Examining Current and Future Connectivity Demand for Precision Agriculture

Note: This is an interim report only. It is subject to change and will be resubmitted in our final report.

October 2020

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Preface

The Connectivity Working Group has been meeting multiple times per month in full Committee and sub-working group level to develop our analysis. This summer we started to meet with the other Working Groups so that we can share and learn from each other's work and discuss the very important issues associated with Precision Agriculture. This preliminary Report reflects the work of our analysis and these discussions. The next phase of our work will focus on expanding our analysis to fully address the questions our Working Group has been asked to analyze. Our analysis will continue to involve coordinating with the other Working Groups.

I. Introduction and Background

Precision agriculture is critical to the future of agriculture operations on U.S. farms and ranches to meet the needs of the United States for food and access to other agriculture-based resources (e.g., paper and ethanol). In order to enable Precision Agriculture, it is critical that connectivity is extended to all areas of the United States, including the most rural and remote portions of the country. To address this issue, the Connectivity Working Group (CWG), has been tasked by the Precision Agriculture Advisory Committee (PAAC) to examine the following critical questions:

- The current and future connectivity needs for Precision Agriculture in terms of coverage, speed, monthly usage, latency, and other factors; the technologies available to meet those needs; and the advantages and limitations of those technologies;
- Whether and how connectivity needs vary by agricultural product geography, and other factors;
- How and why demand for Precision Agriculture needs may change over time due to, for example, population increases and shifts, environmental challenges, changes in diets, and increased demand for knowing where food is sourced; and
- Whether the amount or type of connectivity available is shifting or will shift the choices of agricultural producers, for instance from growing one particular crop or crop type to another.

This report details the current and projected future connectivity needs of agricultural operations, farmers, and ranchers ("the Agriculture Community"), and identifies the benefits of communications technologies that can meet these needs today and in the future. This includes ensuring that the communications networks, including 5G and beyond, are designed to meet the current and future needs of the Agriculture Community. Consistent with our Work Plan in the Preface, we will supplement this in our Final Report with further findings.

The case for action to ensure connectivity for Precision Agriculture technology use by the Agriculture Community is clear, compelling, and requires immediate action. The current and future use cases we examined in this report demonstrate the requirements necessary for the United States to close the connectivity gap and improve connectivity performance throughout rural America, especially on agricultural lands.

To reinforce the case for connectivity now to support Precision Agriculture in the future, this report provides an overview of current and future demand for Precision Agriculture technologies and applications across three main agriculture sectors: 1) row crops and broad acre crops; 2) livestock; and 3) specialty crops production.[1] We then focus on the state of communications technology to meet these demands, including both narrowband and broadband connectivity

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[1] The following definitions are used for each agriculture status:

1. Row crops and broad acre: These are crops that grow in rows and for large-scale crops (e.g., wheat).
2. Livestock: This is farming that focuses on raising livestock such as cows, pigs or goats.
3. Specialty crops: fruits and vegetables, tree nuts, dried fruits and horticulture and nursery crops, including nursery and crops that require special treatment.

solutions, and share use cases to demonstrate the role of connectivity in enabling Precision Agriculture to ensure our farmers and ranchers can meet the demands for food and fuel both today and beyond. Our report concludes with an overview of the benefits of connectivity and our recommendations.

II. Overview of the Need for Connectivity to Meet Precision Agriculture Requirements

The need for connectivity for Precision Agriculture is clear when considering current and future food demand, and demand for agricultural resources such as corn for ethanol, in the United States. As illustrated in Figure 1, The U.S. Census Bureau projects that the U.S. population will increase by ~80 million from 2014 levels in the next 40 years.[2] This means the number of people living across the United States who need to be fed is growing exponentially and food production has to match this need to ensure U.S. food security. In addition, the need for agricultural products to support other needs, such as fuel, continues to grow as well.

The USDA found that about 52% of the 2012 U.S. land base (including Alaska and Hawaii) is used for agricultural purposes, including cropping, grazing (on pasture, range, and in forests), and farmsteads/farm roads.[3] With the continued population growth and development of the United States, as shown in Figure 2, the amount of land base for agriculture purposes will likely decrease, not increase. This means that the Agriculture Community must become more productive and efficient to meet increased United States demand for food and other resources.

In addition, as shown in Figure 3, food security is a problem in the U.S. that will only become worse as the U.S. population increases.[4] While the USDA diagram shows food security peaked in 2011, with unexpected events like the COVID-19 pandemic and continued population growth, we expect food security to be an ongoing issue. This has become especially evident during the 2020 pandemic. When increased food demand is combined with the growth of food waste, it is clear the U.S. has a major problem that must be addressed now. Growing concerns about the future of food security in this country, and the need for agricultural resources for fuel, and other critical supplies (e.g., paper) call for the wide-spread use of Precision Agriculture technologies and practices by our Agriculture Community.

Precision Agriculture is the use of technology and data to generate insights that help the Agriculture Community make better decisions and automate practices to increase agricultural

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[2] Projections of the Size and Composition of the U.S. Population: 2014 to 2060, Colby, S., Ortman, J., March 2015. (Ortman, 2015)

[3] Major Uses of Land in the United States, 2012, Bigelow, D.P. & Borchers, A. (August 2017, United States Department of Agriculture, Economic Research Service)
Website link: https://www.ers.usda.gov/webdocs/publications/84880/eib-178.pdf?v=0#:~:text=Major%20land%20uses%20in%202012,14%20percent)%2C%20miscellaneous%20uses%20(

[4] Food Security and Nutrition Assistance, 2020 (September 2020, United States Department of Agriculture, Economic Research Service, contact: Morrison, R.M.)
Website link: https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/food-security-and-nutrition-assistance/#:~:text=ERS%20monitors%20the%20food%20security,an%20annual%2C%20nationally%20representative%20survey.&text=Reliable%20monitoring%20of%20food%20security,aimed%20at%20reducing%20food%20insecurity.

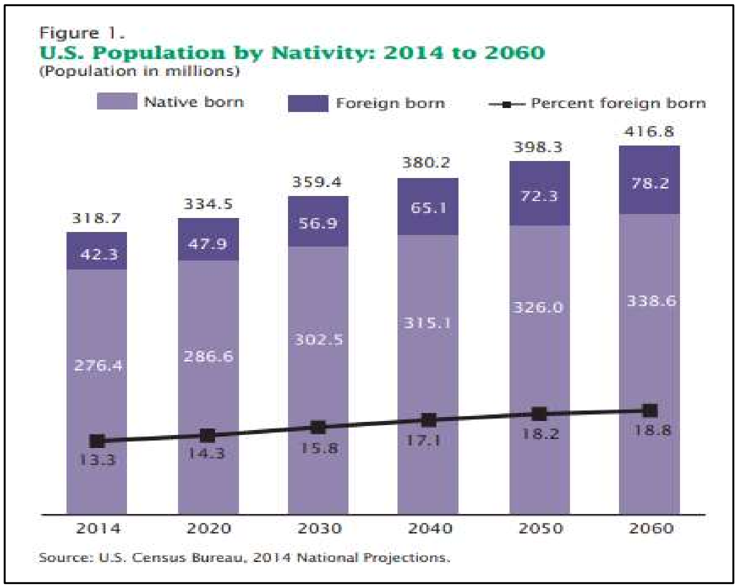
productivity, efficiency, and sustainability. Precision agriculture can, among other things, reduce inputs, increase outputs, lower environmental impact, and increase integration and efficiency in the supply chain. By increasing the use of Precision Agriculture, the U.S. can, among other things, improve food security, meet the growing demand for food, reduce the environmental impact of agricultural practices, reduce food waste, improve the profitability of U.S. agriculture, increase skilled labor demand to support the farm (but not necessarily on the farm), deliver food where it needs to go to fight domestic hunger, and increase U.S. competitiveness internationally.

