrastructure, digital technologies at scale, and on-farm capabilities become available at a level that met estimated producer demand, the U.S. agriculture industry would realize benefits equivalent to nearly 18 percent of total production, based on 2017 levels.

Unlocking this potential value requires America to scale adoption of connected Next Generation Precision Agriculture technologies and expand its rural broadband Internet infrastructure. Greater adoption of these 21st century advancements will depend on equipping producers, expanding equipment interoperability, attracting new talent, and increasing access to reliable broadband e-connectivity as a key prerequisite.

The Trump Administration is taking advantage of this unique opportunity by facilitating rural broadband and Next Generation Precision Agriculture and establishing government, industry, and academic partnerships. Sustained leadership and coordinated action by public and private players can help address these challenges—specifically, by building national support, creating the conditions conducive to innovation, accelerating development of practical solutions, tailoring deployment for rural communities, and providing access to capital to simultaneously build out broadband infrastructure.

USDA is committed to answering this call to action with concerted efforts across Mission Areas, as well as implementation of an intradepartmental Next Generation Precision Agriculture working group. We invite our partners to address the challenge as well, so that together, we can deliver lasting prosperity for all Americans.

REFERENCES

1. Federal Communications Commission. “2015 Broadband Progress Report and Notice of Inquiry on Immediate Action to Accelerate Deployment”. January 29, 2015. https://docs.fcc.gov/public/attachments/FCC-15-10A1.pdf

2. “2018 Broadband Deployment Report.” Federal Communications Commission. 2018. https://www.fcc.gov/reports-research/reports/broadband-progress-reports/2018-broadband-deployment-report

3. “By the Numbers.” Cisco. 2018. https://www.cisco.com/c/en/us/solutions/service-provider/vni-network-traffic-forecast/vni-forecast-info.html

4. “Communications Infrastructure Upgrade: The Need for Deep Fiber.” Deloitte. 2017. https://www2.deloitte.com/us/en/pages/consulting/articles/communications-infrastructure-upgrade-deep-fiber-imperative.html

5. Gandhi, Prashant, Somesh Khanna, and Sree Ramaswamy. “Which Industries Are the Most Digital (and Why)?” Harvard Business Review. 2016. https://hbr.org/2016/04/a-chart-that-shows-which-industries-are-the-most-digital-and-why

6. Lewis, Joshua; Severnini, Edson. “Short- and Long-Run Impact of Rural Electrification: Evidence from the Historical Rollout of the U.S. Power Grid.” IZA – Institute of Labor Economics. 2017. https://www.iza.org/publications/dp/11243/short-and-long-run-impacts-of-rural-electrification-evidence-from-the-historical-rollout-of-the-us-power-grid

7. Brynjolfsson, Erik; Rock, Daniel; Syverson, Chad. “Artificial Intelligence and the Modern Productivity Paradox: A Clash of Expectations and Statistics.” The National Bureau of Economic Research. 2017. https://www.nber.org/chapters/c14007.pdf

8. Barbosa-Cánovas, Gustavo V., Altunakar, Bilge & Mejia-Lorio, Danilo J. "Freezing of fruits and Vegetables An Agri-Business Alternative for Rural and Semi-Rural Areas." FAO Agriculture Services Bulletin. 2005. http://www.fao.org/3/y5979e/y5979e00.htm#Contents

9. USDA Economic Research Service. 2018 "Americans' budget share for food changed little during the last 20 years." https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=76967

10. Crop Values - 2018 Summary." USDA. April 2019, https://downloads.usda.library.cornell.edu/usda-esmis/files/k35694332/g445cn37b/8910k2787/cpvl0419.pdf;

    "Overview of U.S. Livestock, Poultry; and Aquaculture Production in 2017." USDA APHIS. 2018. https://www.aphis.usda.gov/animal_health/nahms/downloads/Demographics2017.pdf

11. Bradford, Jeff; Erickson, Bruce; Lowenberg-DeBoer, Jess. "2017 Precision Agriculture Dealership Survey." Purdue University. 2017. http://agribusiness.purdue.edu/files/file/croplife-purdue-2017-precision-dealer-survey-report.pdf

