ARPA-E: Transformative Energy R&D

Biomass Technical Advisory Committee Meeting

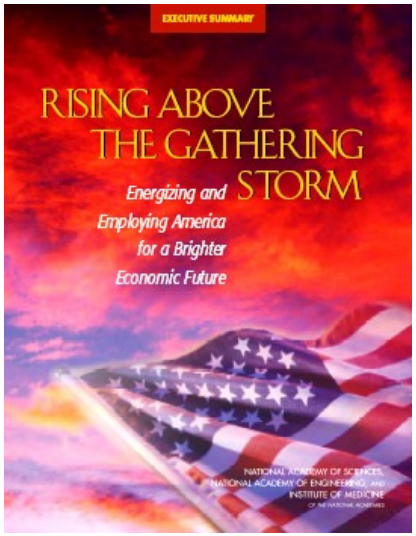
April 1st , 2010

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"

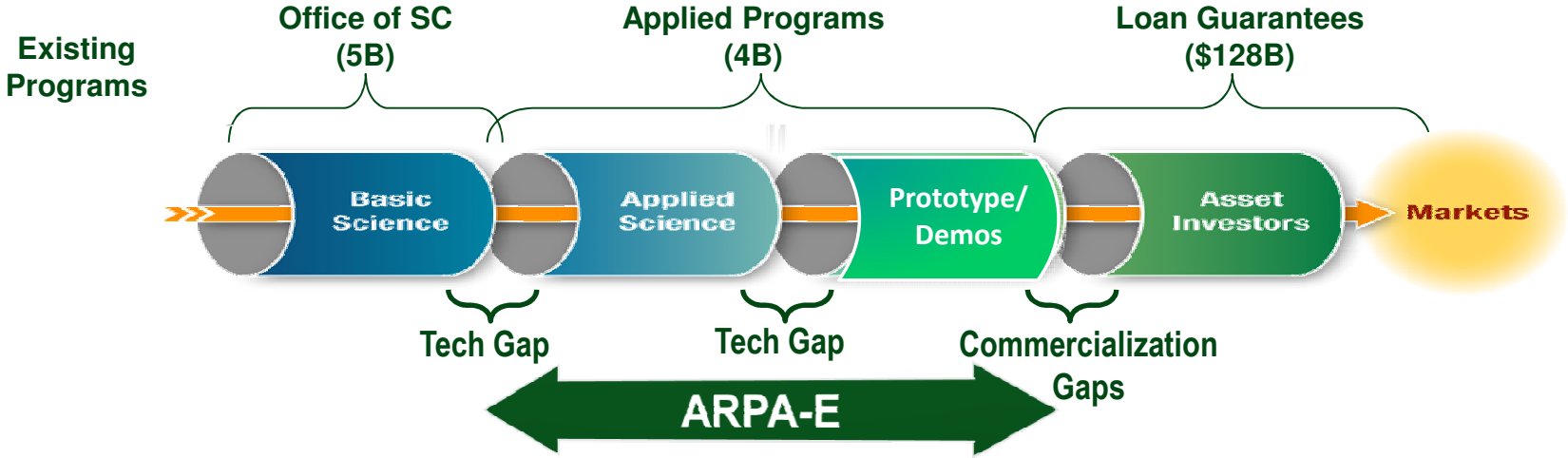
Means

- "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
- 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