For Precision Agriculture to be successfully adopted by the Agriculture Community, it is critical for there to be reliable connectivity across operations on farms and ranches. The value of technologies deployed in agriculture is amplified exponentially when connected, allowing data to flow. Accordingly, connectivity is the enabling fabric of Precision Agriculture.

And yet, there is no silver bullet to delivering connectivity to enable Precision Agriculture. The economics of terrestrial broadband deployment and faster connectivity options for rural communities and areas of high agricultural production can be prohibitive. If it were not so, much greater deployment to these rural areas and increased choices would have been seen by now. In addition, the Agriculture Community has been slow to adopt non-terrestrial technologies, such as satellite.

For the United States to improve food security for the U.S. population and meet other goals for the Agriculture Community and rural America, federal policy must enable the adoption of Precision Agriculture. As with other high-cost areas, policies that promote broadband connectivity across as much agricultural land as possible, including high-speed connectivity, are essential. It is encouraging that the FCC and USDA have begun to recognize the unique needs of agricultural producers. Programs and funding dedicated to expanding rural broadband should take into consideration the connectivity gaps in farming operations, including farm buildings; ranchlands; and croplands where systems, sensors, and equipment operate.

In addition, connections via satellites or drones need to be examined, especially in areas where filling the connectivity gap is especially challenging due to cost and terrain. In addition, other models including not-for-profit entities, such as cooperatives, may be more successful in bringing the agricultural community the connectivity it requires.



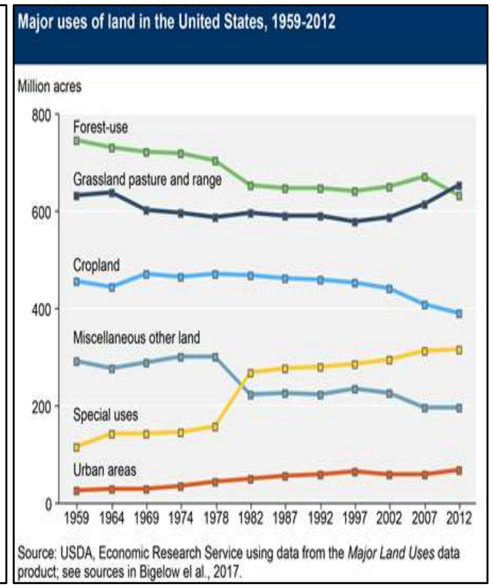


Figure 1. U.S. Population by Nativity: 2014 to 2060

Figure 2. Major Uses of Land in the United States, 1959–2012

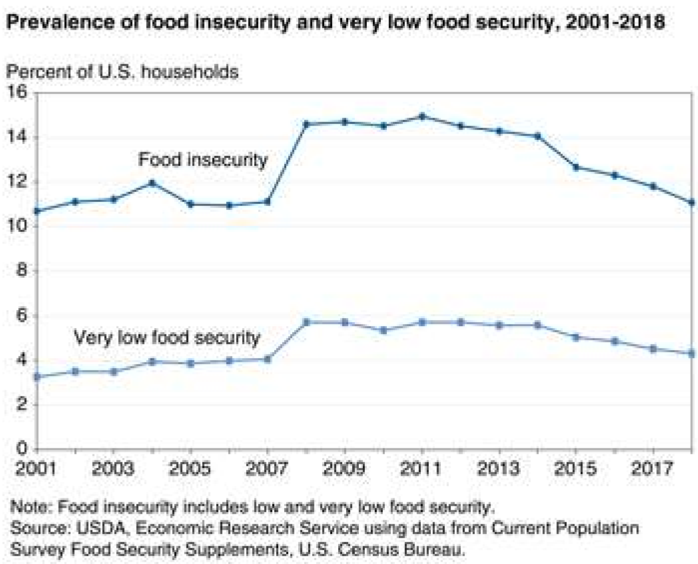


Figure 3. USDA prevalence of food insecurity as of 2018

III. Overview of Uses of Precision Agriculture Today

"Reliable, High-Speed Broadband e-Connectivity is Essential to Enhanced Agricultural Production"

– USDA Report on Rural Broadband and Benefits of Next Generation Precision Agriculture

"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

Agriculture production in the U.S. continues to be a knowledge- and data-driven effort that enables the achievement of the best results for farmers, ranchers, and their consumers. Historically, U.S. farmers and ranchers have kept detailed records to document how they operated (e.g., farming or ranching practices) so they can utilize past achievements to improve future operational improvements. Precision agriculture, using broadband, narrowband, and sensor technologies, allows producers to generate greater amounts of data on a much more granular scale, which creates better insights for making decisions. The end goal of this effort is increasing and making higher quality production, while ensuring cost efficiency in production and supply chains and reducing environmental impacts of agriculture operations.

There are two basic connectivity profiles this committee has identified that would facilitate current technology use and continued adoption.

Table 1. Connectivity Profiles

	Low-Speed, Broad Coverage	**High-Speed, Centralized**
Geographic Coverage	Large areas (i.e., agricultural fields)	Targeted agricultural operational headquarters such as farm or ranch operations center, typically one site per producer.
Network Speed	Slow (< 5 mb/sec)	Broadband and faster (25 mb/sec) +
Network Latency	High latency is tolerable	Low latency
Upload/Download Speeds	Asymmetrical (faster download, slower upload)	Symmetrical (same download and upload speeds)

	Expect small upload and downloads over time from many sensors and field devices	Expect large upload and downloads to support processing of large data files, and online training and support
Usage	• Transmit sensor data from fields • System automation and monitoring • Mobile access to systems and data for workers and decision makers	• Farm-level data aggregation and modeling • Raw data uploads for processing (drone and other sensor data) • Remote training and systems support

Below we set forth, by sector, how current and emerging communications technologies can support the adoption of Precision Agriculture technologies and practices that the U.S. Agriculture Community needs to thrive, stay globally competitive, and ensure that the U.S. agriculture supply chain is safe and secure.

A. Row Crop and Broad Acres Farming

Row Crop and Broad Acres farming involves operations that rely on self-propelled equipment to help with the farming (e.g., tractors and irrigation equipment). Large-scale corn and soybean farmers, which use equipment for planting, irrigating, protecting, harvesting, transporting, and storing large amounts of product, were among the first adopters of Precision Agriculture technologies and connected machines.

