Faculty and Staff Kickoff

NSF Engineering Research Center

for the Internet of Things for Precision Agriculture

Introductions

Bob Brier
Administrative Director

Steven Weiner
Innovation Ecosystem
Tech Transfer

Introductions

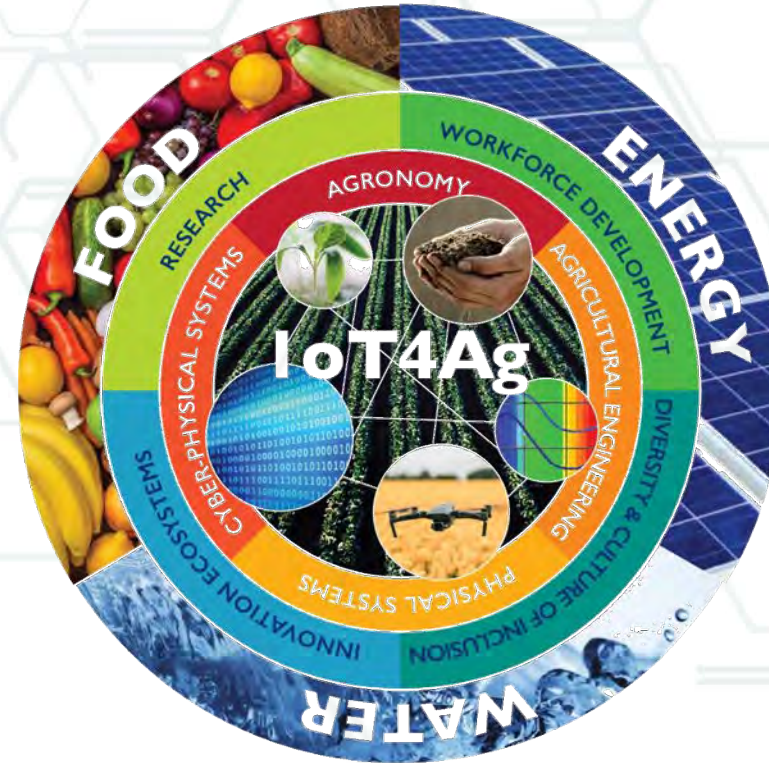Carl Huetteman
Purdue Research Coordinator

Dina Quinn
UF Research Coordinator

Blue Ribbon Panel

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

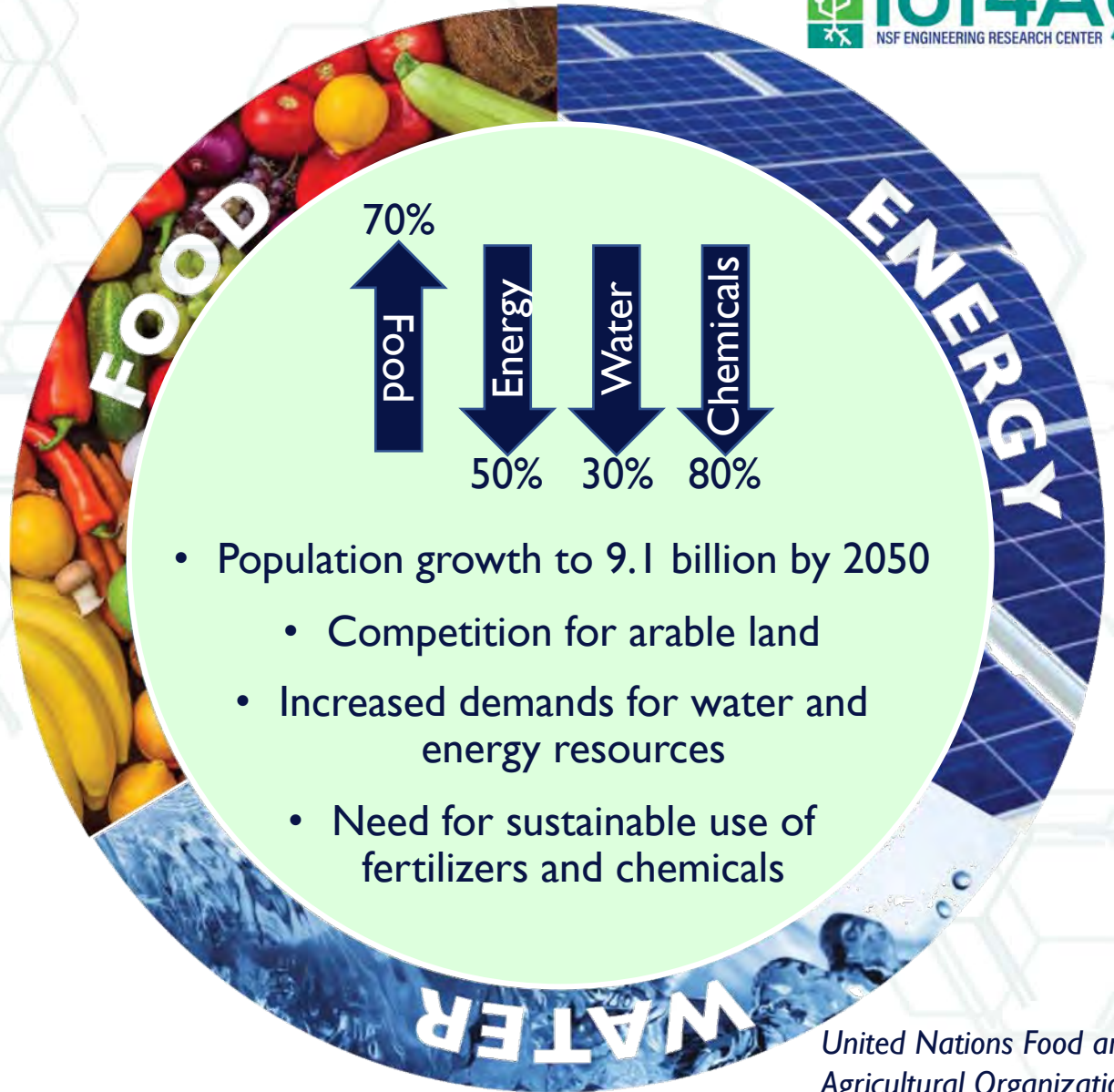| Cherie R Kagan	Catherine Keske	James Krogmeier	Rahul Mangharam	Diane Rowland
University of Pennsylvania	UC Merced	Purdue University	University of Pennsylvania	University of Florida

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

70%

Food ↑ | Energy ↓ | Water ↓ | Chemicals ↓

50% **30%** **80%**

- Population growth to 9.1 billion by 2050
  - Competition for arable land
  - Increased demands for water and energy resources
  - Need for sustainable use of fertilizers and chemicals

United Nations Food and Agricultural Organization

USDA

Penn | PURDUE UNIVERSITY | UNIVERSITY OF CALIFORNIA MERCED | UF UNIVERSITY of FLORIDA | NSF
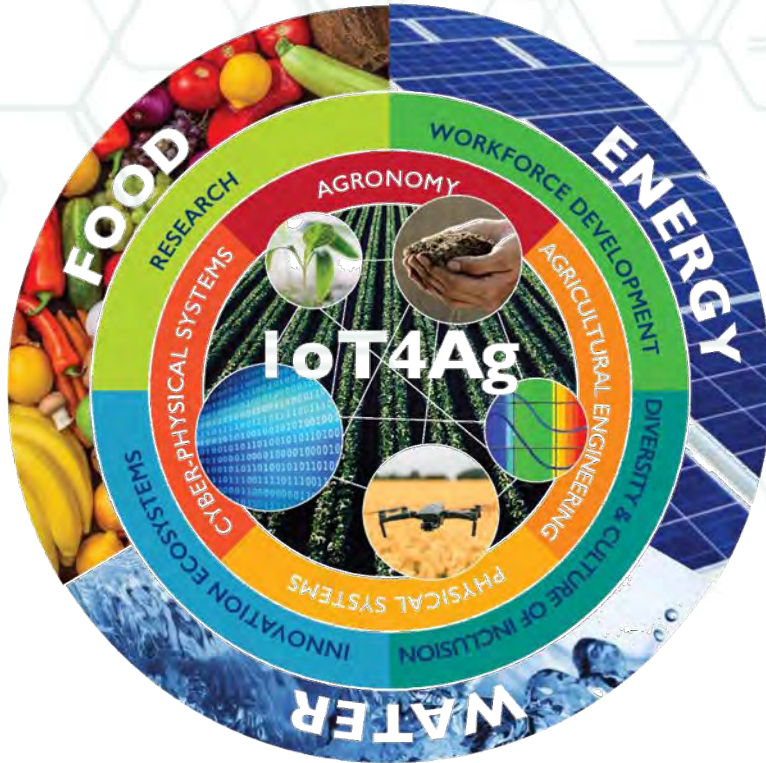
IoT4Ag Mission