Commercialization & Stakeholder Engagement Team

Dr. Srinivas Mirmira
Commercialization

Program Team

Dr. Dave Danielson
Program Director

Dr. Mark Hartney
Program Director

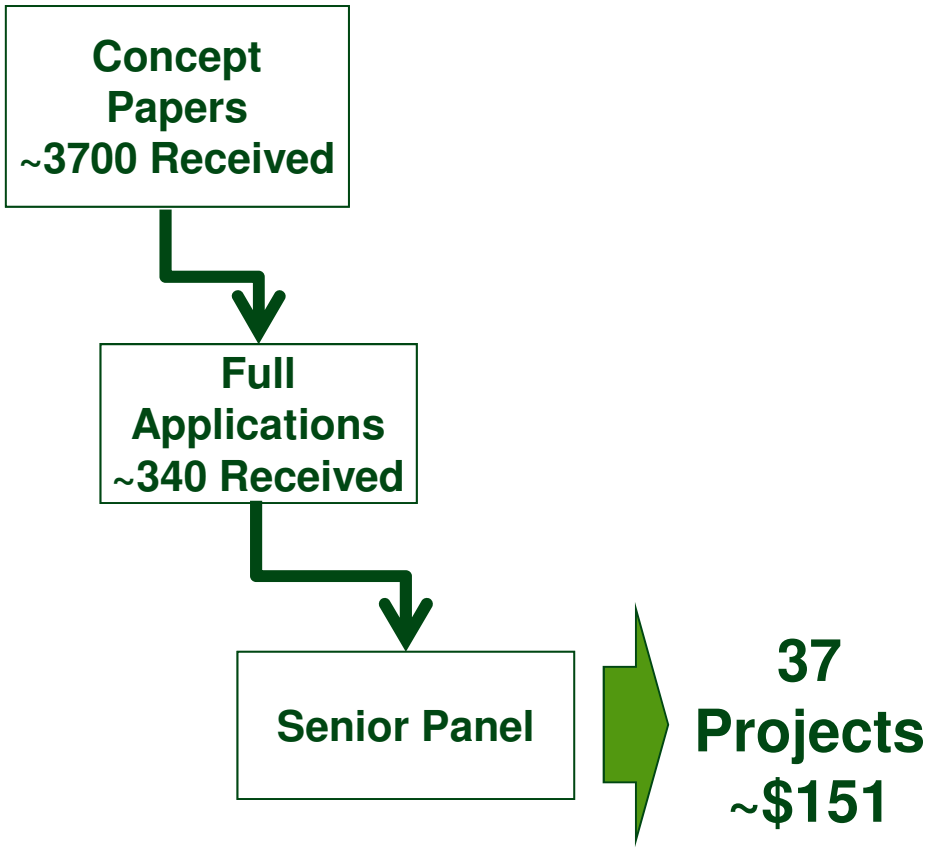
Dr. Eric Toone
Program Director

ARPA-E Fellows

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

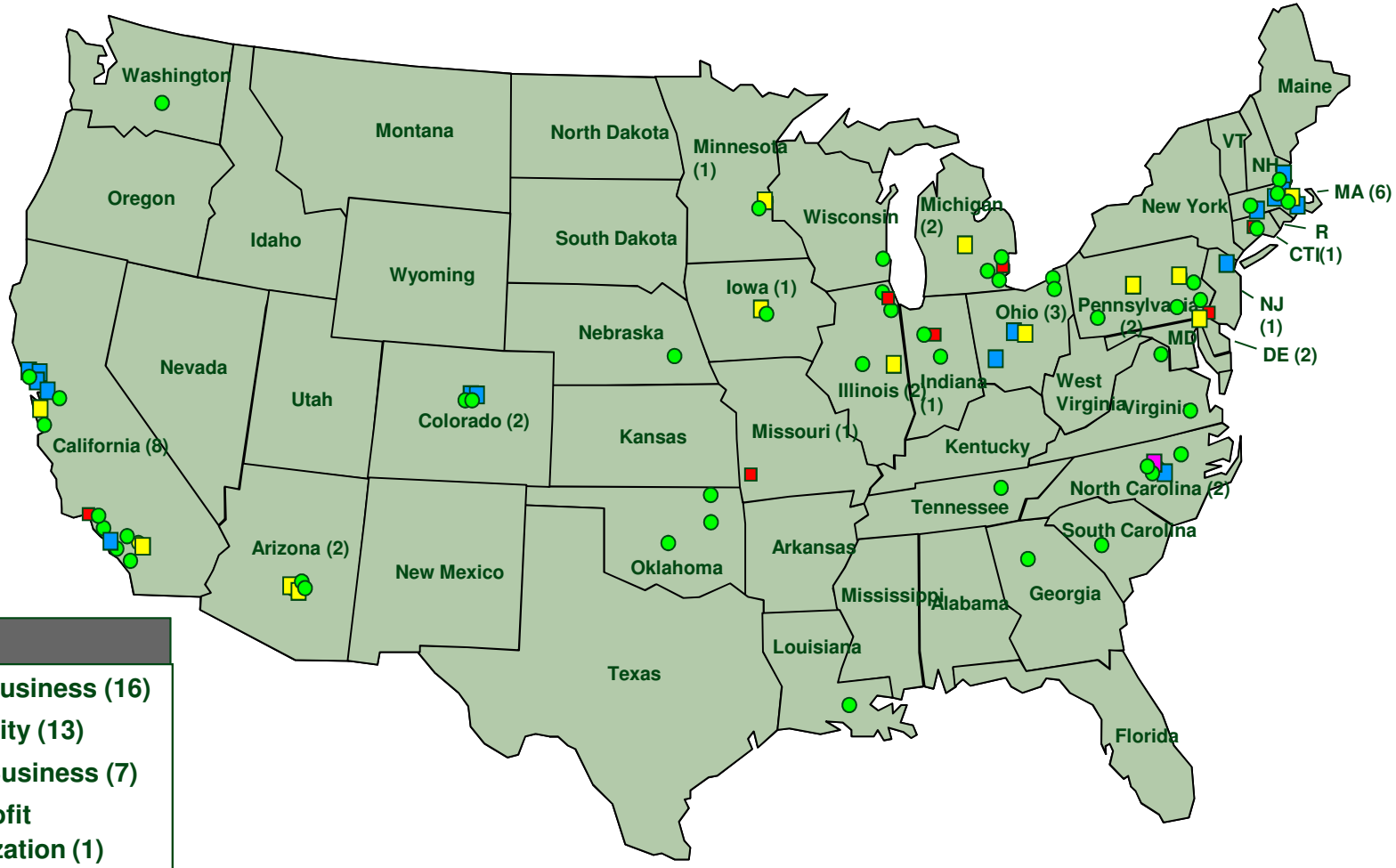
Funding Opportunity Announcement - Round 1

FOA 1 – Open to all energy technologies; yet required to be game changing/high impact (Announced April `09, selections Oct `09)



- Rigorous review process with assistance from academia, industry and government
- Secretary Chu called for Nation's experts assist with reviews
- The Nation responded - Over 500 reviewers participated
  - All reviewers vetted by senior DOE leadership
  - 8,694 review hours; 4.18 person years

FOA 1 awardees and teaming partners are geographically distributed

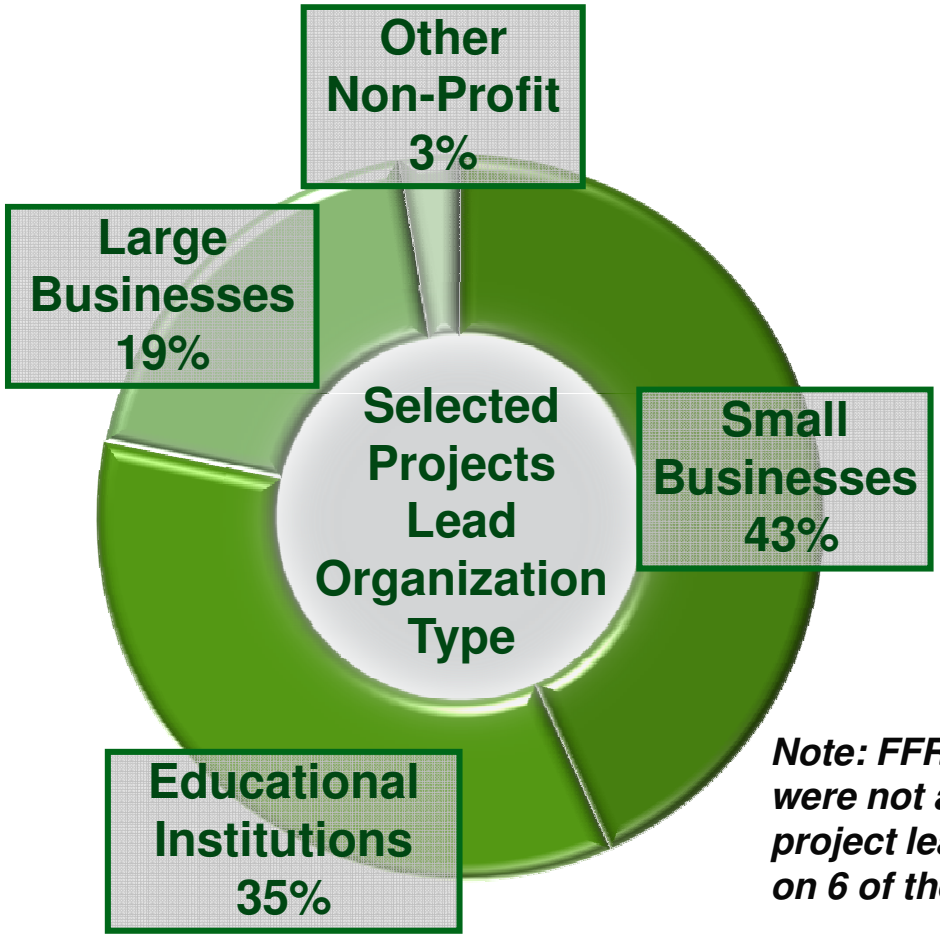


Legend

- Small Business (16)
- University (13)
- Large Business (7)
- Non-profit Organization (1)
- Team Members (54)

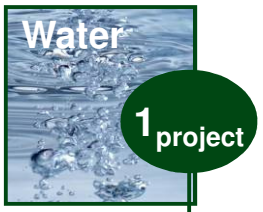
Source: Merit Review Board results; ARPA-E Full Application cover sheet submissions.

