ARPA-E Overview and Funding Opportunity Summary

Navy Energy Forum

Washington D.C.

October 12, 2010

By

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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)

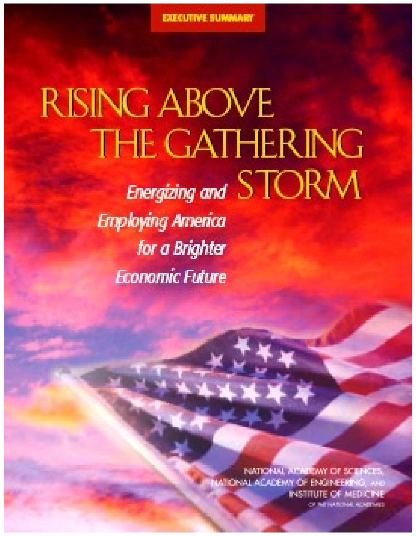
- Establish an Advanced Research Projects Agency for Energy (ARPA-E)
- “Creative, out-of-the-box, transformational” energy research
- Spinoff Benefit – Help educate next generation of researchers
- Secretary Chu (then Director of Berkeley National lab) on committee

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



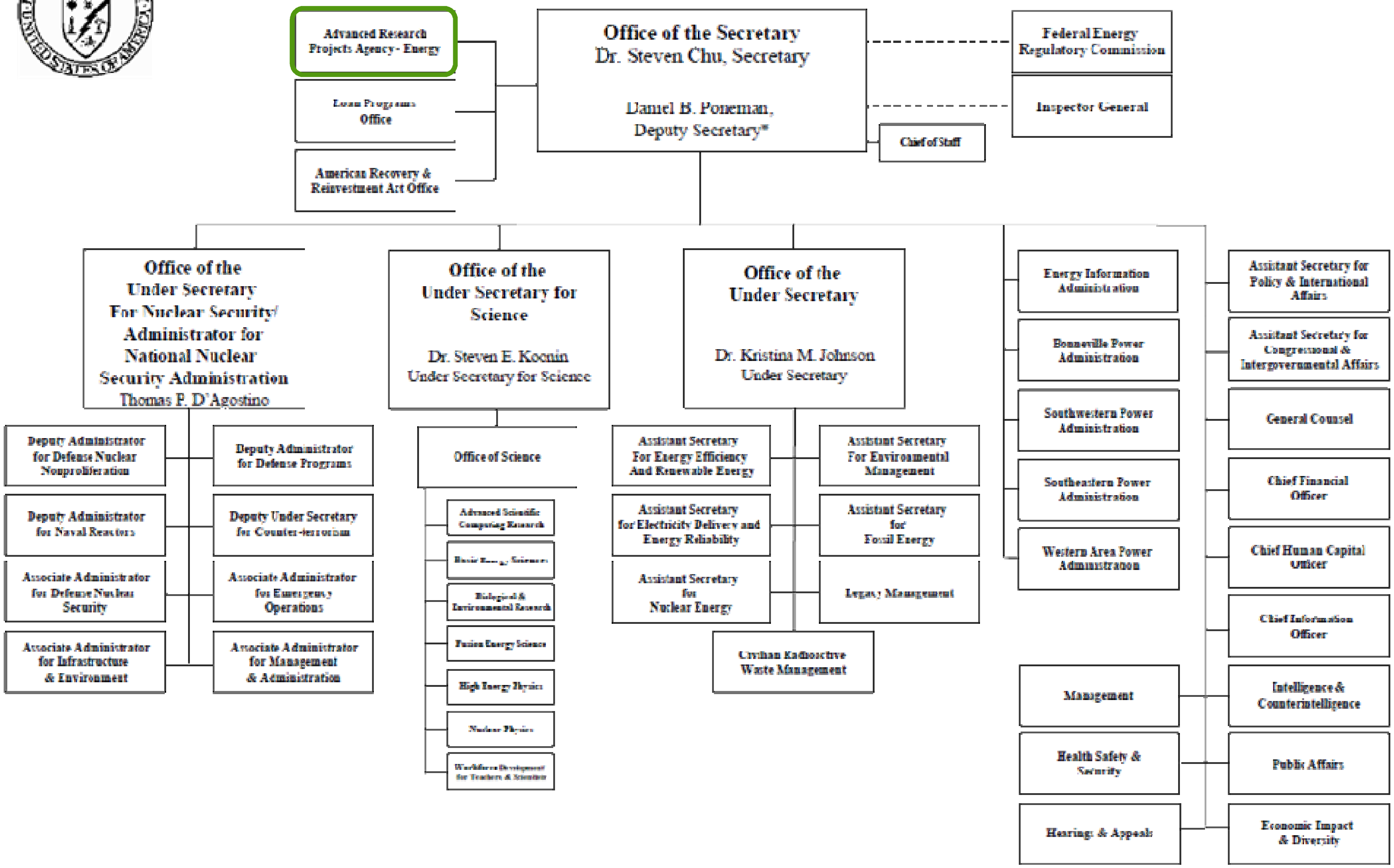
EXECUTIVE SUMMARY

RISING ABOVE
THE GATHERING
Energizing and STORM
Employing America
for a Brighter
Economic Future

NATIONAL ACADEMY OF SCIENCES,
NATIONAL ACADEMY OF ENGINEERING, AND
INSTITUTE OF MEDICINE
OF THE NATIONAL ACADEMIES

ARPA-E's director reports directly to the Secretary of Energy

DEPARTMENT OF ENERGY



- Advanced Research Projects Agency - Energy
- Loan Programs Office
- American Recovery & Reinvestment Act Office

Office of the Secretary
Dr. Steven Chu, Secretary

Daniel B. Poneman,
Deputy Secretary*

- Federal Energy Regulatory Commission
- Inspector General
- Chief of Staff

Office of the Under Secretary For Nuclear Security/ Administrator for National Nuclear Security Administration
Thomas P. D'Agostino

- Deputy Administrator for Defense Nuclear Nonproliferation
- Deputy Administrator for Defense Programs
- Deputy Administrator for Naval Reactors
- Deputy Under Secretary for Counter-terrorism
- Associate Administrator for Defense Nuclear Security
- Associate Administrator for Emergency Operations
- Associate Administrator for Infrastructure & Environment
- Associate Administrator for Management & Administration

Office of the Under Secretary for Science
Dr. Steven E. Koonin
Under Secretary for Science

- Office of Science
  - Advanced Scientific Computing Research
  - Basic Energy Sciences
  - Biological & Environmental Research
  - Fusion Energy Science
  - High Energy Physics
  - Nuclear Physics
  - Workforce Development for Teachers & Scientists

Office of the Under Secretary
Dr. Kristina M. Johnson
Under Secretary

- Assistant Secretary For Energy Efficiency And Renewable Energy
- Assistant Secretary For Environmental Management
- Assistant Secretary for Electricity Delivery and Energy Reliability
- Assistant Secretary for Fossil Energy
- Assistant Secretary for Nuclear Energy
- Legacy Management
- Civilian Radioactive Waste Management

- Energy Information Administration
- Bonneville Power Administration
- Southwestern Power Administration
- Southeastern Power Administration
- Western Area Power Administration
- Management
- Health Safety & Security
- Hearings & Appeals

