# Advanced Micro-Sensor-Systems for Biofuel Feedstock Supply Chains

December 8, 2017

# TERRA/ROOTS

Crops × Bots × Bytes

# Vision: Precision Breeding "System"

*INTEGRATION OF BIOLOGY × ENGINEERING × COMPUTER SCIENCE*

*Crop Genetic Gain and Resilience*

**Genomics**
Plant, Animal, Human and Microbial

*Gene and Trait Associations*

**Phenomics**
Phenotype Reference Standards (Lab & Field)

*High Resolution Crop Phenotypes*

**Sensors**
Plant, Root, Soil, Microbial and Environmental

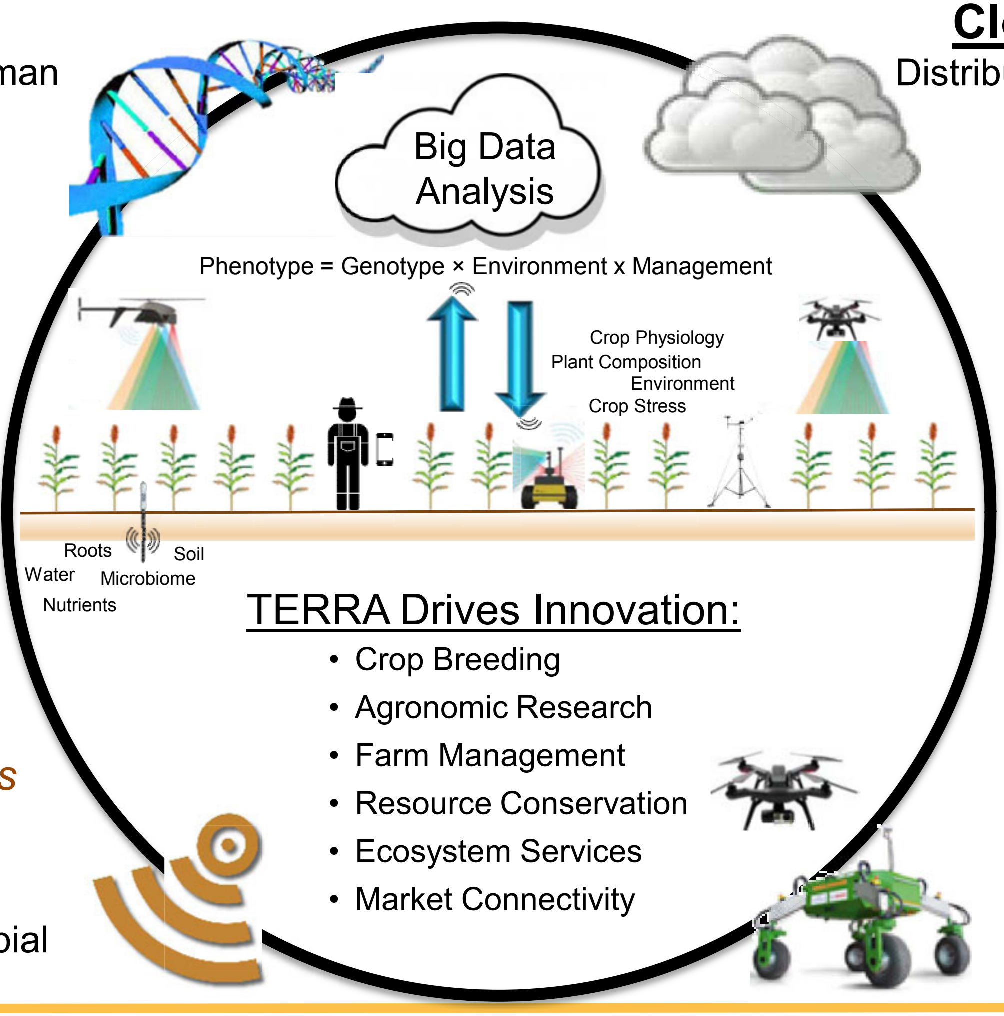
**Cloud Computing**
Distributed Databases, Remote Access, Scalable

