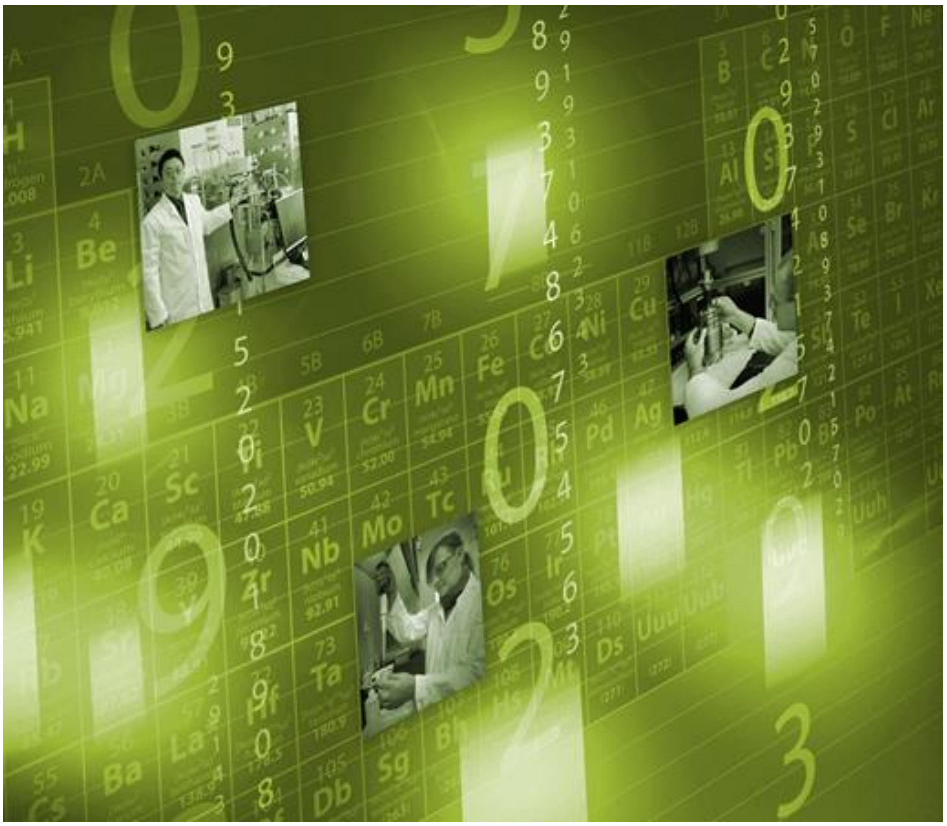
FY21 CARBON UTILIZATION PEER REVIEW OVERVIEW REPORT



July 26, 2021

DISCLAIMER

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INTRODUCTION AND BACKGROUND

The U.S. Department of Energy's (DOE's) Carbon Utilization Program supports research and development (R&D) of technologies to transform carbon dioxide (CO_2) into valuable products in an efficient, economical, and environmentally friendly manner. Supported R&D activities address the challenges and potential opportunities associated with transforming CO_2 into different products, integrating various CO_2 sources with utilization technologies, and performing techno-economic analyses (TEA) and life cycle analyses (LCA) to ensure that technologies are economically and environmentally attractive, respectively. DOE's Carbon Utilization Program supports R&D across three conversion pathways: mineralization of CO_2 (e.g., for building products), biological uptake of CO_2 via algae, and recycling CO_2 to fuels or chemicals via thermochemical or electrochemical methods. Other CO_2 utilization technologies, such as using CO_2 for a working fluid in enhanced oil recovery (EOR), are outside the scope of DOE's Carbon Utilization Program.

- **Mineralization into Inorganic Materials—**The reaction of CO_2 to produce inorganic products, such as carbonate cements and aggregate, or bicarbonates and associated inorganic chemicals. Carbon dioxide mineralizes with alkaline reactants, which can include industrial wastes from power plants, steel, and other industries. Carbonate materials may be an effective long-term storage option for CO_2, especially for use in the built environment.
- **Carbon Uptake using Algae—**The use of CO_2 in agricultural and aquacultural systems for the cultivation and harvesting of biomass. Algae are extremely efficient photosynthetic organisms—sometimes referred to as CO_2-eating machines. The biomass produced in algal systems can be processed and converted to fuels, chemicals, food for fish, animals and humans, soil supplements, and other specialty and fine products.
- **Conversion into Fuels and Chemicals—**The conversion of CO_2 into valuable organic products, ranging from neat fuels and fuel blending stocks to commodity, specialty, and fine chemicals. Conversion pathways can include thermochemical, electrochemical, photochemical, non-equilibrium plasma chemistry, and microbially mediated approaches. Many conversion pathways require catalysts or integrated processes to lower the energy needed to drive these systems. This pathway can transform wasted carbon into products such as synthetic fuels, chemicals, plastics, and solid carbon products like carbon fibers.
- **CO_2 as Working Fluid and Other Services—**The physical use of CO_2 in processes (such as EOR), the use of CO_2 as a solvent, and the use of CO_2 as a refrigerant. R&D in technologies that use CO_2 for EOR is a focus in the Carbon Storage Program. The Carbon Utilization Program is not pursuing technologies in this CO_2 utilization pathway.

