BERKELEY LAB

Lawrence Berkeley
National Laboratory

carboncycle2.0

The Carbon Cycle 2.0 Initiative at LBNL: organizing with labs and industry to meet the demands society will have from science

Paul Alivisatos
Director, Lawrence Berkeley National Laboratory

January 31, 2012

A two minute primer on the DOE National Labs

AMES LABORATORY

Argonne
NATIONAL
LABORATORY

BERKELEY LAB
Lawrence Berkeley
National Laboratory

BROOKHAVEN
NATIONAL LABORATORY

Fermilab

INL
Idaho National Laboratory

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Lawrence Livermore
National Laboratory

Los Alamos
NATIONAL LABORATORY

NETL

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

OAK RIDGE
National Laboratory

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

PPPL
PRINCETON PLASMA
PHYSICS LABORATORY

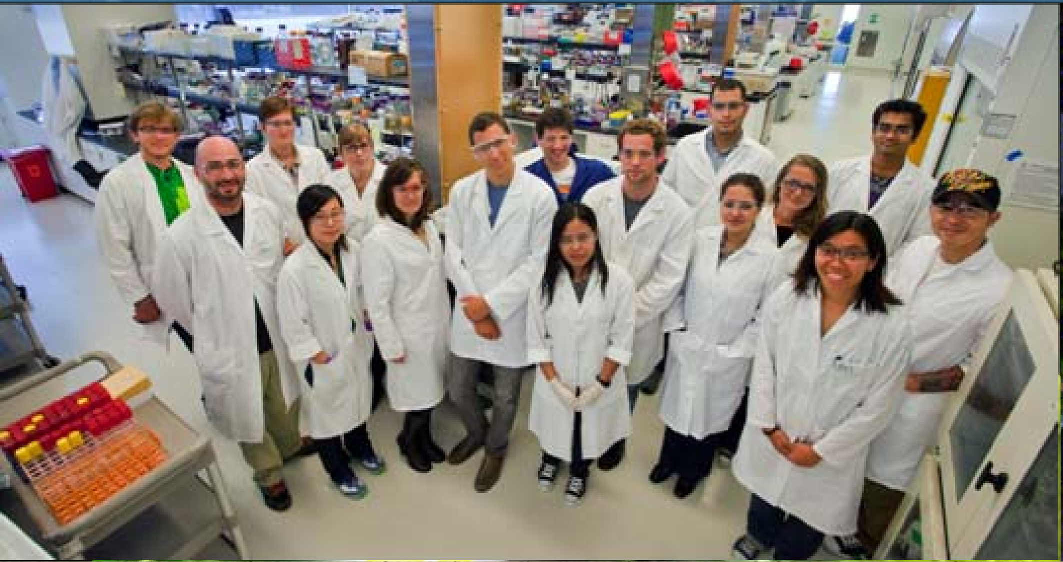
Sandia
National
Laboratories

SLAC
STANFORD LINEAR ACCELERATOR CENTER

SRNL
SAVANNAH RIVER NATIONAL LABORATORY
™

