# Advanced Research Projects Agency – Energy (ARPA-E)

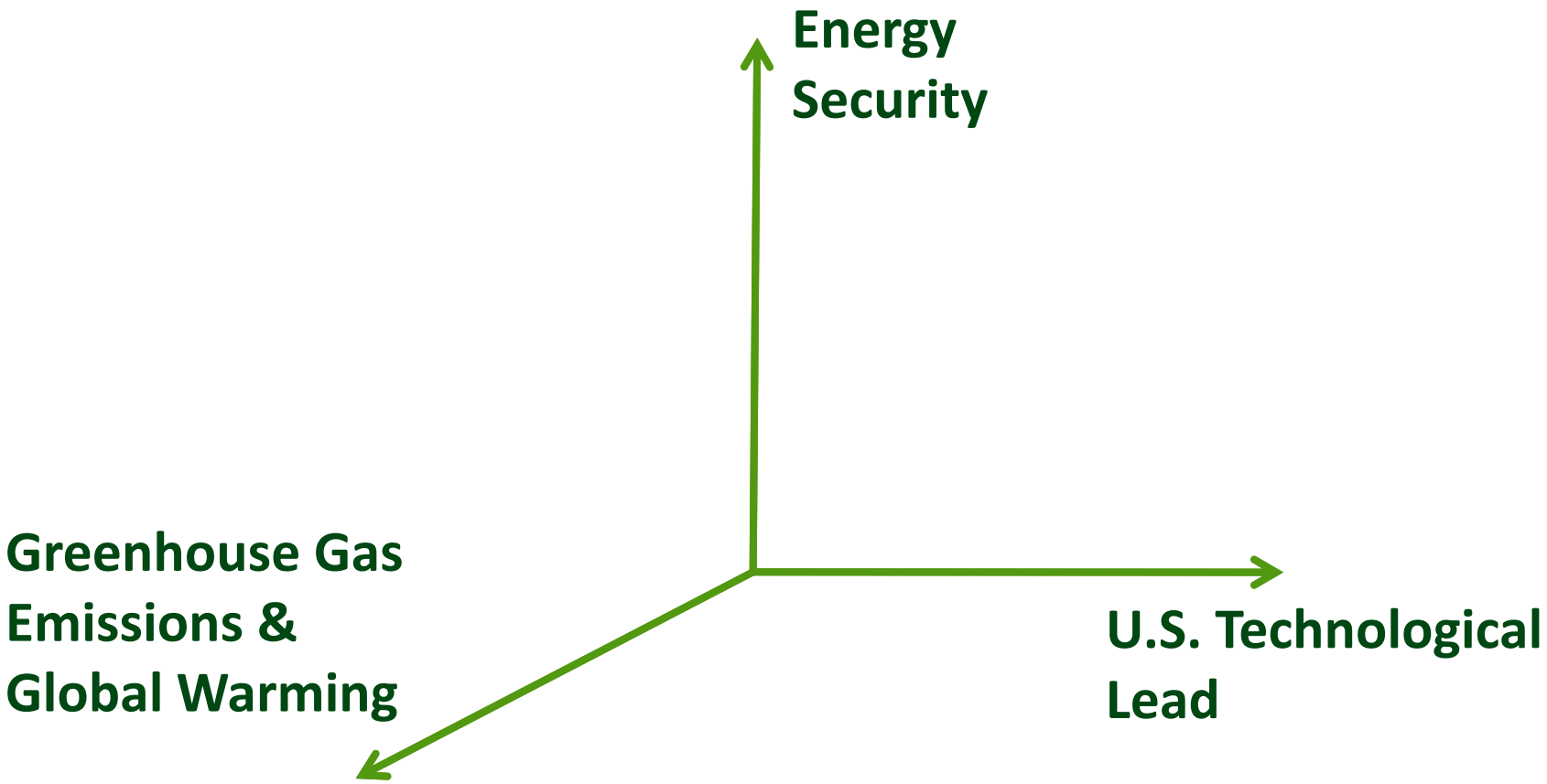
**Dr. Arun Majumdar**

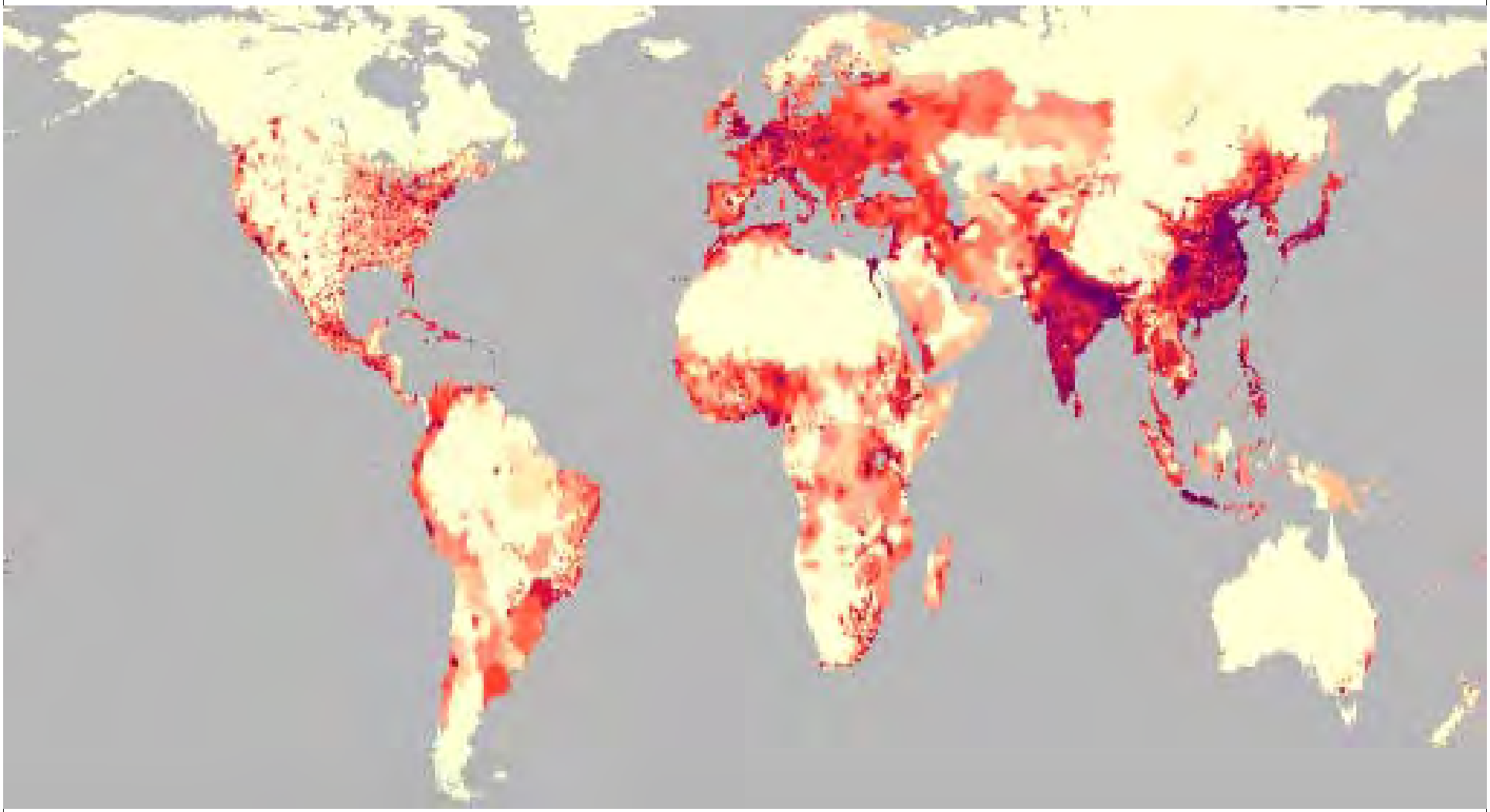
**Director, ARPA-E**

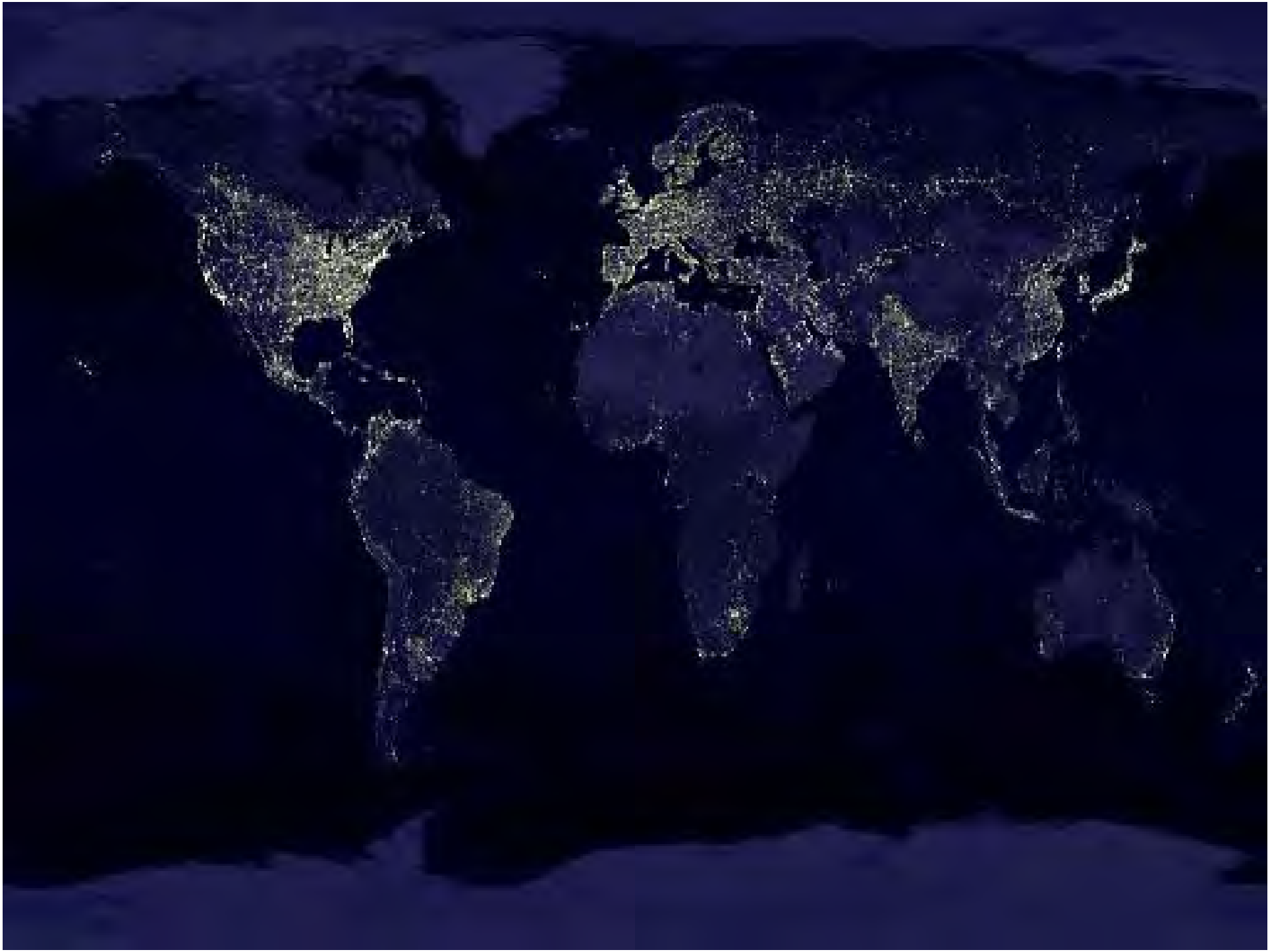
**U.S. Department of Energy**

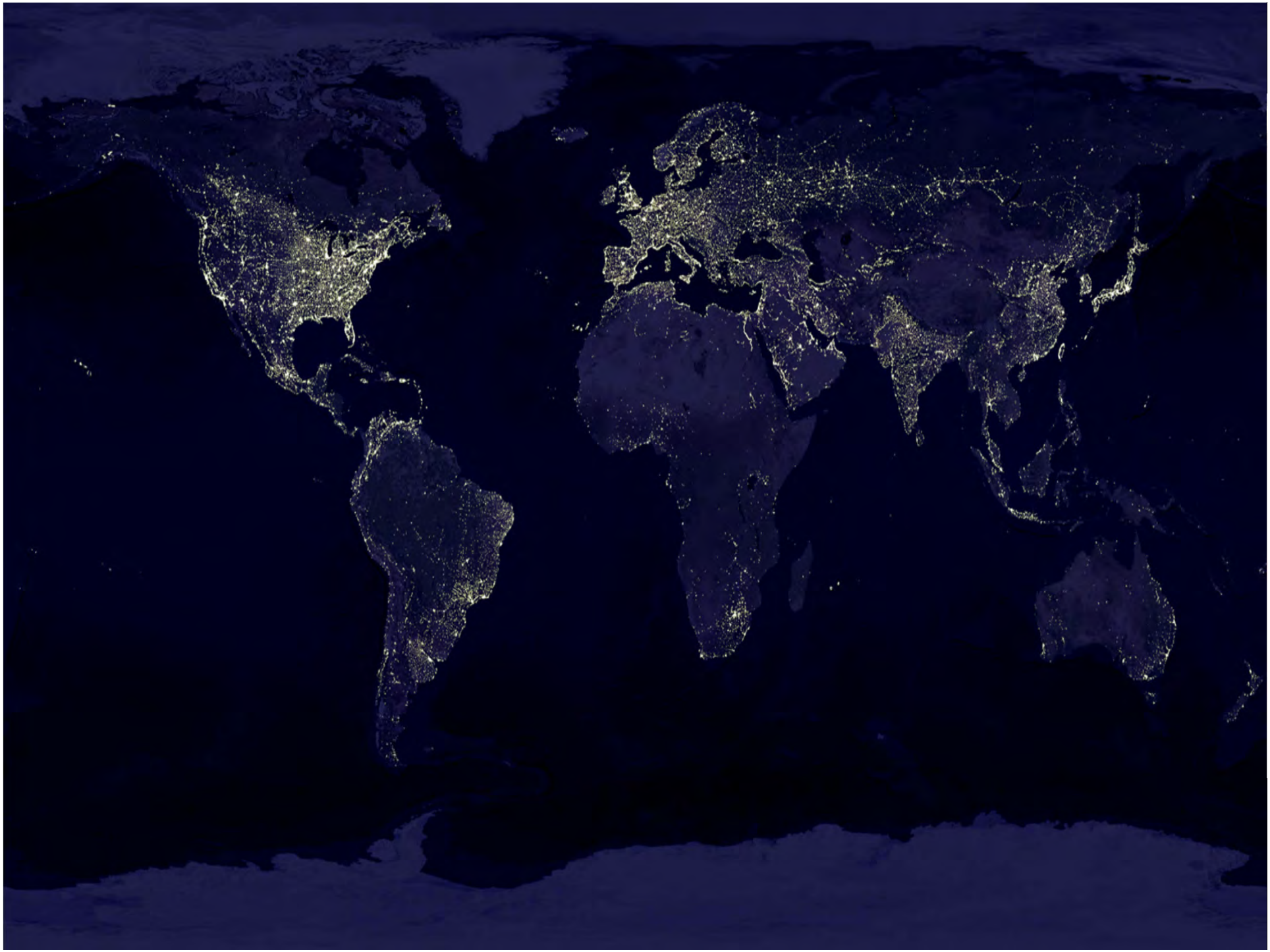
**http://arpa-e.energy.gov/**

# SPUTNIK MOMENT OF OUR GENERATION

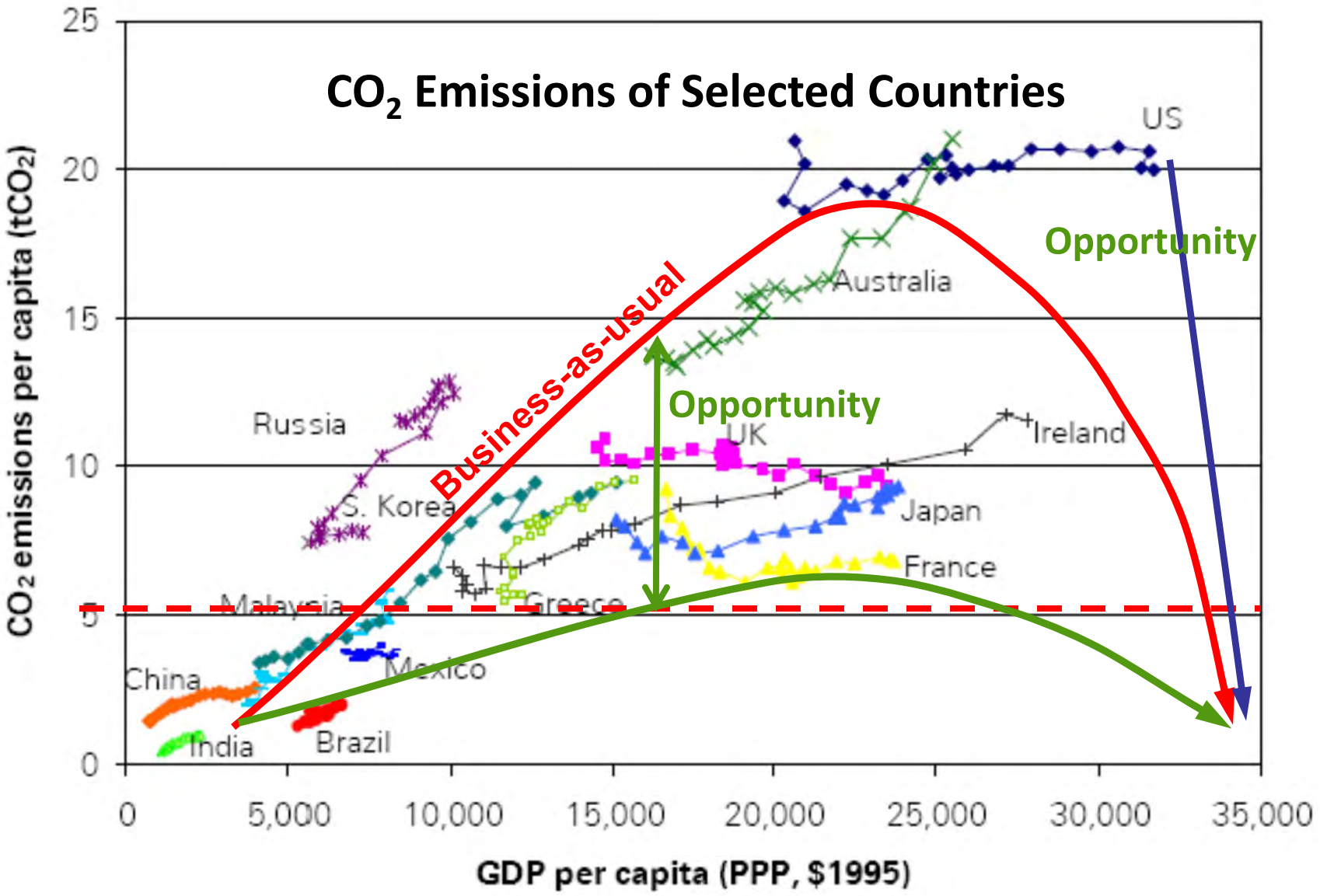








# WHICH PATH SHOULD WE TAKE?

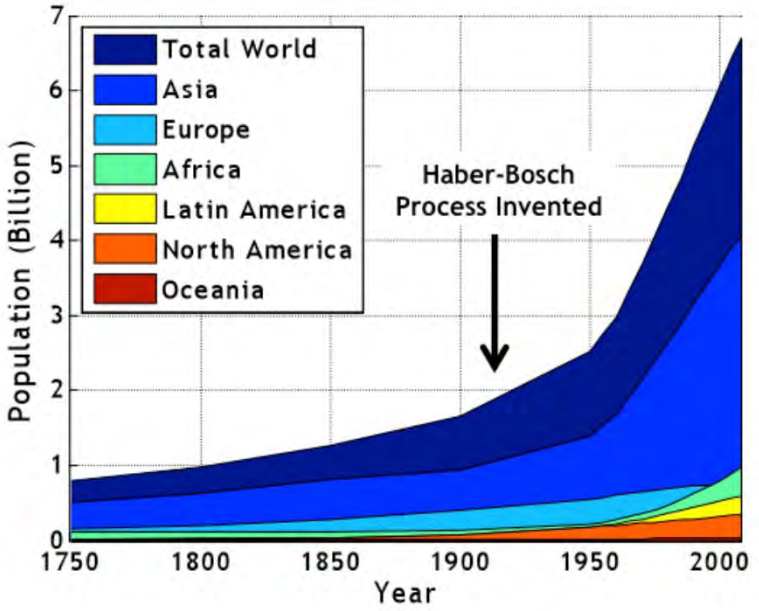