Office of Management and Budget and U.S. Department of Energy Requirements

In compliance with requirements from the Office of Management and Budget and in accordance with the DOE Strategic Plan, DOE and the National Energy Technology Laboratory (NETL) are fully committed to improving the quality of research projects in their programs by conducting rigorous peer reviews. DOE and NETL conducted a Fiscal Year 2021 (FY21) Carbon Utilization Peer Review Meeting with independent technical experts to offer recommendations to strengthen projects during the period of performance and assess three projects' Technology Readiness Level (TRL) progression. KeyLogic, an NETL site-support contractor, convened a panel of four academic and industry experts* on June 8-11, 2021, to conduct a peer review of five Carbon Utilization Program research projects.

TABLE 1. CARBON UTILIZATION PEER REVIEW – PROJECTS REVIEWED

Project Number	Title	Lead Organization	Total Funding		Project Duration	
			DOE	Cost Share	From	To
FE0031710	Novel Algae Technology to Utilize Carbon Dioxide for Value-Added Products*	Helios-NRG, LLC	$1,387,588	$346,898	5/1/2019	7/31/2022
FE0031915	Achieving Unprecedented Carbon Dioxide Utilization in CO_2Concrete: System Design, Product Development and Process Demonstration*	University of California - Los Angeles	$2,000,000	$905,000	9/1/2020	12/31/2022
FE0031718	A Scalable Process for Upcycling Carbon Dioxide (CO_2) and Coal Combustion Residues Into Construction Products*		$1,800,000	$460,265	1/1/2019	6/30/2021
FE0031705	Synthetic Calcium Carbonate Production by Carbon Dioxide (CO_2) Mineralization of Industrial Waste Brines**	University of Wisconsin	$799,995	$199,998	2/15/2019	2/14/2022
FWP-1022426	CO_2 Utilization Technologies (Task 2: Catalytic Conversion of CO_2 to Industrial Chemicals and Evaluation of CO_2 Use and Re-Use Strategies)**	National Energy Technology Laboratory	$4,232,000	$0	04/01/2021	03/31/2024
			$10,219,583	$1,912,161		
			$12,131,744			

* TRL-Based Evaluation: During TRL-based evaluations, the independent panel offers recommendations and assesses the projects' technology readiness for work at the current TRL and the planned work to attain the next TRL.

** Recommendations-Based Evaluation: During recommendations-based evaluations, the independent panel provides recommendations to strengthen the performance of projects during the period of performance.

* Please see "Appendix D: Peer Review Panel Members" for detailed panel member biographies.

OVERVIEW OF THE PEER REVIEW PROCESS

Peer reviews are conducted to help ensure that the Office of Fossil Energy and Carbon Management's (FECM) research program, implemented by NETL, is in compliance with requirements from the Office of Management and Budget and in accordance with the DOE Strategic Plan and DOE guidance. Peer reviews improve the overall quality of the technical aspects of R&D activities, as well as overall project-related activities, such as utilization of resources, project and financial management, and commercialization.

KeyLogic convened a panel of four academic and industry experts to conduct a peer review of five research projects supported by the Carbon Utilization Program. Throughout the peer review meeting, these recognized technical experts offered recommendations to strengthen the projects during the remaining period of performance and provided feedback on three projects' technology readiness for work at the current TRL and the planned work to attain the next TRL. KeyLogic selected an independent Peer Review Panel, facilitated the peer review meeting, and prepared this report to summarize the results.

Pre-Meeting Preparation

Before the peer review, each project team submitted a Project Technical Summary (PTS) and project presentation. The projects subject to a TRL-based evaluation also shared a Technology Maturation Plan (TMP) to facilitate TRL evaluation from the Peer Review Panel (reference Table 1). The Federal Project Manager (FPM) provided the Project Management Plan (PMP), the latest quarterly report, and supplemental technical papers as additional resources for the panel. The panel received these materials prior to the peer review meeting, which enabled the panel members to fully prepare for the meeting with the necessary background information to thoroughly evaluate the projects.

To increase the efficiency of the peer review meeting, multiple pre-meeting orientation teleconference calls were held with NETL, the Peer Review Panel, and KeyLogic staff to review the peer review process and procedures, evaluation criteria, and project documentation, as well as to allow for the Technology Manager to provide an overview of the program goals and objectives.

Peer Review Meeting Proceedings

At the meeting, each project performer gave a presentation describing the project. The presentation was followed by a question-and-answer session with the panel and a closed panel discussion and evaluation. The time allotted for the presentation, the question-and-answer session, and the closed panel discussion was dependent on the project's complexity, duration, and breadth of scope.

