Solutions for Today

CARBON

Options for Tomorrow

Carbon Capture Program



CDR Annual Meeting August 18, 2021



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Carbon Capture Program...Mission

Mission

 Research, develop, and demonstrate advanced cost-effective carbon dioxide removal (CDR) technologies to support decarbonization pathways.

Drivers/Challenges

- Reduce capital & operating costs across a broad
 CDR technology portfolio (DAC, EW, Mineralization, BiCRS)
- Accelerate demonstration of CDR technologies

Goal & Metrics

• Support U.S goal to achieve carbon pollution-free electricity sector by 2035 and zero-carbon economy by 2050





Direct Air Capture (DAC)

Bioenergy Carbon Removal and Storage (BiCRS)



Enhanced Weathering (EW)





Carbon Dioxide Removal vs Carbon Reducing









CDR.. remove CO₂ from the atmosphere and store it in geologic formations, long-lived products, durable terrestrial sinks

Carbon Negative vs. Carbon Reducing

CARBON REDUCING

Point-Source Capture (PSC) for Power Generation and Industrial Sectors



Power Plants



Steel Plants



Cement Plants



CARBON NEGATIVE

Carbon Dioxide Removal (CDR) from Air



Direct Air Capture ⁽¹⁾



TIONAL

HNOLOGY

Enhanced Weathering



Bioenergy Carbon Removal and Storage (BiCRS)

(1) Assume C storage as CO₂ off-take



Develop PSC / CDR technologies for a wide range of feed conditions

Integrated Approach to Carbon Management...

U.S. DEPARTMENT OF



NATIONAL ENERGY TECHNOLOGY

.. Point Source Capture + CDR + Long Carbon Duration Storage

Carbon Capture Program...Evolution







- ✓ Lower CAPEX/OPEX ✓ Reduced regeneration energy
- ✓ Increased working capacity

Transformational **Technologies** 2030: \$30/tonne CO₂





Biphasic Solvent

2015 -

3D Print

- ✓ Water Lean Solvents
- ✓ Adv. Membranes
- ✓ Hybrid Systems
- ✓ Process Intensification



TCM

2018 -

✓ Engineering Scale testing ✓ FEED studies





Reduce cost and risk to enable wider, strategic commercial deployment 6

DAC.. Program Structure

NATIONAL ENERGY TECHNOLOGY LABORATORY





Integrated Approach to Accelerate Technology Development



Carbon Capture Interactive Project Map





Count by technology & scale



Projects by Technology Area

Projects by Scale





DAC Transformational (TRL 2-3).. Materials





enhanced depolarized electromembrane system (solvent/membrane contactor)



DE-FOA-0002188



hybrid sorbent in low vacuum swing adsorption process

Susteon

catalyzed amine-

InnoSepra

physical sorbents

Sorbents

IWVC

amine-functionalized sorbent in novel isothermal pressure swing reaeneration cvcle



membrane adsorbent for rapid temperature swing adsorption

parc A Xerox Company polyamine aerogel sorbent

MOF-based sorbent



amine-encapsulated sorbent embedded in porous fibers

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

fiber-encapsulated nanoparticle organic hybrid materials (NOHMs)-based sorbents



hybrid polymer membrane

echnologies for Tomorrow

Georgia Research Tech Corporation

MOF-based sorbent

INTERNATIONAL MOF- and P-dendrimerbased sorbents



Solvents

HARVARD

UNIVERSITY

Aqueous alkaline solvent with

novel alkalinity concentration

swing (ACS) cycle

Membranes

Materials & Process Devolvement for Next Generation DAC 10

DAC Transformational (TRL 3).. Material Systems









Field Validation (TRL 5).. Sorbents

Electricore, Inc.



Sorbent laminate filter process

Direct Air Capture Process

CHALLENGE:

Improve process efficiency and extend sorbent material life

SOLUTION:

ENERGY

Implementation of vacuum- and temperature-swing desorption and optimization of the sorbent structure geometry

Key Process Features and Objectives

- Svante's solid sorbent laminate filter & Climeworks' DAC Air Contactor
- 30 kg/day integrated field test unit 95+% CO₂



CO₂-free air

Project Development and Goals- 2020 Full characterization of Svante's sorbent after 1,000 hours of operation



Project Benefits

- 12-month field test of the DAC system
- Cost reductions.. reduced pressure drop and innovative heat recovery





Validate Efficient Adsorption/Desorption in a DAC Process 12

Field Validation (TRL 5).. Hybrid System



IWVC LLC

Solid sorbent-based isothermal water vapor and CO₂ capture system



CHALLENGE:

SoCalGas-Brawley Site

Facilitate heat management to reduce energy losses, while minimizing system size and cost

SOLUTION:

Combine CO₂-selective sorbent beds and water extraction unit with novel isothermal pressure swing regeneration cycle

Key Process Features and Objectives

- Potable water gen & CO₂ capture in a single contactor
- Integrate PNNL's amine-functionalized sorbent with desiccant sorbent beds to remove ≥85% of CO₂ from the air
- 30 tonnes CO_2/yr .

