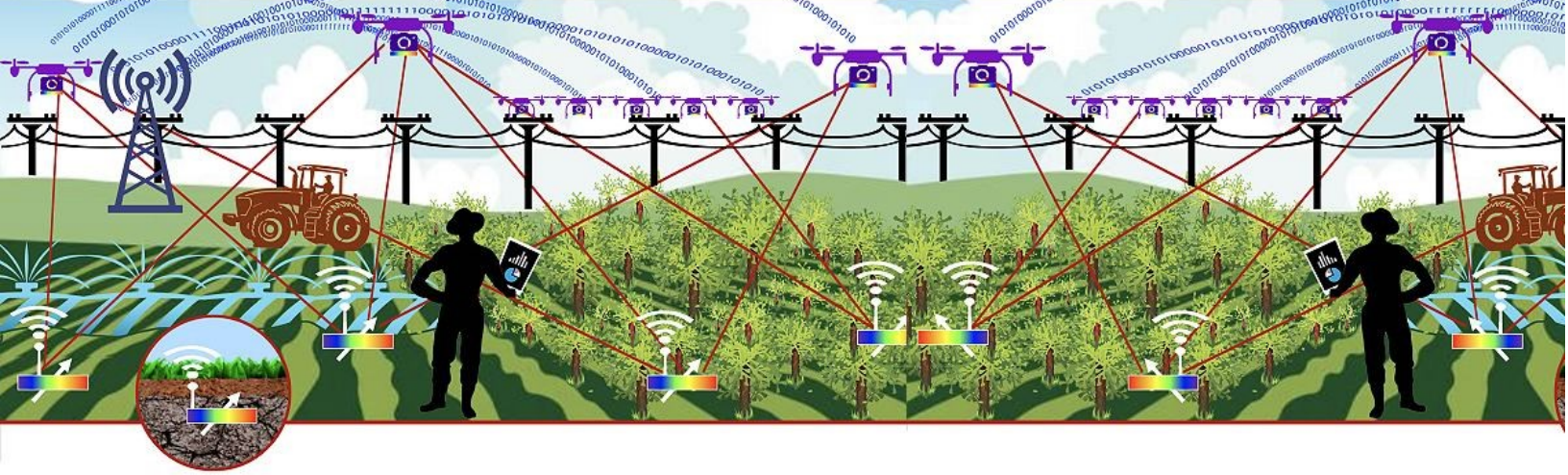


IoT4Ag

A National Science Foundation Engineering Research Center since 2020

Partner Institutions:

- *Purdue University*
- *University of Florida*
- *University of California, Merced*

Vision - **Sustainable, High-Output Precision Agriculture**
To ensure food, energy, and water security by advancing technology to increase crop production, while minimizing the use of energy and water resources and the impact of agricultural practices on the environment.

Mission - **Transform the Future of Agriculture**
To create and translate to practice Internet of Things (IoT) technologies for precision agriculture and to train and educate a diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.

Need - **Food, Energy, and Water Security**
By 2050, the US population is estimated to grow to 400 million and the world population to 9.7 billion. Current agricultural practices account for 70% of global water use; energy use is one of the largest costs on a farm; and inefficient use of agrochemicals is altering Earth's ecosystems. With finite arable land, water, and energy resources, meeting the goal of ensuring food, energy, and water security will require new technologies to improve the efficiency of food production, create sustainable approaches to supply energy, and prevent water scarcity.

Solutions - **Breakthrough IoT Technology and Practitioners** IoT4Ag will create novel, integrated systems that capture the microclimate and spatially, temporally, and compositionally map heterogeneous stresses for early detection and intervention to result in better outcomes in agricultural crop production. The Center will create Internet of Things technologies to optimize practices for every plant—from sensors, robotics, and energy and communication devices to data-driven models constrained by plant physiology, soil, weather, management practices, and socio-economics.

Diverse participant groups will be well-prepared through IoT4Ag education and inclusion programs to have strong science and engineering knowledge and to form a workforce able to discover, innovate, translate, and practice precision agriculture solutions. The Center will establish an innovation ecosystem and will network with academic, industry, investment, and government partners to collaboratively build the future of precision agriculture.

IoT4Ag will deliver more crop for every drop of water and joule of energy to ensure a food, energy, and water secure future!