# HAS THE WORLD FACED SUCH A CHALLENGE BEFORE?

1898: "Calling upon Science to save the world from impending starvation," Sir William Crookes, President, British Assoc. for the Advancement of Science.

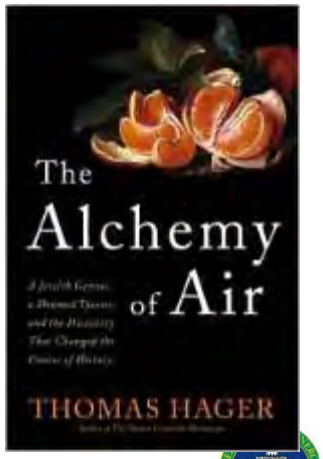
1908: Fritz Haber (Chemist) discovered a catalyst that would combine atmospheric nitrogen with hydrogen to form ammonia. Catalyst - Uranium!!

1913: Carl Bosch (BASF) developed process to mass produce ammonia and made fertilizers.




Haber

Bosch





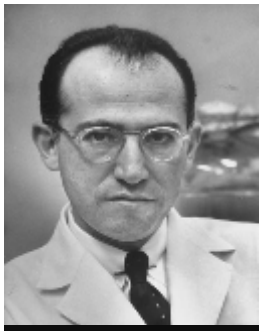
Vaclav Smil, "Detonator of the population explosion," *Nature* 400: 415 (1999).
David Fisher, Marschall Fisher, "The Nitrogen Bomb," *Discover* 22, April (2001)


arpa·e

# OTHER GAME CHANGERS

Norman Borlaug

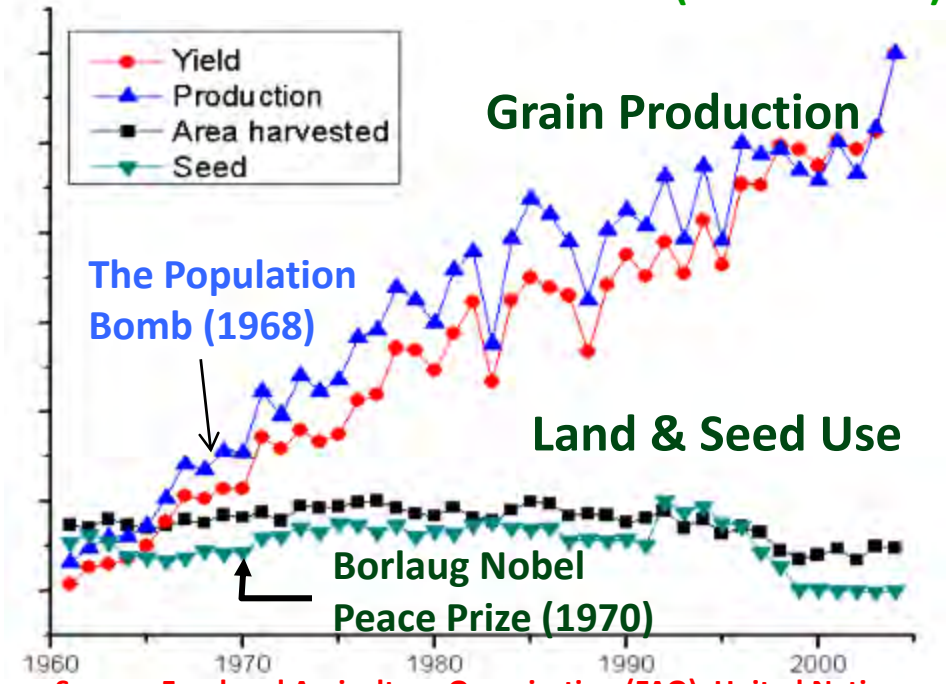
Dwarf Strain of Wheat



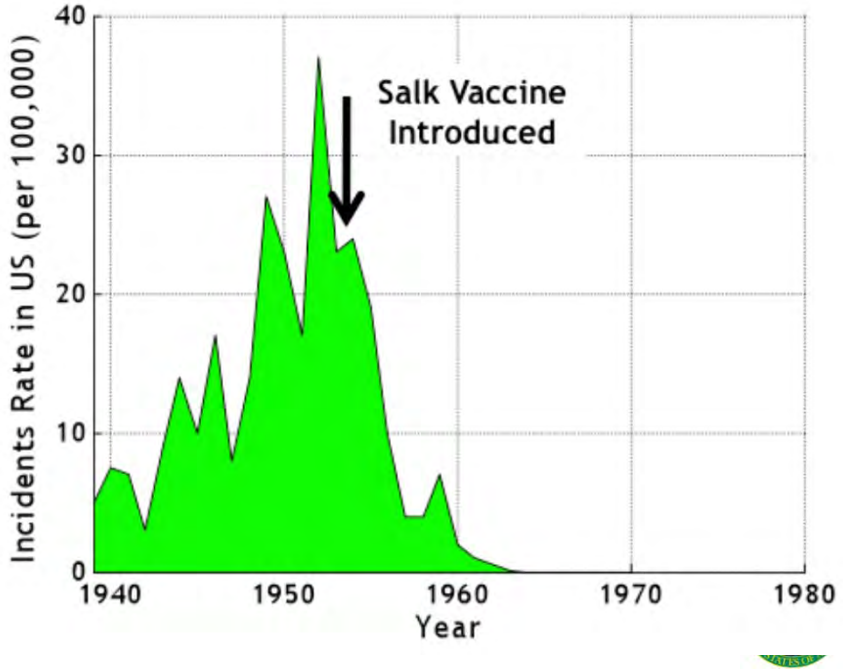
Jonas Salk

Polio Vaccination

World Production of Grain (1961 – 2004)