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.
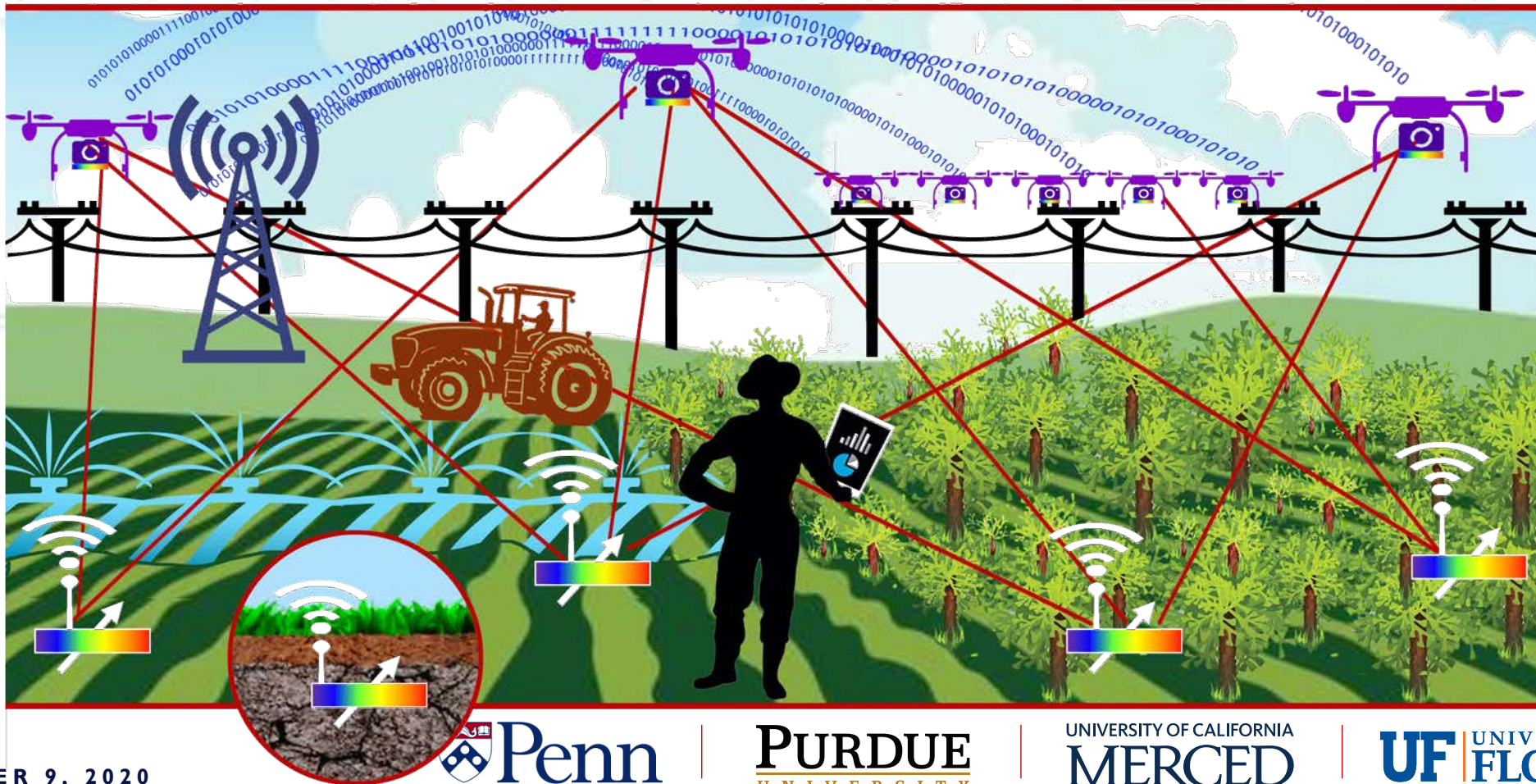
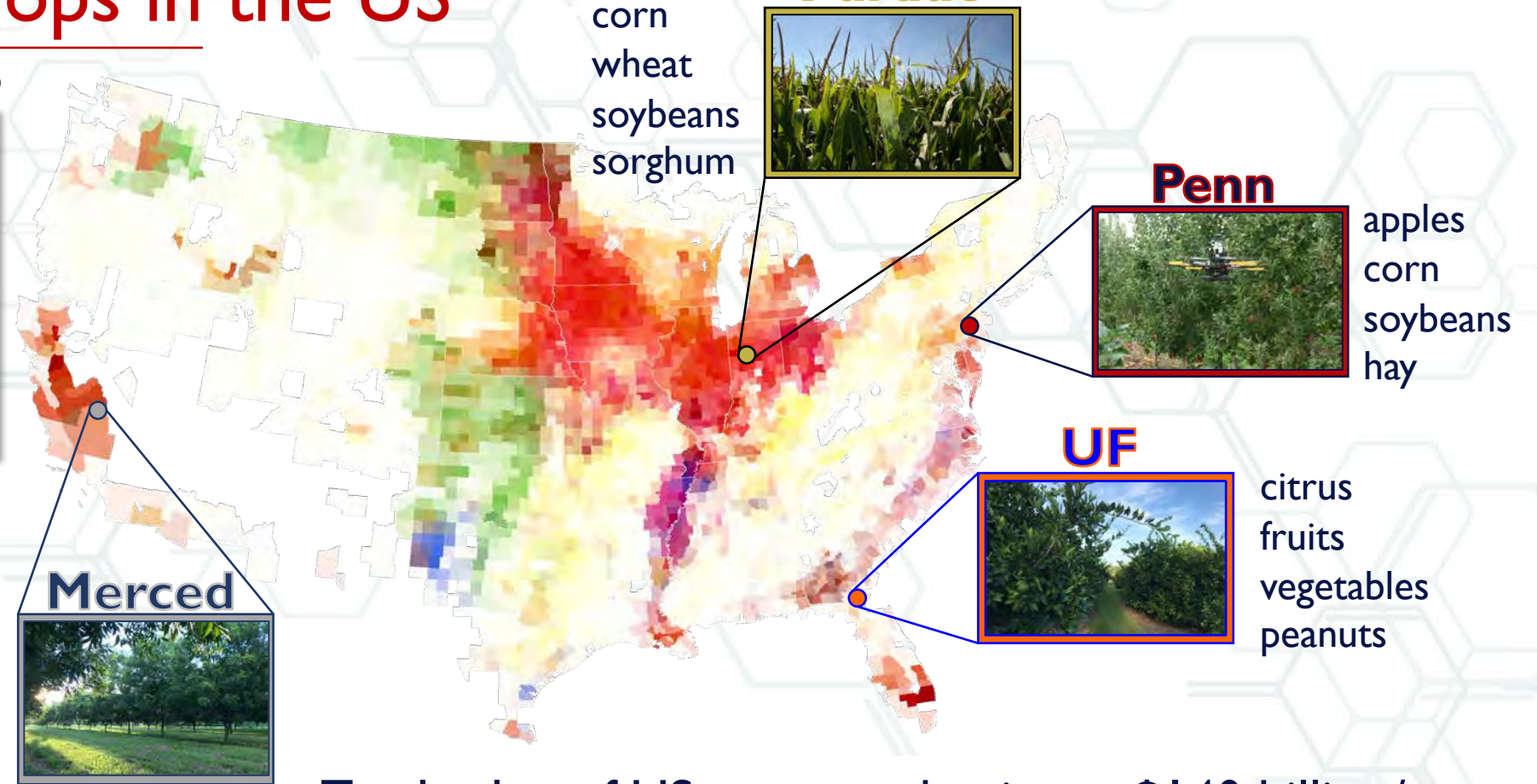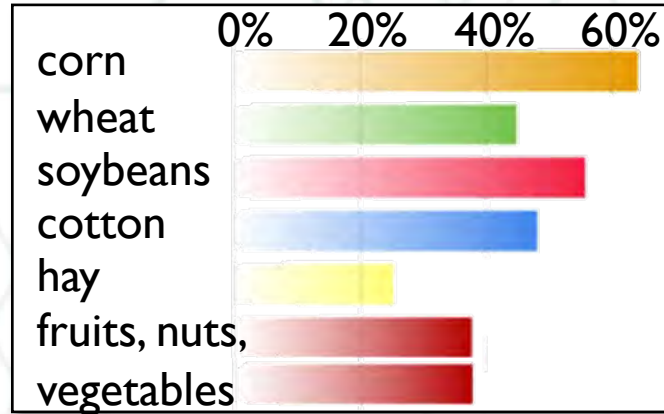# IoT4Ag and the NSF Big Ideas

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

corn
wheat
soybeans
cotton
hay
fruits, nuts,
vegetables

Purdue

corn
wheat
soybeans
sorghum

Penn

apples
corn
soybeans
hay

UF

citrus
fruits
vegetables
peanuts

Merced

fruits
citrus
vegetables
nuts

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

USDA
United States Department of Agriculture

Report to the President of the United States from the Task Force on Agriculture and Rural Prosperity

AGRICULTURE AND RURAL PROSPERITY · TASK FORCE

October 2017

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."