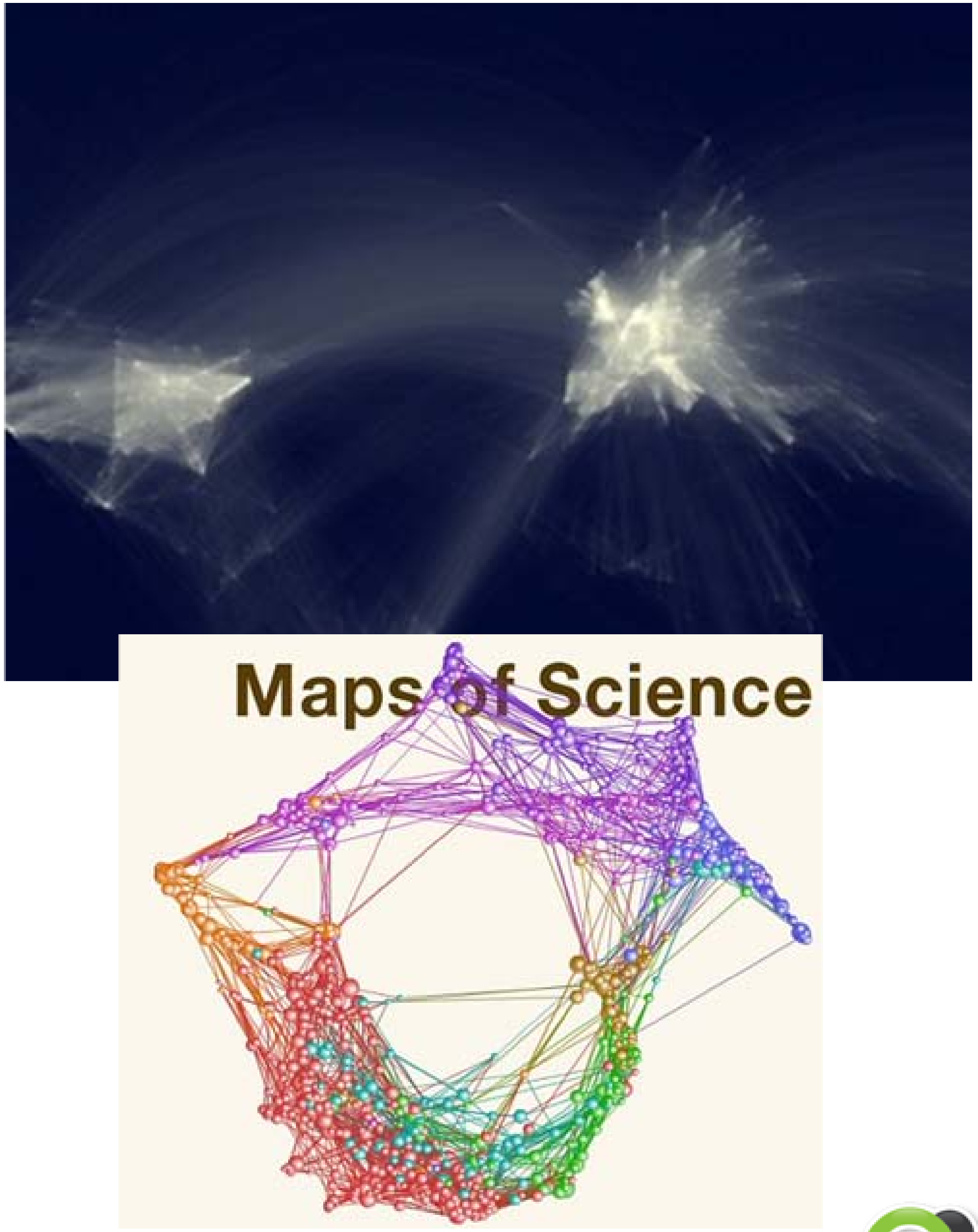
Lawrence’s Big Team Science in 1931

DOE National Labs Today: Special Teams, Unique Facilities

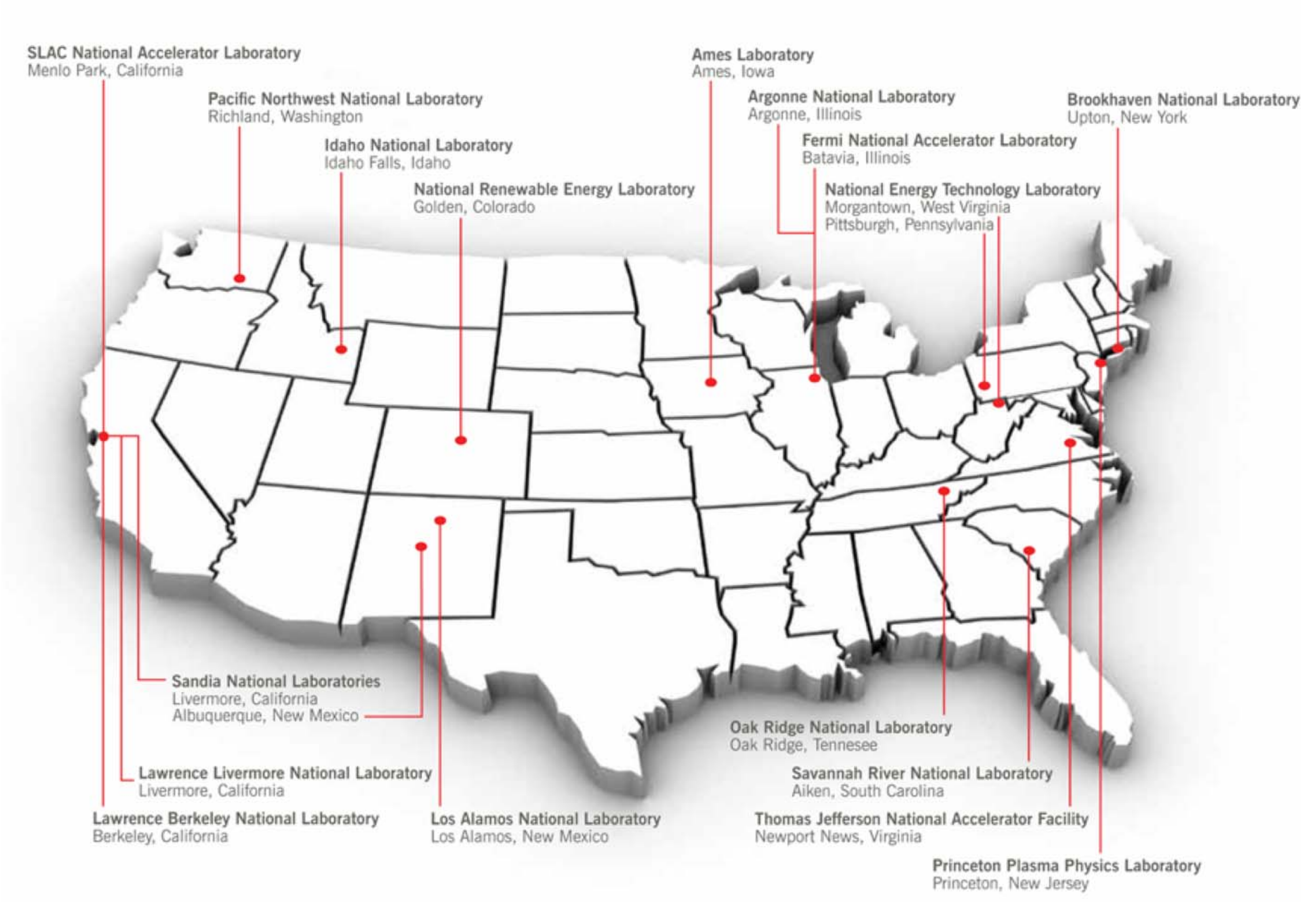


Today Science teams connect the world

- Cutting edge science *requires* teams working across multiple disciplines
- *International* teams are now the norm
- Global connectivity enhances cooperation and gives competitive advantage to those who embrace it
- Society is more dependent upon science
- More industry partnerships with public research institutions could accelerate innovation in the U.S.

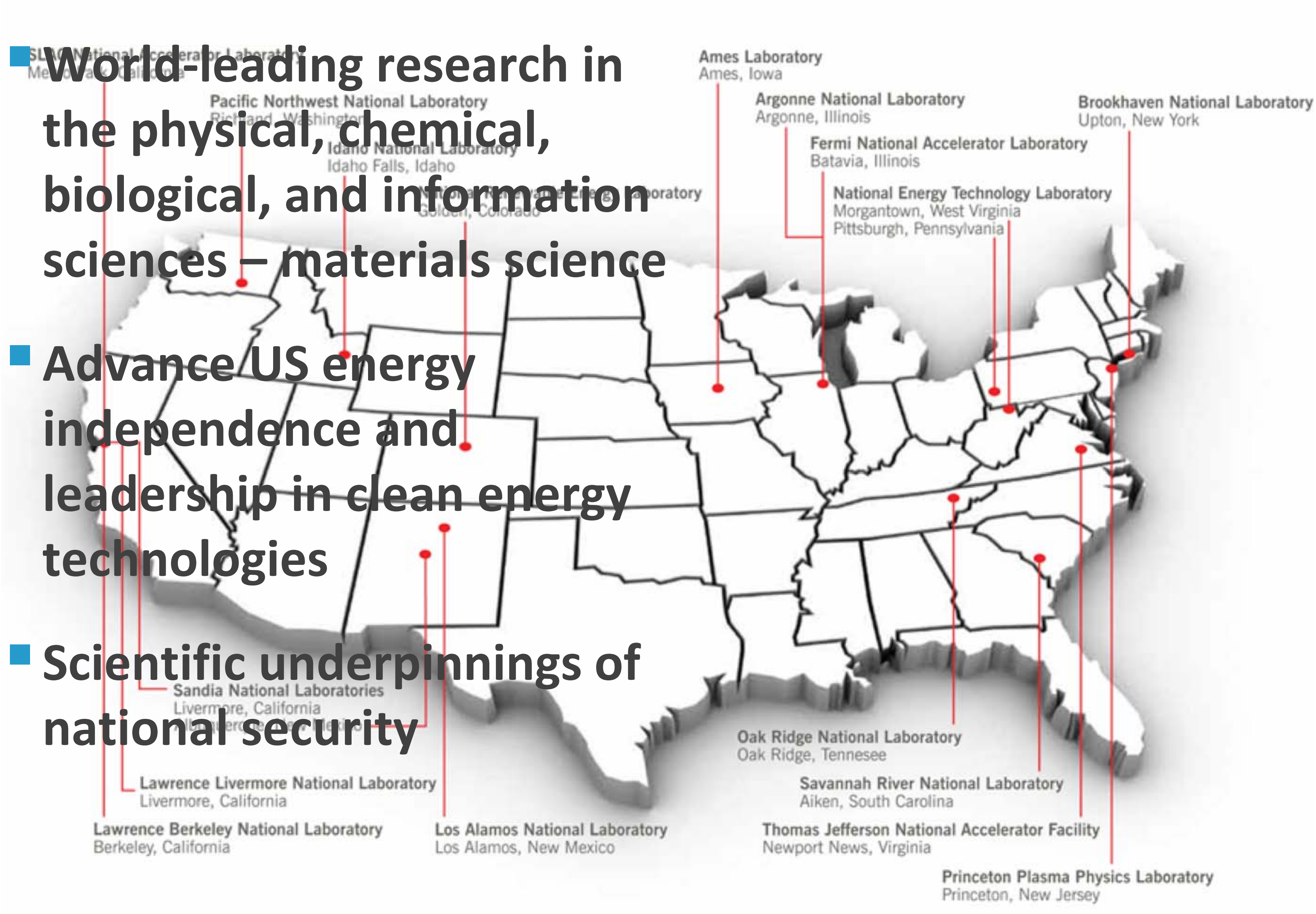


The DOE National Labs

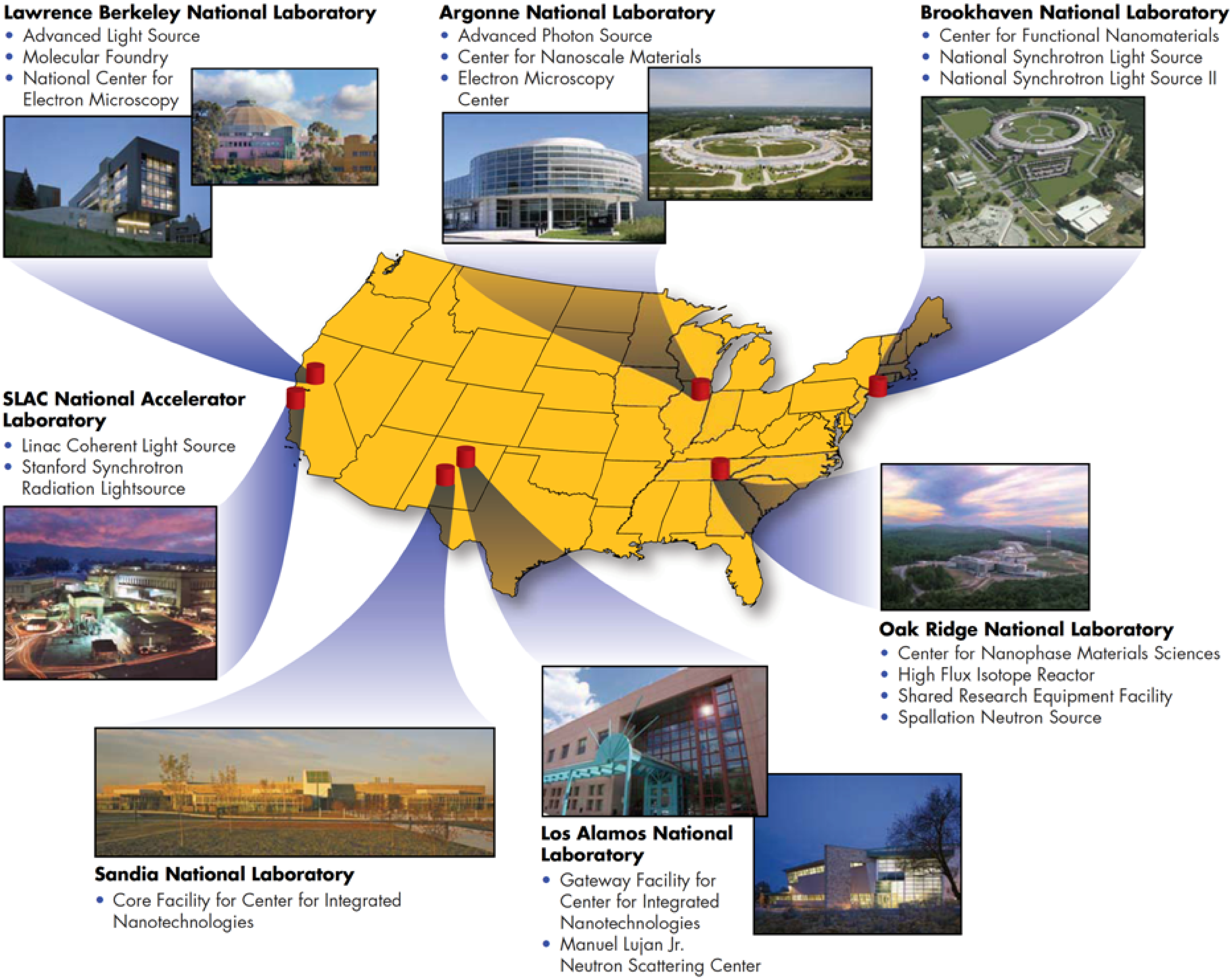


The National Labs:
Strategic Portfolio for DOE Missions

- World-leading research in the physical, chemical, biological, and information sciences – materials science
- Advance US energy independence and leadership in clean energy technologies
- Scientific underpinnings of national security