During the closed sessions of the peer review meeting, the panel discussed each project (identified in Table 1) to identify strengths, weaknesses, and recommendations in accordance with the Peer Review Evaluation Criteria. For two projects, the panel offered prioritized recommendations to strengthen the project during the remaining period of performance. For the remaining three projects, the panel offered prioritized recommendations and an evaluation of TRL progression.

SUMMARY OF KEY FINDINGS

This section summarizes the overall key findings of the projects evaluated at the FY21 Carbon Utilization Peer Review Meeting. The panel concluded that the peer review provided an excellent opportunity to comment on the relative strengths and weaknesses of each project. The presentations and question-and-answer sessions provided additional clarity to complement the pre-meeting documentation. The peer review also provided insight into the range of technology development and the relative progress that has been made by the project teams. The technical discussion enabled the panel to contribute to each project's development by identifying core issues and making constructive, actionable recommendations to improve project outcomes. The panel generated 26 recommendations for NETL management to review and consider.

The panel commended the project performers for the world-class science being conducted at their respective level of technology development. The teams are employing unique, innovative, and creative means for achieving their respective project goals and objectives. A common recommendation offered to the project teams was to pursue potential collaborators (e.g., from either industry or academia) that could provide targeted expertise to steer or advance the technology.

The panel indicated that the projects are researching technologies that may have limited potential for commercial impact due to concerns related to large-scale feasibility and cost effectiveness (e.g., considerations related to marketability, ability to attract financing, profitability). Also, the projects are pursuing a smaller scale than would be needed for real-world impact to address climate change due to the significant amount of CO_2 that would need captured. These scale-up considerations could limit the potential impact of these technologies. The panel expressed concern that some of the projects revealed a lack of investigation and/or evaluation of global markets, and that while this type of research may be funded in the United States, that may not be the case globally.

Finally, the panel confirmed that the projects are aligned with DOE's near- and/or long-term goals and demonstrated noteworthy progress and accomplishments within their respective work scope and budgets. While these projects face technology development challenges, this research signifies progress and is critical to finding solutions for advancing CO_2 utilization technologies to market.

Evaluation of Technology Readiness Level Progression

At the meeting, the panel assessed the readiness to start work towards the next TRL based on a project's strengths, weaknesses, recommendations, issues, and concerns. The panel found that the projects were on track to attaining their respective planned end-of-project TRL based on achievement of the project goals as planned and addressing the panel recommendations.

- Project FE0031710 has attained TRL 4. Upon integration of the multi-stage, continuous flow (MSC) device, photobioreactor (PBR), and DeAqua system under typical operating conditions, Project FE0031710 shall attain TRL 5.
- Project FE0031718 has attained TRL 6. Upon completion of the peer review panel recommendations and planned project efforts, Project FE0031718 shall attain TRL 7. Before attempting to advance TRL, the team should revisit lower TRL requirements to ensure that the technical risks and gaps associated with these TRLs have been adequately addressed.

PROJECT SYNOPSES

For more information on the Carbon Utilization Program and project portfolio, please visit the NETL website: https://netl.doe.gov/coal/carbon-utilization.

FE0031710

NOVEL ALGAE TECHNOLOGY TO UTILIZE CARBON DIOXIDE FOR VALUE-ADDED PRODUCTS

HELIOS-NRG, LLC

Project Description: The goal of the proposed project is to develop an efficient process to convert carbon dioxide (CO_2) to algae biomass and value-added nutraceuticals. The technology comprises three key technologies: algae cultivation using algae with high productivity and robust performance in the flue gas environment, energy-efficient algae dewatering (DeAqua), and production of nutraceuticals. Helios-NRG, LLC is partnering with State University of New York at Buffalo, Northwestern University, Membrane Technology and Research, Inc., and Linde, to advance the technology to achieve high CO_2 capture efficiency and high algae productivity. The project technical activities include designing, building, and operating the multi-stage, continuous flow (MSC) system; optimizing nutraceuticals production; advancing DeAqua gravity table performance; advancing the DeAqua anti-fouling membrane; performing DeAqua module performance tests; conducting a field test of the MSC process; and performing a life cycle analysis (LCA) and techno-economic analysis. State University of New York at Buffalo will develop specialized membranes for dewatering algae in the DeAqua process. Northwestern University will perform the LCA. Linde will assess the potential for use of SolvoCarb technology for gas injection into the algae culture to improve performance/cost. The outdoor MSC system will be tested with actual flue gas at the National Carbon Capture Center (NCCC).