FUTURE of FOOD

Harnessing Digital Technologies to Improve Food System Outcomes

April 2019

WORLD BANK GROUP

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
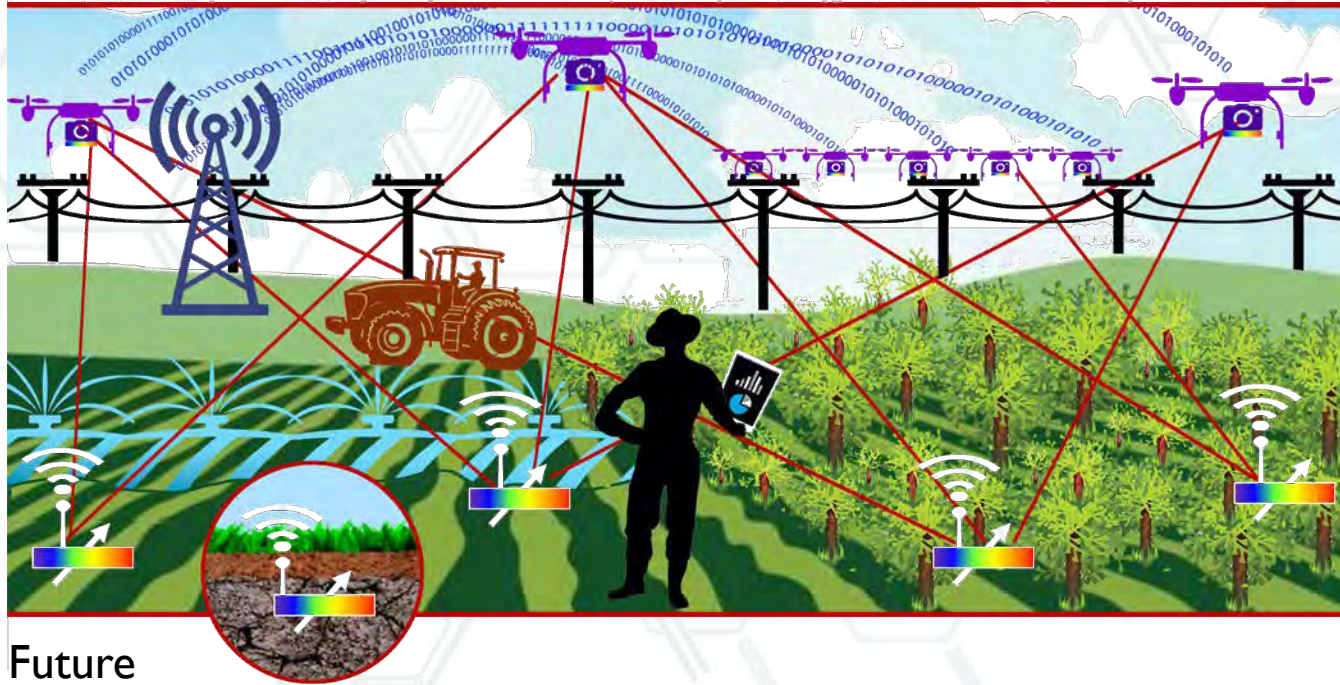
Future

Projected: + $47 billon/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
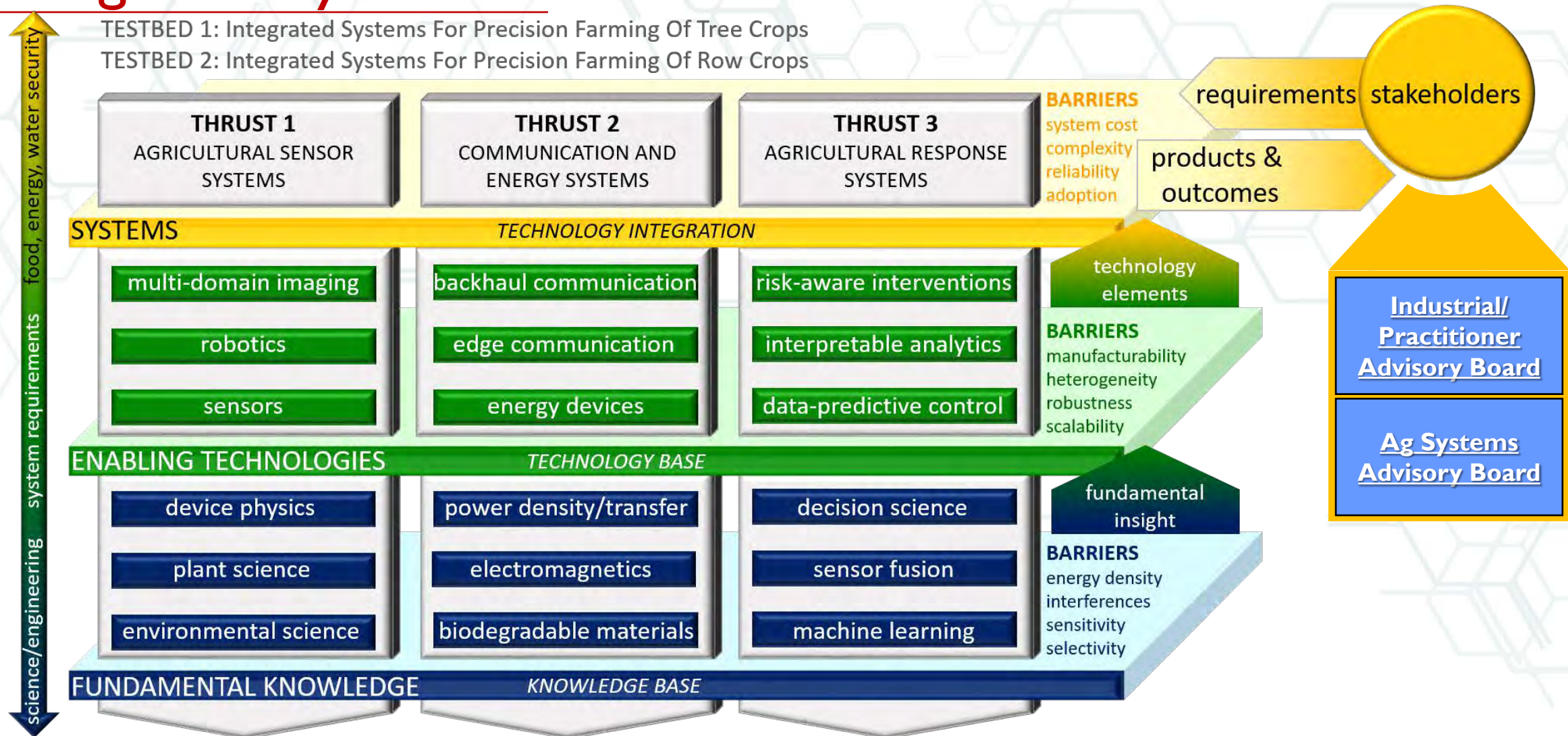
Agronomy Center for Research and Education (ACRE)

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

Integrated-Systems Level Problem

TESTBED 1: Integrated Systems For Precision Farming Of Tree Crops
TESTBED 2: Integrated Systems For Precision Farming Of Row Crops

THRUST 1 AGRICULTURAL SENSOR SYSTEMS	THRUST 2 COMMUNICATION AND ENERGY SYSTEMS	THRUST 3 AGRICULTURAL RESPONSE SYSTEMS

BARRIERS
system cost
complexity
reliability
adoption

requirements stakeholders

products & outcomes

SYSTEMS *TECHNOLOGY INTEGRATION*

multi-domain imaging	backhaul communication	risk-aware interventions
robotics	edge communication	interpretable analytics
sensors	energy devices	data-predictive control

technology elements

BARRIERS
manufacturability
heterogeneity
robustness
scalability

ENABLING TECHNOLOGIES *TECHNOLOGY BASE*

device physics	power density/transfer	decision science
plant science	electromagnetics	sensor fusion
environmental science	biodegradable materials	machine learning

fundamental insight

BARRIERS
energy density
interferences
sensitivity
selectivity

FUNDAMENTAL KNOWLEDGE *KNOWLEDGE BASE*

food, energy, water security
system requirements
science/engineering

Industrial/ Practitioner Advisory Board

Ag Systems Advisory Board

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
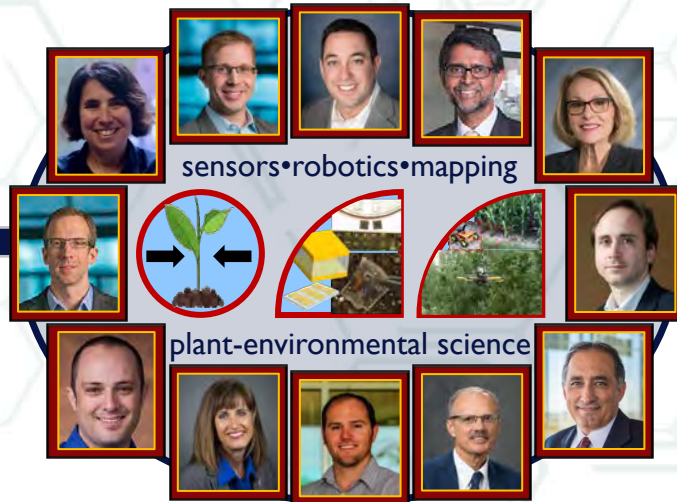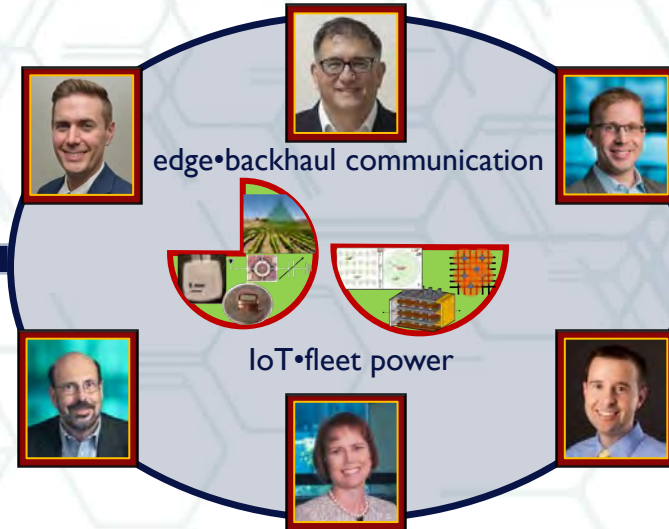