Precision agriculture has brought many benefits to these farms. For example, with a combination of GPS guidance and computer vision, tractors can operate across large tracks of land while ensuring precise and accurate field management. Harvester and offloading systems, both equipped with sensors and machine to machine communication, are able to work in tandem by communicating about how much is being harvested and the capacity of the offloading system to the operations manager in real time. This work has traditionally been done manually, but the introduction of automation has allowed this work to be done on a more cost-effective and efficient basis, reducing labor and harvesting costs over the long term and preventing wasteful grain spillage. As newer connected machines gain access to greater broadband speeds and capabilities, these farming operations will continue to gain cost and resource efficiencies.

Through the use of connected machines, agricultural activities (such as soil preparation, planting, crop protection, and harvesting) can be executed while farm managers remotely monitor metrics for both job progress and job quality. This connectivity can enable just-in-time refueling, refilling of products, and fleet management for optimal execution throughout the day and season. Additionally, the performance and quality of the job can be monitored for possible improvements through the tracking of key metrics, such as seed singulation, grain quality, and grain losses. If parameters fall outside a specific range, alerts are sent wirelessly from the machine to support staff, allowing them to improve the settings of the machines during the operation.

Additionally, remote monitoring of stored commodities after a harvest can improve product quality through continuous monitoring of temperature, moisture content, and carbon dioxide. These systems use collected data, environmental sensors, and commodity-specific algorithms to control aeration systems that maintain or improve the quality of the stored commodity. Broadband connections and cloud-based systems allow efficient, real-time access to inventory and markets. This data can be accessed remotely from multiple locations and devices. Access to real-time data allows sales, trades, and shipments to be made in the most cost-efficient and profitable manner for the operation.

In addition, given the high variability in field characteristics, weather patterns, and crop inputs for production, the utilization of near real-time information to make decisions on how to adjust the seasonal plan or the plan for next season can make the difference for strong output and overall sustainable profitability. For example, producers can use this information to analyze the performance of this season's crop and make decisions on fertilizer and seed selection for both the current crop and next season's crop from the seat of a harvester. For agriculture operations without access to the required connectivity, producers must either wait until the end of the day when they can manually transfer downloaded information to their trusted advisors or until after the year's harvest is completed. Accordingly, connectivity that supports Precision Agriculture can be transformative for row crop and broad acre farming.

Dr. Wesley Porter, University of Georgia Professor of Precision Agriculture and Irrigation, shared his thoughts on workforce inefficiencies in broad-acre farming with our working group. Dr. Porter described common pain points caused by lack of connectivity during the retrieval of data from production practices and stressed the need for advanced data analysis of field conditions and the ability to process data in real-time on field equipment to make production decisions. Due to the lack of broadband access, it is common for farmers to carry a Mi-Fi device during farm operations for data transfer or GPS correction for agricultural vehicles. Dr. Porter expanded on issues caused by limited to no broadband access. Many sensors that are utilized for irrigation scheduling need to collect data, and machinery sensors collect production data at a high rate, which can be valuable to producers for making in-season decisions. "This data needs to be updated frequently to be of use, thus having access to connectivity at the farm level would be optimal."

Dr. Porter also highlighted the benefits Precision Agriculture can have on workforce productivity and operational cost reduction. First, traveling to multiple sites to manually collect data consumes hourly labor and fuel, in some cases traveling as far as 150 miles one-way. Second, soil moisture sensors cost approximately $25 per sensor monthly to transfer the data from the field to the cloud on a daily basis Dr. Porter stated, "in a typical field, three sensors are usually utilized, so this would cost $75/month per field." Typically, the sensors are installed for 5-6 months per year, costing up to $450 per year per field for data management. However, Dr. Porter added, "sensors can have cost savings of up to $20/acre when properly utilized."

B. Livestock

Livestock farming has very different requirements than row crop and broad acre farming, as animals generally require higher levels of care than crops. For example, the dairy industry has embraced smart machines and sensors to help monitor the amount of feed consumed and quantity of milk generated at an individual animal level. This, combined with sensors to track key indicators of animal health, have allowed for significantly improved milk production and greatly increased animal health and welfare. Infections and other health issues can be identified early by smart machines and animal health sensors, allowing for treatment with minimal impact to both the animals and milk production, and often before staff would be able to be aware of the issue. These same capabilities scale well to large operations where a cow or another animal may go days without human interaction. These systems also generate large amounts of data that need to be gathered and processed on a regular basis in order to identify animal-level trends, which in turn requires broadband connections at high speeds.

In addition, robotics are used in the livestock industry. For example, robots that function 24 hours a day can enable cows to come and go from automated milking machines with little to no engagement from operations staff for a more natural and self-regulated low stress environment, improving both milk quality and quantity. These robots preform pre and post milking cleaning activities every time the animal is serviced ensuring industry cleaning standards are met and documented at every servicing.

Tracking movement, behavioral, and biometric data from livestock via sensors feeding real-time information systems give farmers access to precise data allowing them to pinpoint which animals may need specific attention or care. Once activated, control and tracking systems report the data to the cloud at regular intervals for big data analysis and viewing by livestock managers on a dashboard.

In addition, new tools integrate big data solutions into livestock management to help producers increase sustainability and profitability through wireless communications-enabled devices that work with scale systems to automate the feed delivery process. This allows livestock managers to track every pound of feed delivered to manage inventory and farm costs. Accordingly, connectivity to utilize Precision Agriculture for livestock is critical on many fronts, including the health and welfare of the animals.

The table below provides examples of how Precision Agriculture today meets livestock needs.

Table 2. Precision Agriculture Livestock Activities by Relative Bandwidth

Livestock Type	Low	Medium	High
Meat/Beef			
Free-range grazing	• Estrus detection	• Activity monitor • Rumination/Grazing (research focused)	• Body scanner
Feed lots	• Activity monitor • Movement monitoring (time and distance/proximity to feed bunk)	•	• Automated BCS scores • Feed intake
Dairy			

Livestock Type	Low	Medium	High
Replacement calves	• ID Tags, birth weight, calving ease	• Vet data, pedigree, records, automated calf feeding	
Production cows	• Productivity (lbs. of milk),	• Robotic systems (fat/protein content), health, monitoring rumination (accelerometer, etc.) • Carbon monitoring	• Automated BCS scoring, monitoring eating and rumination using AI/ML, remote health/vets, and remote nutritionists
Dry cows	• Estrus monitoring		• Feed monitoring
Milk monitoring	• Bulk tank monitoring • Milk transport		
Poultry			
Layers	• Climate control	• Audio monitoring for chicken health	• Multiple cameras for live monitoring
Swine			
Gestation			• Genomic research
Farrowing/Nursing	• Temperature & Climate monitoring	• Feed intake	• Lactation feed monitoring
Growing & Finishing		• Precision feed mgmt.	• Health monitoring
Aquaculture			
Salmon		• Acoustic Feed monitoring	• Video feed monitoring • Drones for tracking

C. Specialty Crops

Specialty Crops, such as vegetables, fruits, nuts, and nurseries, often deal with delicate products or high-density crops that rely on a large labor force for management and harvesting. Irrigation has been a key requirement for these crops to be successful. Historically, large swaths of land and rows of specialty crops would need to be watered at the same time. However, Precision Agriculture can bring a higher level of accuracy to the management of these often sensitive crops. For example, sensors contained in smart machines can monitor soil moisture at the plant level. Routine checks of pressure variation in leaves and ambient temperature can ensure crops are optimally hydrated and water is only consumed when needed. With this information, smart irrigation systems can determine when to start and stop watering much smaller sections of crops. This level of detail can only be achieved when sensors and control systems can communicate on a regular basis.

