Progress Towards Transformative Energy Technology Innovation

Biomass 2010

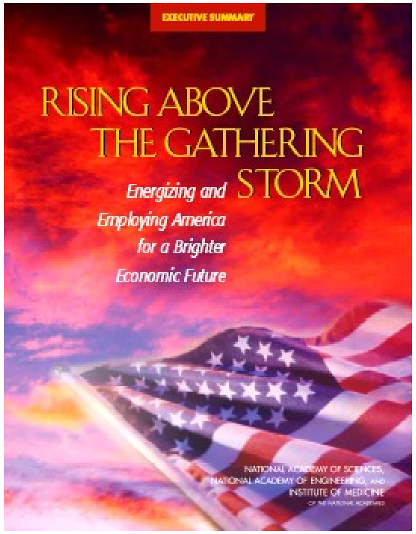
March 30th, 2010

www.arpa-e.energy.gov

The strategic need for ARPA-E stemmed from "Rising Above the Gathering Storm" report

Rising Above the Gathering Storm, 2006 (National Academies)

- Establish an Advanced Research Projects Agency for Energy (ARPA-E)
- "Creative, out-of-the-box, transformational" energy research
- Spinoff Benefit – Help educate next generation of researchers
- Secretary Chu (then Director of Berkeley National lab) on committee



America COMPETES Act, 2007

- Authorizes the establishment of ARPA-E

American Recovery and Reinvestment Act of 2009 (Recovery Act)

- $400M appropriated for ARPA-E
- President Obama launches ARPA-E in a speech at NAS on April 27, 2009

The America COMPETES Act 2007 authorized the establishment of ARPA-E with a clear mission

Mission

- To "enhance the economic and energy security of the U.S." through:
  - "Reduction in energy imports"
  - "Improvement in energy efficiency"
  - "Reduction in energy-related emissions, including greenhouse gasses"
- To "ensure" U.S. "technological lead in developing and deploying advanced energy technologies"

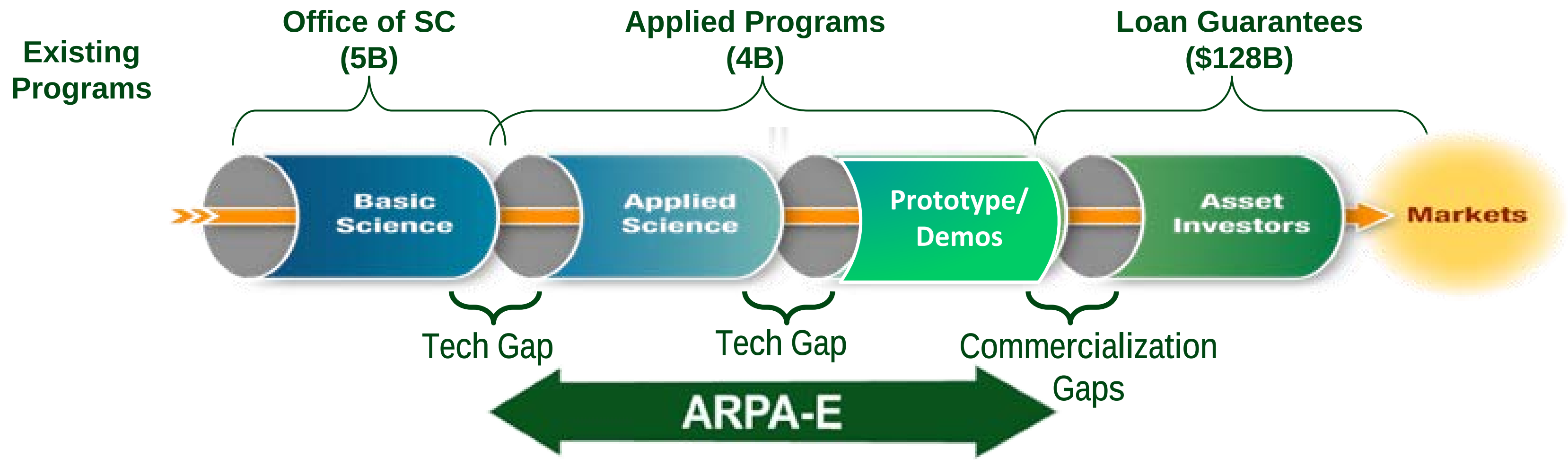
Means

- "Identifying and promoting" [but not itself making] "revolutionary advances in fundamental sciences"
- "Translating scientific discoveries and cutting edge inventions into technological innovations"
- "Accelerating transformational technological advances in areas that industry by itself is not likely to undertake…"
- Authority for: testing and evaluation, demonstration, mfg. technology, tech transfer

