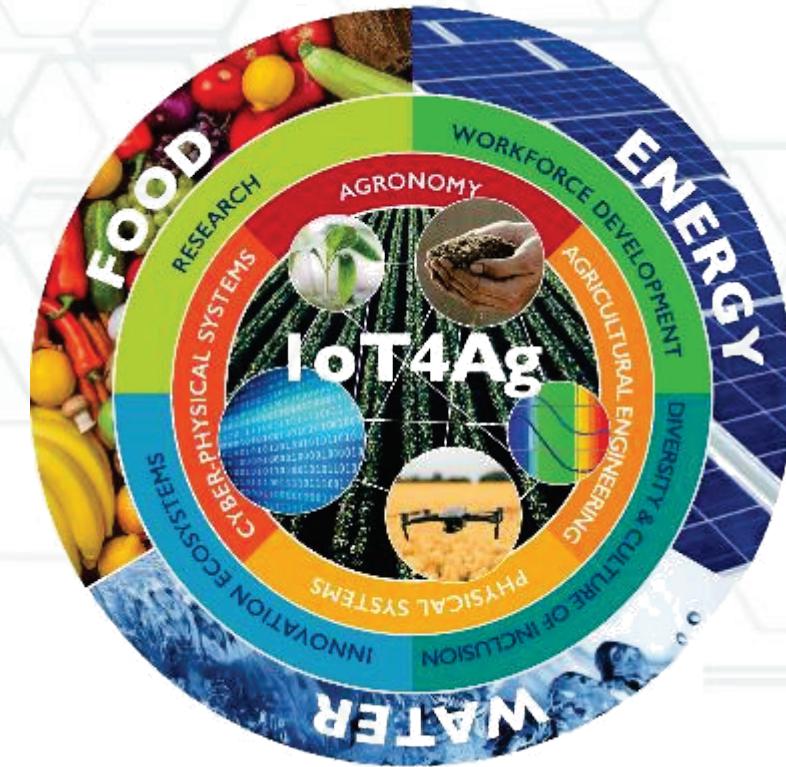


NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)



Cherie R Kagan
University of Pennsylvania

Catherine Keske
UC Merced

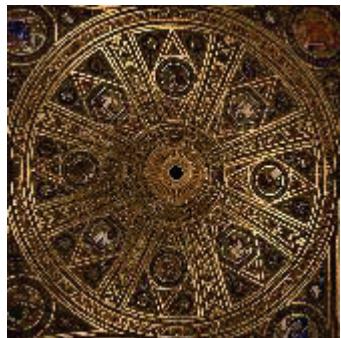
James Krogmeier
Purdue University

Rahul Mangharam
University of Pennsylvania

Diane Rowland
University of Florida

IoT4Ag Vision

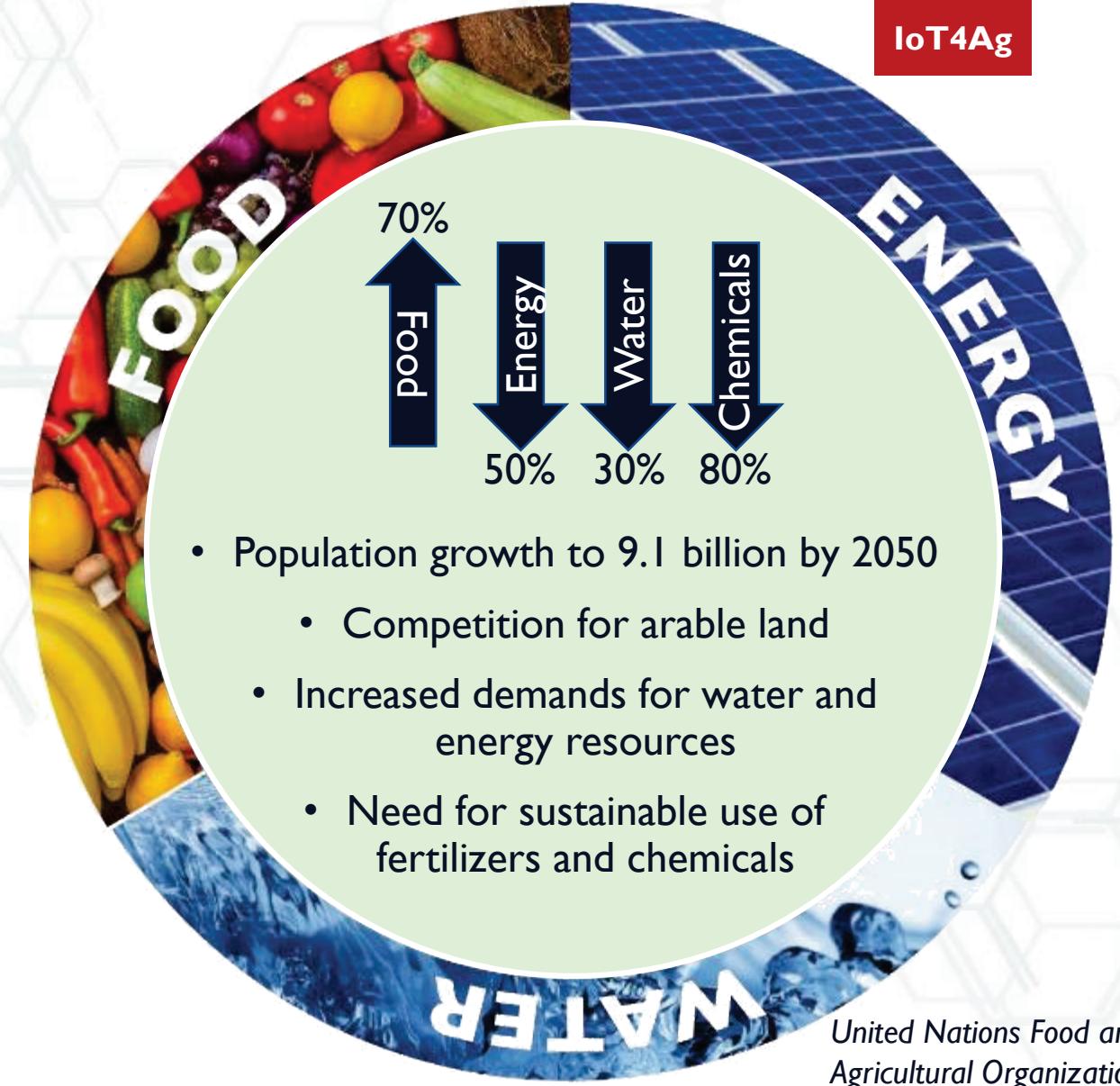
To ensure food, energy, and water security by advancing technology to increase crop production, while minimizing the use of energy and water resources and the impact of agricultural practices on the environment.