Combining data from radar networks (temperature, precipitation, wind speed, and humidity) and a multitude of property-type sensors can inform not only irrigation, but also pest and disease prevention, predictive analytics for crop loads, and inventory management. Specialty crops grown in tightly-controlled areas, including vertical greenhouses, rely on Internet of Things (IoT) sensors and two-way devices to monitor and control greenhouse climate and increase crop cycles annually (up to 12 per year), including decision support for times to plant and harvest.

The deployment of smart machines that incorporate sensor technologies, analytics platforms, and access to third-party data sources can greatly improve performance efficiencies, yields, and inventory management while avoiding spoilage losses. With many fruits decaying 10% per hour in sunlight, decisions on picking, transport, and storage must be made in real-time. During production, these integrated platforms can drive decisions based on weather, disease, insect population, moisture density, and ripeness, triggering smart systems and robots to maximize the harvest of precious fruit at the point of demand.

There are many machine-learning and robot solutions for the fruit industry that rely on real-time data—necessitating reliable connectivity. Machine learning can be used to identify and measure the ripeness of fruit with 3D modeling to measure harvest progress. Robots using software for fruit identification and classification can reduce fruit decay with fewer hours in the sun before shipping. Paired color and stereo cameras can be used to locate ripe fruit and follow the harvesting process with an autonomous ground robot with a fruit-sucking vacuum in real-time. Computer vision with sensors can also be used for harvesting by guiding a robot arm to the position of the detected fruit without damaging the tree or bruising the fruit at the point of harvest.

Robotic components are also used to remove leaves from harvested fruit. Once picked and sorted, decision-support systems assist in proper storage to minimize fruit decay and determine the optimal time to transport the product to cold storage. These real-time decision support systems not only track inventory but can also include fleet management analytics to assist in conducting cost-benefit analyses of sending a partially or fully loaded truck to cold storage. Sensors in shipping containers provide quality assurance by providing alerts for temperature and pressure changes.

In the nursery sector, robots are being used effectively to automate transplanting of seedlings into larger pots, to move plants across conveyers to be scanned by sensors to assess health and apply treatment if needed, and to space out plants so they have room to grow. These tasks are tremendously tedious and perfect for robots; however, these robots require broadband to access centralized data to effectively evaluate the large variety of crops at a nursery. Autonomous ground robots can be used to scan and assess the current opportunity to harvest specialty crops from the greenhouse to the fields. This includes cameras and sensors linked to learning software.

From a preventive maintenance standpoint, weeding robots use intelligence to evaluate between weeds and plants before taking action.

Tracking and inventory are critical for all specialty crops. In the nursery sector, thousands of plants can be moved at any given time. Tracking these movements to the plant level can help optimize product movements. In both nursery and fruits and vegetables areas, inventory management of product at it's various stages can be critical to support destination markets, such as big-box-chains, maintain their inventory. This is especially challenging due to the huge variety of plants produced. We have also begun to see an increase in these sectors of integration with direct-to-consumer demand. Both destination markets and direct-to-consumer demand can provide critical alerts to the farms on when to pick or harvest. This level of tracking can also track product attributes back to the farmland for regulatory, imagery and reporting purposes. Moreover, data input can be used for Community Supported Agriculture (CSA), week-to-week buyer demand, and supply availability on e-commerce platforms. Accordingly, connectivity to support Precision Agriculture is a key requirement for the success of specialty crops.

Table 3 shows the requirements for communications technology in terms of speeds for different aspects of specialty crop farming.

Table 3. Precision Agriculture Specialty Crop Activities by Relative Speed

Bandwidth	Low	Medium	High
Fruit/Nut Trees			
Weather Modeling	Bioimpedance sensors, meteorological sensors, moisture sensors, temp sensors, and rain gauges		3D digital Surface Models with Unmanned Aerial Vehicle (UAV)/ satellite and use of object-based image analysis techniques
Machine Learning and Visioning	Dendrometers, photometric sensors, photosynthesis sensors, leaf area index sensors, and accelerometers	Fruit grading QA/QC platforms and optical sensors (hyperspectral, multispectral, fluorescence, and thermal)	High-resolution imaging sensors with computer visioning to capture the amount of light energy released by a plant
Outdoor Smart Irrigation	Chlorophyll meters, biological sensors, hygrometers, temperature sensors, and Micro Electro Mechanical System sensors (MEMS)	Water content and irrigation management system	Gateway appliance to support aggregate data from smart sensors to the cloud

Bandwidth	Low	Medium	High
Robotic Harvesting	MEMS, navigation/ obstacle sensors, Leaf Area Index (LAI) sensors, GPS, position sensors, and accelerometers	Range finders and optical cameras	Image processing (vision sensors/LiDAR) and algorithms for picking, automatic harvesting (fruit detection, location detection, and the physical harvesting equipment to grasp and detach fruit from the plant), UAVS and imaging, Robotics and Autonomous Systems (RAS), and Convolution Neutral Network (CNN) for analyzing visual imagery
Vegetables			
Frost Detection	Temperature sensors, leaf wetness sensors, and air flow sensors	Gateway appliance (point to multipoint, low-power sensors)	
Pest Prevention	Weed seekers, chemical analyzers, microorganisms sensors, and position sensors	Pest and disease image sensors and low-resolution image sensors for assessing crops across a large area	Point-to-multipoint aggregation
Ground Harvesting	MEMS, navigation/ obstacle sensors, GPS, and position sensors	Range finders	Navigation using RAS, Autonomous Ground Vehicles, and CNN for analyzing visual imagery with Single Shot MultiBox Detector
Ground Input Use and Management	Various property-type sensors and MEMS	Data-driven decision support systems and optical cameras	Gateway appliance to support aggregate data from smart sensors to the cloud

Bandwidth	Low	Medium	High
Nursery/Greenhouses			
Indoor Smart Irrigation	Water probes, meteorological sensors, moisture sensor, air flow sensors	Evapotranspiration (ET) controllers, two-way communication from local weather data to adjust irrigation schedules	Gateway appliance to support aggregate data from smart sensors to cloud
Food Waste Management	Biosensors (chemical/ gas), level sensors, microorganism sensors, and block-chain	Applications to analyze vegetative health and integration with direct consumer demand to know when to pick	Image sensors and RAS
Storage Monitoring	Temperature sensors, pressure sensors, and level sensors (silos)	Gateway appliance to support aggregate data from sensors from cold storage, supply chain management platforms across regulatory, imagery, and fleet management and reporting tools	Autonomous ground vehicles (real-time picking and fruit decay management)

Forestry is another important form of specialty crop agriculture. The traditional cycle for most agricultural practices falls under a 12-month cycle. Forestry cycles typically range from 10–50 years, sometimes even longer. Forestry measurements today are typically acquired via drone to measure the canopy and a human walk-through under the canopy. Both data sets are then merged to produce a point-cloud of the forest. This composite dataset enables foresters to establish an inventory of trees with key quality measurements. For typical forest production needs, broadband coverage is essential at headquarters where data from above and below canopy data gathering can be uploaded and crunched with specialized hardware, typically GPU-based processing systems, to generate their data. This practice requires bandwidth similar to the farm house where a symmetrical profile to upload and download significant amounts of data is necessary.

