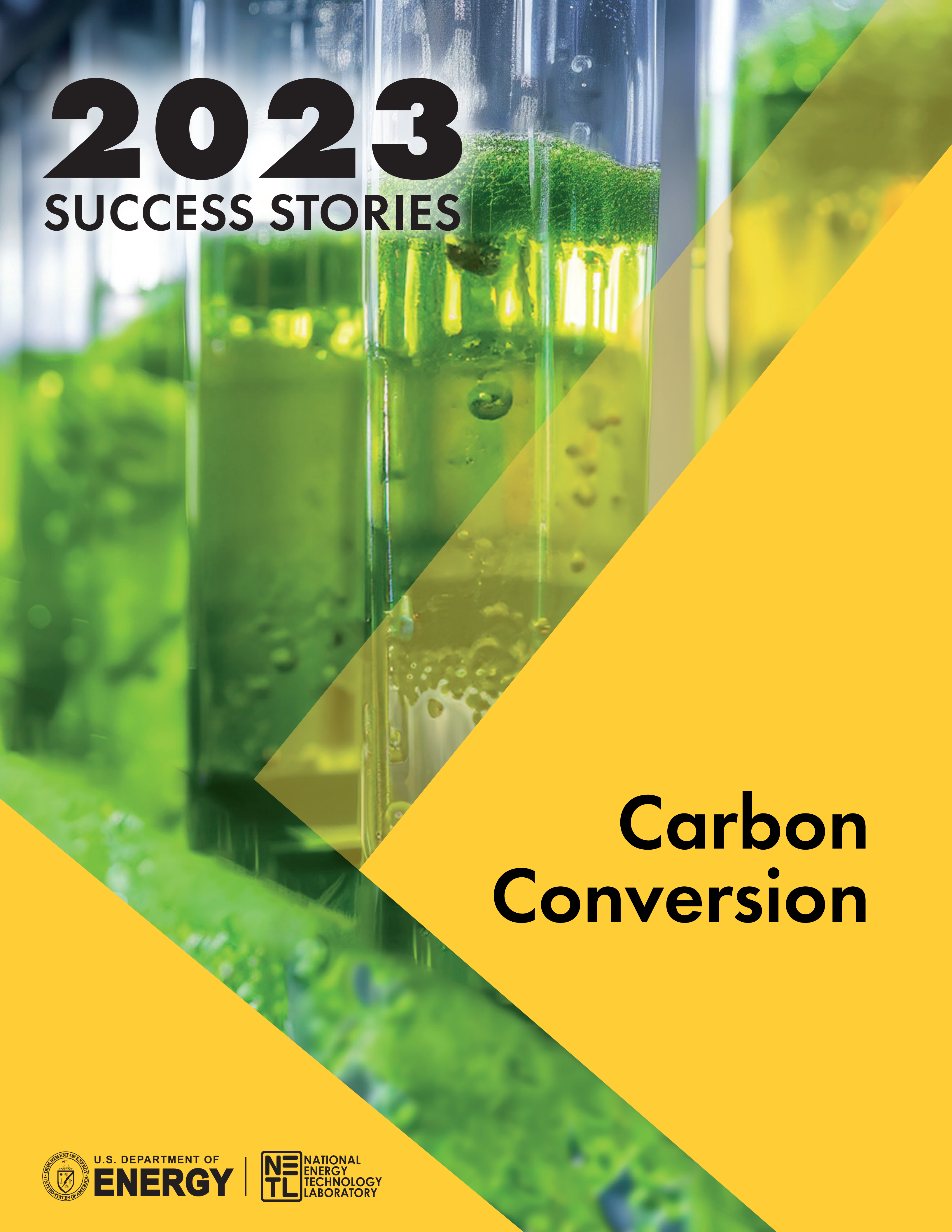


2023 SUCCESS STORIES

Carbon Conversion

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

Award No. FE0031915

Achieving Unprecedented Carbon Dioxide Utilization in Concrete

CO_2Concrete™ products are projected to reduce the global warming potential (GWP) by at least 45% compared to OPC-concrete of equivalent performance grade