World class user facilities at the National Labs



Lawrence Berkeley National Laboratory
- Advanced Light Source
- Molecular Foundry
- National Center for Electron Microscopy

Argonne National Laboratory
- Advanced Photon Source
- Center for Nanoscale Materials
- Electron Microscopy Center

Brookhaven National Laboratory
- Center for Functional Nanomaterials
- National Synchrotron Light Source
- National Synchrotron Light Source II

SLAC National Accelerator Laboratory
- Linac Coherent Light Source
- Stanford Synchrotron Radiation Lightsource

Oak Ridge National Laboratory
- Center for Nanophase Materials Sciences
- High Flux Isotope Reactor
- Shared Research Equipment Facility
- Spallation Neutron Source

Sandia National Laboratory
- Core Facility for Center for Integrated Nanotechnologies

Los Alamos National Laboratory
- Gateway Facility for Center for Integrated Nanotechnologies
- Manuel Lujan Jr. Neutron Scattering Center

Synchrotron Light Sources

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Nanoscience Facilities

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High-performance computing and networking

Argonne National Laboratory

Berkeley Lab
Lawrence Berkeley National Laboratory

Oak Ridge National Laboratory

Los Alamos National Laboratory

Sandia National Laboratories

Lawrence Livermore National Laboratory

Powerful new means of harnessing nature's most sophisticated systems in plants and microbes for practical applications

BESC
BioEnergy Science Center

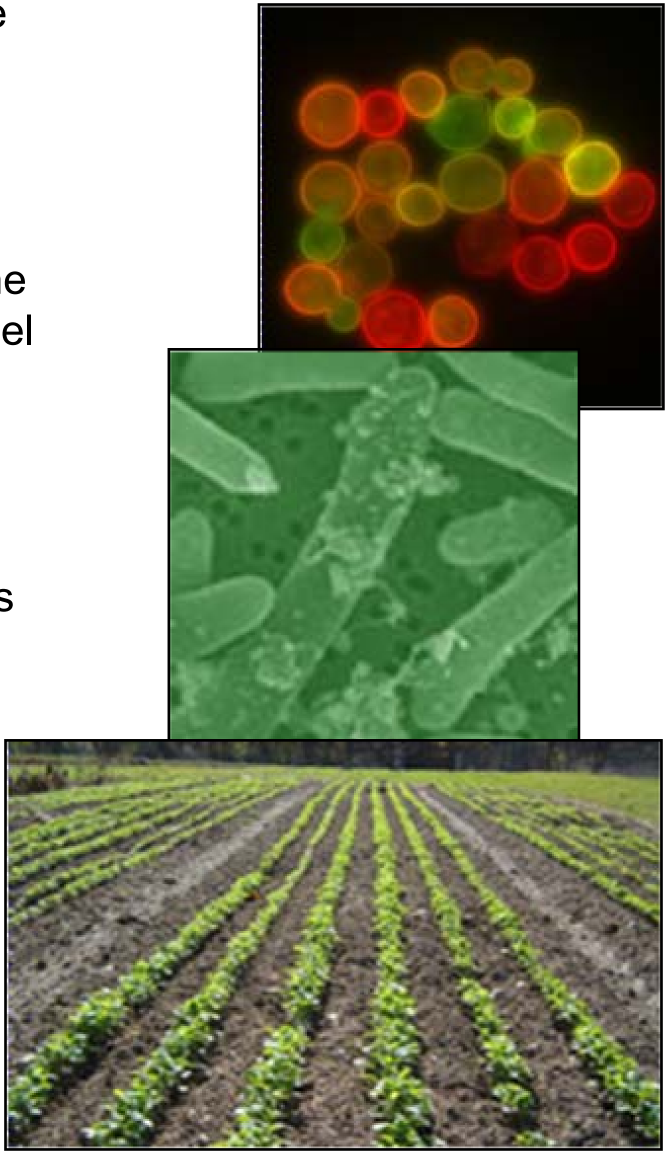
- Developed modified switchgrass that enable a 30% improvement in the yield of ethanol

jbei
Joint BioEnergy Institute

- Used synthetic biology toolkit to construct the first microbes to produce an advanced biofuel (biodiesel) directly from biomass.

GREAT LAKES
BIOENERGY
RESEARCH CENTER

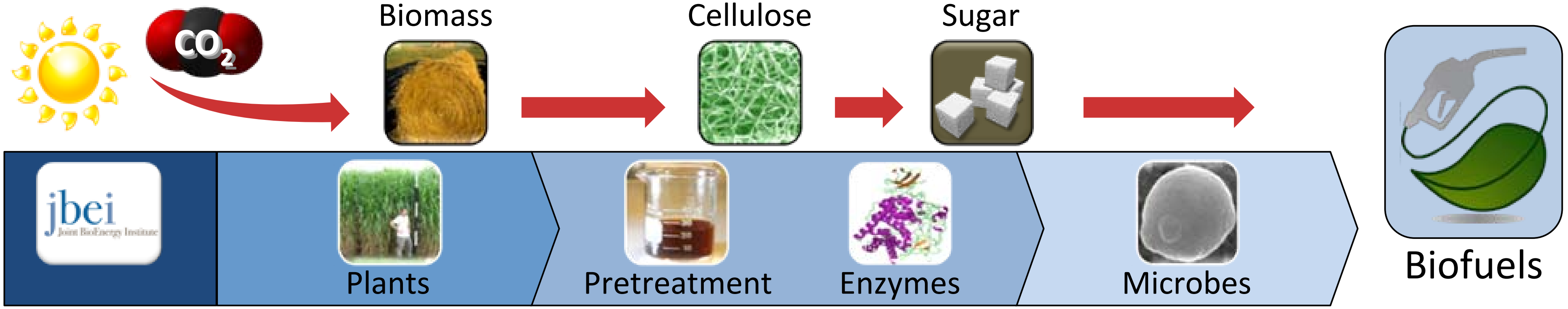
- Characterized impacts of biomass crop agriculture on marginal lands, studying shifts in microbial community and potential for changes in greenhouse gas emissions.



In the first three years of operations, the BRCs together had 66 inventions in various stages of the patent process, from disclosure to formal patent application, and over 400 peer-reviewed publications.

The JBEI Model

- **Mission:** Provide scientific basis for converting plants into renewable liquid transportation fuels that are compatible with existing and proposed engines and current fuel-distribution infrastructure.
- **Structure:** *Partnership of 4 national labs, 3 academic institutions*
- **History:** JBEI is one of three DOE Bioenergy Research Centers created in response to the Energy Independence and Security Act of 2007.
- **Budget:** $134M over 5 years by DOE's Office of Biological and Environmental Research (200 staff)



Mission & Science Achievements	Engineered Plants to Control Lignin Production	New Pretreatment Process to Completely	Microbes Produce Fuels Directly From Biomass	Tools for the Biofuels Research Community
Commercial Achievements	**88** Invention Disclosures Twice national average compared to other research institutes*	**29 (of 45)** Patent Applications in Licensing Negotiations Exceeds national academic standard*	**1** Patent **4** Licenses/Options **4** Startups Originating from JBEI	*Source: Association of University Technology Managers FY2009 survey of academic institutions, calculated per funding dollar

The Carbon Cycle 2.0 Initiative at Berkeley Lab

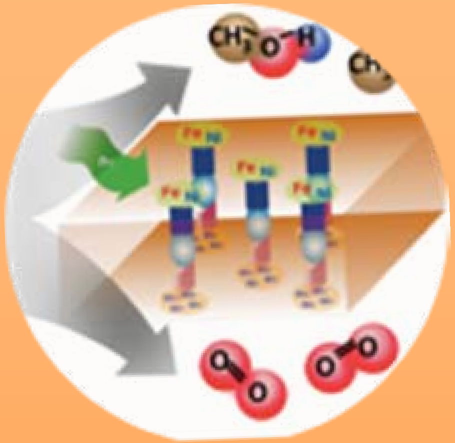
- What are key trends in the evolution of science as we move to 2030?
- How do we fit into the DOE National Lab system and work with industry?
- How can we organize to meet the demands society will have from science?