Key Takeaways

- Creates a new organization within DOE, reporting directly to the Secretary (PAS)
- Hiring and management unrestricted by civil service laws
- Lean, flat organization
- Separate budget line and Treasury Fund account
- Can engage universities, industry, and when in consortia with others, FFRDC labs

ARPA-E was created with a vision to bridge gaps in the energy innovation pipeline



what ARPA-E will do

- Seek high impact science and engineering projects
- Invest in the best ideas and teams
- Will tolerate and manage high technical risk
- Accelerate translation from science to markets
- Proof of concept and prototyping

what ARPA-E *NOT* will do

- Incremental improvements
- Basic research
- Long term projects or block grants
- Large-scale demonstration projects

ARPA-E as an organization is intended to be nimble and flat

Dr. Arun Majumdar
ARPA-E Director

Shane Kosinski
Deputy Director of Operations

- **Operations Team**
  - Matt Dunne — Acting Chief Counsel
  - John Harris — Contracting Officer
  - Antony DiGiovanni — Budget Officer
- **Program Team**
  - Dr. Dave Danielson — Program Director
  - Dr. Mark Hartney — Program Director
  - Dr. Eric Toone — Program Director
  - Dr. Mark Johnson — Program Director
  - ARPA-E Fellows
- **Commercialization & Stakeholder Engagement Team**
  - Dr. Srinivas Mirmira — Commercialization

ARPA-E is expanding the Program Team with new Program Directors coming on board soon.

Nearly 3,700 concepts were received, processed and reviewed in FOA 1; 37 projects were selected for funding

FOA Selection Review Process

CP Review
~400 reviewers
2.5 weeks

Topical Panel Review
~100 reviewers
3 weeks

Senior Panel Review
8 reviewers
2 weeks

Mon, April 27
FOA Issued

Wed, June 10
Concept Paper submissions due

Tue, July 28
Concept Paper feedback provided

Fri, Aug 28
Full application submission deadline

Mon Sept 21 - Tues Sept 22
Topical panel members (~100) met in DC, discussed and provided final scores / evaluations

Wed, Oct 7
Senior panel met in DC, discussion and final evaluation input to ARPA-E

