Low-Cost and Recyclable Oxygen Carrier and Novel Process for Chemical Looping Combustion
DE-FE0031534

By

Junior Nasah
Institute for Energy Studies

12/01/2017 to 11/30/2020
Presentation Overview

• Project Overview
• Background on existing CLC projects at UND/Envergex LLC
• Project Objectives
• Technical Approach
• Scope of Work
• Questions/Discussion
**Overall Goal:** Demonstrate transformational technology that overcomes two key CLC technology gaps:

- high cost of OC replacement/loss
- incomplete fuel conversion, resulting in reduced CO₂ capture efficiency and an oxygen demand downstream of the CLC reducer reactor.

**Funding:** Department of Energy $1,500,000; Cost-share - $375,000

**Project Participants:**
1. University of North Dakota – Institute for Energy Studies (Lead)
2. Envergex LLC
3. Barr Engineering
4. Microbeam Technologies, Inc. (pending)
5. Carbontec Energy Corporation
Existing Projects

1. Attrition Evaluation
2. Char Stripping
3. Spout – Fluid Bed Development
   – Developing a novel reactor geometry to be used for chemical looping combustion
   – Developing a modeling tool co-currently with the reactor geometry to facilitate scale up
Unique oxygen carrier composition and manufacturing platform:

- **Main component enriched iron oxide powder**: abundant and low-cost domestic production
- **Blending in a small proportion of low-cost additives** to avoid agglomeration tendency of pure iron oxide
- **Preliminary attrition results promising**
Technical Approach – Overall Process

Tested in laboratory scale reactor (High Temperature Redox Attrition Test Unit):

- Hydrogen conversion very good
- CO conversion also promising
Technical Approach – Overall Process

SPOUT FLUID-BED REDUCER DESIGN:
- High velocity in draft tube (turbulent to transport regime)
- Low velocity in annulus (low to minimum fluidization velocity)
  - Annulus operates like a “moving bed”
  - Better solid-gas interactions
Technical Approach – Overall Process

- Pressure drop over material bed (inches of water vs. time)
- Top Annulus Temperature (°C vs. time)
- Bar charts showing CO and H2 output for different days and processes:
  - Day 1: Spouted Bed, Pseudo Bubbling Bed (1.3 x SB flow)
  - Day 2: Spouted Bed, Pseudo Bubbling Bed (1.0 x SB flow)
  - Day 3: Bubbling Bed (1.0 x SB flow), Pseudo Spouted Bed

Check marks indicate successful outcomes.
Technical Approach – Overall Process

- **3-D MFiX Models – Hydrodynamics**
  - Cylindrical draft tubes replaced with rectangular → Simplifies modeling
  - Use to investigate flow patterns of OC
  - 3-D isothermal case with variable material inlet and outlet mass flows
  - Implementing custom solver to run simulations more robustly
Technical Approach – Overall Process

Residence Time and Circulation

- OC cooled to < 5°C
- Thermocouples used to monitor effect of circulation and feed rate
- High Circulation vs Low Circulation
- Compare experimental and simulation data
Technical Approach – Overall Process

• Use unique hydrodynamics available with the SFB reducer design
  – Thermodynamics limits combination of fuel gas conversion and deep OC reduction
  – Counter-current operation of the annulus in the SFB can help to improve on this limit
• Incorporate the PCS carbon stripper technology
• Goal: 90% CCR with no/minimal reducer exhaust oxygen demand
Specific Objectives:

1. Demonstrate novel OC manufacturing platform: high performance of “engineered” OCs, but with cost structure of natural ores

2. Identify OC phase transformations and interactions with coal impurities that could impact OC/process performance and OC recyclability; identify mitigation strategies

3. Test a novel combination of CLC components at the 10 kW\textsubscript{th}-scale using existing projects at UND and Envergex LLC.

4. Perform economic assessment to demonstrate progress towards DOE cost of CO\textsubscript{2} capture and cost of electricity targets
Scope of Work

• Task 1 – Project Management and Planning
• Task 2 – Laboratory-scale OC Manufacturing & Assessment
• Task 3 – Modeling and Laboratory-scale Evaluation of OC Performance with Coal
• Task 4 – $10 \, \text{kW}_{\text{th}}$ Integrated System Installation
• Task 5 – Scaled-up OC Manufacturing
• Task 6 – $10 \, \text{kW}_{\text{th}}$ Testing
• Task 7 – Process Design and Techno-Economic Analysis
Task 2 Overview

Subtask 2.1 – OC Manufacturing
- ~40 unique OC formulations
- Composition, binder loading, particle size, granulation method, curing

Subtask 2.2 – OC Characterization and Performance Testing
- Determine physical/chemical characteristics before/after exposure to CLC tests
- Perform CLC testing: reducing gas conversions, impact of sulfur, attrition, agglomeration
- Parameters to include: temperature, gas/solid contact time, reducing gas composition, jet velocity
- **Down-select to 2 OCs based on testing**

Subtask 2.3 – Longer-term Operation and Recyclability Evaluation
- ~500 redox cycles; Evaluate long term performance
- Collect fines generated and evaluate CLC performance/characteristics of reformulated fines compared to fresh OC
Task 3 Overview

Subtask 3.1 – Fluidized Bed Testing with Coal
• Use coal as reductant instead of reducing gases
• Parametric and longer-term testing
• Down-select to 1 OC formulation

Subtask 3.2 – Experimental Evaluation of OC/Coal Ash Interactions
• TGA-DSC: Identify zones of phase transformations/reactions of OC/coal ash; characterization to determine OC transformations
• Temperature, contact time, gas phase composition, ash type/composition