- Assistant Secretary for Policy & International Affairs
- Assistant Secretary for Congressional & Intergovernmental Affairs
- General Counsel
- Chief Financial Officer
- Chief Human Capital Officer
- Chief Information Officer
- Intelligence & Counterintelligence
- Public Affairs
- Economic Impact & Diversity

* The Deputy Secretary also serves as the Chief Operating Officer

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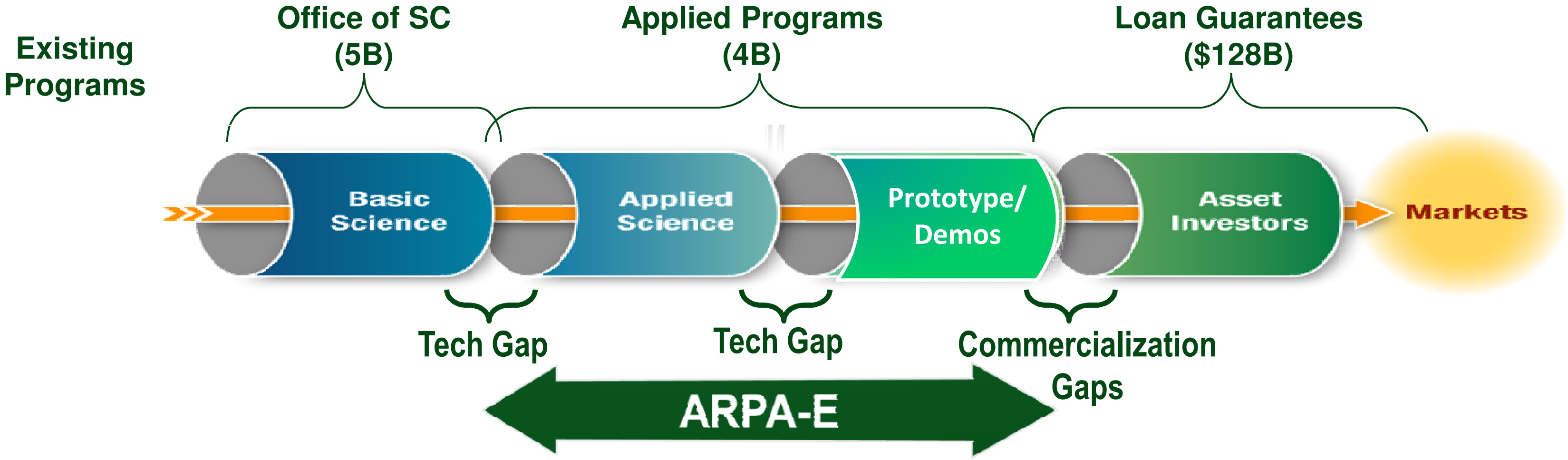
ARPA-E was created with a vision to bridge gaps in the energy innovation pipeline



Existing Programs

Office of SC (5B)

Applied Programs (4B)

Loan Guarantees ($128B)

Basic Science

Applied Science

Prototype/ Demos

Asset Investors

Markets

Tech Gap

Tech Gap

Commercialization Gaps

ARPA-E

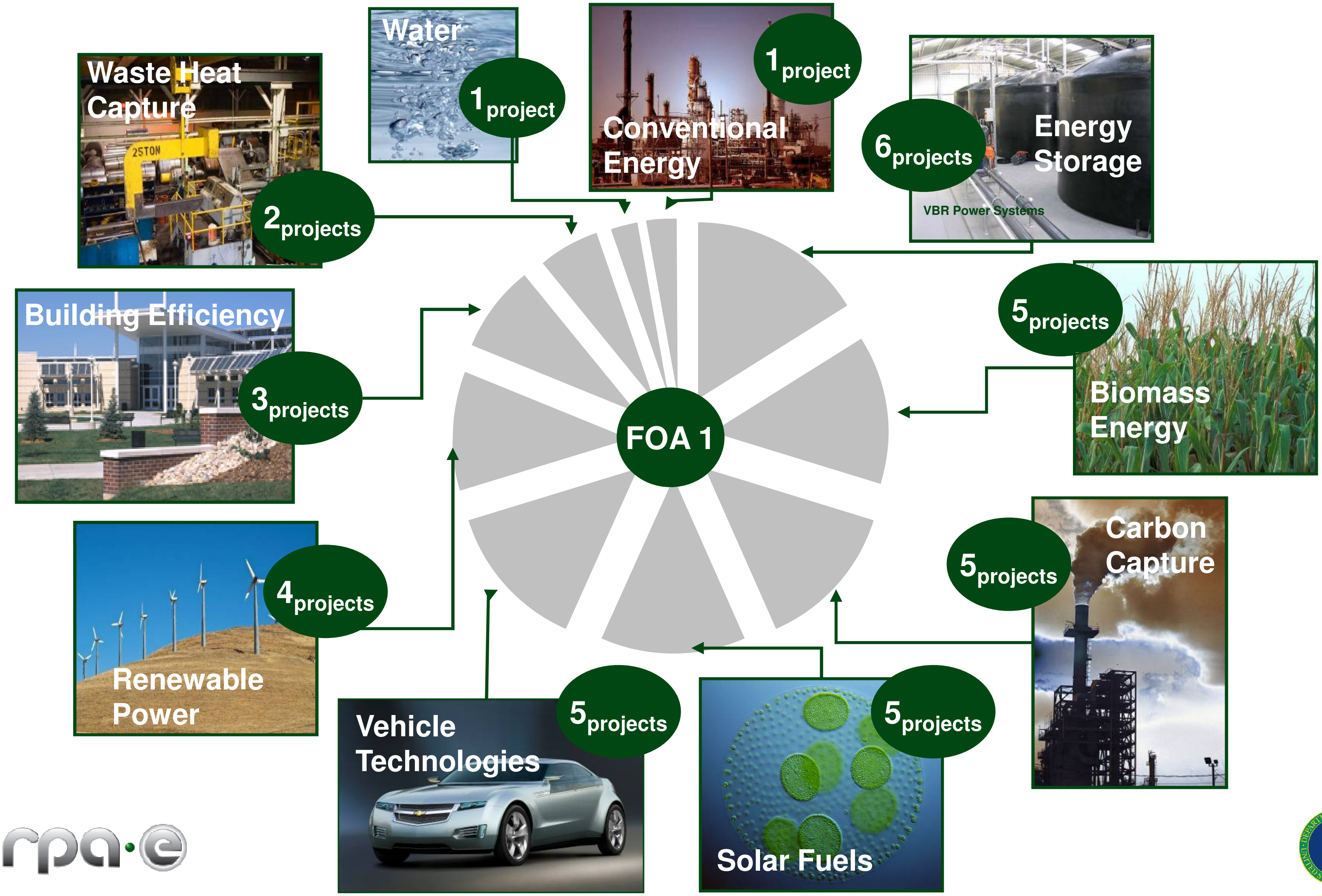
what ARPA-E will do

- 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 will NOT do

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

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



- Waste Heat Capture: 2 projects
- Water: 1 project
- Conventional Energy: 1 project
- Energy Storage: 6 projects
- Biomass Energy: 5 projects
- Carbon Capture: 5 projects
- Solar Fuels: 5 projects
- Vehicle Technologies: 5 projects
- Renewable Power: 4 projects
- Building Efficiency: 3 projects