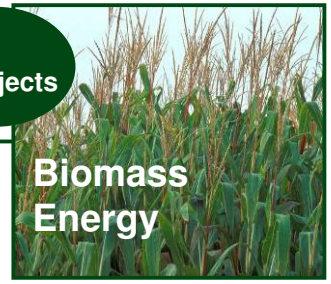
Small businesses represent the largest fraction of FOA1 project leads

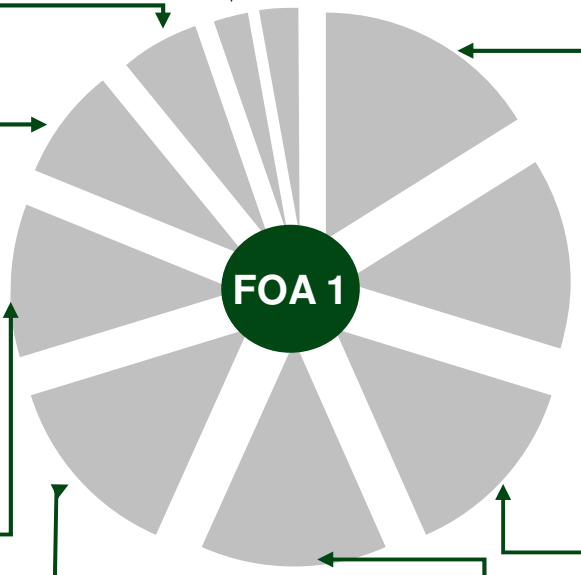


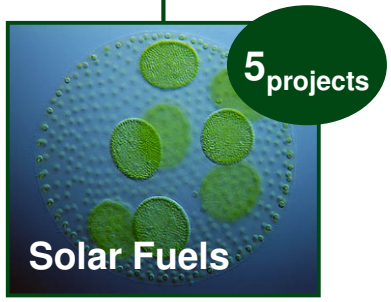
Note: FFRDCs/DOE National Labs were not allowed to submit as project leads but are represented on 6 of the 37 projects (19%)

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



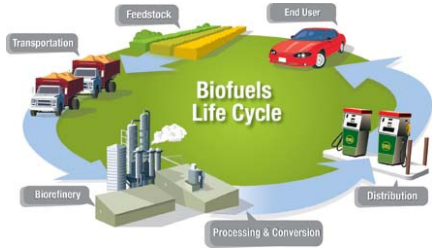






ARPA-E FOA 1 "Biomass Energy" programs target critical aspects of the biomass energy supply chain

Sustainability Challenges

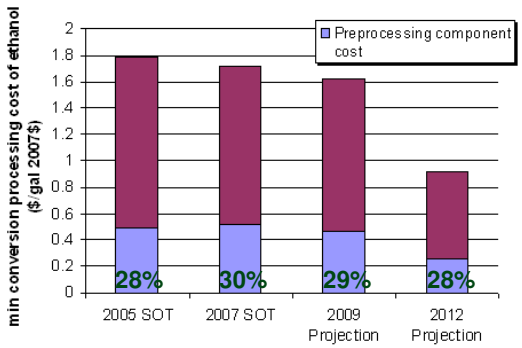


Credit Office of the Biomass Program

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

$6.2M	Ceres, Inc. High Yielding, Low Input Energy Crops *Trait development to increase biomass yields while decreasing use of nitrogen fertilizers*
$18M	El du Pont de Nemours & Company MacroAlgae Butanol *Produce isobutanol from macroalgae, an advantaged, environmentally sustainable feedstock*
$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



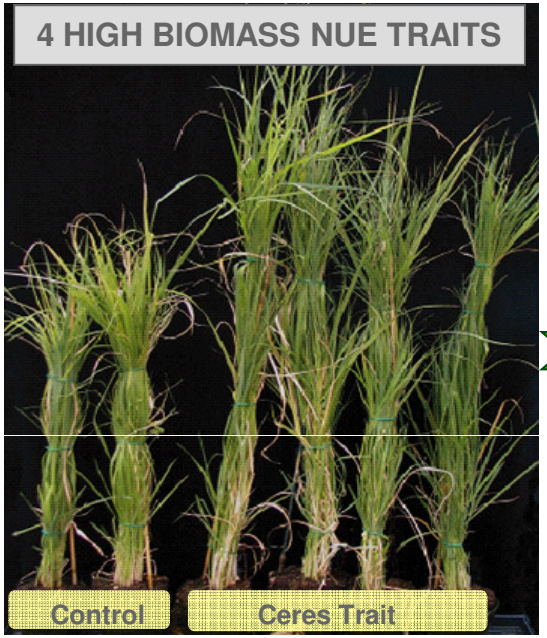
Office of the Biomass Program, MYPP

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

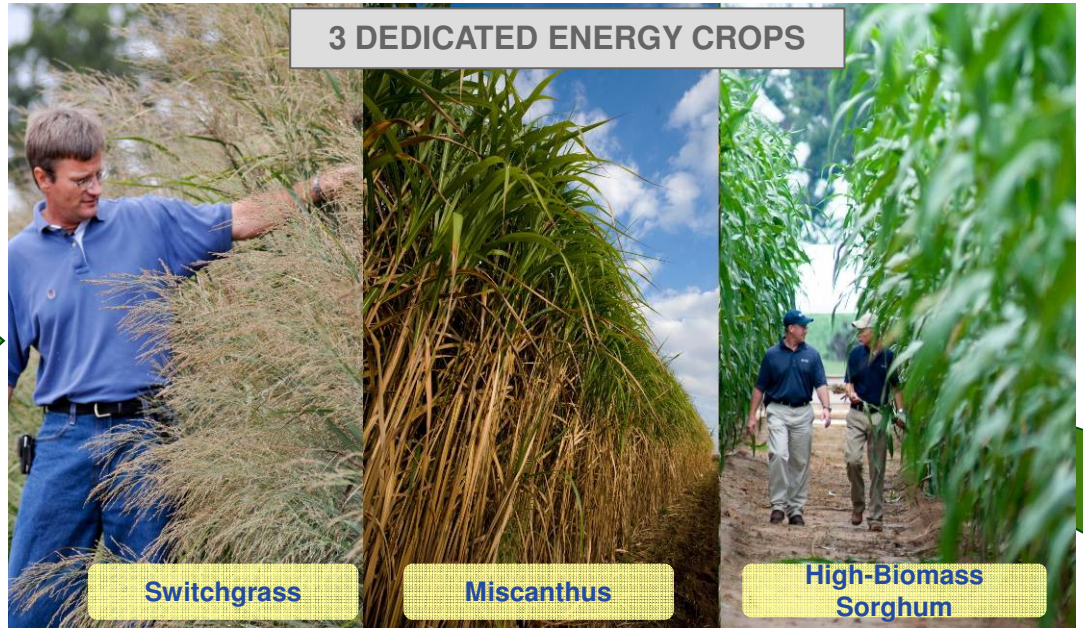
$5.7M	Agrivida Conditionally Activated Enzymes Expressed in Cellulosic Energy Crops *Produce inactive enzymes within plant biomass for conditional activation, and pretreatment cost/impact reduction*
$3.9M	RTI International Catalytic Biocrude Production in a Novel Short-Contact Time Reactor *Novel single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

