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

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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

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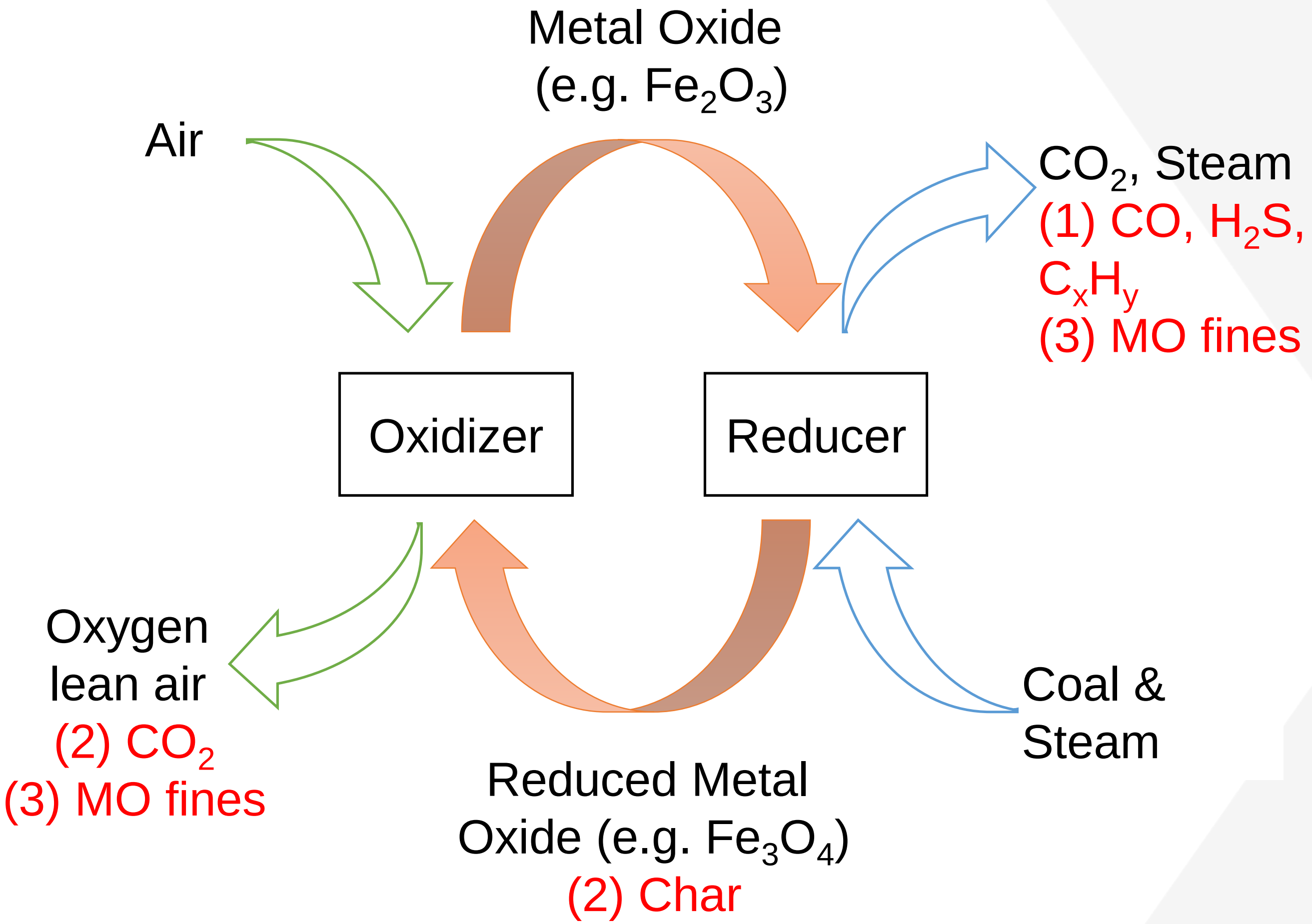
Chemical Looping Combustion

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)



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Main Project Objectives

- **Funding Objective**: Advance CLC technologies towards meeting 90% CO_2 capture and 99% carbon conversion.