RESEARCH

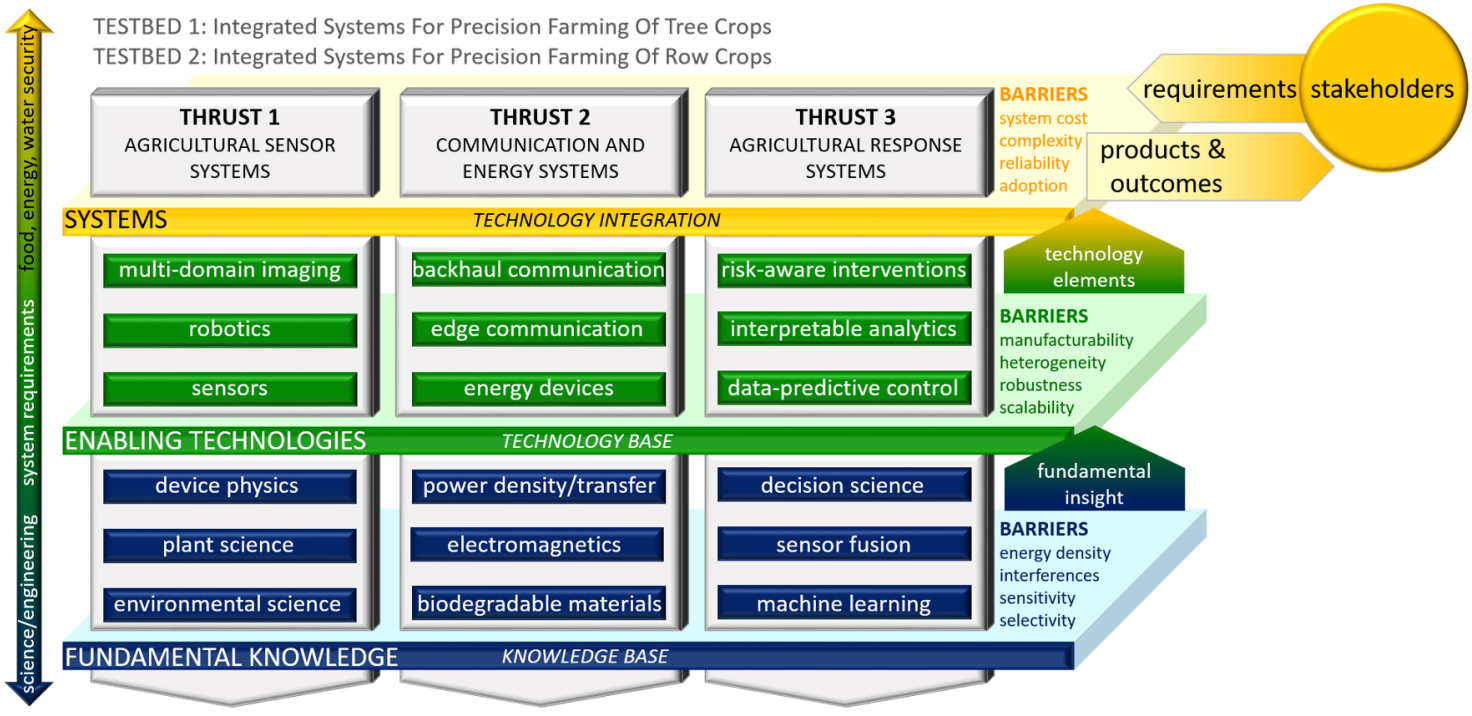
Monitoring of agricultural crops is still accomplished primarily through the expensive, labor-intensive, and time-consuming process of "crop scouting," by manual sampling and documenting the state of the field. Precision agriculture involves the use of technology to acquire and analyze data from the field. However, currently technologies such as sensors are limited or non-existent that can spatially, temporally, and compositionally monitor the state of the field; data is coarse-grained and siloed in equipment; communications infrastructure is limited or non-existent on the farm; and interventions are reactive and over-provisioned, increasing economic and environmental costs. While the concept of precision agriculture has existed for 30 years, *the exponential growth in information technology and data science and the reduction in their cost is setting the stage for the next revolution in agricultural practices.*

The IoT4Ag team unites a convergence of expertise in agronomy, agricultural engineering and economics, and environmental science, and in the science and engineering of physical and cyber-physical systems. The Center is structured into three thrusts that vertically integrate fundamental knowledge and technology from different disciplines and that are horizontally integrated to achieve next-generation engineered systems for agriculture.

