arpa·e

CHANGING WHAT'S POSSIBLE

ARPA-E Portfolio in Carbon Capture Utilization and Sequestration

Dr. Dane Boysen, Program Director

Transformational Carbon Capture Workshop
September 23, 2014, Washington DC

Roadmap

- Who is ARPA-E?
- Where is the state of the art?
- What have we done in carbon capture?
- What are we doing now?

What are the top 10 actions, in priority order, that federal policy-makers could take to enhance the science and technology enterprise so that the United States can successfully compete, prosper, and be secure in the global community of the 21st Century?

Senators Lamar Alexander & Jeff Bingaman
Senate Committee on Energy and Natural Resources

Representatives Sherwood Boehlert & Bart Gordon
House Committee on Science

Action B-5: Create in the Department of Energy (DOE) an organization like the Defense Advanced Research Projects Agency (DARPA) called the Advanced Research Projects Agency-Energy (ARPA-E).

National Academies, 2006
Rising Above the Gathering Storm

History

2009 - present: 362 projects, $900M

2006
National Academies

2007
America COMPETES

2009
Recovery Act

2009
1st Director Majumdar

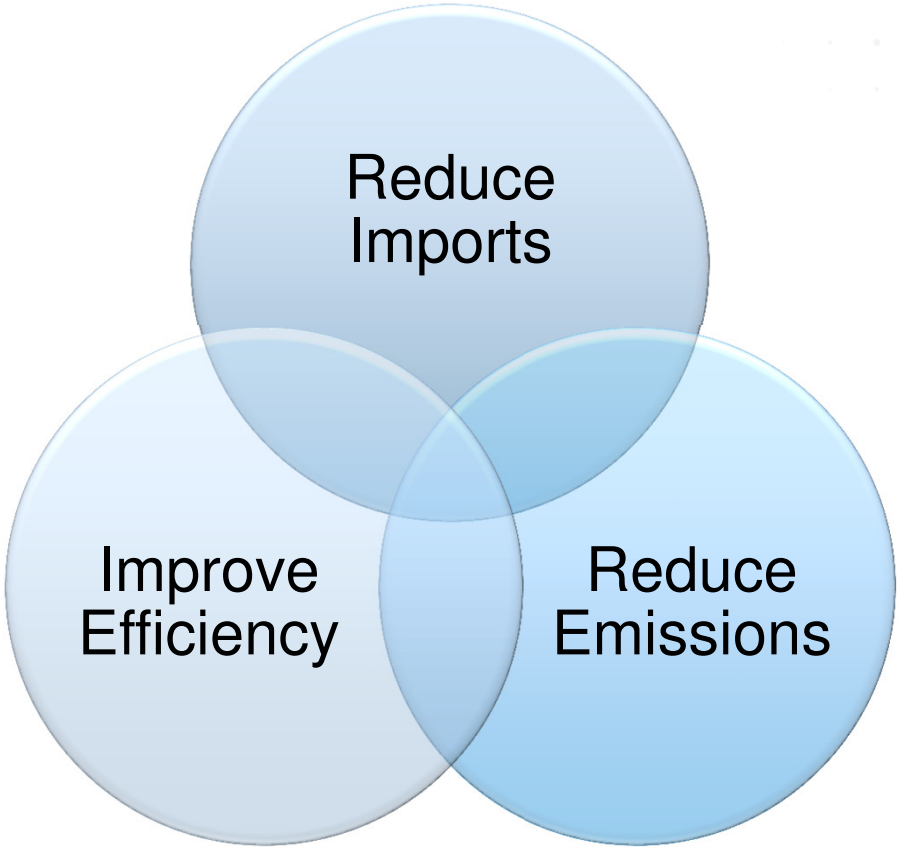
2013
Acting Director Martin

Mission

catalyze and support the development of transformational, high-impact energy technologies

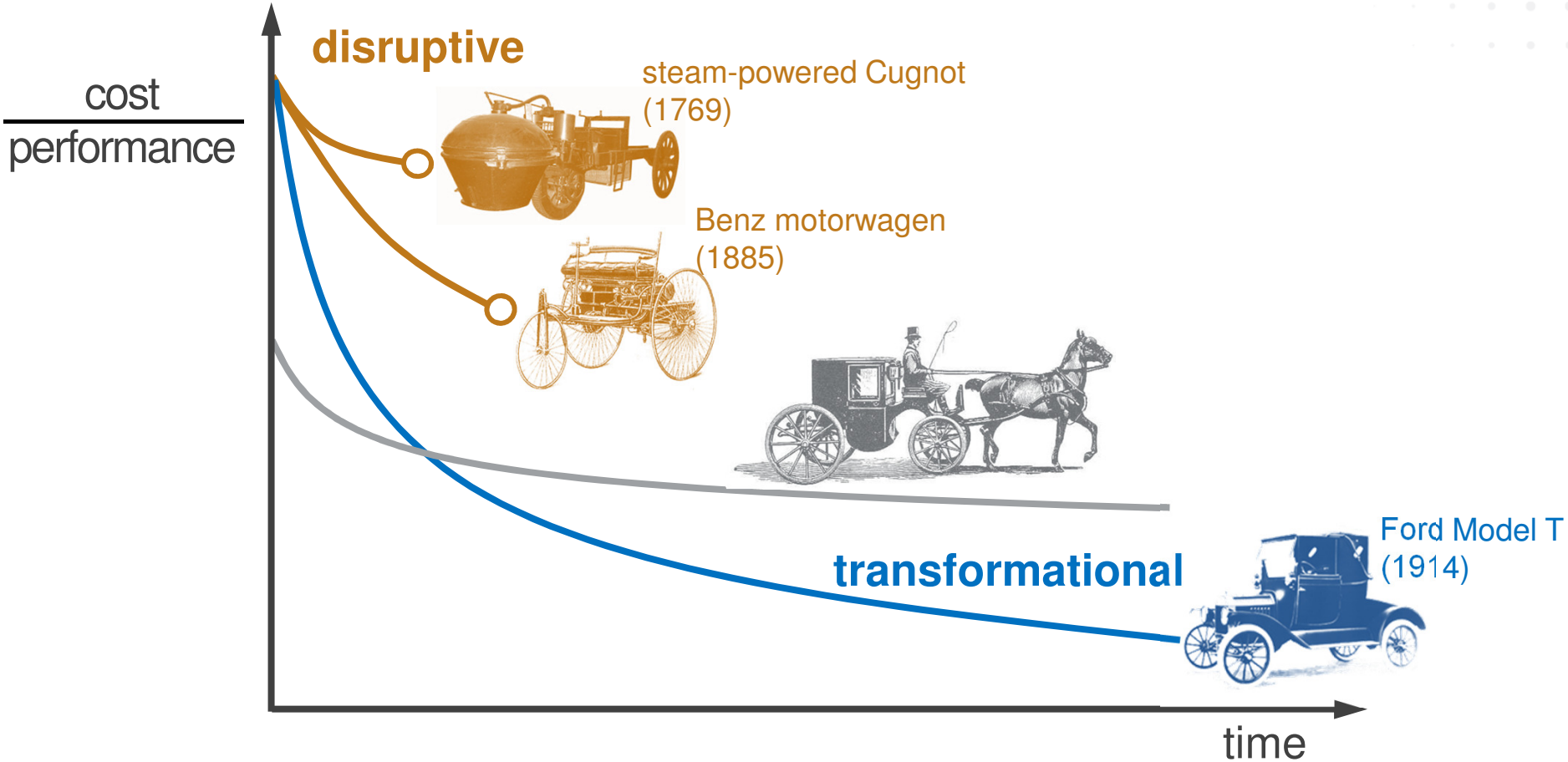
Ensure America's

- National Security
- Economic Security
- Energy Security
- Technological Lead



Approach

identify fundamentally disruptive technologies
with potential to transform the marketplace



Program Directors

thought leadership, program creation,
active program management

2009 2010 2011

BEEST Electrofuels IMPACCT GRIDS REACT ADEPT SolarADEPT GENI BEETIT HEATS PETRO MOVE SBIR AMPED

2012 2013 2014

REMOTE Electrofuels II RANGE FOCUS METALS SWITCHES REBELS MONITOR

3-year term limited positions

Where are we now?

CO_2 Separation Today

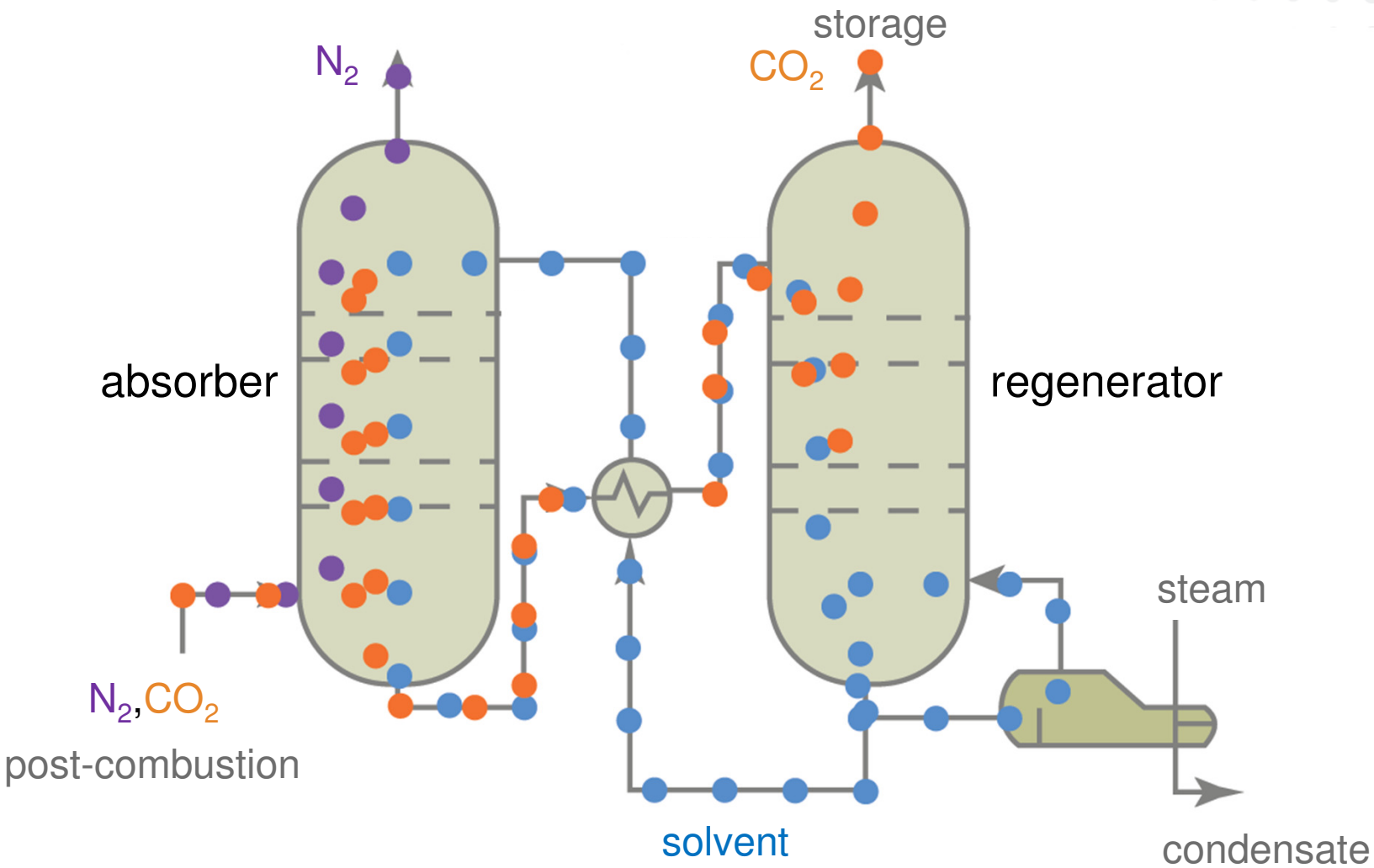
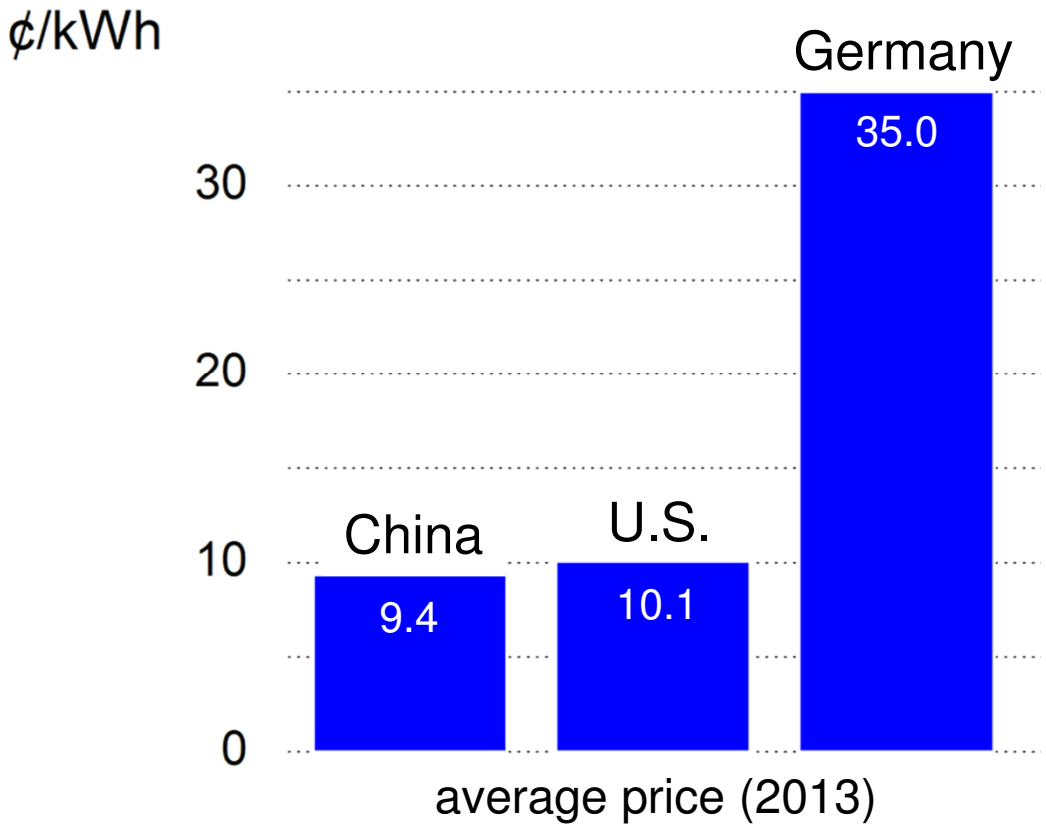