BERKELEY LAB
Lawrence Berkeley National Laboratory

carboncycle2.0

Societal needs for technical solutions to energy and environment problems will intensify

BERKELEY LAB



Nanoscience
will create advanced materials and designed systems

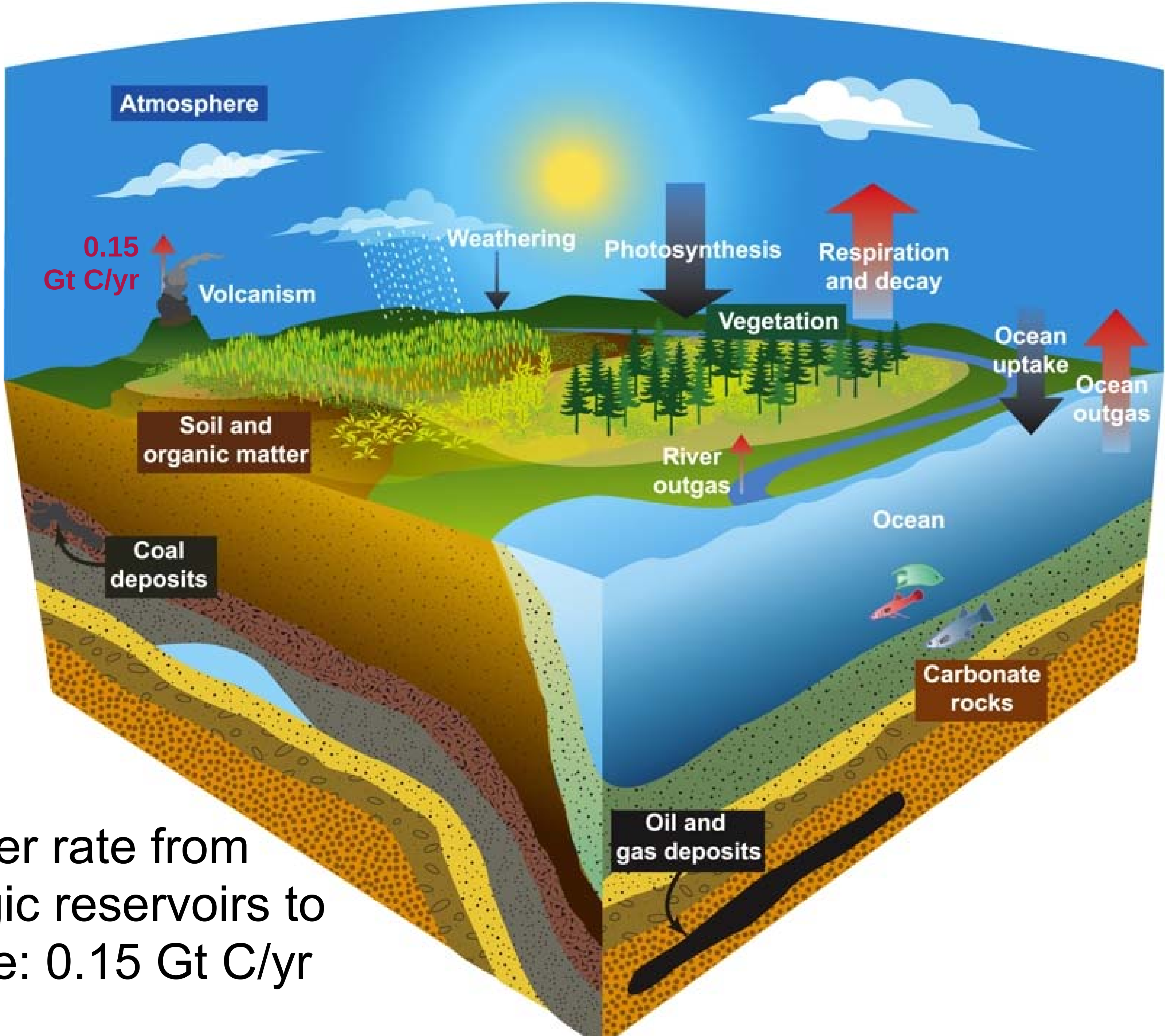
The biology revolution
will deepen and impact other disciplines

Reliance on computation
will expand while massive data sets will challenge

Physics Chemical Sciences Materials Science Mathematics

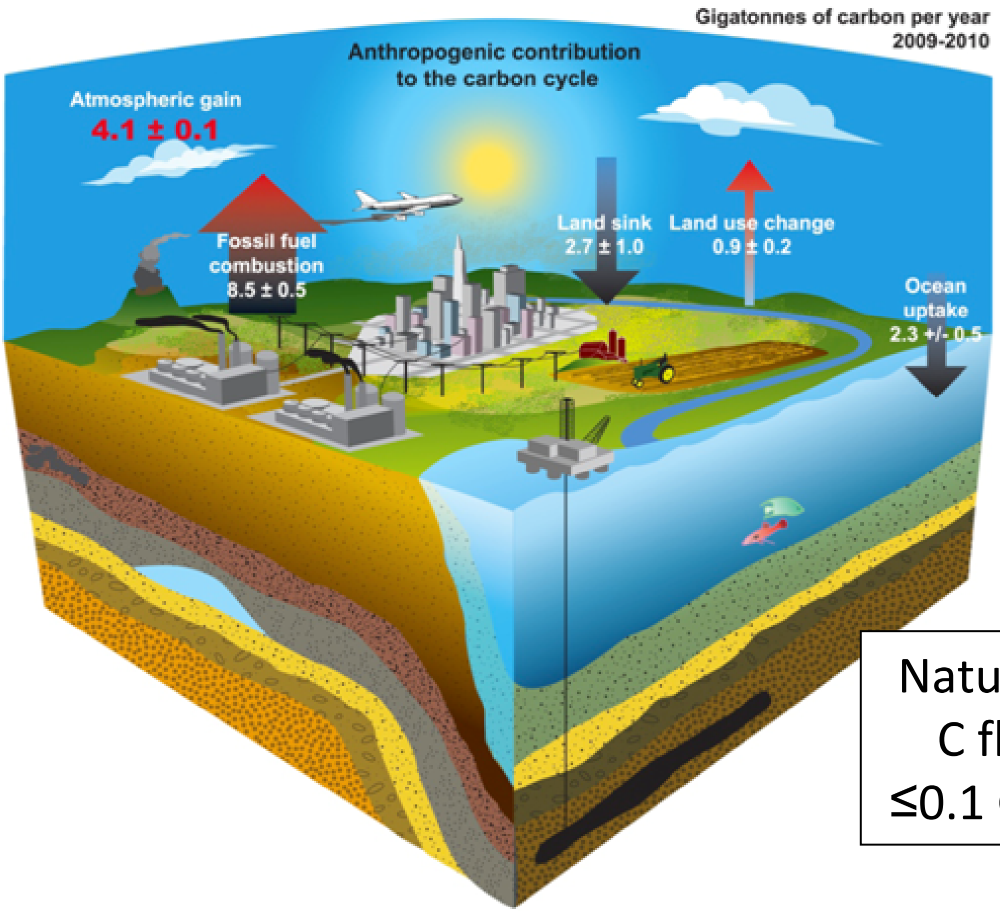
A Foundation of Basic Science

Carbon Cycle 1.0: Natural Carbon Cycle



Transfer rate from geologic reservoirs to surface: 0.15 Gt C/yr

Current *open-ended* C cycle
Carbon Cycle 1.x (2010 AD)