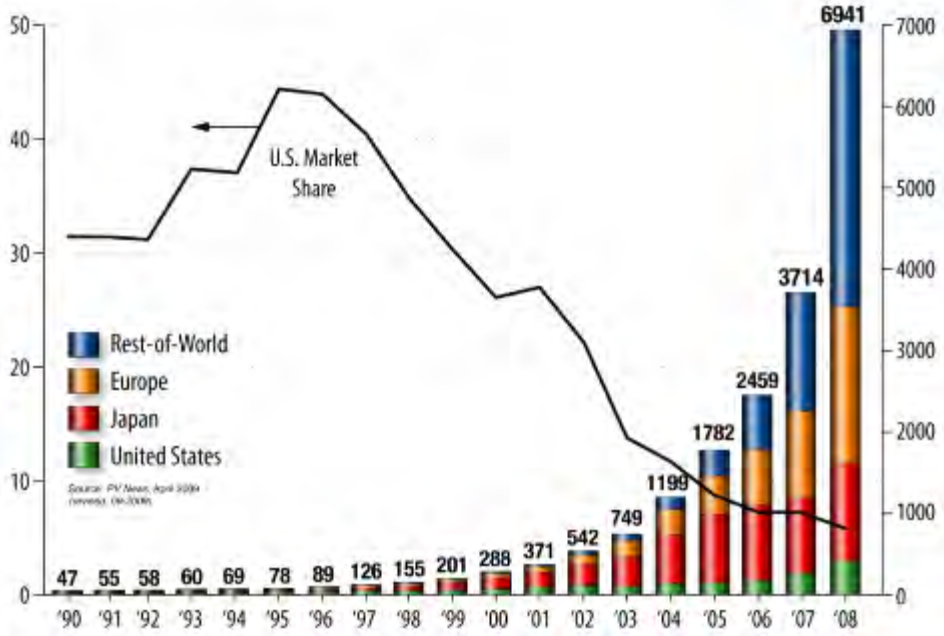



Source: Food and Agriculture Organization (FAO), United Nations

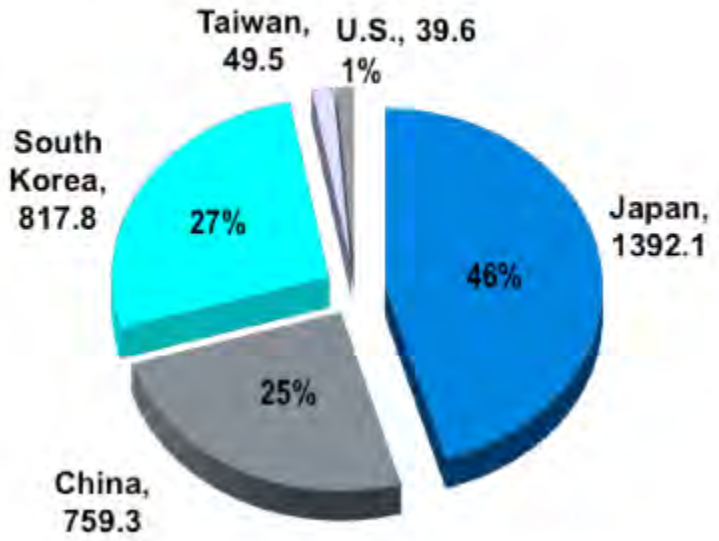


# THE U.S. IS FALLING BEHIND IN THE CLEAN ENERGY RACE

## Worldwide shipments of Solar Cells in 2008 (Megawatts)




## Lithium-ion battery manufacturing




THE ENRICO FERMI AWARD

**2009**

**John Goodenough, U. Texas at Austin**

# PACE AND SCALE OF INNOVATIONS NEEDED IN ENERGY TECHNOLOGIES

## Game Changers from 20th Century

100 years

- Artificial Fertilizers
- Green Revolution
- Polio Vaccination
- Antibiotics
- Airplanes
- Electrification
- Nuclear Energy
- Transistor
- Integrated Circuits
- Fiber Optic Communication
- Wireless Communication
- Internet

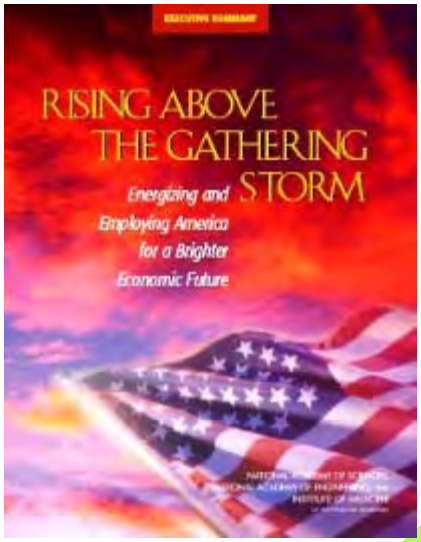
20 years

**Imagine all of this happening in the next 20 years…**

- Solar electricity generation at cost lower than that produced from fossil fuels ($1/W fully installed)
- Carbon capture and utilization at net cost lower than its market price
- Car batteries with 3X energy density and 4X lower cost
- Transportation fuels from sunlight and/or agricultural waste at cost lower than petroleum
- 50-80% reduction in energy consumption in homes and buildings
- Low-cost desalination of water
- Cement, steel, glass … production at 5X lower carbon emissions
- Real-time optimization, security and storage for grid
- …….

arpa·e

# CREATION OF ARPA-E




**2006**
***Rising Above the Gathering Storm***
**(National Academies)**

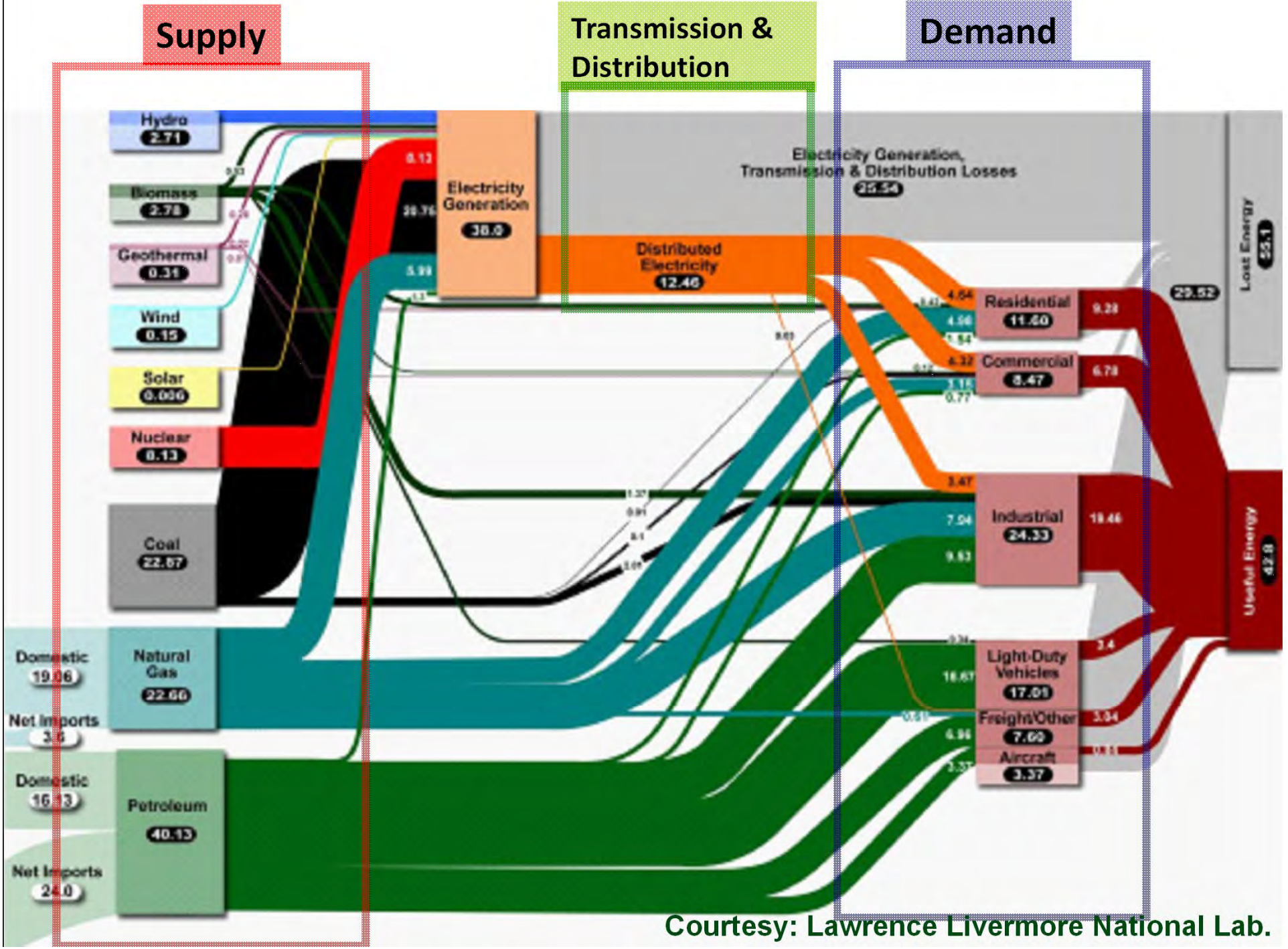
**2007**
**America COMPETES Act**

**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**


arpa·e


Supply
Transmission & Distribution
Demand
Hydro
2.71
Biomass
2.78
Geothermal
0.31
Wind
0.15
Solar
0.086
Nuclear
8.13
Coal
22.87
Domestic
19.06
Natural Gas
22.86
Net Imports
3.8
Domestic
16.13
Petroleum
40.13
Net Imports
24.0
Electricity Generation
38.0
Electricity Generation, Transmission & Distribution Losses
Distributed Electricity
12.46
Residential
11.60
Commercial
8.47
Industrial
24.33
Light-Duty Vehicles
17.09
Freight/Other
7.09
Aircraft
3.37
29.52
Lost Energy
Useful Energy
42.8
Courtesy: Lawrence Livermore National Lab.