Figure courtesy RTI International

Electricity Price and Cost

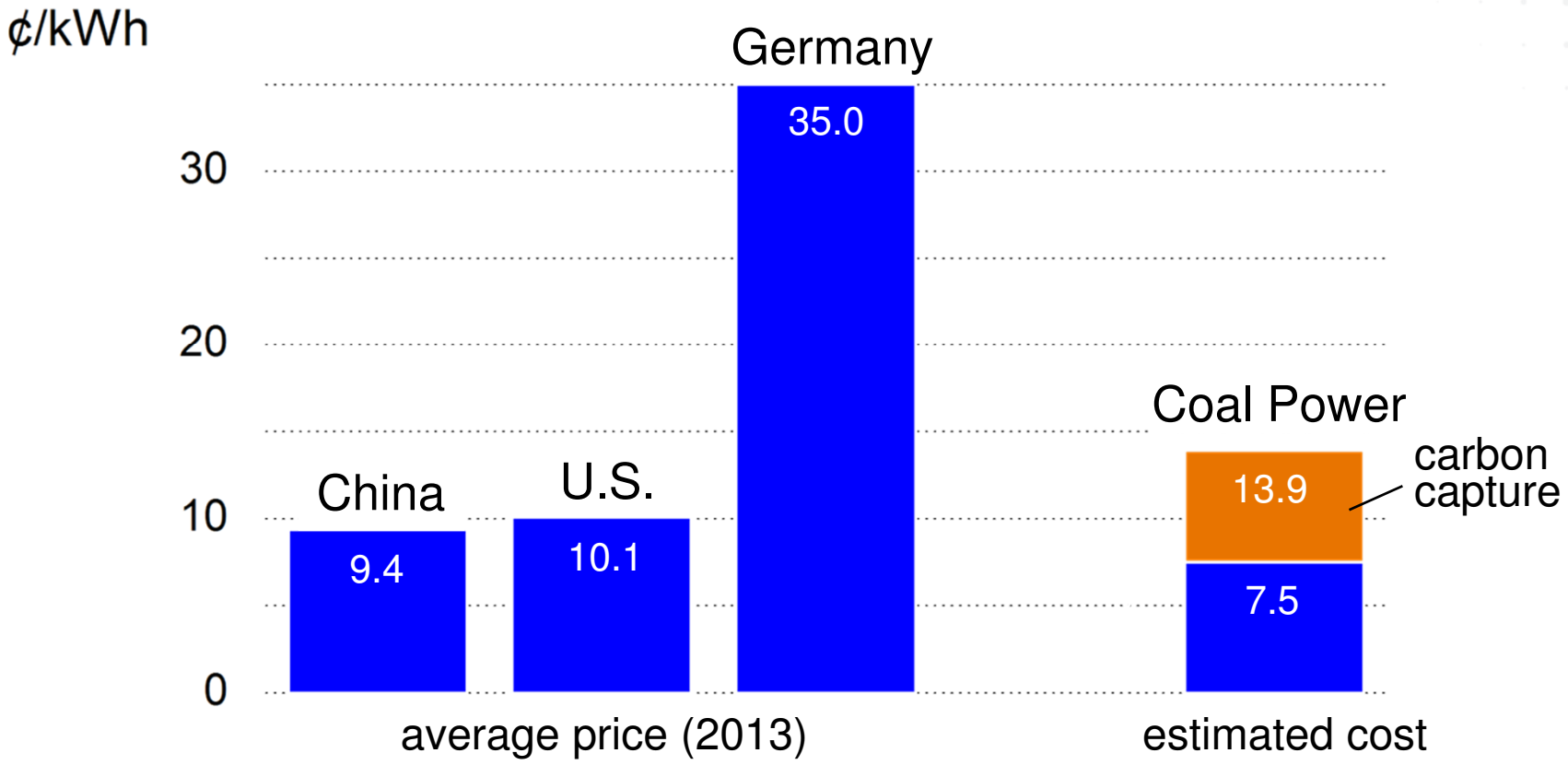


the U.S. enjoys low electricity prices

Source: *EIA, DOE, 2013.*

Electricity Price and Cost

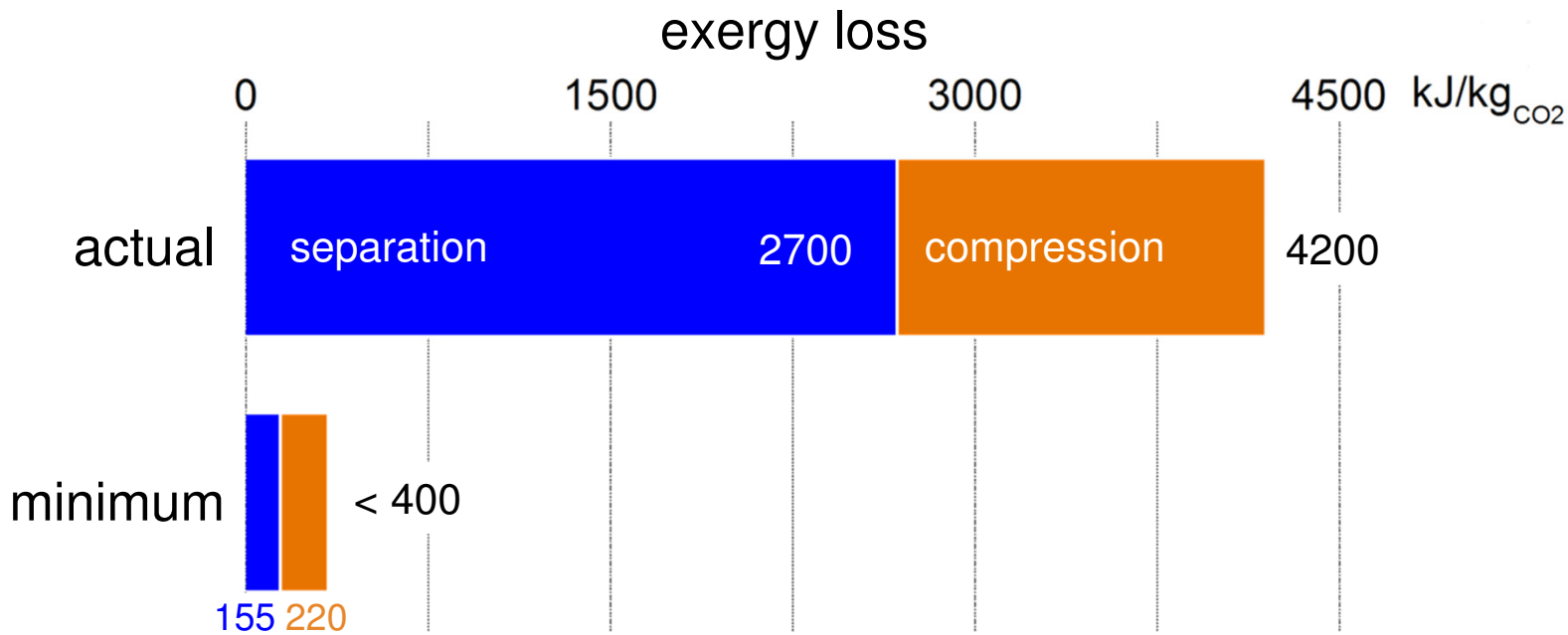
carbon capture doubles coal power cost



Source: *Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity*. Revision 2a, September 2013. DOE/NETL-2010/1397. PC Subcritical-Case 9 & 10, levelized cost of electricity.

Exergy for Carbon Capture

low anergy = low cost



parasitic energy calculations typically assumes 100% separation energy from electrical work

Source: Herzog, et al., Advanced Post-Combustion CO2 Capture, Clean Air Task Force (2009)

What are we doing in carbon capture, utilization, and sequestration?