- The CO_2-to-concrete process was field tested at the Integrated Test Center in Gillette, Wyoming and a pilot-scale demonstration was performed at Plant Gaston (1,800 MW) which provides flue gas for the National Carbon Capture Center in Wilsonville, Alabama
- Approximately 15,000 blocks were carbonated
- Testing was successful with coal and natural gas flue gas without upfront CO_2 capture
- Achieved in excess of 75% CO_2 utilization efficiency
- CO_2Concrete product complied with industry standard specifications. Production price parity was achieved with conventional concrete blocks

- ✓ Cement production emits nearly 10 % of global CO_2
- ✓ 0.9 tons of CO_2 are emitted per ton of cement produced; 4.5 billion tonnes of cement produced annually
- ✓ Global concrete market ~ $1 trillion /year

Waste CO_2 is incorporated and locked into the CO_2Concrete™ product.

CO_2Concrete™ Has Advantages that Solve Challenges

- Potential gigaton(s) CO_2 Utilization in Concrete by 2030
- Lower temperature routes for binder production; portlandite (800 °C) vs. Portland cement (1500 °C)
- Insensitivity to SOx and NOx enables direct use of stack flue gas (without CO_2 capture step)
- Mineralization is the only "thermodynamically downhill" process for CO_2 utilization
- Abundant and Low-value coal combustion residues (CCRs) used as reactants
- Manufacturability of multiple product designs: hollow core slabs, wall panels, and beams. Alternate manufacturing methods may be unlocked (3DP)

Potential CO_2 Utilization in Concrete by 2030 (gigatons)

Deployment will remediate waste CO_2 and coal combustion residues (CCRs).

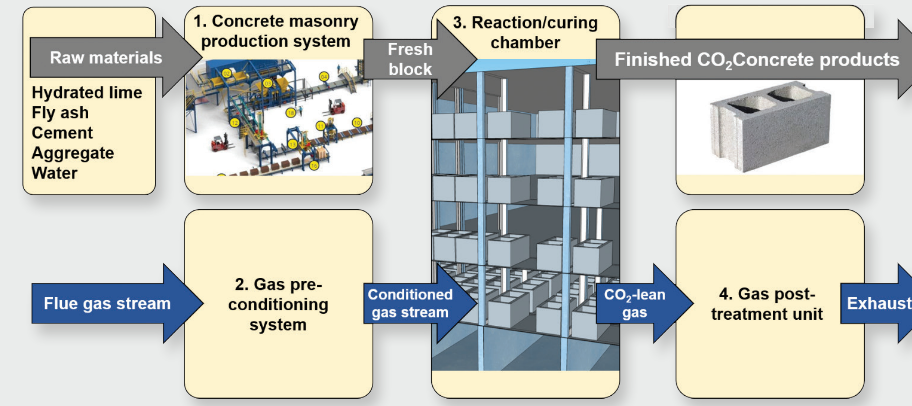
Process Demonstrated at Pilot Scale

Field-tested using actual flue gas at the National Carbon Capture Center

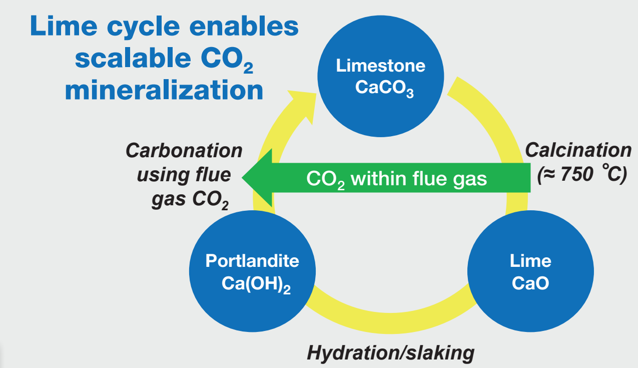
- CO_2Concrete™ Products exhibit compressive strength, water absorption, etc. that comply with industry standard performance criteria (ASTM C90, PCI design manual)

Upcycle industrial wastes and CO_2

- Produce low-carbon CO_2 concrete products from coal combustion residues, flue gas CO_2, and low-grade waste heat



Low-carbon CO_2 concrete test samples.



