CHANGING WHAT'S POSSIBLE

ARPA-E AgroEnergy Initiatives

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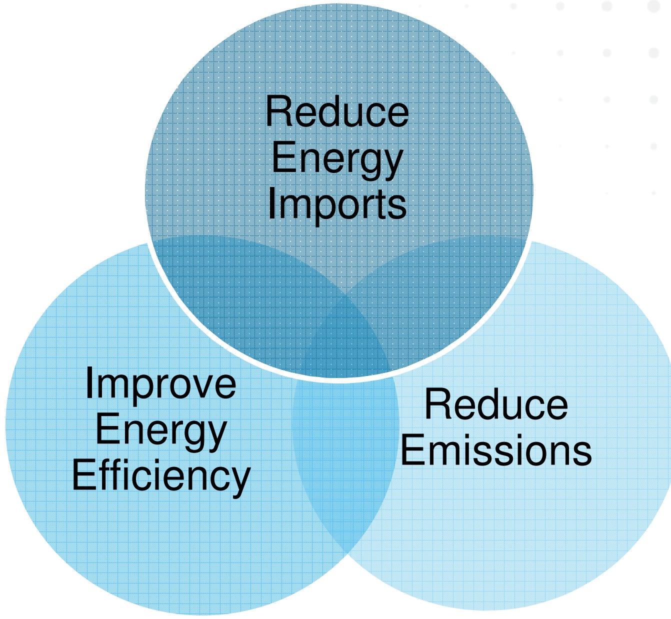
Technology to Market Advisor
ARPA-E

ARPA-E

Mission: To overcome long-term and high-risk technological barriers in the development of energy technologies



Goals: Ensure America's

- Economic Security
- Energy Security
- Technological Lead in Advanced Energy Technologies

Means:

- Identify and promote revolutionary advances in fundamental and applied sciences
- Translate scientific discoveries and cutting-edge inventions into technological innovations
- Accelerate transformational technological advances in areas that industry by itself is not likely to undertake because of technical and financial uncertainty

Program Directors and T2M Advisors

Program Directors and T2M advisors serve 3-year terms

ROLES & RESPONSIBILITIES - PD

- Perform technical deep dive soliciting input from multiple stakeholders
- Present & defend program concept in climate of constructive criticism
- Actively manage portfolio projects from merit reviews through project completion
- Develop milestones and work “hands-on” with awardees in value delivery
- Represent ARPA-E as a thought leader in the program area

ROLES & RESPONSIBILITIES – T2M

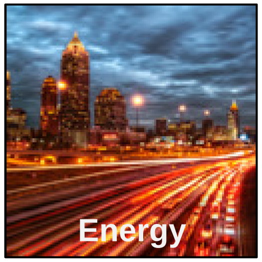
- **Manage t**he Commercialization progress of project technologies
  - Manage project teams’ T2M efforts through T2M Plans and jointly developed milestones
- **Advise:** support project teams with skills and knowledge to align technology with market needs
  - IP and competitor management
  - Value Chain and Market analysis
  - Product hypothesis
  - Economic analysis
  - Partner discovery and engagement

Agro-Energy Goal: Sustainable, Economical, Crop Production

FOOD – FUEL – FEED - FIBER

Context:

Economic		Environment		Natural Resources	



Demand Doubles | 2° C | 9.9 GtC | 70% H_20 | 120 GtC

- ✓ Agriculture has the capacity and scale to deliver significant benefits.
- ✓ However, agriculture is significantly behind its productivity pathway.
- ✓ Increased yield can be achieved through breeding,

BUT

- Breeding is slow and inefficient

- Investment in crop development is sub-optimal

- Small stakeholders are disadvantaged from the development pipeline

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Summary of ARPA-E Agro-Energy Initiatives

PETRO: "Plants Engineered To Replace Oil"

- Launched in 2011
- Goal: Develop plants that produce value added products

TERRA: "Transportation Energy Resources From Renewable Agriculture"

- Launched in 2015
- Goal: Develop rapid phenotyping methods to identify cultivars for enhanced crop (biomass) productivity

Terrestrial GHG Biosequestration through Root Architecture

- FOA release pending (3/2016)

Macroalgae as a potential biomass resource

- (Deep Dive in progress)

PETRO

HIGHER PRODUCTIVITY CROPS FOR BIOFUELS

Mission

Develop non-food crops that directly produce transportation fuels to be cost-competitive with petroleum without impact on U.S. food supply.

Program Director	Dr. Jonathan Burbaum
Year	2011
Projects	10+3
Total Investment	$62 Million