- TO SCIENCE
- PILOT OF INDUSTRY
- MULTIPLIER OF THE HARVEST

National Academy

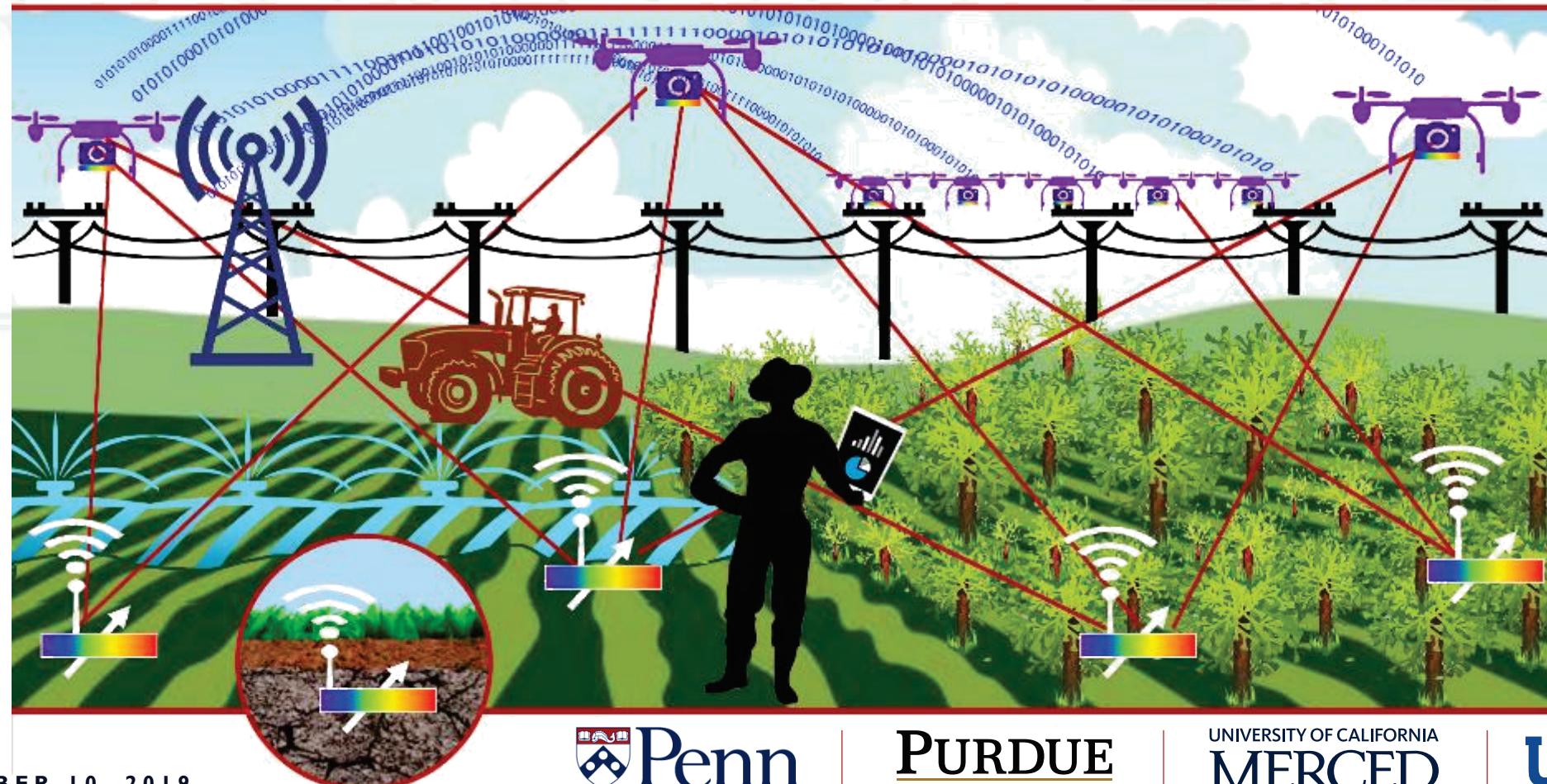
DECEMBER 10, 2019



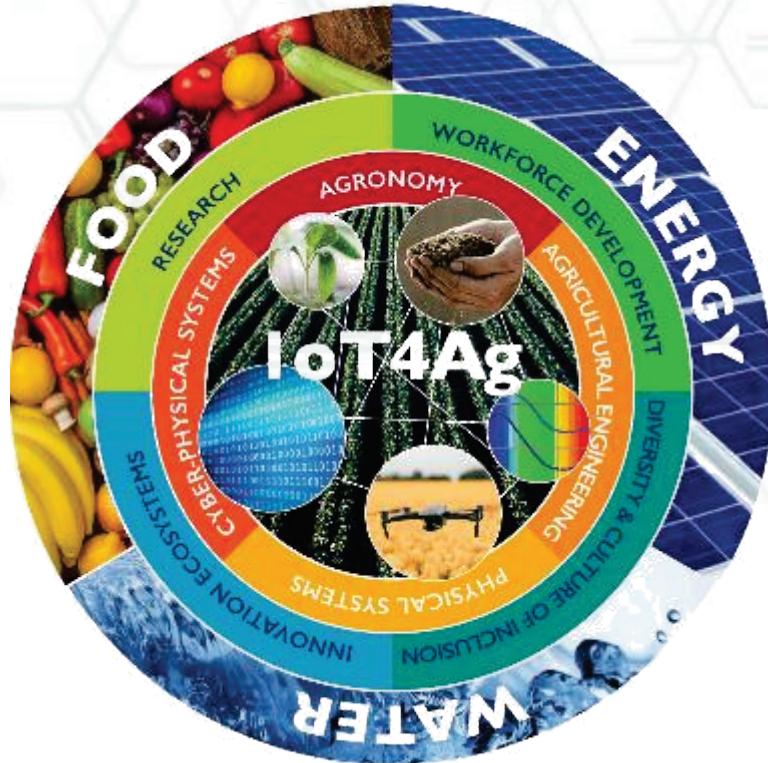
United Nations Food and Agricultural Organization
USDA

IoT4Ag Mission

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.



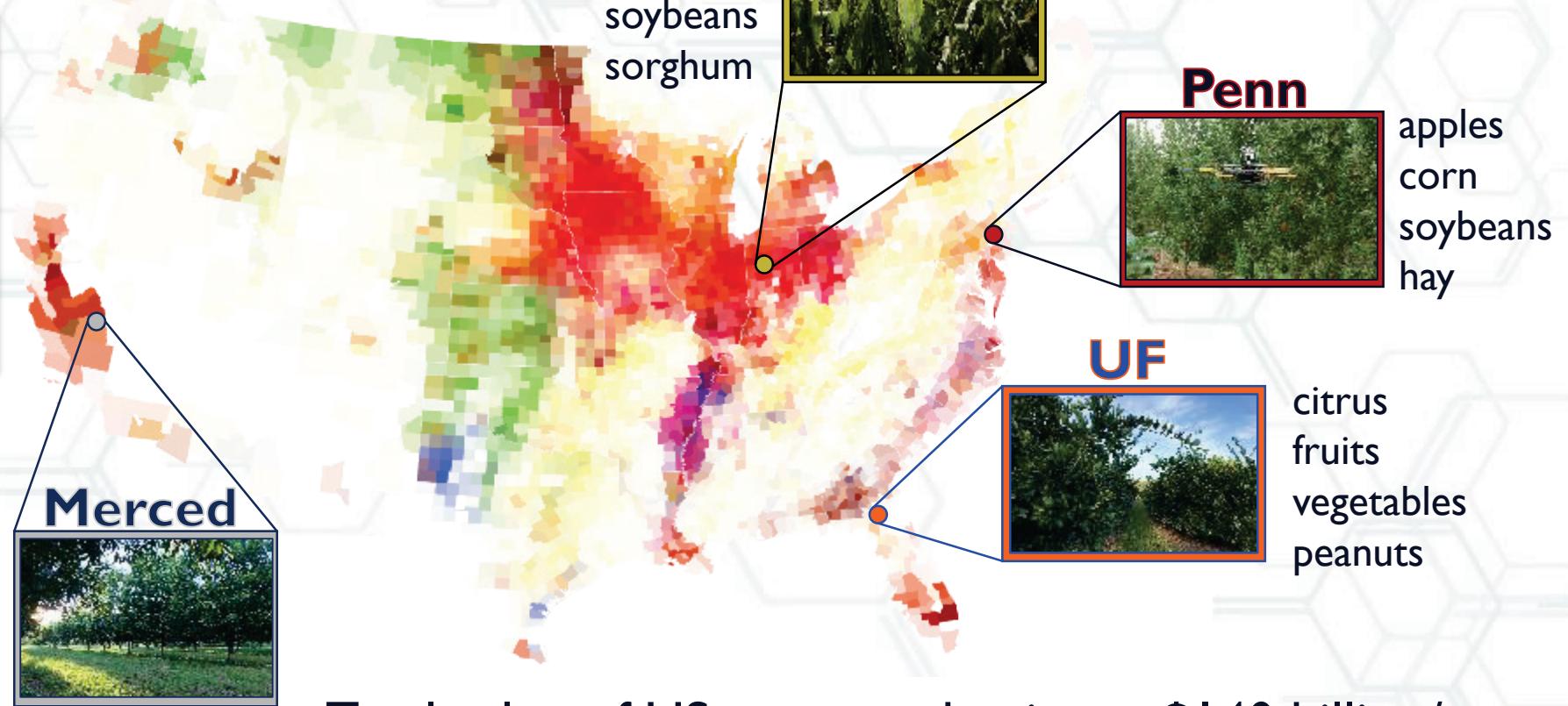
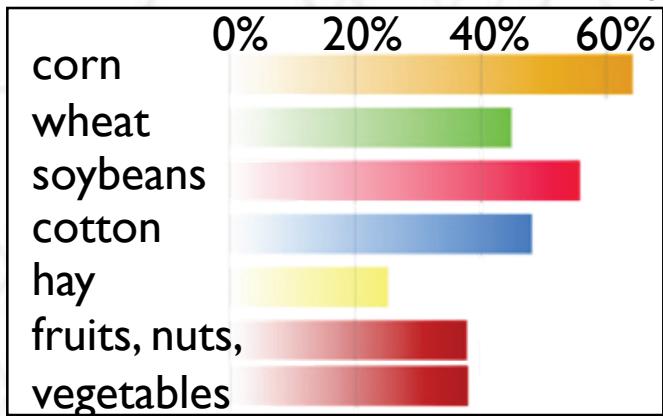
IoT4Ag and the NSF Big Ideas



Future of Work
Harnessing the Data Revolution
Growing Convergence Research
Mid-scale Research Infrastructure
NSF INCLUDES
Understanding the Rules of Life

Agricultural Crops in the US

Percent land devoted to each crop

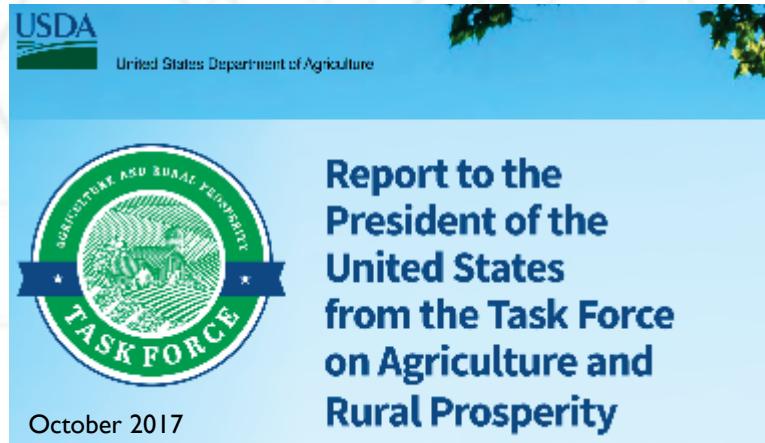


Total value of US crop production > \$140 billion/year

Represent diversity of crops and different agricultural environments for IoT4Ag testbeds

<https://www.vox.com/a/explain-food-america>

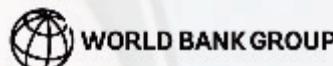
Precision Agriculture in the US and Around the World



FUTURE of FOOD

Harnessing Digital Technologies to Improve Food System Outcomes

April 2019



DECEMBER 10, 2019



Key message: "... it is critical that productivity growth not rely on more cultivated land, water, or energy, but instead harness the power of innovation and technology."

Key message: "Digital technologies have the potential to improve efficiency, equity, nutrition and health, and sustainability in the food system."