Forest management practices, however, require a different type of connectivity. General forest management practices focus on monitoring extremely broad acres, typically in the thousands of acers per forest. While the forest service leverages satellite imagery for much of their work, they also maintain thousands of sensors across managed forests to monitor basic weather conditions and, more importantly, detect fire. The deployment of these sensors is similar in nature to the need for low-speed but extremely broad coverage areas to enable sensors equipped with antennas above the canopy to transmit data back to monitoring stations such as the Remote Sensing Applications Center (RSAC). The ability to identify and assess basic characteristics of forest health and a fire early on are absolutely key to effectively managing limited firefighting resources. Low-speed coverage over the US's forested lands could enable the deployment of additional sensors to assist the federal government with identification and risk management, potentially leading to millions of dollars of savings to the US economy and residence.

IV. Communications Technology Overview

With the advancement of terrestrial and non-terrestrial wireless technologies, we are beginning to have real-life experience with the potential of what precision applications can deliver to the Agriculture Community. However, the lack of connectivity to much of our agriculture lands has a detrimental impact on the Agriculture Community and the surrounding areas. While the technology is available today for connectivity, the United States must focus on how to expand the level of connectivity that is required to support all the demands of the Agriculture Community for Precision Agriculture, no matter how rural and remote the location.

For years, rural America, including the Agriculture Community, has suffered with poor broadband connectivity resulting in a lack of technology adoption. Recently with COVID-19, these struggles have been amplified. Many of the latest yield-maximizing farming techniques require broadband connections for data collection and analysis performed both on the farm and in remote data centers. However, 25% of U.S. farms have no access to the Internet according the USDA report.[5] Where connectivity allows, farmers and ranchers have embraced technologies that allows their farming businesses to be more efficient, economical and environmentally friendly.[6]

A. Data and Bandwidth

The connectivity necessary for the Agriculture Community is both broadband and narrowband. Initially, there are two types of broadband coverage that are necessary to increase the adoption of Precision Agriculture equipment and practices: 1) Low-speed, broad coverage, asymmetrical and 2) high-speed, targeted coverage, symmetrical. These two connectivity profiles work together and enable sensor data aggregation fused with decision support systems that can issue commands back out into the field achieving detailed data gathering and initial automation capabilities.

Currently the FCC defines advanced telecommunications capability as 25 Mbps down and 3 Mbps up, which is an asymmetrical profile. When looking at the activities typically carried out at the farm, there are higher bandwidth activities, such as equipment system updates and troubleshooting, uploading of large data sets obtained from autonomous vehicles, and viewing of large data sets. These activities together require a more symmetrical profile where the upload speed is just as fast as the download speed, which makes processing locally acquired data

[5] Food Security and Nutrition Assistance 2020 (Sept. 2020, U.S.D.A. Economic Research Service, contact: Morrison, RM).
[6] Farm Computer Usage and Ownership 2019 (Aug. 2019, USDA, National Agricultural Statistics Service).

possible. This is quite different than the typical residential asymmetrical profile and more commonly seen in a typical business model.

In addition, narrowband voice and data is a requirement for the Agriculture Community. This traffic can be carried on a low or higher latency basis. This is an important form of connectivity since a fair amount of traffic from field bases sensors requires low data speeds per device.

In the future, as increased bandwidth becomes available with lower latency across a wider coverage area, we expect to see equipment able to stream vast amounts of data as it's generated, allowing faster decision making rather than the current acquire, return to home and upload for processing methods used today.

We cannot wait to begin the adoption of Precision Agriculture equipment and techniques until high speed connectivity across all agricultural lands can be achieved. Significant progress can be made with current technologies and those that will be deployed in the near term leveraging low-speed, higher latency connectivity across agricultural lands with targeted high-speed connections to agricultural operation centers. Each geographic area has unique challenges to meet and there will not be a one-size-fits-all approach to supporting the Agriculture Community adoption of Precision Agriculture but without connectivity, its value is low and so will be its rate of adoption.

B. Spectrum

The life blood of wireless connectivity is spectrum, which, can have different technical characteristics. Lower spectrum is ideal for many agricultural applications using terrestrial wireless technologies. At the lower frequencies, the transmissions travel much farther, and they propagate very well through crops and canopies. This leads to two key benefits. First, fewer towers are needed to cover a region. Second, the battery life of devices increases so they can reach the same distance at a lower transmit power, reducing the labor and expense needed to recharge devices.

The FCC has demonstrated leadership in enabling regulations for dynamic spectrum sharing, in the Citizen Broadband Radio Service (CBRS) and TV White Space (TVWS) spectrums. The TVWS spectrum is especially beneficial for precision agriculture because TV towers are typically in cities, meaning many TV channels are unused and available for farms in rural areas. Since each TV Channel is 6 MHz wide and there are typically 20+ channels in rural areas, a large amount of bandwidth is typically available for precision agriculture applications. TVWS are also in the lower frequencies and provide very favorable propagation characteristics.

Dynamic spectrum sharing is a trailblazing step that opens up several new scenarios for Precision Agriculture. Additional policies can help increase adoption of broadband spectrum and devices for agricultural applications. Geo-fencing farms to allow for more flexible use of spectrum in the farm can drive innovative applications. For example, a single tower might be able to provide coverage to the entire farm, the base station would be able to communicate with diverse devices, and satellite to terrestrial relays could lead to innovative connectivity solutions. And the appropriate spectrum could be used for each application.

Spectrum is the life blood for non-terrestrial technologies as well. Today's high-throughput broadband geostationary satellites rely on bands in the millimeter wave frequency, as do the planned mega-non-geostationary orbit constellations. These systems can be used for backhaul for terrestrial systems and direct-to-the-farm communications. In addition, narrowband satellite communications rely primarily on frequency bands below 3 MHz. In order to ensure these systems are able to support the needs of the Agriculture Community, it is critical that the FCC ensure adequate interference-free spectrum is available for these uses.

V. The Possibilities of the Future

Precision Agriculture is evolving rapidly and offers many benefits both on and off the farm in rural communities, but if the Precision Agriculture ecosystem is allowed to grow through both innovation and expanded access to connectivity, the types and impact of these benefits can grow exponentially.

A key note about connectivity for all of these technologies is that they currently rely on fast network speeds with low latency in order to process data quickly and return a result. We expect these technologies to begin their adoption in centralized locations where fast network connectivity is available. We are beginning to see some of these technologies deployed on field equipment with the added burden and cost of the computing power necessary to process generated data. This model likens back to early personal computer models, which require significant support and maintenance for basic operations. Compare this model to the smart phone, which has limited processing storage and relies on the power of connectivity to quickly and efficiently deliver constantly-evolving and improving service with minimal effort from users. This later model is what we envision for many Precision Agriculture tools, but it relies on an ever-evolving connectivity layer to keep up with agriculture demands.