$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

Commercialization efforts are supported by meeting best-in-class industry performance standards.

Prize Winning Technology

UCLA Wins Rigorous NRG - Canada's Oil Sands Innovation Alliance (COSIA) Carbon XPRIZE Global Competition

XPRIZE CARBON | nrg | cosia

- In part through an NETL sponsored project, CarbonBuilt Inc., a University of California-Los Angeles (UCLA) spin-off, won a $7.5 million grand prize in the NRG - Canada's Oil Sands Innovation Alliance (COSIA) Carbon XPRIZE Global Competition for their process that locked away and incorporated CO_2 from the emissions of power plants and industrial facilities into marketable, industrial-strength concrete
- The UCLA group became the first university team to win the grand prize in the NRG COSIA Carbon XPRIZE

Target CO_2Concrete™ Products include hollow core slabs, wall panels, and beams.

PARTNERSHIP WITH:

UCLA Samueli Chemical & Biomolecular Engineering

SCAN FOR MORE INFORMATION:

Award No. FWP-78606

Economically Competitive, CO_2-Negative-Emission Decking Material Composites

Large-Volume Biopolymers can be Large Volume CO_2 Sinks when Modified for Decking Applications

Lignin (and/or) lignite can be upgraded through reaction with CO_2. The CO_2 modification provides the "velcro" to help lignin and lignite bond securely to other polymer matrixes. CO_2-upgraded lignin/lignite (CO_2LIG) is then used as a filler material to form CO_2LIG/plastic composites for decking applications.

CO_2LIG composites produced with 60% and 70% lignin filler show higher tensile strength and elastic modulus than wood plastic composite (WPC).

3.55 billion linear board feet of synthetic decking is sold in the U.S. per year - a $2.8 billion market.

Minimum CO_2LIG selling price ($/kg)	
Lignin	0.375
Chemicals	0.085
Utilities	0.028
By-product credits	-0.043
Capital depreciation	0.071
O&M	0.088
Return on Investment	0.106
Others (tax, etc.)	0.112
TOTAL	**0.820**

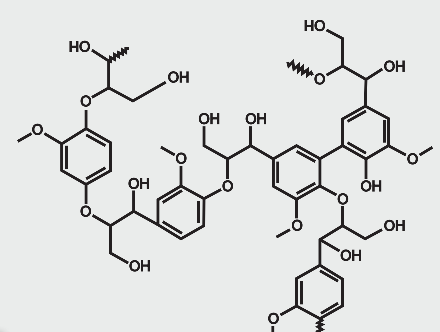
Preliminary Economic Analysis

Lignin is a biopolymer that provides structural support in plants

Lignite is formed from naturally compressed peat

CO_2LIG could be a CO_2 negative building material at lower cost ($0.82/kg) than conventional building materials (HDPE, $1/kg).

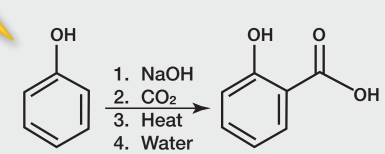
CO_2 Upgrading of Lignin and/or Lignite Filler



Incorporating CO_2 into the structure of lignin/lignite improves the compatibility and strength of adhesion with the polymer matrix materials used in decking products.