- **Project Objectives:**
    - Develop low cost, low attrition and “recyclable” oxygen-carrier
    - Develop a 10 kW unit that:
        - Uses unique hydrodynamics of spouted fluid bed (SFB) to improve coal char reduction
        - Incorporates particle char separator (PCS) technology to improve char conversion
        - 90% CO2 Capture (90% fuel conversion)

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Project Updates

- **Project Objectives:**
  - **Develop low cost, low attrition and "recyclable" oxygen-carrier**
  - Develop a 10 kW unit that:
    - Use unique hydrodynamics of spouted fluid bed (SFB) to improve coal char reduction
    - Incorporate particle char separator (PCS) technology to improve char conversion
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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**

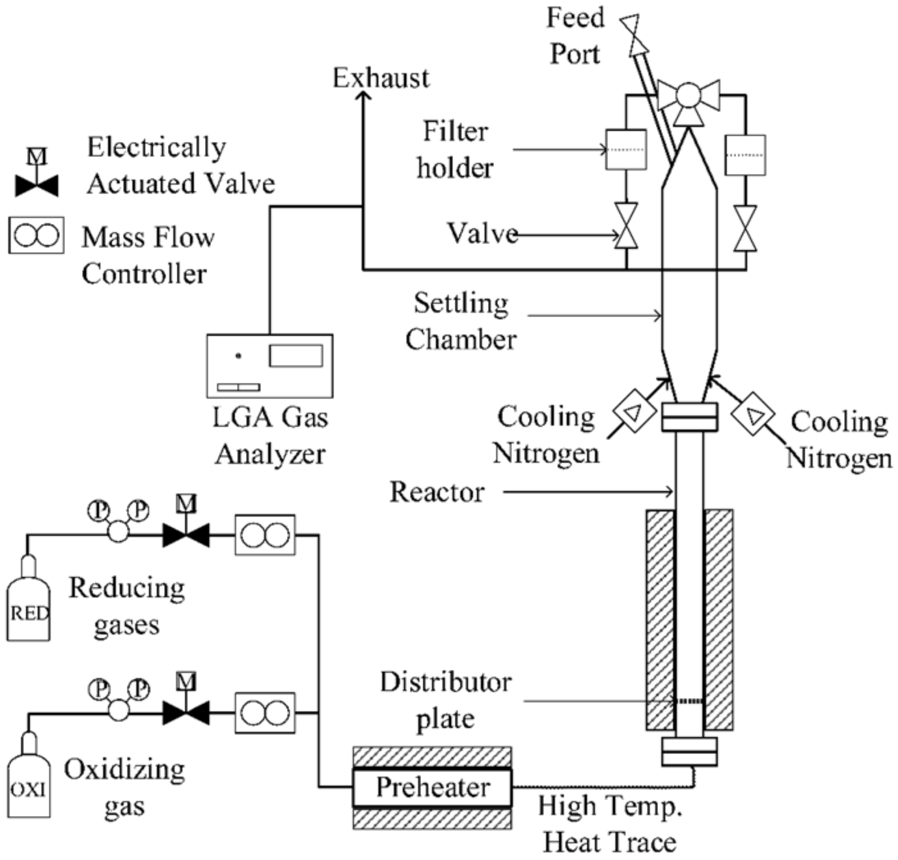

Pelletizing tumbler (screens not shown)