*Prediction Algorithms*

**Data Analytics**
High Performance Data Pipelines

*AI -Machine Learning*

**Robotics**
Field Deployable, Scalable and Economical

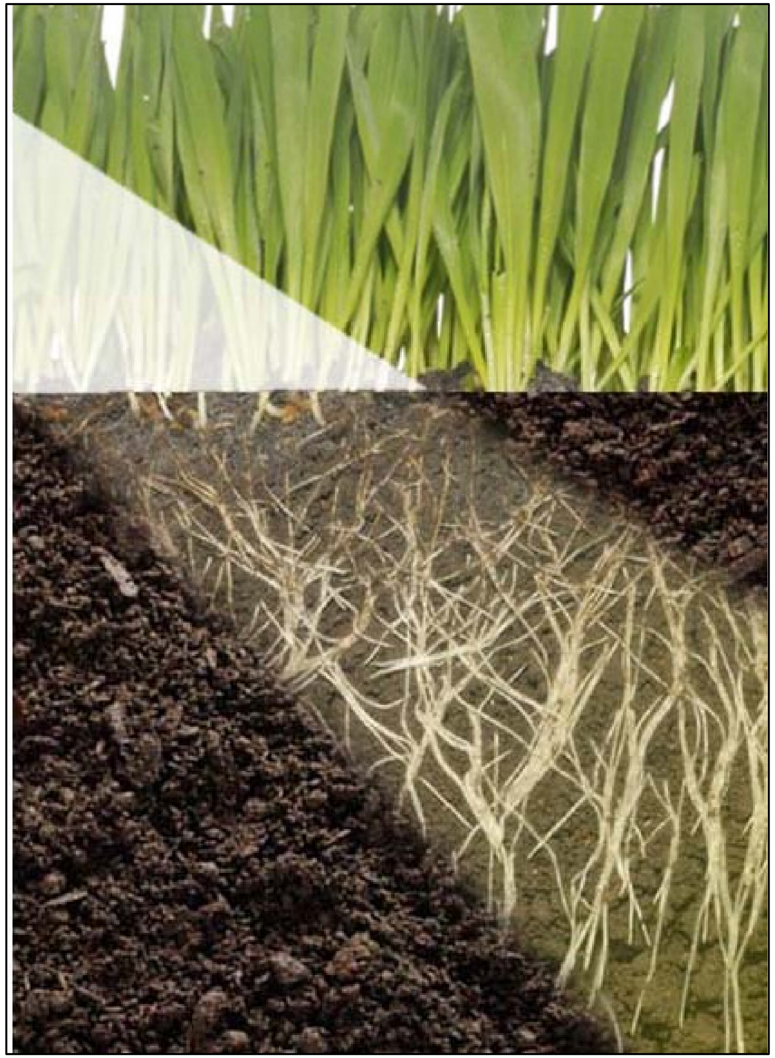


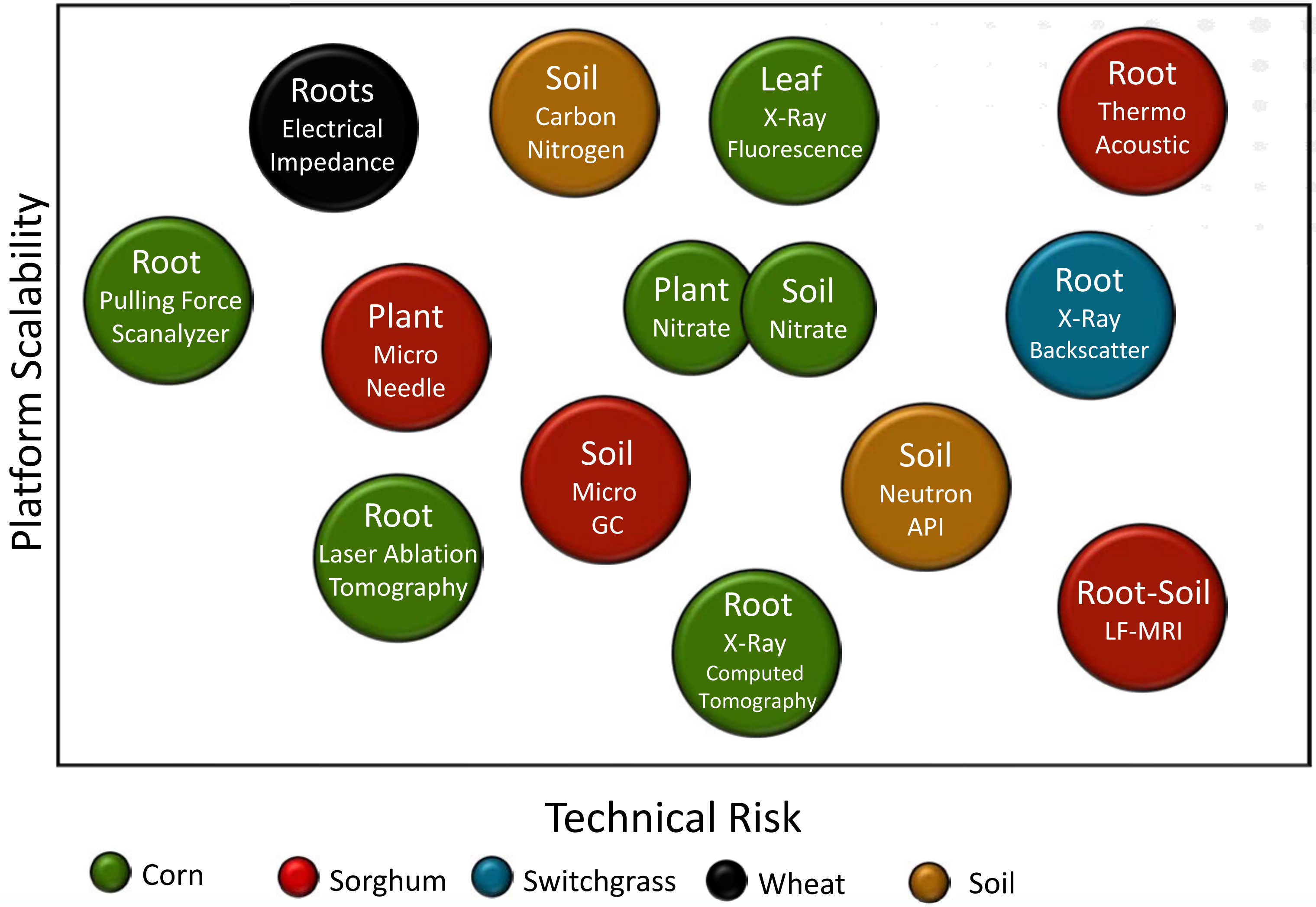

*High Throughput Field Data Acquisition*

ROOTS
SOIL CARBON CAPTURE

# Diverse Portfolio of Technologies

**PHENOTYPES × SENSORS × COMPUTATIONS × GENETICS × ENVIRONMENTS**



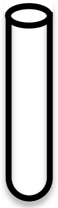


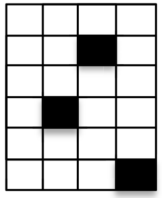
# Bioenergy has a scaling challenge

TERRA

Crops × Bots × Bytes

ROOTS





- **How will farmers unlock the genetic potential of biomass feedstocks?**
- **How will processors mitigate supply variability (yield *and* quality)?**
- **How do we connect – and optimize – the supply chain?**

**Breeding** **Selection**

**G x E**

*Breeders apply best management practices to small plots in order to find the best genetic varieties.*

*TERRA demonstrates the value of data capture in the field; ROOTS will achieve this belowground.*

**Feedstock Production**

**E x M**

*60-100% yield gap between best practices and state averages; breeder "visibility" does not scale.*

*Yield and quality are dominated by the field **Environment** and **Management** in production.*