# FIRST ROUND OF FUNDING

**Concept Paper Phase**

**3700 Received**

**April - June 2009**

**Review**
**312 Encouraged Full Applications**

**June - July 2009**

**Full Application Phase**

**Panel Reviews**

**September – Early October 2009**

**Final Selection**

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

**Announced on October 26**

## Award Negotiation

- October 26, 2009 – January 15, 2010:
  - 35 out of 37 of award agreements signed
  - $142 M out of $151 M (94%) total FOA 1 funding awarded

**"In my 30 years of doing Government contracting…..I have never seen any government project move from selection to contracts and to actual work with such speed anywhere near what we are seeing out of ARPA-E….." CEO, Diversified Energy Corporation, Gilbert, AZ - 01/27/10**

# WHAT ARPA-E IS LOOKING FOR

**High Impact on ARPA-E Mission Areas –**

- 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

**Disruptive, Innovative Technical Approach –**

- ARPA-E is focused on high risk/high reward R&D
- Interested in –
  - New technical approaches that move to entirely new learning curves
  - Fundamentally new areas of research with uncharted white space

**Best-in-class People & Teams**

- Complementary, cross-discipline skill sets
- Strong interest to bring in new, talented scientists and engineers to energy technology research
- Break down barriers between science and engineering

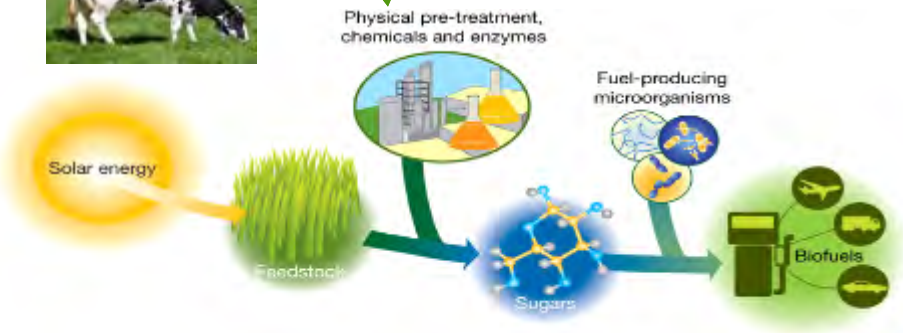
**Strong Impact of ARPA-E Funding Relative to Private Sector –**

- Invest in areas too risky for the private sector
- ARPA-E investments derisk technologies and catalyzes follow on private sector investments

# EXAMPLES FROM FIRST ROUND OF FUNDING

## Cellulosic Biofuels

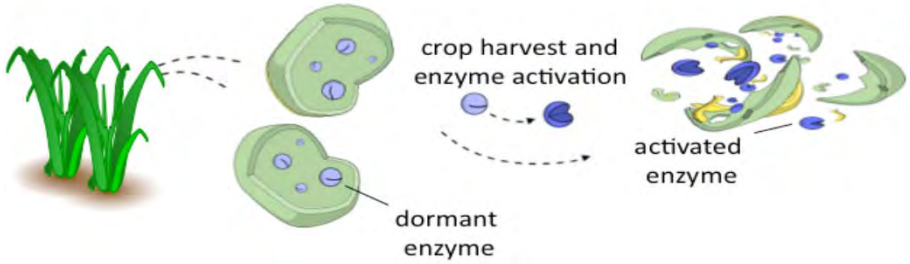
**Artificial Cellulose Breakdown is Expensive ($$)**




## Agrivida

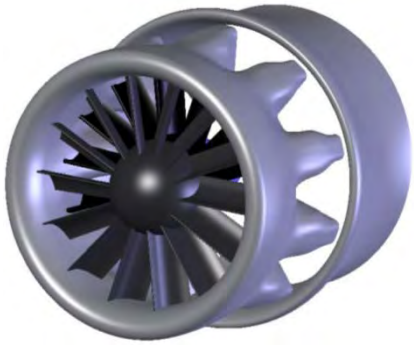
**GreenGenes™ Technology**

**Putting the cow inside the plant!**




**Plant produces all the enzymes & chews itself from the inside!!**

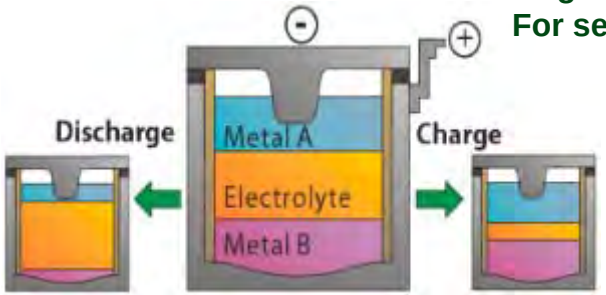
## Breakthrough High Efficiency Mixer/Ejector Wind Turbine (MEWT) – FloDesign Wind Turbine Corp.



- **Mimic jet engines, not propellers, for wind turbine**
- **40% lower cost expected vs. horizontal axis wind turbines (HAWT)**

## Grid-Level Electricity Storage - MIT

**Megawatts of storage For several hours**




**Potential Cost: $50/kW-hr**

Lithium Ion Laptop Battery: $2000/kW-hr
Lithium Ion Car Battery: $1000/kW-hr

# Second Round of Funding

## Announced Dec. 7th

**Wayne Gretzky**

***"I skate where the puck is going to be, not where it has been"***

***"You miss 100% of the shots you don't take"***

# BATTERIES FOR ELECTRICAL ENERGY STORAGE FOR TRANSPORTATION (BEEST)

## Where We Are Now

- Expensive cars
- Powered by Li-ion batteries
- Battery Cost: approx. $15,000
- Limited range: 40 miles
- Cell-level energy density: 150 W-hr/kg
- Cost: approx. $1000/kW-hr

**Majority of Current Investments :**

***Improvement in Today's Lithium Ion Batteries***

## Where We Need to Go

- Broad range of vehicle types
- Battery Cost < $10,000
- Range of 300+ miles
- Targets:
  - Cell-level energy density: 400 W-hr/kg
  - Cost: $250/kW-hr
  - New architectures & manufacturing processes

Examples

- Metal-air batteries
- Li-S batteries

***Japanese gov't investing $60M/yr***

# INNOVATIVE MATERIALS AND PROCESSES FOR ADVANCED CARBON CAPTURE TECHNOLOGIES (IMPACCT)

**Today:** $CO_2$ +

**Amine Chemistry**

**Bind, Isolate & Release** →

**Cost: \$70-100/t$CO_2$**
**Cost Above Price = Loss!**

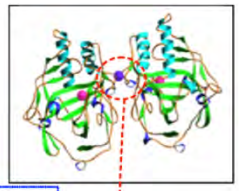
**High-Temperature Heat** ↑

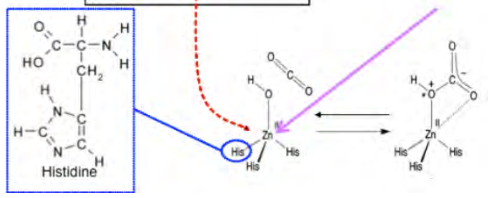
**Market Price of $CO_2$: ≈ \$30/t$CO_2$**