Ceres seeks to develop high biomass dedicated energy crops with increased nitrogen use efficiency

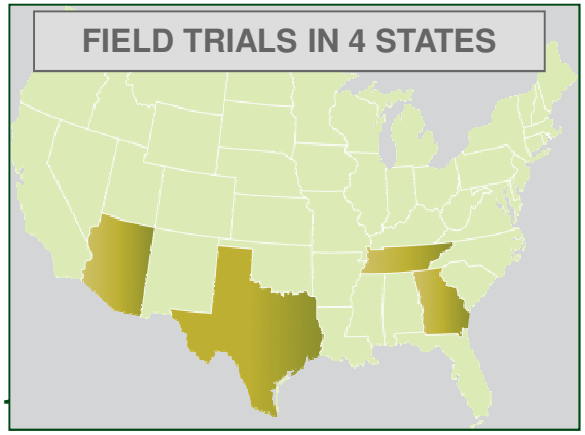
4 HIGH BIOMASS NUE TRAITS



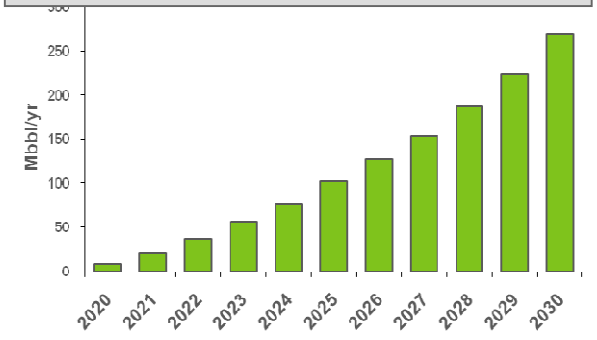
3 DEDICATED ENERGY CROPS



FIELD TRIALS IN 4 STATES



ENERGY & ENVIRONMENT IMPACT



ceres
the energy crop company®

DuPont and BAL – Macroalgae and biobutanol technology combined provide a sustainable biofuel

Seaweed:

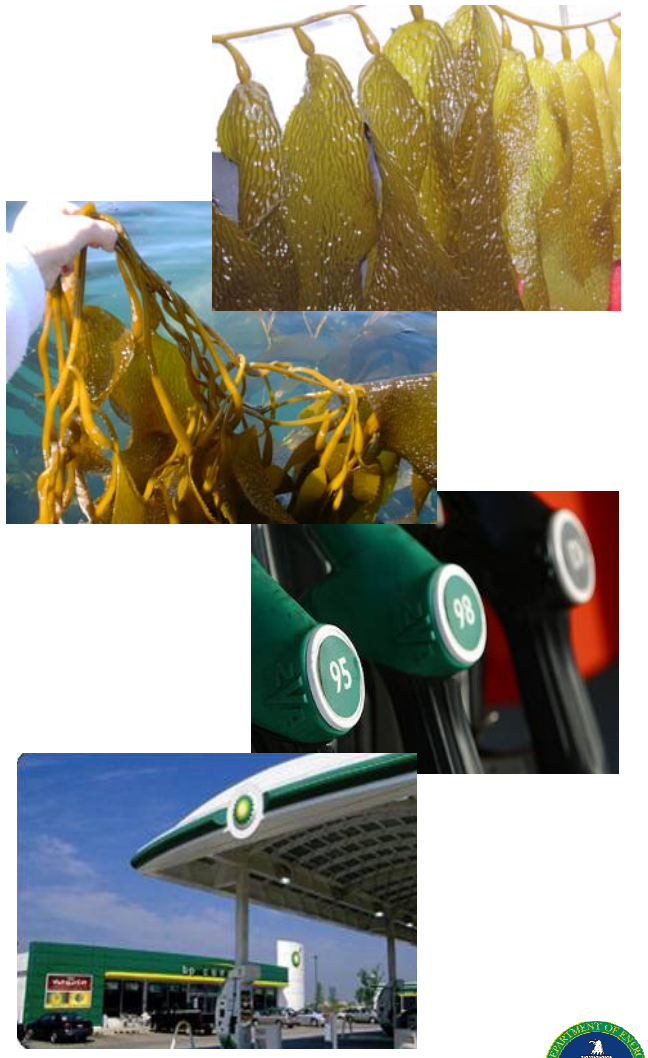
- Scalable production allowing for high volume of biomass to be produced
- Potential to reduce GHG emissions by >90% compared to petroleum based fuels
- Grown at large scale today, can leverage existing agricultural systems

Biobutanol:

- Can be produced from a range of feedstocks
- Compatible with current infrastructure (pipelines, tanks, pumps, current vehicle fleet)
- Physical properties which create value throughout the fuels supply chain (high energy density, high octane, low vapor pressure, water immiscibility)
- Can be blended at 16% in gasoline – providing twice as much renewable energy content in the gasoline supply as is possible today

Approach:

- Technoeconomic Feasibility: Process analysis and feasibility-scale pilot for cost effective feedstock production and conversion
- Biocatalyst Feasibility: Develop isobutanol producing yeast that converts macroalgal carbohydrate to isobutanol in high yield
- Commercialization Strategy: Technology developed in this program will be further advanced, piloted and ultimately commercialized by the DuPont/BP Joint Venture, Butamax™ Advanced Biofuels, LLC., chartered to develop and commercialize biobutanol from multiple feedstocks – growing biofuels within the transportation fuel supply