| Thrust 1 | Thrust 2 | Thrust 3 |
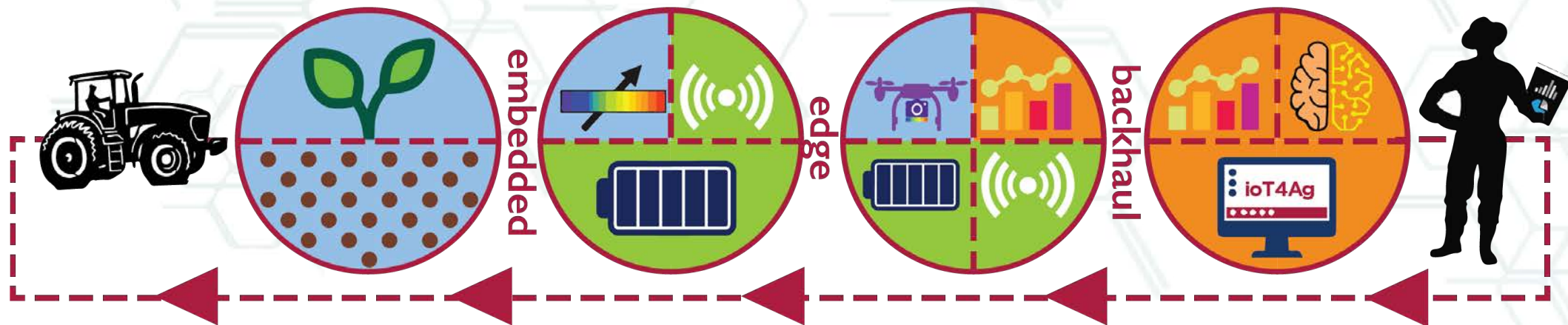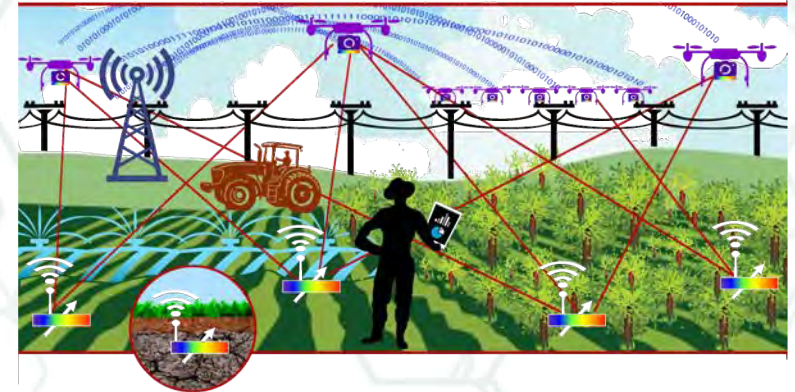
IoT4Ag Team: Convergence of Experts
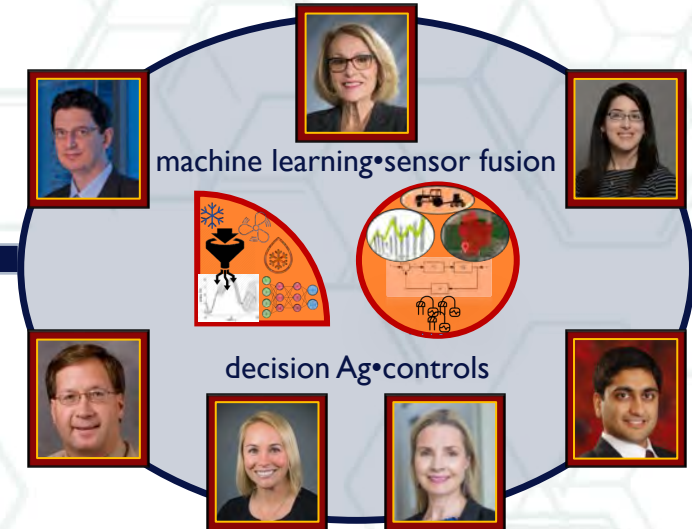

Thrust 1: Agricultural Sensor Systems

Thrust 2: Communication and Energy Systems

Thrust 3: Agricultural Response Systems

sensors•robotics•mapping

plant-environmental science

4 Universities • 8 Departments

edge•backhaul communication

IoT•fleet power

3 Universities • 4 Departments

machine learning•sensor fusion
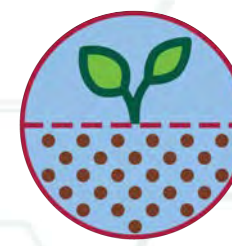
decision Ag•controls

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

plant targets

environmental targets

growth/leaf area index ⟶

nutrient status ⟶

disease ⟶

water deficit stress ⟶

pests ⟶

yield ⟶

⟵ soil type
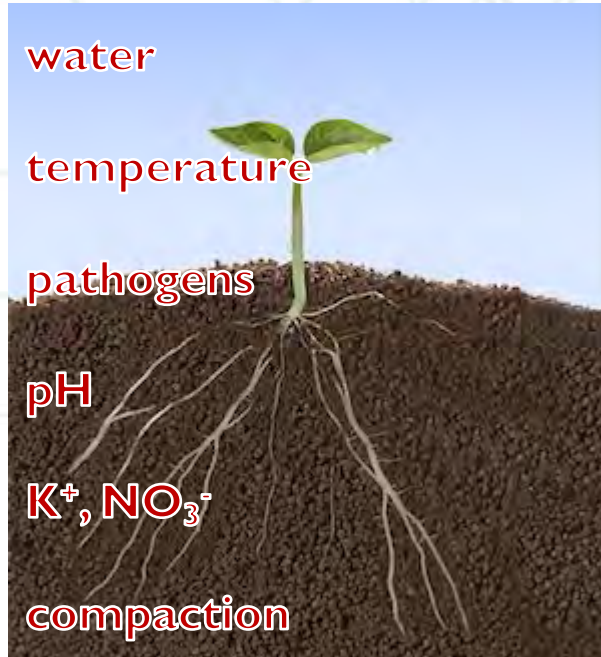
⟵ soil nutrients

⟵ disease

⟵ compaction

⟵ water

⟵ weeds

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

water

temperature

pathogens

pH

K⁺, NO₃⁻

compaction

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

optical

adaptive polymer

NR n'

RF

C
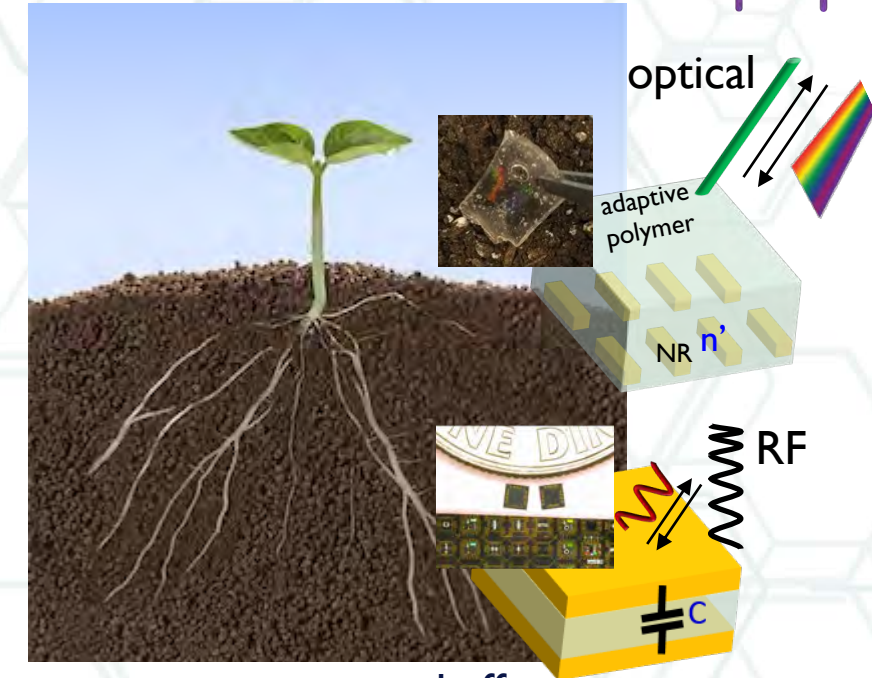
sensor chaff zero-/near-zero power, scale to ~10^5 sensors/acre <1¢ – $1 /sensor/season

Penn | PURDUE UNIVERSITY | UNIVERSITY OF CALIFORNIA MERCED | UF UNIVERSITY of FLORIDA | NSF

Autonomous Fleet Operation

Biglerville, PA

IoT4Ag fleet

Orange Cove, CA

counting oranges

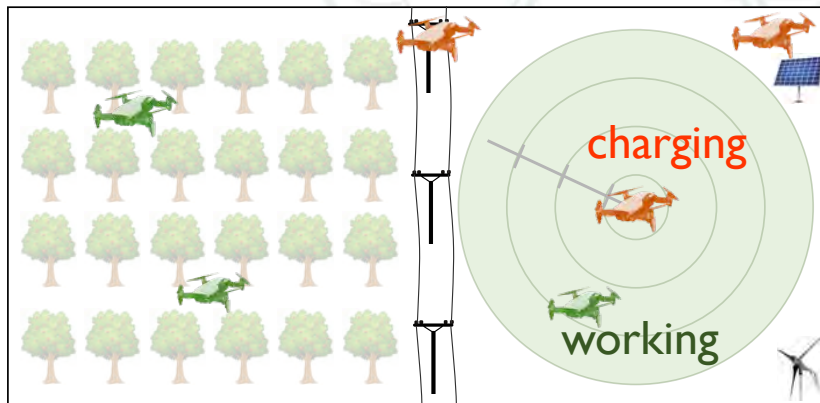robots autonomously navigating above and below the canopy

semantic mapping at scale in unstructured environments

charging

working

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

Ag-Specific Communication Solutions

Sense

Control

Plan

- 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
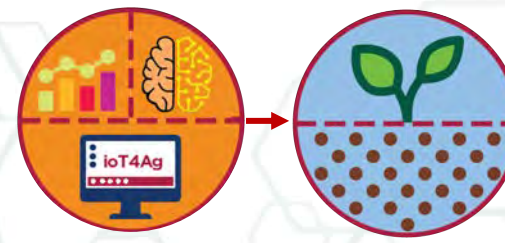
Data-driven Models

