ARPA-E: Launching Energy Innovation in the 21st Century

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Deputy Director for Technology
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http://arpa-e.energy.gov/
The Creation of ARPA-E

Innovation based on science and engineering will be primary driver of our future prosperity & security

2007
America COMPETES Act

2006
Rising Above the Gathering Storm (National Academies)

2009
American Recovery and Reinvestment Act
($400M appropriated)

2011
FY2011 Budget
($180M appropriated)

2012
FY2012 Budget
($180M House Bill
$250M Senate Bill)

President Obama launches ARPA-E at National Academies on April 27, 2009
To enhance the economic and energy security of the U.S.

To ensure U.S. technological lead in developing and deploying advanced energy technologies

Reduce Energy Imports

Reduce Energy-Related Emissions

Improve Energy Efficiency

ARPA-E’s Mission and Means

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

(A) identifying and promoting revolutionary advances in fundamental sciences; 
AND

(B) translating scientific discoveries and cutting-edge inventions into technological innovations; 
AND

(C) accelerating transformational technological advances in areas that industry by itself is not likely to undertake because of technical and financial uncertainty.
ARPA-E seeks to identify and support technologies that will be both transformational and disruptive

New energy technologies matter only to the extent that they are:

- Both transformational and disruptive
- Adopted and deployed by private industry
- Meaningful way to consumers
- Able to hit a key price tipping point

Steam-powered Cugnot (1769)

Benz Motorwagen (1885)

Ford Model T (1914)
ARPA-E’s program development process is extremely fast.

Program Development Cycle:

- **Envision**
  - Program Conception (Idea / Vision)
  - Technical Deep Dive
  - Workshop
  - Internal Debate
  - Further Refinement & FOA Development
  - FOA Announced

- **Establish**
  - Project Selection
  - Proposal
  - Further Refinement & FOA Development
  - Concept Paper Review
  - Full Proposal Panel Review

- **Engage**
  - Contract Negotiation and Awards
  - Award Announcements

- **Evaluate**
  - Proposal Rebuttal Stage
  - Program Selection
  - Final Proposal
  - Panel Review
  - Internal Debate
  - Proposal Rebuttal Stage

- **Program Execution**

Timeline: 6-8 Months from Program Conception to Execution
To date ARPA-E has made 121 awards from the first seven FOAs to a wide variety of organizations.

Project Breakdown by Lead Organization Type (% based on award value)*

*Total Value of Awards = $366 million
Projects from ARPA-E’s first broad solicitation fall into ten energy technology areas:
ARPA-E has 11 focused programs, five of which are currently in the contracting phase.

**Transportation**
- **Electrofuels**
  - BEEST
- **End-Use Efficiency**
  - PETRO
  - HEATS
  - BEETIT

**Stationary Power**
- **IMPACCT**
- **ADEPT**
- **GRIDS**
- **Solar ADEPT**
- **GENI**
- **REACT**

*BEEST: 5-6¢/kWh fully installed at the MW scale by 2020*
“Electrofuels,” a program area for mid-to-long term solutions to many current biofuel production inefficiencies

Assimilate Reducing Equivalents: other than reduced carbon or products from Photosystems I & II (ex. direct current, $H_2$, $H_2S$, etc.)

Pathways for Carbon Fixation: reverse TCA, Calvin-Benson, Wood-Ljungdahl, Hydroxpropionate-hydroxybutyrate, or newly designed biochemical pathways

Fuel synthesis: metabolic engineering to direct carbon flux to fuel products

Butanol, Alkanes, Etc.

“Electrofuels” targets the first application of non-photosynthetic, autotrophic microorganisms for the production of infrastructure compatible biofuels.

13 projects, $45M ARPA-E, $56M Total
OPX Biotechnologies is developing a *Ralstonia*-based system for the conversion of $H_2$ and $CO_2$ to hydrocarbons.