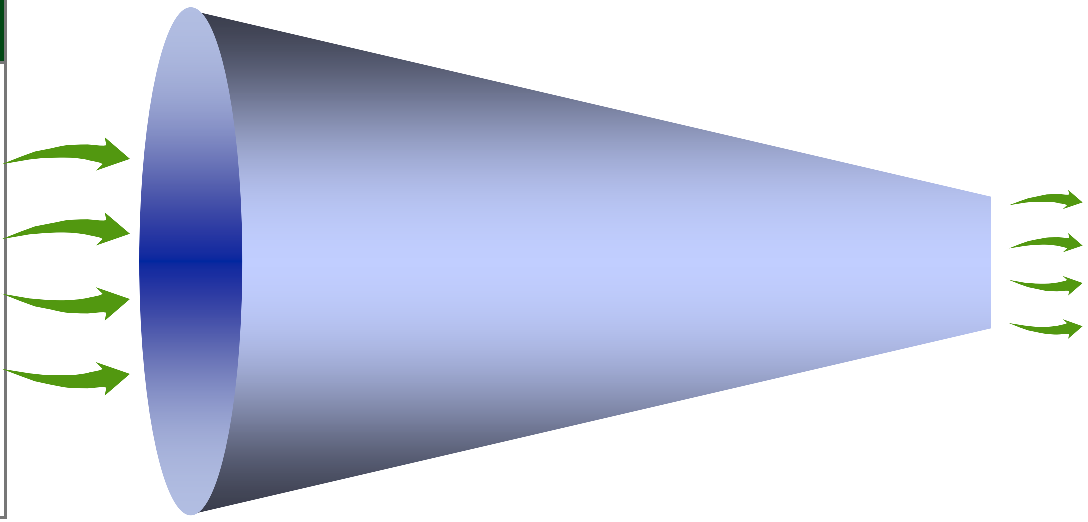
FOA 1

VBR Power Systems

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

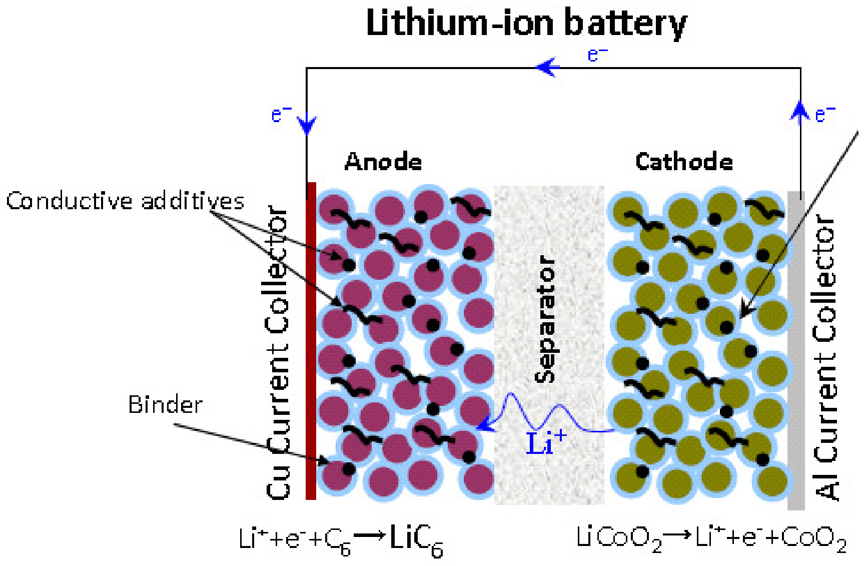
Round 2 & Round 3 FOAs

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

Batteries for Electrical Energy Storage for Transportation (BEEST)

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

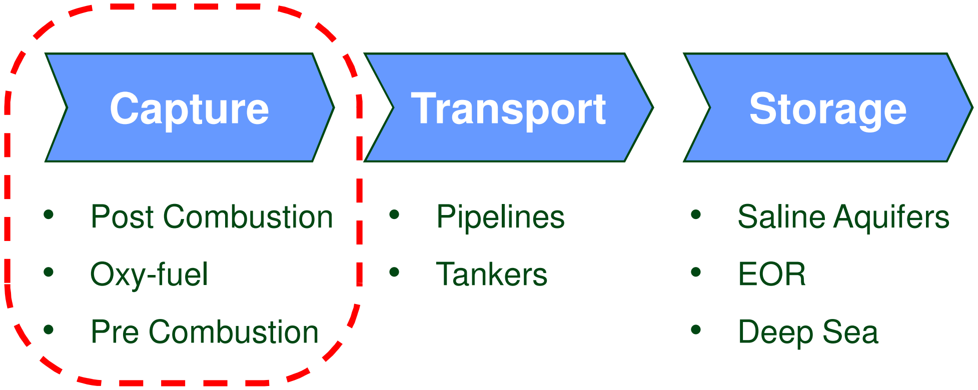
- Advanced Lithium-ion batteries that exceed energy density of traditional Li-ion systems
- Li-sulfur battery approaches that address the low cycle life and high self-discharge of existing state of the art technology
- Metal air battery approaches that address the low cycle life, low power density, and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