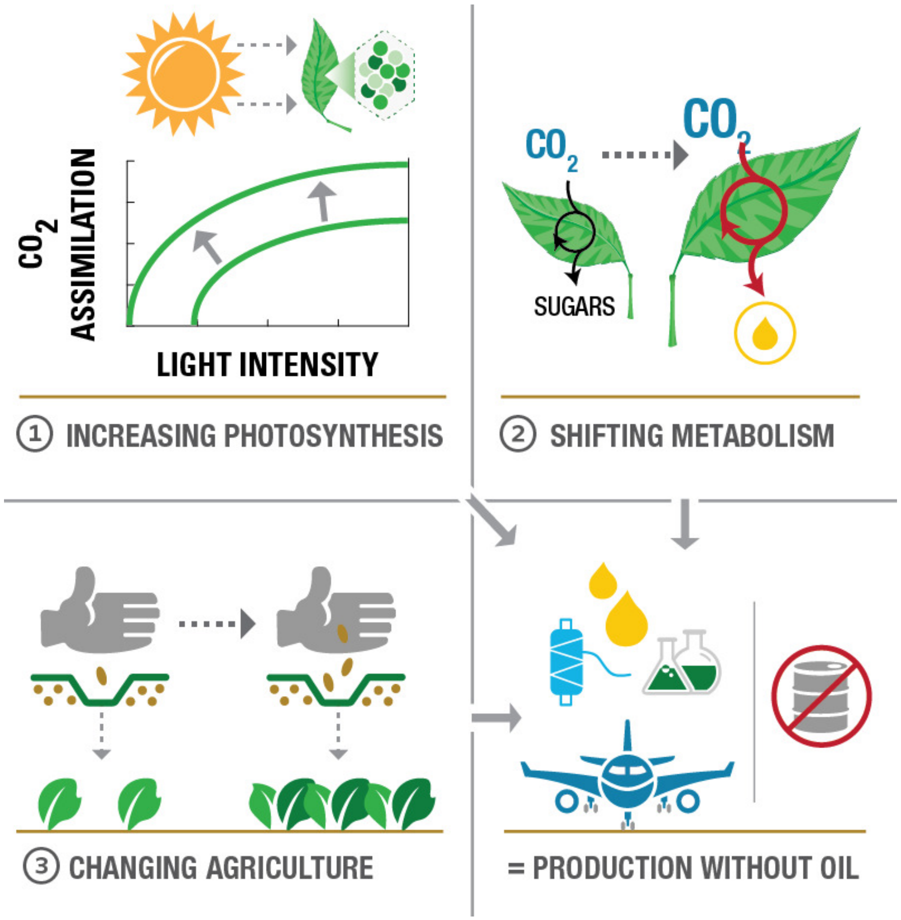
Goals

Yield	Energy Density	Cost
160 GJ/Ha/yr (2X corn EtOH)	>26 MJ/L (EtOH)	< $10/GJ ($50/BOE)

Highlight Approaches

- Develop pine trees that will accumulate 20% of their biomass as high energy terpene molecules
- Develop tobacco that produces oil directly, together with high planting density agriculture
- Introduce multiple metabolic pathways into oilseed crops to significantly improve photosynthesis

Developing Enhanced Dedicated Biofuel Crops



Oilseeds:
Camelina sativa

Trees:
Loblolly Pine

C_4 Grasses:
Sugarcane
Sorghum

Other:
Tobacco
Sugar beet

Developing Dedicated Biofuel Crops

DONALD DANFORTH PLANT SCIENCE CENTER

NC STATE UNIVERSITY

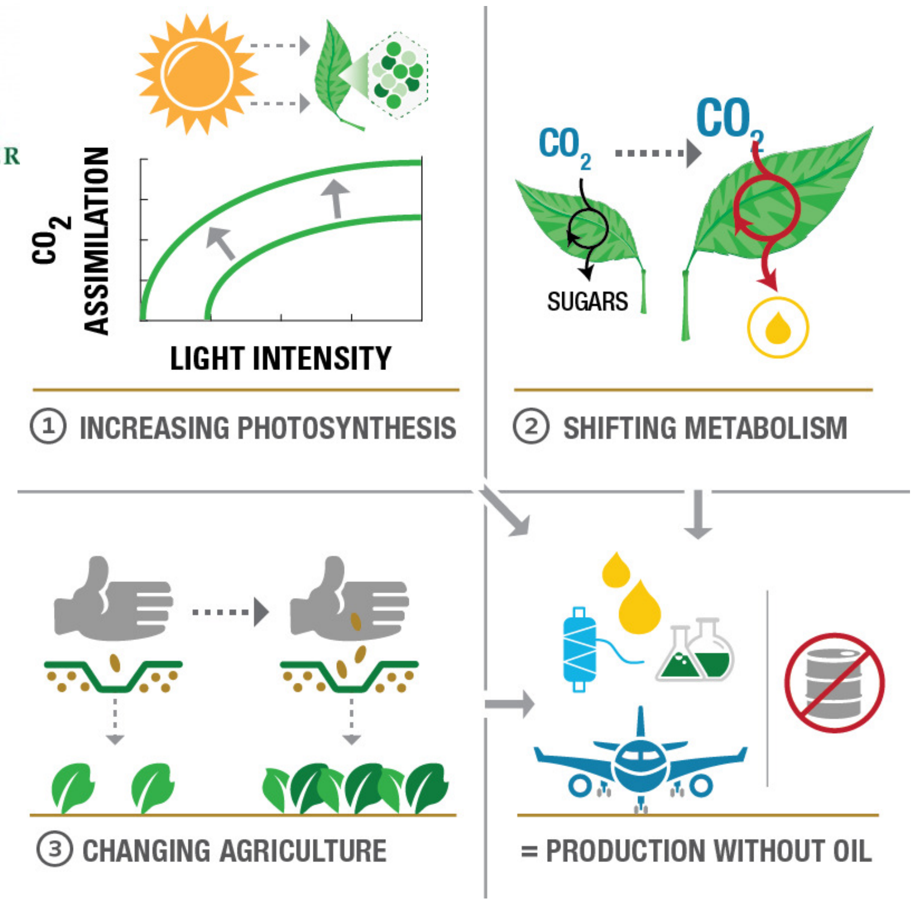
ILLINOIS

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

UMASS AMHERST

UCLA

Colorado State University



Allylix

Agrivida

BERKELEY LAB

UF UNIVERSITY of FLORIDA

Chromatin, Inc.