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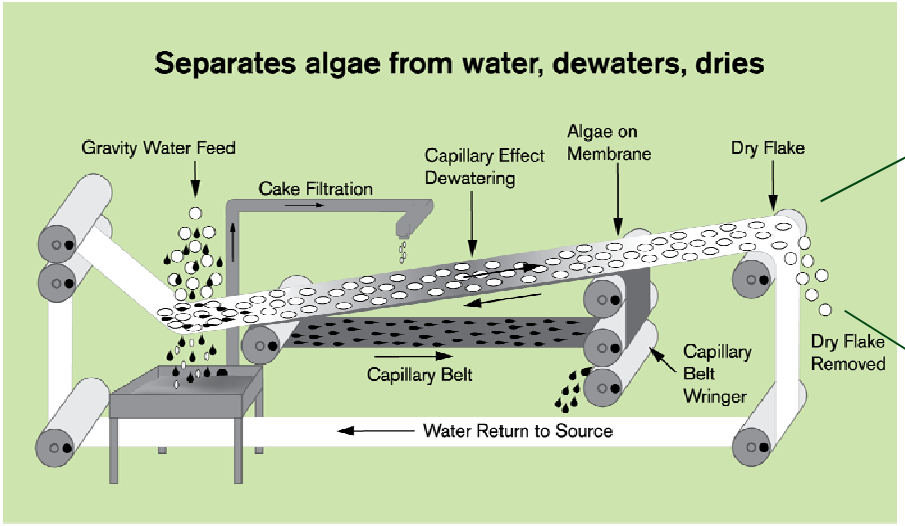
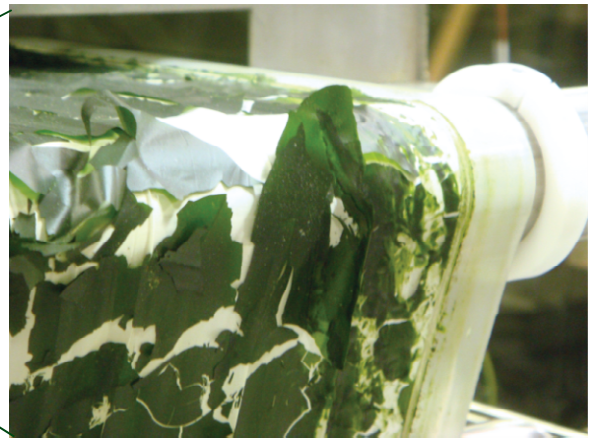
bal bio architecture lab

DUPONT

Univenture/Algaeventure seeks to reduce the energy/economic cost of dewatering & drying microalgae

- **Algaeventure Systems is developing a new and inexpensive method for harvesting algae utilizing low energy surface chemistry properties in a mechanical-electrical device.**
- **Algaeventure Systems has designed and fabricated an innovative algae harvesting dewatering and drying system that is far more energy-efficient than existing techniques. If successful, this technology could dramatically reduce the energy cost necessary to harvest, dewater, dry algae and potentially transform the economics of algae-based bio-fuel production.**





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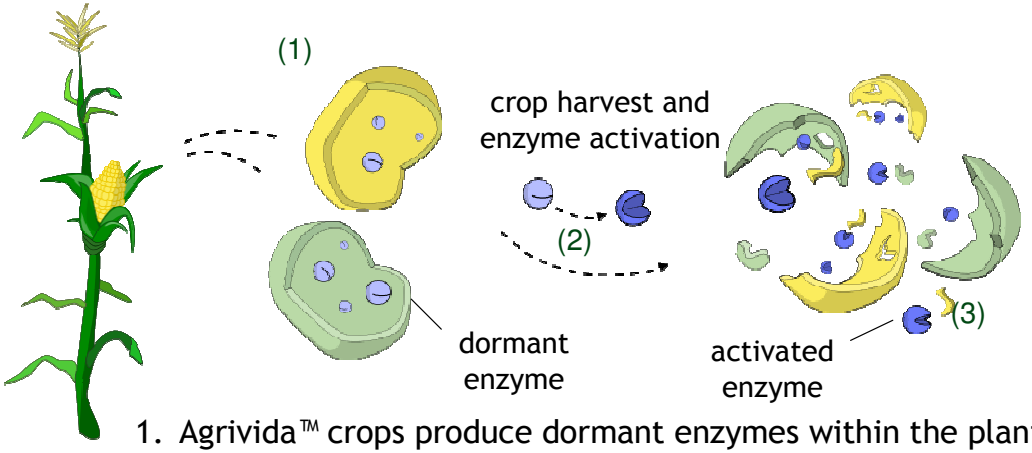
Algaeventure systems a Univenture, Inc. company

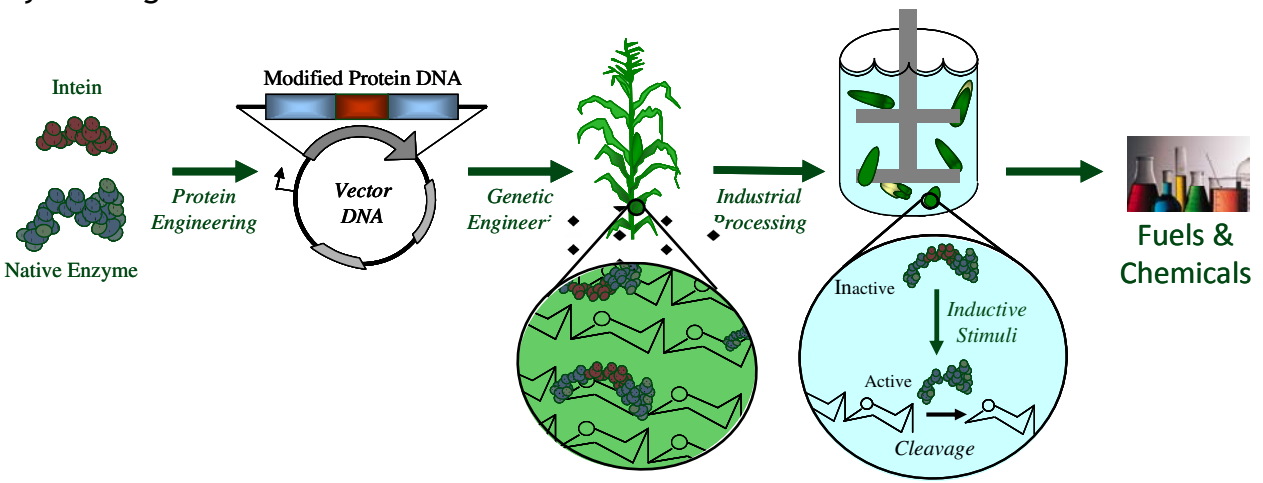
Agrivida will develop intein-modified pro-enzymes which can be conditionally activated within plant biomass



Agrivida

1. Agrivida™ crops produce dormant enzymes within the plant.
2. The dormant enzymes are activated after harvest.
3. The activated enzymes degrade the cell wall.