Subtask 3.3 – Thermochemical Equilibrium Modeling
• HSC Chemistry 9.0: model reactions of OC with coal ash
• Investigate agglomeration potential using viscosity models
• Develop mitigation strategies to minimize detrimental impacts

Subtask 3.4 – OC Fines Separation and Recyclability
• Tests to identify impact of coal impurities on OC recyclability
Tasks 4-6 Overview

Task 4 – 10 kW\textsubscript{th} System Installation
- Leverage existing and to-be-constructed equipment from existing projects
- SFB reducer, PCS carbon stripper, Novel process configuration
- Circulating CLC system

Task 5 – Scaled-up OC Manufacturing
- ~1000 kg of down-selected OC formulation
- Evaluate physical/chemical characteristics to compare to lab quantities

Task 6 – 10 kW\textsubscript{th} Testing
- Reducer/oxidizer temperature, OC residence time
- Reducer coal/char residence time
- OC/Coal ratio
- ~100 hours of testing at optimized conditions for two coal types
Task 7 Overview

Task 7 – Process Design and Techno-Economic Assessment

- Process modeling using Aspen Plus®
- Determine economic metrics
- Led by qualified 3rd party A&E Firm – Barr Engineering Company

### Project Schedule

#### Note: Actual Start date January 18, 2018

<table>
<thead>
<tr>
<th>Task/Subtask/Milestone Description</th>
<th>Start Date</th>
<th>End Date</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Task 1 - Project Management &amp; Planning</strong></td>
<td>11/01/17</td>
<td>10/31/20</td>
</tr>
<tr>
<td>Milestones</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Update Project Management Plan</td>
<td>11/30/17</td>
<td></td>
</tr>
<tr>
<td>Kickoff Meeting</td>
<td>11/30/17</td>
<td></td>
</tr>
<tr>
<td>Quarterly Report</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Technical Report</td>
<td>10/31/20</td>
<td></td>
</tr>
<tr>
<td><strong>Milestones</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Task 2 - Lab-scale OC Manufacturing &amp; Assessment</strong></td>
<td>11/01/17</td>
<td>08/31/18</td>
</tr>
<tr>
<td>Subtask 2.1 - OC Manufacturing</td>
<td>11/01/17</td>
<td>05/31/18</td>
</tr>
<tr>
<td>Subtask 2.2 - OC Characterization and Testing</td>
<td>11/01/17</td>
<td>05/31/18</td>
</tr>
<tr>
<td>Subtask 2.3 - Long-term Cyclic Testing and Recyclability Evaluation</td>
<td>06/01/18</td>
<td>08/31/18</td>
</tr>
<tr>
<td>Milestones</td>
<td>05/31/18</td>
<td></td>
</tr>
<tr>
<td><strong>Task 3 - Modeling and Laboratory-scale Evaluation of OC Performance with Coal</strong></td>
<td>09/01/18</td>
<td>07/31/19</td>
</tr>
<tr>
<td>Subtask 3.1 - Fluidized Bed Testing</td>
<td>09/01/18</td>
<td>01/31/19</td>
</tr>
<tr>
<td>Subtask 3.2 - TGA Testing</td>
<td>01/01/19</td>
<td>03/31/19</td>
</tr>
<tr>
<td>Subtask 3.3 - Thermodynamic Modeling</td>
<td>03/01/19</td>
<td>04/30/19</td>
</tr>
<tr>
<td>Subtask 3.4 - OC Fines Separation and Recyclability</td>
<td>04/01/19</td>
<td>07/31/19</td>
</tr>
<tr>
<td>Milestones</td>
<td>01/31/19</td>
<td></td>
</tr>
<tr>
<td>Down-selection to one OC type</td>
<td>01/31/19</td>
<td></td>
</tr>
<tr>
<td>OC Characterization and Testing Summary Report</td>
<td>08/31/19</td>
<td></td>
</tr>
<tr>
<td><strong>Task 4 - 10 kWth Integrated System Installation</strong></td>
<td>03/01/19</td>
<td>10/31/19</td>
</tr>
<tr>
<td>Milestones</td>
<td>04/30/19</td>
<td></td>
</tr>
<tr>
<td>System Design Package Report</td>
<td>10/31/19</td>
<td></td>
</tr>
<tr>
<td>System Commission</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Task 5 - Scaled-up OC Manufacturing</strong></td>
<td>03/01/19</td>
<td>09/30/19</td>
</tr>
<tr>
<td><strong>Task 6 - 10 kWth Testing</strong></td>
<td>11/01/19</td>
<td>07/31/20</td>
</tr>
<tr>
<td>Milestones</td>
<td>08/31/20</td>
<td></td>
</tr>
<tr>
<td>10 kWth Testing Summary Report</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Task 7 - Process Design and Technical and Economic Analysis</strong></td>
<td>07/01/20</td>
<td>10/31/20</td>
</tr>
<tr>
<td>Milestones</td>
<td>10/31/20</td>
<td></td>
</tr>
<tr>
<td>Technical and Economic Analysis Report</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Acknowledgement and Disclaimer

Acknowledgement: “This material is based upon work supported by the Department of Energy under Award Number DE-FE0031534.”

Disclaimer: “This report was report prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.”
Questions/Discussions

Junior Nasah
Institute for Energy Studies
University of North Dakota
junior.nasah@engr.und.edu
701-777-4307

Dr. Srivats Srinivasachar
Envergex LLC
srivats.srinivasachar@envergex.com
508-347-2933