A. Computer Vision/Machine Learning (CVML) and Smart Machine Technology

With the advent of high-performance computing, new techniques in development (such as advanced algorithms, robotics technologies that actuate algorithmic outcomes in milliseconds, CVML, and Smart Machine Technology) hold significant promise for unlocking agricultural productivity and improved environmental sustainability. However, in order to adequately train a computer to recognize images and drive actuation rapidly, the system requires a significant amount of data to be captured, processed, and labeled. It is estimated that hundreds of thousands to millions of images are required in order to drive a system robust enough to provide value to producers.[7] In practice today, these images are captured by humans or machines deployed throughout the rural area. The data is stored on hard drives and either transferred via overnight delivery or via the rural broadband environments where connectivity can be found, albeit greatly restricted by the speed at which large volumes of data can be transferred. The lack of connectivity impedes the speed of the "machine learning" process, which in turn inhibits producers from gaining value from this technology in their operation. However, as systems are deployed in a commercial setting with connectivity at higher speeds, these systems will have the

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[7] Davis T and Murphee, J., It's Time for Solid Rural Broadband Connections, Farm Bureau Viewpoints/Focus on Agriculture, Aug, 5, 2020

ability to capture more images, transfer them wirelessly for analysis, and ultimately make the machine learning model more robust and able to perform better over time.

In a study combining computer vision and deep learning for phenotypic analysis of lettuce, the AirSurf-Lettuce open source platform was found to be capable of scoring and categorizing iceberg lettuces with very high accuracy (>98%). Furthermore, novel analysis functions have been developed to map lettuce size distribution across the field based on which tagged harvest subregions (tagged by GPS) have been identified. This enables farmers to implement Precision Agriculture practices to improve both the actual yield as well as crop marketability before the harvest.[8] It is important to note that the multispectral images used to feed this model were 1.5-2 GB per image. At minimum, LTE 5G broadband speeds would be required to transfer these images for processing.

B. Unmanned Aerial Vehicles (UAVs)

The ability to see in great detail how the land is structured, the crop or livestock health, or how external factors such as weather are impacting outcomes across the course of time is significantly enabled through the use of UAVs. These systems use satellites to guide their path of flight and to interconnect to the public internet. They gather a large amount of geo-referenced data that can be used to make day-to-day decisions on what actions the producer should take to improve productivity. With connectivity, this data can be sent to cloud-based analysis tools for processing and recommendations on actions to take next. If connectivity is non-existent, slow, or unreliable, decisions are delayed and outcomes related to actions taken are diminished, due primarily to the lag in time between data capture and executing the decision. The lack of ability to act in a timely manner undermines the effectiveness and impedes the adoption of these technologies. The certainty of taking the right action at the right time further declines due to the variable nature of weather and other factors that impact agriculture each and every day.

C. Autonomous Systems/Robotics

Similar to the technologies in computer vision, machine learning, and smart machines, this technology relies heavily on the capture, processing, labeling, and training of computer algorithms with large amounts of data. However, this technology is distinctly different in that the system will have the ability to execute without human oversight in near proximity. To achieve this will require the system to have a high speed, low latency, and highly reliable connectivity infrastructure. Current autonomous systems still require a fair amount of human oversite. Faster connectivity will drive improvements to the point where human monitoring of the machine will be limited to either recognition of an obstacle or specific job execution parameters being out of specification. Agricultural practices and processes require large investments on the part of the producer, and mistakes can lead to total crop failure and large business impacts. The ability of autonomous systems to adequately report back to farm managers is essential and relies on connectivity as a mission-critical enabler to system performance and health.

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[8] (Bauer et all, 2019).

A typical topology for a robotic fleet requires a master external computer connected to the fleet units through a wireless communication system that runs a mission manager (mission planner and mission supervisor) that sends commands to (and receives data from) the fleet mobile units. [9]

Table 4 provides examples of the opportunities that robotics and autonomous systems could enable, and the benefits associated with their deployment for U.S. producers in various sectors of agriculture.

Table 4. Benefits to the Agriculture Community of Highly Automated and Autonomous Systems Adoption

Opportunity	Benefits
Weed from Plant ID and actuation on only weeds	• 50-90% reduction in herbicide usage, with associated cost savings • Reduced environmental impact footprint from spraying operations
Nitrogen deficiency or adequacy in crops	• Improved yields/output • Optimize use of Nitrogen within the field where a yield response is most likely • Improved nitrogen management practices (right source, right amount, right place, right time) favorably impact the environment
Early Pest or Disease ID and actuation in the area of issue	• Improved yields/output • Reduced use of crop protection products in season or more precise application only in areas where needed (versus broadcast application)
Autonomous Machines executing Agricultural Tasks/Jobs	• Aids in agricultural productivity where limited skilled labor can be allocated to other tasks • Allows for farming around the clock during narrow task execution windows. • Potential for smaller robotic machines doing more on farms, reducing soil compaction
Self-Optimization of Equipment Systems	• Reduces the need for highly skilled labor in difficult environments and minimizes downtime associated with maintaining equipment and system performance at the highest level possible
Phenotyping of Livestock or Crops	• Improves resiliency of next-generation breeding processes for adapting to environmental condition changes

[9] Airsurf-Lettuce: an aerial image analysis platform for ultra-scale field phenotyping and Precision Agriculture using computer vision and deep learning, 2019, Bauer, et al. (January 2019); available at: https://www.biorxiv.org/content/10.1101/527184v1

VI. Ensuring Connectivity to Enable Precision Agriculture Can Help Meet the Country's Goals for Food Scarcity, Food Security, and More

Ensuring connectivity to enable Precision Agriculture will advance the country's goals for food security and food scarcity. Direct benefits could include greater efficiency in farming operations, greater productivity to meet growing demand, improved economics for the individual farmer, improved supply chain management, and improved health and welfare of livestock.

There are also significant indirect benefits that we can expect to see as connectivity becomes more accessible for farmers and the rural communities where they are located. These benefits include:

- Decreased population flight from rural communities;
- Improved rural economic opportunities, including through development of tech-supporting business and services;
- Improved delivery of health care and education through tele-health and tele-education;
- Greater civic engagement through e-government platforms; and
- Increased access to goods and services not available in the rural community.

It is important to note that solving rural connectivity does not solve for agricultural connectivity needs, however solving for agricultural connectivity needs does include and solve for rural connectivity needs.

A. Benefits for Food Scarcity and Security

As previously noted, Precision Agriculture and its enabling connectivity is critical to United States food security, including strengthening the nation's food supply chain.

It is estimated that 30%-40% of food is currently wasted due to poorly operated food supply chains.[10] With more effective inventory tracking and logistics beginning during production, food supply can be more optimally matched with demand to reduce waste. This will require broadband capabilities at all stages of the food supply chain to access the vast quantity of information necessary to track products. Increased access to better information across the food supply chain can improve decision-making and resource allocation, as well as make up for the labor shortages and succession issues that have plagued the Agriculture Community.

In addition, Precision Agriculture can trace food contamination problems within seconds using block-chain enabled records.[11] Precision technologies that almost instantaneously pinpoint the source of food tainting will greatly improve the country's ability to respond to such events.