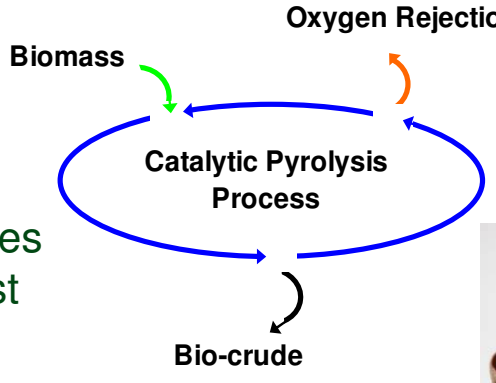
Molecular biology discovery platform



RTI will develop a novel catalytic biomass pyrolysis process to produce stable bio-crude

Project Objectives:

- Develop multi-functional catalysts with selective oxygen removal and cracking functionalities for producing a pyrolysis product similar to crude oil
- Develop a biomass pyrolysis process that optimizes carbon conversion, catalyst performance, and cost
- Establish solid foundation for process scale-up, catalyst scale-up, bio-crude upgrading to fuels to accelerate technology transition



Biomass → Catalytic Pyrolysis → Bio-crude → Fuel Upgrading → Bio-gasoline Green Diesel

Catalyst Development and Novel Reactor Concepts

Minimal H_2

Hydrotreating/Hydrocracking
Petroleum refinery co-feed
Infrastructure compatibility

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 –

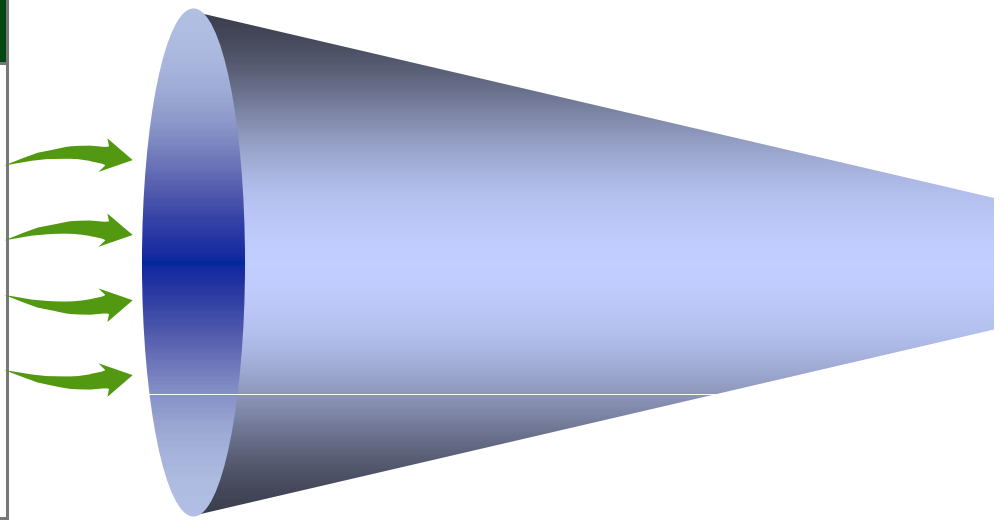
- Culture refinement, maintenance, & viability
- Production rate & yield
- Photobioreactor design & cost
- Downstream processing of fuel precursors
- Overall economic feasibility

ASU Arizona State University — $6.5M	Arizona State University Cyanobacteria Designed for Solar-Powered Highly Efficient Production of Biofuels *Engineer photosynthetic Synechocystis cyanobacteria to enable highly efficient production and secretion of fatty acids in a continuous culture maintained in stationary phase*
STATE — $5.5M	Iowa State University A Genetically Tractable Microalgae Platform for Advanced Biofuel Production *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 Shewanella as an Ideal Platform for Producing Hydrocarbon Biofuels *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

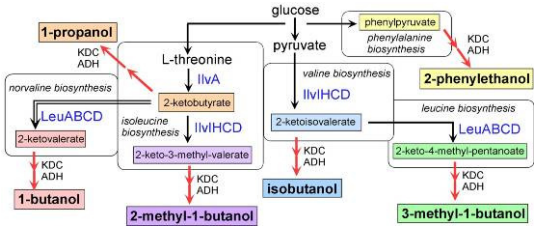
Round 2 & Round 3 FOAs

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

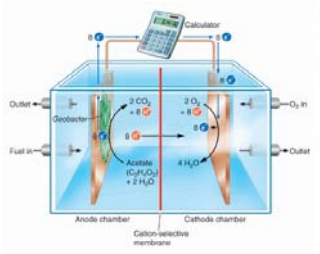
"Electrofuels" FOA - Can we develop non-photosynthetic, autotrophic systems to directly reduce CO_2 to complex liquid fuels?

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 electrical 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

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

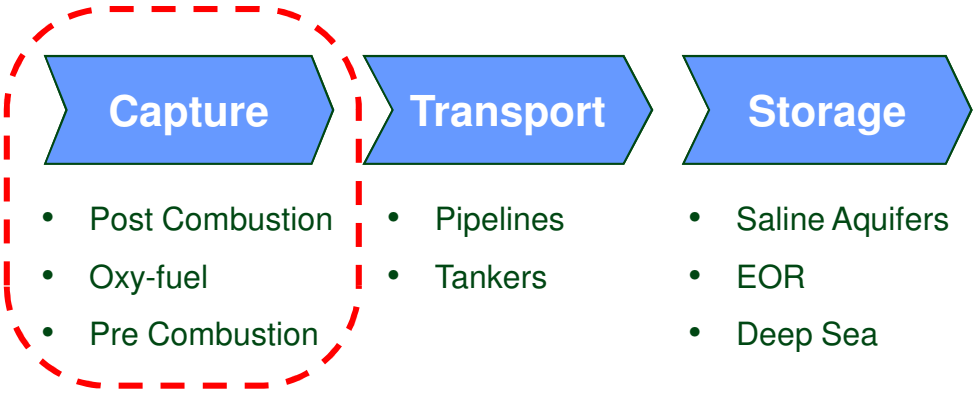
Many microorganisms communicate electrically with their surroundings as a means to transfer and assimilate energy. This phenomenon was the basis for the development of microbial fuel cells, funded by DOE, DoD, & DARPA. Very recently it has been demonstrated that reverse microbial fuel cells are feasible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