TEXAS A&M UNIVERSITY

Plant Sensory Systems

THE UNIVERSITY of TENNESSEE KNOXVILLE

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PETRO

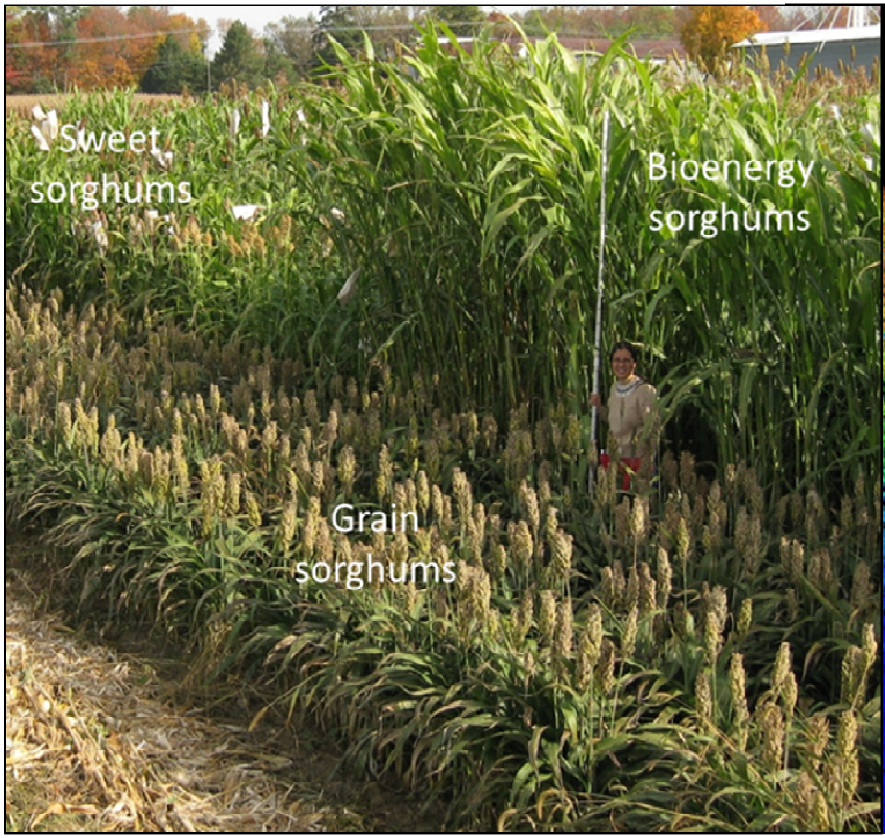
Field demonstrations of PETRO technologies

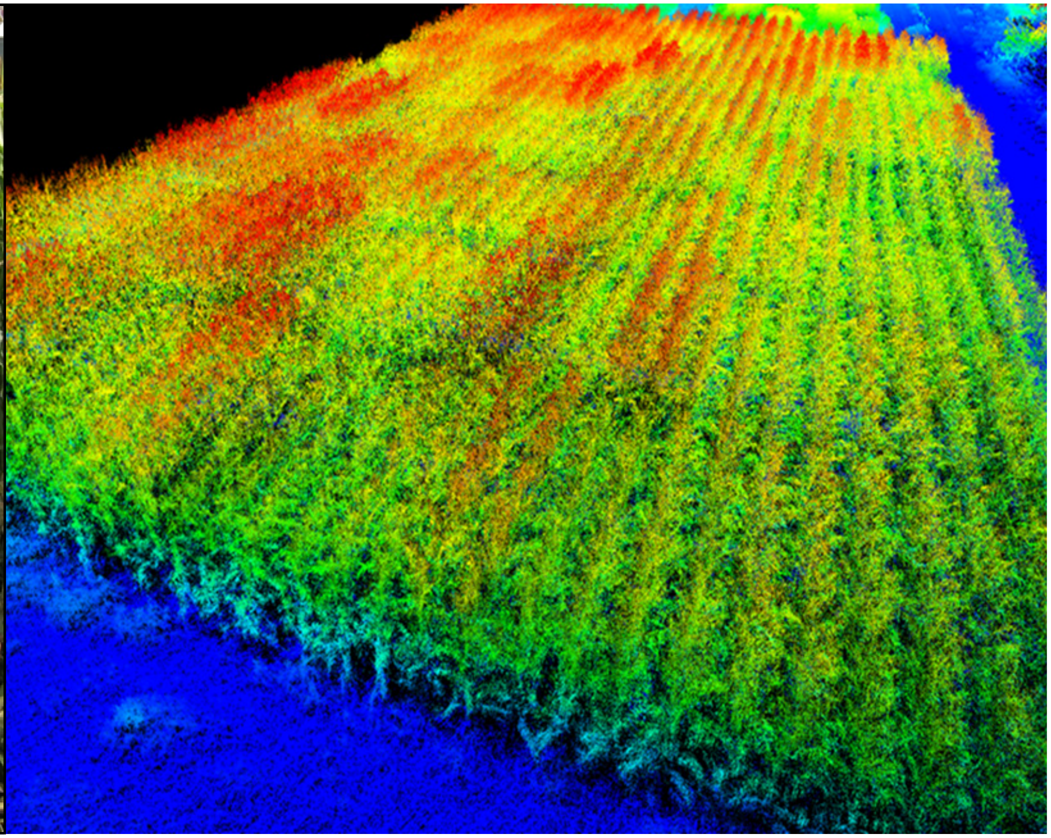
    

Tobacco	Camelina	Sugarcane	Switchgrass	Pine
• Conventional varieties planted over two acres to optimize biomass yields. • Grown under high density with multiple harvests, and expect 20 tons/hectare (10X increase).	• Transgenic lines planted at multiple sites under APHIS permits. • Engineered lines showed oil yields >30% over non-transgenic camelina.	• Transgenic lines have increased photosynthesis and accumulate TAG in leaves and shoots. • PETRO cane contain 5% TAG by DW (100X increase).	• Transgenic lines planted under APHIS permit. • Lines engineered to modify their cell walls and improve biomass saccharification.	• Existing stands were tapped to extract terpene rich resin. • Developed bio-technology strategies to double the yields of oleoresins over control trees.