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

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



Capture

- Post Combustion
- Oxy-fuel
- Pre Combustion

Transport

- Pipelines
- Tankers

Storage

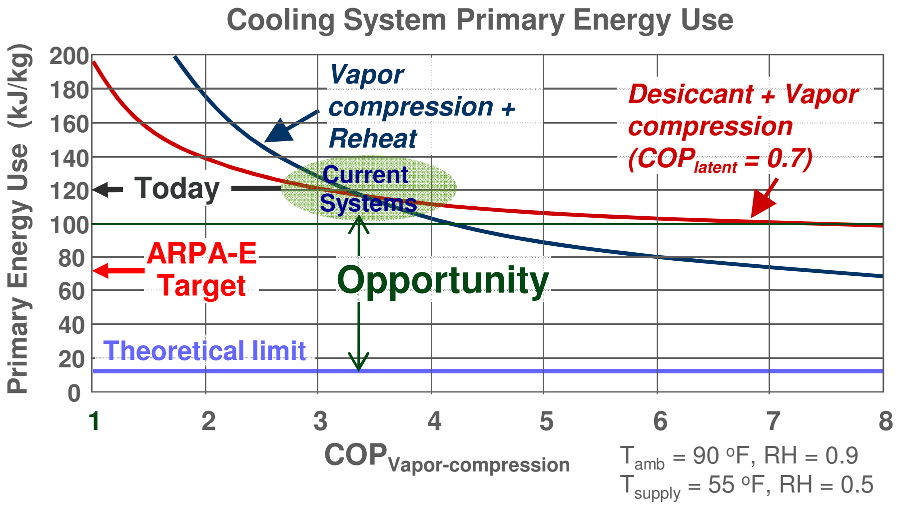
- Saline Aquifers
- EOR
- Deep Sea

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

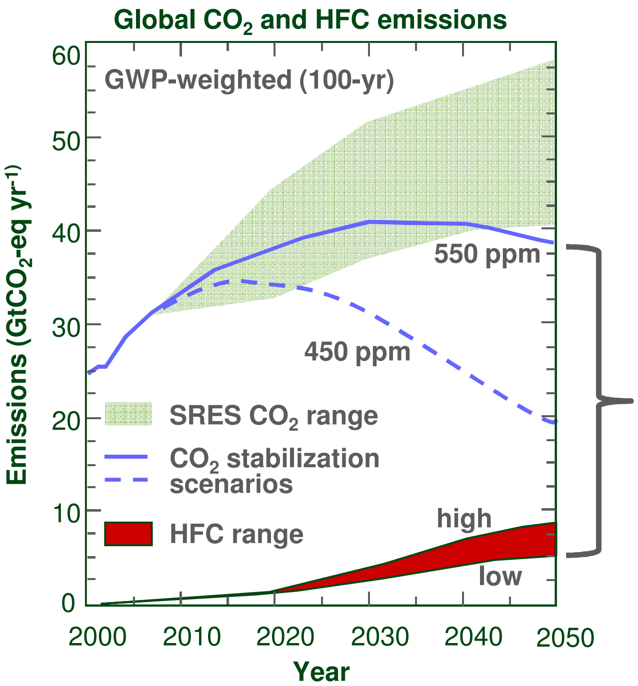
Building Energy Efficiency Through Innovative Thermodevices (BEETIT) – Building Cooling

- ***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

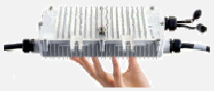
Source: Velders et al, PNAS 106, 10949 (2009)

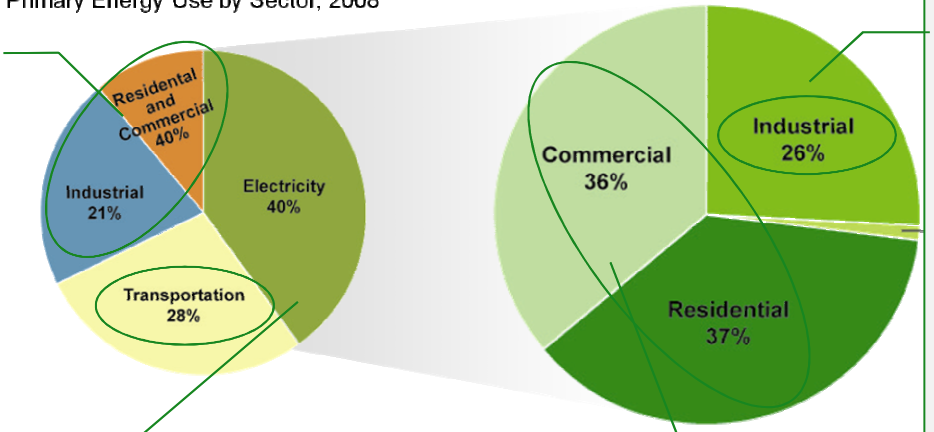
Agile Delivery of Electrical Power Technology (ADEPT)

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)

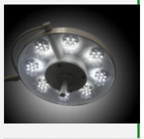
Automotive

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

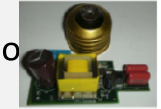
Approach: Package integrated high-temperature converters with high-frequency switches and magnetics.

Lighting

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



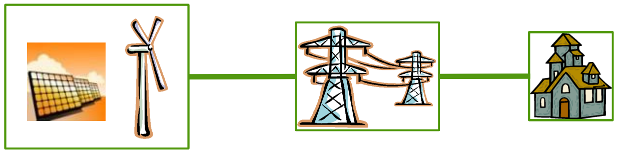
Approach: Power electronics to facilitate so state lighting (20-40% more efficient than state-of-art LEDs)

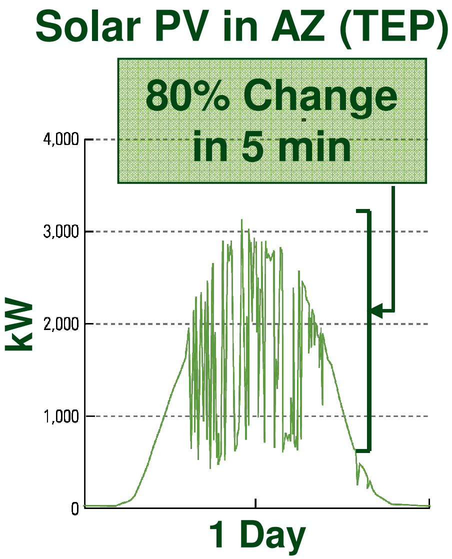


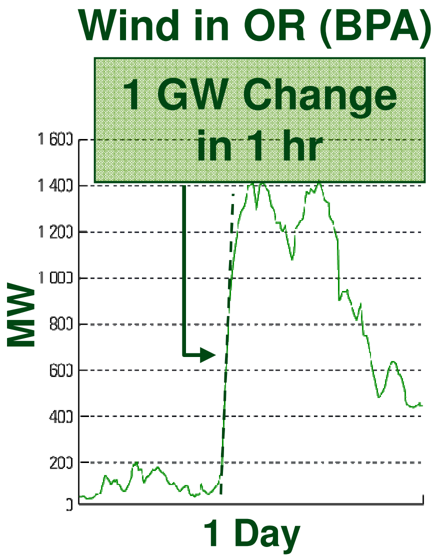
Advanced power electronics for
12% reduction in total US energy consumption

Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS)

Renewables Today

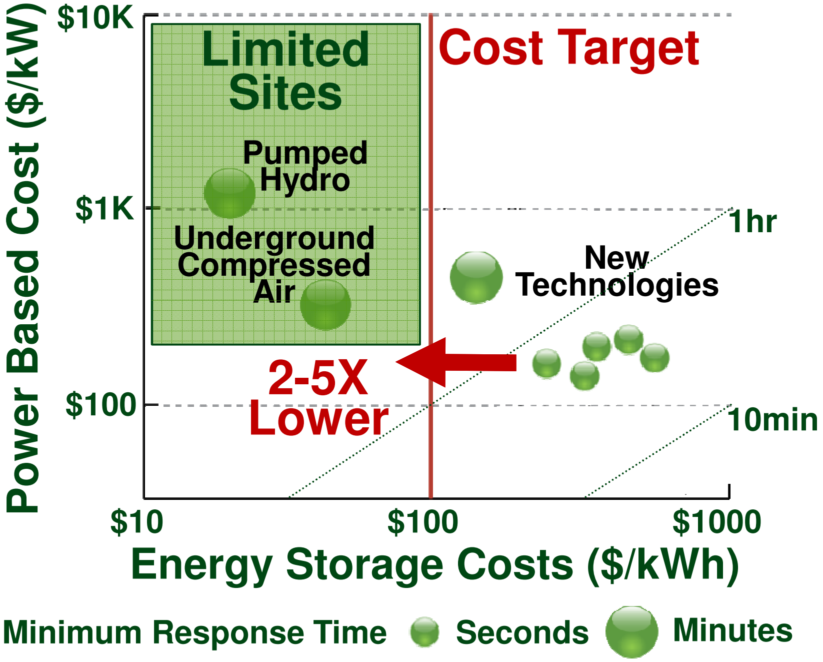



Solar PV in AZ (TEP)