- The Kolbe-Schmidt carboxylation reaction is used to bind CO_2 to aromatic phenolates that are common in the lignin/lignite structure. This forms durable carbon-carbon bonds that lock CO_2 into the lignin/lignite structure
- It is possible to incorporate 1-5 wt.% CO_2 into the lignin/lignite structure through chemical modification – due to the size of the U.S. market, this implies that through this process, hundreds of thousands of tonnes of CO_2 per year could be sequestered in CO_2LIG composites for decking applications

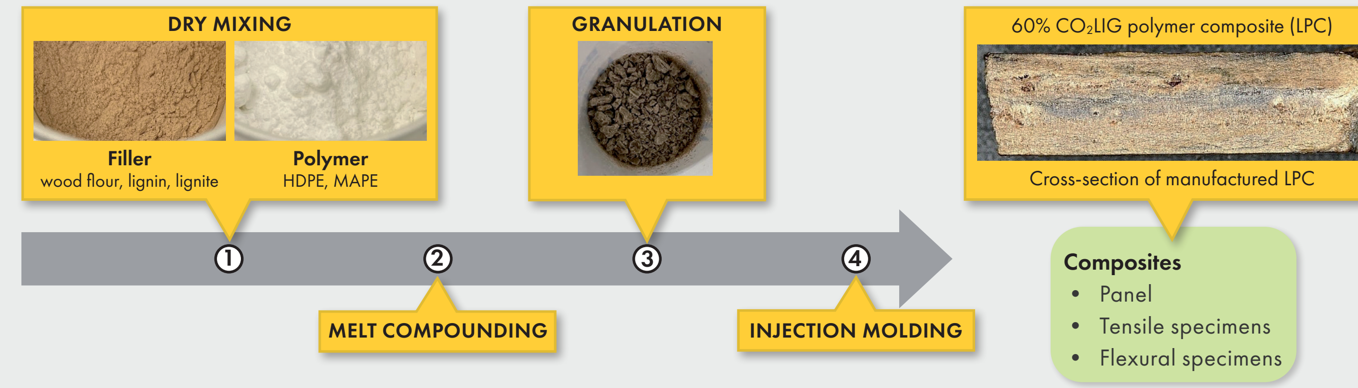
Kolbe-Schmidt Reaction



Waste CO_2 is incorporated and locked into the composite decking product.

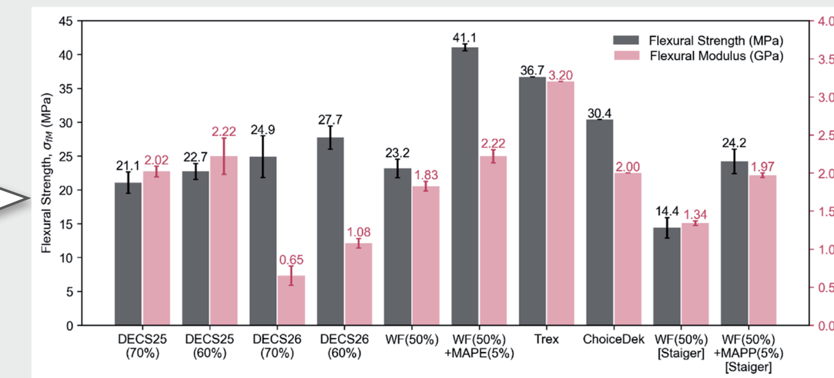
Composite Development Efforts are Showing Promise

The process conditions for manufacturing CO_2LIG-polymer composites have been identified



The composites produced have shown favorable mechanical properties

60% and 70% CO_2LIG polymer composites (**DEC25** and **DEC26**) show comparable mechanical properties to other composite materials: WF = wood flour plastic composites. MAPE = maleic anhydride polyethylene



CO_2LIG composites show comparable mechanical properties to commercial products.