12. Rogers, Everett M. "Diffusion of Innovation." New York: The Free Press of Glencoe, 1962. Social Forces, Volume 41, Issue 4, May 1963. https://academic.oup.com/sf/article-abstract/41/4/415/2227721?redirectedFrom=fulltext

13. Archambault, Patrick; Bonin, Andrew; Koort, Robert; Moawalla, Mohammed; Nannizzi, Michael; Revich, Jerry; Samuelson; Adam. "Precision Farming: Cheating Malthus with Digital Agriculture," page 3. Goldman Sachs. 2016. https://docdrop.org/static/drop-pdf/GSR_agriculture-N1sH6.pdf

14. Schimmelpfennig, David. "Farm Profits and Adoption of Precision Agriculture." USDA ERS. 2016. https://www.ers.usda.gov/webdocs/publications/80326/err-217.pdf?v=0

15. Van der Wal, Tamme. "Precision farming could help reduce climate gas emissions." Future Farming. 2018. https://www.futurefarming.com/Smart-farmers/Articles/2018/3/Precision-agriculture-helps-reduce-climate-gas-emissions-266218E

16. Gee, Kelsey. "Live Cattle Auctions Make a Comeback Online." Wall Street Journal. 2016. https://www.wsj.com/articles/live-cattle-auctions-make-a-comeback-online-1481976001

17. Why MarketMaker. MarketMaker. https://foodmarketmaker.com/main/why

18. About Us. BoxChain. https://www.boxchain.com/about-us/

19. Indigo Marketplace. Indigo. https://www.indigoag.com/for-growers/indigo-marketplace

20. Cenacchi, Nicola; Cox, Cindy M.; Fisher, Myles; Garrett, Karen; Koo, Jawoo; Perez, Nicostrato D.; Ringler, Claudia; Robertson, Richard D.; Rosegrant, Mark W.; Sabbagh, Pascale. "Food Security in a World of Natural Resource Scarcity." International Food Policy Research Institute. 2014. http://www.ifpri.org/publication/food-security-world-natural-resource-scarcity-role-agricultural-technologies

21. Aitken, Roger. "IBM & Walmart Launching Blockchain Food Safety Alliance In China With Fortune 500's JD.com." Forbes. 2017. https://www.forbes.com/sites/rogeraitken/2017/12/14/ibm-walmart-launching-blockchain-food-safety-alliance-in-china-with-fortune-500s-jd-com/#7e30bea57d9c

22. Al-Ghobari, Hussein M.; Mohammad, Fawzi S. "Intelligent irrigation performance: evaluation and quantifying its ability for conserving water in arid region." Springer Link. 2011. https://link.springer.com/article/10.1007/s13201-011-0017-y;
"Thirsty Food." National Geographic. https://www.nationalgeographic.com/environment/freshwater/food

23. "The Future of Agriculture." The Economist. 2016. https://www.economist.com/technology-quarterly/2016-06-09/factory-fresh

24. Melendez, Steven. "These Technologies Are Changing Farms in Some Surprising Ways." NBC News. 2017. https://www.nbcnews.com/mach/tech/these-technologies-are-changing-farms-some-surprising-ways-ncna780261

25. Definition of "killer application". Merriam-Webster Dictionary. 2019 https://www.merriam-webster.com/dictionary/killer%20app

26. Forest Products. USDA RD. 2014. https://www.fs.fed.us/research/forest-products

27. Rural Americans at higher risk of death from five leading causes." CDC. 2017. https://www.cdc.gov/media/releases/2017/p0112-rural-death-risk.html

28. Opioid Misuse in Rural America." USDA. 2017. https://www.usda.gov/topics/opioids;

Rural Mental Health Models and Innovations. https://www.ruralhealthinfo.org/topics/mental-health/project-examples

29. Schmitz, David F. "Written Testimony." United States House Committee on Small Business Subcommittee on Health and Technology. 2017. https://republicans-smallbusiness.house.gov/uploadedfiles/7-20-17_schmitz_testimony.pdf

30. Beginning Farmers and Age Distribution Farmers. USDA ERS. 2017. https://www.ers.usda.gov/topics/farm-economy/beginning-disadvantaged-farmers/beginning-farmers-and-age-distribution-of-farmers