TERRA

TRANSPORTATION ENERGY RESOURCES FROM RENEWABLE AGRICULTURE



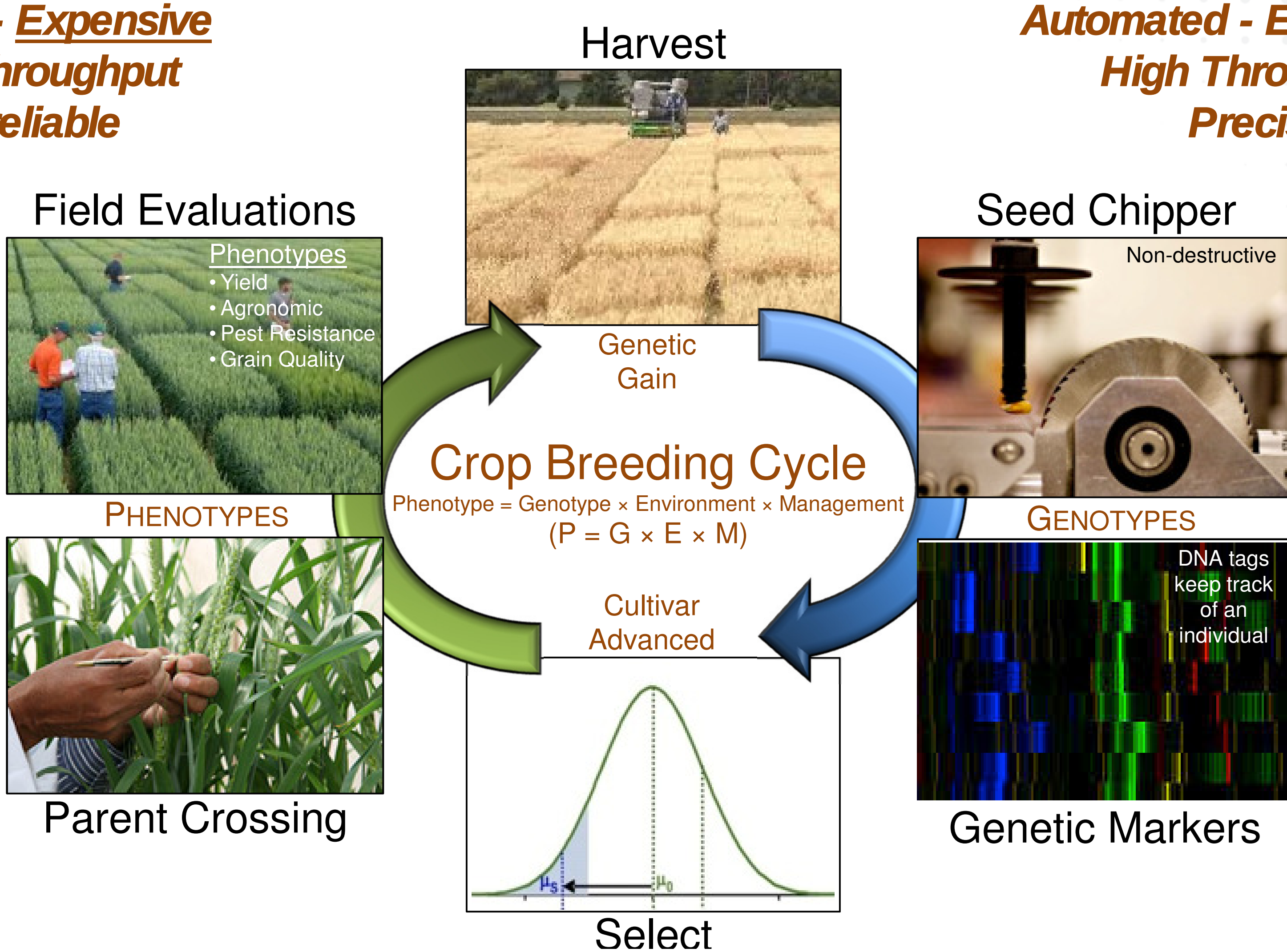


Crop Improvement Process… 8 -10 years / new hybrid

Phenotyping is the Bottleneck for Trait Discovery and Cultivar Development

Manual - Expensive
Low Throughput
Unreliable

Automated - Economical
High Throughput
Precise



Major breeding objectives: yield, composition, disease and insect resistance and tolerance to abiotic stresses.