FE0031915

ACHIEVING UNPRECEDENTED CARBON DIOXIDE UTILIZATION IN CO_2CONCRETE: SYSTEM DESIGN, PRODUCT DEVELOPMENT AND PROCESS DEMONSTRATION

UNIVERSITY OF CALIFORNIA—LOS ANGELES

Project Description: The University of California—Los Angeles (UCLA) will accelerate and enhance carbon dioxide (CO_2) utilization in their CO_2Concrete™ process to maximize CO_2 valorization and process economics for a suite of CO_2Concrete™ products that are compliant with best-in-class industry standards. Detailed studies of carbonation reactions will be used to develop process models that inform the scale-out of the process to produce diverse precast concrete components. This will involve elaboration of material formulations, reactor designs, process parameters, and control systems to manufacture three different product designs (e.g., hollow core slabs, wall panels, and beams). The performance of the CO_2 mineralization system will be field-tested using actual flue gas at the National Carbon Capture Center (NCCC) in operational trials, and the resulting products will be shown to meet/exceed industry standards. Techno-economic and life cycle analyses will rigorously quantify the market viability and life cycle impact of the CO_2Concrete™ technology and identify optimal routes for further development and scale-up leading to practical commercialization.

FE0031718

A SCALABLE PROCESS FOR UPCYCLING CARBON DIOXIDE (CO_2) AND COAL COMBUSTION RESIDUES INTO CONSTRUCTION PRODUCTS

UNIVERSITY OF CALIFORNIA—LOS ANGELES

Project Description: The overall goal of this project is to accelerate the development of a CO_2 mineralization process that synergistically utilizes CO_2 in flue gas and coal combustion residues (CCRs) to synthesize CO_2NCRETE, a functional replacement for traditional concrete. Over the course of this project, UCLA, with support from Susteon Inc., will design, fabricate, and optimize a field-scale CO_2 processing (carbonation) system designed to consume about 100 kilograms of CO_2 per day directly from coal-derived flue gas, without a CO_2 capture or enrichment step. UCLA will evaluate the system's performance at the Integrated Test Center (ITC) using real coal flue gas from the Dry Fork Station, during which critical data on energy inputs and CO_2 uptake rates achievable at the field-scale will be compiled. The performance data and optimization sequence that the team collects will inform design and scaling analysis required for development of a commercial-scale CO_2 mineralization system, which will be achieved prior to the completion of this project.

FE0031705

SYNTHETIC CALCIUM CARBONATE PRODUCTION BY CARBON DIOXIDE (CO_2) MINERALIZATION OF INDUSTRIAL WASTE BRINES

UNIVERSITY OF WISCONSIN

Project Description: The overall goal of this project is to develop and evaluate methods to produce precipitated calcium carbonate while simultaneously utilizing carbon dioxide (CO_2) and industrial solid and liquid wastes. In the proposed process, waste brines are either used as a medium to carbonate coal combustion ashes (e.g., fly ash, bottom ash), or carbonated directly (i.e., CO_2 mineralization is enabled by the calcium ions present in the liquid [brine] stream). The University of Wisconsin, in partnership with the University of California—Los Angeles (UCLA), will investigate the physical and chemical processes involved in the two proposed carbonation pathways and optimize process parameters to produce high-purity calcite through each of the mineralization routes. A laboratory-scale system will also be constructed to demonstrate the process.

FWP-1022426

CO_2 UTILIZATION TECHNOLOGIES (TASK 2: CATALYTIC CONVERSION OF CO_2 TO INDUSTRIAL CHEMICALS AND EVALUATION OF CO_2 USE AND RE-USE STRATEGIES)

NATIONAL ENERGY TECHNOLOGY LABORATORY

Project Description: The Carbon Utilization Field Work Proposal (FWP) represents the National Energy Technology Laboratory's (NETL) in-house research to address emerging carbon mitigation strategies. The efforts directly support the U.S. Department of Energy's (DOE) mission to ensure sustainable fossil energy use by converting fossil-derived carbon dioxide (CO_2) emissions into value-added chemicals. Task 2 conducts early-stage research to identify, develop, and evaluate emerging catalyst concepts to selectively and efficiently convert CO_2 into industrially relevant chemical feedstocks. Efforts combine fundamental materials research, applied catalyst development, and bench-scale evaluation in laboratory-scale reactors. Emphasis is placed on validating materials that demonstrate clear promise for further development, and the project actively engages with potential industry partners for scaling and licensing opportunities. Technologies of interest include electrochemical conversion of CO_2 into industrially relevant chemical feedstocks, and microwave-assisted conversion of CO_2 and methane (CH_4) into carbon-neutral carbon monoxide (CO) and hydrogen (H_2) (CH_4 dry reforming). Developing such technologies will broaden the market for CO_2 originating from power plants and other large emission sources and provide a positive revenue stream to offset the cost of carbon capture strategies.

APPENDIX A: PEER REVIEW EVALUATION CRITERIA

Peer reviews are conducted to ensure that the Office of Fossil Energy and Carbon Management's (FECM) research program, implemented by the National Energy Technology Laboratory (NETL), is compliant with the U.S. Department of Energy (DOE) Strategic Plan and DOE guidance. Peer reviews improve the overall quality of the technical aspects of research and development (R&D) activities, as well as overall project-related activities, such as utilization of resources, project and financial management, and commercialization.