<table>
<thead>
<tr>
<th>Title</th>
<th>Novel biological conversion of hydrogen and carbon dioxide directly into biodiesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team Lead</td>
<td>OPX Biotechnologies, Boulder, CO</td>
</tr>
<tr>
<td>Project Budget</td>
<td>$8.6 Million</td>
</tr>
<tr>
<td>POP</td>
<td>7/12/2010 - 7/11/2013 (36)</td>
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OPX has succeeded in engineering key biological steps, including conversion of acetyl-CoA to malonyl-CoA.

**Task 1** Optimize hydrogenase and rubisco activity

**Task 2** Optimize free fatty acid biosynthesis

**Task 3** Optimize FAME biosynthesis

**Task 4** Bioprocess optimization

**Task 5** Catalytic conversion of FAME to diesel

**Task 6** Commercial technology evaluation

**Malonyl-coA flux screening in C. necator**

wt | wt + vector | wt + THNS
**Direct electron transfer: UMass will leverage the ability of some microbes to make electrical contacts with electrodes**

<table>
<thead>
<tr>
<th>Title</th>
<th>Electrofuels via Direct Electron Transfer from Electrodes to Microbes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team Lead</td>
<td>U. of Massachusetts; Amherst, MA</td>
</tr>
<tr>
<td>Project Budget</td>
<td>$4.1 Million</td>
</tr>
<tr>
<td>POP</td>
<td>7/01/2010 - 7/01/2013 (36)</td>
</tr>
</tbody>
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*Geobacter metallireducens* can form conductive biofilms on the surface of electrodes.

*Acetogenes* such as *Sporomusa ovata* have demonstrated the ability to produce acetate directly from electrons with high coulombic efficiency.

*Clostridium ljungdahlii* will be engineered to produce butanol from electricity.
Columbia University’s approach is to engineer ammonia metabolizing microorganisms to produce butanol

<table>
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<tr>
<th>Title</th>
<th>Biofuels from CO$_2$ using Ammonia-Oxidizing Bacteria in a Reverse Microbial Fuel Cell</th>
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<tbody>
<tr>
<td>Team Lead</td>
<td>Columbia University; New York, NY</td>
</tr>
<tr>
<td>Project Budget</td>
<td>$0.6 Million</td>
</tr>
<tr>
<td>POP</td>
<td>7/01/2010 - 6/30/2012 (24)</td>
</tr>
</tbody>
</table>

• *Nitrosomonas europaea* are chemolithoautotrophic ammonia-oxidizing-bacteria that are found in wastewater treatment operations. Combustion of CO$_2$ drives chemolithoautotrophic ammonia production.

- Ammonia is used as the soluble energy redox carrier, thus the microbes do not need to be in direct contact with an electrode.
- Nitrite can be electrochemically reduced back to ammonia.
- *N. europaea* can be grown on electricity and air.
- *N. europaea* cells are tolerant of high ammonia and high nitrite concentrations.
- Cells are not impacted by electrochemical reduction of media.
- Genetic modification of *N. europaea* cells for isobutanol production currently is underway.
NCSU & UGA seek to transfer novel CO$_2$ fixation enzymes to convert heterotrophs into autotrophs

<table>
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<tr>
<th>Title</th>
<th>H$_2$-Dependent Conversion of CO$_2$ to Liquid Electrofuels by Thermophilic Archaea</th>
</tr>
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<tbody>
<tr>
<td>Team Lead</td>
<td>North Carolina State U.; Raleigh, NC</td>
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<td>Project Budget</td>
<td>$3.3 Million</td>
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<td>POP</td>
<td>7/01/2010 - 6/23/2013 (36)</td>
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</tbody>
</table>

- Leverage NADPH-dependent soluble hydrogenase activity from *Pyrococcus furiosus*
- Incorporate novel 3-hydroxypropionate/4-hydroxybutyrate CO$_2$ fixation cycle from *Metallosphaera sedula*
Thank you

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