Significant Knowledge Gained and Shared for Manufacturing CO_2-Negative Building Composites

- 2 Submitted U.S. Patent/Provisional Patent Applications
- 1 Invention Disclosure
- 3 Manuscript Publications in Preparation
- 1 Keynote Talk at Baker Hughes's Energy Frontier Summit
- 2 Presentations (Workshop at University of Minnesota and 2023 Spring ACS Meeting)
- 3 Abstracts Submitted to Conferences (47th International Technical Conference on Clean Energy and 2023 AIChE Annual Meeting)

Dissemination of project results benefits the R&D community.

PARTNERSHIP WITH: Pacific Northwest NATIONAL LABORATORY | SoCalGas

SCAN FOR MORE INFORMATION:

Award No. FWP-1022426 Task 6

NETL Produces Syngas with Massive Carbon Savings using Proprietary Microwave Technologies

NETL Microwave Catalysts Produce Syngas by Consuming Waste Greenhouse Gases and Using Little Energy

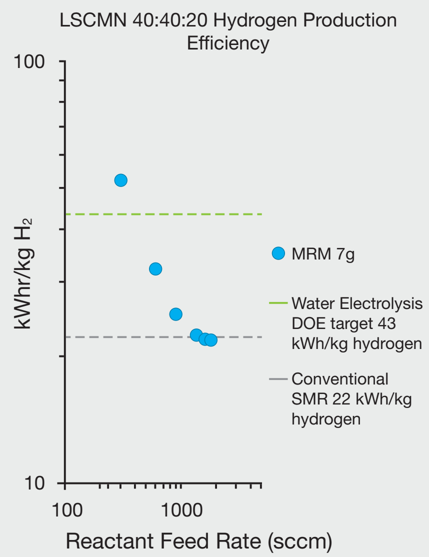
NETL has used microwave technologies to demonstrate mixed reforming of methane (MRM) to generate syngas in a 2:1 ratio (H_2:CO). Syngas with this composition is an ideal chemical precursor used in the production of common industrial chemicals.

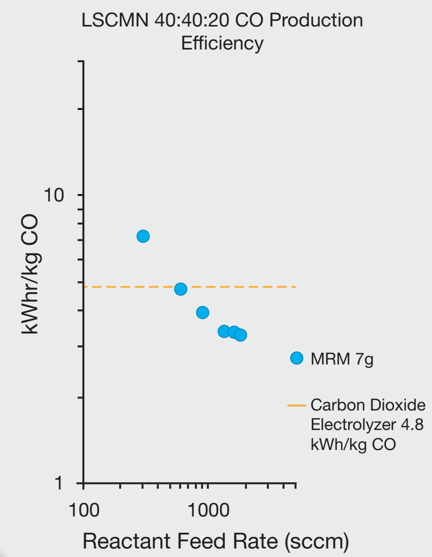
NETL's microwave catalysts can produce syngas by generating H_2 with just 22 kWh/kg energy use and simultaneously produce CO with just 3.3 kWh/CO energy use.

Such low energy use is far below the DOE water electrolysis energy use target of 43 kWh/kg H_2 and well below the conventional carbon dioxide electrolyzer energy use of 4.8 kWh/kg CO.

$CO_2 + CH_4 \rightarrow 2CO + 2H_2$

Greenhouse gases → Syngas





Energy requirements for H_2 and CO production through microwave-assisted mixed reforming of methane (MRM), steam methane reforming (SMR), and electrochemical processes.

NETL's microwave-assisted production of syngas uses only slightly more energy as fossil-based production but consumes waste CO_2 and is powered by clean electricity.