20th Century Crop Phenotyping SOA

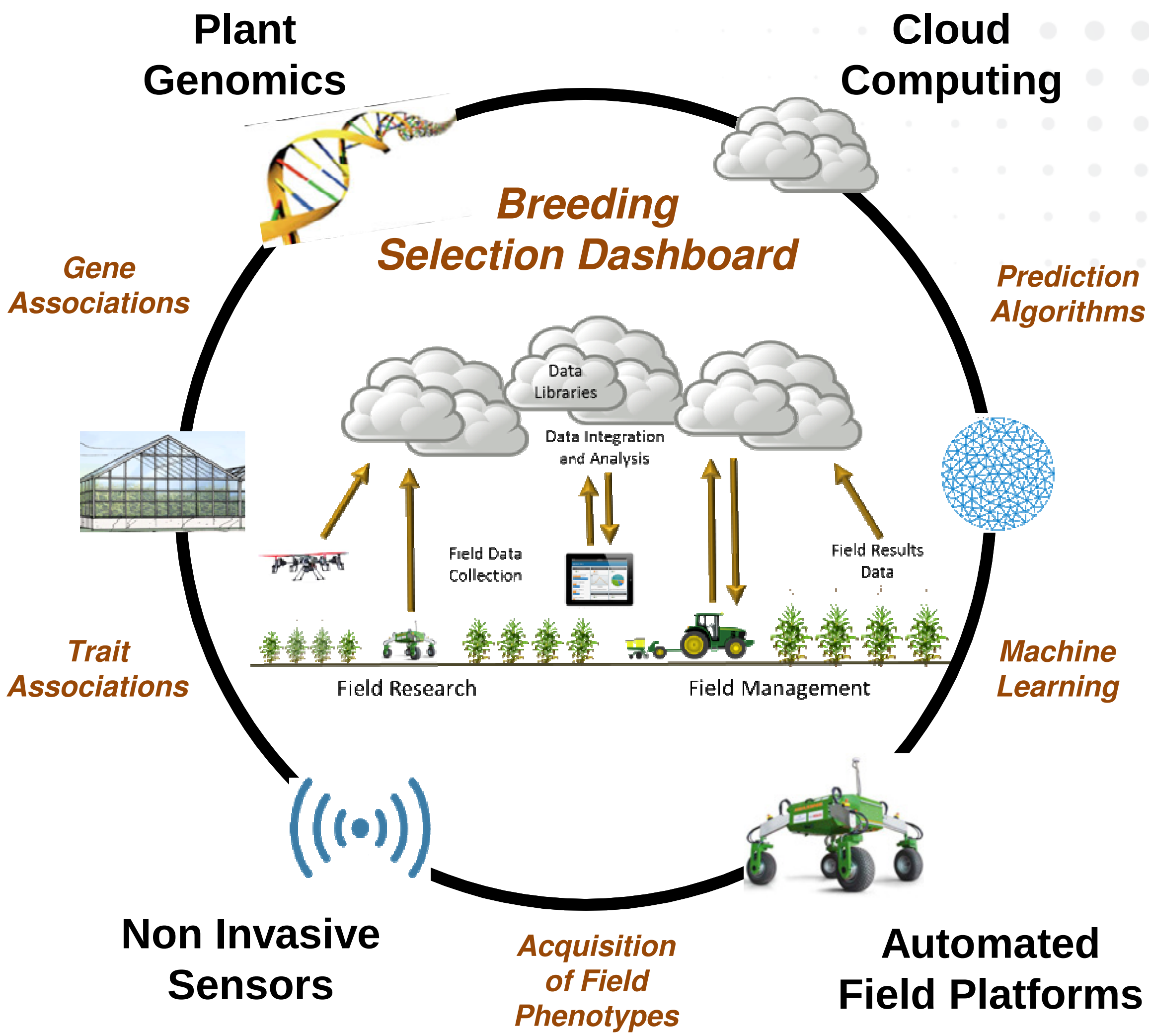
TERRA

Crops × Bots × Bytes

BIOLOGY × ENGINEERING × COMPUTER SCIENCE

Transportation Energy Resources from Renewable Agriculture

- ARPA-E is funding 6 crop phenotyping projects focused on sorghum at $35M.
- Projects range from 2-4 years, and were contracted in September, 2015.
- ARPA-E purchased and is funding the installation of a state of the art sensing platform (GFE), which will be operated by the public reference team. ($3.5M)



"More Carbon / Area / Time"

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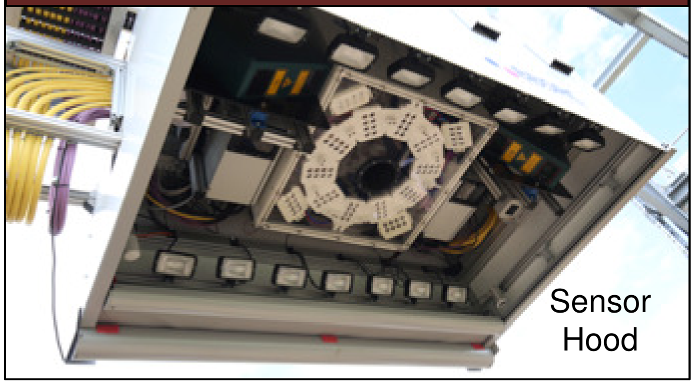
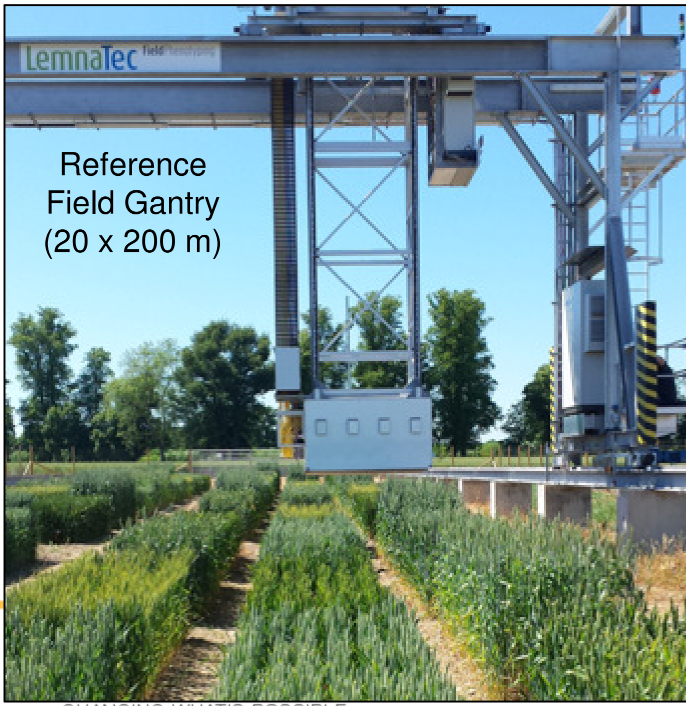
$\Delta G \approx h^2 \sigma_p i / L$

TERRA Robotic Platforms are Diverse and Data Rich

GFE Reference Field Phenotyping Platform
Danforth Center, USDA, UAZ



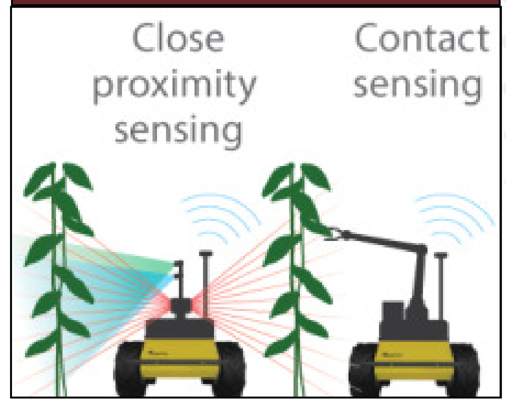


Performance Comparison	Current Breeding Manual	TERRA Ground & Aerial Vehicles
# Breeder Plots	1,000	1,000
# Phenotypes	10's	1000's
Resolution	1 m	1 cm
Bandwidth (nm)	400 700	100 2500
Data Collection	Bytes	Terabytes
Cycle Time	8 hrs	1 min UAV 4 hrs AGV