Agriculture Today

Present Day



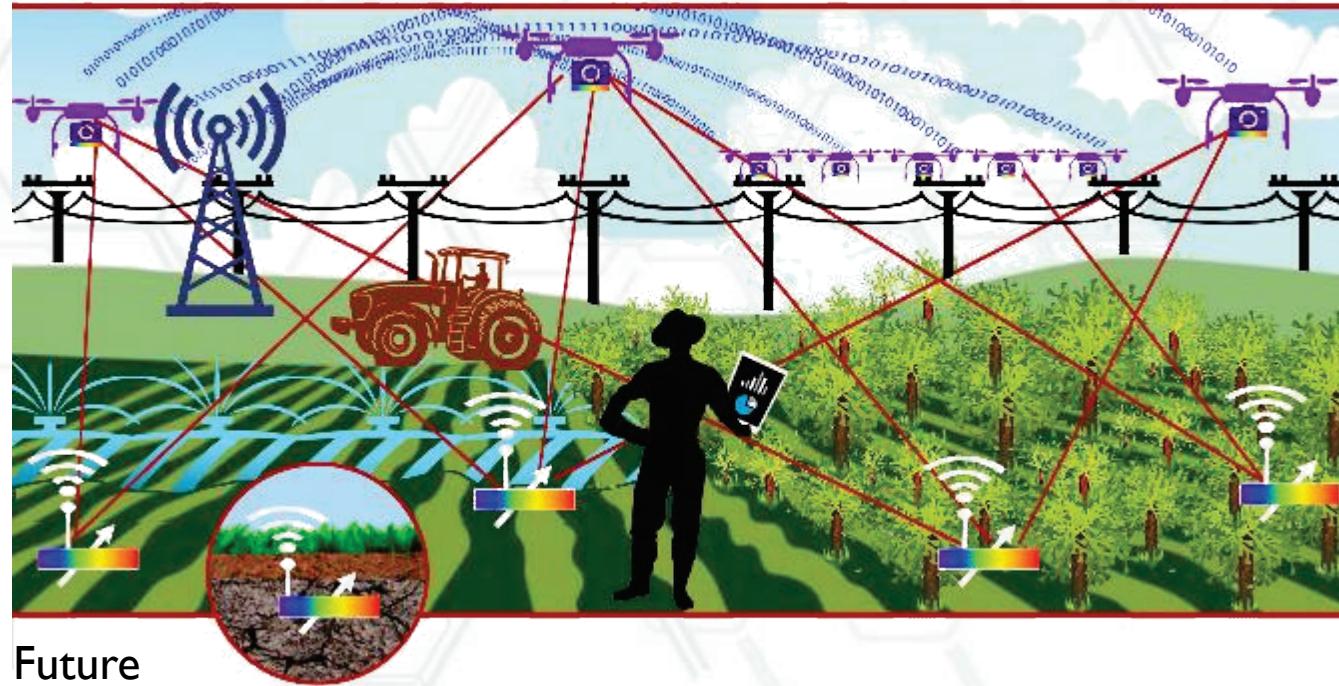
Pathogens and pests are estimated to reduce crop yield by ~10-40% (varying by crop) globally

Nature Ecology & Evolution, March 2019

Problems:

- Sensor technologies are limited or non-existent to spatially, temporally, and compositionally monitor the state of the field
- Data is coarse-grained, siloed in equipment
- Communications infrastructure is limited or non-existent on the farm
- Interventions are reactive and over-provisioned, increasing economic and environmental costs

Transforming the Future of Agriculture



Projected: + \$47 billion/year value
of precision agriculture to US Crop
Production

USDA, April 2019

IoT4Ag Integrated Systems: capture microclimate and spatially, temporally, and compositionally map heterogeneous stresses to predict and efficiently control the state of the farm

The **time is right:** 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



Testbeds

Testbed 1: Integrated Systems for Precision Farming of Tree Crops



UF Research & Education Centers

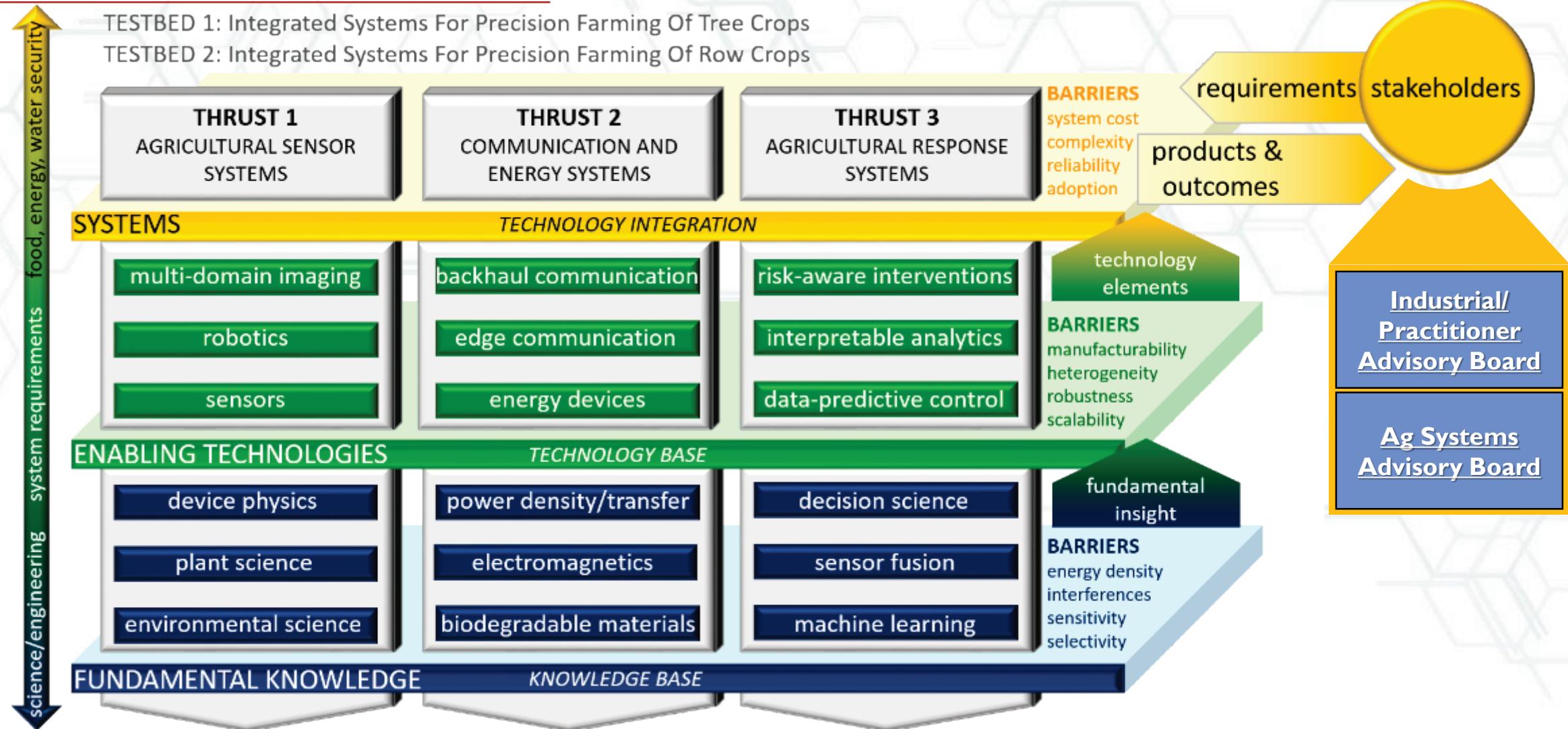
Testbed 2: Integrated Systems for Precision Farming of Row Crops



Agronomy Center for Research and Education (ACRE)

Mainstays of the food supply chain and agriculture in the US and abroad

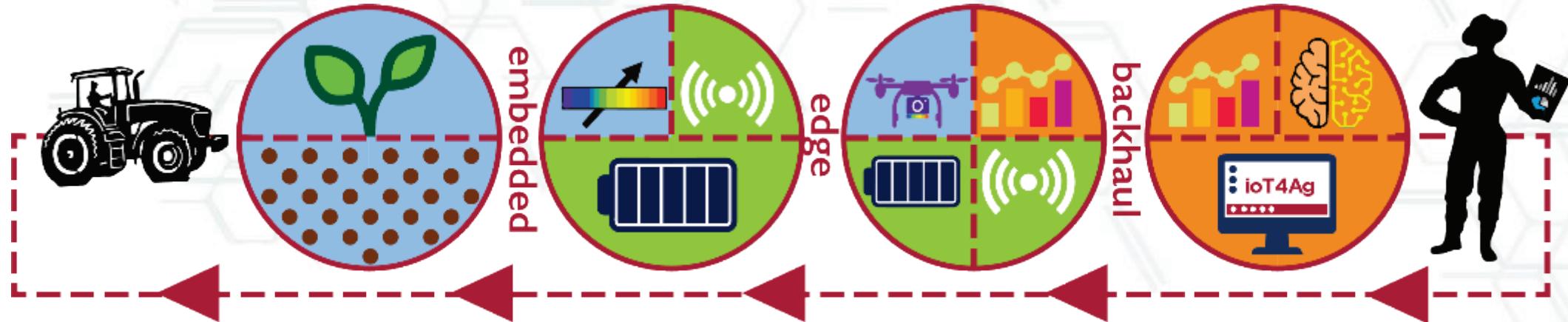
Integrated-Systems Level Problem



IoT4Ag Integrated Systems: Solutions for a Food, Energy, and Water Secure Future

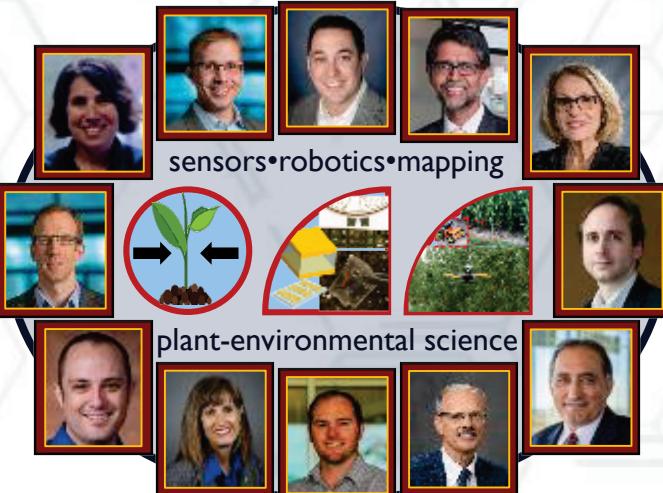
Integrated systems for early detection and intervention
to improve outcomes in agricultural crop production