Wind in OR (BPA)

Problem:
Minutes-to-Hours Changes in Power

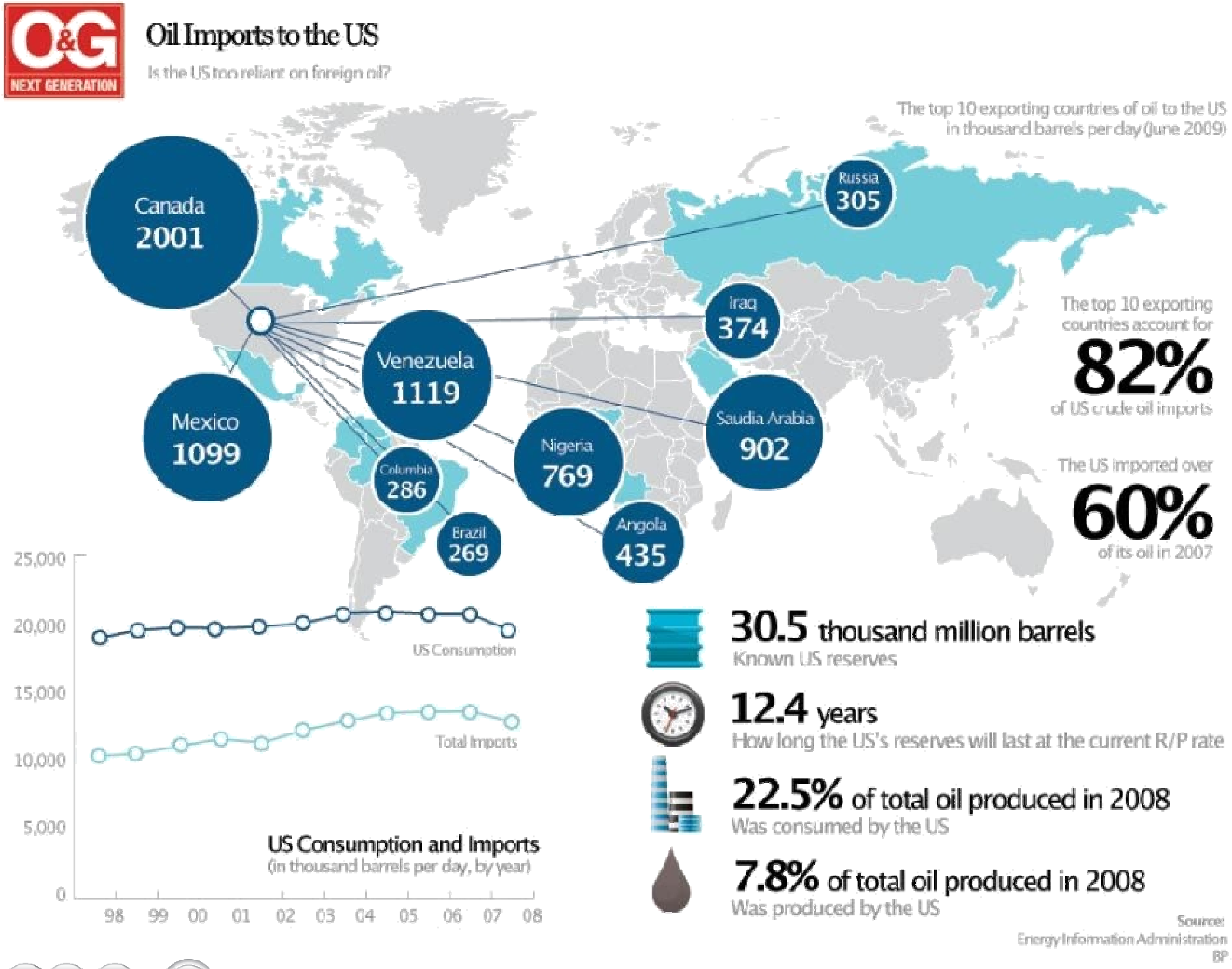
Storage for Renewables Tomorrow



***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

The U.S. dependence on imported oil is an economic weakness as well as a political and environmental challenge



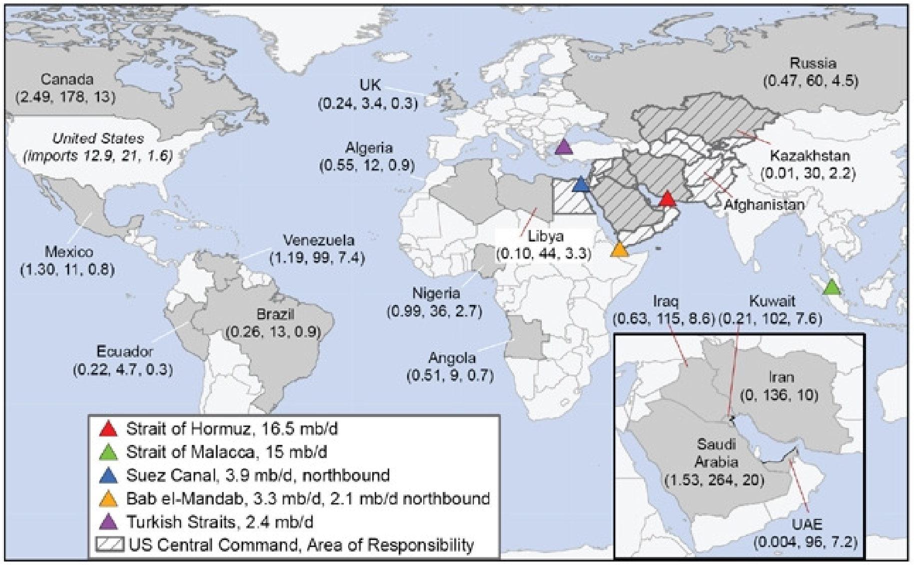
Source:
Energy Information Administration
BP

In 2007, with oil at $70 per barrel, the U.S. trade deficit in petroleum products was **36%** of the total of $819 billion deficit.

The U.S. dependence on imported oil has driven U.S. military positioning and consumed significant military resources

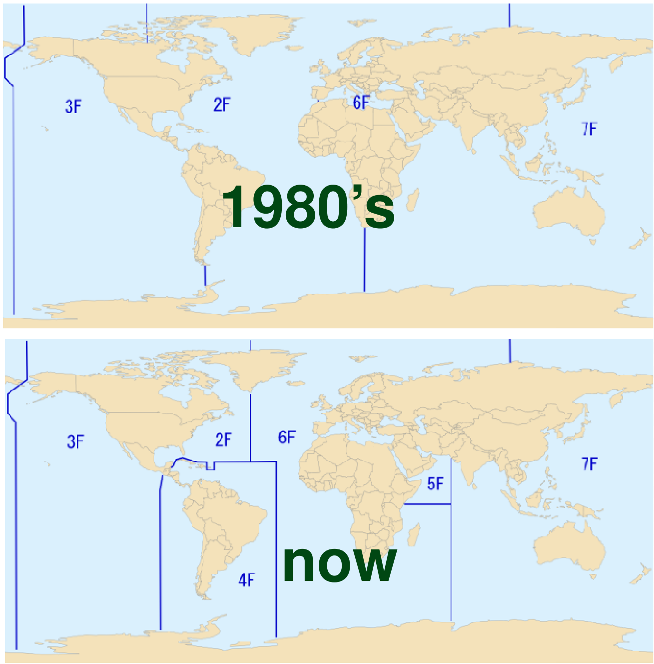
The U.S. Navy has reorganized in the last 20 years as a result of the U.S. dependence on oil.

