The Energy-Smart Farm

Distributed Intelligence Networks for Highly Variable Resource Constrained Crop Production Environments

February 13, 2018
Imagine… an Ag Sector
That in the next thirty years:

- Doubles Productivity (2x Yield)
- Cuts Emissions in Half (5% GHG)
- Conserves Resources (30% Water)
- Triple Renewables (1B Tons Biomass)
Agricultural is BOTH a Consumer and Producer of U.S. Energy

In 2014 the Agricultural Sector Consumed 1.7 Quadrillion BTU of Energy…

... and Generated 4.9 Quadrillion BTU of Primary Energy from Biomass

With Unintended Consequences: 9% U.S. GHG Emissions and 80% U.S. Fresh Water Use
U.S. has Capacity to Produce >1.4 Billion dry tons of Biomass
Without Impacting Food or Export

Potential Bioenergy Feedstocks: High-yield scenario

<table>
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<tr>
<th>New Forestry</th>
<th>New Ag Residue</th>
<th>New Energy Crops</th>
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<tr>
<td>142 million dry tons</td>
<td>200 million dry tons</td>
<td>736 million dry tons</td>
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Current Agriculture + Forestry Bioenergy Feedstocks
365 million dry tons

With the Potential to Supply 20% of U.S. Energy Demand

U.S. Department of Energy
2016 BILLION-TON REPORT
Advancing Domestic Resources for a Thriving Bio-economy

Domestically, 1.4 Billion dry tons biomass could be available by 2040:

• At a roadside price of $60/DT
• From a diversity of biomass resources (annual & perennial)
• 2-4% annual crop genetic gain

Without Impacting Food or Export
We Are Off the Pace to Feed and Fuel the World
Evidenced by Declining Rate of Genetic Gain in Core Crops

"Improvement in yield is below 1.16-1.31 %/y rates required to meet projected demand."

Hall et.al.
Fossil Fuels Enabled the First Green Revolution…

…but Future Productivity Relies on Data!

Productivity gains during the 20th century were achieved by leveraging existing technologies:

- Irrigation infrastructure
- Synthetic fertilizers
- Chemical pesticides
- Crop varieties

The 21st century requires a new revolution that will sustainably double crop productivity in the face of competition for arable land and increasing exposure to climatic shocks.
Crop Feedstocks Have Significant Upside Genetic Potential

Energy Sorghum Example

YIELD = Genotype x Environment x Management

- Metabolic Maximum for a C4 Crop
- University Research Trials
- Farm Actual

Biomass Energy Yield = (S_j) x (E_i) x (E_c) x (E_p)

Energy content of dry biomass ~17 MJ/kg
Yield Contest Winners Reveal a 60-100% Yield Gap
Best Management Practice vs State Average

Sorghum Example: 3 year average yield (bu/ac)

NSP Yield Contest Winner vs State Average

Arkansas  Colorado  Georgia  Illinois  Kansas  Louisiana  Missouri  Nebraska  North Carolina  Oklahoma  South Dakota  Texas
Farmers Make Over 40 Yield-Impacting Decisions Each Season

YIELD = Genotype x Environment x Management

- **Planning**
  - Rotation
  - Genetics
  - Inputs

- **Pre-Plant**
  - Field Selection
  - Field Tillage
  - Fertilizer App

- **Planting**
  - Planting Date
  - Seeding Rate
  - Pest Control

- **In-Season**
  - Irrigation
  - Nutrients
  - Pest Control

- **Harvest**
  - Harvest Date
  - Storage
  - Marketing

- Planting Date and Harvest Timing can result in a 10% swing in yield
- No silver bullet … impacts fall ~1-3% but add up quickly
Due Diligence: Opportunity for Distributed Intelligence

Problem: In-Field Variability Complicates Management and Increases RISK

- Soil
- Water
- Nutrient
- Microclimate
- Disease
- Insects
- Weeds
Due Diligence: Opportunity for Distributed Intelligence

Solution: In-Field Spatiotemporal Monitoring
Due Diligence: Opportunity for Distributed Intelligence

Problem: In-Field Variability Increases RISK

Solution: In-Field Spatiotemporal Monitoring

Distributed Intelligence Networks for Highly Variable Resource Constrained Crop Production Environments