ENERGY



Project Development and Goals- 2021

- Finalize system design
- Optimize cold spray deposition process for sorbent deposition/surface coating on aluminum support



Project Benefits

- 3-month field test at real conditions
- Reduced OPEX (zero water consumption & use of low-grade heat)
- Can operate in regions with low or zero water availability & below freezing temperatures





SIEMENS

Hybrid System.. DAC and Water Generation

Bench Scale (TRL 4).. HVAC/DAC Integration



Oak Ridge National Laboratory

Testing of DAC processes incorporated into building HVAC systems



Testing on HVAC Equipment

Project Development and Goals- 2020

- Assessment of existing building infrastructure and evaluation of integration options
- Characterization of DAC materials/modules • and regeneration approaches



Project Benefits

Targeted reduction in the energy consumption and cost of DAC systems while minimizing water and land use

CHALLENGE:

Centralized DAC processes are expensive, with infrastructure, air movement, and heat required

SOLUTION:

Implementation into HVAC systems in existing buildings provides most necessary infrastructure for DAC operation

Key Process Features and Objectives

- Utilization of existing HVAC equipment allows for massive number of applicable sites
- Limited amount of additional energy consumption for buildings

OAK RIDGE National Laboratory



Test Feasibility of DAC within Infrastructure of Existing Buildings 14

Bench Scale (TRL 4).. 'Reactive" DAC for RNG NE



 In-situ Methanation/Regen. over Dual Functional Material (DFM) using H2 (Tail Gas PSA):

 $\begin{array}{c} Na_2O - CO_2/AI_2O_3 + 4H_2 \\ \rightarrow Na_2O/AI_2O_3 + CH_4 \end{array}$



- Reduce overall cost for CO₂ capture and conversion to RNG
- Perform bench-scale testing and process modeling to design a pilot unit (SBIR Phase II)



NET NATIONAL ENERGY TECHNOLOGY LABORATORY

Impact

- Synergistic with low-cost carbon-free H₂ streams
- Lower energy and carbon intensity
- Deployable for sites available with waste or low-cost hydrogen

Key Takeaways

- Process intensified system for making RNG from CO₂
- Structured bed with low pressure drop, and self-accelerated heat exchange for cyclic operation
- DFM compositions and operating conditions identified
- Commercially viable platform for CO₂
 capture from air and utilization

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK





Pre-FEEDs (TRL 6+)... Gen 1 DAC Systems TECHNOLOGY



Input:

- DAC Technology (TRL 6), 100,000 tpy net CO₂
- 3 host sites from the pre-defined geographical areas ٠

Output:

Pre-FEEDs for three individual case studies including:

- Energy source integration ٠
- CO₂ storage pathways ٠
- Business case analysis (i.e. LCFS / 45 Q credits)
- TEA, LCA ٠



DE-FOA-0002402

NATIONAL



FEEDs for DAC Systems... Notice of intent

Office of Fossil Energy and Carbon Management

DOE Announces Intent to Fund Direct Air Capture FEED Studies

JULY 23, 2021

Office of Fossil Energy and Carbon Management » DOE Announces Intent to Fund Direct Air Capture FEED Studies

Today, the U.S. Department of Energy's (DOE) Office of Fossil Energy and Carbon Management (FECM), in collaboration with the Office of Nuclear Energy and the Office of Energy Efficiency and Renewable Energy's Geothermal Technology Office, issued a notice of intent (NOI) for a Funding Opportunity Announcement (FOA) expected to support front-end engineering design (FEED) studies of direct air capture (DAC) combined with dedicated storage and coupled to existing low-carbon energy.



DAC systems with dedicated carbon storage and existing low-carbon energy

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Assessment of potential of RNG-based BECCS

<u>Hypothesis</u>:

An alliance of RNG+NG+BECCS can leverage NG infrastructure for biomass scale-up and decarbonization.

<u>Objective</u>:

Quantify the potential contribution that RNG+NG+BECCS can make to decarbonization (quantity and cost of CO_2) in the US.

<u>Approach</u>: Model 1) aggregation of biomass resources to NG pipelines, 2) biomass conversion to RNG, injection into pipelines, and CCS, 3) associated costs and CO₂ benefits, and 4) develop carbon avoidance cost curves of RNG+NG+CCS for gasification (dry biomass) and AD (wet waste and macroalge) pathways.

<u>Expected impact</u>: Analysis of pathways to scale for negativeemissions CCS and renewable energy based on an alliance of biomass/RNG and NG.





Natural Gas Pipelines (EIA 2020)





Carbon Dioxide Removal – FY22 Congressional Marks NE NATIONAL

CROSSCUTTING INITIATIVES (EERE, FECM, Office of Science)

- The Department is directed, pursuant to section 5001 and 5002 of the Energy Act of 2020 to establish the Carbon Dioxide Removal Program and Carbon Dioxide Removal Task Force to advance the development and commercialization of carbon dioxide removal, direct air capture, sequestration, and any other relevant technologies on a significant scale. (pg. 73)
- The Committee supports direct air capture prize competitions. (pg. 74)
- The recommendation provides not less than \$120,000,000 for research, development, and demonstration of carbon dioxide removal technologies, including not less than \$20,000,000 from EERE, not less than \$50,000,000 from FECM, and not less than \$35,000,000 from the Office of Science. Within available funds for carbon dioxide removal, the recommendation provides not less than \$75,000,000 for direct air capture. (pg. 74)

FECM

• The recommendation provides \$5,000,000 for a competitive solicitation for a study for the development of a direct air capture facility co-located with a geothermal energy resource. Priority for such a grant shall be given to entities that are engaged in the generation of electricity from geothermal resources. (pg. 105)



Carbon Capture Program.. Outreach







Carbon Capture Newsletter

Carbon Capture Program R&D Compendium



Carbon Capture Program Website

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Questions

http://www.netl.doe.gov/research/coal/carbon-capture

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