From 1976 to 2007 the cost of keeping U.S. aircraft carriers in the Persian Gulf (securing oil shipments) totaled $7.3 trillion[1]



Countries in gray export oil to the U.S. at >0.2 mb/d or have >20 billion barrels of oil reserves. Country labels in parentheses indicate: 1) U.S. imports designated in mb/d, 2) oil reserves in billion barrels, and 3) the percentage of global reserves. 2006 data

U.S. Navy Fleets



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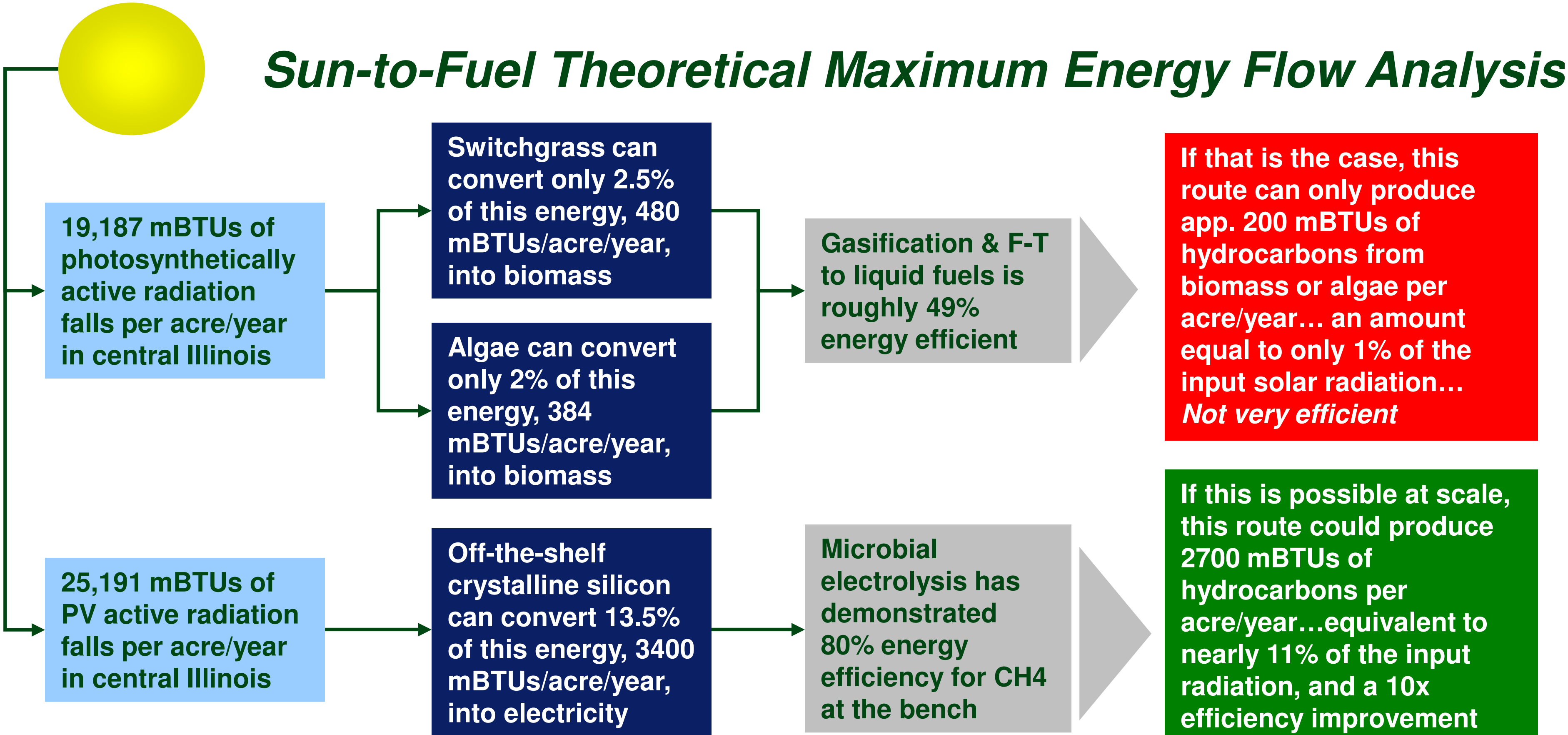
[1] 1: Stern, R.J. United States cost of military force projection in the Persian Gulf, 1976–2007, Energy Policy, 2010.

Electrobiofuels is a potentially high-efficiency paradigm for the production of liquid fuels from solar energy

Sun-to-Fuel Theoretical Maximum Energy Flow Analysis



19,187 mBTUs of photosynthetically active radiation falls per acre/year in central Illinois

Switchgrass can convert only 2.5% of this energy, 480 mBTUs/acre/year, into biomass

Algae can convert only 2% of this energy, 384 mBTUs/acre/year, into biomass

Gasification & F-T to liquid fuels is roughly 49% energy efficient

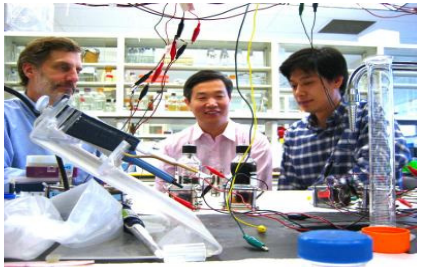
If that is the case, this route can only produce app. 200 mBTUs of hydrocarbons from biomass or algae per acre/year… an amount equal to only 1% of the input solar radiation… *Not very efficient*

25,191 mBTUs of PV active radiation falls per acre/year in central Illinois

Off-the-shelf crystalline silicon can convert 13.5% of this energy, 3400 mBTUs/acre/year, into electricity

Microbial electrolysis has demonstrated 80% energy efficiency for CH4 at the bench

If this is possible at scale, this route could produce 2700 mBTUs of hydrocarbons per acre/year…equivalent to nearly 11% of the input radiation, and a 10x efficiency improvement over biomass F-T