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[10] https://www.usda.gov/foodwaste/faqs

[11] https://www.usda.gov/sites/default/files/documents/case-for-rural-broadband.pdf

B. Lessons Learned from the COVID-19 Pandemic

Agricultural supply chains were roiled during the first few months of the COVID-19 pandemic. The longstanding business of supplying food to restaurants and educational facilities evaporated overnight. At the same time, direct demand from supermarkets, farmers markets, and farmers rose as consumers prepared more meals at home. Suddenly, institutionally sized food packages had no market, packaging was needed that could go from the supermarket to the home refrigerator. Some food products, typically consumed in greater quantities in restaurants than in the home, for example mushrooms, initially saw demand vanish. Many farmers had to seek alternative markets for their livestock and crops.

The situation with farmers markets and farmers who market directly is an interesting example of the benefit of improved Internet capability on the farm. As supplies tightened in supermarkets during the pandemic, consumers turned towards these food sources. This also occurred because consumers felt comfortable with the safety of these suppliers; they had face-to-face relationships. Farmers markets saw growth increases, and farmers saw more interest in direct sales. These groups turned towards creating online marketplaces to satisfy this demand.

For some farmers markets and farmers, COVID-19 forced them into using the Internet to sell their products for the first time. They struggled with poor broadband infrastructure, knowledge gaps, and a lack of a consistent framework for modeling consumer-facing portals. Consequently, for consumers, there is a lack of consistency when shopping farm to farm. Along with improved connectivity to support farm direct sales, education to provide recommendations on the look and feel of consumer/farmer online interaction would be most useful.

C. Community Benefits

Broadband connectivity directed at Precision Agriculture will result in many benefits for communities near farms and ranches. One benefit being improved broadband access for the surrounding residents, home and small businesses, tele-health, tele-education, and e-government, among other activities. The increased adoption of precision technologies, enabled by improved connectivity, will also spur new tech-based businesses in rural communities (and the associated training and education) to meet the rising demand for agronomic, data analytics, software, and computer support services. Further, by expanding broadband to agricultural communities, rural flight and the educational disparities between rural and suburban/urban areas, which has become so apparent during the COVID-19 pandemic, will likely decrease.

D. Environmental Benefits Through Efficiencies in Agriculture Operations

There are also significant environmental benefits that can be obtained through Precision Agriculture. For example, improved fertilizer, soil, and water management can significantly reduce greenhouse gas emissions, while maintaining similar yields and reducing production costs: a typical win-win. In 2019, USDA estimated 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 across the country.[12] Further, USDA has estimated that variable rate technologies (VRT) can lead to 40% less fuel consumed, 20-25% less water utilization, and up to an 80% reduction in chemical application. [13]

These sustainability benefits are significant and offer a real public good to rural communities and to the country as a whole. These gains can be realized only if policies that promote broadband infrastructure investment necessary to support the adoption of these technologies is recognized and addressed.

E. Wildland Fire Risk Mitigation

The broadest benefit to the U.S. economy for precision forestry is the example where risk mitigation and early fire detection and assessment is absolutely critical. Below is a table from Bureau of Land Management with the costs broken down from specific wildland fires. The Other Direct costs column includes property losses and all claims submitted to federal agencies following the fire.

Table 5. Wildland Fires and Associated Costs[14]

	COST CATEGORY							
FIRE	Suppression Costs	Other Direct Costs	Rehabilitation Costs	Indirect Costs	Additional Costs	Total Costs	Total / Suppression	Suppression / Total
Canyon Ferry Complex (MT 2000)	$9,544,627	$400,000	$8,075,921	$55,310	n/a	$18,075,858	1.9	53%
Cerro Grande (NM 2000)	$33,500,000	$864,500,000	$72,388,944	n/a	n/a	$970,388,944	29.0	3%
Hayman (CO 2002)	$42,279,000	$93,269,834	$39,930,000	$2,691,601	$29,529,614	$207,700,049	4.9	20%
Missionary Ridge (CO 2002)	$37,714,992	$52,561,331	$8,623,203	$50,499,849	$3,404,410	$152,803,785	4.1	25%
Rodeo-Chedeski (AZ 2002)	$46,500,000	$122,500,000	$139,000,000	$403,000	n/a	$308,403,000	6.6	15%
Old, Grand Prix, Padua (CA 2003)	$61,335,684	n/a	$534,593,425	$681,004,114	n/a	$1,276,933,224	20.8	5%

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[12] https://www.usda.gov/sites/default/files/documents/case-for-rural-broadband.pdf
[13] https://www.usda.gov/sites/default/files/documents/case-for-rural-broadband.pdf

[14] Source: The True Cost of Wildfire in the Western U.S., April 2010, available at https://www.blm.gov/or/districts/roseburg/plans/collab_forestry/files/TrueCostOfWilfire.pdf

The costs of wildland fires are real and significant. If more agricultural and wildland are provided with at least low speed connectivity, we could support additional fire monitoring stations to promote early detection and enable improved risk assessment and communication to potentially affected communities.

VII. Preliminary Recommendations

The Connectivity Working Group recommends enabling broadband connectivity over a range of technologies (both terrestrial and non-terrestrial) to support the connections required for Precision Agriculture. Broadband availability is a critical first step to supporting the adoption of Precision Agriculture best practices but by itself falls short of a workable solution.

Agriculture, like every other industry, must experience a complete and total "Digital Transformation" in order to compete on the world stage. While Digital Transformation implies many things, it really means automation. Automation in a digital world brings efficiency, quality, sustainability, and maximum production yields.

Agricultural automation requires Cloud Computing, Connectivity, and Precision Ag Software Applications. The Ag applications will leverage the analytics of machine learning, computer vision, and robotics. These are the tenets of what is commonly referred to as the next industrial revolution which in effect is an "Agricultural Revolution" The pillars of this Agricultural Revolution are:

Industry 4.0

Cloud Computing

Connected Everything

Artificial Intelligence/Machine Learning

In sum, to achieve the vision of and effectuate the Agricultural Revolution, the Cloud must be brought all the way down to the farms and ranches into the fields and pastureland. This requires that edge servers be installed at farms and ranches and connected to existing broadband service. Terrestrial and non-terrestrial wireless coverage of various types must be everywhere. It must, eventually, be lightning fast and of the highest quality. 5G and its successors are our best current path to achieve this vision including a variety of technologies both terrestrial and non-terrestrial. Everything must be connected: sensors, devices, controls, machines and drones. Precision Agriculture software applications must be made available and these software-based applications and technologies adopted by farmers, ranchers and growers.

To bring Precision Agriculture to rural America the following must occur:

1) Cloud Edge infrastructure is needed to bring the cloud to farms and ranches so that the promise of automation can truly be realized. The Edge infrastructure must be located at farms and ranches and connected to the broadband fiber present today.

2) Private 5G wireless systems are needed at every farm and ranch to connect and collect the massive amounts of data from the sensor's devices, machines, and drones. These systems will provide service to the farmhouse, utility yards, barns, stockyards and outbuildings. These same wireless systems could provide 5G coverage that extends for miles around the center of the farming/ranching operation.

3) The fields and pastureland must have 4G/5G network coverage and connectivity. The network service providers must be interconnected to the private 5G wireless systems at farms and ranches for seamless interoperability and data flow.