In the upcoming NETL peer review, a significant amount of information about the projects is covered in a short period. For that reason, NETL has established a set of guidelines for governing the meeting.

The following pages contain the criteria used to evaluate each project. Each criterion is accompanied by multiple characteristics to further define the topic. Each reviewer is expected to independently assess all the provided material for each project prior to the meeting and engage in discussion to generate feedback for each project during the meeting.

NETL Peer Review – Technology Readiness Level-Based Evaluation

At the meeting, the Facilitator leads the Peer Review Panel in assessing a project's readiness to start work towards the next Technology Readiness Level (TRL) based on a project's strengths†, weaknesses‡, recommendations, issues, and concerns.

NETL Peer Review – Recommendations-Based Evaluation

At the meeting, the Facilitator leads the Peer Review Panel in identifying strengths, weaknesses, prioritized recommendations, and overall score for each project. The strengths and weaknesses serve as a basis for the determination of the overall project score in accordance with the Rating Definitions and Scoring Plan.

Under a recommendation-based evaluation, strengths and weaknesses are characterized as either "major" or "minor" during the Review Panel's discussion at the meeting. For example, a weakness that presents a significant threat to the likelihood of achieving the project's stated technical goal(s) and supporting objectives is considered "major," whereas relatively less significant opportunities for improvement are considered "minor."

† A strength is an aspect of the project that, when compared to the evaluation criterion, reflects positively on the probability of successful accomplishment of the project's goal(s) and objectives.

‡ A weakness is an aspect of the project that, when compared to the evaluation criterion, reflects negatively on the probability of successful accomplishment of the project's goal(s) and objectives.

A recommendation emphasizes an action that is considered by the project team and/or DOE to correct or mitigate the impact of weaknesses, expand upon a project's strengths, or progress along the technology maturation path (TRL-based evaluation). A recommendation has as its basis one or more strengths or weaknesses. Recommendations are ranked from most important to least, based on the major/minor strengths/weaknesses.

Peer Review Evaluation Criteria – Carbon Utilization
1. Degree to which the project, if successful, supports the U.S. Department of Energy (DOE) Program's near- and/or long-term goals.
• Program goals are clearly and accurately stated. • Performance requirements[1] support the program goals. • The intended commercial application is clearly defined. • The technology is ultimately technically and economically viable for the intended commercial application.
2. Degree to which there are sufficient resources to successfully complete the project.
• There is adequate funding, facilities, and equipment. • Project team includes personnel with the needed technical and project management expertise. • The project team is engaged in effective teaming and collaborative efforts, as appropriate.
3. Degree of project plan technical feasibility.
• Technical gaps, barriers, and risks to achieving the performance requirements are clearly identified. • Scientific/engineering approaches have been designed to overcome the identified technical gaps, barriers, and risks to achieve the performance requirements. • Remaining technical work planned is appropriate considering progress to date and remaining schedule and budget. • Appropriate risk mitigation plans exist, including Decision Points when applicable.
4. Suitability of lifecycle analysis and technoeconomic analysis.
• Comprehensiveness of the comparative technical and economic analysis (including estimated required selling price [RSP] for the primary product[s]), and the demonstrated potential for the proposed technology to offer an improvement over current production methods or technologies. • Technoeconomic analysis commensurate to the Technology Readiness Level (TRL) of the proposed technology, as informed by the results of testing. • Demonstration that the carbon lifecycle of the product(s) offers a path toward environmental sustainability and commercial viability.
5. Degree to which progress has been made towards achieving the stated performance requirements.
• The project has tested (or is testing) those attributes appropriate for the next TRL. The level of technology integration and nature of the test environment are consistent with the aforementioned TRL definition. • Project progress, with emphasis on experimental results, shows that the technology has, or is likely to, achieve the stated performance requirements for the next TRL (including those pertaining to capital cost, if applicable). • Milestones and reports effectively enable progress to be tracked. • Reasonable progress has been made relative to the established project schedule and budget.
6. Degree to which an appropriate basis exists for the technology's performance attributes and requirements.
• The TRL to be achieved by the end of the project is clearly stated[2]. • Performance attributes for the technology are defined[2]. • Performance requirements for each performance attribute are, to the maximum extent practical, quantitative, clearly defined, and appropriate for and consistent with the DOE goals as well as technical and economic viability in the intended commercial application.
7. The project Technology Maturation Plan (TMP) represents a viable path for technology development beyond the end of the current project, with respect to scope, timeline, and cost. *(This criterion is not applicable to a recommendations-based evaluation)*
[1] *If it is appropriate for a project to not have cost/economic-related performance requirements, then the project is evaluated on technical performance requirements only.* [2] *Supported by systems analyses appropriate to the targeted TRL.*

<u>NETL Peer Review – Rating Definitions and Scoring Plan</u> (not applicable to TRL-based evaluation)

The Review Panel assigns an overall score to the project after strengths, weaknesses, and prioritized recommendations are generated at the meeting. Intermediate whole number scores are acceptable if the Review Panel feels it is appropriate. The overall project score must be justified by, and consistent with, the identified strengths and weaknesses.