Thrust 1: Agricultural sensor systems will design and manufacture resilient, networked, intelligent sensor-robotic systems that monitor the state of plant and soil health over extended areas. Thrust 1 will address fundamental scientific questions to uncover how the complex system of abiotic and biotic variables affect crop yield and resilience, and with this knowledge design technologies and systems that will be deployed with the spatial, temporal, and compositional resolution needed to capture the state of the field.

Thrust 2: Communication and energy systems will enable advanced approaches for powering IoT devices and robots in the field and for data communication from heterogeneous platforms of sensors, robots, and farming equipment. Thrust 2 will establish the knowledge and technologies specifically needed in agriculture, from powering devices and communicating from below the soil surface to deploying technologies at field scales.

Thrust 3: Agricultural response systems will create and deploy smart response systems that are driven by machine learning and decision-based models for precision agriculture. Thrust 3 will create techniques to manage uncertainty and fuse the spatially, temporally, and compositionally heterogeneous data from the field to collect not just more, but better data. The



IoT4Ag 3-Plane Diagram

Thrust will build models, constrained by the biophysics of plants in agricultural fields, to establish a decision-Ag interface for growers to intelligently manage their fields in a cost-effective manner.

IoT4Ag Breakthrough Technologies:

- Multi-mode, low-cost, distributable, environmental and soil sensor technologies
- Autonomous aerial and ground-based robots
- Energy storage and delivery technologies for field -scale operation
- Ag-specific communications
- Biophysically-constrained data analytics to produce decision-Ag interventions and improve outcomes in agricultural fields

IoT4Ag Testbeds:

IoT4Ag "sense-communication-response" technologies will be evaluated in two Testbeds: Integrated Systems for Precision Farming of (1) Tree Crops and (2) Row Crops. These testbeds will be used to assess and demonstrate IoT4Ag solutions in the different agricultural environments of orchards and row crops, many of which are mainstays of the food supply chain. IoT4Ag technologies will be deployed in phases from control facilities to plot- and field-scale university testbeds and then to our industry and agricultural partners.

EDUCATION

IoT4Ag will prepare diverse groups of pre-college, community college, and university students and agricultural professionals through national and international partnerships with educational institutions, museums, and organizations and via our industrial practitioner and Ag-systems advisory boards.

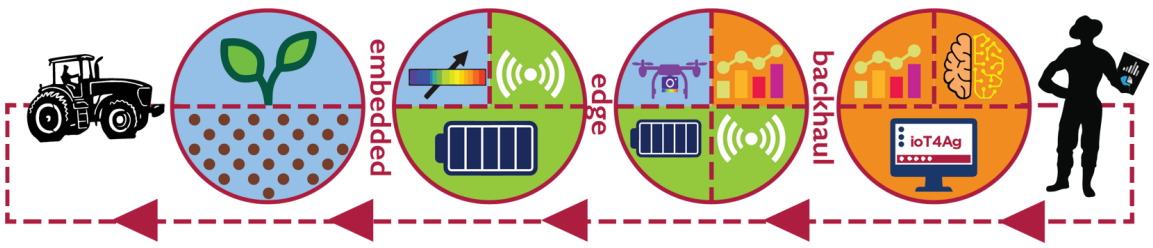
Pre-College Education: Faculty, students, and staff at all university partners' sites will co-develop audience-specific lesson plans, hands-on labs and kits, and exhibits to increase K-12 STEM interest and competency.

Community College Education: The Center will engage students pursuing certificates and two-year degrees in fields related to precision agriculture at Community College partner institutions through guest lectures and technology demonstrations, hands-on laboratory activities, field demonstrations, and research experiences. IoT4Ag aims to increase the knowledge and pipeline of Ag and engineering students via education and training in innovative Ag technologies.

University Education: IoT4Ag will educate undergraduate and graduate students and postdoctoral fellows to prepare Ag–Tech leaders through collaborative co-education and co-training in and across our classrooms, labs, and agricultural research and education extension facilities, and with international partners. The Center will create and deliver multi-disciplinary educational activities mirroring our disciplinary diversity and convergent research, through virtual and in-person bootcamps, coursework, professional development, international exchange, intra-ERC research exchange, and research experiences.