31. Overview. USDA ERS. 2018. https://www.ers.usda.gov/topics/rural-economy-population/population-migration.aspx

32. "Research Report: The Implications of Digital Agriculture and Big Data for Australian Agriculture." Australian Farm Institute. http://www.farminstitute.org.au/publications/research_report/big-data-report.html;

Nolet, Sarah. "Why Australia's Set to Become a Global Leader in Agtech Innovation." AgFunder News. 2016. https://agfundernews.com/australia-set-become-global-leader-agtech-innovation.html/;

Vidot, Anna. "Almost half of regional Australians report internet is 'very poor', 'inadequate': University of Canberra survey." ABC. 2016. https://www.abc.net.au/news/rural/2016-06-21/almost-half-of-regional-australia-reports-internet-very-poor/7529734

33. Bindi, Tas. "Australian government offering AU$60m in grants to encourage smart farming." ZDNet. 2017. https://www.zdnet.com/article/australian-government-offering-au60m-in-grants-to-encourage-smart-farming

34. Morgan-Schmidt, Verity. "Look beyond the Akubra: Farming isn't quaint, it's a hot bed of innovation." ABC. 2017. https://www.abc.net.au/news/2017-11-21/farmers-innovation-national-agriculture-day/9175106

35. Digital Agriculture. CSIRO. https://www.csiro.au/en/Research/AF/Areas/Digital-agriculture

36. “How well placed is Australia for the digital revolution in agriculture?” Grain Central. 2018. https://www.graincentral.com/ag-tech/how-well-placed-is-australia-for-the-digital-revolution-in-agriculture

37. Moran, Craig. “China is Spearheading the Future of Agriculture.” RealClear Science. 2018. https://www.realclearscience.com/articles/2018/06/30/china_is_spearheading_the_future_of_agriculture.html

38. Brown, Sara. “China Using Artificial Intelligence to Monitor Pigs.” AGWeb. 2018. https://www.agweb.com/article/china-using-artificial-intelligence-to-monitor-pigs-naa-sara-brown

39. Zhanghai, Chen Hua; Liu, Jianfeng; “A new cash cow in the dairy field.” Huawei. 2018. https://www.huawei.com/en/about-huawei/publications/communicate/84/new-cash-cow-in-dairy-field

40. Inouye, Abraham. “People’s Republic of China Dairy and Products Annual Imports To Decrease For First Time in Years.” USDA – FAS. 2017. https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Dairy%20and%20Products%20Annual_Beijing_China%20-%20Peoples%20Republic%20of_11-1-2017.pdf

41. “Netherlands: Two million euros for precision farming.” Hortidaily. 2017. https://www.hortidaily.com/article/32439/Netherlands-Two-million-euros-for-precision-farming

42. Viviano, Frank. “This Tiny Country Feeds the World.” National Geographic. 2017. https://www.nationalgeographic.com/magazine/2017/09/holland-agriculture-sustainable-farming

43. Presidential Memorandum on Developing a Sustainable Spectrum Strategy for America’s Future. October 25, 2018. https://www.whitehouse.gov/presidential-actions/presidential-memorandum-developing-sustainable-spectrum-strategy-americas-future

44. GISC. https://www.gisc.coop/; Barnes, Beck. “MoneyBall: Bringing a Data Revolution to Cotton.” Cotton Grower. 2016. https://www.cottongrower.com/crop-inputs/precision-agriculture/moneyboll-bringing-a-data-revolution-to-cotton

45. Agricultural research sustains productivity growth and earns high returns.” USDA-ERS. 2008. https://www.ers.usda.gov/amber-waves/2008/february/agricultural-research-sustains-productivity-growth-and-earns-high-returns

FURTHER READING

1. Dalton, David; et al. “Beefing up Blockchain.” Deloitte Insights. 2018. https://www2.deloitte.com/content/dam/Deloitte/ie/Documents/Technology/Deloitte_Beefing%20up%20Blockchain_how%20blockchain%20can%20transform%20the%20beef%20supply%20chain_Oct%202018%20(003).pdf

2. Erickson, Bruce. “2017 Precision Agriculture Dealership Survey”. Purdue University. 2017. http://agribusiness.purdue.edu/files/file/croplife-purdue-2017-precision-dealer-survey-report.pdf

3. Giles, Frank. “Realizing the Benefits of Precisions Agriculture.” Growing Produce. 2018. https://www.growingproduce.com/fruits/realizing-benefits-precision-agriculture