Cured OC Material


Ball Milling System

Oxygen Carrier Screening

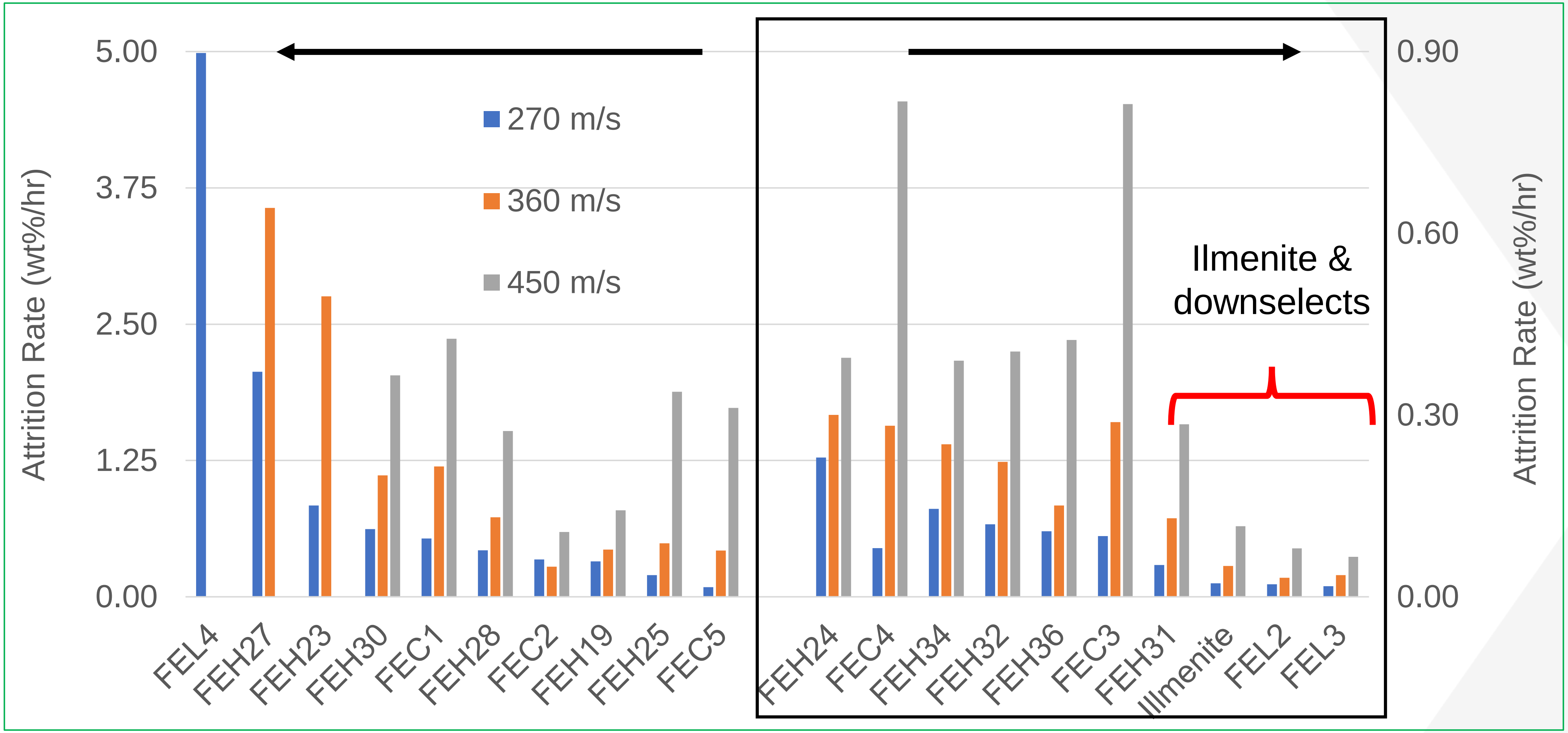
- Screening occurs during strength curing
- **Final screening** used jet attrition system[1] under cyclic conditions:
  - *Bed Temperature*: **900°C**
  - *Reducing conditions*: **H_2, CO, CO_2 each 5 vol%.**
  - *Oxidizing conditions*: **10 vol% O_2**
  - *Bed Velocity*: **40, 50, 65 cm/s**
  - *Kinetic power:* **75 W/kg**
  - *Jet velocity*: **270, 350, 440 m/s**