Thrust 1 Thrust 2 Thrust 3



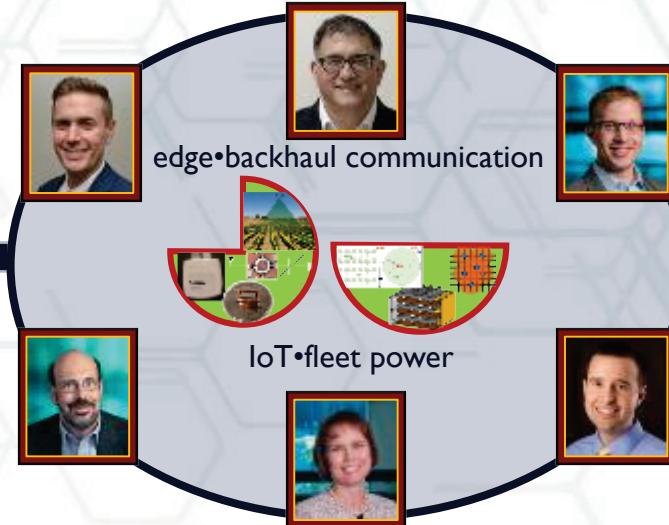
IoT4Ag Team: Convergence of Experts

Thrust 1: Agricultural Sensor Systems



4 Universities • 8 Departments

Thrust 2: Communication and Energy Systems



3 Universities • 4 Departments

Thrust 3: Agricultural Response Systems

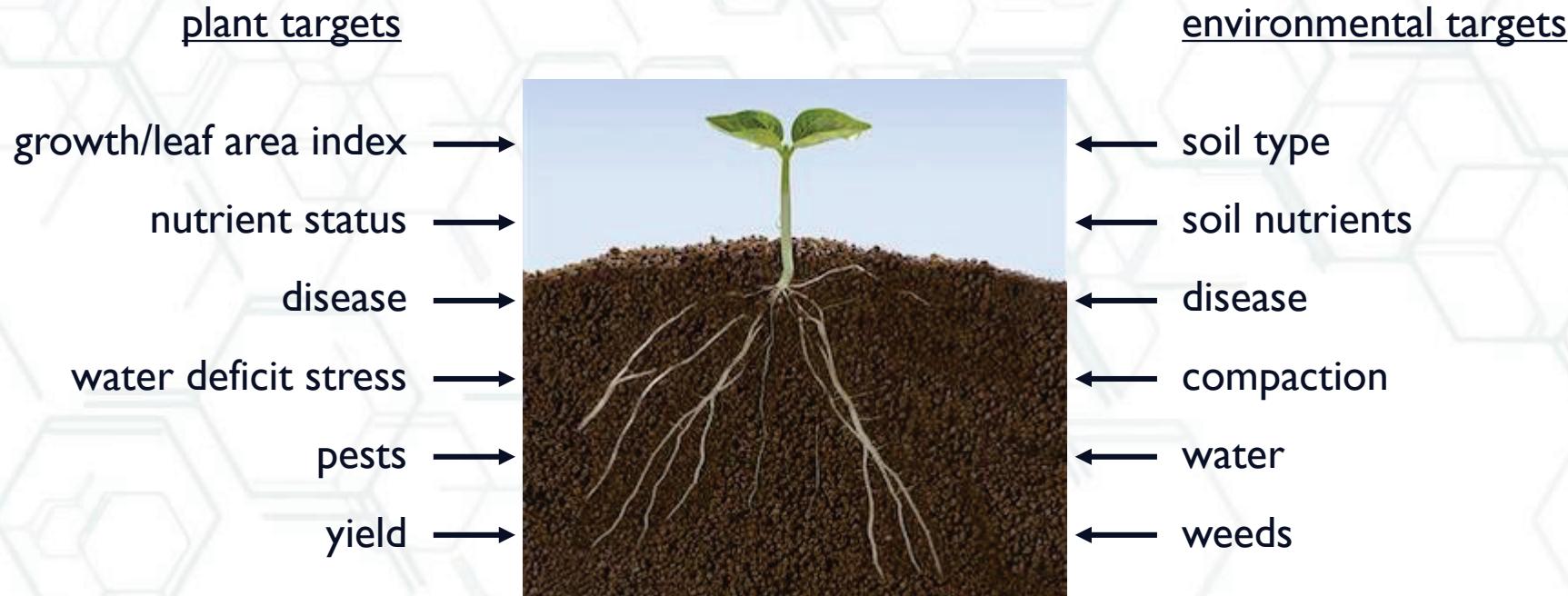


4 Universities • 7 Departments

IoT4Ag Integrated Systems

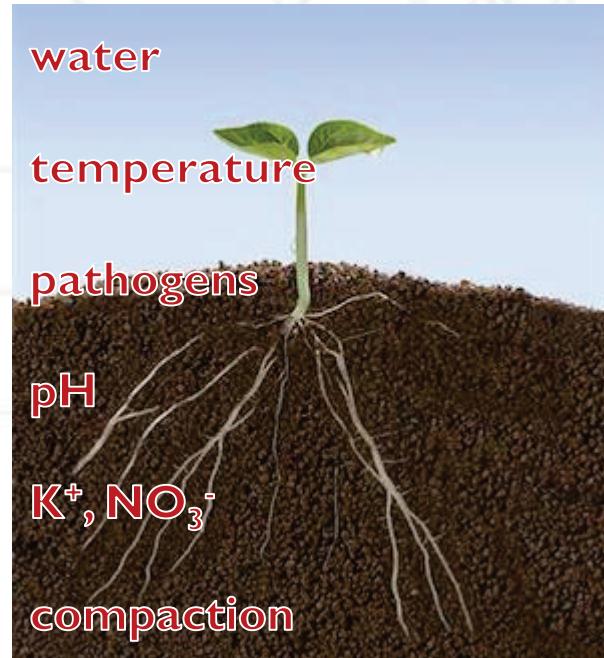
The **right team**: integrating expertise in agronomy, agricultural engineering and economics, and environmental science and in the science and engineering of physical and cyber-physical systems

Plant and Environmental Science



How do the complex system of abiotic/biotic variables affect crop yield and resilience?
On what timescales and with what spatial resolution should we deploy technologies to capture these variables?

Multi-Mode Sensor Science and Technology



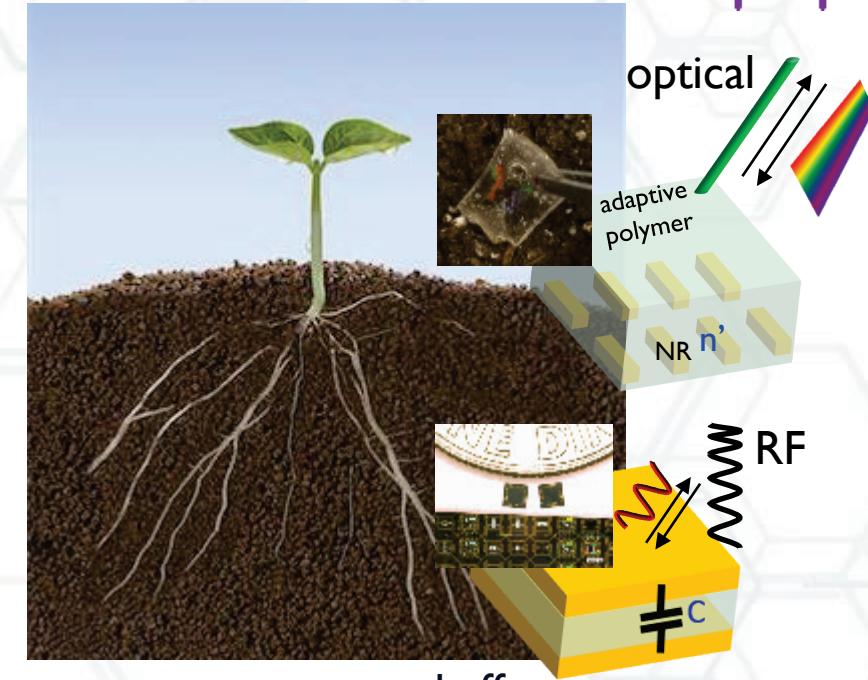
sensor technologies that measure target variables which cannot be observed directly



conventional sensor technologies
limited power, limited placement
~0.01 sensors per acre,
~\$1K /sensor/season



edge communication to robots and farm infrastructure



sensor chaff
zero-/near-zero power,
scale to ~10⁵ sensors/acre
<1¢ – \$1 /sensor/season