Fri, Oct 9
Final Selection Recommendations

Mon, Nov 23
First award made

Mon, Dec 28
50% of awards made

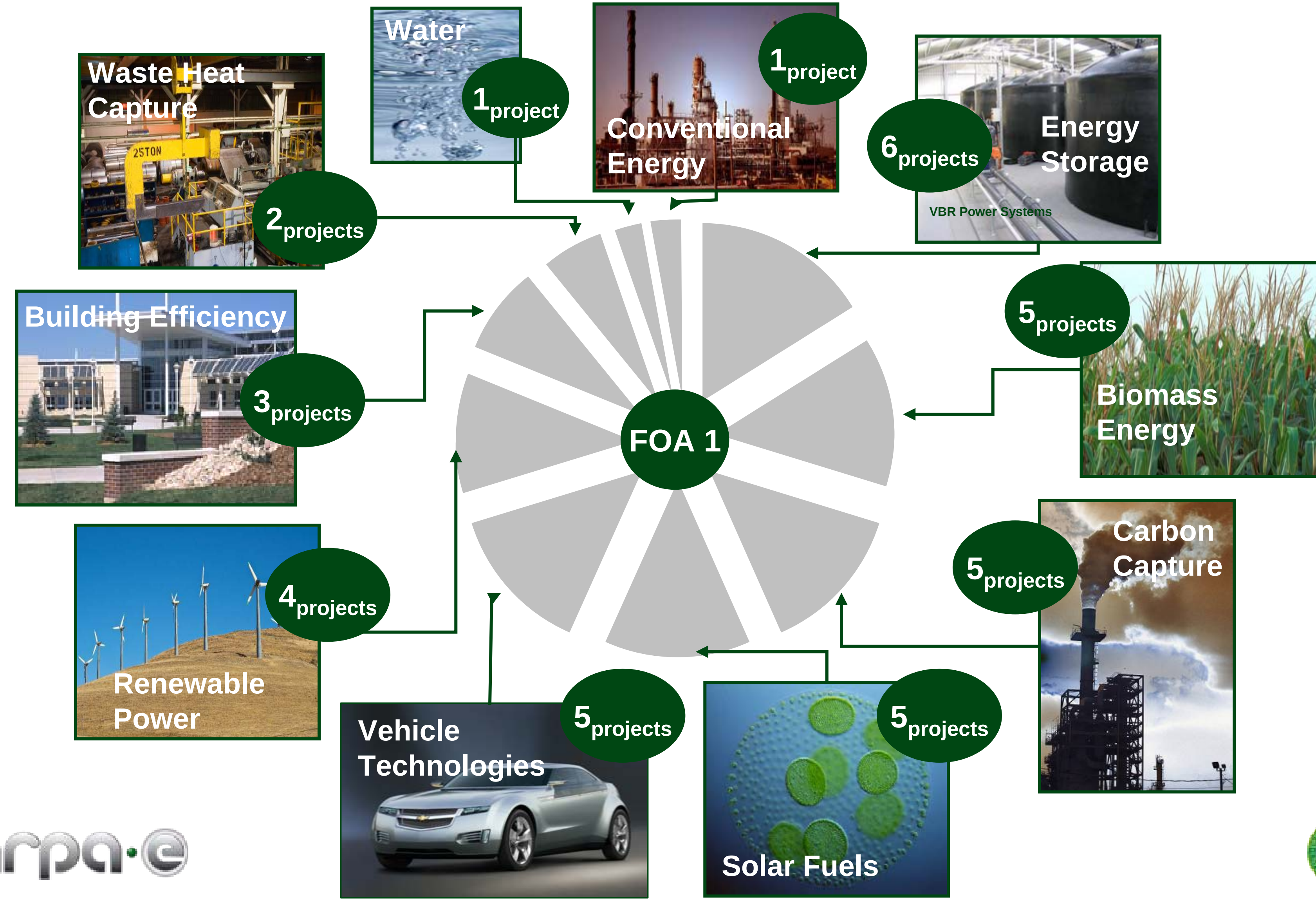
Fri, Jan 15
95% of awards made

Panels held on Sept 21	Panels held on Sept 22
- Conventional Energy	- Biological Energy
- Vehicles / Transportation	- Solar Energy
- Energy Efficiency	- Grid Scale Storage / Renewable Power

37 Projects
(avg. $4M)
(2-3 years)

arpa·e

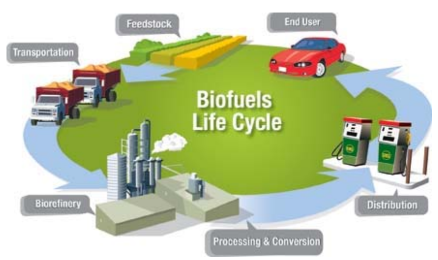
ARPA-E FOA 1 projects can be categorized into one of ten energy technology areas



arpa·e

ARPA-E FOA 1 “Biomass Energy” programs target critical aspects of the biomass energy supply chain

Sustainability Challenges

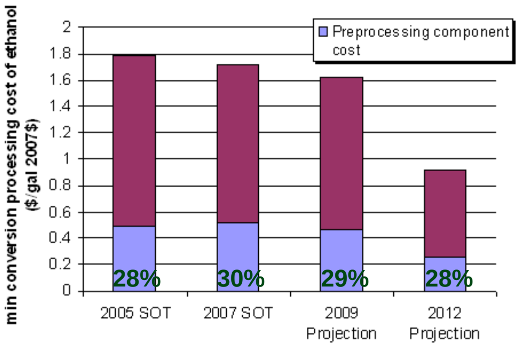


Credit Office of the Biomass Program

- Land & resource competition
- Market impacts (food & feed)
- Environmental impacts (nitrogen, etc.)
- Economic viability/parity with traditional fuels

ceres the energy cro… **$6.2M**	Ceres, Inc. High Yielding, Low Input Energy Crops *Trait development to increase biomass yields while decreasing use of nitrogen fertilizers*
DUPONT The miracles of science **$18M**	EI du Pont de Nemours & Company MacroAlgae Butanol *Produce isobutanol from macroalgae, an advantaged, environmentally sustainable feedstock*
Univenture inventing & manufacturing **$7.5M**	Univenture/Algae Venture Systems Scaling and Commercialization of Algae Harvesting Technology *Transform economics of algae-based fuels by dramatic energy cost reductions*