NETL Peer Review Rating Definitions and Scoring Plan	
10	**Excellent -** Several major strengths; no major weaknesses; few, if any, minor weaknesses. Strengths are apparent and documented.
8	**Highly Successful -** Some major strengths; few (if any) major weaknesses; few minor weaknesses. Strengths are apparent and documented, and outweigh identified weaknesses.
5	**Adequate -** Strengths and weaknesses are about equal in significance.
2	**Weak -** Some major weaknesses; many minor weaknesses; few (if any) major strengths; few minor strengths. Weaknesses are apparent and documented, and outweigh strengths identified.
0	**Unacceptable -** No major strengths; many major weaknesses. Significant weaknesses/deficiencies exist that are largely insurmountable.

APPENDIX B: DOE TECHNOLOGY READINESS LEVELS

The following is a description of U.S. Department of Energy (DOE) Technology Readiness Levels (TRLs).

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	TRL 9	Actual system operated over the full range of expected mission conditions	The technology is in its final form and operated under the full range of operating mission conditions. Examples include using the actual system with the full range of wastes in hot operations.
System Commissioning	TRL 8	Actual system completed and qualified through test and demonstration	The technology has been proven to work in its final form and under expected conditions. In almost all cases, this Technology Readiness Level (TRL) represents the end of true system development. Examples include developmental testing and evaluation of the system with actual waste in hot commissioning. Supporting information includes operational procedures that are virtually complete. An Operational Readiness Review (ORR) has been successfully completed prior to the start of hot testing.
	TRL 7	Full-scale, similar (prototypical) system demonstrated in relevant environment	This represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing full-scale prototype in the field with a range of simulants in cold commissioning (1). Supporting information includes results from the full-scale testing and analysis of the differences between the test environment, and analysis of what the experimental results mean for the eventual operating system/environment. Final design is virtually complete.
Technology Demonstration	TRL 6	Engineering/pilot-scale, similar (prototypical) system validation in relevant environment	Engineering-scale models or prototypes are tested in a relevant environment. This represents a major step up in a technology's demonstrated readiness. Examples include testing an engineering-scale prototypical system with a range of simulants (1). Supporting information includes results from the engineering-scale testing and analysis of the differences between the engineering-scale, prototypical system/environment, and analysis of what the experimental results mean for the eventual operating system/environment. TRL 6 begins true engineering development of the technology as an operational system. The major difference between TRL 5 and 6 is the step-up from laboratory scale to engineering scale and the determination of scaling factors that will enable design of the operating system. The prototype should be capable of performing all the functions that will be required of the operational system. The operating environment for the testing should closely represent the actual operating environment.

Technology Development	**TRL 5**	Laboratory-scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity, laboratory scale system in a simulated environment with a range of simulants (1) and actual waste (2). Supporting information includes results from the laboratory scale testing, analysis of the differences between the laboratory and eventual operating system/environment, and analysis of what the experimental results mean for the eventual operating system/environment. The major difference between TRL 4 and 5 is the increase in the fidelity of the system and environment to the actual application. The system tested is almost prototypical.
Technology Development	**TRL 4**	Component and/or system validation in laboratory environment	The basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of ad hoc hardware in a laboratory and testing with a range of simulants and small-scale tests on actual waste (2). Supporting information includes the results of the integrated experiments and estimates of how the experimental components and experimental test results differ from the expected system performance goals. TRL 4–6 represent the bridge from scientific research to engineering. TRL 4 is the first step in determining whether the individual components will work together as a system. The laboratory system will probably be a mix of on hand equipment and a few special purpose components that may require special handling, calibration, or alignment to get them to function.

Research to Prove Feasibility	**TRL 3**	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development (R&D) is initiated. This includes analytical studies and laboratory-scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative tested with simulants (1). Supporting information includes results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. At TRL 3 the work has moved beyond the paper phase to experimental work that verifies that the concept works as expected on simulants. Components of the technology are validated, but there is no attempt to integrate the components into a complete system. Modeling and simulation may be used to complement physical experiments.
Research to Prove Feasibility / **Basic Technology Research**	**TRL 2**	Technology concept and/or application formulated	Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies. Supporting information includes publications or other references that outline the application being considered and that provide analysis to support the concept. The step up from TRL 1 to TRL 2 moves the ideas from pure to applied research. Most of the work is analytical or paper studies with the emphasis on understanding the science better. Experimental work is designed to corroborate the basic scientific observations made during TRL 1 work.
Basic Technology Research	**TRL 1**	Basic principles observed and reported	This is the lowest level of technology readiness. Scientific research begins to be translated into applied R&D. Examples might include paper studies of a technology's basic properties or experimental work that consists mainly of observations of the physical world. Supporting Information includes published research or other references that identify the principles that underlie the technology.