1. Nelson, T. et al. (2019) Int. J. of Greenhouse Gas Control, 91, 102837

Oxygen Carrier Benchmark Testing

- 20 oxygen carrier formulations, including ilmenite evaluated in attrition unit



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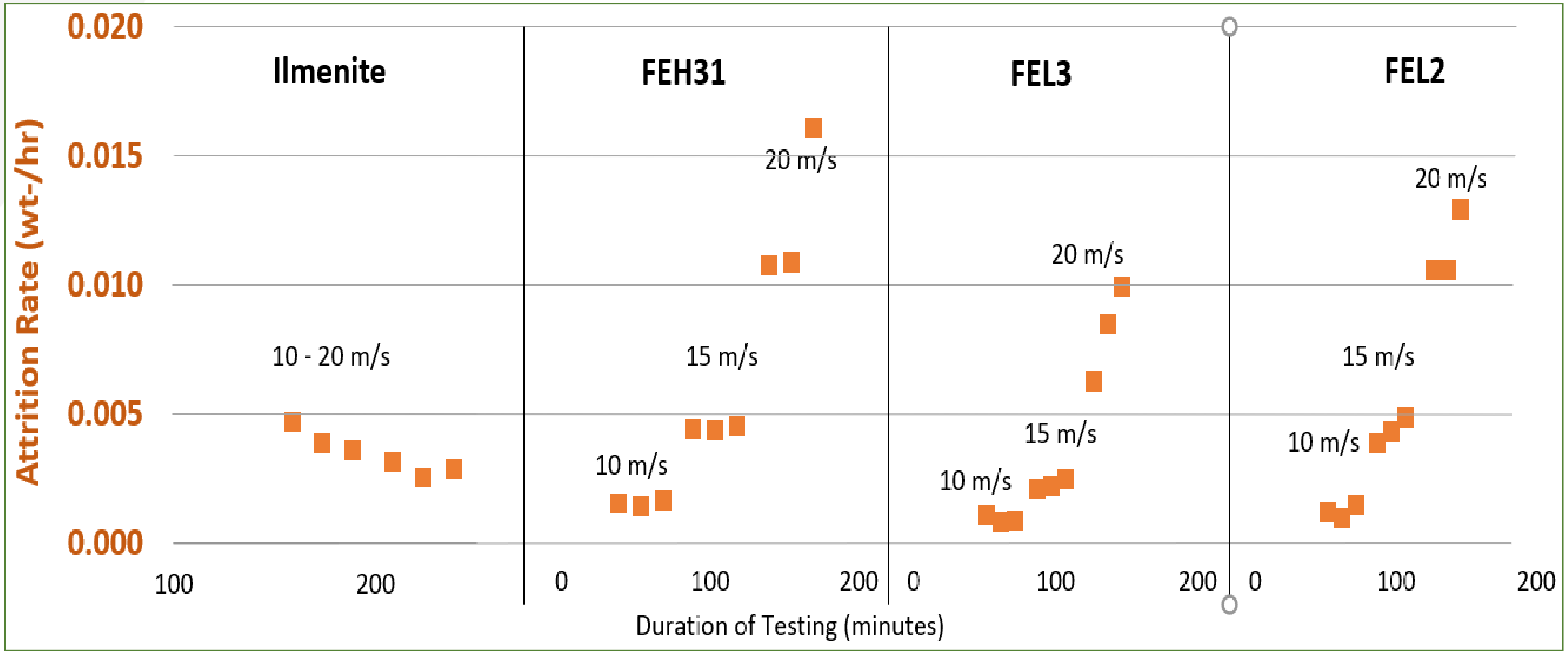
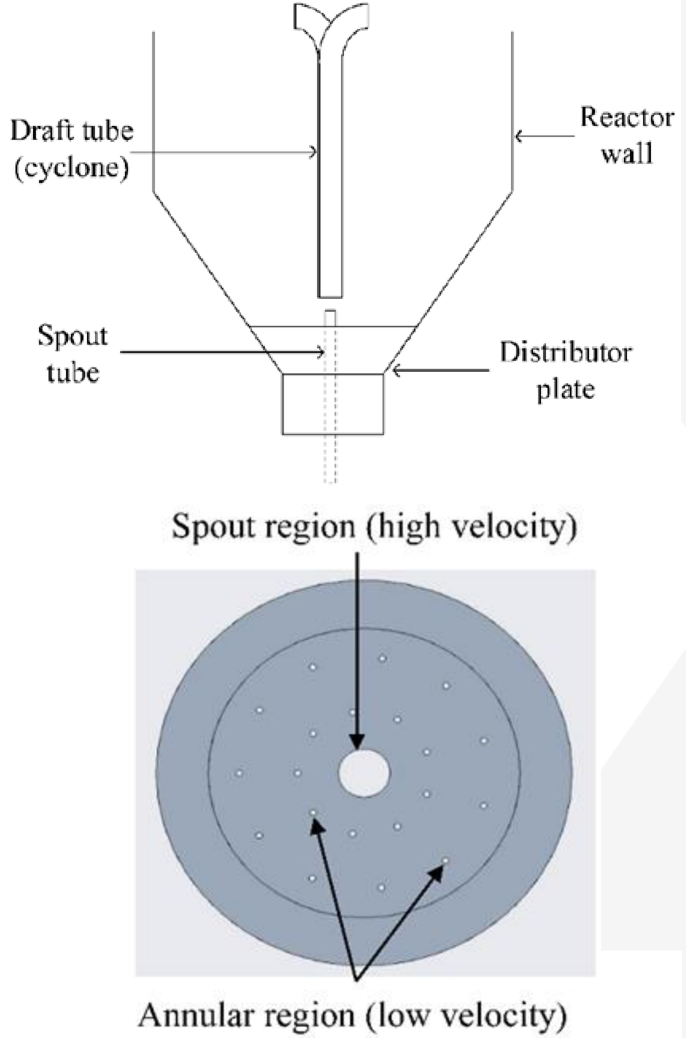
Oxygen Carrier Benchmark – Down-selection