ARPA-E CO_2 Projects and Programs

23 projects, one dedicated program, $64M

Dr. Hartney

Dr. Sawyer

Drs. Klausner, Gonzalez, Liu, Willson

OPEN 2009

2009 → 2014

5 projects

IMPACCT

2010 → 2015

15 projects

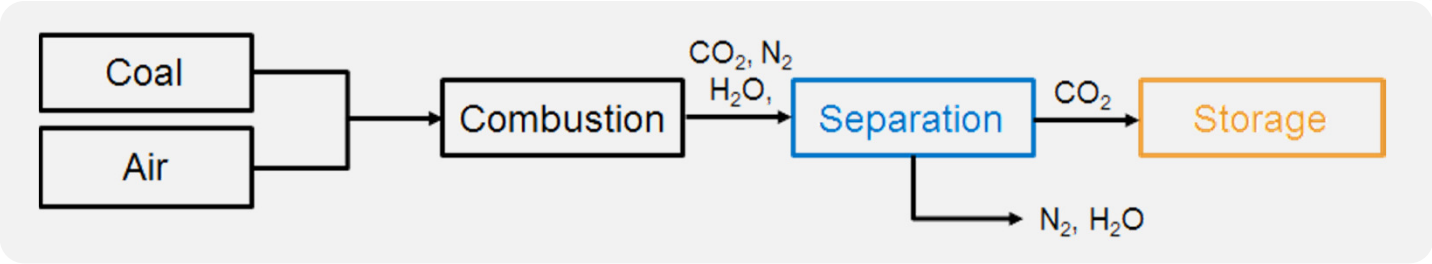
OPEN 2012

2013 → 2016

3 projects

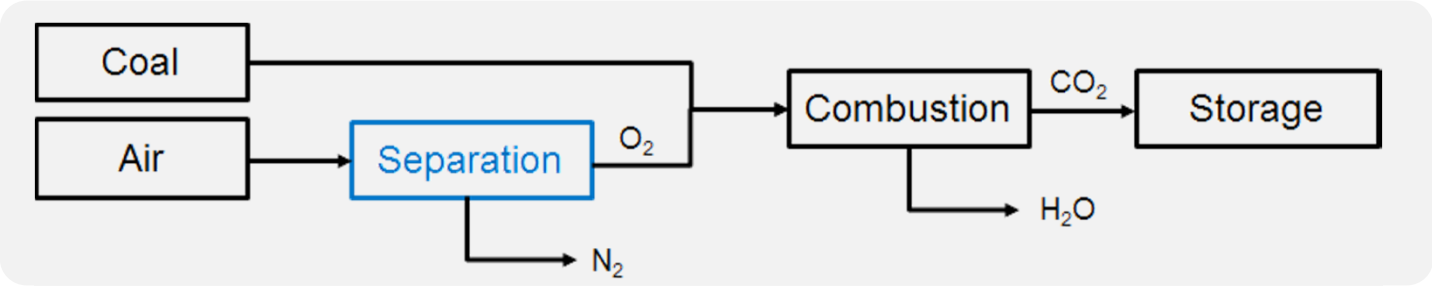
Carbon Capture Approaches

Post-Combustion

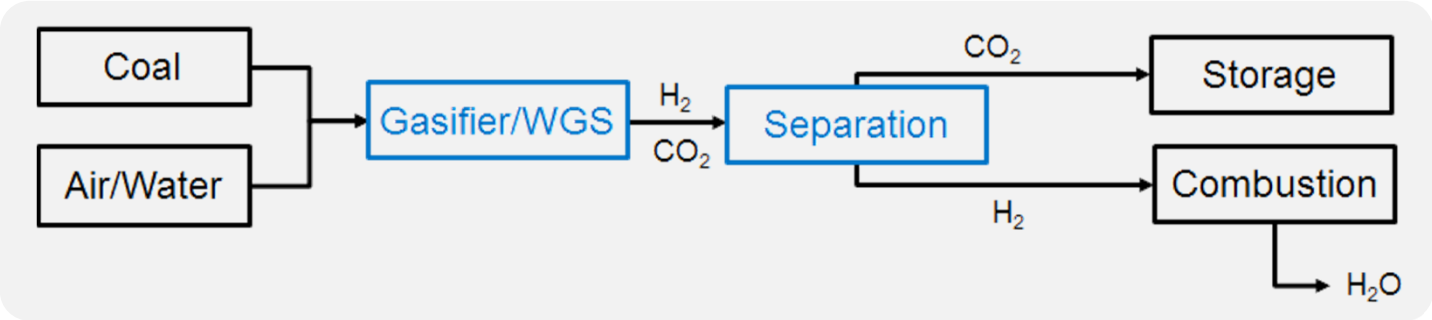


IMPACCT
Primary Focus

Oxy-Combustion

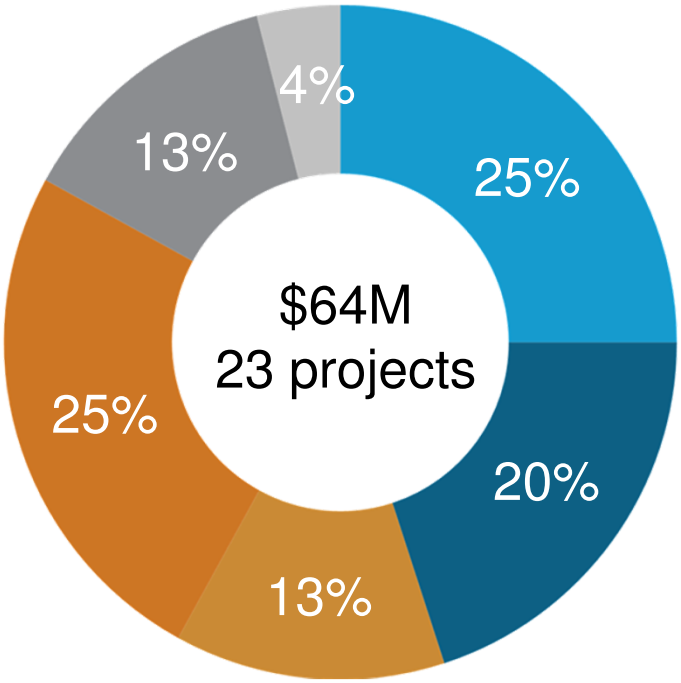


Pre-Combustion



ARPA-E CO_2 Technology Projects

Funding by Technology



- solvents
- phase change
- membranes
- chemical looping
- sorbents
- enhanced oil recovery

Current Projects

UC Berkeley	adsorbent
SES	cryogenic
ASU	electrochemical
U Pittsburgh	EOR
Dioxide Materials	CO_2 to fuel

Classification of Separation Approaches

Physical Separation

- Adsorption $CO_2(g) = CO_2(ads)$
- Absorption $CO_2(g) = CO_2(abs)$
- Liquefaction $CO_2(g) = CO_2(l)$
- Solidification $CO_2(g) = CO_2(s)$

no electrons involved

(includes membranes)

Chemical Separation

- Electrochemical pump
- Redox cycle

electrons transferred

ARPA-E CCUS Projects

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2	abs	Codexis	$4.7
3	abs	Nalco	$1.6
4	abs	GE	$3.7
5	abs	Prorifera	$1.2
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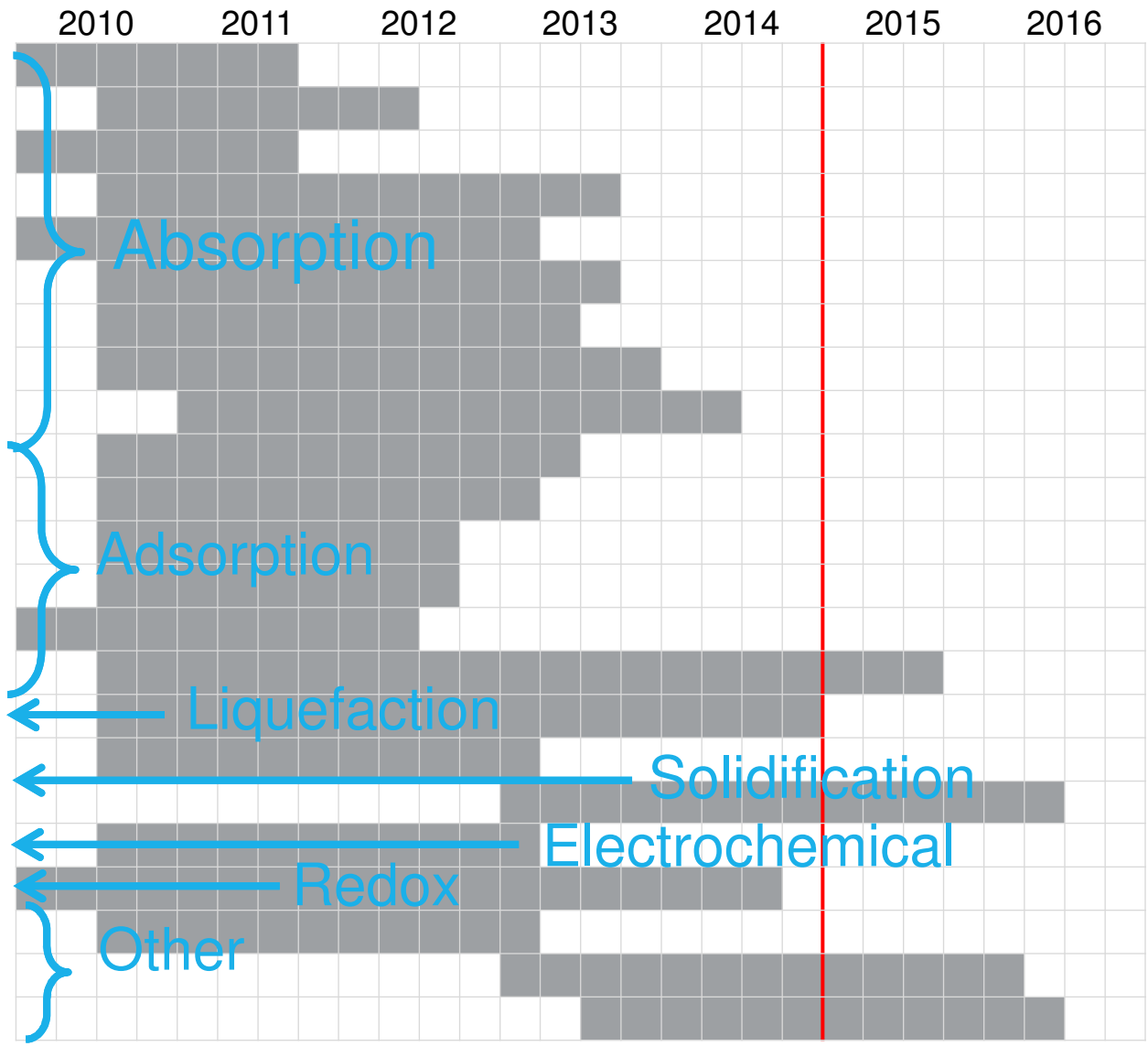