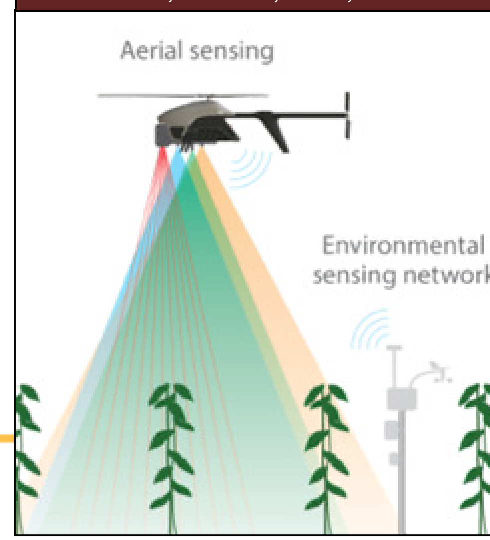
Reference Field Gantry Sensors:

- Hyperspectral i350-2500 nm
- Thermal infrared
- Dedicated NDVI sensor
- Dedicated PRI (photochemical reflectance)
- PAR sensor
- Color sensor
- Height Scanner
- 8 MP RGB down camera
- 2 side looking cameras
- Active reflectance in-field
- Fluorescence
- Environmental temperature, humidity, rainfall, wind, CO_2

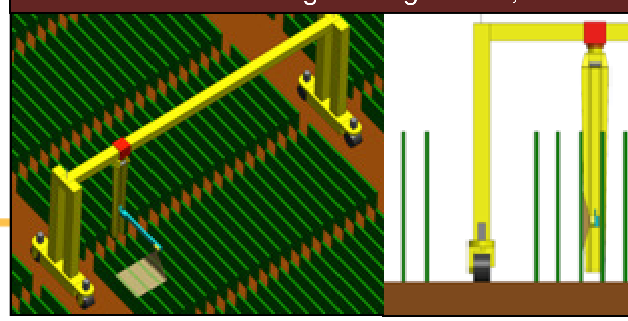
Ground Plant Phenotyping Systems
Carnegie Mellon, UIUC, Purdue



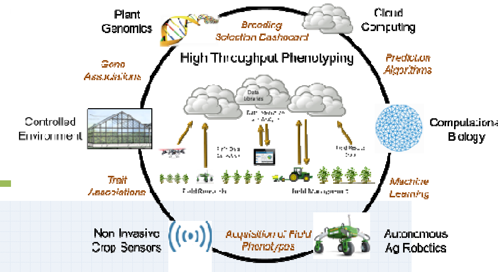
Aerial Plant Phenotyping Systems
Near Earth, Purdue, KSU, Blue River



Deployable Gantry Plant Phenotyping Systems
National Robotics Engineering Center, TAMU



TERRA Reference System



Project Summary

- Multi-team program organized by Danforth Center, includes University of Arizona/USDA-MAC, Kansas State, Hudson Alpha, UIUC
- Launch Q1'16 LemnaTec Field Scanalyzer, first sorghum planting late March early April 2016, durum wheat diversity panel planted January 2016
- All data will be made public through sorghum phenotype portal to provide analytics experts from other fields an opportunity to work on sorghum
- Establishing modular design with data standards and reference phenotypes to allow addition of existing data or additional field sites and platforms