Benefits of Microwave-Assisted Catalytic Processes

- Can reduce carbon emissions by converting greenhouse gases into value-added products
- Rapid and selective heating of catalysts and/or reactants which allows for the use of smaller reactors and smaller downstream separation units
- Flexible and tunable microwave fields can be used to respond to variations in feed rate and feed composition
- Just like state-of-the-art electrochemical technologies, microwave systems can be powered by clean, low-carbon electricity
- Low energy use (highly efficient) and high product yield

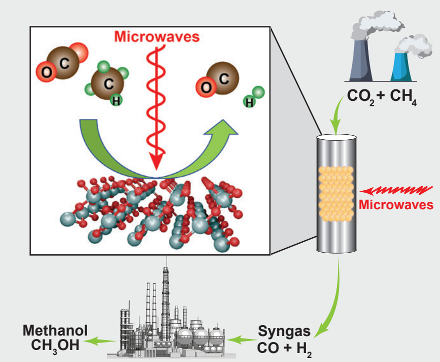
Pre-pilot Scale Microwave Demonstrations

Unlocking the benefits of microwave technology could promote the commercialization of low-carbon or net-negative carbon products.

Microwave Development Efforts are Showing Diversified Promise and Go Beyond Syngas Production

NETL is developing microwave-active materials that convert waste CO_2 into chemical feedstocks (syngas) used for industrial chemicals production, is pursuing the identification and scale-up of microwave-active catalysts for use in reactive capture and conversion applications, and is pursuing the microwave-assisted conversion of CO_2 into polycarbonates.

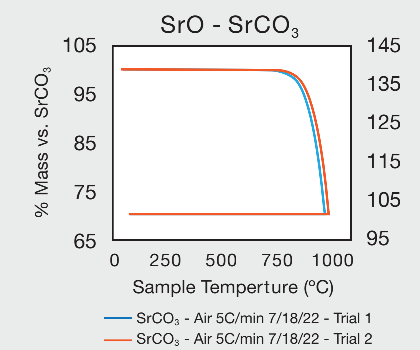
CO_2-derived Methanol Production



Techno-economic analysis (TEA) shows the NETL-developed microwave process can produce CO_2-derived methanol (using syngas as a precursor) at prices ($1-2/gallon) approaching those of current industrial practices.

Sorbents for Microwave Reactive Capture and Conversion

The performances of SrO, CaO, BaO, Li_2O, and La_2O_3 have been screened in their oxide and hydroxide forms to down-select the most efficient and selective CO_2 reactive capture material. SrO was selected for further development due to its superior stability and run-to-run consistency.



Conversion of CO_2 into polycarbonates

Initial development efforts are targeting to demonstrate 10% diol conversion and at least 20% polycarbonate yield at reaction times < 8 hrs.

- Initial reaction runs show that unintended moisture must be removed from the reaction media as its presence results in low equilibrium carbonate yield. However, the microwave systems had less water than thermal systems and reached equilibrium faster than the thermal baseline.

Microwave technologies are being applied to multiple processes and products.

Critical Findings are Being Patented and Shared and Scale-Up Efforts are Ongoing

These efforts have resulted in several discussions with potential industrial partners, and the team has successfully produced 10-kg scale batches of its microwave catalysts for near-term, commercial-scale demonstration.

NETL has filed patents and published many peer-reviewed articles demonstrating proof-of-concept of this technology.

INTELLECTUAL PROPERTY PATENTED INTELLECTUAL PROPERTY

Engagement of industrial partners is underway.

NATIONAL ENERGY TECHNOLOGY LABORATORY

SCAN FOR MORE INFORMATION:

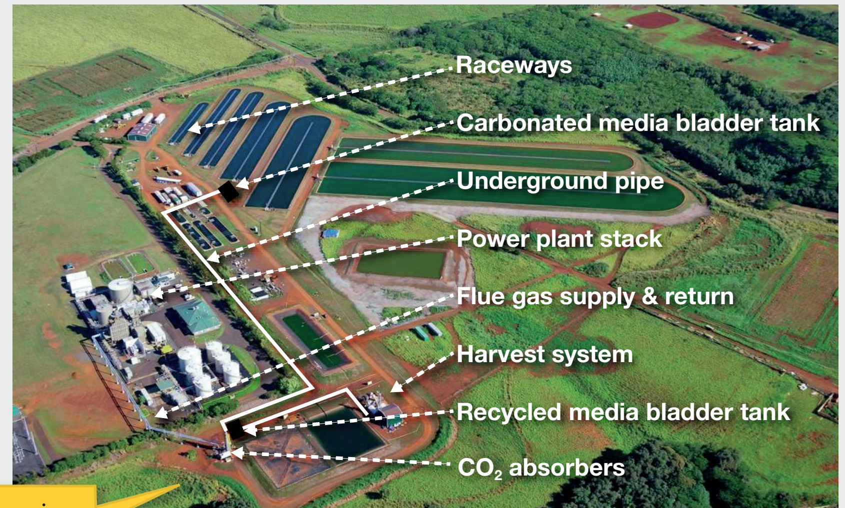
Award No. FE0032104

Testing Integrated Capture and Conversion at Engineering Scale through Algae Cultivation

Successfully Scaled the Integrated Algae Cultivation System to a 3.2 Acre Raceway

The 0.2 acre, 0.3 acre, and 3.2 acre-raceways were updated to improve scalability and productivity while using Global Algae's proprietary cultivation technology

- The integrated system, as shown to the right, includes power plant flue gas supply, CO_2 capture absorbers, algae cultivation raceways, harvesting system, and product processing systems.
- Parametric testing and integrated tests (~ten 7-day long tests) were performed using power plant CO_2 (~3.5% CO_2 concentration) with full media recycle.



Operations Overview

Flue gas CO_2 is incorporated and locked into bio-derived products.

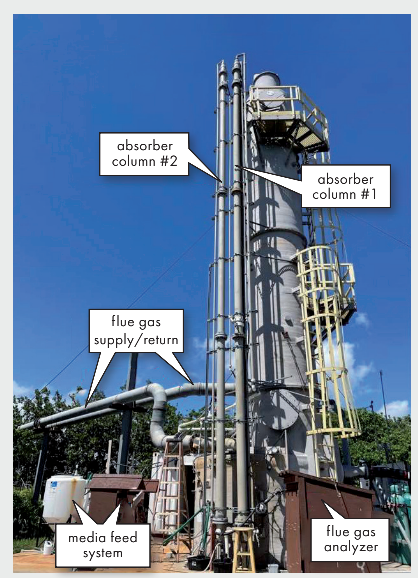
New Upgrades Bring Advantages

The integrated system, with new pumps and lines to connect the absorber, raceways, and harvester with the new water bladder tanks enables the capture and storage of CO_2 for 24 hours/day to account for variable demand.

- Eliminates the need for raceway gas distribution systems and controls
- The absorber demonstrated ~88% CO_2 capture efficiency
- Expected to result in $25-50/ton CO_2 captured, stored, and delivered to the raceway
- 90%-100% CO_2 utilization efficiency is projected