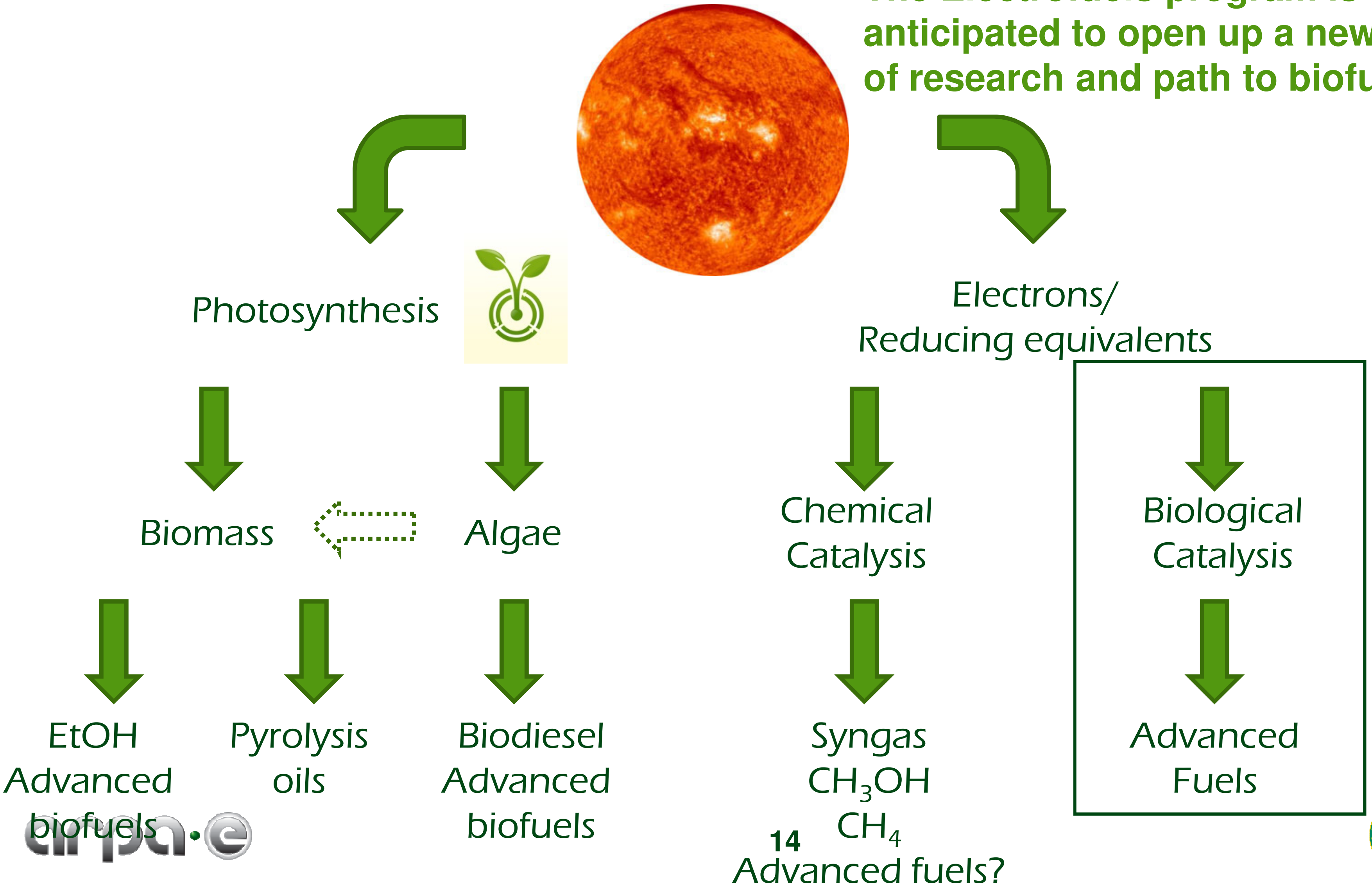


"We have a microbe that is self perpetuating that can accept electrons directly, and use them to create methane."

- Dr. Bruce Logan, Kappe Professor of Environmental Engineering, Penn State

ARPA-E's Electrofuels program seeks to address U.S. oil dependence with significantly more efficient biofuels

The Electrofuels program is anticipated to open up a new area of research and path to biofuels



Photosynthesis

Biomass

Algae

EtOH
Advanced
biofuels

Pyrolysis
oils

Biodiesel
Advanced
biofuels

Electrons/
Reducing equivalents

Chemical
Catalysis

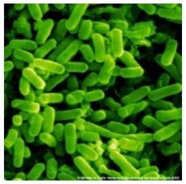
Syngas
CH_3OH
CH_4
Advanced fuels?

Biological
Catalysis

Advanced
Fuels

Electrofuels approach is non-photosynthetic, modular, and solutions can be mixed- and- matched

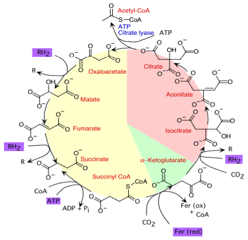
Assimilate Reducing Equivalents



Reducing equivalents: *other than reduced carbon or products from Photosystems I & II*

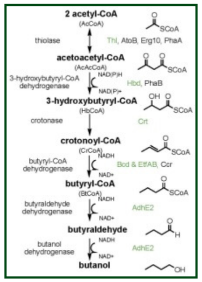
H_2S H_2 Direct Current NH_3 Fe^{2+}

Fix CO_2 for Biosynthesis

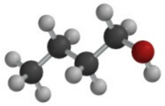


Pathway for carbon fixation: *reverse TCA, Calvin- Benson, Wood-Ljungdahl, hydroxpropionate/hydroxybutyrate, or newly designed biochemical pathways*

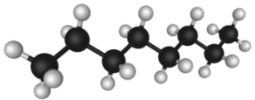
Generate Energy Dense Liquid Fuel



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



butanol



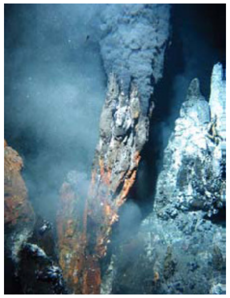
alkanes

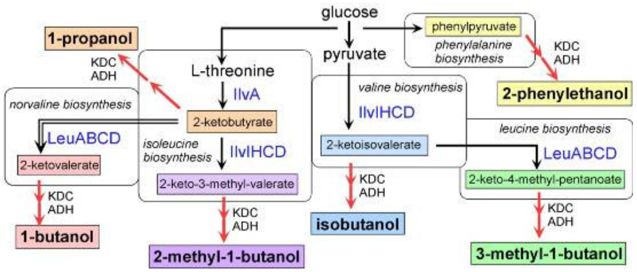
+ numerous possibilities

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

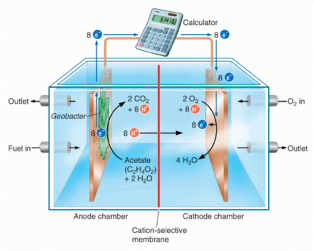
The Proposal: Utilize metabolic engineering and synthetic biological approaches for the high efficiency conversion of CO_2 to liquid transportation fuels in organisms capable of extracting energy from hydrogen, from reduced earth-abundant metal ions or/and organic cofactors, directly from electrical current, or other sources other than reduced carbon (e.g. sugars).