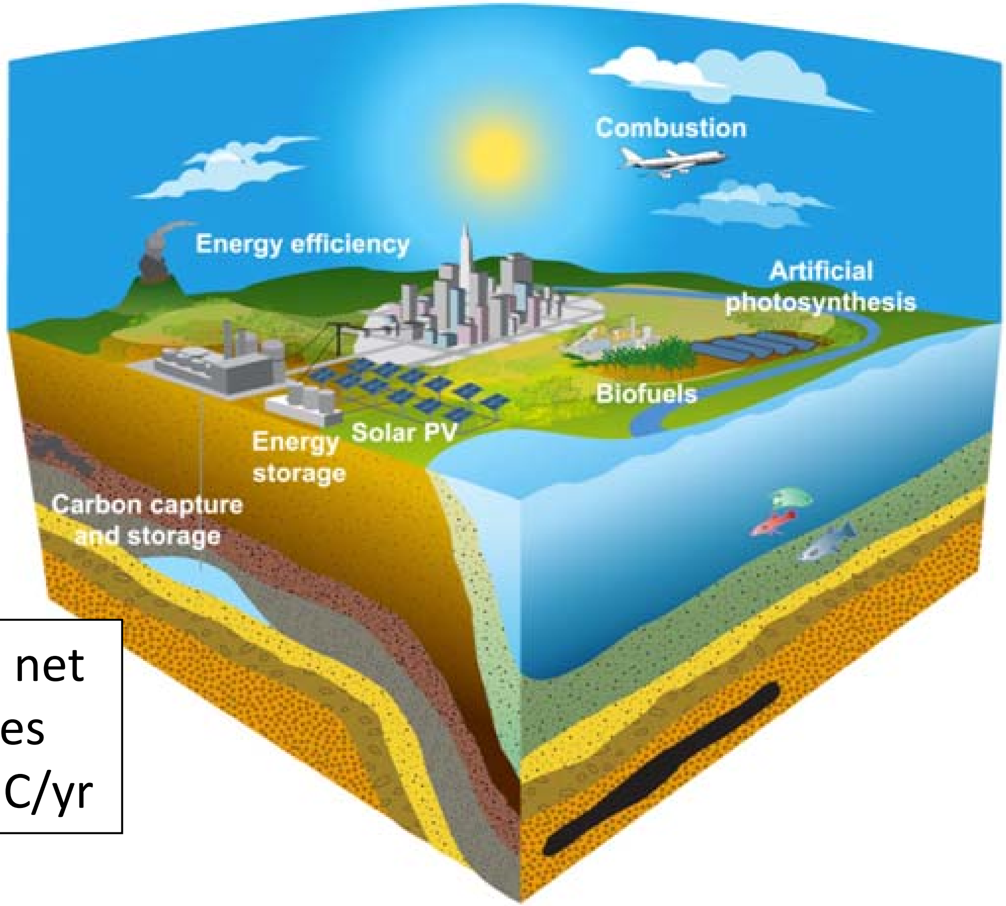


140 PWh/yr energy production
8.5 Gt/yr carbon emissions

60 Mt C / PWh

Natural net
C fluxes
≤0.1 Gt C/yr

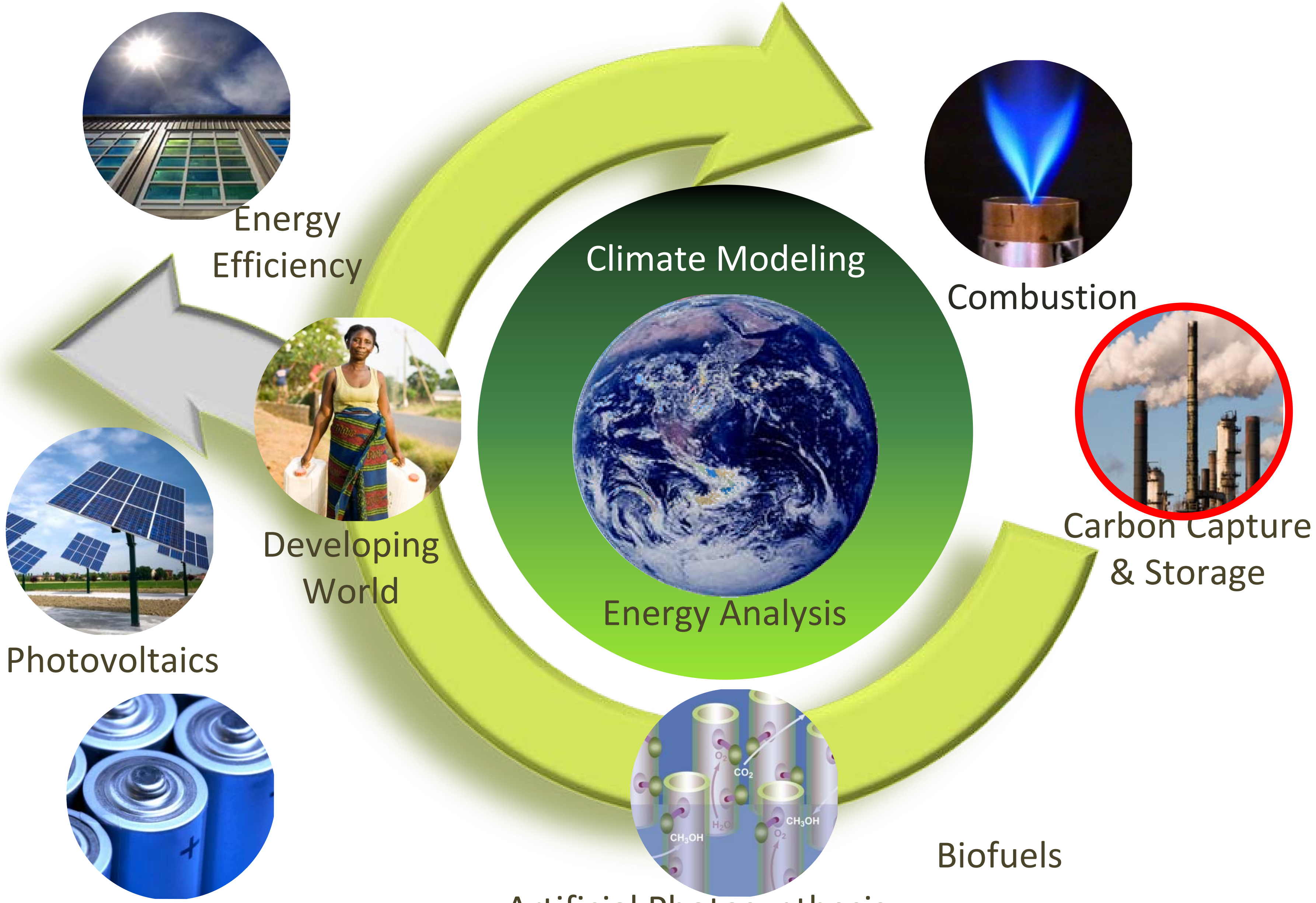
Future *balanced* C cycle
Carbon Cycle 2.0 (2100 AD?)