Recycled Media Bladder Tank


Carbonated Media Bladder Tank

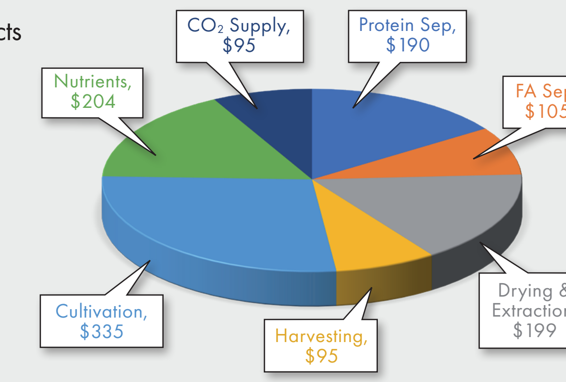


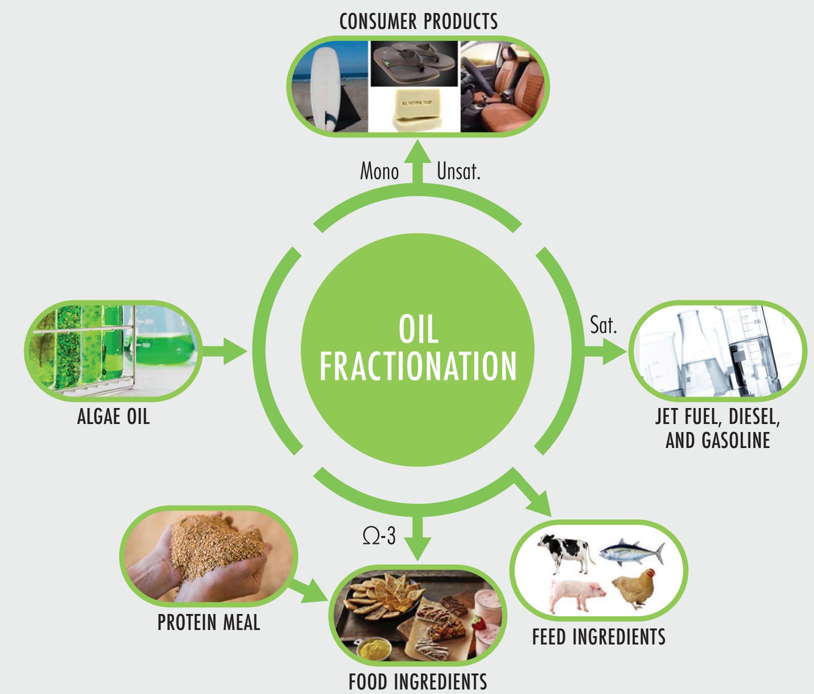
Absorber System

Integrated system supports low total cost of CO_2 capture, storage, and delivery.

Favorable Performance and Economics Expected for the Fully Integrated System

Techno-economic analysis shows that the total product production cost is $1224/mt whereas the value of the composite product (includes all products in the adjacent table) is $1400/mt, which indicates that this approach can profitability utilize CO_2 and convert it into value-added products.



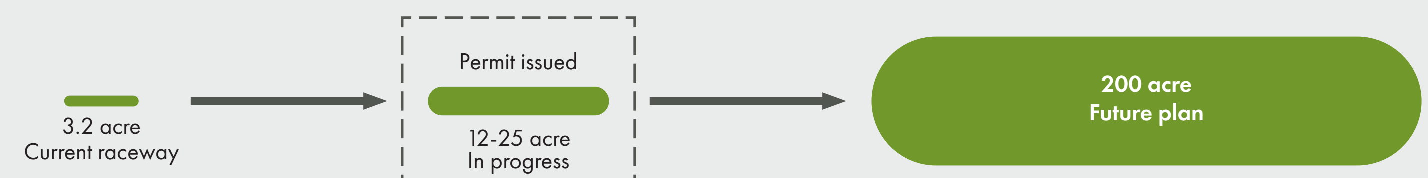


Product	% of AFDW	Value ($/mt)
Protein concentrate	12%	1800
M. unsat. fatty acid	17%	2300
Sat. fatty acid	17%	1400
Omega-3	6%	4200
Glycerin	5%	1100
Protein meal	43%	570
Composite price	**100%**	**1400**

Favorable economics justify further scaleup and investment.

Grading Permit Issued for Further Scaleup

Going beyond favorable economics, scaleup is encouraged due to demonstrated absorber performance that matches process model predictions, algae productivity that is same whether CO_2 from fresh bicarbonate or CO_2 absorbed from flue gas is used, and because test output performance can be predicted with 97% accuracy based on input variables.



Scaleup and commercialization efforts are rapidly progressing.

PARTNERSHIP WITH: GLOBAL ALGAE

SCAN FOR MORE INFORMATION:

For more information on Carbon Conversion, visit us at:

https://netl.doe.gov/carbon-management/carbon-conversion

Get Social with Us

There are several ways to join the conversation and connect with NETL's Carbon Conversion activities:

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