Autonomous Fleet Operation

Biglerville, PA

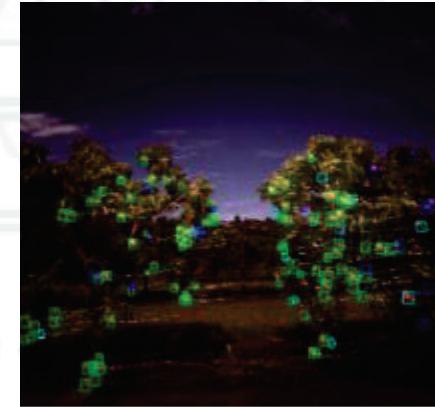


robots autonomously navigating above and below the canopy

IoT4Ag
fleet



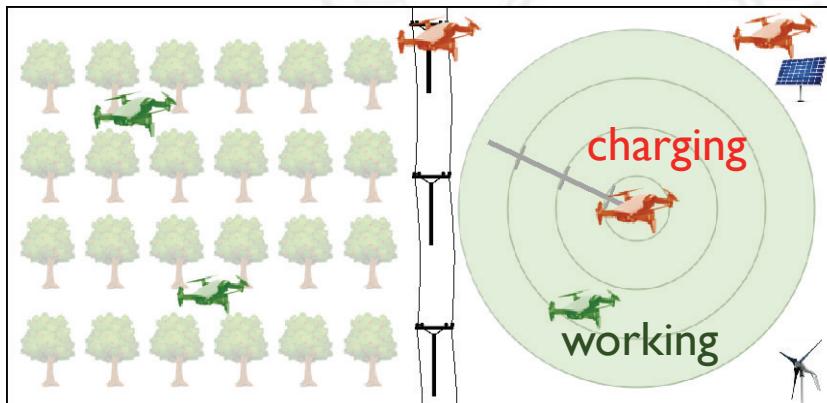
Orange Cove, CA



counting oranges

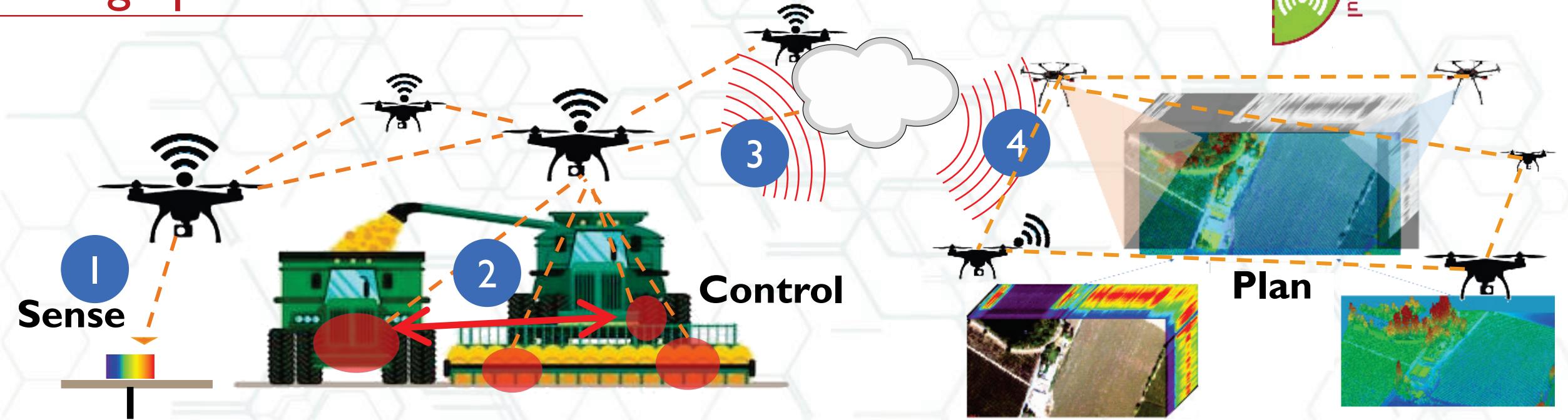


semantic mapping at scale in unstructured environments



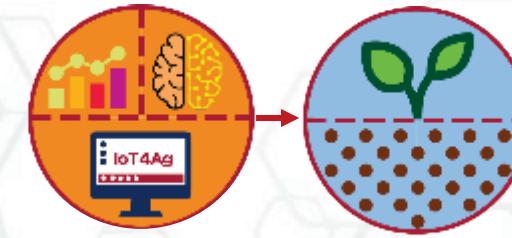
power the fleet to operate at agricultural scales
via distributed drone recharging and high power
density, rapid recharging batteries

Ag-Specific Communication Solutions



- Ag fields located in rural areas with poor broadband coverage
- Develop new multi-scale communication capabilities for the unique Ag use-cases
 - 1 Sensor-level: Low power wireless communication
 - 2 Machine-to-machine: Millimeter wave frequencies and above
 - 3 Massive MIMO (multiple-input, multiple output) for range and rate
 - 4 Multi-hop and distributed backhaul
- Multiple-instance, multiple-resolution sensor fusion for multi modality data analysis

Decision Ag Interventions

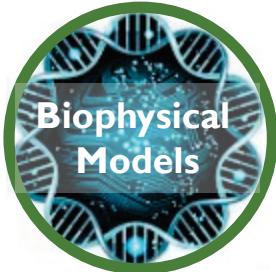


Data-driven Models

- Feature extraction
- Multi-temporal, multi-modal architecture

Biophysical Models

- Plant physiology
- Soils
- Weather
- Management practices



DECEMBER 10, 2019

Autonomy for Better Data

- Targeted sensing to improve data-driven models

Farm Models → Decisions

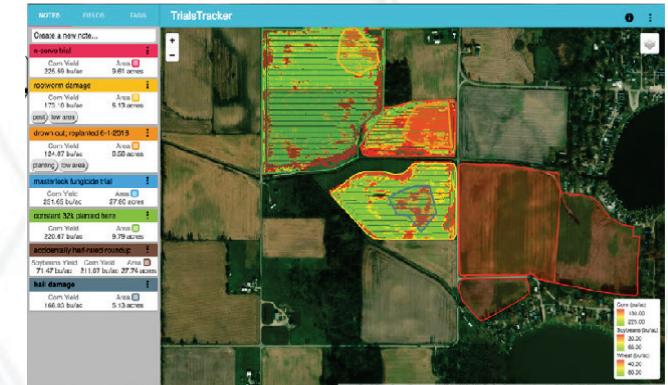
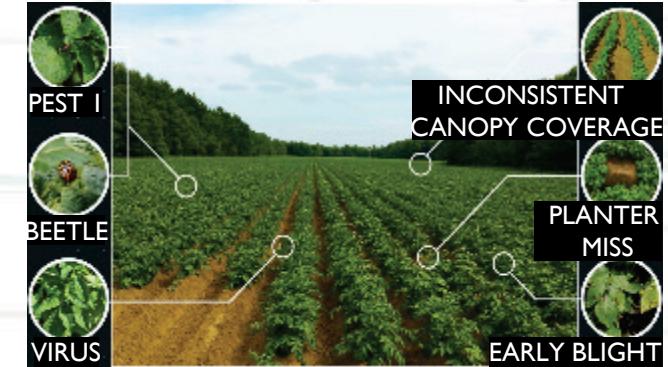
- Heterogeneous data & model architecture
- Biophysically-constrained machine learning

Make the Invisible Visible

- Bridging machine learning and control models
- Uncertainty reduction with optimal sensor fusion

Economic Analysis

- Socioeconomic adoption models and analysis
- Transfer learning to scale across fields



Facilities: Convergence of Technology and Agriculture

- Well-equipped PI labs
- World-class shared facilities
- Agricultural Research and Extension Centers
- Dedicated IoT4Ag Headquarters



