Advanced Manufactured Carbonate Materials for Algal Biomass Production: Joint LLNL-SNL Program

NETL CO₂ Capture Technology Project Review Meeting

August 16, 2018

LLNL: Jennifer Knipe, Sarah Baker, Maira Ceron-Hernandez, Matthew Worthington, Sean McCoy, William Bourcier

SNL: Todd Lane, Mary Tran-Gyamfi

DOE NETL Project Manager: Andrew Jones
## Budget - 1 year FWP 10/1/17-9/30/18

### Government Share

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>Amount</th>
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<tbody>
<tr>
<td>Lawrence Livermore National Laboratory</td>
<td>$390,000</td>
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<tr>
<td>Sandia National Laboratory</td>
<td>$360,000</td>
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<td><strong>Total</strong></td>
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### Lawrence Livermore National Laboratory - Fiscal Year 1

<table>
<thead>
<tr>
<th></th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Total Project</th>
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<tr>
<td><strong>Federal Share</strong></td>
<td>$112,500</td>
<td>$92,500</td>
<td>$92,500</td>
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<td><strong>Total Planned</strong></td>
<td>$112,500</td>
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### Sandia National Laboratory - Fiscal Year 1

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<th>Q3</th>
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<td>$360,000</td>
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</table>
Project Objectives

Task 1: Project planned and managed by Lawrence Livermore National Laboratory

Task 2: Select the most promising material and geometry

Task 3: Demonstrate CO₂ storage in materials and delivery to support algal culture in an algal test bed at pilot scale

Task 4: Evaluate the economics and gate-to-gate GHG emissions of the coupled capture-transport
# Milestone Schedule

<table>
<thead>
<tr>
<th>Task</th>
<th>Milestone Description</th>
<th>Project Duration</th>
<th>Planned Start Date</th>
<th>Planned End Date</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Start: October 1, 2017</td>
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<td></td>
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<td>End: September 30, 2018</td>
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<td>Project Year (PY) 1</td>
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<td></td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
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<tr>
<td>1.0</td>
<td>Project Management and Planning</td>
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<tr>
<td>2.1</td>
<td>Synthesize multigram quantities of carbonate materials</td>
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<td></td>
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<tr>
<td>2.2</td>
<td>Measurements of CO₂ release rates and quantities</td>
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<td>x</td>
<td></td>
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<tr>
<td>2.3</td>
<td>Materials Biocompatibility Evaluation</td>
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<td>x</td>
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<tr>
<td>2.4</td>
<td>Materials Selection for scale-up and TEA</td>
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<td>x</td>
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<tr>
<td>3.1</td>
<td>Material delivery method determined</td>
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<td></td>
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<tr>
<td>3.2</td>
<td>Scaleup materials synthesis to kg scale</td>
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<td></td>
<td>x</td>
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<tr>
<td>3.3</td>
<td>Pilot scale testing</td>
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<tr>
<td>3.4</td>
<td>Measure material capacity during cycling</td>
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<tr>
<td>4.1</td>
<td>Identify Process Configurations for capture, transport, delivery</td>
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<td>x</td>
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<tr>
<td>4.2</td>
<td>Refine Process Configuration and cost model</td>
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<td>x</td>
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<tr>
<td>4.3</td>
<td>Finalize results of technoeconomic and lifecycle assessments</td>
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</tbody>
</table>
Success Criteria

Carbonate materials can support algal growth at laboratory scale.

June 30, 2018 (FY18)

Carbonate materials can be loaded with CO₂ and unloaded in marine media with <10 % loss in capacity over 10 cycles.

Sept. 30, 2018 (FY18)
# Team

<table>
<thead>
<tr>
<th>Key Personnel</th>
<th>Institution</th>
<th>Time</th>
<th>Tasks</th>
<th>Title, Roles</th>
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</thead>
<tbody>
<tr>
<td>J. Knipe</td>
<td>LLNL</td>
<td>30%</td>
<td>Tasks 1,2,3</td>
<td>Post Doctoral Researcher, Task Lead 2-3, Co-PI</td>
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<tr>
<td>S. Baker</td>
<td>LLNL</td>
<td>10%</td>
<td>Tasks 1,2,3,4</td>
<td>Staff Scientist, Co-PI</td>
</tr>
<tr>
<td>M. Worthington</td>
<td>LLNL</td>
<td>30%</td>
<td>Tasks 2,3</td>
<td>Post-Collegiate Appointee, Carbonate Materials Characterization</td>
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<tr>
<td>M. Ceron-Hernandez</td>
<td>LLNL</td>
<td>30%</td>
<td>Tasks 2,3</td>
<td>Staff Scientist, Carbonate Materials Design and Scale-up</td>
</tr>
<tr>
<td>S. McCoy</td>
<td>LLNL</td>
<td>20%</td>
<td>Task 4</td>
<td>Energy analyst, Process Design and Economic Analysis</td>
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<td>W. Bourcier</td>
<td>LLNL</td>
<td>10%</td>
<td>Task 2</td>
<td>Geochemist, Model carbonate species and pH response</td>
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<tr>
<td>T. Lane</td>
<td>SNL</td>
<td>15%</td>
<td>Tasks 2,3</td>
<td>Sandia PI, Lead Phycologist</td>
</tr>
<tr>
<td>M. Tran-Gyamfi</td>
<td>SNL</td>
<td>50%</td>
<td>Tasks 2,3</td>
<td>Technical Staff, Algae cultivation, characterization of nutrients, biomass, and growth</td>
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</table>
**CO₂-loaded materials can be used for algae production**