**ARPA-E High-Risk/ High-Payoff:**

**Existence Proof: Carbonic Anhydrase**

$CO_2$ +



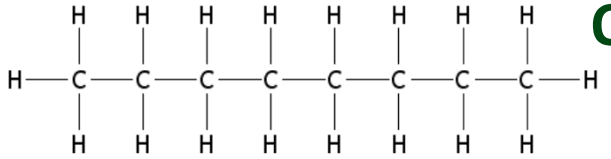



**New Approaches** →

**Cost Below Price = Profit!**

↑ **Low-Temperature Heat**

# ELECTROFUELS



**Octane**

**$CO_2$**

***3. Greenhouse gas emissions***

**Gasoline**

***4. 60% imported***

**$H_2$**

***2. Difficult to store***

**Electricity**

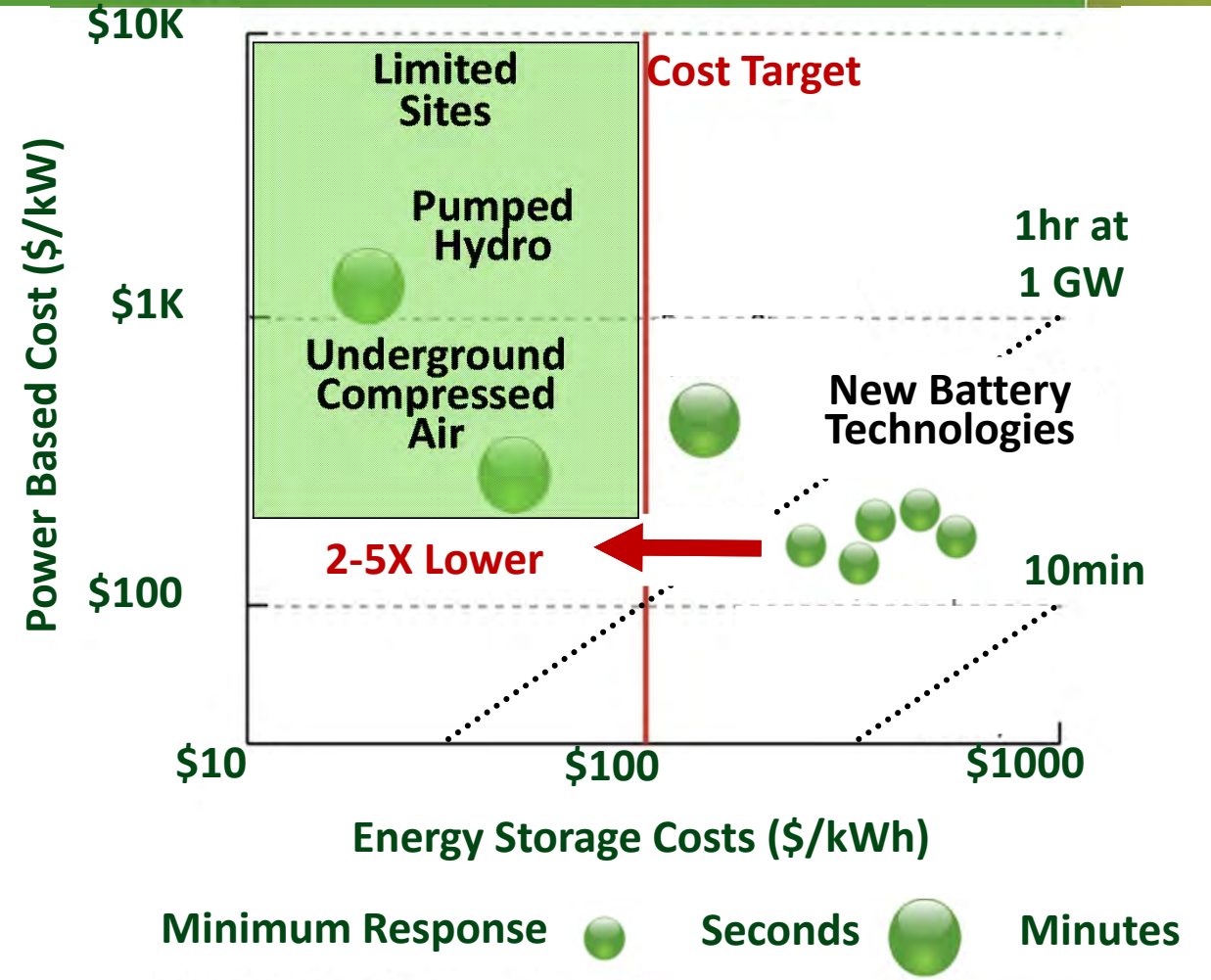
***1. Difficult to store***

arpa·e

# Third Round of Funding

## Announced March 2nd

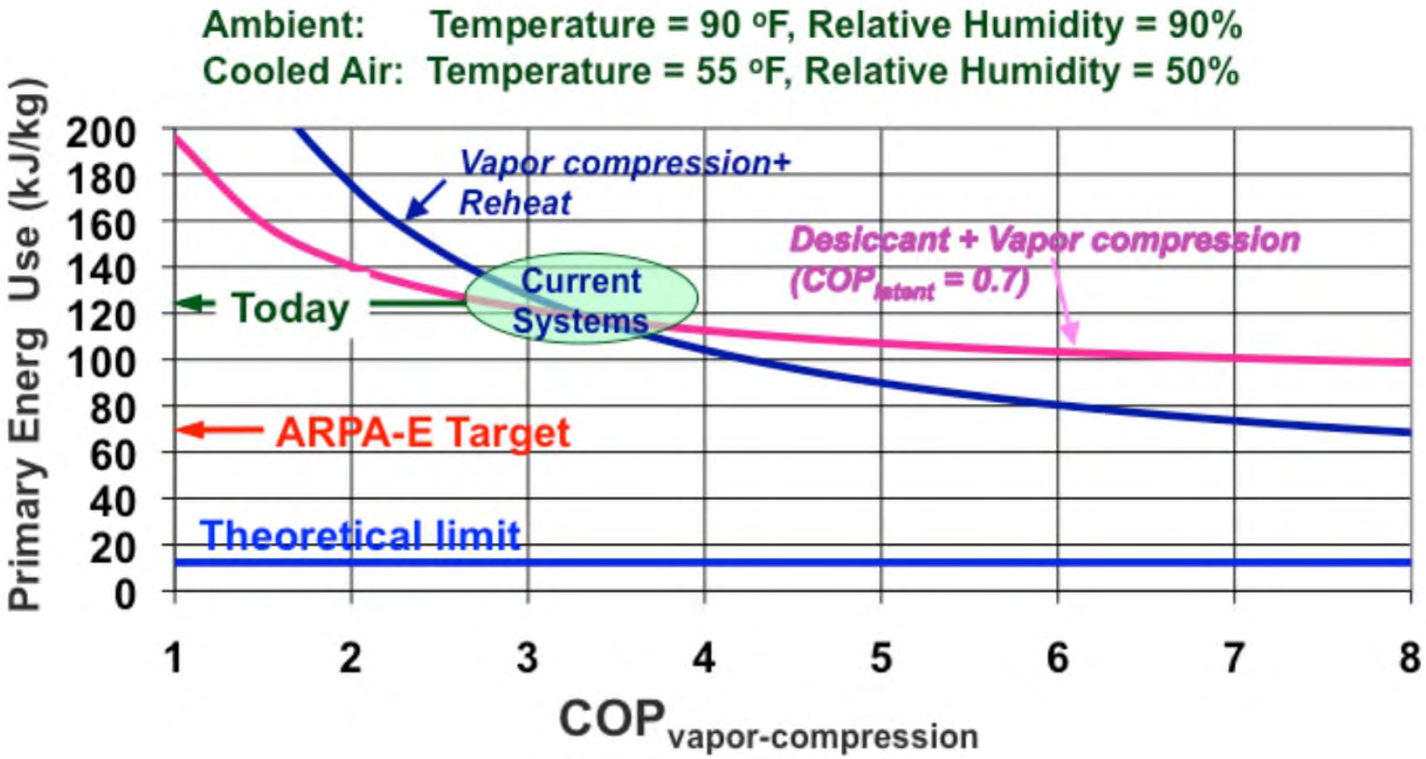
# Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS)




**ARPA-E Focus:**
**Transformational approaches to energy storage that enable grid-scale deployment at very low cost (~$100/kWh)**

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

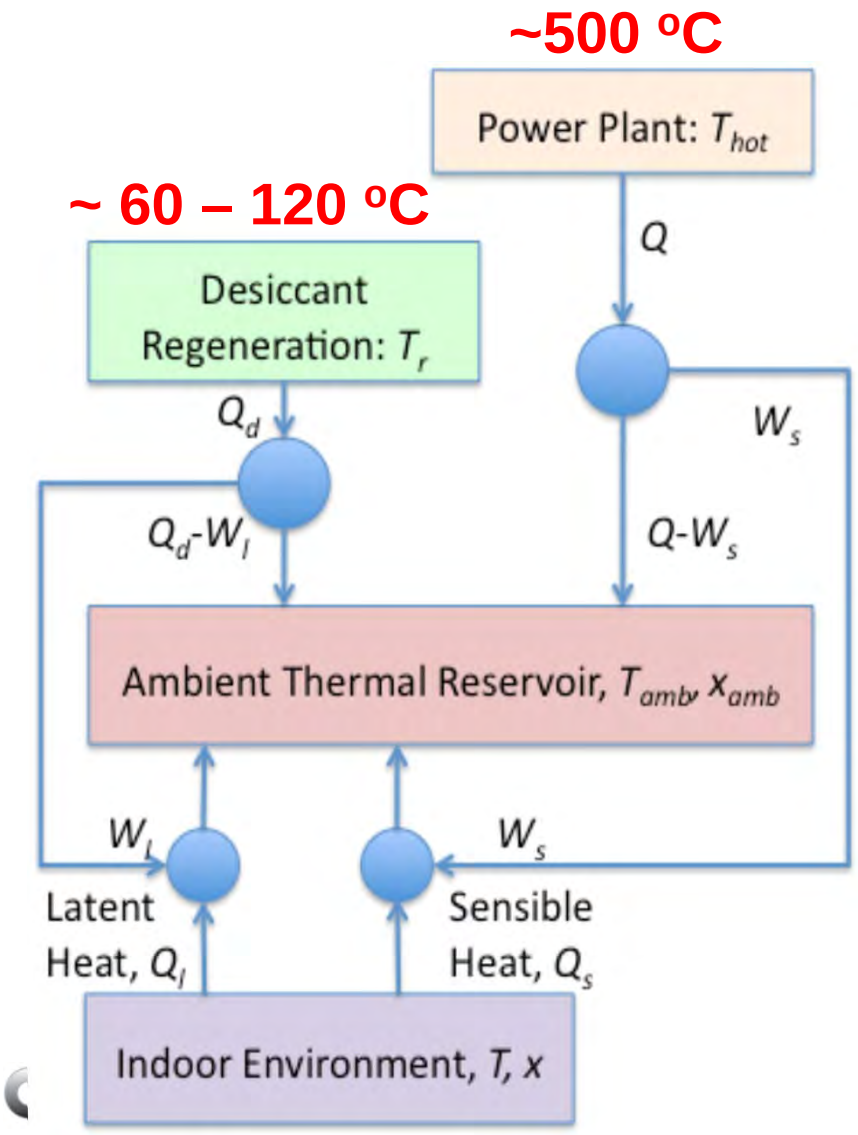
# FOA 3: Building Energy Efficiency Through Innovative Thermodevices (BEETIT) – Building Cooling




**ARPA-E Focus:**
**Cut cooling energy consumption and GHG emissions by 25 – 40%**

- **Increasing the COP of vapor compression (without loss of water!)**
- **Increasing the COP of the desiccant system**

# IDEAL SYSTEM AT THERMODYNAMIC LIMIT




## Latent Load COP

$$\eta_{Carnot} = \frac{W_l}{Q} = 1 - \frac{T_{amb}}{T_r}$$

$$COP_{latent} = \frac{Q_l}{Q_d} = \frac{Q_l}{W_l / \eta_{Carnot}}$$

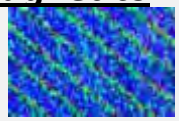
**Ideal $COP_{latent}$ = ~ 2.5-6.5**

***Real COP*** **= ~ 0.7 – 1.0**

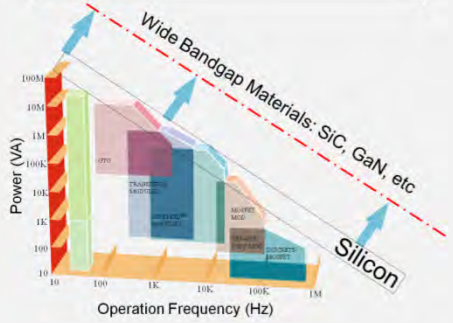
# AGILE DELIVERY OF ELECTRICAL POWER TECHNOLOGY (ADEPT)