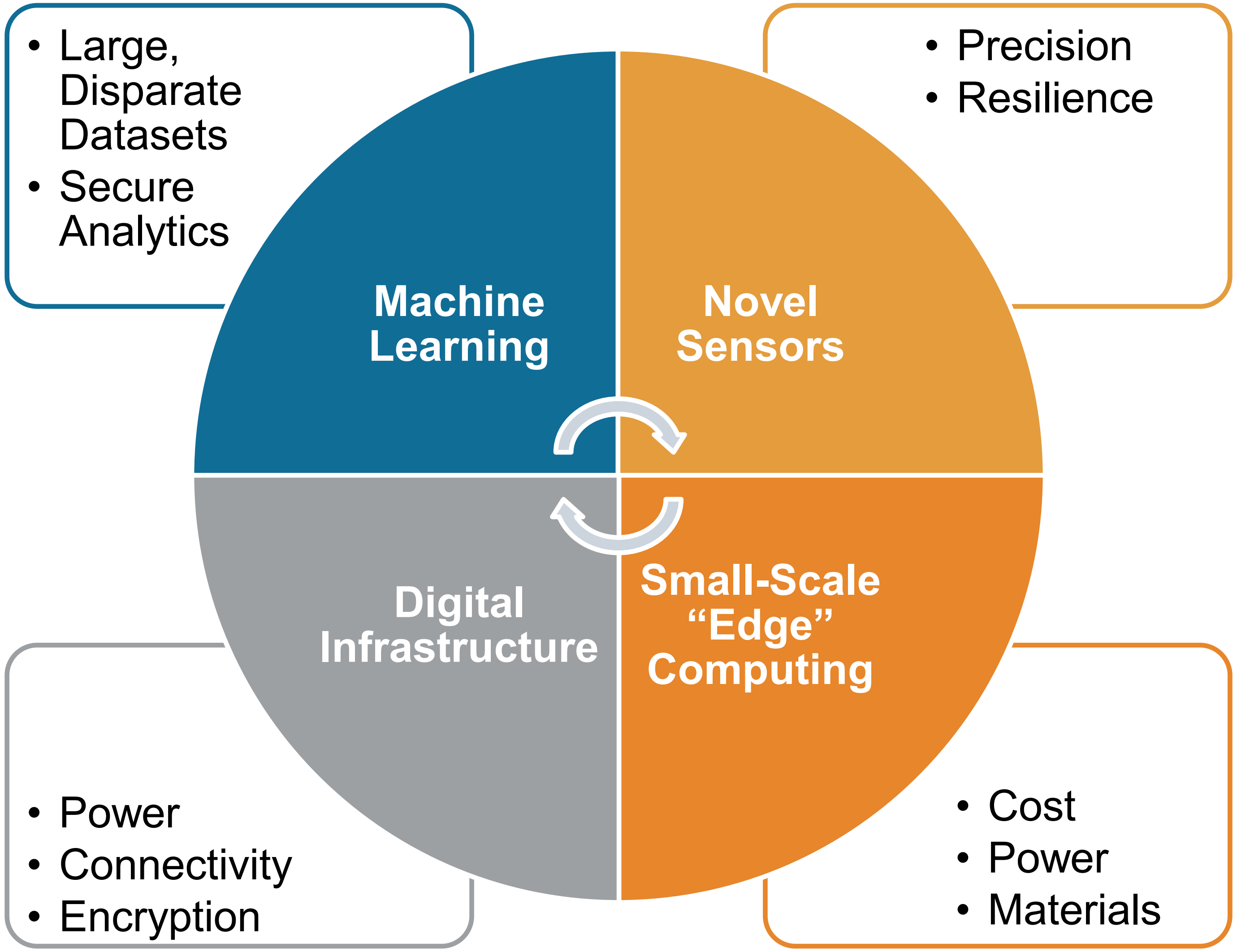
**Processing**

**G x E x M**

*Today's feedstock systems cannot reliably support large-scale processing.*

*Next-gen conversion technologies can benefit from supply chain insights; advanced logistics for multi-feedstock refineries are being explored.*

# The Opportunity: Digital Assets for Biofuel Value Chains




## Objectives

**Maximize System Productivity**
(energy yield)
while optimizing resource inputs.

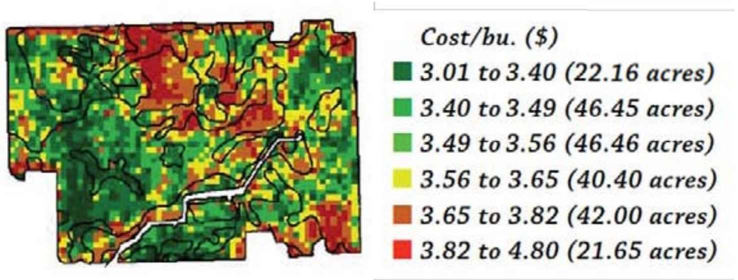
**Minimize Unfavorable Outcomes**
(loss + waste)
while maximizing product quality.