[1] Simulants should match relevant chemical and physical properties.

[2] Testing with as wide a range of actual waste as practicable and consistent with waste availability, safety, as low as reasonably achievable (ALARA), cost, and project risk is highly desirable.

APPENDIX C: MEETING AGENDA

FY21 Carbon Utilization Peer Review
June 8-11, 2021
Virtual Meeting

**** All times Eastern ****

Day 1 – Tuesday, June 8, 2021

12:00 – 12:30 p.m.	Peer Review Panel Kickoff Session *DOE HQ/NETL, KeyLogic Peer Review Support Staff, and Panel Members Attend* - Facilitator Opening, Review Panel Introductions, NETL Welcome, Peer Review Process and Meeting Logistics
12:30 – 1:15 p.m.	Project FE0031710 – Novel Algae Technology to Utilize Carbon Dioxide for Value-Added Products *Fred Harrington* – Helios-NRG, LLC
1:15 – 2:00 p.m.	Question-and-Answer Session
2:00 – 2:15 p.m.	BREAK
2:15 – 3:45 p.m.	Closed Discussion (Peer Review Panel Evaluation – Technology Readiness Level-Based) *DOE HQ/NETL and KeyLogic Peer Review Support Staff Attend as Observers*
3:45 p.m.	Adjourn

**** All times Eastern ****

Day 2 – Wednesday, June 9, 2021

12:00 – 12:10 p.m.	Kickoff Session
12:10 – 12:55 p.m.	Project FE0031915 – Achieving Unprecedented Carbon Dioxide Utilization in CO_2Concrete: System Design, Product Development and Process Demonstration *Gaurav Sant* – University of California - Los Angeles Project FE0031718 – A Scalable Process for Upcycling Carbon Dioxide (CO_2) and Coal Combustion Residues Into Construction Products *Gaurav Sant* – University of California - Los Angeles
12:55 – 1:40 p.m.	Question-and-Answer Session
1:40 – 2:00 p.m.	BREAK
2:00 – 3:30 p.m.	Closed Discussion (Peer Review Panel Evaluation – Technology Readiness Level-Based) *DOE HQ/NETL and KeyLogic Peer Review Support Staff Attend as Observers*
3:30 p.m.	Adjourn

**** All times Eastern ****

Day 3 – Thursday, June 10, 2021

12:00 – 12:10 p.m.	Kickoff Session
12:10 – 12:55 p.m.	Project FE0031705 – Synthetic Calcium Carbonate Production by Carbon Dioxide (CO_2) Mineralization of Industrial Waste Brines *Bu Wang* – University of Wisconsin
12:55 – 1:40 p.m.	Question-and-Answer Session
1:40 – 2:00 p.m.	BREAK
2:00 – 3:30 p.m.	Closed Discussion (Peer Review Panel Evaluation – Recommendations-Based) *DOE HQ/NETL and KeyLogic Peer Review Support Staff Attend as Observers*
3:30 – 4:15 p.m.	Peer Review Panel Discussion *DOE/NETL and KeyLogic Peer Review Staff Attend*
4:15 p.m.	Adjourn

**** All times Eastern ****

Day 4 – Friday, June 11, 2021

12:00 – 12:10 p.m.	Kickoff Session
12:10 – 12:55 p.m.	Project FWP-1022426 – CO_2 Utilization Technologies (Task 2: Catalytic Conversion of CO_2 to Industrial Chemicals and Evaluation of CO_2 Use and Re-Use Strategies) *Douglas Kauffman* – National Energy Technology Laboratory
12:55 – 1:40 p.m.	Question-and-Answer Session
1:40 – 2:00 p.m.	BREAK
2:00 – 3:30 p.m.	Closed Discussion (Peer Review Panel Evaluation – Recommendations-Based) *DOE HQ/NETL and KeyLogic Peer Review Support Staff Attend as Observers*
3:30 – 4:00 p.m.	Peer Review Panel Wrap-Up Session (Common Themes & Logistics/Process Feedback) *DOE HQ/NETL, KeyLogic Peer Review Support Staff, and Panel Members Attend*
4:00 p.m.	Adjourn

APPENDIX D: PEER REVIEW PANEL MEMBERS

FY21 Carbon Utilization Peer Review
June 8-11, 2021
Virtual Meeting

Brent Constantz, Ph.D.