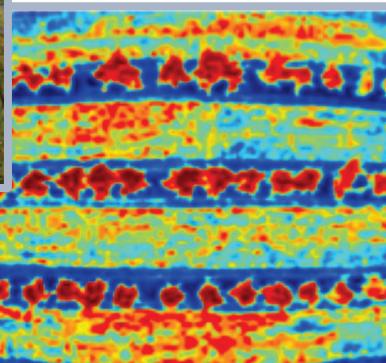
Fabrication



Manufacturing



Testing



Data

Controlled Facilities

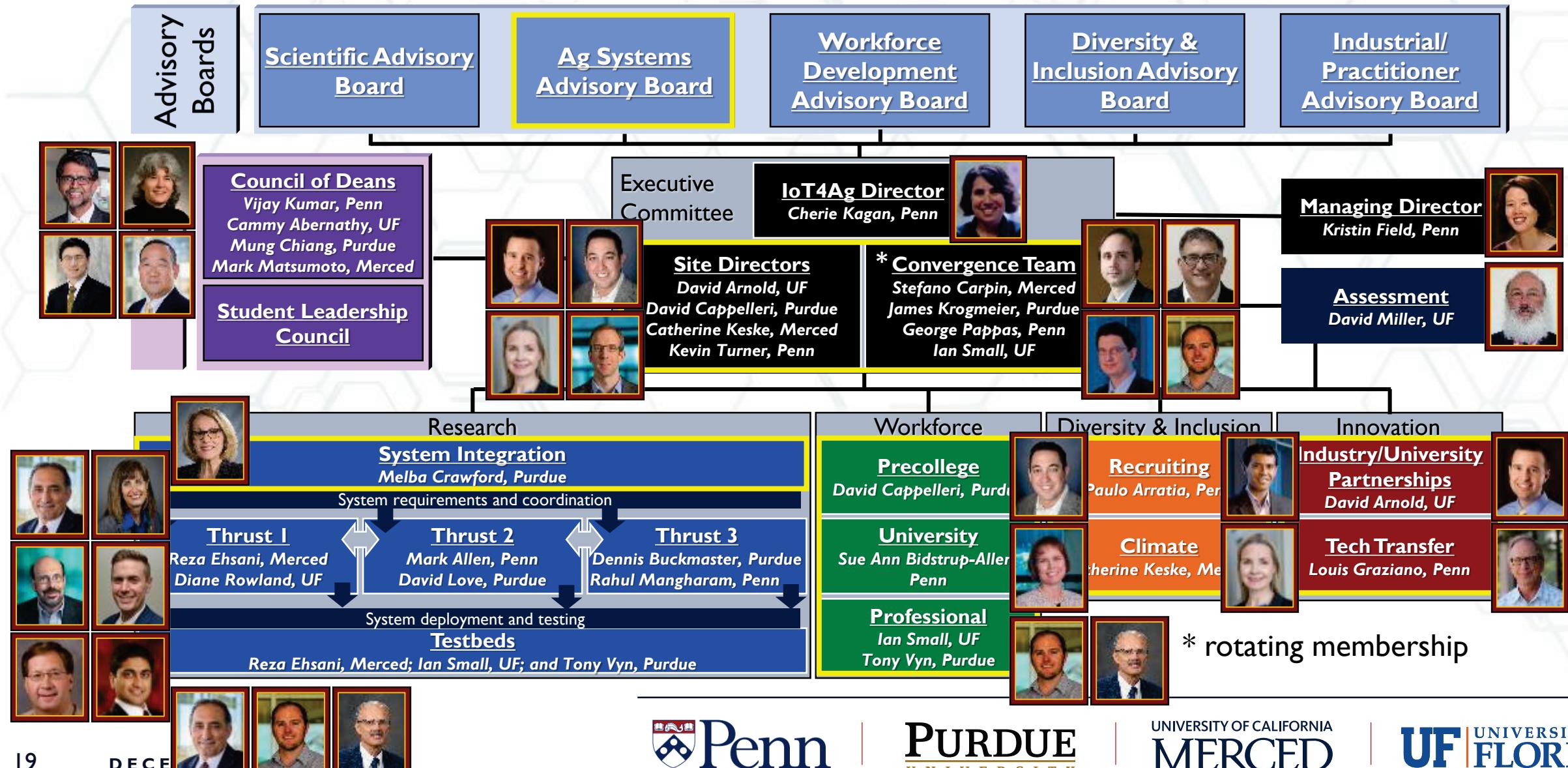


Plot Scale



Field and Farm Scale

IoT4Ag Organization



Systems Integration

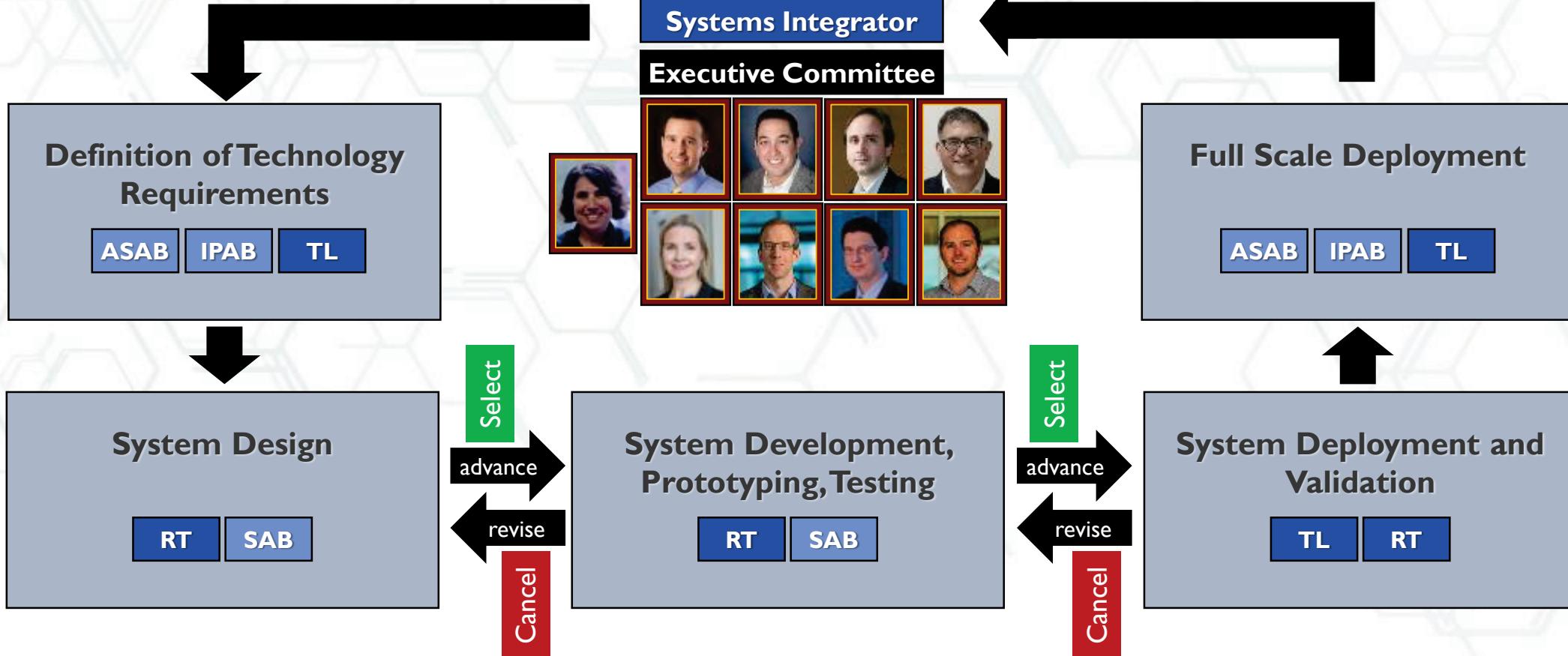
ASAB = Ag Systems Advisory Board

IPAB = Industrial Practitioner Advisory Board

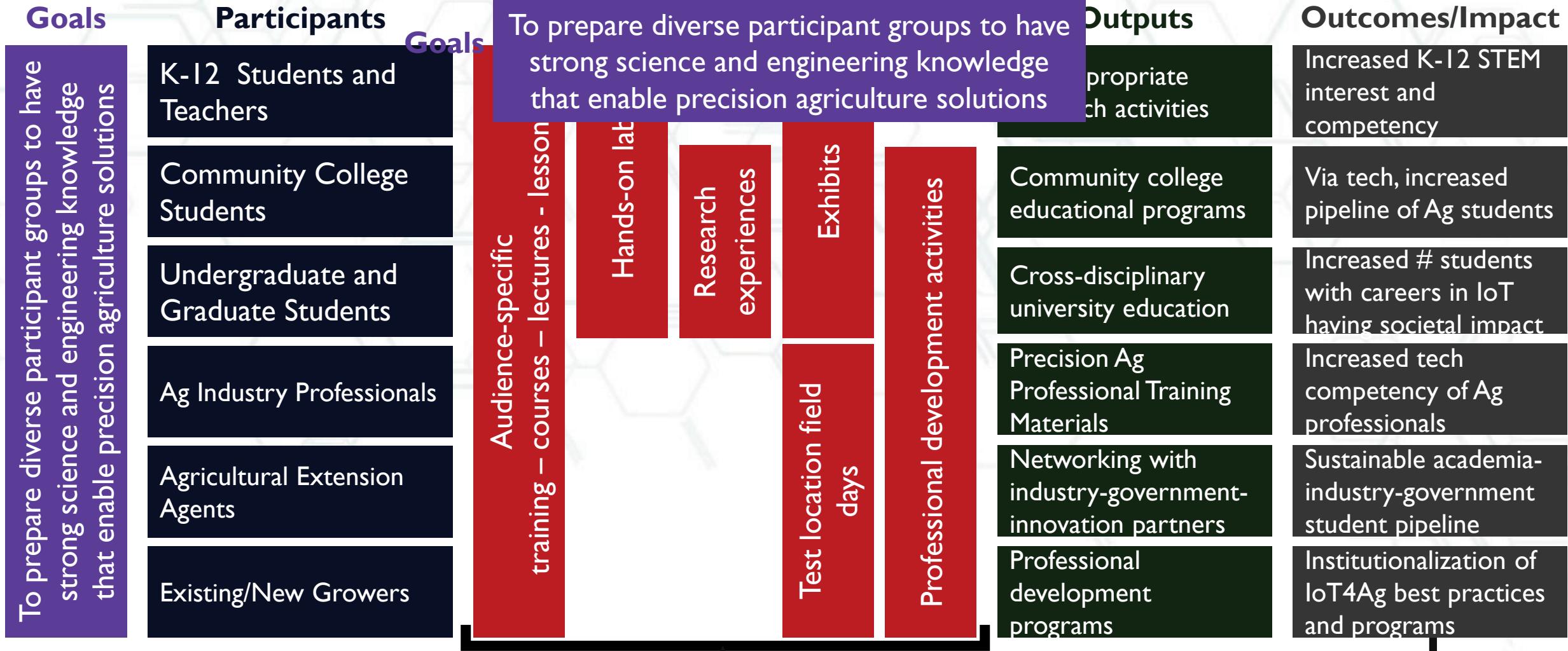
SAB = Scientific Advisory Board

TL = Testbed Leaders

RT = Research Thrusts



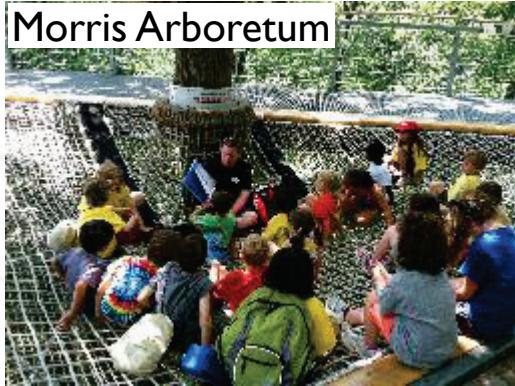
Workforce Development



Workforce Development: Pre-College

Co-development of lesson plans, hands-on/lab kits, and exhibits to increase K-12 STEM interest and competency