**Expand Freedom of Choice**
(transparency)
while preserving privacy.

# Distributed sensing and analytics enable bioenergy innovations

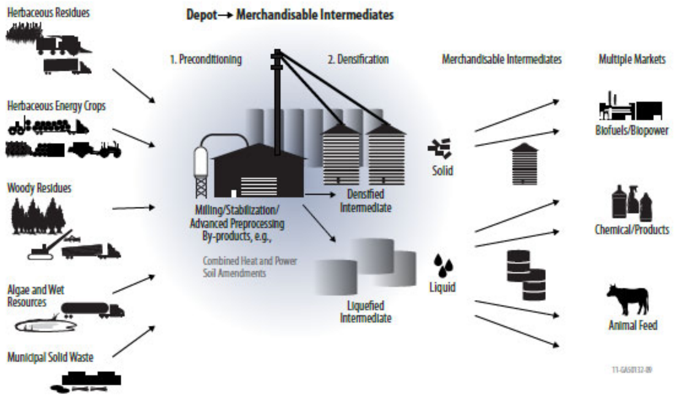
## *Program successes benefit the entire bioenergy value chain*

### Management / Profitability




*Frieberg, D. Data can show cost per bushel. 2015.*

### Advanced Bioenergy Logistics




*DOE-BETO Advanced Feedstock Supply System (AFSS)*

### Re-wired Anaerobic Digestion

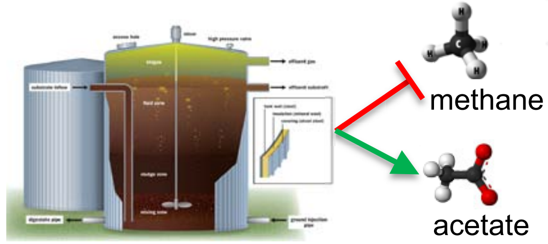



*Image from Triad Recycling*

## Shared Challenges:

Sensing:
pH, temperature, humidity, chemical and nutrient concentrations, biological detection

Power:
non-toxic, durable, environmental harvesting, passive sensing

Analytics:
No central hub, ML without full dataset

Communications:
No line of site, swarm coordination

# Next Steps: Workshop Planning (Early 2018)

Attendees will be asked to evaluate promising technical pathways toward:

- Helping growers achieve **maximum theoretical yields**
- Measuring, mapping and modelling **feedstock quality**
- Securing data architectures for **protected analytics and value chain transparency**

**Specific technical interests based on ARPA-E due diligence:**

- **Low-cost, small-scale computing "at the edge"**: secure, low-power data computation and transmission; identifying and overcoming materials challenges for in-field devices.
- **Sensors**: a range of biological, chemical, and mechanical sensors (e.g. CNT, photonic crystal, etc.) that have potential to be down-scaled with minimal precision sacrifice and can withstand a wide range of conditions.
- **Analytics and Machine Learning**: deep learning tools for combined use of remote-sensing, point-sensor, genomic, weather, and other data to optimize yields in practice.
- **Advanced infrastructure for system-level digitization**: power and connectivity in remote areas; privacy-protecting / encrypted technologies for secure data management and transmission.