- Large Disparate Datasets
- Relevant
- Secure

Machine Learning

- Scalable
- Connectivity
- Encryption
- Economical

Secure Networks

 Novel Sensors

- Accurate
- Reliable
- Compact
- Economical

Edge Computing

- Power
- Speed
- Size
- Storage
Due Diligence: Emerging Breakthrough Technologies
Capturing, Storing, Communicating, Processing, and Predicting

Innovation Frontiers:

Sensing: microclimate, metabolic, chemical, nutrient, biologic, acoustic

Power: zero power, energy harvesting, non-toxic, bio-electrons

Analytics: no central hub, ML without full datasets, multiscale crop models

Communications: no line of site, swarm coordination, just in time

Examples:

Printed Circuits
Lab on a Chip
In Planta Batteries
Ultra-Low Power Platforms
Ultra-Compact Computers

 Schnable, P. et al. Iowa State. 2017
 Z. Qian et al. Zero-power infrared digitizers based on plasmonically enhanced micromechanical Photoswitches. 2017

Challenge: Highly Variable, Resource Constrained, Dynamic Environments
Program Hypothesis: The Data-Driven Energy-Smart Farm

Rooted in Biology, Powered by Engineering, Enabled by Analytics

Develop new innovative technologies and decision support tools that maximize sustainable economic returns by increasing yields, conserving resources, and creating new market opportunities.

Deploy high-resolution wireless sensing systems

Monitor biotic and abiotic conditions that limit growth

Integrate multiscale, multimodal datasets
Program Challenge: Design, Build and Test

‣ Create a fully integrated, low-cost, scalable sensor network with:
  – Communication connectivity standards
  – State of the art computational capabilities
  – System-wide data security protocols
  …in a highly variable resource constrained environment.

‣ Implement a prototype broad-acre decision support ecosystem:
  – Monitor real time abiotic stress (water, temperature, nutrients, etc.)
  – Monitor real time biotic stress (pathogens, insects, weeds, etc.)
  – Monitor real time environmental conditions (light, moisture, soil, etc.)
  – Make prescriptive management decisions with a yield and economic prediction.
  – Integrate data pipelines and system components into a user-friendly interface.
Technical challenges are application agnostic:

- Available tools and technologies often **do not follow the same standards/platforms**.
- In many remote locations, **strong, reliable internet connectivity and power are not available**.
- It is next to **impossible to monitor and manage every single data point** - technology is only useful when users can make sense of the data.
- Operating parameters and performance targets are not uniform (large differences between crops); **systems need to be flexible in deployment and operation**.
- **Automation advances – and the operational efficiencies expected from them - are limited to available data**.
- **Failure/breakdown is unacceptable**.
- **Security is essential**.
WORKSHOP: What Does a Transformational System Look Like?

- Availability… cost and size
- Performance… power, speed, storage and computation
- Connectivity... range and bandwidth
- Reliability... mean down time
- Relevance... simplicity and utility

System Metrics

- Establish low-power/high-bandwidth connectivity within the farm
- Dense deployment of sensor network across the farm (1 to 10m²)
- Scalable to 200 hectares by year 4 (average U.S. Farm size 2016)
- One complete crop cycle (12 Months) pre plant to post harvest
- Less than 10% system failure down time
- System cost 2 orders of magnitude cheaper/faster than SOA

Sample Metrics
**Workshop Agenda:**
*Rooted in Biology, Powered by Engineering, Enabled by Analytics*

### Day 1: Platform Priorities

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<td>Parker Liautaud</td>
<td>Breakout Overview, Move to Breakout Rooms</td>
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#### Breakout Session 1
- **Group 1**: Bioenergy Crop Production Priorities
- **Group 2**: Abiotic Sensors & Platforms
- **Group 3**: Biotic Sensors & Platforms
- **Group 4**: Decision Support Analytics

### Day 2: System Design

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<td>Dr. Kevin Dooley</td>
<td>Supply Chain Alignment of Farm-Level Metrics</td>
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<td>Raja Ramachandran</td>
<td>Transforming Agricultural Supply Chains</td>
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<td>Parker Liautaud</td>
<td>Breakout 2 Introduction, Move to Rooms</td>
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#### Breakout Session 2
- **Group 1**: Straw Model System Design
- **Group 2**: Straw Model System Design
- **Group 3**: Straw Model System Design
- **Group 4**: Straw Model System Design

**Workshop Concludes**
Group Introductions by Table

Please stand and share your:

- Name
- Organization
- Technology Interests