Data-driven Models
- Feature extraction
- Multi-temporal, multi-modal architecture

↕

Biophysical Models
- Plant physiology
- Soils
- Weather
- Management practices
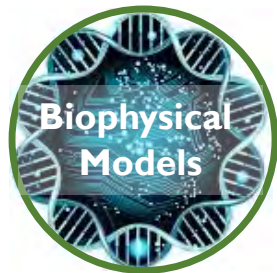
Biophysical Models

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

PEST 1
BEETLE
VIRUS
INCONSISTENT CANOPY COVERAGE
PLANTER MISS
EARLY BLIGHT

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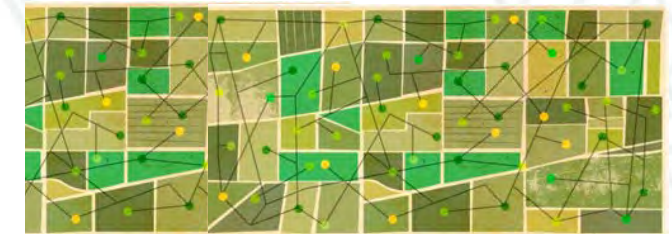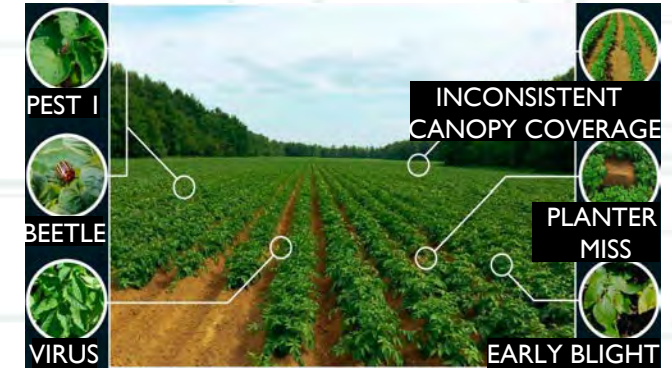
Facilities: Convergence of Technology and Agriculture

- Well-equipped PI labs

- World-class shared facilities

- Agricultural Research and Extension Centers

- Dedicated IoT4Ag Headquarters

Fabrication

Manufacturing

Testing

Data

Controlled Facilities

Plot Scale

Plot: 4810

Field and Farm Scale
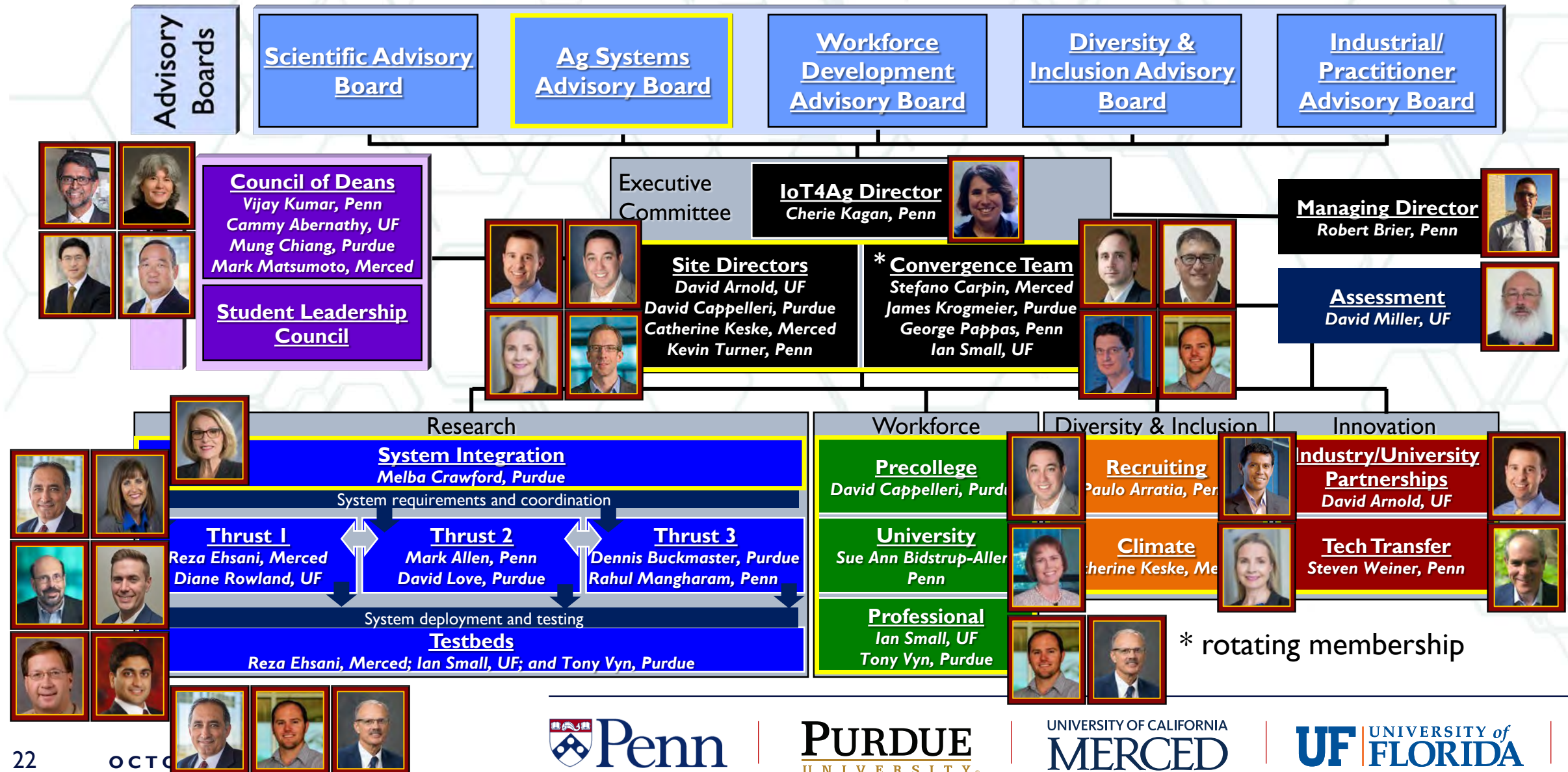
Systems Integration

Workforce Development

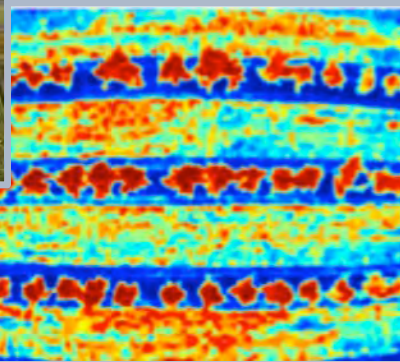| Goals	Participants	Goals					Outputs	Outcomes/Impact
To prepare diverse participant groups to have strong science and engineering knowledge that enable precision agriculture solutions	K-12 Students and Teachers	Audience-specific training – courses – lectures - lesson	Hands-on lab	Research experiences	Exhibits	Professional development activities	appropriate ch activities	Increased K-12 STEM interest and competency
	Community College Students						Community college educational programs	Via tech, increased pipeline of Ag students
	Undergraduate and Graduate Students						Cross-disciplinary university education	Increased # students with careers in IoT having societal impact
	Ag Industry Professionals				Test location field days		Precision Ag Professional Training Materials	Increased tech competency of Ag professionals
	Agricultural Extension Agents						Networking with industry-government-innovation partners	Sustainable academia-industry-government student pipeline
	Existing/New Growers						Professional development programs	Institutionalization of IoT4Ag best practices and programs

To prepare diverse participant groups to have strong science and engineering knowledge that enable precision agriculture solutions

Assessment

Workforce Development: Pre-College

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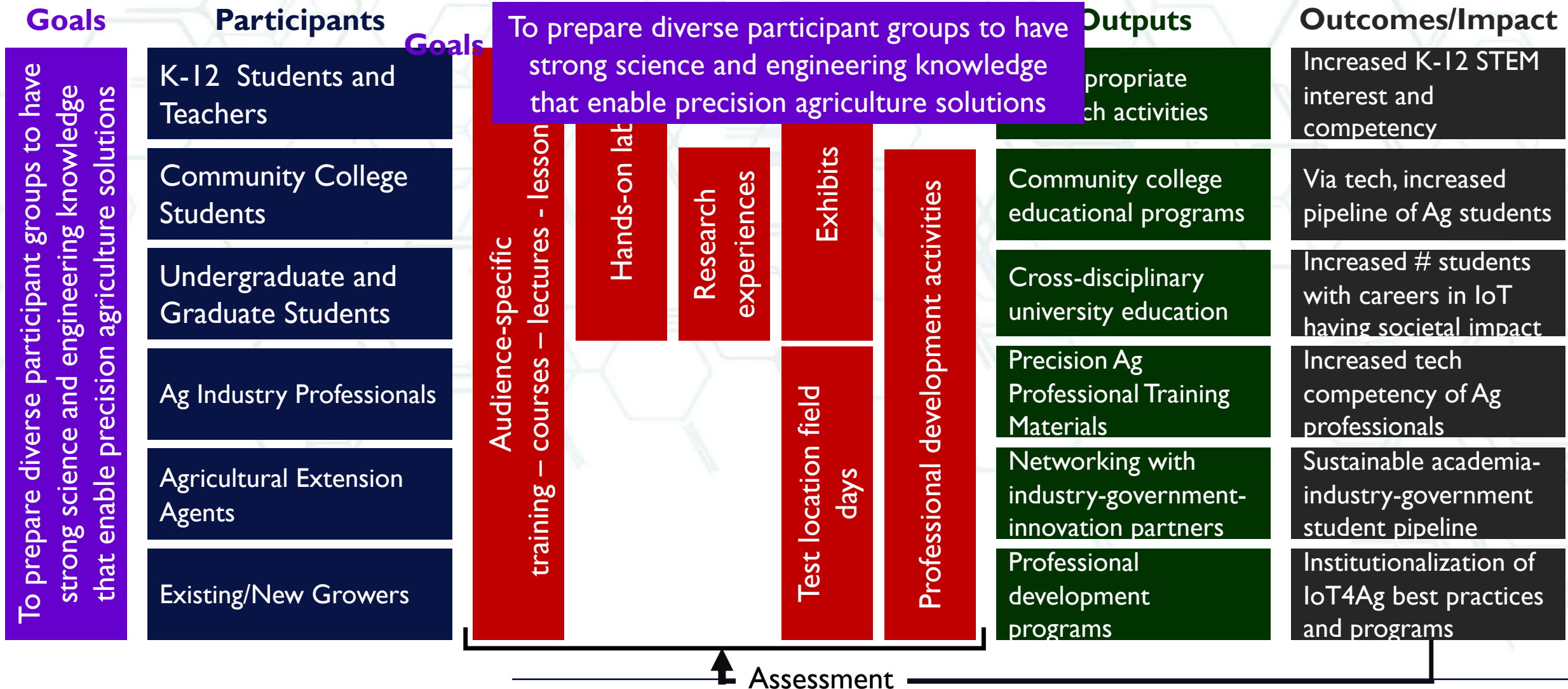