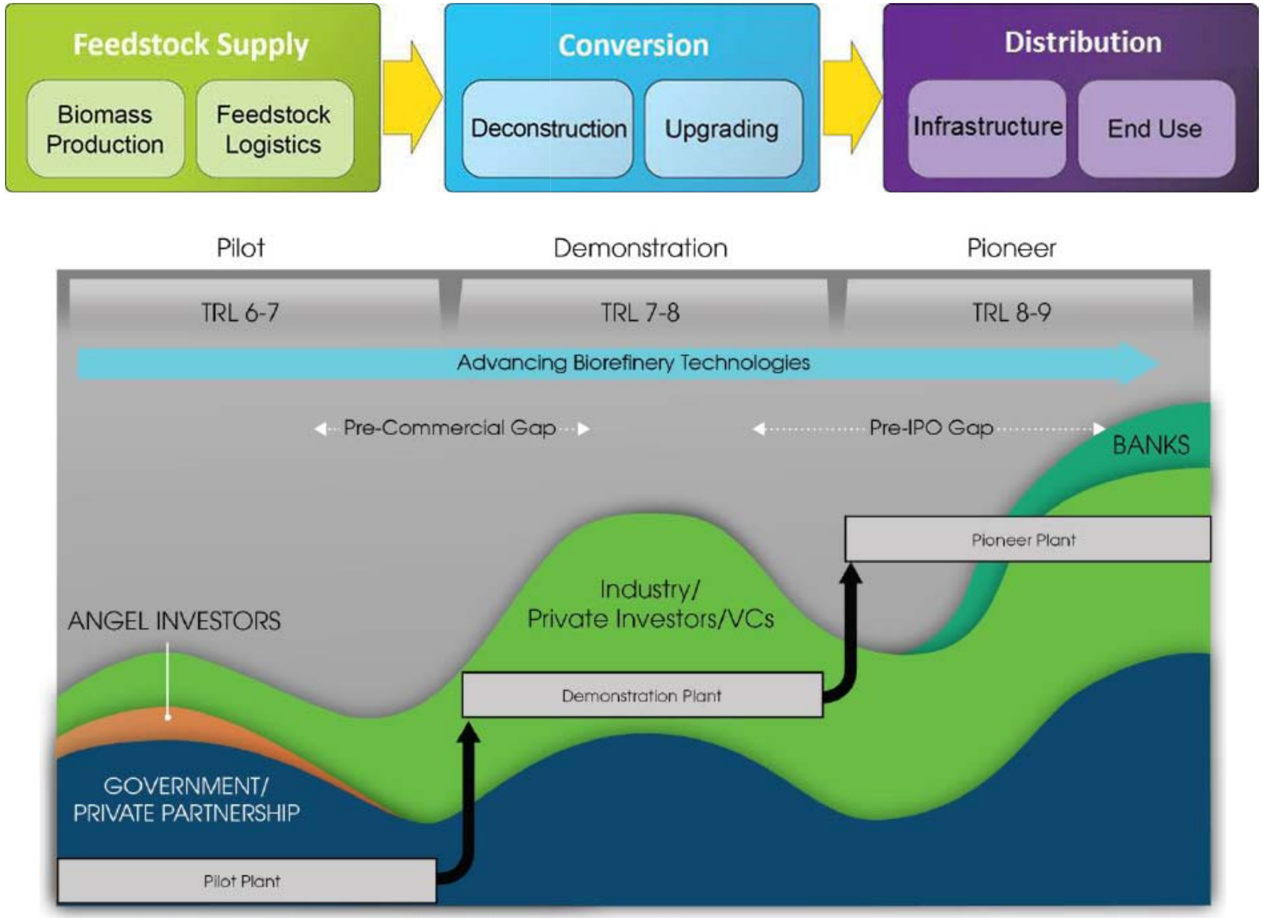
# What we're asking…

- What is being measured today? How (e.g. handheld, UAV)? Where (e.g. farm, storage, reactor)?
- What data are we missing? Do we need new/advanced tools for capture?
- To what extent do we understand the underlying mechanisms dictating feedstock yield and quality?
- How might digital assets be used to reduce feedstock losses and/or boost quality?
- How might having the necessary information impact pre-processing and/or processing? What is the value of this information to processors?
- To what extent are data shared across the supply chain? Is there a demand for greater transparency and/or connectivity? What are the major concerns?
- How might these tools facilitate multi-feedstock systems and be more broadly applicable to other agricultural supply chains?
- How far are we from the fully-connected farm and supply chain – 5, 10, 20 years? What do we need to get there?

