Low-Cost and Recyclable Oxygen Carrier and Novel Process for Chemical Looping Combustion
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Project Partners

1. University of North Dakota (Prime)
2. Envergex LLC
3. Carbontec Energy Corporation
4. Microbeam Technologies, Inc.
5. BARR Engineering
Presentation Overview

• Background – Chemical Looping Combustion
• Project Objectives
• Project Results
• Current status of project / highlights
• Future work
• Conclusions & Questions
**What is Chemical Looping Combustion (CLC)?**
- Advanced coal combustion process
- CO$_2$ capture-ready process
- Higher combustion efficiency
- Oxygen Carrier (OC) = Metal Oxide

**Challenges Facing CLC:**
1. Incomplete coal conversion
2. Incomplete char conversion
3. Attrition (loss) of metal oxide (MO)
Main Project Objectives

• **Funding Objective:** Advance CLC technologies towards meeting 90% CO$_2$ capture and 99% carbon conversion.

• **Project Objectives:**

  o Develop low cost, low attrition and “recyclable” oxygen-carrier

  o Develop a 10 kW unit that:
    
    o Uses unique hydrodynamics of spouted fluid bed (SFB) to improve coal char reduction
    
    o Incorporates particle char separator (PCS) technology to improve char conversion
    
    o 90% CO2 Capture (90% fuel conversion)
• **Project Objectives:**

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Oxygen Carrier Development

Formulations:

- **Active looping ingredient**: Taconite, bauxite waste, ilmenite, steel processing wastes, manganese oxides
- **Attrition inhibitors**: iron based x 2, calcium based x 4 and carbon based x 1.

Raw material sourcing: commodity suppliers, bulk availability

Formulation Method:

- **Communition** via ball milling
- **Micro-pelletization**, tumbler and screens
- **Strength curing**
Oxygen Carrier Screening

- Screening occurs during strength curing
- **Final screening** used jet attrition system\(^1\) under cyclic conditions:
  - **Bed Temperature**: 900\(^\circ\)C
  - **Reducing conditions**: H\(_2\), CO, CO\(_2\) each 5 vol%.
  - **Oxidizing conditions**: 10 vol% O\(_2\)
  - **Bed Velocity**: 40, 50, 65 cm/s
  - **Kinetic power**: 75 W/kg
  - **Jet velocity**: 270, 350, 440 m/s

Oxygen Carrier Benchmark Testing

- 20 oxygen carrier formulations, including ilmenite evaluated in attrition unit
Oxygen Carrier Benchmark – Down-selection

- Modified attrition system to a spout-cyclonic reactor\(^1\)
- System simulates attrition in cyclone systems
- Low-efficiency cyclones recommended

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Oxygen Carrier – Down-selection

Milestone: FEL3 and FEH31 down-selected

• FEH31 down-selected due to difference in formulation (taconite only)
• Further testing performed to down-select:
  • Extended attrition performance
  • Reactivity
Oxygen Carrier Testing – Extended Attrition

- Testing conditions
  - 900°C
  - Jet velocity – 180 m/s
  - Cyclic capacity: 1 wt% (90 cycles), 2 wt% (50 cycles)
  - Kinetic Power – 25 W/kg
  - Best long term performance: FEL3
    - bulk density stabilized at 60 cycles.
Oxygen Carrier Benchmarking - Reactivity

**Reactivity:** Evaluated by TGA (TA instruments)

- Evaluated CO conversion
  - CO / CO2 Ratio: **0.33 & 1**
  - CO concentration: **4% and 10%**
- Rate of O₂ consumption ($R_{O_2}$, mmol/g/min)
- Extent of OC reduction ($X$, wt.%)

\[
X = \left(\frac{M_t=0 - M_t}{M_{t=0}}\right) \times 100
\]

\[
R_{O_2} = \frac{1}{M_{t=0}} \frac{dN}{dt}
\]

N = millimol of O-atom; N = $M_t \frac{M_t (g)}{16000 (g mmol)}$

M = Mass (grams) at “t”; t = Time (minutes)
Oxygen Carrier Benchmarking - Reactivity

Reactivity:

- Engineered OC show 5 to 8 times higher reactivity
- At higher CO levels, deeper reductions observed
- At ~2.5 wt%, reaction order changes; diffusion or rate controlled?
Oxygen Carrier Final Down-Select

• **Milestone: Down-selected FEL3** (best attrition performance)

• **FEH31** selected as alternate.

• Currently evaluating recyclability of FEL3

  • Material subjected to CLC - char testing is being re-formulated using formulation process.
Oxygen Carrier Future Work

- Scaled-up manufacturing of FEL3
  - Produce **1000 lbs**
  - Procured Jet mill for communion step (top picture)
  - Negotiating lease of micro-pelletizer for making pellets. In discussion with Lancaster Products for lease of a micro-pelletizer
    - Rotary kiln for curing step (bottom picture)
- Delay in procuring active looping ingredient has resulted in project schedule delay
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10 kW Construction

- **Reducer Design** – Spout Fluid Bed design\(^1\)
- **Char Stripper** – Particle Char separator\(^2\)
- **Volatile reducer** – moving bed; coal feed location

10 kW Construction

- **Cold flow model** (left) to verify solid circulation
- **10 kW unit** (right) constructed
- **Propane burner** (not shown) added to oxidizer to minimize heat loss
10 kW Operation

Solids Circulation (~300 lbs/hr):

- Target temperature achieved in riser (2)
- Temperature reducer (4, 5) ~ 800°C
- Solids residence time in oxidizer < 1 sec.
10 kW Oxidizer Modification

- **Oxidizer Design** – Several additions to minimize heat loss and wall temperatures
  - First added propane burner
  - Re-designed oxidizer to include **refractory-lined wall** and increase **residence time**
  - Modification ongoing, target completion 10/01/2020
Current Project Status / Highlights

• Evaluated > 40 OC formulations using a mechanical mixing method

• Best performers benchmarked against ilmenite

• Down-selected one engineered OC (FEL3) and one alternate (FEH31), reactivity up to 8 times better than baseline ilmenite

• One year project extension requested to accommodate delays in execution.
• Recyclability of FEL3 currently being evaluated.
• Completion of 10 kW Modification on track (October)
• Testing with benchmark Ilmenite will resume upon completion
• Scaled-up production of 1000 lb of FEL3 pending procurement of final ingredient
Thank you!

Questions?