400 PWh/yr energy production
≤3 Gt/yr carbon emissions

7.5 Mt C / PWh

Carbon Cycle 2.0 at Berkeley Lab



Climate Modeling

Energy Analysis

Energy Efficiency

Developing World

Photovoltaics

Energy Storage

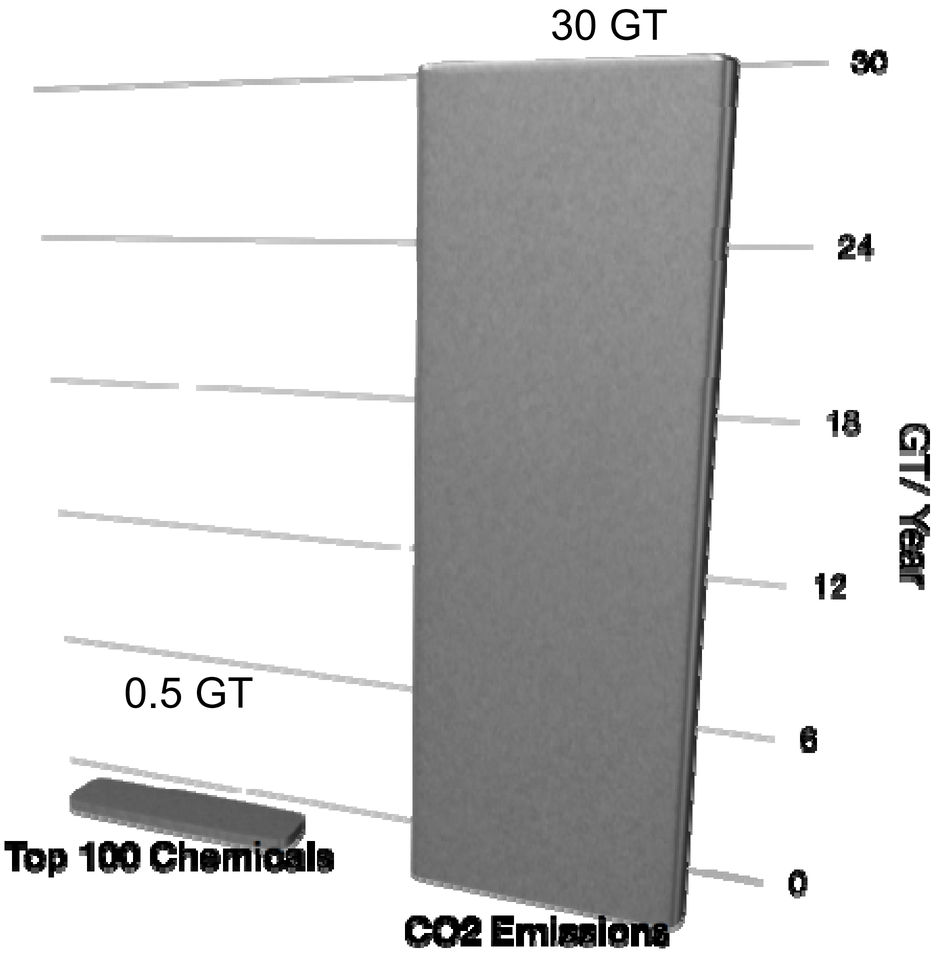
Combustion

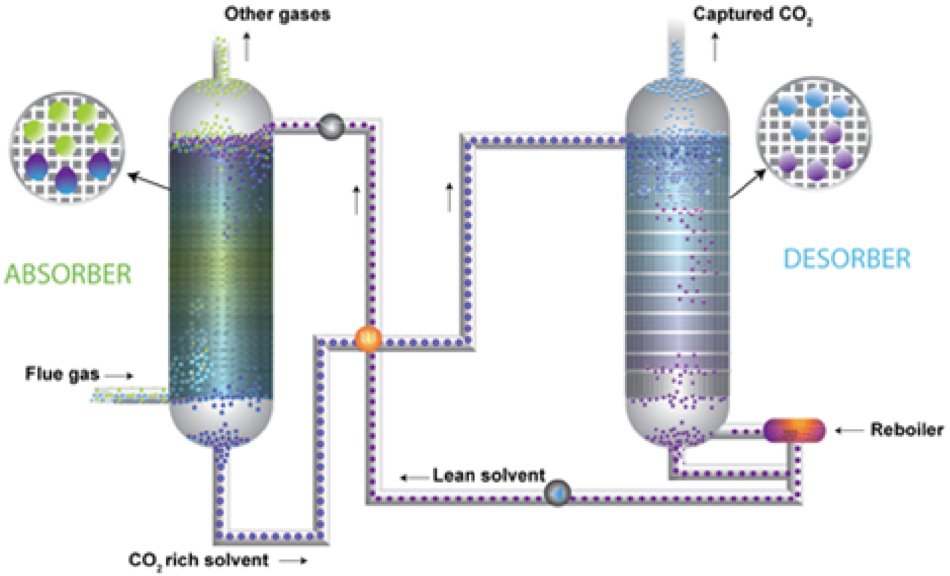
Carbon Capture & Storage

Biofuels

Artificial Photosynthesis

Carbon Capture and Sequestration - scale and scope of the problem

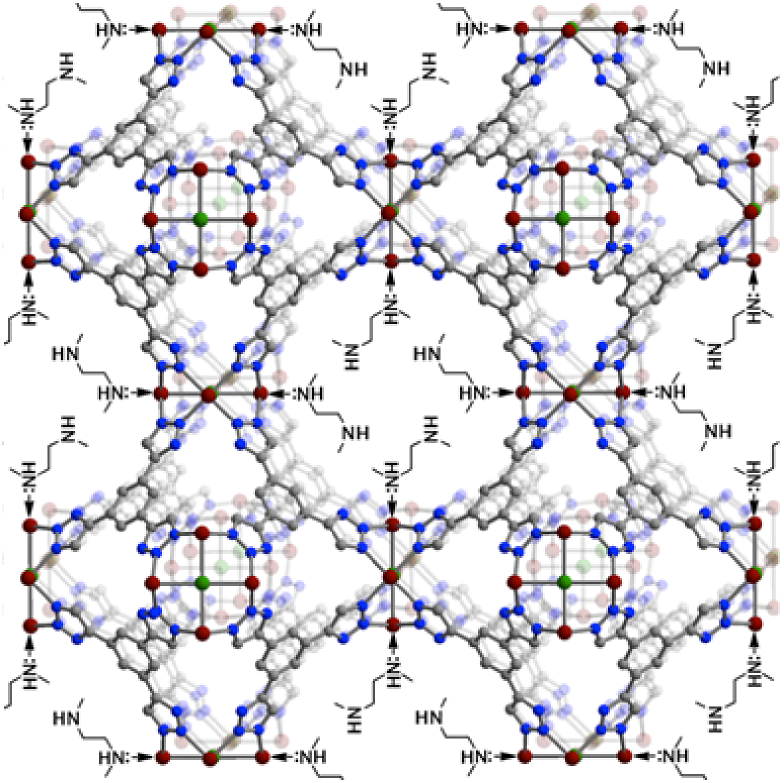




Current amine process energy intensive
~25% of the power of a plant required
~8¢/KWh

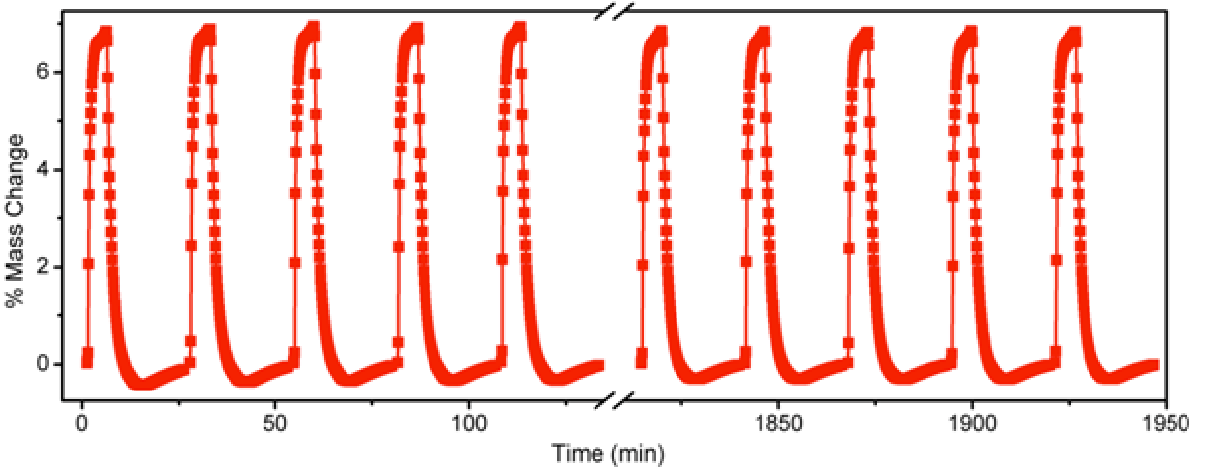
Carbon Capture - New materials

The challenge: develop a material that can capture and release vast quantities of CO_2 at 1/3rd today's cost of ~8¢/KWh



Metal Organic Frameworks

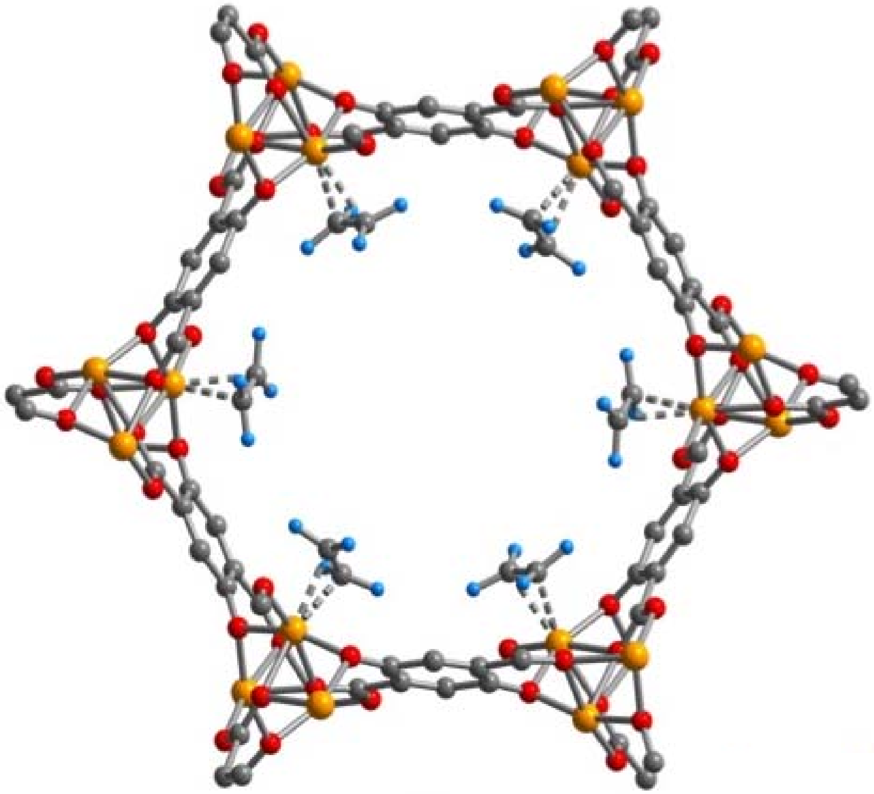
capture CO_2 w/ secondary alkylamines



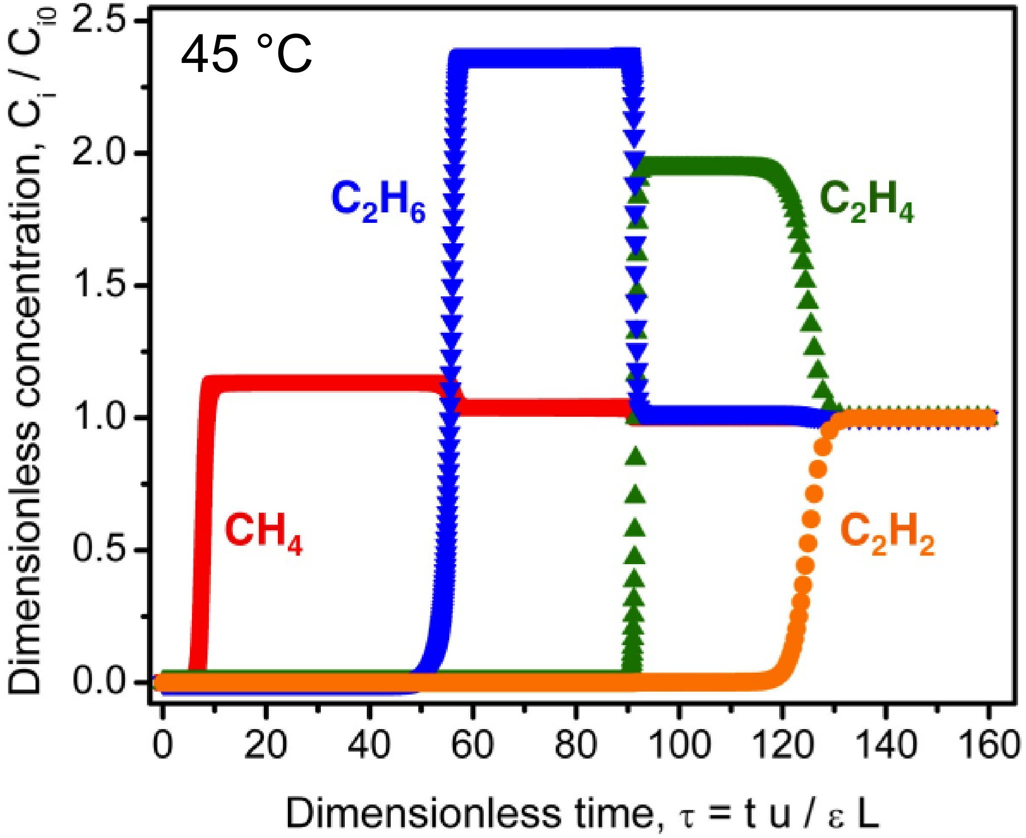
- 6.9 wt % cycling capacity for dry flue gas
  - Feed gas is 15% CO_2 in N_2
  - Adsorption within 5 minutes at 25 °C
  - Desorption within 5 minutes at 60 °C
- Per kg of CO_2 captured, regeneration energy is approximately one third of the energy required for 30% $MEA_{(aq)}$ solutions

Long, J. R. and coworkers. *Chem. Sci.* **2011**, *2*, 2022

Nanoscience will enable the design of new MOFs impacting a wide range of energy technologies