4) Edge computing, private 5G systems and precision Ag apps must be included as essential infrastructure in all rural broadband incentive programs from the FCC, USDA, other federal agencies and in state and county programs. Broadband by itself is a bridge halfway. A complete infrastructure and software solution are required for the adoption and realization of Precision Agriculture.

Based on the analysis of current and future needs of the Agriculture Community for connectivity for Precision Agriculture technology, we have the following preliminary recommendations.

A. Overall Preliminary Recommendations:

1. The Connectivity Working Group strongly recommends the FCC include up to $500 million in incentives and subsidies from the $9 billion (in addition to the one billion identified for precision agriculture) allocated for the 5G Fund for Rural America for the creation of 1) Edge Computing; 2), Private 5G Systems; and 3) Precision Agriculture applications so that the critical infrastructure and tools needed to deploy Precision Agriculture can be developed and deployed. Additionally, the Connectivity Working Group recommends that additional funding be set aside on future versions of the USDA Reconnect Program.
2. The Connectivity Working Group also recommends the Commission provide incentives to network service providers for high speed, low latency, mobile coverage of agricultural fields and pasturelands as a provision within the 5G Fund for Rural America. We also encourage the Commission to promote and incent the adoption of virtual solutions such as OpenRAN while making additional unlicensed and shared spectrum available in rural and highly agricultural areas. With incentives and subsidies programs highlighted in recommendation 1 and 2, there should be a closed-loop audit process to ensure that the proposals that were awarded funding are implemented and meet the objectives stated in the proposal.
3. Work within the standards bodies (e.g., 3GPP) to develop data standards for Precision Agriculture that will promote economies of scale and ease the burden of adoption for the Agriculture Community. This includes establishing minimum up/down transmission thresholds (increase from 25/3) for realities of Precision Agriculture and quality of service standards. Particular focus should be placed on increasing the upload speeds to meet the evolving demands of precision agriculture data creation and utilization for improved value. Perfect symmetry of the download and upload are not the goal but

rather driving increased capacity of the bandwidth both directions to meet new demands. Both non-terrestrial and terrestrial technologies are important to include in this work.

4. Liaise with state legislative bodies on current and proposed policies incentivizing broadband and technology investment across agricultural lands for model frameworks (i.e., what is working and what is not) before defining federal programs or allocated funding.
5. Incent the resiliency of communications networks supporting Precision Agriculture to ensure that the Agriculture Community is able to function even during the worst natural and manmade disasters. This should include path diversity of different networks and technologies.
6. Administer an email survey in early 2021 to a large sample size of broad acre and specialty farmers, ranchers, communication service providers, equipment manufacturers, and software providers to capture qualitative and quantitative feedback on aggregate bandwidth usage from current Precision Agriculture technologies, satisfaction with current connectivity options, methods, and costs of Internet connections to systems and endpoint devices, willingness to adopt or try new technologies, inflection points for investment in Precision Agriculture technologies, and ranking of Precision Agriculture use cases and forward-looking verbatim to uncover trends. Leverage survey data to accurately capture current broadband usage by farm type/size/geography and forecast aggregate connectivity demand.

B. Recommendations for other Taskforce Working Groups

In order for a connected Precision Agriculture tool to be accepted it must demonstrate that it can work consistently without slowing or halting productivity in the fields. The lack of full field coverage could be the end of the tool before it is even considered. Delays in the field lead to added time at the end of that window, assuming the weather holds. In order to ensure successful adoption of Precision Agriculture tools and practices, we recommend a tightly integrated plan and oversight for the identification and prioritization of broadband deployment over a targeted geographic area, along with marketing, education, and job training necessary for owners and agricultural workers in the newly connected areas to adopt precision agriculture practices. As noted, we strongly recommend oversight of any organization that receives federal support for broadband deployment to ensure their efforts are leading to the adoption of Precision Agriculture tools and practices. Specifically, we make the following recommendations to the other working groups:

1. Mapping and analyzing connectivity
    a. Identify types of connectivity maps and metrics that would be the most appropriate to determine the need for additional broadband coverage to support Precision Agriculture adoption.
    b. Make recommendations to the USDA on how they can obtain regular data to determine usage levels of Precision Agriculture as a method to evaluate adoption levels in geographic areas where implementation or expansion of bandwidth

options that meet Precision Agriculture needs are added. This could be the basis of a measure of accountability for funds awarded.

c. There are no national bandwidth coverage maps currently in production, but there are several states that have formal programs to capture this data. We recommend using a state model to generate various maps of connectivity with USDA agriculture data to capture more accurate data in near real-time of terrestrial broadband and RF coverage across targeted lands. Engage each state to determine such data in production or under development, then document best practices. Benefits derived should demonstrate the need for a national bandwidth coverage map.

2. Accelerating broadband deployment on unserved agricultural lands
    a. Determine what kind of outreach and marketing would be most successful to drive the adoption of Precision Agriculture by farm owners and agricultural workers.
    b. Work with the USDA to identify key farm metrics and crops to target the expansion of broadband coverage that will maximize food security of the United States and maximize economic stability or promote growth by enabling expanded use of Precision Agriculture practices.
    c. Determine the best methods to promote the adoption of precision technologies and practices through targeted incentives, such as tax credits, that are commensurate with public benefits generated from adoption.
    d. Evaluate best practices for municipality-deployed passive optical networks across unserved agricultural lands and public-private partnership structures with communications services providers to share in common infrastructure for middle to last-mile capital cost reduction.
    e. Engage each mobile network operator (AT&T, Verizon Wireless, T-Mobile, and Dish) requesting deployment roadmaps and long-range plans that can be shared (i.e., made publicly available) for low-, mid-, and high-band 5G availability across unserved agricultural lands.
    f. Measure the impact that recent and future RF auctions (such as CBRS PAL) will have on wireless broadband availability.
    g. We urge the Deployment Working Group to move forward with analyzing the spectrum requirements to support terrestrial and non-terrestrial precision agriculture deployment and connectivity.

3. Adoption and Jobs
    a. Determine key and baseline technologies required to support the adoption of Precision Agriculture tools and processes in each of the three agricultural areas.
    b. Determine which organizations are most appropriate to educate farm owners and agriculture workers in Precision Agriculture practices.

c. Catalog functional jobs for each Precision Agriculture discipline that must be performed on the farm and jobs that can be performed remotely.

d. Measure losses in workforce productivity when available Precision Agriculture technologies are not adopted and develop general ROI guidelines.

e. Determine how long these educational offerings should be provided, pre- and post-broadband connectivity deployment to support a 25% increase in the use of Precision Agriculture.

f. Encourage producer education and training in advanced precision technologies to drive adoption among all farm types and sizes. This should be done through public-private partnerships with the USDA, the local farm and agriculture bodies, and the private sector, including equipment manufacturers, communications service providers, and the Agriculture Community. This should include program funding for USDA Rural Development offices nationwide to establish a joint training program launched with each state's economic development arm. Program examples include a Precision Agriculture playbook by farm type, in-person use case training, and other educational materials.

Appendix A Working Group Members

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Members:

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Andy Bater, Engineer and Farmer Fifth Estate Growers LLC

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