The Good

NETL Handoffs

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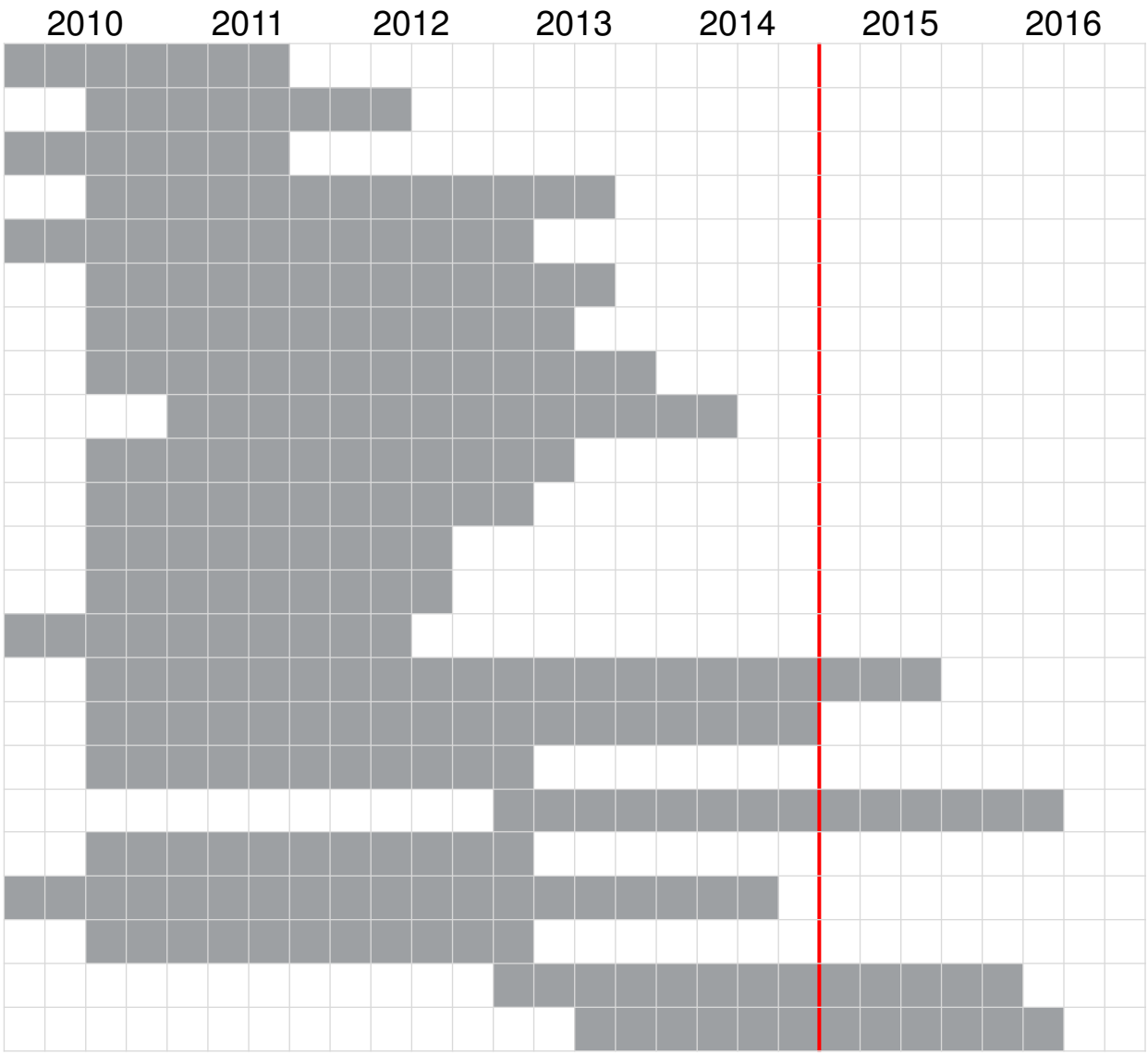

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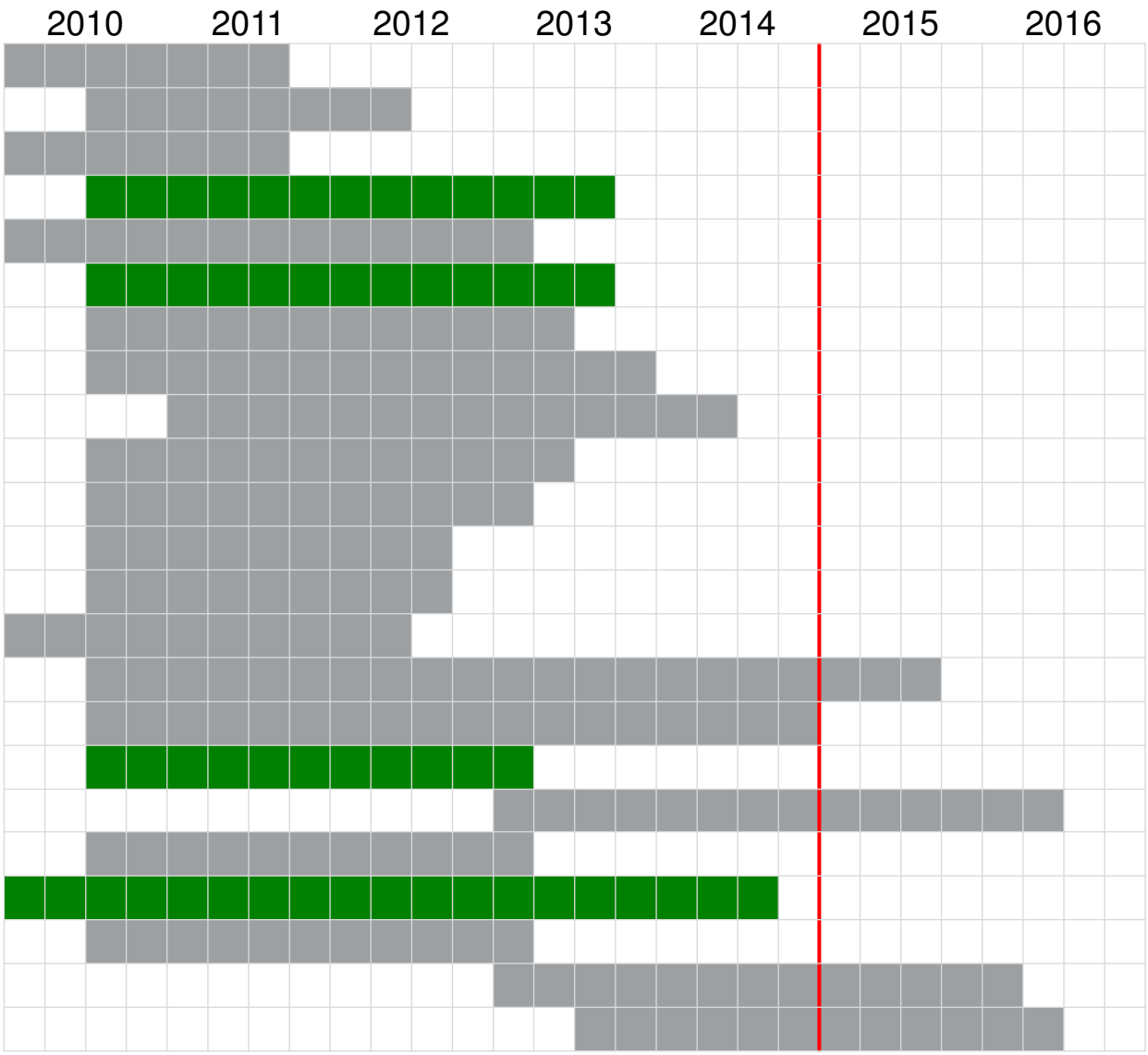


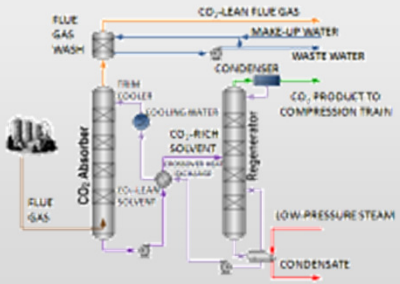
Project Handoffs

Supersonic Carbon Capture

ATK and ACENT Labs took an aerospace problem, supersonic condensation, and turned it into a viable clean energy solution for carbon capture that could reduce the cost of carbon to under $35/ton

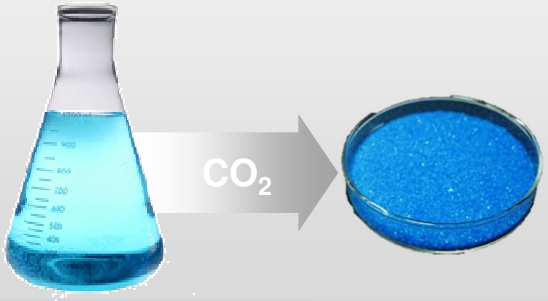
Non-Aqueous CO_2 Solvent

RTI developed an aqueous solvent system that removes CO_2 from flue gas with the potential to reduce the CO_2 capture energy to under 2000 kJ/kg_{CO2}—reducing parasitic power to less than 20%

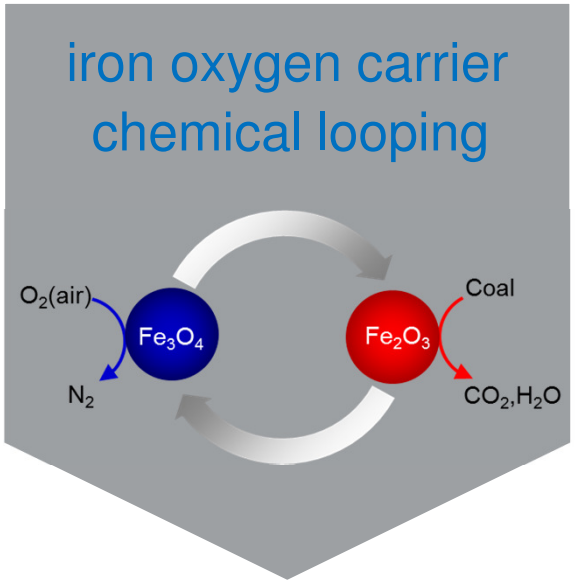


Liquid-to-Solid CO_2 Absorbent

GE and U Pitt developed a liquid absorbent that changes to solid upon contact with CO_2 and once in solid form, the material can be easily separated—reducing parasitic power to less than 10% ($24/ton)



Ohio State – Chemical Looping Process



est. 60% efficient
8 ¢/kWh

partners

ARPA-E Plus-Ups

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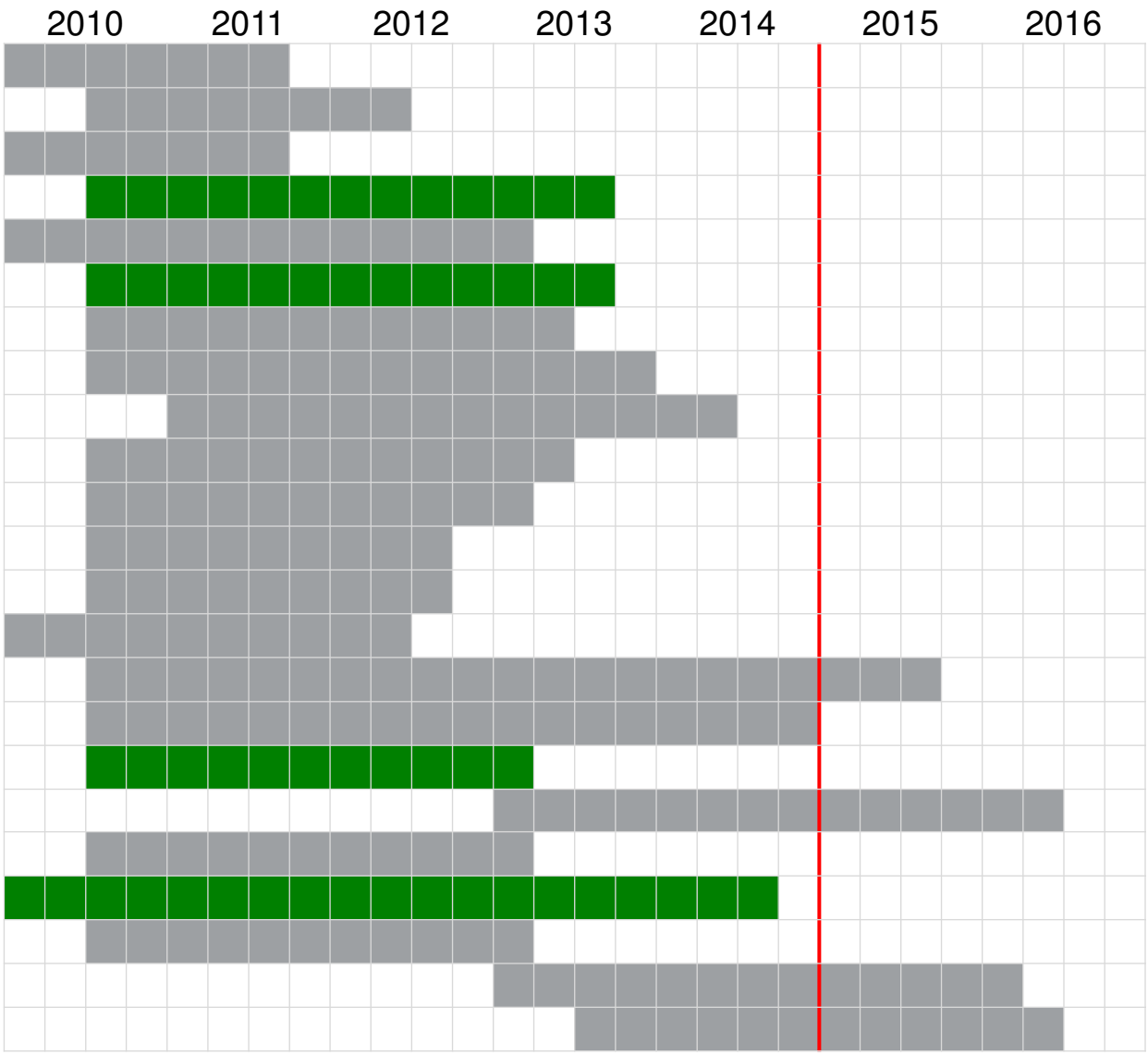