Innovative Materials and Processes for Advanced Carbon Capture Technologies (IMPACCT) FOA

The Need: The state-of-the-art CO_2 capture technology, aqueous amine solvents, imposes a ~25-30% parasitic power load on a coal-fired power plant, increasing levelized cost of electricity by ~80%

The Goal: Develop *materials* and *processes* that drastically reduce the parasitic energy penalty required for CO_2 capture from a coal-fired power plant

Approx. 80% of the capital costs of carbon capture and storage arise from the capture process



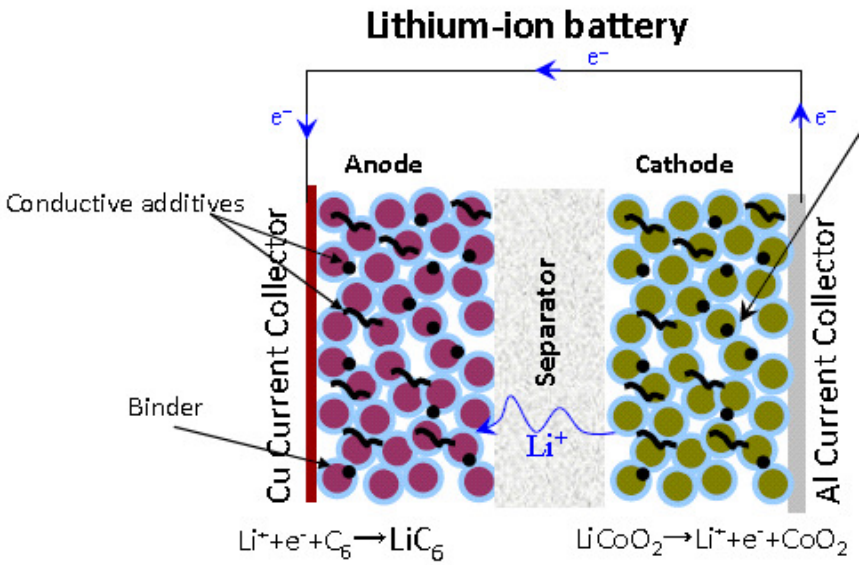
Example areas of interest

- Low-cost catalysts to enable systems with superior thermodynamics that are not currently practical due to slow kinetics
- Robust materials that resist degradation from caustic contaminants in flue gas
- Advanced capture processes, such as processes that utilize thermodynamic inputs other than temperature or pressure

Batteries for Electrical Energy Storage for Transportation (BEEST) FOA

The Need: Development of novel battery storage technologies beyond carbon-based anode/Li-intercalation cathode systems and slurry coating based coating processes that enable U.S. manufacturing leadership in the next generation of high performance, low cost EV batteries.

The Goal: Develop advanced battery chemistries, architectures, and manufacturing processes with the potential to provide EV battery system level specific energies exceeding 200 Wh/kg and 300 Wh/l at system level costs < $250/kWh.

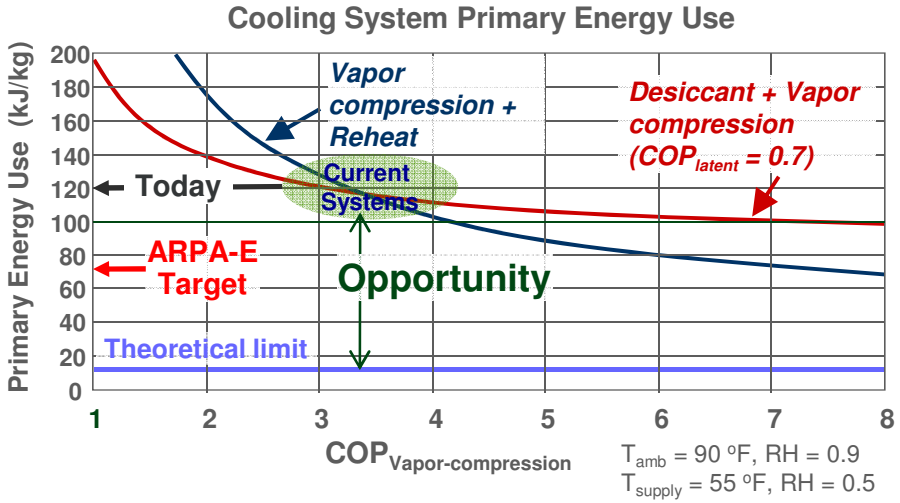


Example areas of interest

- Advanced Lithium-ion batteries that exceed energy density of traditional Li-ion systems
- Li-sulfur battery approaches that address the low cycle life and high self-discharge of existing state of the art technology
- Metal air battery approaches that address the low cycle life, low power density, and low round trip efficiency of current approaches

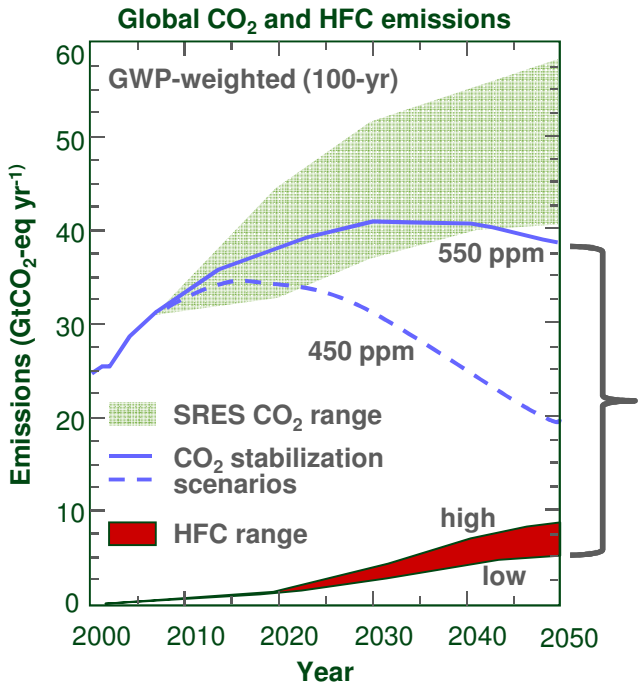
Building Energy Efficiency Through Innovative Thermodevices (BEETIT) – Building Cooling

- ***Building cooling is responsible for ~5% of U.S. energy consumption & CO_2 emissions***
- ***Majority of the systems are air cooled***



- **Achieve effective COP equivalent to water cooled chiller *without* loss of water for:**
  - **Warm & humid climate**
  - **Hot and dry climate**
- **This will cut cooling energy consumption & GHG emissions by 25-40%**