## *Advancements in power electronics materials…*

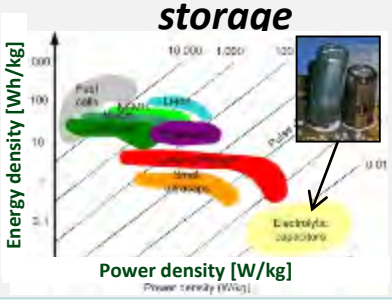
### *Soft magnetics*



### *High voltage switches*




### *High-density charge storage*



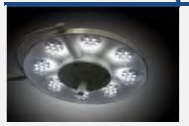

## *…coupled with advanced circuit architectures and scalable manufacturing processes…*

### Advanced circuit architectures


### Scalable manufacturing processes

## *…results in low-cost, higher performance power electronics across many applications.*

### *Fully integrated, chip scale power converters (10-50W, >100V)*



Solid State Lighting

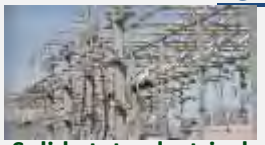
Computers

### *Kilowatt scale package integrated power converters (3 –10 kW, >600V)*

Inverters

Motors

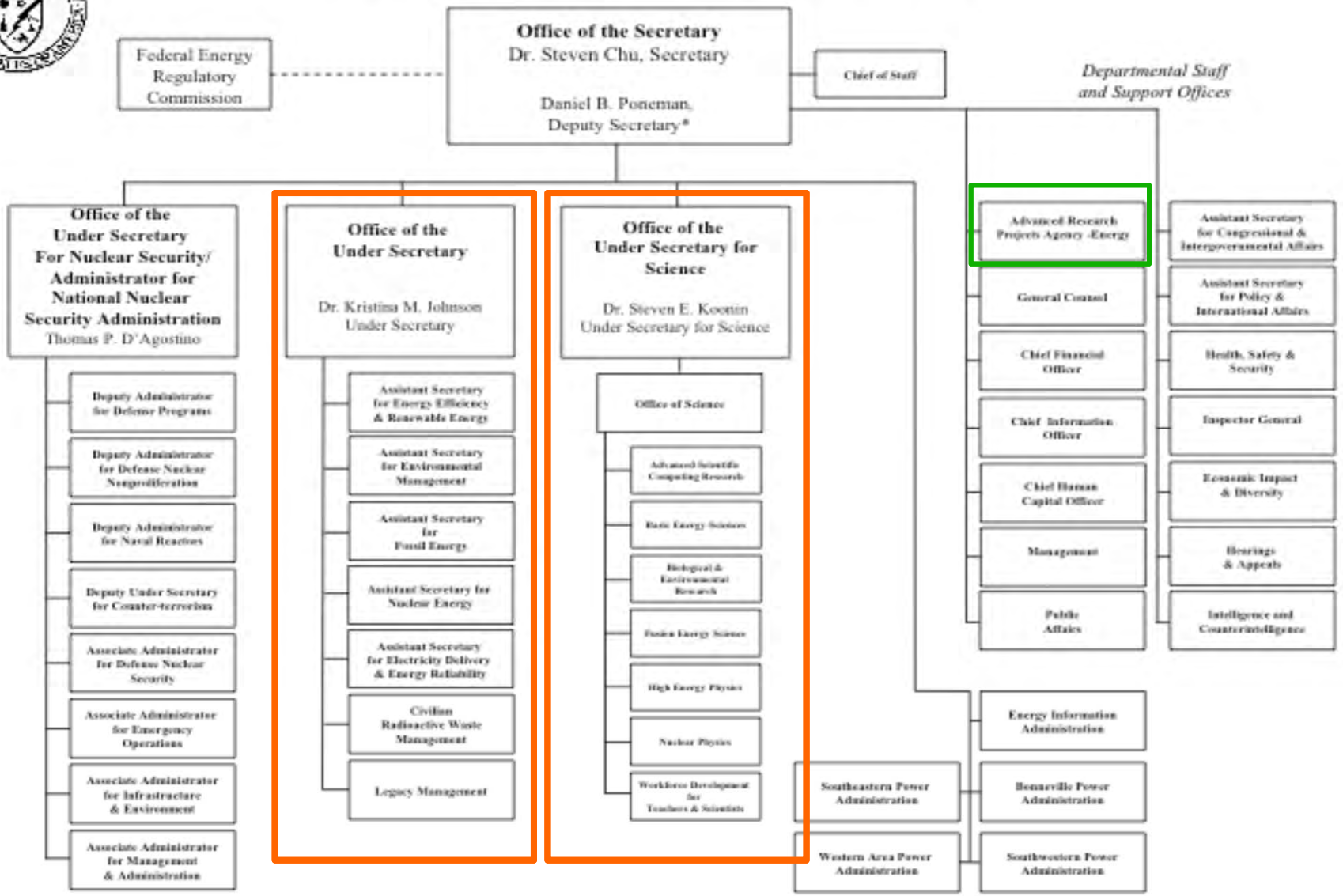
### *Lightweight, solid state, medium voltage energy conversion (1MW, 13kV)*



Solid-state electrical substations

Wind turbines

# DEPARTMENT OF ENERGY




* The Deputy Secretary also serves as the Chief Operating Officer

26 May 09

# ARPA-E ORGANIZATION
## Lean, Nimble, Collaborative, Flat

Coordinates with Office of Science

Technology Push Office

All-Star Program Directors (4 yrs max)

APPLIED SCIENCE AND TECHNOLOGY OFFICE

| Marketing & Decision Science | Information Science & Device Engineering | Electronic & Structural Materials Science & Device Engineering | Thermal Science & Device & Process Engineering | Chemical & Biological Science & Process Engineering |
|---|---|---|---|---|

- Break down stovepipes
- Encourage debate and partnership between technology pushers and pullers
- Provide thought leadership to create new programs

BEETIT

BEEST

IMPACCT

GRIDS

ADEPT

Electrofuels

INTEGRATED ENERGY SYSTEMS OFFICE

- Buildings & Appliances (Homes, Buildings, Data Centers)
- Transportation
- Carbon Dioxide Capture & Utilization
- Industrial Power Generation & Use (Cement, Metals, Glass, Paper)
- Transmission & Distribution
- Carbon-Free Heat & Power (Nuclear, Solar, Wind, Hydroelectric, Geothermal)
- Fuels Synthesis
- Water & Agriculture

Technology Pull Office

Coordinates with Applied Energy Offices

# BUILDING ON OUR STRENGTHS

- Best R&D infrastructure in the world
- Best innovation ecosystem in business and entrepreneurship
- Highly energized youth, ready to deeply engage
  - **ARPA-E Fellows Program** (Launched Dec 8th at MIT Energy Club): bring best and brightest scientist, engineers, and technical entrepreneurs in to ARPA-E and create a think tank

# RECRUITING

- **Program Directors (Max. 4 yrs): Active researchers who have one foot in science & engineering and the other in technology development and business**
  - Active academics or national lab researchers who have started businesses or who actively work with industry
  - Researchers from the industry who are active in research & technology development (publishing, patents, etc) and who have participated in business

- **ARPA-E Fellows (Max. 2 yrs): Best and the brightest scientists, engineers and technical entrepreneurs to form a think tank - identify challenges, opportunities, and new approaches to address energy technologies.**
  - Fellows < 3 years after PhD
  - Senior Fellows > 3 years after PhD