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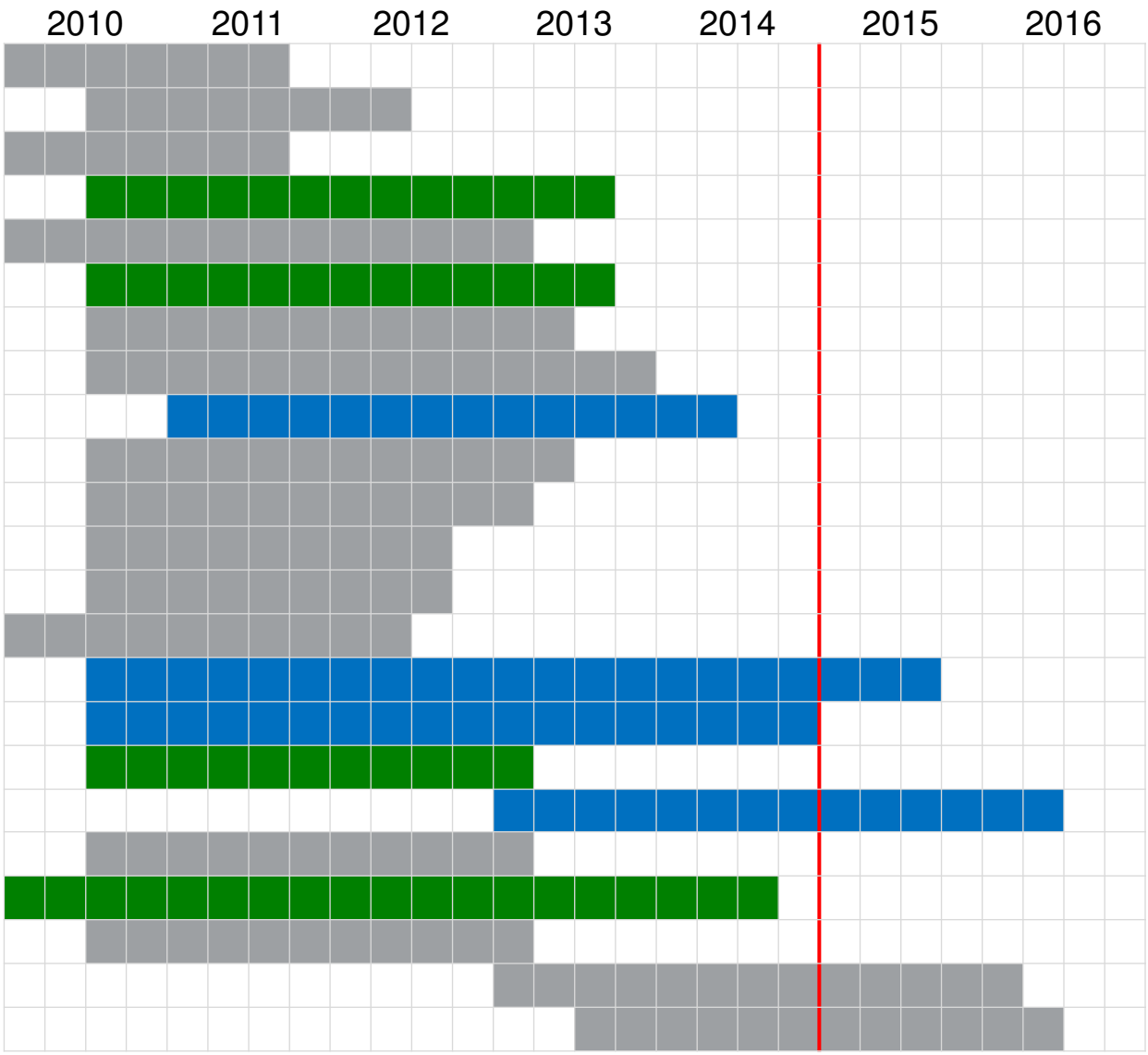

The Bad

Cancelled

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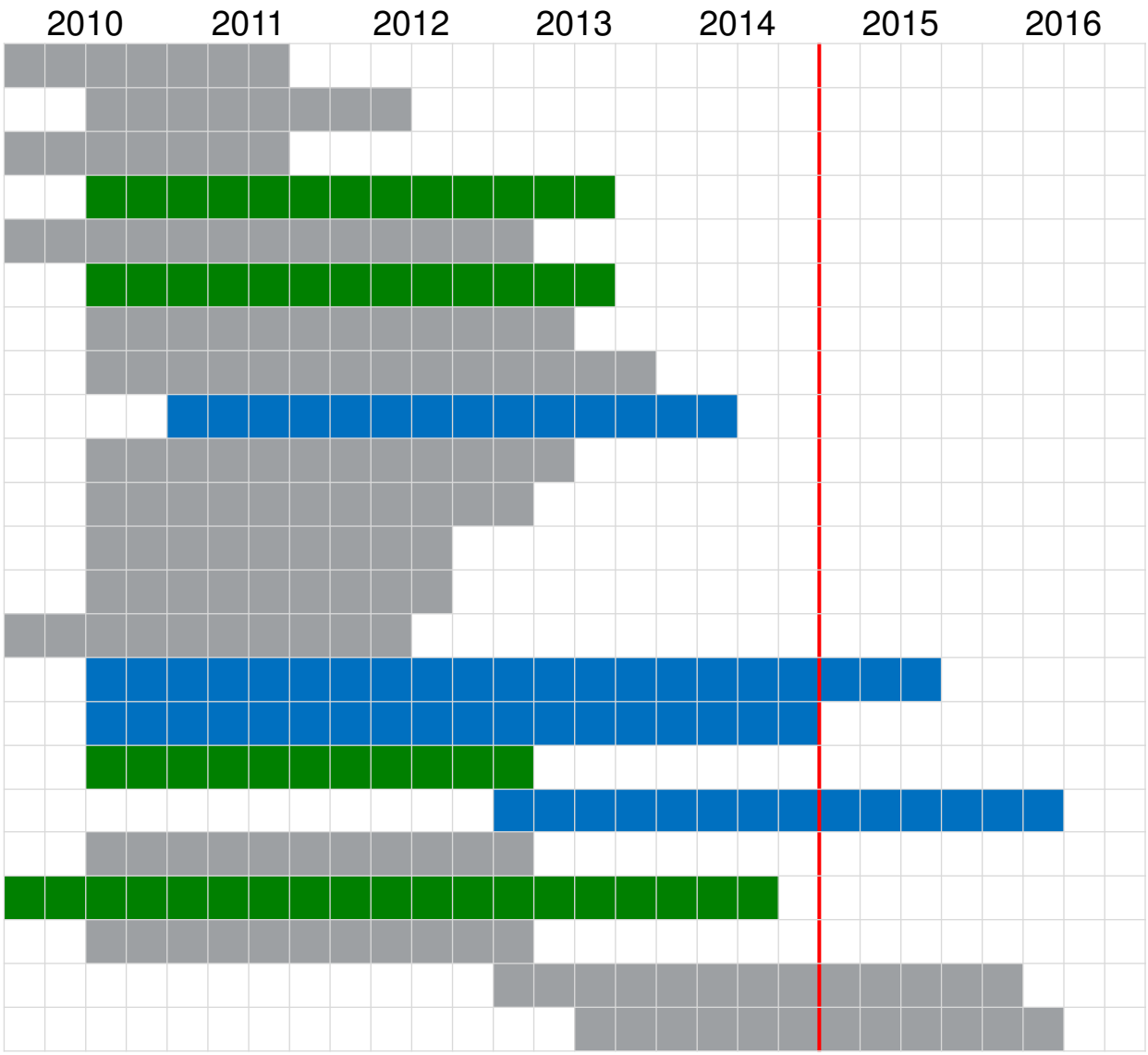

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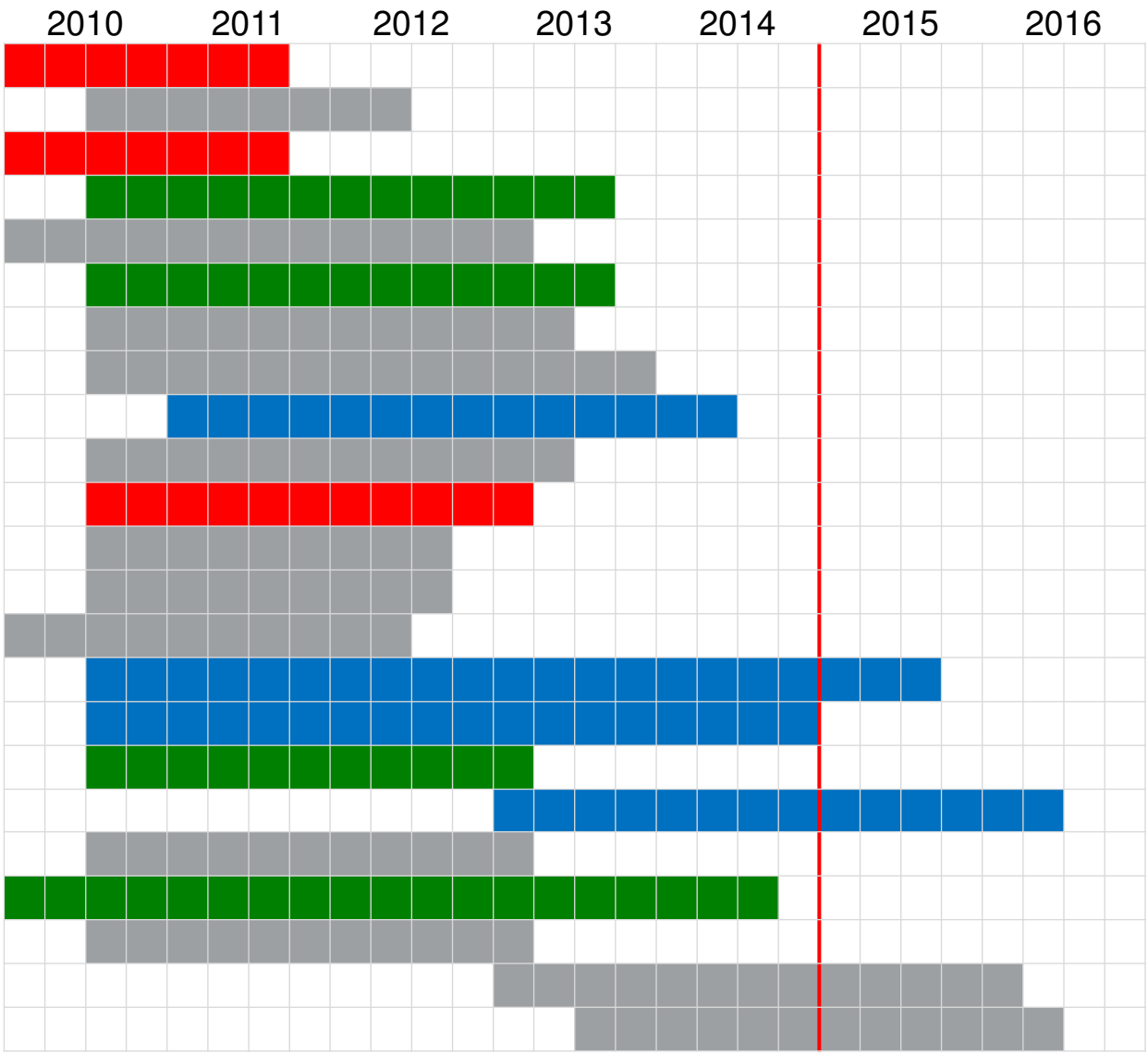