Field Gantry Installation

Controlled Environment

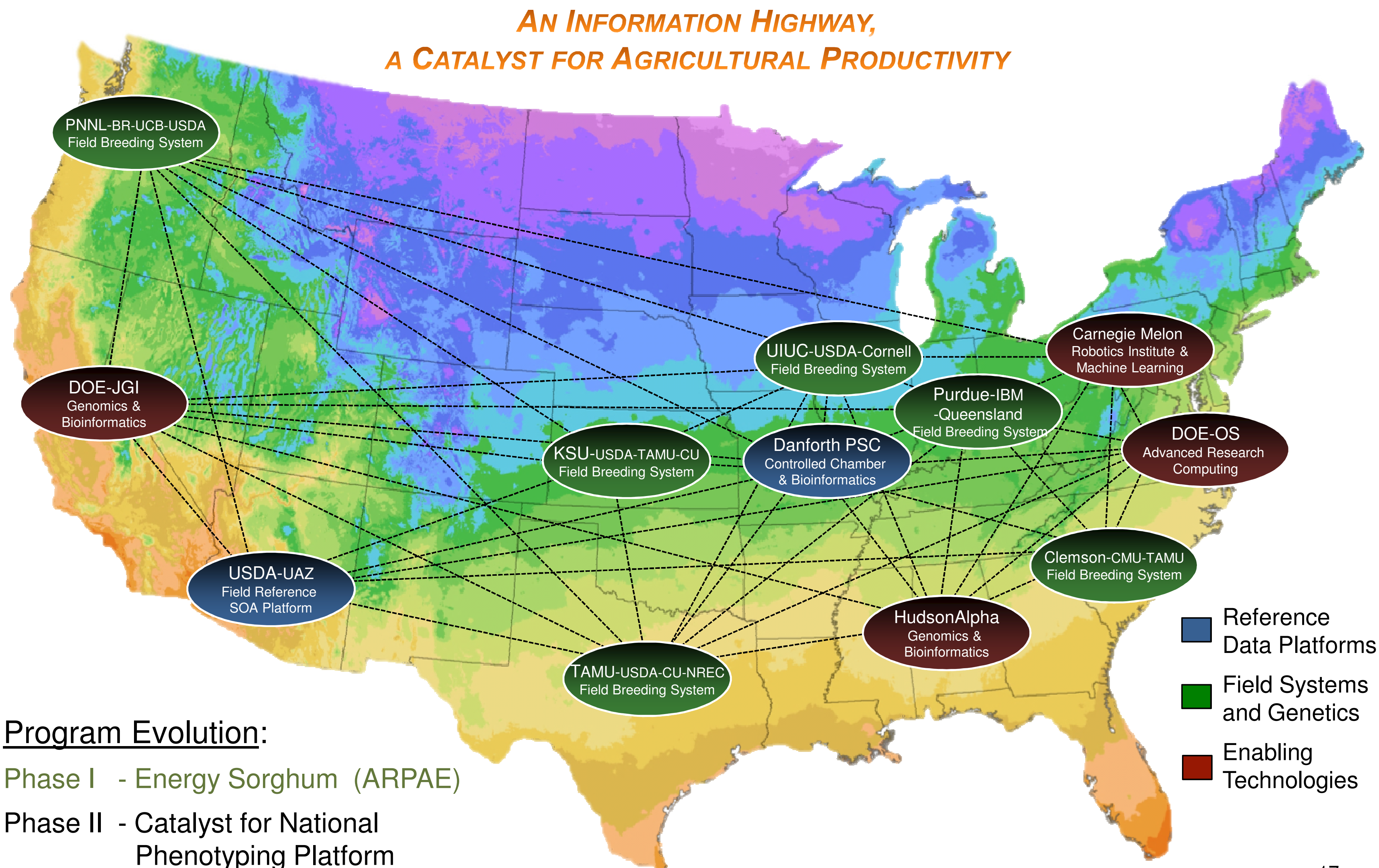
Phenotyping Tractor/UAV

TERRA Data Products (Public Reference Project)

Genomic data	• De novo genome assembly of a diverse panel of 30-50 sorghum varieties to generate a pan genome
Field plant data of the reference field (20x200 m) 1-3 times per week	• Hyperspectral (380 nm – 2500 nm) scans • Thermal infrared • NDVI/PRI • Laser depth scans • RGB images and pre-processed stereo pairings • Fluorescence
Algorithms for:	• 3-D reconstructions of individual plants • Terminal biomass yield • Accurate image registration • Time dependent phenotype prediction
Environmental data	• Light intensity • Temperature • Humidity • CO2

TERRA: Integrated Phenotyping Network

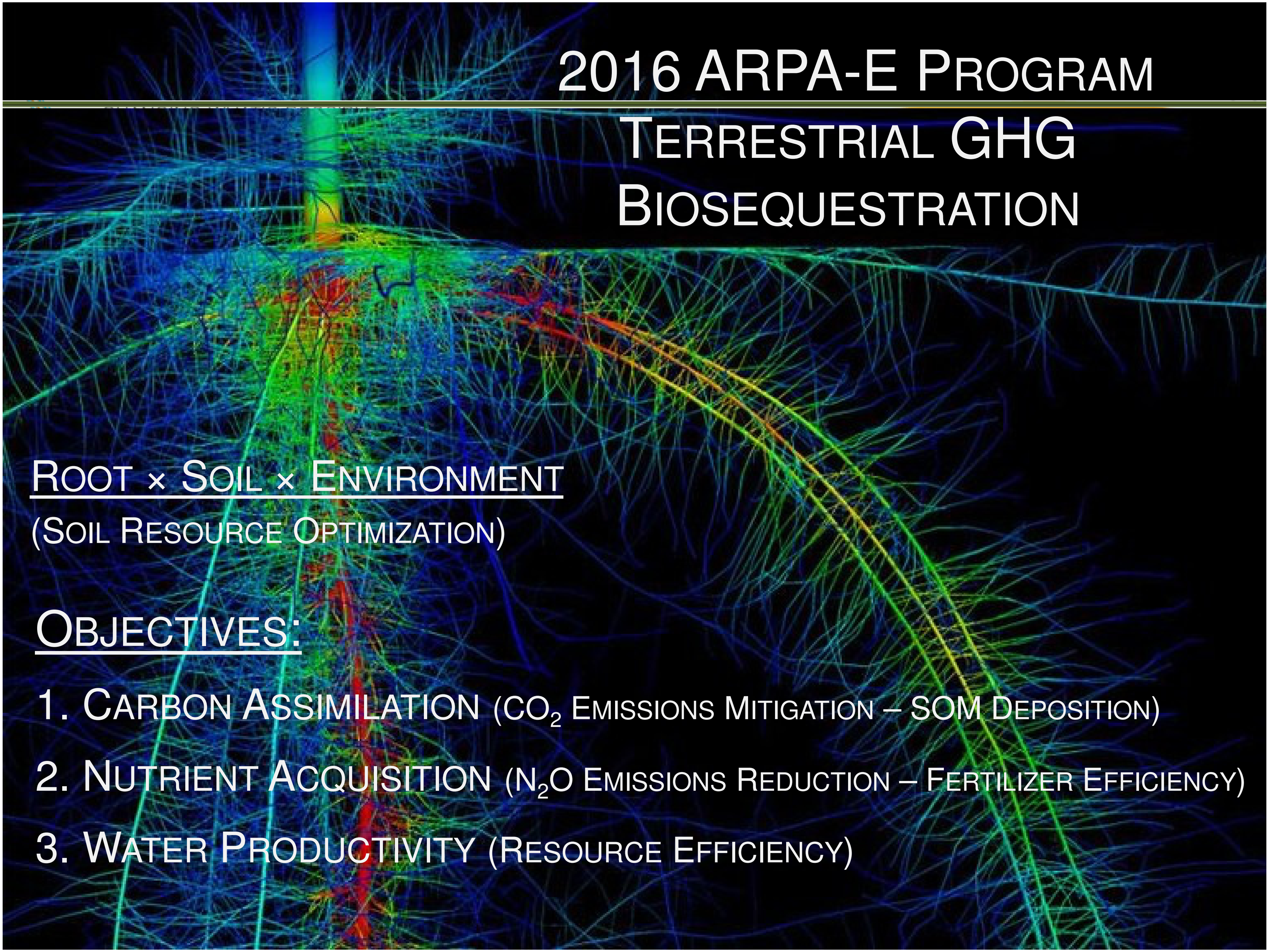
Breeding-Agronomy-Genetics-Physiology- Robotics-Sensors-Computation-Machine Learning