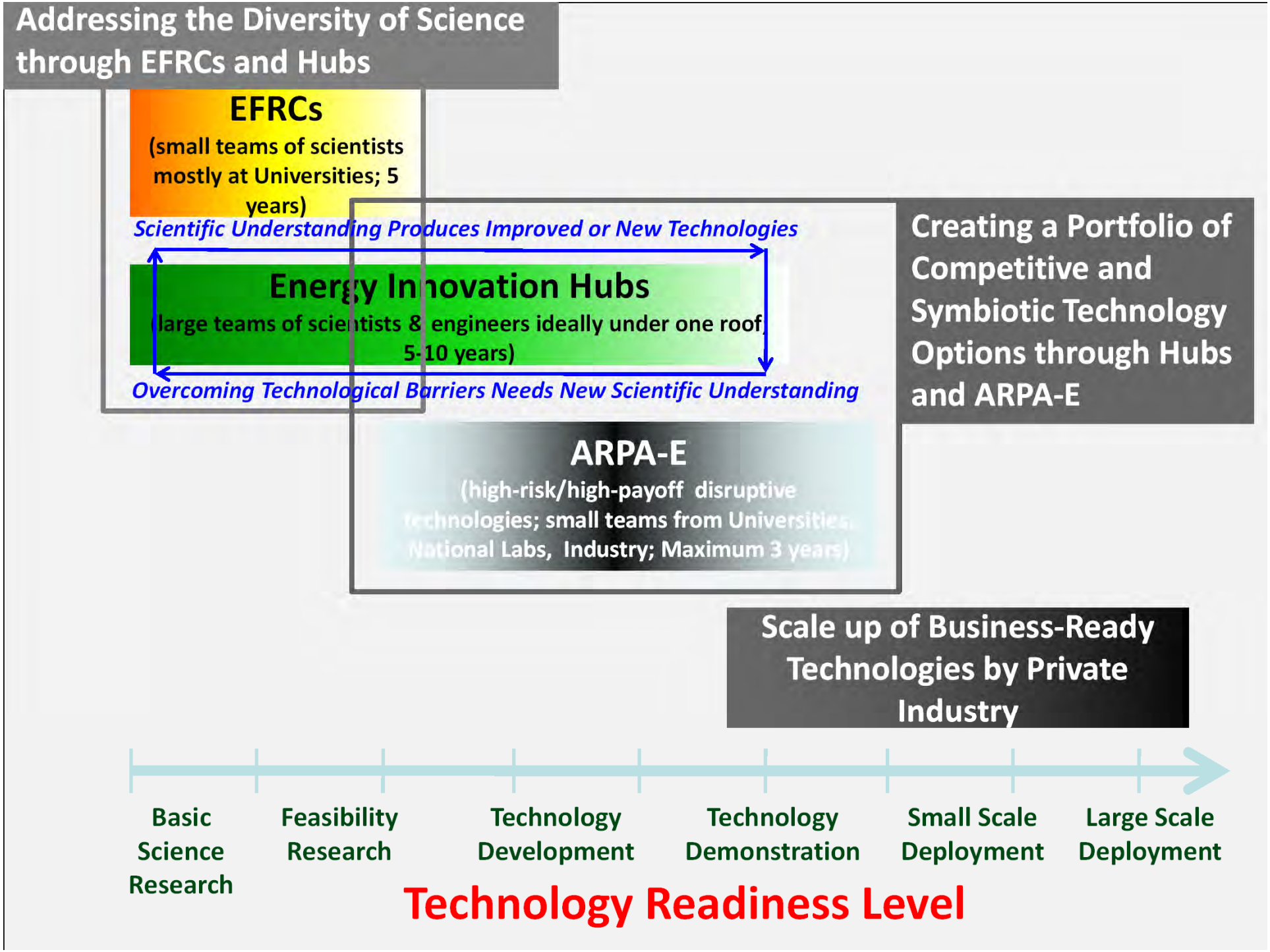
# MANAGING EXPECTATIONS

**NOW** **3 - 5 YRS** **10+ YRS**

- 3700 concept papers
- Recruiting all-star program directors who span science, technology, and business (#)
- Investment in "white spaces" with high potential mission impact ($)
- Innovative organizational structure/processes
- ARPA-E Energy Innovation Summit
- Follow on investment post ARPA-E award ($)
- Increase in enterprise value of company ($)
- Companies created (#)
- Initiating new technology-business ecosystems
- Accelerated market entry - Products to market (#) / product sales ($)
- Patents filed and licensed (#)
- Papers published in top journals (#)
- World Record-setting "best-in-class" performance (#)
- Help identify mechanisms for scaling innovations

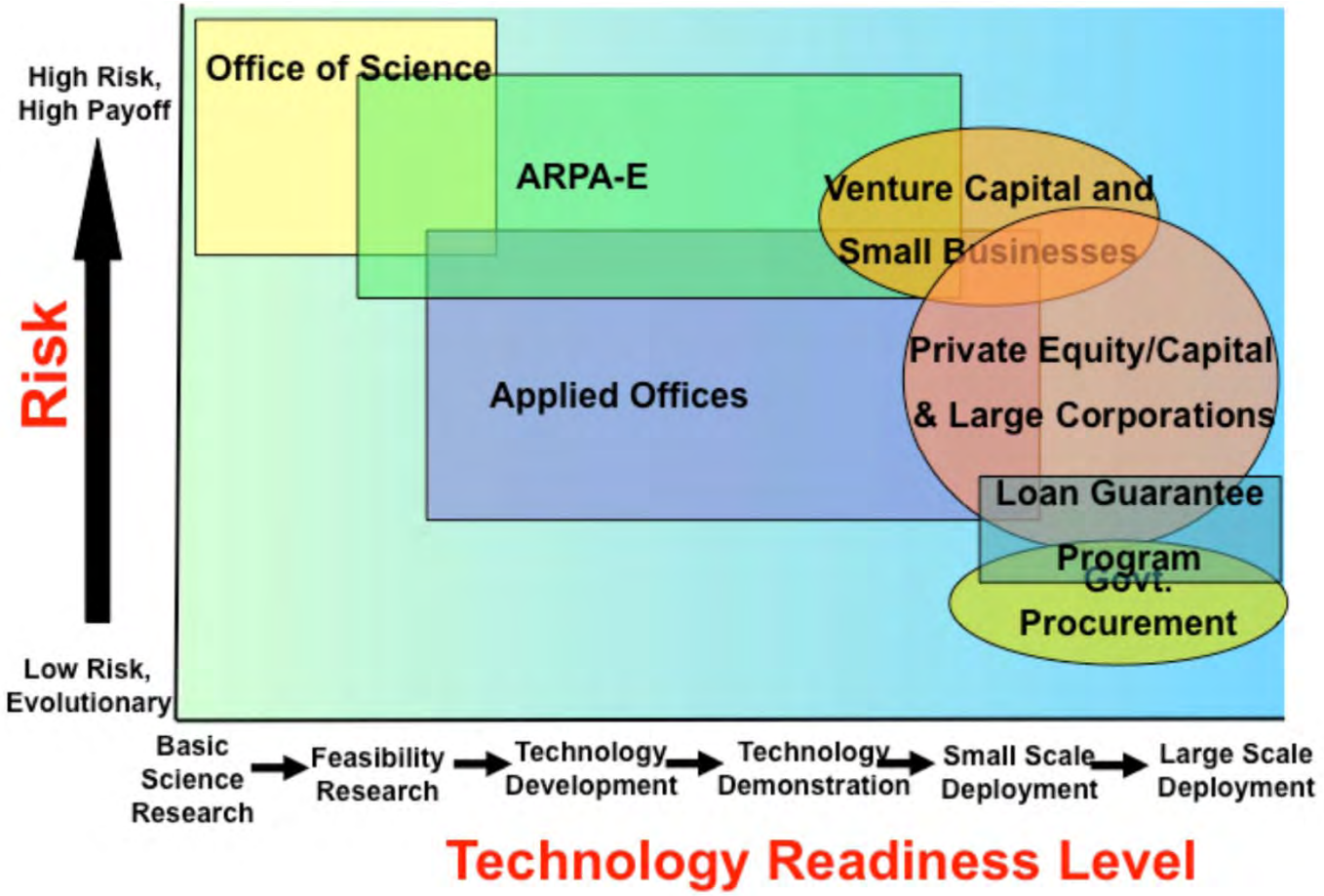
## Home Runs

- Domestic and global sales, US market share ($)
- Avoided greenhouse gas emissions ($tCO_2$ equivalent)
- Reduced oil imports (barrels of oil equiv.)
- Creation of new technology/business or new industry ecosystem (#)
- Jobs created (#)
- Beating current projections and trajectories (Moving McKinsey GHG abatement cost curves, EIA & IPCC projections, etc.)


Addressing the Diversity of Science through EFRCs and Hubs
EFRCs
(small teams of scientists mostly at Universities; 5 years)
Scientific Understanding Produces Improved or New Technologies
Energy Innovation Hubs
(large teams of scientists & engineers ideally under one roof; 5-10 years)
Overcoming Technological Barriers Needs New Scientific Understanding
ARPA-E
(high-risk/high-payoff disruptive technologies; small teams from Universities, National Labs, Industry; Maximum 3 years)
Creating a Portfolio of Competitive and Symbiotic Technology Options through Hubs and ARPA-E
Scale up of Business-Ready Technologies by Private Industry
Basic Science Research
Feasibility Research
Technology Development
Technology Demonstration
Small Scale Deployment
Large Scale Deployment
Technology Readiness Level

# ENERGY INNOVATION PIPELINE

**Historically:** (a) Change is slow; (b) Energy is a ubiquitous commodity; (c) Investments & systems can last a long time

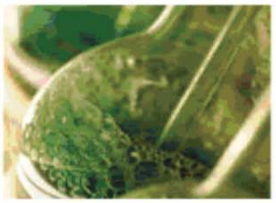


ARPA-E ENERGY INNOVATION SUMMIT

MARCH 1ST – 3RD, 2010
GAYLORD CONVENTION CENTER
WASHINGTON, DC








**Scientist/Engineer (Academia, National Labs, Industry); Investors; Small/Large Industry Senior Management; Policy Groups; Congress; White House**

**Panel Topics**

- **How do we foster and identify game-changers? Is it random or is there a system?**
- **How do we go from lab to market with disruptive energy technologies that challenge business-as-usual?**
- **How do we scale innovations in the US? How do we accelerate the pace?**
- **How do we balance global competitiveness and partnerships?**
- **How do we ensure national security through energy technologies?**
- **How do we build and engage regional innovation clusters through private-public partnerships?**
- **How can DOE play a role in energy innovation?**

# ARPA-E Energy Innovation Summit – Highlights

- Over 1,700 attendees from 49 states and 15 foreign countries
  - Over 40% hold PhDs
- 12 National Labs and dozens of universities participated

Quotes:

- "Probably the best conference I have ever attended with extremely high caliber speakers and panelists. Great job!" – *Exec from large corporation*
- "Great event. Came away with renewed enthusiasm for DOE's ability to be part of the solution." – *Academic researcher*