4. Hemken, Melissa. “Storage Allows a Market Waiting Game.” Western Farmer-Stockman. 2018. https://www.westernfarmerstockman.com/crops/storage-allows-market-waiting-game

5. “How Artificial Intelligence and Machine Learning Can Help Farmers Diagnose Crop Diseases?” AI.Business. 2017. http://ai.business/2017/01/30/how-artificial-intelligence-and-machine-learning-can-help-farmers-diagnose-crop-diseases

6. Kite-Powell, Jennifer. “Why Precision Agriculture Will Change How Food Is Produced.” Forbes. 2018. https://www.forbes.com/sites/jenniferhicks/2018/04/30/why-precision-agriculture-will-change-how-food-is-produced/#1f9487416c65

7. Lowenberg-Deboer, Jess. “The Precision Agriculture Revolution.” Foreign Affairs. 2015. https://www.foreignaffairs.com/articles/united-states/2015-04-20/precision-agriculture-revolution

8. Margaritoff, Marco. “Drones in Agriculture: How UAVs Make Farming More Efficient.” The Drive. 2018. https://www.thedrive.com/tech/18456/drones-in-agriculture-how-uavs-make-farming-more-efficient

9. Molteni, Megan. “Wearables Reveal the Secret Lives of Farm Animals.” Wired. 2017. https://www.wired.com/2017/06/wearables-reveal-secret-lives-farm-animals

10. Ray, Brian. “An In-Depth Look At IoT In Agriculture & Smart Farming Solutions.” Link Labs. 2017. https://www.link-labs.com/blog/iot-agriculture

11. Revich, Jerry; Koort, Robert; Archambault, Patrick; Samuelson, Adam; Nannizzi, Michael; Moawalla, Mohammed; Bonin, Andrew. "Profiles in Innovation: Precision Farming." Goldman Sachs. 2016. https://docdrop.org/static/drop-pdf/GSR_agriculture-N1sH6.pdf

12. "Robust New Technology Driving a New Future for Pork Production." National Hog Farmer. 2018. https://www.nationalhogfarmer.com/buildings/robust-new-technology-driving-new-future-pork-production

13. Sarni, Will; et al. "From Dirt to Data." Deloitte Review (Issue 18). 2016. https://www2.deloitte.com/insights/us/en/deloitte-review/issue-18/second-green-revolution-and-internet-of-things.html

14. Schimmelpfennig, David. "Cost Savings From Precision Agriculture Technologies on U.S. Corn Farms," Amber Waves, USDA. 2016. https://www.ers.usda.gov/amber-waves/2016/may/cost-savings-from-precision-agriculture-technologies-on-us-corn-farms

15. Sulecki, James. "Specialty Crop Growers Take Unique Path to Precision," Growing Produce. 2018. https://www.growingproduce.com/fruits/specialty-crop-growers-take-unique-path-precision

16. "The Future of Precision Ag: Stories of AgTech Startups." AgroNews. 2018. http://news.agropages.com/News/NewsDetail---28096.htm

17. Thomasson, Alex. "Identifying Obstacles to Applying Big Data in Agriculture Conference." Texas A&M University. 2018. https://www.agbigdataobstacles.com

18. Varinsky, Dana. "These Robots are Milking Cows Without Any Humans Involved, and the Cows Seem Into It." Business Insider. 2017. https://www.businessinsider.com/automation-dairy-farms-robots-milking-cows-2017-6

19. Wilson, Philip; et al. "Deep Deployment of Fiber Optics is a National Imperative: The Success of 5G Wireless Will Hinge on Deep Fiber." Deloitte Insights. 2018. https://www2.deloitte.com/us/en/pages/consulting/articles/communications-infrastructure-upgrade-deep-fiber-imperative.html

20. Wolfert, Sjaak; et al. "Big Data in Smart Farming: A Review," Agricultural Systems. 2018. https://www.sciencedirect.com/science/article/pii/S0308521X16303754

21. West, Darrell M.; Karsten, Jack. "Rural and urban America divided by broadband access." Brookings. 2016. https://www.brookings.edu/blog/techtank/2016/07/18/rural-and-urban-america-divided-by-broadband-access