Morris Arboretum

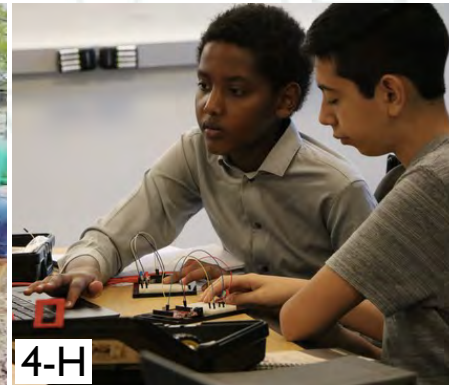Cade Museum for Creativity and Invention

Future Farmers of America

NextGen Expo

Ag in the Classroom

Saul High School of Agricultural Sciences

4-H

deaf kids CODE

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

Santa Fe College
Gainesville, FL

Ivy Tech Community College
of Indiana

- 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

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

- Bootcamps
- Coursework
- Professional development
- International exchange
- Intra-ERC research exchange
- Research experiences for undergraduates

UF
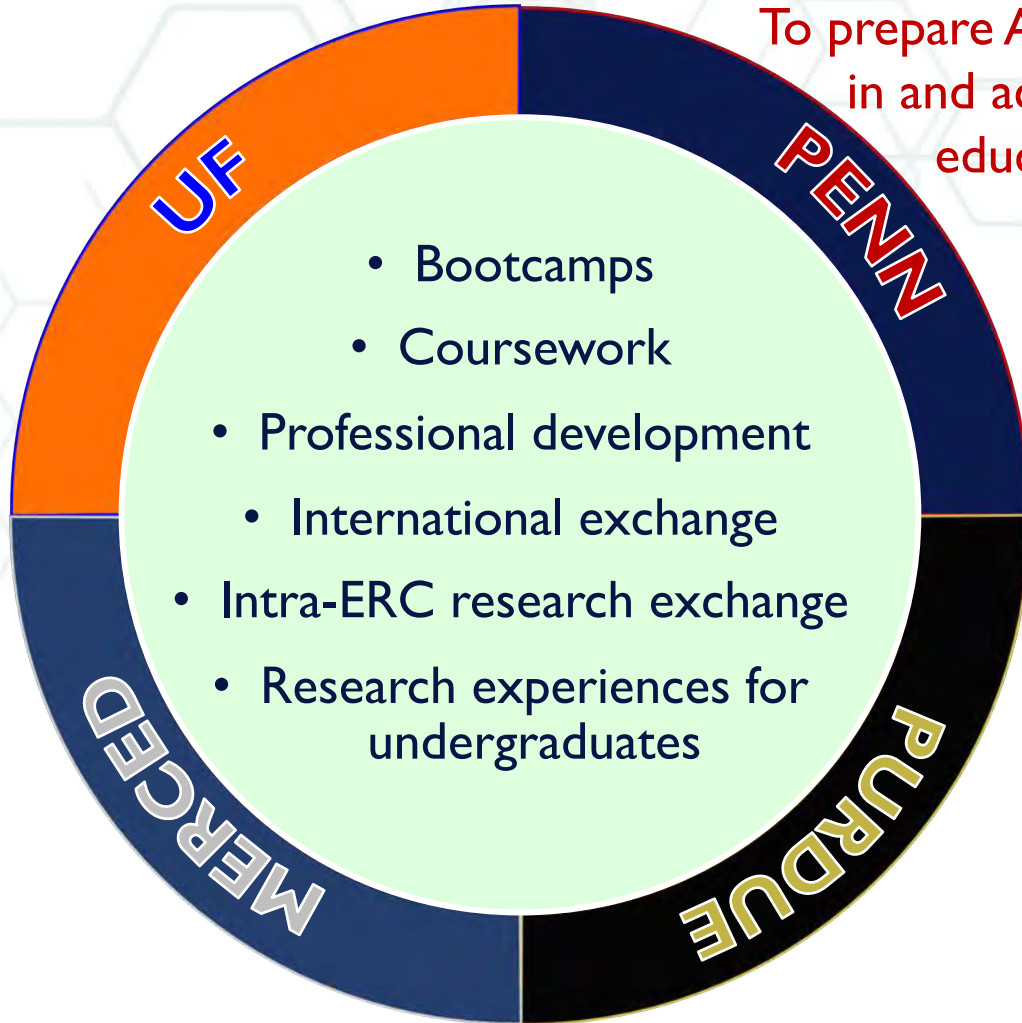
PENN

MERCED

PURDUE

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
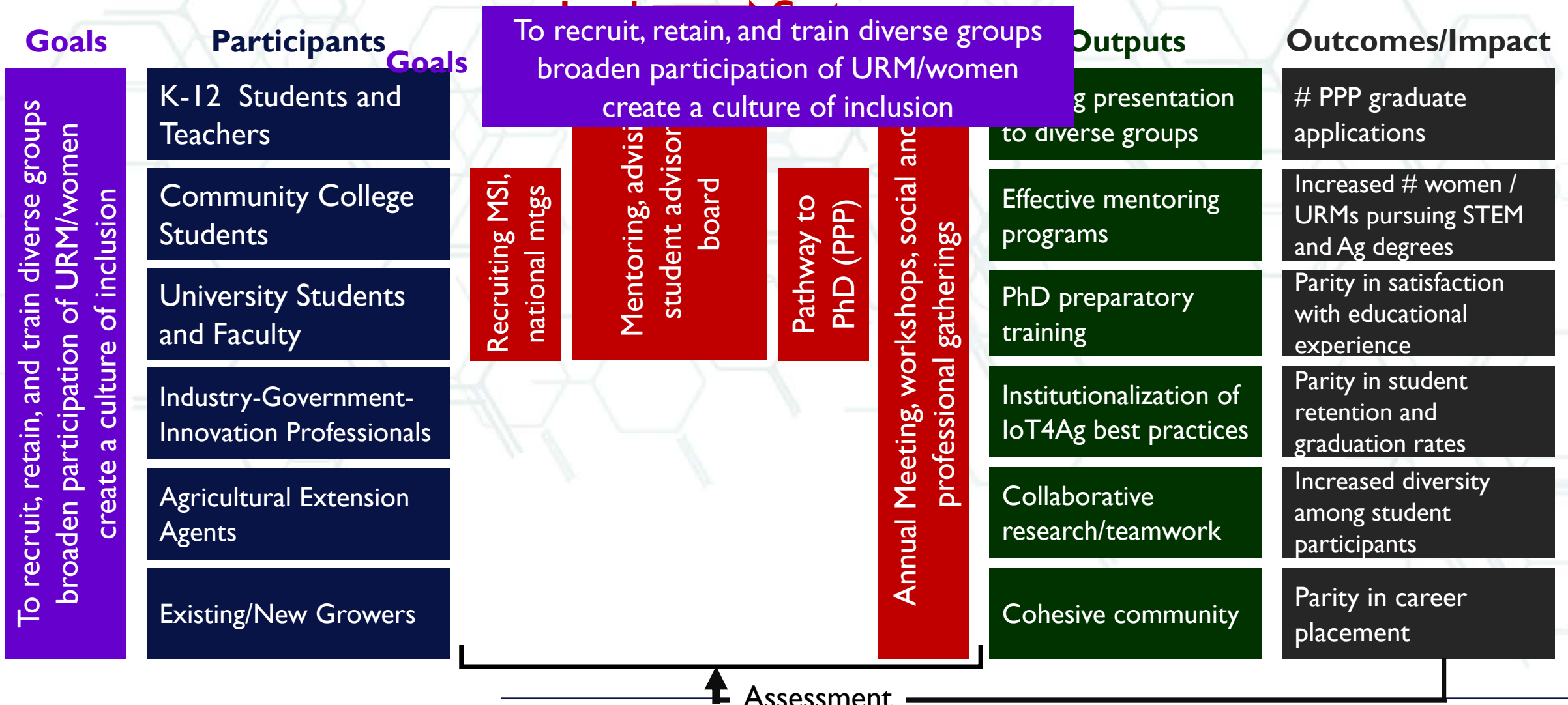- Workshops and consultations
- Computer networking

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

Diversity and Culture of Inclusion

Goals	Participants	Goals				Outputs	Outcomes/Impact

To recruit, retain, and train diverse groups broaden participation of URM/women create a culture of inclusion