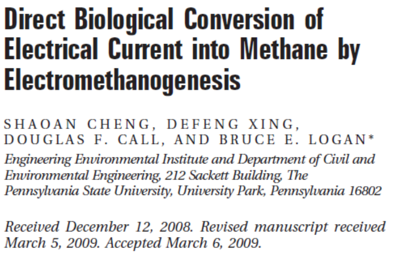
Foundational R&D has been demonstrated to support the concept…………*what’s next?*





- Autotrophic organisms (e.g. extremophiles, acetogens, methanogens,) utilize energy inputs other than photons or reduced carbon
- 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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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, the basis for the development of microbial fuel cells, funded by DOE, DoD, & DARPA
- Reverse microbial fuel cells are feasible and can fix CO_2 using electrical current as an energy input

ARPA-E's investment should be considered both high-risk and very early stage

To achieve the intent of the Electrofuels FOA, all projects must address the following components:

- Specify liquid fuel type (diesel fuel, JP-8 aviation fuel, and/or high octane fuels for four-stroke internal combustion engines); liquid fuels 85 research octane or 40 cetane are desirable

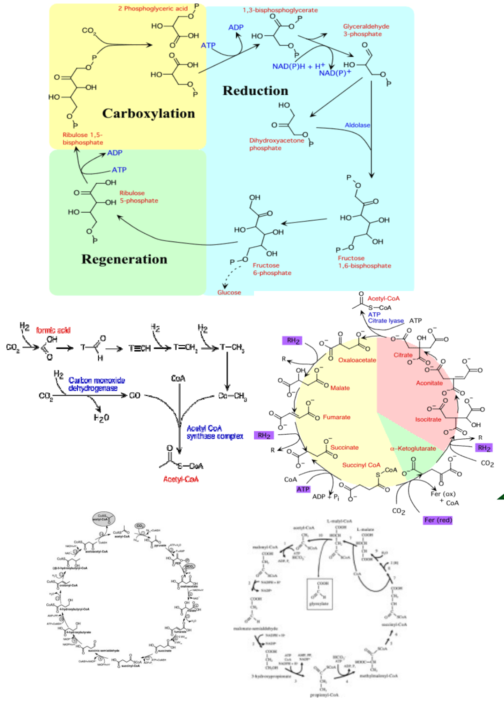
- Anticipated liquid fuel energy density 32 MJ/Kg is desired

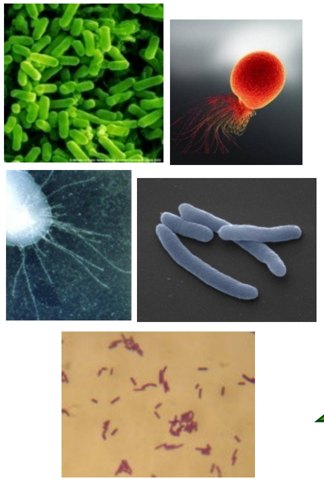
- Anticipated liquid fuel heat of vaporization < 0.5 MJ/Kg is desired

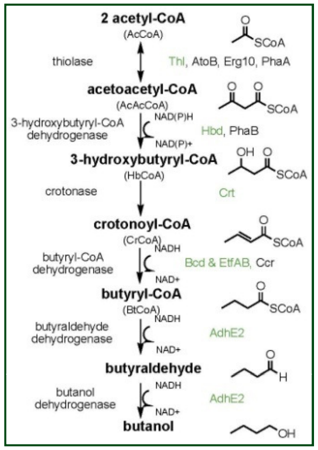
- Anticipated liquid fuel-energy-out to photon/electrical energy-in of the envisioned system; an overall energy efficiency > 1% is required

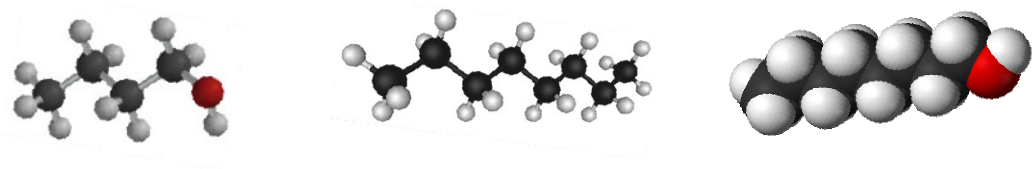
- Rare earth elements or organic redox shuttles that cannot be deployed economically at scale should be avoided

Electrofuels concepts explores many carbon fixation pathways, state-of-the art synthetic biology & metabolic engineering









The 13 projects selected create a program which includes a diverse portfolio of approaches

	Reducing Equivalents				CO_2 Fixation Pathways				Organism Platforms						
	H_2	E-	NH_3	NADH	CB	WL	4HB	rTCA	Ral-stonia	E-coli	Clost-ridium	Geo-bacter	Rhodo-bacter	Shew-anella	Pyro-cocus
		●				●	●				●	●			
	●				●								●		
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		●			●									●	
	●	●				●					●				
	●						●			●					●
	●				●				●						
		●			●			●		●	Synechocystis		Rhodopseudomonas		
		●				●					●	Acetobacterium			
			●		●				Nitrosomonas europaea						
	●				●				●						

ARPA-E selected Full Applications from leading scientists

Biochemists

Dr. David Baker (Washington)

- New computational techniques for protein structure prediction and design
- Design of proteins for fuel-cell catalysis,
- Solar hydrogen production and nanopatterning of materials

Dr. Greg Stephanopoulos (MIT)

- Metabolic Engineering
- Metabolomics
- Novel approaches to intracellular flux determination.

Dr. Anthony Sinskey (MIT)

- Engineering biodegradable polymers
- Turning environmental contaminants into pharmaceuticals with Rhodococcus
- Biosynthesis of essential amino acids in Corynebacterium glutamicum

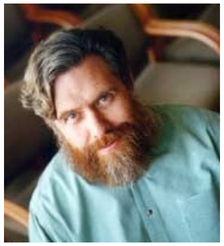
Synthetic Biologists

Dr. James Liao (UCLA)

- Metabolic engineering,synthetic biology, and systems biology principles to produce next generation biofuels

Dr. Pamela Silver (Harvard)

- Cell-based machines, developing protein-based logic for design of novel therapeutics, and engineering cells as sources of bio-energy and optimization of carbon dioxide fixation

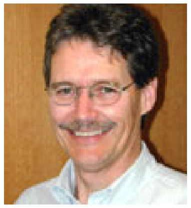


Dr. George Church (Harvard)

- Synthesizing bacterial genomes with new genetic codes, new protein types, and thereby immune to all existing viruses

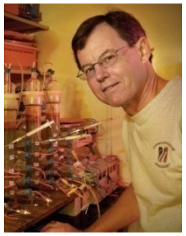
ARPA-E selected Full Applications from leading scientists

Microbiologists



Dr. Mike Adams (Georgia)

- Physiology, metabolism, enzymology, bioinorganic chemistry, and functional and structural genomics of anaerobic microorganisms, particularly archaea and particularly those growing near and above 100℃, hyperthermophiles



Dr. Derek Lovley (UMass Amherst)

- Physiology and Ecology of Anaerobic Microorganisms.
- Microbial Fuel Cells
- Directed and Natural Evolution of Anaerobic Respiration
- Anaerobic Biofilms
- Extracellular Electron Transfer Mechanisms

Dr. Robert Kelly (NCSU)

- Biochemical engineering
- Biocatalysis at extremely high temperatures
- Microbial physiology
- Enzyme engineering

Thank you

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