Dr. Brent Constantz is the Chief Executive Officer (CEO) of Blue Planet Ltd. He is an entrepreneur with expertise in the area of biomineralization, the process by which living organisms produce minerals, such as the formation of calcite (i.e., calcium carbonate) from carbon dioxide (CO_2) and calcium. Over the past 25 years, Dr. Constantz has founded and led three medical device companies that pioneered advanced mineralization technologies for orthopedic bone cement. He also founded and served as CEO for Norian Corporation, Corazon Technologies, Skeletal Kinetics, Calera Corporation, DeepWater Desal, and Blue Planet.

Dr. Constantz is also a consulting associate professor at Stanford University, where he teaches biomineralization. Dr. Constantz discovered the basic process used by corals to form their skeletons in the 1980s, which he based modern biological bone cements on—these are found in most operating rooms around the world that perform orthopedic surgery. In 2007, he launched efforts to address climate change by storing anthropogenic CO_2 as building materials, specifically concrete. A Fulbright Scholar, Dr. Constantz has been awarded grants from governments, including the United States, Canada, and Australia; testified before the U.S. Senate and the U.S. House of Representative about climate change; and won a number of awards and honors. Dr. Constantz is the inventor on more than 100 issued U.S. patents, with more than 100 more currently pending. He earned his B.A., M.S., and Ph.D. from the University of California.

Anne Gaffney, Ph.D.

Dr. Anne Gaffney is the Director of Process Science and Technology at Idaho National Laboratory and recently appointed Laboratory Fellow. Dr. Gaffney has more than 30 years of industrial chemistry and catalysis experience, having worked at ARCO, DuPont, Rohm and Haas, and Lummus Technology in various research and development (R&D) and leadership roles.

Dr. Gaffney received a Ph.D. in physical organic chemistry from the University of Delaware and a B.A. in chemistry and mathematics from Mount Holyoke College. She has been a prolific inventor and author, with more than 150 U.S. patents and more than 90 publications. Dr. Gaffney has received many awards, including the Eugene J. Houdry Award in 2015, the American Chemical Society (ACS) Award in Industrial Chemistry in 2013, ACS Fellow in 2010, the Tribute to Women in Industry Award in 2007, and the Catalysis Club of Philadelphia Award in 1999

Kevin McCabe

Kevin McCabe supports environmental technology verification (ETV) activities for 350Solutions as a lead project and technology engineer. He is a mechanical engineer with data processing experience and experience in technology R&D, process operations, laboratory analytical work, and catalyst development. Over the past two years he has led performance verification of numerous carbon conversion technologies at both laboratory and pilot scale. Mr. McCabe is proficient in engineering modeling capabilities, including ASPEN and COMSOL, and has extensive experience as an analytical engineer collecting, calculating, and evaluating data, while improving data quality measures to correct errors. As a lead operator he was responsible for following pilot plant operations through a series of detailed steps and processes.

Mr. McCabe's duties include process modeling, such as techno-economic and life cycle analyses (TEA/LCA); design of operating procedures and test protocols; specification and selection of equipment for process development units and testing systems; and collection and interpretation of pilot plant and laboratory data. Mr. McCabe has conducted TEA/LCA on a range of technology development programs. He earned an M.S. in mechanical engineering (material science) from Northeastern University and a B.S. in physics and chemistry from Northeastern University.

Brian Turk, Ph.D.

Dr. Brian Turk is an independent consultant responsible for providing technical expertise in the design and development of a field-testing system for curing approximately 10 tons of concrete blocks with process waste gas with high CO_2 concentrations per day. He previously worked as a Senior Engineering Fellow at Susteon Inc. as a project leader responsible for developing, marketing, executing, and reporting for research projects and supervising lab- and bench-scale testing programs for material and process development. Dr. Turk had a leadership role in the design, engineering, commissioning, start-up, troubleshooting, and operation of offsite pilot and demonstration testing projects. Dr. Turk also served in multiple roles during his tenure with RTI International as Director of the Syngas Program. One of his key accomplishments was advancing a suite of technologies for removing contaminants from syngas, including sulfur, mercury, arsenic selenium, ammonia, hydrogen chloride, and CO_2. Under his supervision, the technologies moved from lab-scale testing into pilot-scale and slipstream testing with real syngas and, ultimately, pre-commercial demonstration.

Dr. Turk also led the operation of the 50-megawatt demonstration plant at Tampa Electric Company (TECO), which integrated a novel desulfurization process and a solvent-based CO_2 capture process (Activated Methyldiethanolamine™ [aMDEA™]) and achieved more than 90% CO_2 capture. He has supported a number of other research activities, including development of a novel catalytic material; sorbents; fixed- and fluidized-bed processes; a transport reactor-based methanation process; an attrition-resistant, high-temperature, water-gas shift catalyst and transport reactor-based process; and an attrition-resistant, iron-based material. Dr. Turk is at the author of several journal articles and final technical reports for the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) and is a member of the American Institute of Chemical Engineers (AIChE). Dr. Turk has a Ph.D. from the University of Houston and a B.S. from Purdue University, both in chemical engineering.