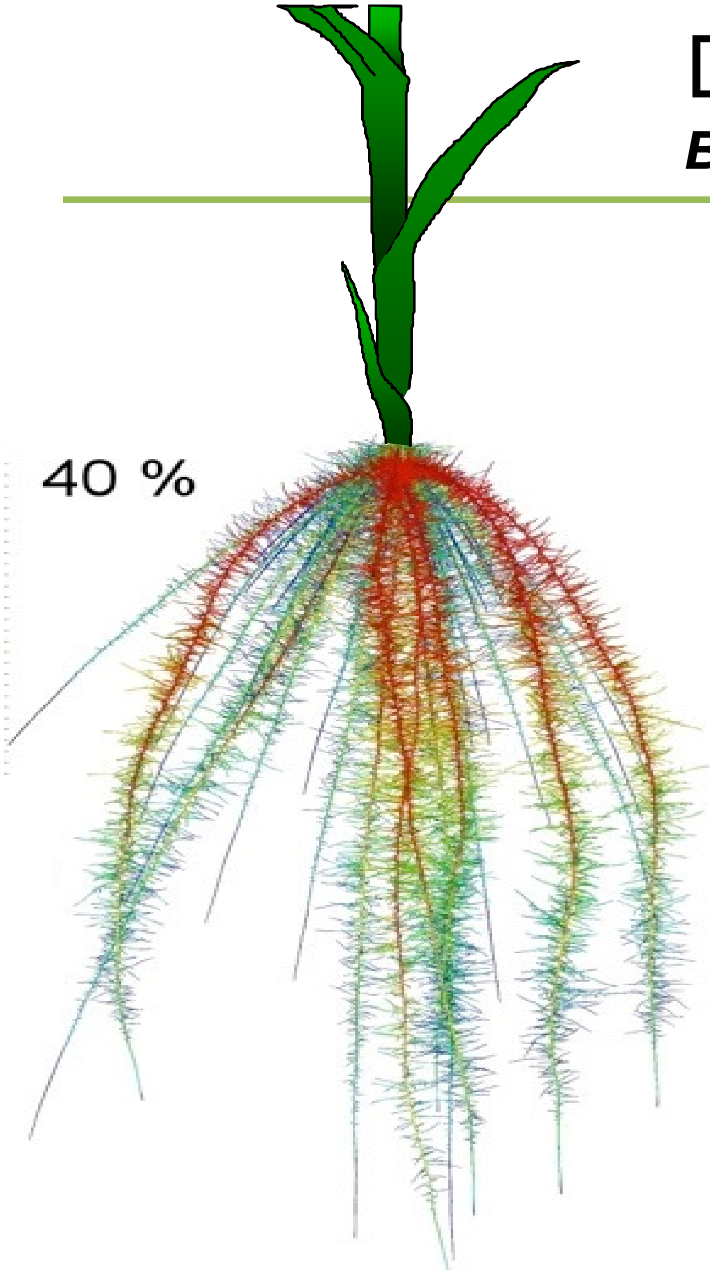


<u>Program Evolution</u>:

Phase I - Energy Sorghum (ARPAE)

Phase II - Catalyst for National Phenotyping Platform


2016 ARPA-E PROGRAM
TERRESTRIAL GHG
BIOSEQUESTRATION
ROOT × SOIL × ENVIRONMENT
(SOIL RESOURCE OPTIMIZATION)
OBJECTIVES:
1. CARBON ASSIMILATION (CO_2 EMISSIONS MITIGATION – SOM DEPOSITION)
2. NUTRIENT ACQUISITION (N_2O EMISSIONS REDUCTION – FERTILIZER EFFICIENCY)
3. WATER PRODUCTIVITY (RESOURCE EFFICIENCY)



Deep Roots are a Triple Win

Benefiting Agriculture and Society

Carbon:

- → Fix and Sequester Atmospheric CO_2
- → Enhance Soil Quality (physical, chemical, biological)

Nitrogen:

- → Improve Nutrient Use Efficiency
- → Reduce Fertilizer Runoff
- → Raise Crop Yield Potential

Water:

- → Boost Soil Water Holding Capacity
- → Provide Crop Yield Assurance
- → Enhance Crop Climate Resilience

Source: J. Lynch

Potential Program Impact

- **CO_2:** DOUBLING of Soil Carbon
  - 1-1.5 Gt $CO_{2\text{-eq}}$ / year
- **N_2O:** 50% annual reduction from row crop
  - 0.1 Gt $CO_{2\text{-eq}}$ / year
- **Genetic Root Improvements**
  - Increased Yield
  - Crop resiliency – biotic and abiotic stress resistance
- **Soil Quality:** Chemical, Physical, Biological
  - Increased Yield
  - Stress Resistance – water / nutrient holding
  - (Bio) Energy and Food Security

**Comparison
US Transportation Sector:

- 27% US Emissions (EPA)
- 1.7 Gt $CO_{2\ eq}$ / year

FOA March 2016, Awards Anticipated Fall 2016

TERRA Contacts

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