The Ugly

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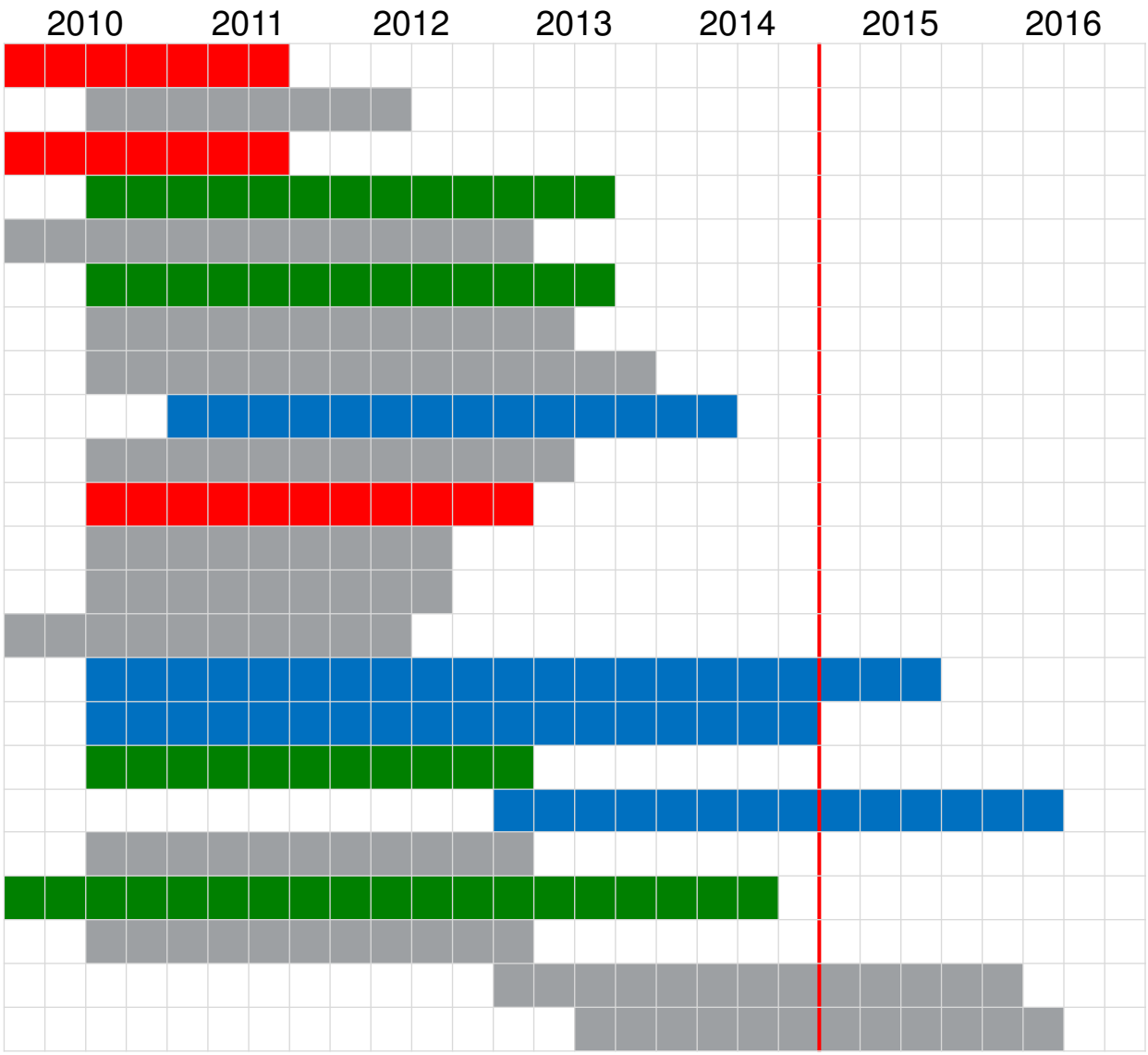

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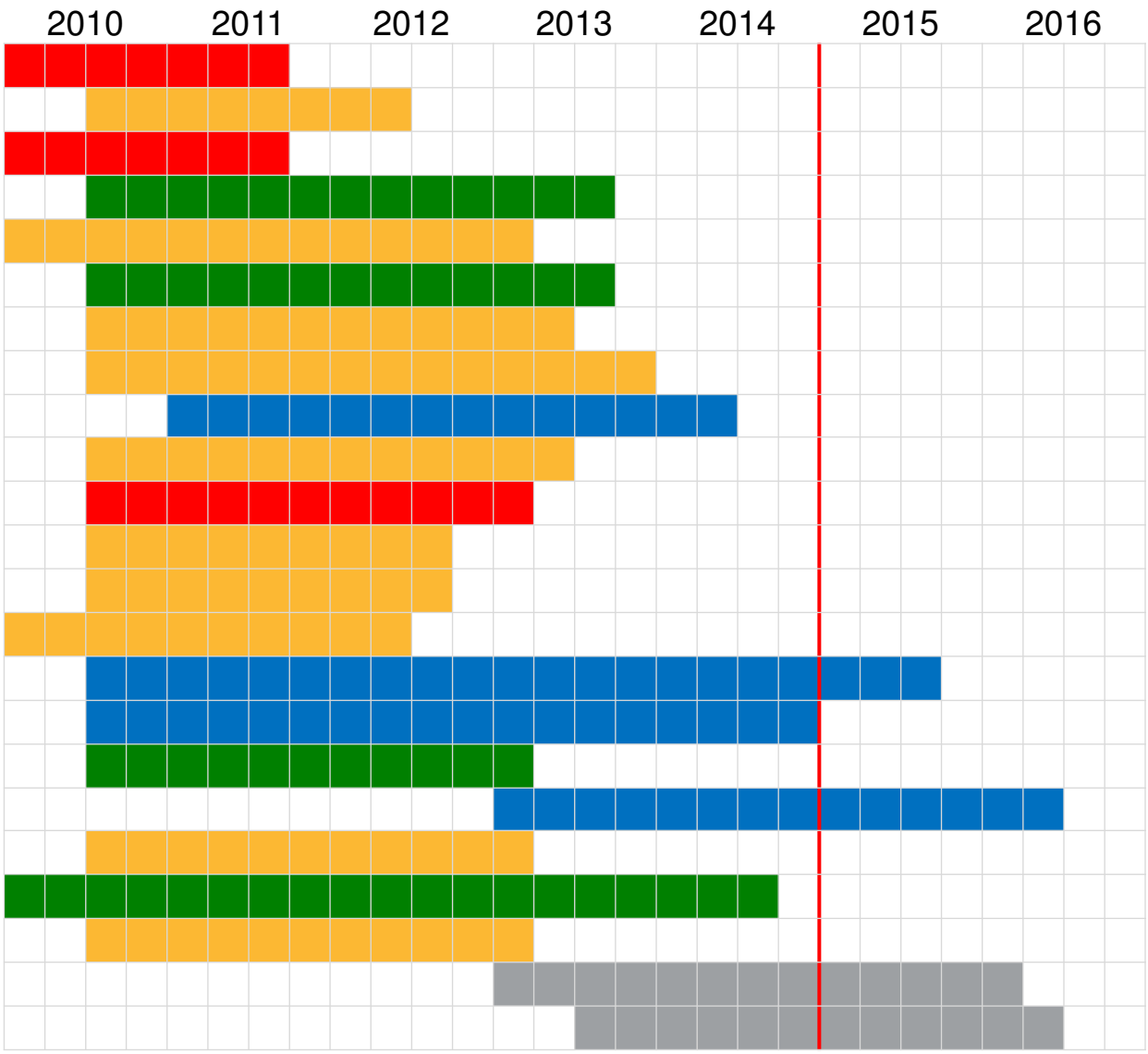

What’s left?

Current Projects

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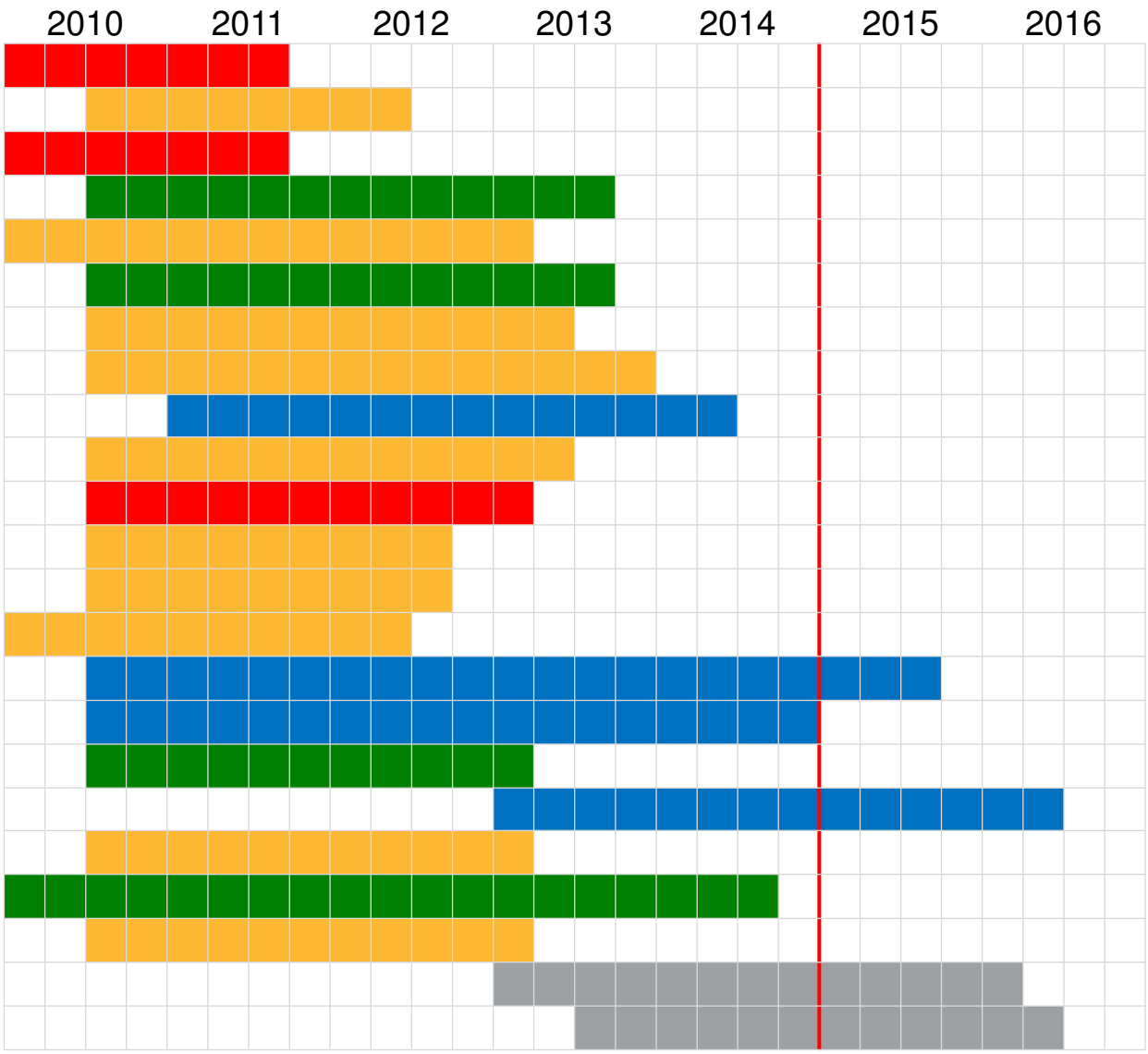