Pretreatment Challenges



Office of the Biomass Program, MYPP

- Despite cost reductions, pretreatment cost component is expected to remain at 30%
- Preprocessing is deleterious to downstream biochemical processing

Agrivida **$5.7M**	Agrivida Conditionally Activated Enzymes Expressed in Cellulosic Energy Crops *Produce inactive enzymes within plant biomass for conditional activation, and pretreatment cost/impact reduction*
RTI INTERNATIONAL **$3.9M**	RTI International Catalytic Biocrude Production in a Novel Short-Contact Time Reactor *Novel single step catalytic biomass pyrolysis process to maximize carbon conversion efficiency and yield a low oxygen-content biocrude*

The selection process also revealed opportunities for transformational photosynthetic direct solar fuels


Innovative Approaches for Photosynthetic Solar Fuel Production

Benefits –
- Photosynthetic CO_2 reduction
- Direct fuel/fuel precursor production bypasses biomass feedstock production, logistics & conversion
- Genetically tractable organisms for tailor-made fuel production

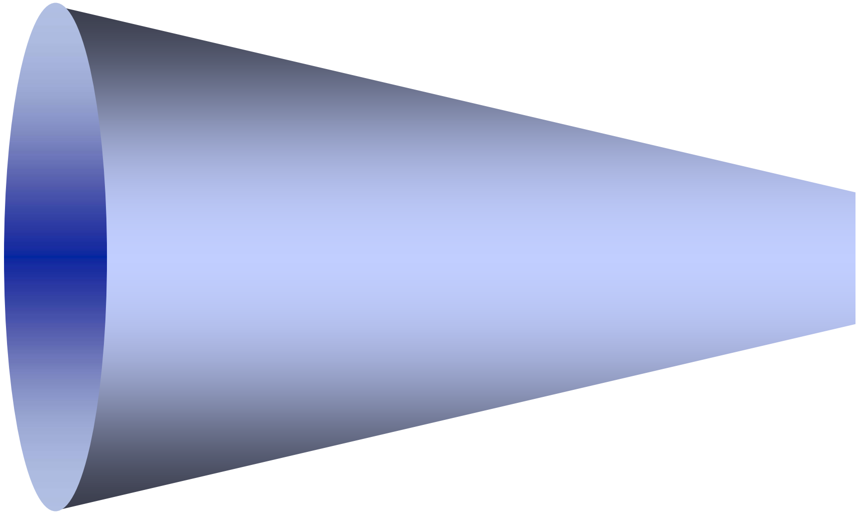
Challenges –
- Culture refinement, maintenance, & viability
- Production rate & yield
- Photobioreactor design & cost
- Downstream processing of fuel precursors
- Overall economic feasibility

Arizona State University — $6.5M	Arizona State University <u>Cyanobacteria Designed for Solar-Powered Highly Efficient Production of Biofuels</u> *Engineer photosynthetic Synechocystis cyanobacteria to enable highly efficient production and secretion of fatty acids in a continuous culture maintained in stationary phase*
$5.5M	Iowa State University <u>A Genetically Tractable Microalgae Platform for Advanced Biofuel Production</u> *Empower the economic viability, versatility, and sustainability of the algae-based fuels industry via development of a genetically tractable Chlamydomonas microalgal platform*
$2.8M	University of Minnesota <u>Shewanella as an Ideal Platform for Producing Hydrocarbon Biofuels</u> *Develop a co-culture with photosynthetic cyanobacteria and Shewanella bacteria to produce and continuously harvest hydrocarbons for fuel production*

ARPA-E has transitioned away from the wide-open FOA1 to more focused energy technology programs