Research Experiences for Undergraduates (REUs): IoT4Ag will recruit six REUs for the summer to participate in the Center's research projects, with two REUs per the Center's three partner institutions: University of Pennsylvania, University of Florida (UF), and Purdue University. IoT4Ag aims to obtain an REU site award to expand the number of REUs, including adding REUs at the fourth partner institution, the University of California, Merced.

Professional Education: The Center will increase precision agriculture technology competency of the end-user community of growers and support certification of Ag professionals through our Ag-systems advisory board and in cooperation with university and state Extension Facilities located near Merced, Purdue, and UF. IoT4Ag will contribute to end user development by creating educational materials for Certified



A "Wiring" or "Flow" Diagram describing the integration of IoT4Ag thrusts to create knowledge, technologies, and systems for precision farming of row and tree crops. Thrust I – Agricultural Sensor Systems (blue) aims to monitor plants, soil, and the environment by embedding sensors and deploying robots at the edge. Thrust 2 – Communication and Energy Devices (green) will advance devices to power and communicate data from embedded sensors to robots and machinery operating at the edge and via backhaul to the cloud. Thrust 3 – Agricultural Response Systems (orange) will create machine learning and decision-based models for precision agriculture to come full cycle to allow growers to intelligently manage their fields.

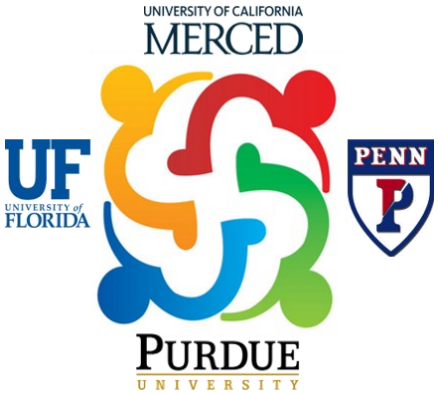
Crop Advisor (CCA) training, for tech service industry and extension agent training, and for transferring IoT4Ag technologies to growers.

DIVERSITY AND CULTURE OF INCLUSION

IoT4Ag is committed to creating, sustaining, and promoting a diverse community of students, scientists, and staff. As such, IoT4Ag recognizes value in creating its own Diversity and Culture of Inclusion (DCI) activities, while also leveraging resources and initiatives at all partner universities. DCI is a pipeline, which involves recruiting as a first step, followed by developing a climate that seeks to retain IoT4Ag members (from students to advisory board members), and creates an environment where all can thrive. DCI requires partnership with local programs to meet the needs of different student populations and Center-wide programs to foster a sense of belonging to the IoT4Ag program and Center identity. Through continuous improvement, IoT4Ag successes will strengthen DCI for affiliated organizations and partners, and ultimately, the scientific community.

Recruiting: IoT4Ag will build on and establish partnerships with national scholars' programs and minority-serving institutions and engage students by sharing IoT4Ag research, education, inclusion, and innovation at meetings of national minority-serving societies and organizations. The Center will create a new signature Pathway to PhD (PPP) program. PPP is a 2-day workshop and network building program designed to address the often-observed lack of awareness by under-represented minority (URM) and first-generation low-income (FGLI) students about graduate school. PPP will prepare students to apply to graduate programs and fellowships, and to connect students to faculty and peer mentors in support of their future.

Climate: The Center will initiate, organize, and monitor activities that aim to create and sustain a positive climate and an inclusive environment. To this end, the Center will create educational and training sessions/modules on topics related to implicit bias, sexual harassment, and conflict resolution (in the workplace), and other topics. Hierarchical peer-to-peer (between graduate and undergraduate students) and faculty-student mentoring programs will be developed and assessed via triannual teleconference



check-ins. The check-ins are intended to build a sense of belonging to the Center, and to facilitate a positive climate and inclusion. IoT4Ag will explore diversity and inclusion topics at its meetings and workshops, build and value diversity through social and professional gatherings, and feature IoT4Ag students, faculty, staff, and professionals on our webpage and through our newsletters and social media.