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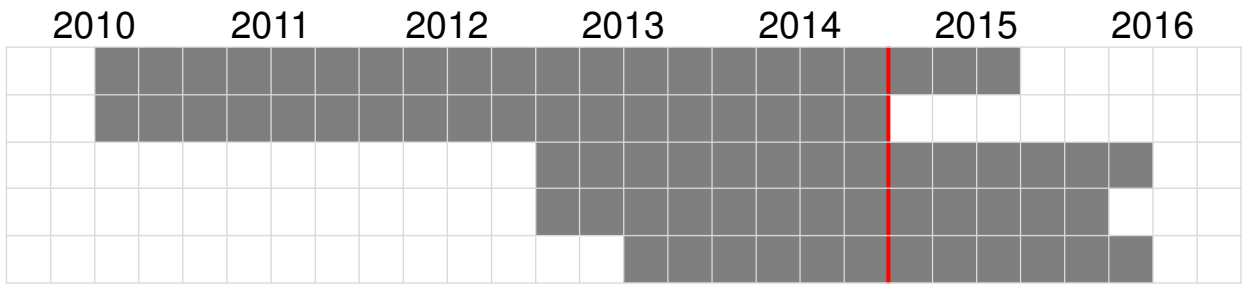


UC Berkeley	adsorbent
SES	cryogenic
ASU	electrochemical
Dioxide Materials	CO_2 to fuel
U Pittsburgh	EOR

UC Berkeley – Atomically Engineered Adsorbents

Innovation

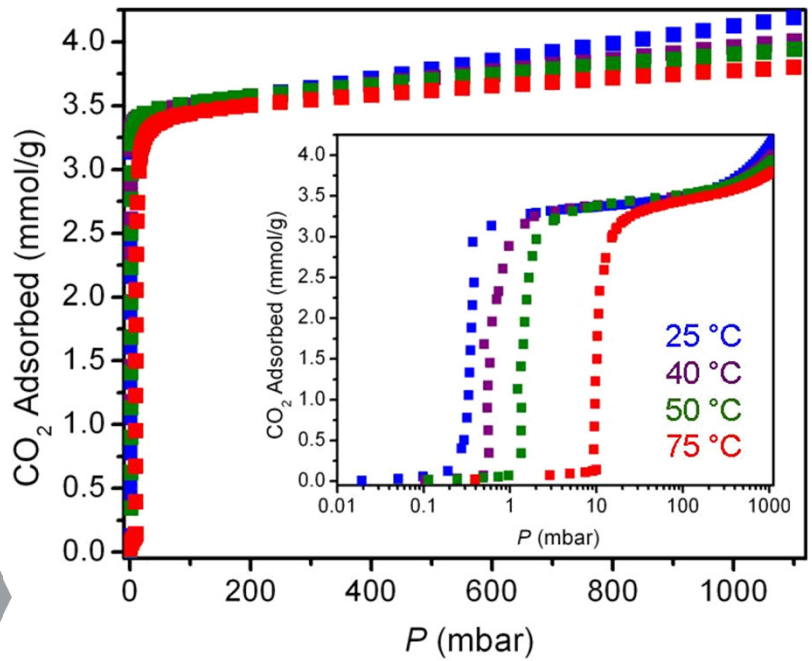
(1) High throughput synthesis,
(2) Non-classical MOF adsorbents

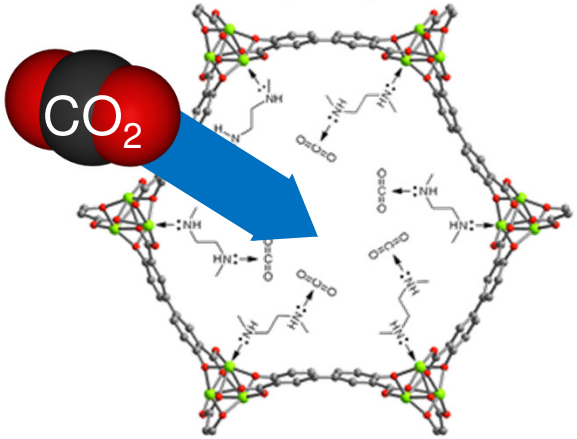
Challenge

(1) Low-cost, large scale material synthesis
(2) System design and demonstration

Impact

Potential to reduce parasitic energy for carbon capture by 50% and achieve LCOE that approaches 12¢/kWh





mmen-Mg_2(dobpdc) + CO_2

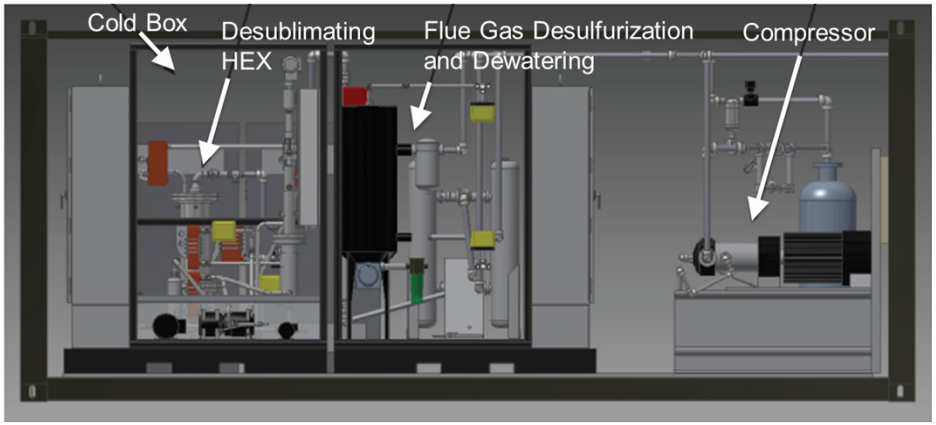
University of California, Berkeley
PI: Jeffrey Long
Award: $5.0M
POP: 7/10 to 9/15

McDonald, Lee, Mason, Wiers, Hong, Long *J. Am. Chem. Soc.* **2012,** *134*, 7056

SES – Cryogenic Carbon Capture

Innovation

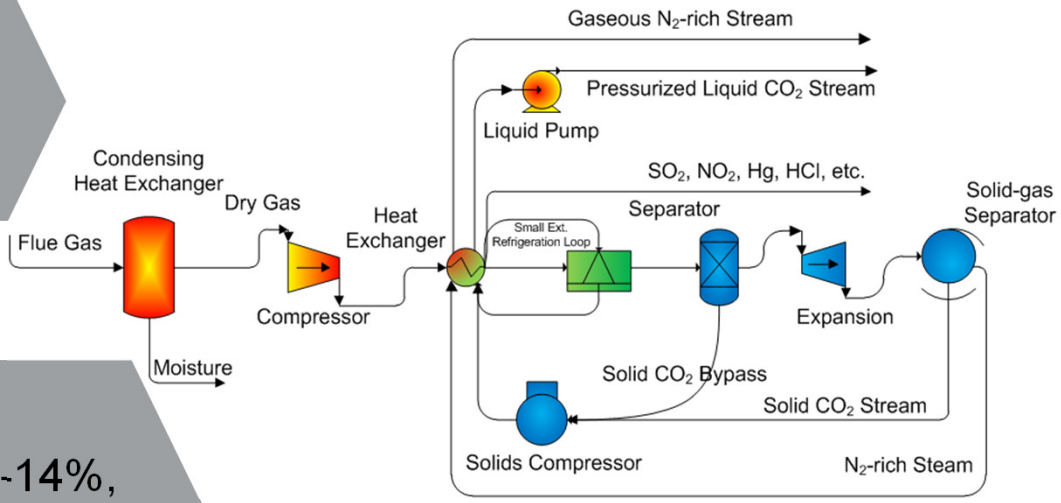
Capture CO_2 as solid and deliver as a liquid to avoid compression cost



20' shipping container

Challenge

Low cost, high efficiency heat exchange



Impact

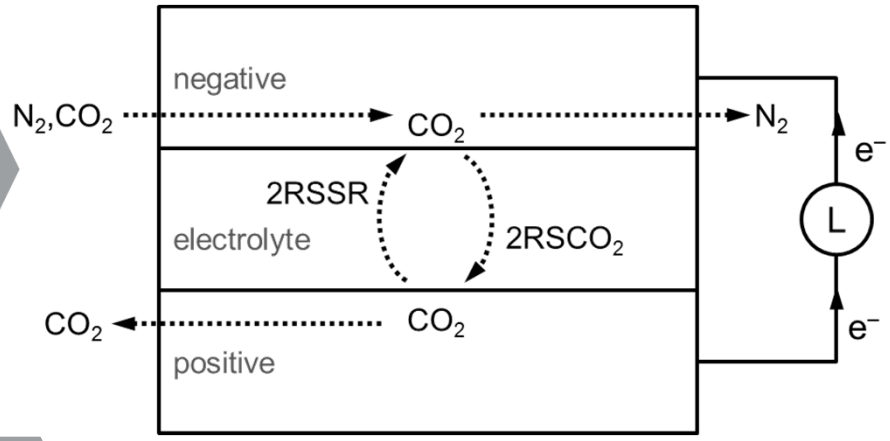
Estimated parasitic load 11-14%, increase COE ~40%, LCOE ~ 11 ¢/kWh