To recruit, retain, and train diverse groups broaden participation of URM/women create a culture of inclusion	K-12 Students and Teachers					presentation to diverse groups	# PPP graduate applications
	Community College Students	Recruiting MSI, national mtgs	Mentoring, advising student advisory board	Pathway to PhD (PPP)	Annual Meeting, workshops, social and professional gatherings	Effective mentoring programs	Increased # women / URMs pursuing STEM and Ag degrees
	University Students and Faculty					PhD preparatory training	Parity in satisfaction with educational experience
	Industry-Government-Innovation Professionals					Institutionalization of IoT4Ag best practices	Parity in student retention and graduation rates
	Agricultural Extension Agents					Collaborative research/teamwork	Increased diversity among student participants
	Existing/New Growers					Cohesive community	Parity in career placement

Assessment

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
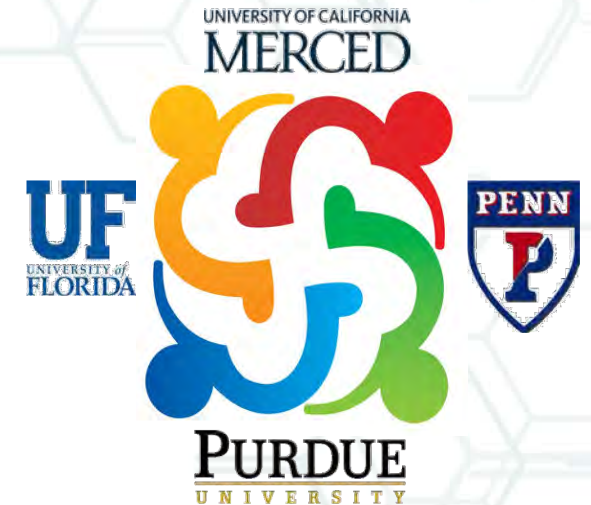
Institutional Partnership and Commitment to Innovation
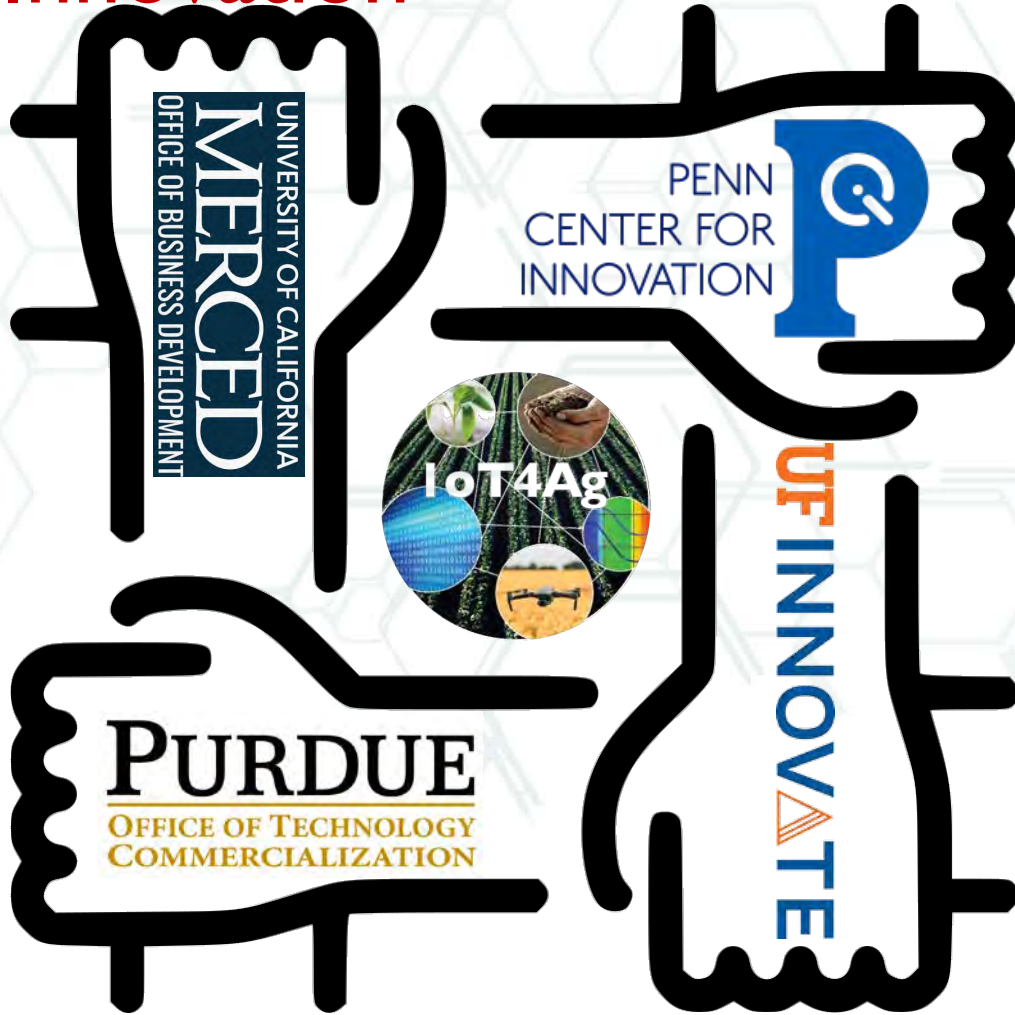
- Relationships with companies & investment partners

- 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

IoT4Ag
NSF ENGINEERING RESEARCH CENTER

Companies

Med/Large Companies · Start-ups · Entrepreneurship · Policy /regulation

Agricultural sensor systems

BOSCH
intel
MicaSense
DJI
GGB
PRECISIONHAWK
STRELLA BIOTECHNOLOGY
AG·R AUGEAN ROBOTICS

Communication and energy systems

LOCKHEED MARTIN
QUALCOMM
BLUE RIVER TECHNOLOGY
Headwall PHOTONICS
CNH INDUSTRIAL
SunSouth
agribugs
Trefo LLC

Agricultural response systems

CORTEVA agriscience
suez
FMC
THE CLIMATE CORPORATION
USGA
Cotton Incorporated

Government and Innovation partners

imec
MIST CENTER
INDIANA iot LAB FISHERS
PANTHEON education center
élevate ventures
bridg
Bridging the Innovation Development Gap
N-MaC
Ben Franklin Technology PArtners
Southeastern Pennsylvania
WHIN
pennsylvania DEPARTMENT OF AGRICULTURE
Indiana A State that Works
FLORIDA DEPARTMENT OF AGRICULTURE AND CONSUMER SERVICES

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

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University Incubators and Innovation Prizes

PENNOVATION WORKS

PURDUE RESEARCH PARK OF WEST LAFAYETTE

UC MERCED VENTURE LAB

Sid Martin Biotech

- Blend of state-of-the-art wet and dry labs, offices, and production spaces

- Meeting and maker spaces
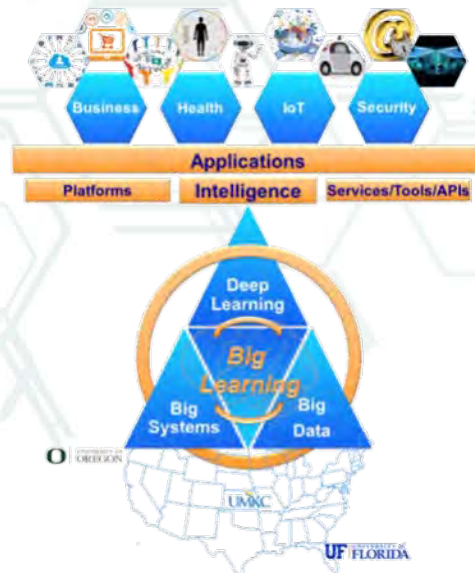
- Co-located with university innovation offices

- 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

70%
Food

Energy 50%

Water 30%

Chemicals 80%
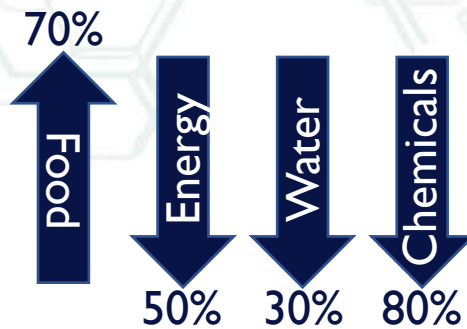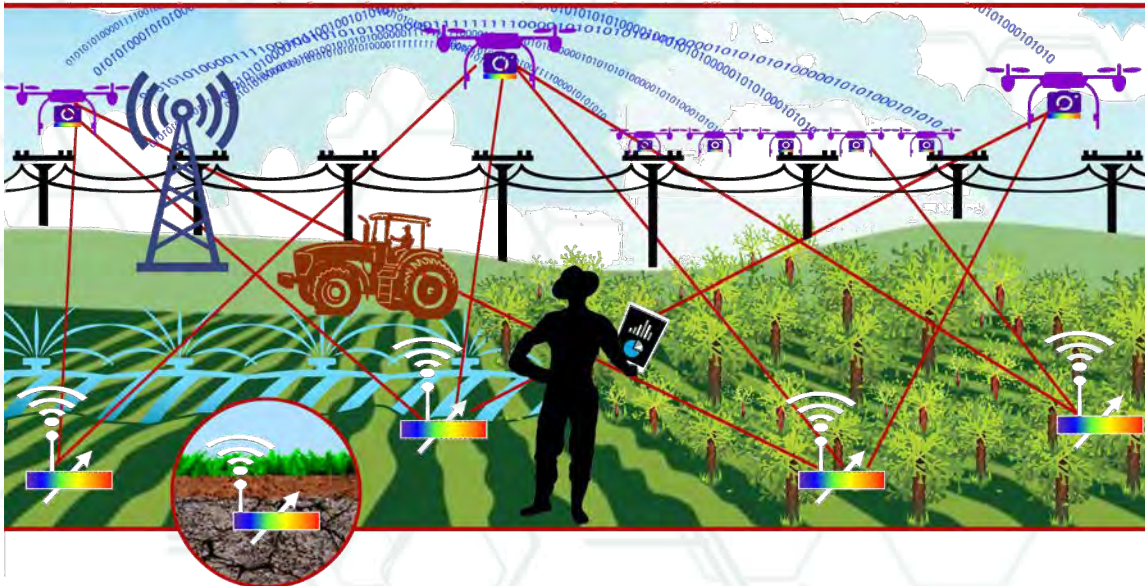
- Transformative science and engineering to create integrated systems for precision agriculture
- Transdisciplinary collaborations
- A diverse, well-educated workforce for the future of Ag
- More crop for every drop of water or Joule of energy
- Sustainable agricultural processes
- $47 billion dollar/year increase in crop market value in the US