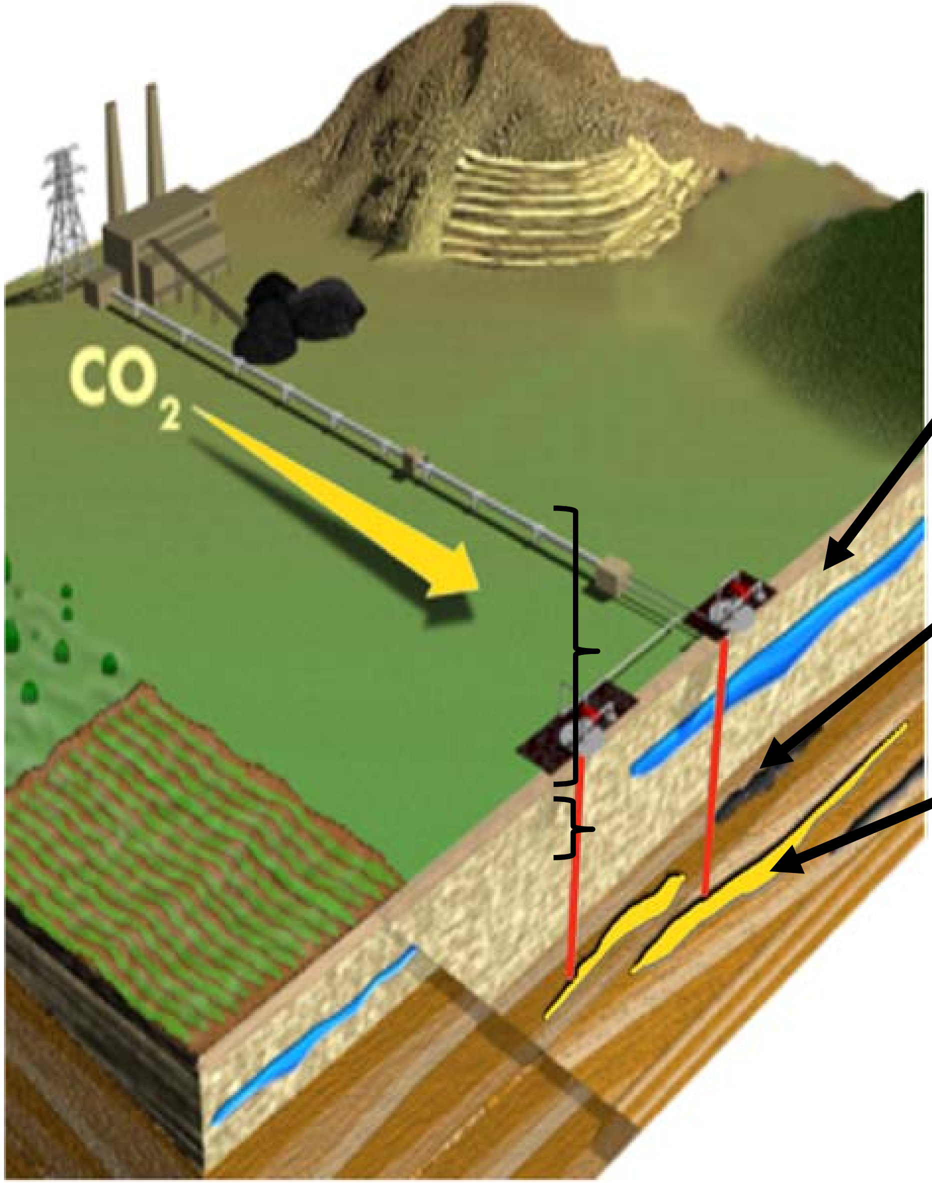
$Fe_2(dobdc)\cdot 2C_2H_4$



- A single MOF can be used to fractionate a mixture of CH_4, C_2H_6, C_2H_4, and C_2H_2
- Ethylene/ethane normally separated cryogenically…

Bloch, Queen, Krishna, Zadrozny, Brown, Long, manuscript in preparation

Carbon Sequestration - understand risks



Monitoring outside of the Reservoir

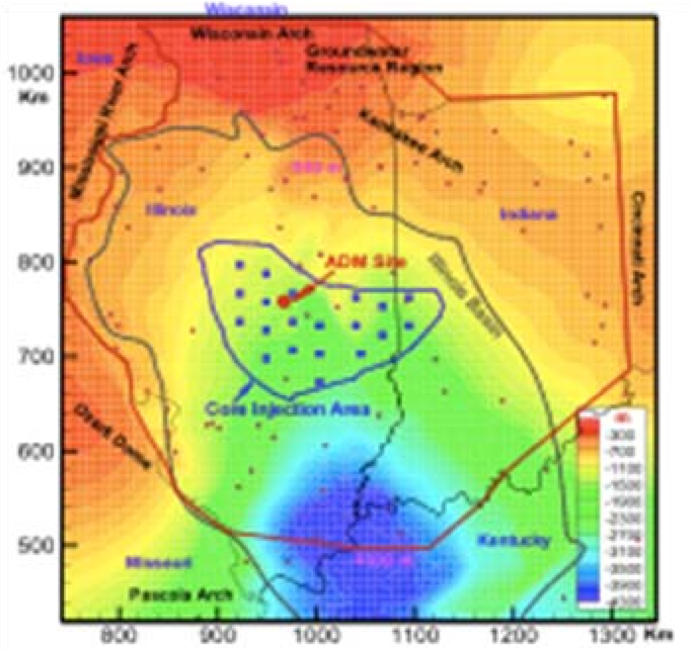
Seal must be robust

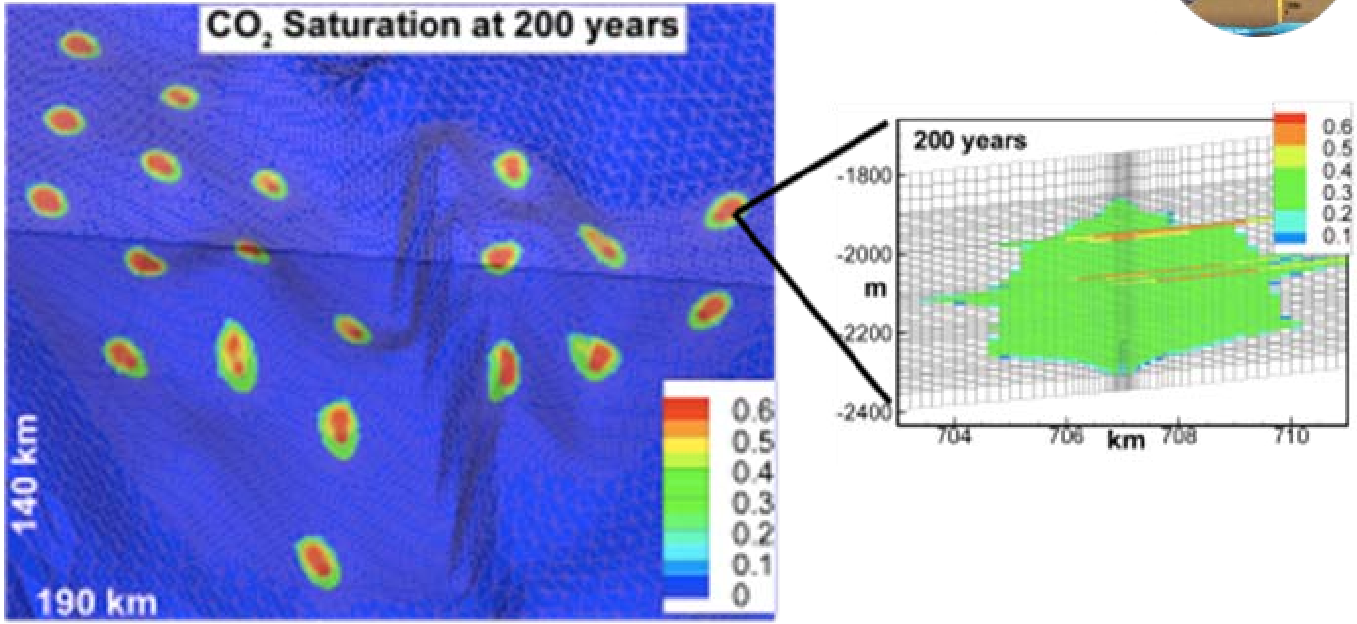
Reservoir

- Plume movement in reservoir (CO_2, brine, pressure front)
- Impacts from introducing CO_2 into the reservoir

The challenge: simulate long term fate of CO_2 injected underground ***from nanometers to kilometers***

Carbon Sequestration - simulations



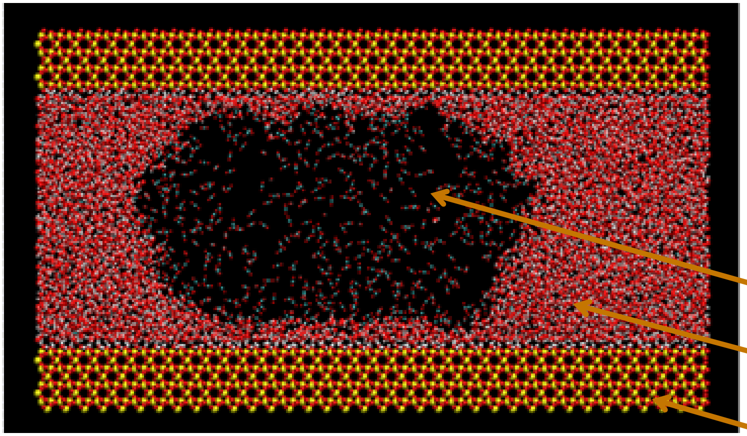


Simulated injection 5 Gt CO₂, Over 50 years at 20 sites

No transport between sites, gases move down

Peak pressure rise 30 bar dissipates over time *- brine*

Zhou and Birkholzer GHGST, 2011



MD simulation snapshot of a 7 nm-wide pore (31,000 atoms) at 373 K

H_2O

Quartz

Carbon Sequestration - lifecycle analysis

Analysis of water, energy, and carbon intensities of brine management from CCS:

- Sequestering CO_2 in saline aquifers may require brine extraction
- Extracted brine can be either a waste product or a resource
- Optimal management options will vary with brine characteristics and location

Cost analysis of brine mineral recovery for three disparate saline aquifers

based on CCS for 10 1GW coal-fired power plants

Southern San Joaquin

evaporation ponds: 100 km^2

\$2.42/tCO_2 Salt value
(\$3.90)/tCO_2 Salt recovery
(\$1.48)/tCO_2

Jasper Interval

evaporation ponds: 1400 km^2

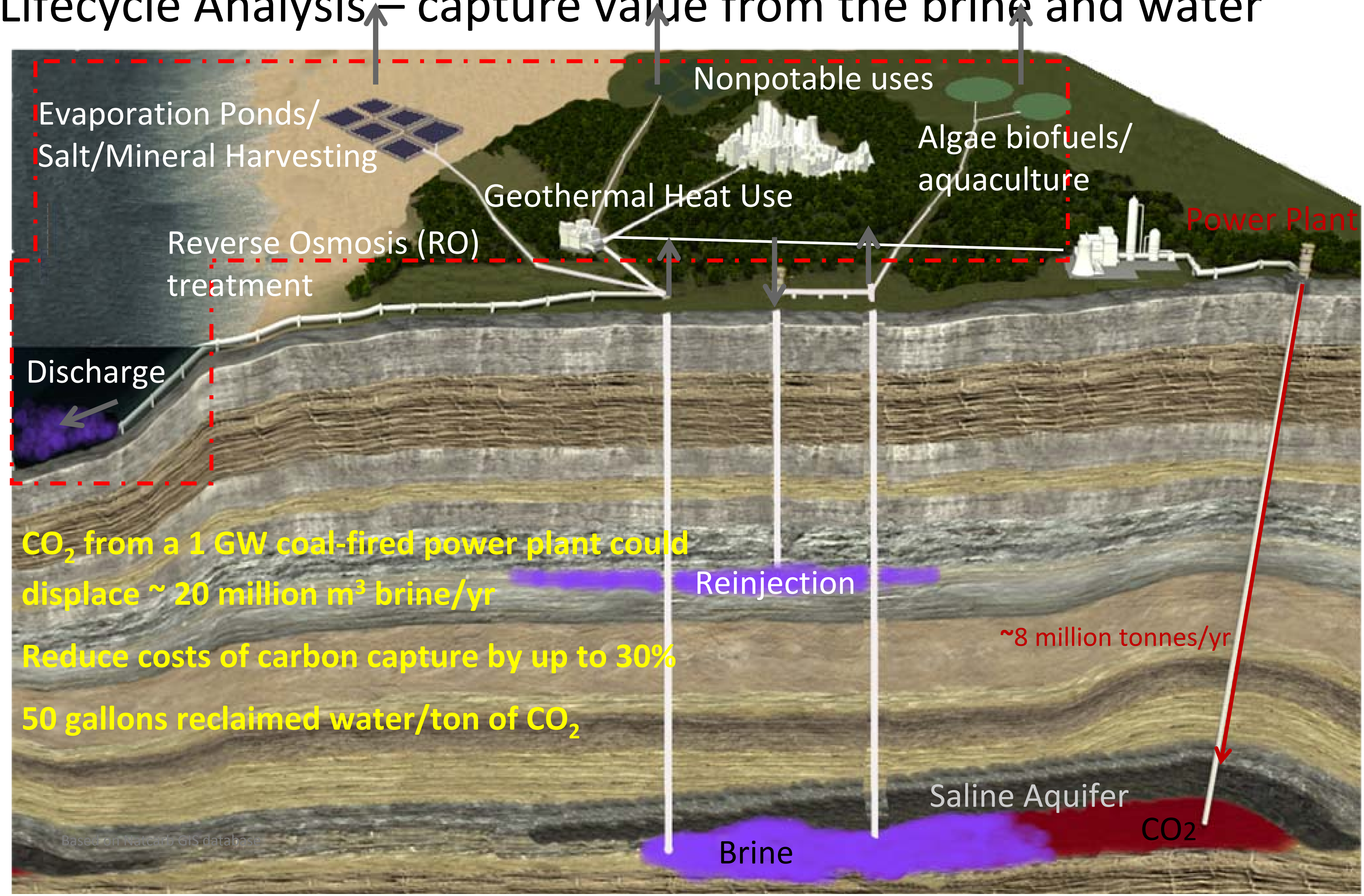
\$7.90/tCO_2 Salt value
(\$4.63)/tCO_2 Salt recovery
\$3.27/tCO_2

Mt. Simon Sandstone

evaporation ponds: 350 km^2

\$21.16/tCO_2 Salt value
(\$4.21)/tCO_2 Salt recovery
\$16.94/tCO_2

Lifecycle Analysis – capture value from the brine and water



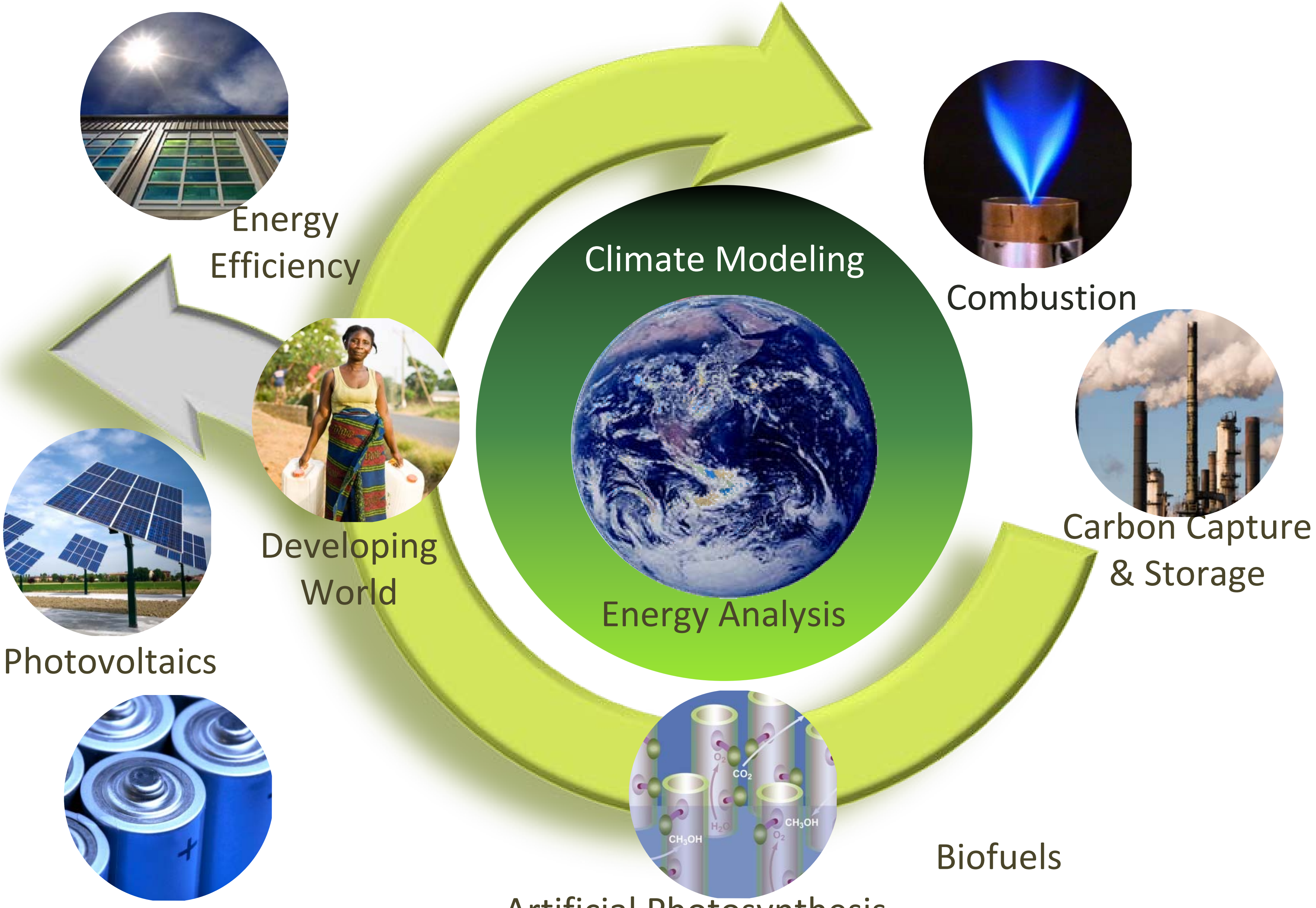
CO_2 from a 1 GW coal-fired power plant could displace ~ 20 million m^3 brine/yr

Reduce costs of carbon capture by up to 30%

50 gallons reclaimed water/ton of CO_2

*Brine in this study refers to any water of high salinity. **To be completed in future studies.

Carbon Cycle 2.0 at Berkeley Lab



Energy Efficiency

Climate Modeling

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Developing World

Carbon Capture & Storage

Photovoltaics

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Biofuels

Energy Storage

Artificial Photosynthesis