ARPA-E AgroEnergy Initiatives

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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** the 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:

<table>
<thead>
<tr>
<th>Economic</th>
<th>Environment</th>
<th>Natural Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>Climate</td>
<td>Fresh Water</td>
</tr>
<tr>
<td>Energy</td>
<td>Greenhouse Gas</td>
<td>Soil Carbon</td>
</tr>
<tr>
<td>Demand Doubles</td>
<td>2°C</td>
<td>9.9 GtC</td>
</tr>
</tbody>
</table>

- 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
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)
**Goals**

<table>
<thead>
<tr>
<th>Yield</th>
<th>Energy Density</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>160 GJ/Ha/yr</td>
<td>&gt;26 MJ/L (EtOH)</td>
<td>&lt; $10/GJ ($50/BOE)</td>
</tr>
</tbody>
</table>

**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
- **C₄ Grasses:** Sugarcane, Sorghum
- **Other:** Tobacco, Sugar beet
Developing Dedicated Biofuel Crops

1. Increasing Photosynthesis
2. Shifting Metabolism
3. Changing Agriculture

= Production without Oil
### Field demonstrations of PETRO technologies

<table>
<thead>
<tr>
<th>Tobacco</th>
<th>Camelina</th>
<th>Sugarcane</th>
<th>Switchgrass</th>
<th>Pine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional varieties planted over two acres to optimize biomass yields.</td>
<td>Transgenic lines planted at multiple sites under APHIS permits.</td>
<td>Transgenic lines have increased photosynthesis and accumulate TAG in leaves and shoots.</td>
<td>Transgenic lines planted under APHIS permit.</td>
<td>Existing stands were tapped to extract terpene rich resin.</td>
</tr>
<tr>
<td>Grown under high density with multiple harvests, and expect 20 tons/hectare (10X increase).</td>
<td>Engineered lines showed oil yields &gt;30% over non-transgenic camelina.</td>
<td>PETRO cane contain 5% TAG by DW (100X increase).</td>
<td>Lines engineered to modify their cell walls and improve biomass saccharification.</td>
<td>Developed biotechnology strategies to double the yields of oleoresins over control trees.</td>
</tr>
</tbody>
</table>
TRANSPORTATION ENERGY RESOURCES FROM RENEWABLE AGRICULTURE
Major breeding objectives: yield, composition, disease and insect resistance and tolerance to abiotic stresses.
20th Century Crop Phenotyping SOA
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)
TERRA Robotic Platforms are Diverse and Data Rich

**TERRA Ground & Aerial Vehicles**

<table>
<thead>
<tr>
<th>Performance Comparison</th>
<th>Current Breeding Manual</th>
<th>TERRA Ground &amp; Aerial Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td># Breeder Plots</td>
<td>1,000</td>
<td>1,000</td>
</tr>
<tr>
<td># Phenotypes</td>
<td>10’s</td>
<td>1000’s</td>
</tr>
<tr>
<td>Resolution</td>
<td>1 m</td>
<td>1 cm</td>
</tr>
<tr>
<td>Bandwidth (nm)</td>
<td>400 700</td>
<td>100 2500</td>
</tr>
<tr>
<td>Data Collection</td>
<td>Bytes</td>
<td>Terabytes</td>
</tr>
<tr>
<td>Cycle Time</td>
<td>8 hrs</td>
<td>1 min UAV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 hrs AGV</td>
</tr>
</tbody>
</table>

Reference Field Gantry Sensors:
- Hyperspectral (350-2500 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, CO₂

Reference Field Gantry (20 x 200 m)

Deployable Gantry Plant Phenotyping Systems
National Robotics Engineering Center, TAMU

Ground Plant Phenotyping Systems
Carnegie Mellon, UIUC, Purdue

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

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

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genomic data</td>
<td>• De novo genome assembly of a diverse panel of 30-50 sorghum varieties to generate a pan genome</td>
</tr>
</tbody>
</table>
| Field plant data                | • 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 |
Program Evolution:

Phase I - Energy Sorghum (ARPAE)

Phase II - Catalyst for National Phenotyping Platform
ROOT × SOIL × ENVIRONMENT
(SOIL RESOURCE OPTIMIZATION)

OBJECTIVES:
1. CARBON ASSIMILATION (CO₂ EMISSIONS MITIGATION – SOM DEPOSITION)
2. NUTRIENT ACQUISITION (N₂O EMISSIONS REDUCTION – FERTILIZER EFFICIENCY)
3. WATER PRODUCTIVITY (RESOURCE EFFICIENCY)
Deep Roots are a Triple Win
Benefiting Agriculture and Society

Carbon:
→ Fix and Sequester Atmospheric CO₂
→ 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

DEEP, STEEP AND CHEAP!
**Potential Program Impact**

- **CO₂:** DOUBLING of Soil Carbon
  - 1-1.5 Gt CO₂-eq / year
- **N₂O:** 50% annual reduction from row crop
  - 0.1 Gt CO₂-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 CO₂ eq / year

FOA March 2016, Awards Anticipated Fall 2016
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