IoT4Ag will …
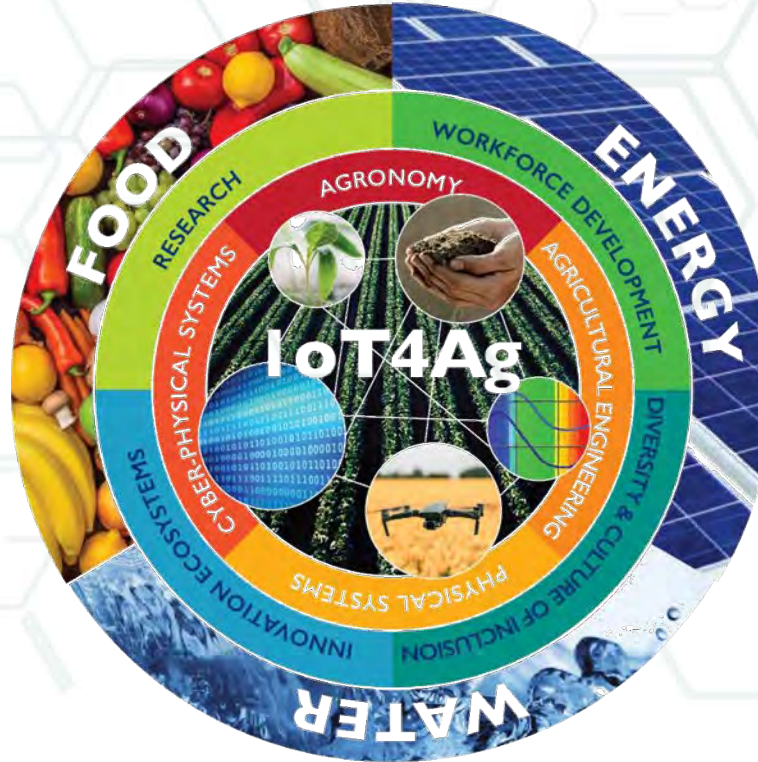
Deliver Internet of Things (IoT) technologies for precision agriculture that enable a food, energy, and water secure future

Budget Revisions

Functional Budget Template (Year 1)	
Function	%
Thrust 1 Agricultural Sensor Systems	20.1
Thrust 2 Communication and Energy Systems	10.1
Thrust 3 Agricultural Response Systems	11.9
Research Total	42.1
Engineering Workforce Development Programs	3.6
Diversity and Culture of Inclusion Programs	0.8
Innovation Ecosystem Programs	4.8
Research Experiences for Undergraduates Program	1.1
General & Shared Equipment	0
New Facilities/New Construction	0
General Operating Expenses	1.0
Leadership/Administration/Management	14.2
Center Related Travel	3.3
Other (indicate expense in Footnote)	0
Indirect Cost	29.1
Total	100

Functional Budget Template (Year 1)	
Function	%
Thrust 1 Agricultural Sensor Systems	21.3
Thrust 2 Communication and Energy Systems	10.7
Thrust 3 Agricultural Response Systems	14.0
Research Total	46.0
Engineering Workforce Development Programs	6.4
Diversity and Culture of Inclusion Programs	3.1
Innovation Ecosystem Programs	9.0
Research Experiences for Undergraduates Program	1.2
General & Shared Equipment	0
New Facilities/New Construction	0
General Operating Expenses	0.6
Leadership/Administration/Management	3.6
Center Related Travel	1.0
Other (indicate expense in Footnote)	0
Indirect Cost	29.1
Total	100

Increased dollars in engineering workforce development and diversity and culture of inclusion

Information Exchange

- Microsoft OneDrive
  - Later today your will receive an invitation

- Microsoft Teams

NSF Reporting

- NSF ERC webpage for annual data metrics (coming soon):
  - Personnel – demographics, role, and project involvement
  - Institutions – partner and collaborations institutions (research, workforce dev)
  - Supporting Organizations – membership paying (i.e., industry)
  - Projects and Thrusts – create unique project identifiers
  - Financial – revenue and expenses
  - Outputs and Impact metrics – publications, outreach events, curriculum activities, students degrees and jobs, etc.
- NSF ERC website will generate a significant number of Excel spreadsheets and graphs

IoT4Ag Web-based Database

- IoT4Ag web-based database to assist with data collection and reporting

- Students, faculty, and leadership team will update their profiles and outputs and impact throughout the year

- Bob Brier will oversee the database, and send friendly reminders to keep us up to date (and avoid a stressful end-of-the-year rush)

Financial Reporting: Team of Business Administrators

- Terry Torres, Penn email: torrest@seas.upenn.edu

- Allison Granger, Purdue University email: agrange@purdue.edu

- Anna Boyanovsky, Merced email: aboyanovsky@ucmerced.edu

- Missy Wood, University of Florida email: wood.m@ufl.edu

NSF Deliverables: Due December 1

NSF is sending us to school
Oct 14-15 Gen-4 Kickoff
We will bring back what we learn

- Strategic Plan and Logic Model

- Evaluation and Assessment Plan

- Center Governance Model and Organizational Chart

- Innovation Ecosystem Membership Agreement

- Intellectual Property Policy

- Establishment of Charters for Boards, Councils, and Committees

- Data Management Plan

- Center-Level Risk Management Plan

Year 1 Milestones

Pre-Kickoff activities:
Sep 21- Oct 13

Kickoff activities:
Oct. 14-15, 2020

Set 2021 Fall site visit date to establish funding year

90-Day PTC/Cooperative Agreement Strategic plan:
Dec. 1, 2020

6-month deliverables:
March 1, 2021

Ramp-up site visit with assigned PD (In-person, COVID19 permitting)

Not a formal site visit
Reviews deliverables from 90 days and 6 months

Full reports and site visits yearly beginning in year 2

Onboarding Students and the Student Leadership Council

- Identification and contact information for students
- Identify students to be members of the Student Leadership Council
  - Advise Executive Committee
  - Organize students talk session at Annual Meeting
  - Conduct yearly SWOT analysis (research, education, diversity and culture of inclusion, industry and entrepreneurial activities)
  - Meet 6 times per year
- Think about co-mentorship, serving on student committees

Student Leadership Council

- 12 members across IoT4Ag sites
- 2 graduate and 1 undergrad per site
- Elected president and vice-president, each from a different site

IoT4Ag Virtual Kickoff Bootcamp

- Weekly, virtual, 1-hour, recorded Center education
- Library of introductory, transdisciplinary, key questions/problems in the field
- Topics: Plant and soil science (Rowland, Small, Vyn)

    (Un)conventional sensors (Ehsani, Kagan, McLamore, Olsson, Turner)

    Robotics (Cappelleri, Crawford, Kumar)

    Agricultural Communications (Krogmeier, Love)

    Energy Harvesting Technologies (Allen, Arnold, Bidstrup Allen)

    Imaging and Sensor Fusion (Hestir, Pappas, Zare)

    Machine Learning and Artificial Intelligence (Carpin, Crawford, Pappas)

    Decision Agriculture and Controls (Buckmaster, Mangharam)

    Agricultural Socio-economics (Keske)

DRAFT
Starting Oct. 23

Research Thrusts

- Thrust PI Meetings to discuss goals and capabilities and to define Thrust Projects and Milestones to support the Strategic Plan
- Suggested names for the Scientific Advisory Board

Scientific Advisory Board

- Six members

- Experts in IoT4Ag-relevant fields

- Industry, government, academic members

- All members external to IoT4Ag center

Workforce Development, Diversity and Inclusion, Evaluation

- NSF Workforce Development, Diversity and Culture of Inclusion, Evaluation, and Student Leadership Workshop
  - November 9 and 10
- Activities and programs that can be carried out virtually during the pandemic
- Suggested names for the Workforce Development Advisory Board and the Diversity and Culture of Inclusion Advisory Board

Workforce Development Advisory Board

- Six members
- Four non-IoT4Ag experts in education, extension, outreach (one from each partner university)
- One K-12 representative
- One community college representative

Diversity and Inclusion Advisory Board

- Eight members
- One representative from the Diversity & Inclusion Office at each of the four partner universities)
- Two external academic members
- Two student members

Innovation Ecosystem

- Onboarding members
- Membership Agreement
- Industry Brochure
- Industry Slide Deck

Reaching back to industry, government, and innovation partners who wrote letter of commitment, and recruit new members!

Website Under Construction

iot4ag.us

- Phase 1:   Home page to be posted shortly

- Phase 2:   More extensive webpage news, about us, research, workforce development, diversity and culture of inclusion, innovation ecosystem, members only access, events …

HQ Under Construction