Morris Arboretum



Cade Museum for Creativity and Invention



Future Farmers of America



NextGen Expo



Ag in the Classroom



Saul High School of Agricultural Sciences



4-H



Workforce Development: Community College Partnerships

To increase the knowledge and pipeline of Ag and engineering students via education and training in innovative Ag technologies

- IoT4Ag guest lectures and technology demonstrations
 - Hands-on lab activities
- Participation in NextGen Expo
 - Research Opportunities
 - Matriculation into 4-year engineering and agriculture degree programs



- 13% female, 29% Hispanic, 5% AA, 17% first-generation college student
- Non-traditional students: ~20% single parents, >75% working students, average age is 28
- Launching 2-year certificate and degree programs in Precision Agriculture Equipment Technology



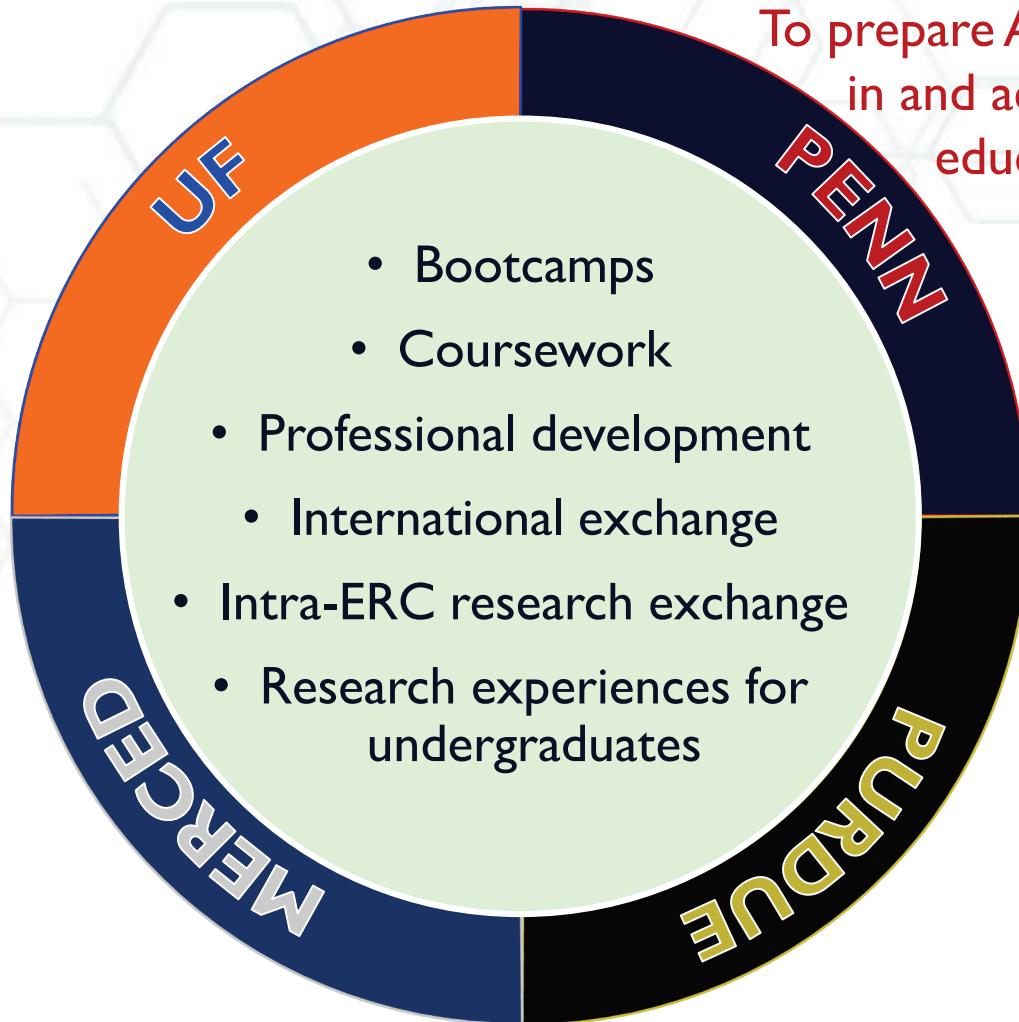
Penn

PURDUE
UNIVERSITY

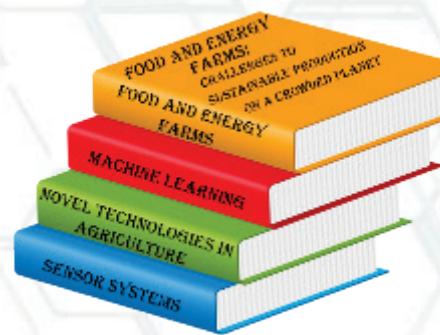
UNIVERSITY OF CALIFORNIA
MERCED

UF UNIVERSITY of
FLORIDA

Workforce Development: University Education



To prepare Ag – Tech leaders through collaborative co-education and co-training in and across our classrooms, in our labs, in our agricultural research and education extension facilities, and with our international partners



Workforce Development: Professionals

To increase precision agriculture tech competency and support certification of Ag professionals

- IoT4Ag guest lectures and technology demonstrations
 - Educational materials
 - Field days
 - Certified Crop Adviser certification
- Workshops and consultations
 - Computer networking



Purdue, UC, UF Extensions :“bring science-based solutions ... to agricultural and natural resource industries” and “to make knowledge accessible to enhance the quality of human life”

Quote: UF Extension



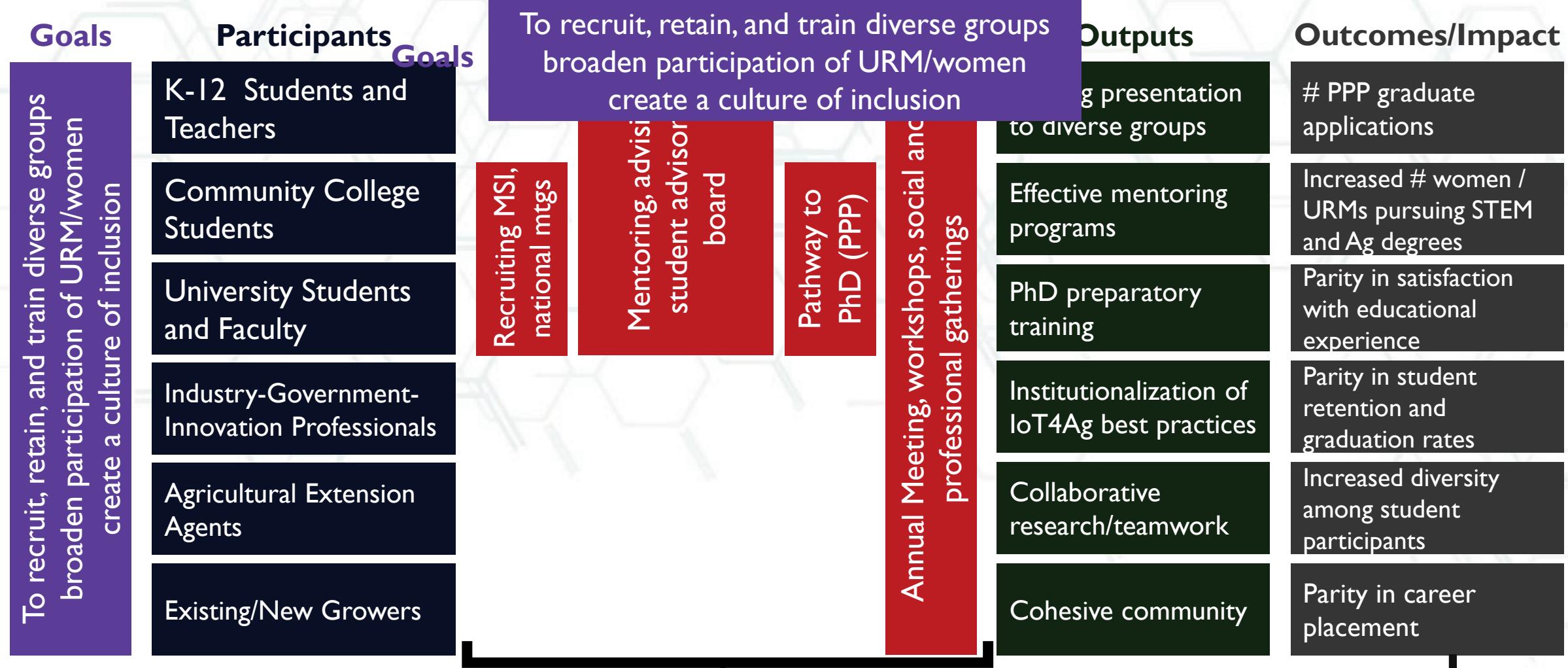
Penn

PURDUE
UNIVERSITY

UNIVERSITY OF CALIFORNIA
MERCED

UF UNIVERSITY of
FLORIDA

Diversity and Culture of Inclusion



Diversity & Culture of Inclusion

recruit, retain, and train

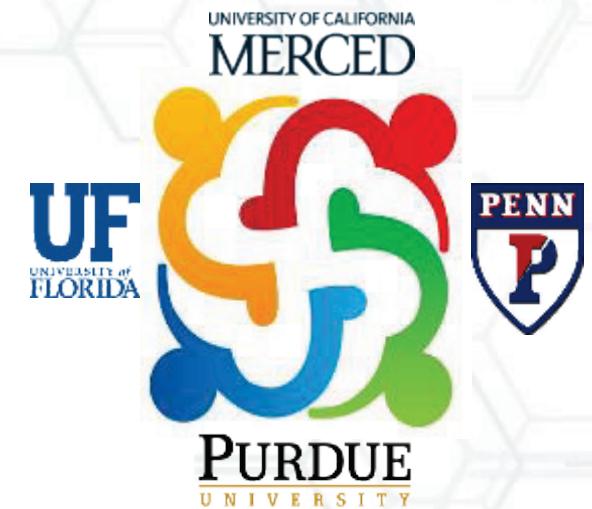
- Operate locally through Offices of Diversity & Inclusion at each site and extend programs to IoT4Ag
 - National scholar programs (GEM, LSAMP, Meyerhoff, McNair)
 - Relationship building with minority serving institutions
 - National meetings (NSBE, SHPE, IVY+)
- Create new programs, e.g. Pathway to Ph.D. Program, a signature IoT4Ag program
- Establish a culture of inclusivity via education, mentoring/tri-annual advising, social and professional activities