**Challenges to CO₂ Capture & Utilization:**
- Corrosivity, evaporative losses, and fouling
- Transportation

**CO₂ is at least 20% of cost of algae cultivation**

1) Provide tunable transport, storage, and delivery
2) Eliminate need to co-localize
3) Reduce capture costs up to 75%

**Absorption**

\[ \text{CO}_2(g) \rightarrow \text{CO}_2(aq) \downarrow \text{HCO}_3^- \]

**Release (Algae Pond)**

\[ \text{CO}_2(aq) \uparrow \text{HCO}_3^- \]

**Additional notes:**
- CO₂ is at least 20% of the cost of algae cultivation.
- CO₂-loaded materials can provide tunable transport, storage, and delivery.
- Eliminates the need for co-localization.
- Reduction in capture costs up to 75%.
Microencapsulation: an enabling technology for CO₂ solvents

Core Solvent: Sodium Carbonate
Sorbent-polymer composites printed with Direct Ink Write (DIW)

- Ink can be loaded with as much as ~60 wt% carbonate
- Particulate sizes sieved as small as possible for best performing ink
Subtask 2.1 – Scaled material synthesis to multigram quantities for testing

100s g/day produced
Subtask 2.2 - Measured CO$_2$ absorption and release rates and quantities

Measure pH of marine media over time to monitor rate of CO$_2$ release

Measure CO$_2$ pressure drop over time to monitor CO$_2$ absorption
Subtask 2.2 - Measured CO$_2$ absorption and release rates and quantities of capsules

- Loading capacity decreases with cycling
- pH drop less & slower than predicted

Capsules not fully releasing CO$_2$??
Subtask 2.2 - Measured CO$_2$ absorption and release rates and quantities of composite mesh

**pH increase & mass loss indicate carbonate leaching**

Sylgard coating prevents carbonate leaching

- Cycle 0 SE-1700 DI water
- Cycle 1 SE-1700 DI water
- Cycle 1 Sylgard DI water
- Cycle 1 SE-1700 media
- Cycle 1 Sylgard media

**pH**

- 2018_0706 Cycle 1
- 2018_0711 Cycle 2
- 2018_0717 Cycle 3
- 2018_0718 Cycle 4
- 2018_0720 Cycle 5

**Mass loss (wt%)**

- 10 wt% bicarbonate
- 20 wt% bicarbonate
- 30 wt% bicarbonate
Subtask 2.3 - Materials are biocompatible
Subtask 3.1 – Material delivers CO₂ for algal growth

- Increased pH and precipitant indicate leaching of carbonate
- Mesh 1 leached ~15% and Mesh 2 leached ~10%
- Drying between cycles required to prevent excessive swelling and leaching
Subtask 3.4 – Material capacity maintained over cycling

- 20 wt% carbonate with sylgard coating- not dried between cycles
- Lower carbonate loading lost <1 wt%
- Loading very reproducible but not all CO₂ is released
- pH drop tracks with TIC increase as expected

![Graph showing CO₂ and pH changes over cycles](image)
Task 3: Testing selected materials to support algal growth and CO₂ cycling

- **Subtask 3.2 – Scale up materials synthesis**
  - Synthesis of selected carbonate material(s) at kilogram scale
  - The scale-up method employed may require different manufacturing techniques such as using a vibrating coaxial tip rather than microfluidics to produce encapsulated carbonate solutions

- **Subtask 3.3 – Pilot-scale testing**

n. salina control media with ammonia

100 ml → 500 ml → 1000 L
Task 4. Process synthesis and Techno-economic analysis

- **Subtask 4.1 - Identify process configurations for capture, transport and delivery**
  - Identify an integrated process to capture, transport, and deliver CO₂ using carbonate materials
  - Include details of transport of carbonate materials to algal farms, on-site delivery of CO₂ to algal ponds or bioreactors, and recovery and recycling of the carbonate materials

- **Subtask 4.2 - Refine process configuration and cost model**
  - Estimate the capital and operating costs of the process for several different CO₂ supply scenarios to provide a per ton estimate of the cost of CO₂ supply and profitability of the system
  - GHG emissions will also be estimated and reported

- **Subtask 4.3 - Finalize results of techno-economic and lifecycle assessments**
  - Complete an initial TEA and LCA
  - Compare the results of the TEA and gate-to-gate LCA to an equivalent system that delivers liquefied CO₂
Summary

- Measured CO$_2$ loading/release rates in marine media with two material formulations
- Verified biocompatibility and selected carbonate composite meshes for scale-up
- Demonstrated cyclability of material in marine media
- Continuing Task 3: Scale up & Pilot Scale and Task 4: Process Design & TEA
  - Demonstration of comparable algal growth with CO$_2$ delivered from material at mL to L scales
  - Obtaining data for process design & TEA
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