- ***Current refrigerants have a Global Warming Potential (GWP) over 1000 x greater than CO_2***



Global hydrofluorocarbon (HFC) refrigerant emissions are projected to account for the equivalent of 9-19% of CO_2 emissions in 2050

Achieve 1 Ton of cooling using refrigerants with GWP ≤ 1

Source: Velders et al, PNAS 106, 10949 (2009)

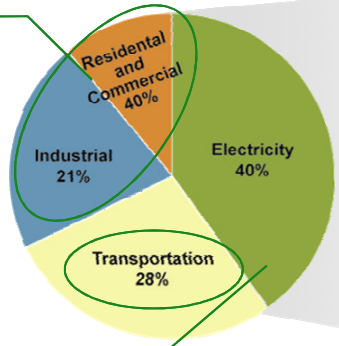
Agile Delivery of Electrical Power Technology (ADEPT)

Photovoltaics

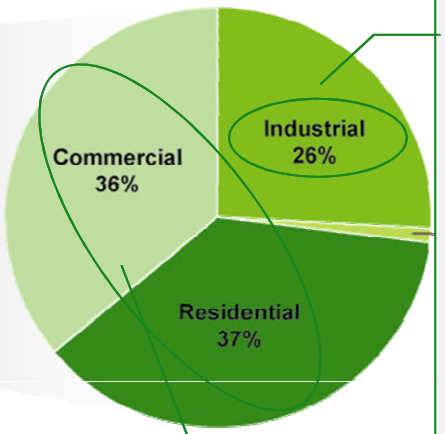
Goal: Levelized Energy Cost for photovoltaic (PV) systems of $0.05 - 0.10 / kWh

Approach: Reduce inverter cost by factor of 3

Primary Energy Use by Sector, 2008



Share of Electricity Consumed by Major Sectors of the Economy, 2008



Industrial

Goal: Improve energy efficiency of industrial motors [65% of industrial electricity consumption]

Approach: Power electronics for variable speed drive electric motors (88% more efficient than constant drive)

Automotive

Goal: Increase of inverter specific power density & temp. from 5.5kW/L at 85C to greater than 9kW/L at 105 C.

Approach: Package integrated high-temperature converters with high-frequency switches and magnetics.

Lighting

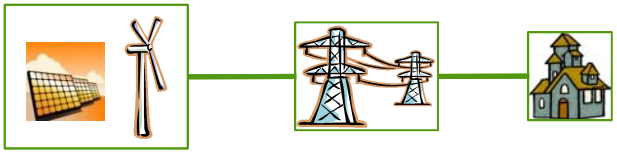
Goal: Substantially reduce energy consumption of lighting [nearly 1/5 of commercial and residential electricity use]

Approach: Power electronics to facilitate so state lighting (20-40% more efficient than state-of-art LEDs)

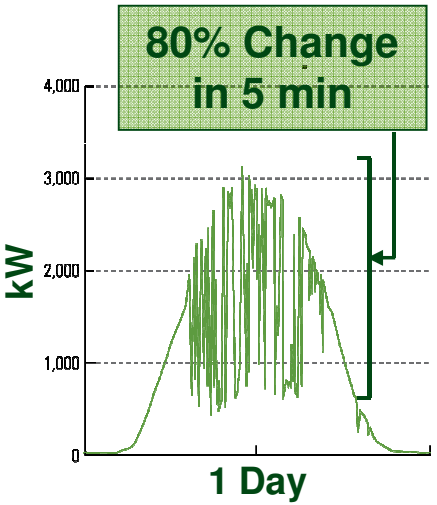
Advanced power electronics for
12% reduction in total US energy consumption

Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS)

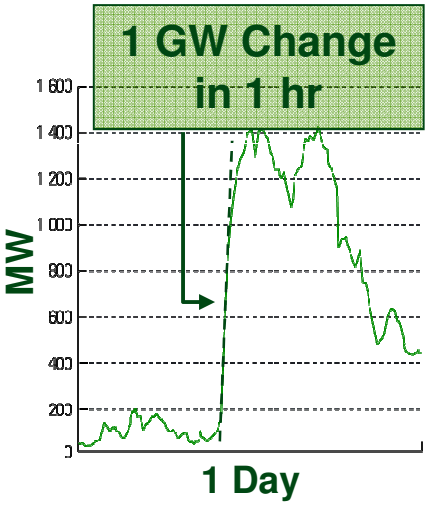
Renewables Today



Solar PV in AZ (TEP)

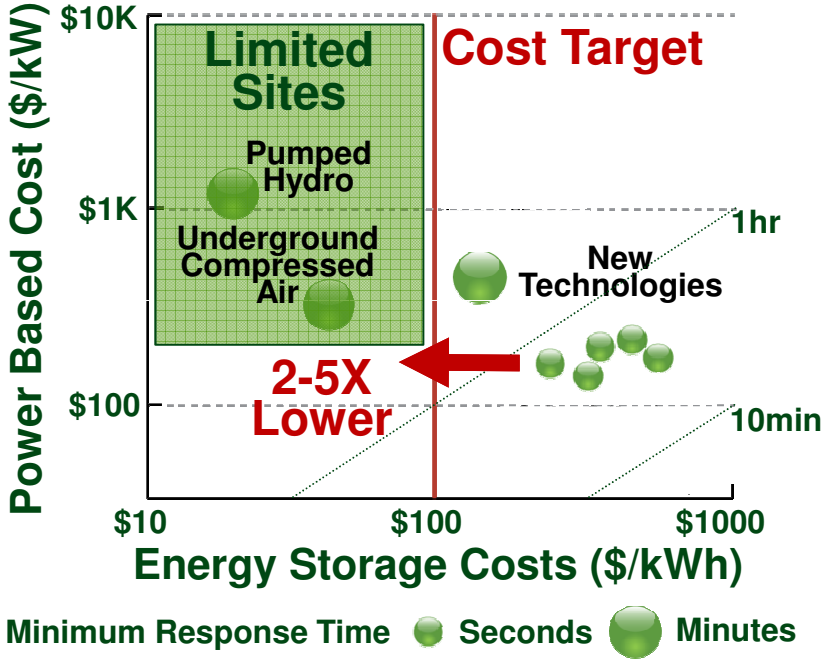


Wind in OR (BPA)



Problem:
Minutes-to-Hours Changes in Power

Storage for Renewables Tomorrow



Need: **Innovative Technologies for Cost-Effective Energy Storage**

Goal: Grid storage that is dispatchable and rampable
ARPA-E Focus: Transformational approaches to energy storage to enable wide deployment at very low cost

Thank you for your attention!

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