Sustainable Energy Solutions
PI: Larry Baker
Award: $5.3M
POP: 7/10 to 1/15

ASU –Electrochemical CO_2 Separation

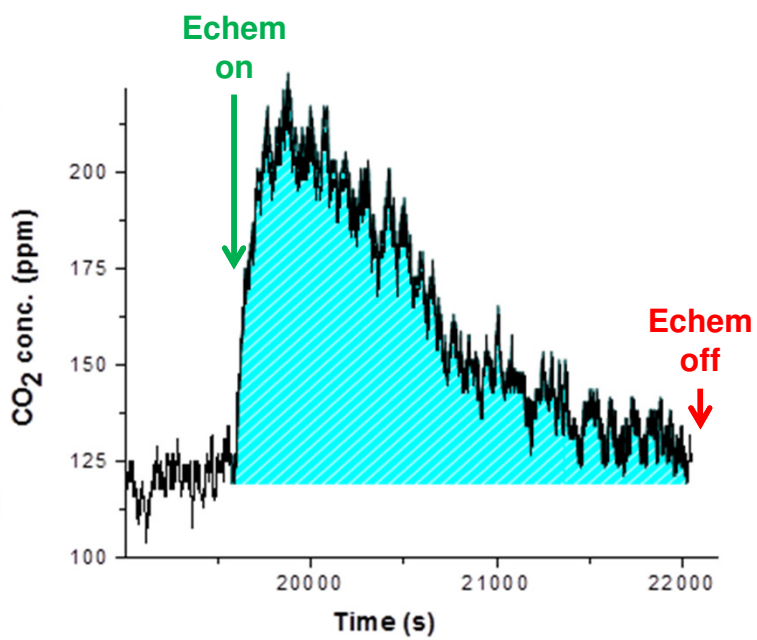
Innovation

Electrochemical pumping of CO_2 for post-combustion carbon capture



Challenge

High efficiency—must minimize charge transfer overpotentials—need fast electrode kinetics



Impact

Modular solution for carbon capture—pathway to carbon neutral cycle

Arizona State University
PI: Dan Buttry
Award: $3.8M
POP: 3/13 to 4/16

U Pittsburgh – CO_2 Thickners for EOR

Innovation

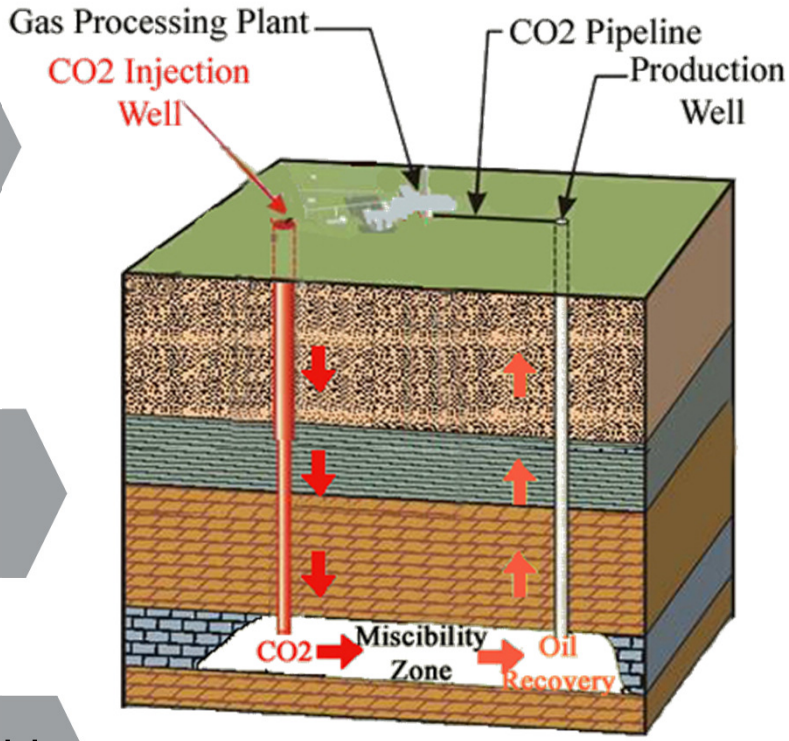
Compound that increases viscosity of liquid CO_2 to improve performance of enhanced oil recovery

Challenge

Low cost liquid CO_2 thickner

Impact

Improved performance could lower cost and increase the efficiency of EOR recovery, and enable CO_2 replacement of water-based recovery



University of Pittsburgh
PI: Robert M. Enick
Award: $2.4M
POP: 5/13 to 5/16

Dioxide Materials – CO_2 to Fuels/Chemicals

Innovation

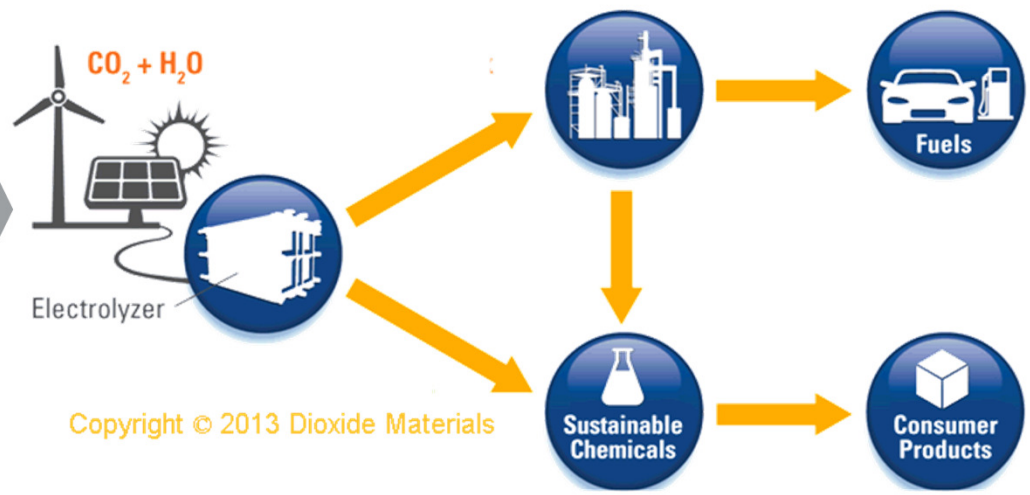
Electrolyzer used to convert CO_2 into C_1's then into fuels and chemicals

Challenge

Efficiency and cost

Impact

Pathway to carbon neutral fuel cycle



DIOXIDE MATERIALS™

3M

Dioxide Materials
PI: Dr. Rich Masel
Award: $4.0M
POP: 2/13 to 2/16

Is electrochemical capture of CO_2 from post-combustion power plants a realistic approach?

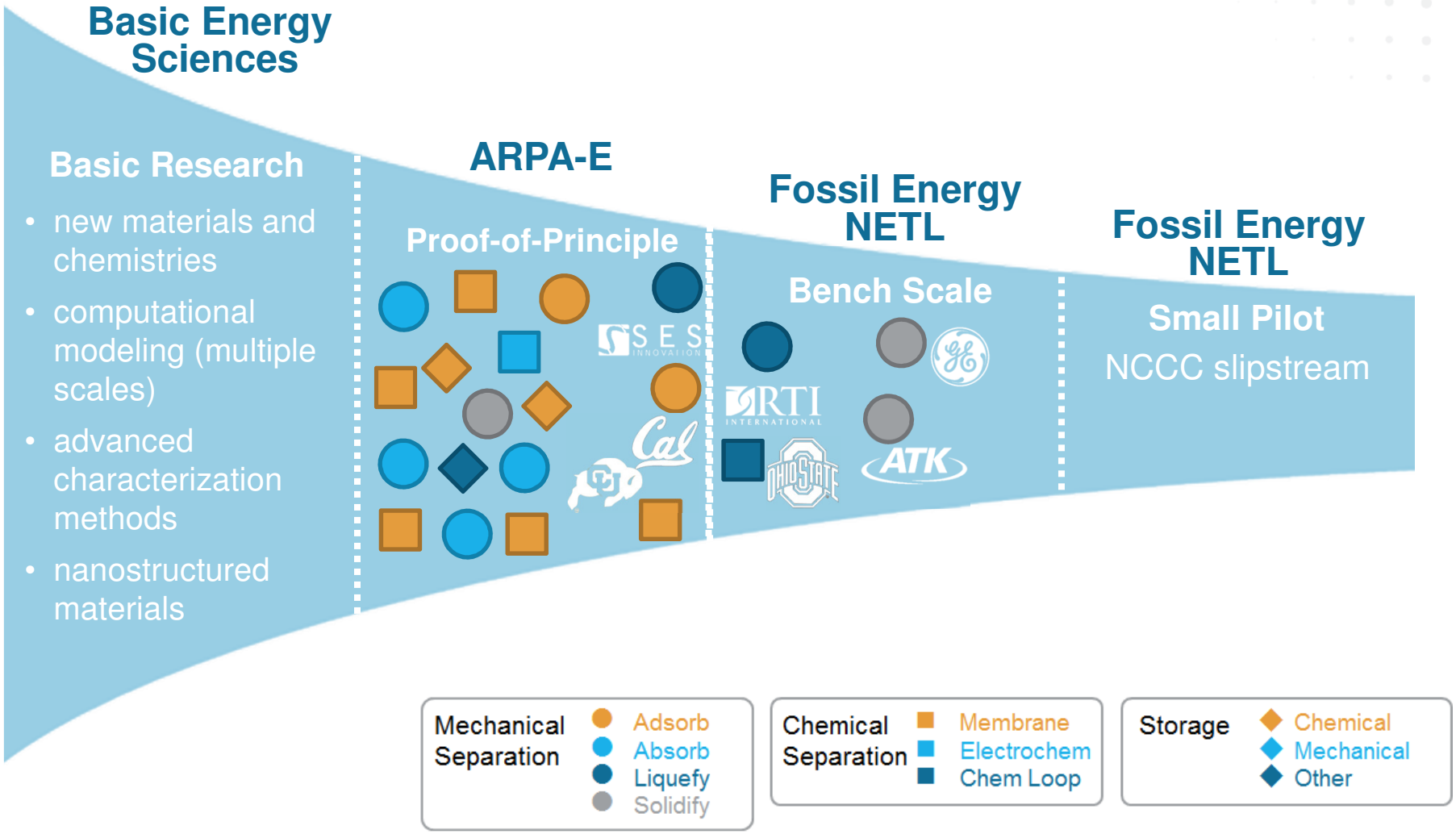
In my opinion, NO

electricity = high exergetic value
heat = lower exergetic value

lesson – if possible, use heat

Carbon Capture Technology Pipeline

U.S. DEPARTMENT OF ENERGY



IMPACCT Program Analysis

STRENGTHS

- Good collaboration with Fossil Energy/NETL
- Materials and processes with significantly lower parasitic energy
- Addresses one the most important problems in energy

WEAKNESSESS

- Too many Program Directors to have cohesive strategy
- No Program Director heir apparent

OPPORTUNITIES

- Nearest term potential to impact GHG levels
- CO2 separation for oil and gas production

THREATS

- Without price on carbon, no clear path to market
- Even without CCS pulverized coal power generation is not competitive with gas turbine power generation

What will ARPA-E do next in carbon capture?

Program Directors

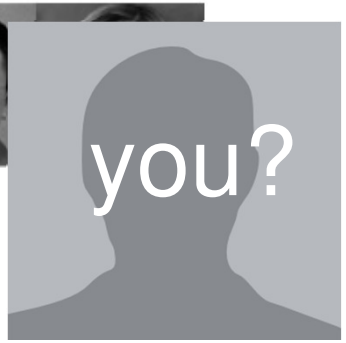
thought leadership, program creation,
active program management

2009 2010 2011

BEEST Electrofuels IMPACCT GRIDS REACT ADEPT SolarADEPT GENI BEETIT HEATS PETRO MOVE SBIR AMPED

2012 2013 2014

REMOTE Electrofuels II RANGE FOCUS METALS SWITCHES REBELS MONITOR



3-year term limited positions

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