INNOVATION ECOSYSTEM

IoT4Ag will develop a vibrant innovation ecosystem that will engage our industrial, government, non-profit, and innovation partners, and the end-use grower community in guiding the direction of Center research, workforce development, and diversity and inclusion activities. We will establish two bodies for outside stakeholders: an Industrial Practitioner Advisory Board (IPAB), and an Ag-Systems Advisory Board (ASAB) that will help balance "tech push" vs. "industry pull." This ecosystem will also ensure transfer of knowledge and technology from IoT4Ag university labs to application through entrepreneurship and commercialization by industry partners and adoption by growers. Engagement with our IPAB and ASAB partners throughout the life cycle of IoT4Ag research, from problem definition to evaluation and deployment of our systems to technology transfer, is essential to maximize impact of the Center. Early and frequent engagement of IPAB and ASAB partners in research, education, inclusion, and innovation will ensure that IoT4Ag pursues research that has a clear value proposition for industry and that is well-suited for commercialization and adoption by the farming community, and that IoT4Ag educates a diverse workforce to create, translate, and put to practice the Center's technologies.

Industrial/Practitioner Advisory Board: We have recruited and will continue to pursue industrial, government, and innovation partners with interests that align with each of the three thrusts, spanning agroscience, technology, and protection; sensor, communication, and energy devices; robotics; and data science and decision-making in food, energy, and water security.

Ag-Systems Advisory Board: The Board will include representatives from farming associations, commodity producer boards (row, vegetable, fruit and nut crops), crop consultant associations, farm cooperatives with precision Ag advisors, and Ag and horticulture extension agents.

FACILITIES

IoT4Ag headquarters is located in the Pennovation Works facility, which blends offices, labs, and production space to host researchers, entrepreneurs, and industry partners that collaboratively will translate ideas and research into commercial products and ventures. Headquarters includes the Director's office and office space for IoT4Ag staff and gives all IoT4Ag researchers and partners access to shared conference room space, a machine shop, and a maker space; and co-locates IoT4Ag with the Penn Center for Innovation (PCI). IoT4Ag will have full access to individual faculty research labs and centralized user facilities across Penn, Purdue, Merced, and UF campuses, spanning fabrication, characterization, robotics, and computing and maker and incubator spaces. The Center will also carry out its work at control, plot, and field scale agricultural facilities at UF's North Florida Research & Education Center, Purdue's Agronomy Center for Research and Education, and UC's Kearny Agricultural Research and Extension Center. IoT4Ag will also have access to all partner university collaborative and virtual learning spaces and classrooms.

CENTER CONFIGURATION, LEADERSHIP, TEAM STRUCTURE

The Internet of Things for Precision Agriculture (IoT4Ag) Center is a partnership of four universities, including University of Pennsylvania (PENN) (primary), Purdue University, University of California-Merced (UCM), and University of Florida (UF). The leadership team is led by the Executive Committee, who will oversee and be ultimately accountable for the success of the IoT4Ag collaborative research program, university and pre-college education, diversity and inclusion activities that broaden participation, and innovation and industrial engagement activities across the four campuses. Research Systems Integration, Thrust, and Testbed leaders and the Workforce Development, Diversity and Culture of Inclusion, and Innovation Ecosystem Directors will be responsible for leading the Research, Education, Diversity and Inclusion, and Innovation Ecosystem enterprises. They work with participating faculty, students, pre-college and community college partners, international partners, government and industry partners, and agricultural professionals and growers to meet IoT4Ag goals and milestones. These leaders

Pennovation Works - the location of the IoT4Ag offices (Credit: JLL)

and Directors report to and are supported by the Center Director and Site Directors. The Executive Committee will expand the leadership to include a Convergence team to represent the disciplinary and institutional diversity of the Center. The Convergence team will be rotated to broaden technical, institutional, and gender/racial participation of current and future IoT4Ag team members in the executive committee. The leadership team will be led from headquarters at PENN by the Center Director and Administrative Director, who will work collaboratively with the Site Directors.

The IoT4Ag leadership will work in partnership with its Councils and Advisory Boards selected to support the IoT4Ag mission, which are the following:

- Council of Deans
- Student Leadership Council
- Scientific Advisory Board
- Workforce Development Advisory Board
- Diversity & Inclusion Advisory Board
- Industrial/Practitioner Advisory Board
- Ag-Systems Advisory Board

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