Inputs to Focused FOA Development

- FOA 1: Unprecedented Snapshot of U.S. Energy Technology Landscape
- 550 Responses to ARPA-E's "Request for Information" Suggesting High Impact Program Areas
- 7 Focused Workshops



FOCUSED FUNDING OPPORTUNITIES ($30-$35M programs)

Round 1

- Wide-open "Early Harvest" solicitation
- Seeking to support the best U.S. energy technology concepts across the board

Round 2 & Round 3 FOAs

- Focused funding opportunities around specific markets or technical challenges
- Metrics driven programs with clear "over the horizon" cost and/or performance metrics

arpa·e

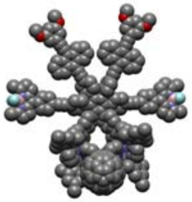
Current pathways for liquid fuels from solar energy have low energy efficiency and many challenges

Photosynthesis Biomass Paradigm

+ CO_2
+ H_2O = Biomass → Biochem / Thermal / Hybrid / Catalytic → Fuel
+ light

Considering the efficiency of photosynthesis, biomass based approaches, including algae, are practically only 1% energy efficient (E_{out}/E_{in}), and biomass logistics are problematic.

'Classical' Direct-solar Fuels Paradigm



+ CO_2
+ H_2 Photocatalysis → Syngas, CH_3OH, CH_4
+ light

Photocatalysis beyond water oxidation is very limited – very little capacity to form carbon-carbon bonds – and systems under consideration may be difficult to deploy.

Can we achieve high photon efficiencies <u>and</u> generate complex liquid fuels?

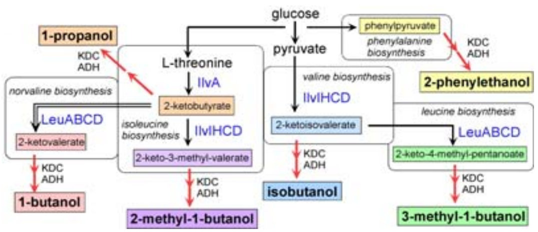
arpa·e

“Electrofuels” concept - Can we develop systems that bypass photosynthesis and directly reduce CO_2 to complex liquid fuels?

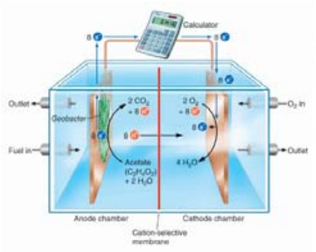
The Goal: Develop modular biosynthetic systems that can assimilate energy from abundant sources which could be generated in high yield from solar energy. A possible sub-goal might involve the export of electrons from photosynthetic bacteria, or the co-culture of photoactive bacteria.

The Proposal: Utilize metabolic engineering and synthetic biological approaches for the high efficiency conversion of CO_2 to liquid transportation fuels in organisms capable of extracting energy from hydrogen, from reduced earth-abundant metal ions or/and organic cofactors, or directly from solar current.

Foundational R&D has been demonstrated to support the concept…………*what’s next?*



An extraordinary number of autotrophic organisms (e.g. extremophiles, acetogens, methanogens,) utilize energy inputs other than photons or reduced carbon, but little is known about their fundamental biochemistry. Synthetic biology and metabolic engineering have demonstrated a remarkable capacity to create an astonishing array of molecules, including fuel precursors.



Direct Biological Conversion of Electrical Current into Methane by Electromethanogenesis

SHAOAN CHENG, DEFENG XING, DOUGLAS F. CALL, AND BRUCE E. LOGAN*
Engineering Environmental Institute and Department of Civil and Environmental Engineering, 212 Sackett Building, The Pennsylvania State University, University Park, Pennsylvania 16802

Received December 12, 2008. Revised manuscript received March 5, 2009. Accepted March 6, 2009.

Many microorganisms communicate electrically with their surroundings as a means to transfer and assimilate energy. This phenomenon was the basis for the development of microbial fuel cells, funded by DOE, DoD, & DARPA. Very recently it has been demonstrated that reverse microbial fuel cells are feasible and can fix CO_2 using electrical current as an energy input.

Thank you for your attention!

Eric Toone
Eric.Toone@hq.doe.gov