Pathway to PhD Program

Increase number and diversity of applicants to graduate school and graduate fellowships (NSF, GEM, etc)

- Share IoT4Ag research to exemplify the role of engineering in benefiting society as a vehicle to encourage diverse groups to pursue PhD studies
- 2-day workshops, yearly in September at all IoT4Ag institutions
 - UG research students + REU + women/URM students
 - Travel allowance will be provided; it is budgeted for
- Main workshop activities
 - Dispel URM/FGLI student misconceptions about graduate school
 - Draft resumes, personal statements, and application by end of workshop
 - IoT4Ag faculty and graduate students will serve as mentors; maintain relationship to provide continuity and encouragement



Institutional Partnership and Commitment to Innovation



- Relationships with companies & investment partners
- Educational programming supporting commercialization and entrepreneurship
- Innovation awards and prizes
- Incubators to translate research to production and new venture creation
- Intellectual property and licensing
- Contracts and agreements

Innovation Ecosystem

22 Companies
10 Innovation Partners
2 Government Partners

Policy / regulation Entrepreneurship Start-ups Med/Large Companies

Companies	Agricultural sensor systems	Communication and energy systems	Agricultural response systems
	     	    	     
Government and Innovation partners	  	   	    

Member Benefits:

- **IPAB** membership
- option to sponsor research
- option to send visiting scientists
- early access to IoT4Ag IP
- attend technical meeting
- seminars and short courses
- online resources and newsletters
- guide IoT4Ag system integration
- help create and maintain a technology outlook and roadmap for precision agriculture

University Incubators and Innovation Prizes

PENNOVATION WORKS



UC MERCED VENTURE LAB



PURDUE RESEARCH PARK OF WEST LAFAYETTE



- Blend of state-of-the-art wet and dry labs, offices, and production spaces
- Meeting and maker spaces
- Co-located with university innovation offices



WHAT'S YOUR
BIG IDEA?



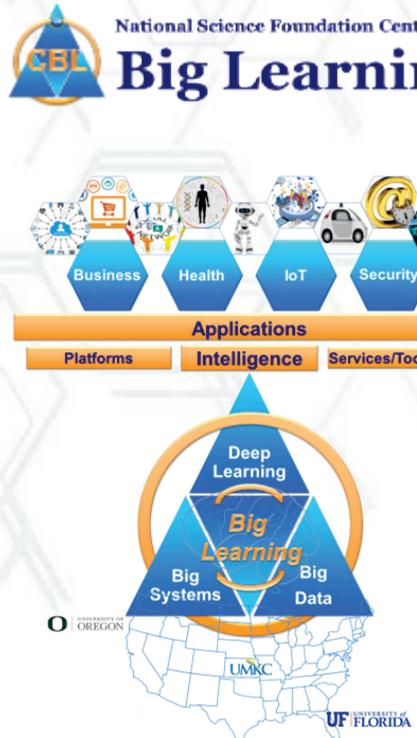
**BURTON D. MORGAN
BUSINESS PLAN
COMPETITION**

- Awards to support student innovation and entrepreneurship

Partnership with NSF-Supported Activities

UF's NSF I/UCRCs

Industry-University Cooperative Research Centers



Penn, Purdue, and Merced NSF I-CORPS



Exploit vibrant programs and cultures for industry-university partnerships and entrepreneurship

Assessment

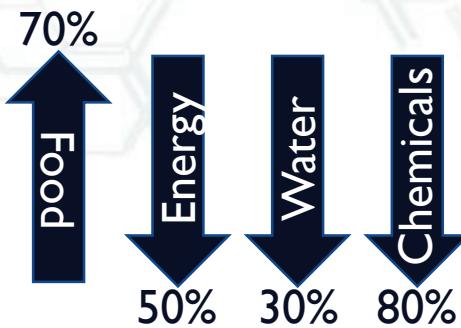
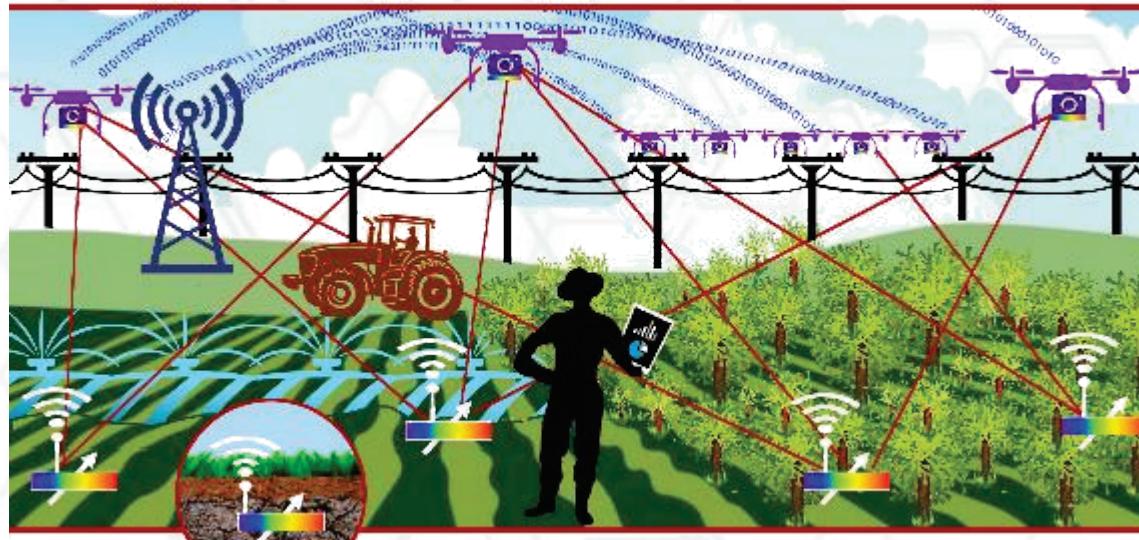
Feedback cycle of programs – assessment to improve IoT4Ag outcomes in our research, workforce development, diversity and inclusion, and innovation ecosystem

- University of Florida, College of Education
 - Formative and summative assessment of implementation, effectiveness, impact, and sustainability
 - Longitudinal tracking, surveys, focus groups, secondary analysis of institutional data
 - IRB approval
- Annual Meeting with leadership to review and act on assessment to improve programs
 - University of Florida, College of Education evaluation
 - Scientific, Workforce Development, Diversity and Inclusion, Industrial Practitioner, and Ag System Advisory Board input
 - Student Leadership Council input



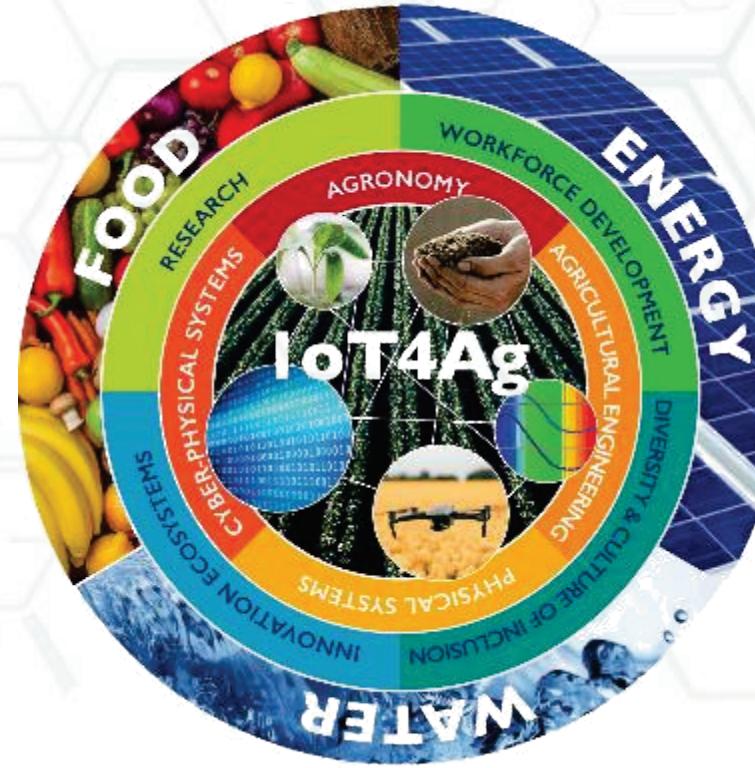
Over the Next 10 Years ...

integrated sensor-communication-response systems



- Transformative science and engineering to create integrated systems for precision agriculture
- Transdisciplinary collaborations
- A diverse, well-educated workforce for the future of Ag
- More crop for every drop of water or Joule of energy
- Sustainable agricultural processes
- \$47 billion dollar/year increase in crop market value in the US

IoT4Ag will ...



Deliver Internet of Things (IoT) technologies for precision agriculture that enable a food, energy, and water secure future