# BACK-UP SLIDES

# Feedstock variability limits industry expansion

***BETO MYPP 2016***




TRL = technology readiness level, IPO = initial public offering, VC = venture capital

**How can ARPA-E help?**

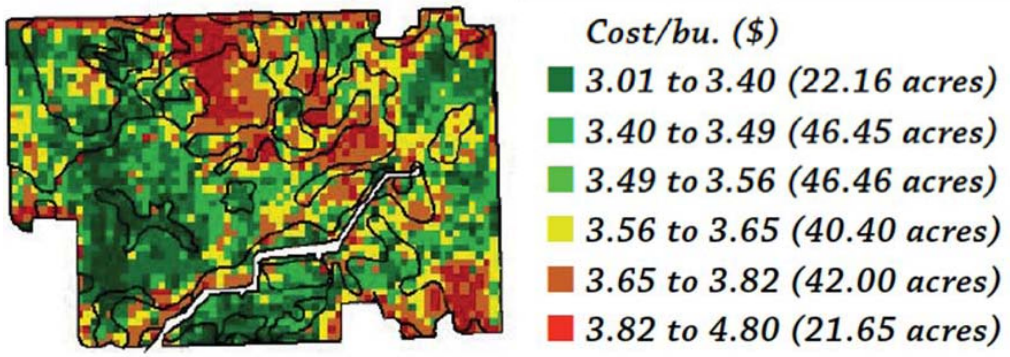
Feedstock characteristics - chemical, physical and mechanical – must be measurable *and* understood for process development, scale-up, and integration.

Various groups throughout DOE and beyond are investigating the mechanisms behind these characteristics. This early-stage applied research is a necessary step toward scalability and maximizing yields

ARPA-E sees an opportunity to complement this work by focusing its efforts on developing the tools required to take these insights to commercial production.

# Unusual conditions can threaten yields without management mitigation

## In-field variability can be costly…




*Frieberg, D. Data can show cost per bushel. 2015.*

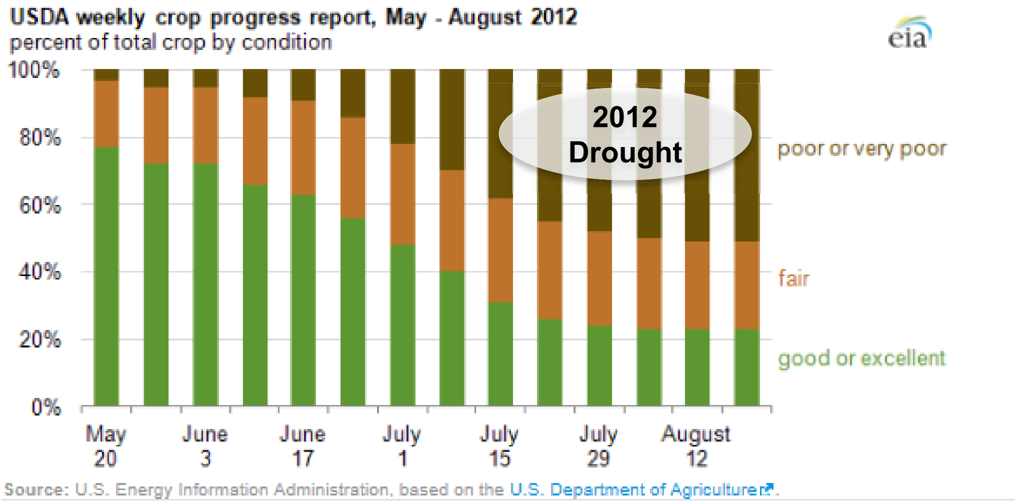
(a) Shallow (b) Deep

**Figure 5. Actual field traverse using a nominal 30-foot swath width plus resulting raw soil EC data collecting across a field; (a) represents the shallow, zero-to-1 foot map and (b) illustrates the deep or zero-to-3 foot map. Red points represent low values (less than 10 µS/cm) up to green areas representing high soil EC values (greater than 20 µS/cm).**

*Hawkins, E., Fulton, J., Port, K. Using Soil Electrical Conductivity (EC) to Delineate Field Variation. 2017.*

## …and vital questions remain unanswered

- How does my management strategy impact yield and quality?
- How can I cost-effectively mitigate variable sub-field conditions?
- How do we scale up digitization without increasing cost or sacrificing throughput?



# Variability in environment and management drives uncertainty