- Modified attrition system to a spout-cyclonic reactor[1]
- System simulates attrition in cyclone systems
- Low-efficiency cyclones recommended



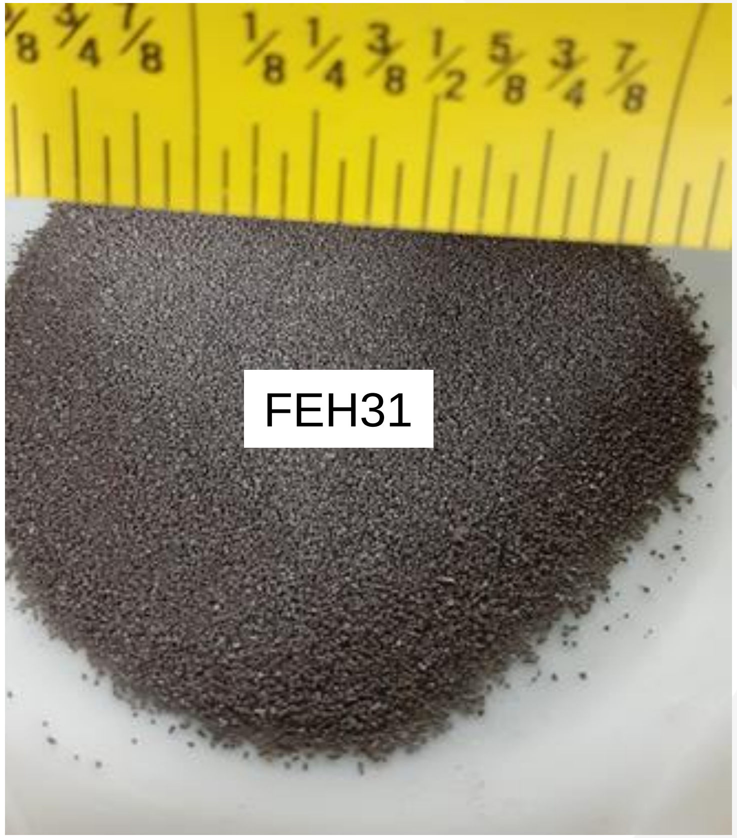


1. Nelson, T. et al. (2019) Int. J. of Greenhouse Gas Control, 91, 102837

Oxygen Carrier – Down-selection

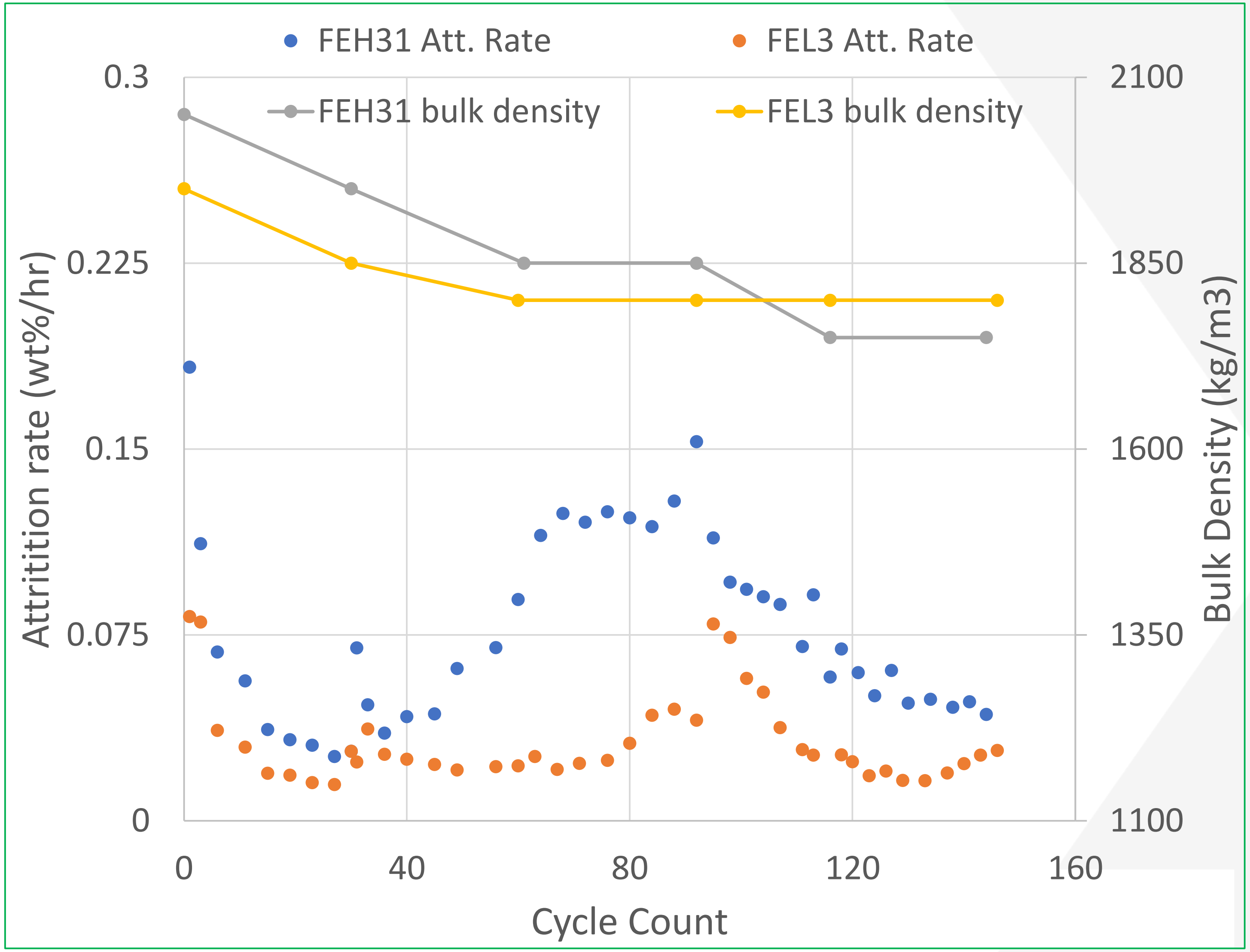
Milestone: FEL3 and FEH31 down-selected

- 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)

$$X = \frac{M_{t=0} - M_t}{M_{t=0}} * 100$$

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

$$R_{o_2} = \frac{1}{M_{t=0}} * \frac{dN}{dt}$$

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

M = Mass (grams) at “t”; t = Time (minutes)

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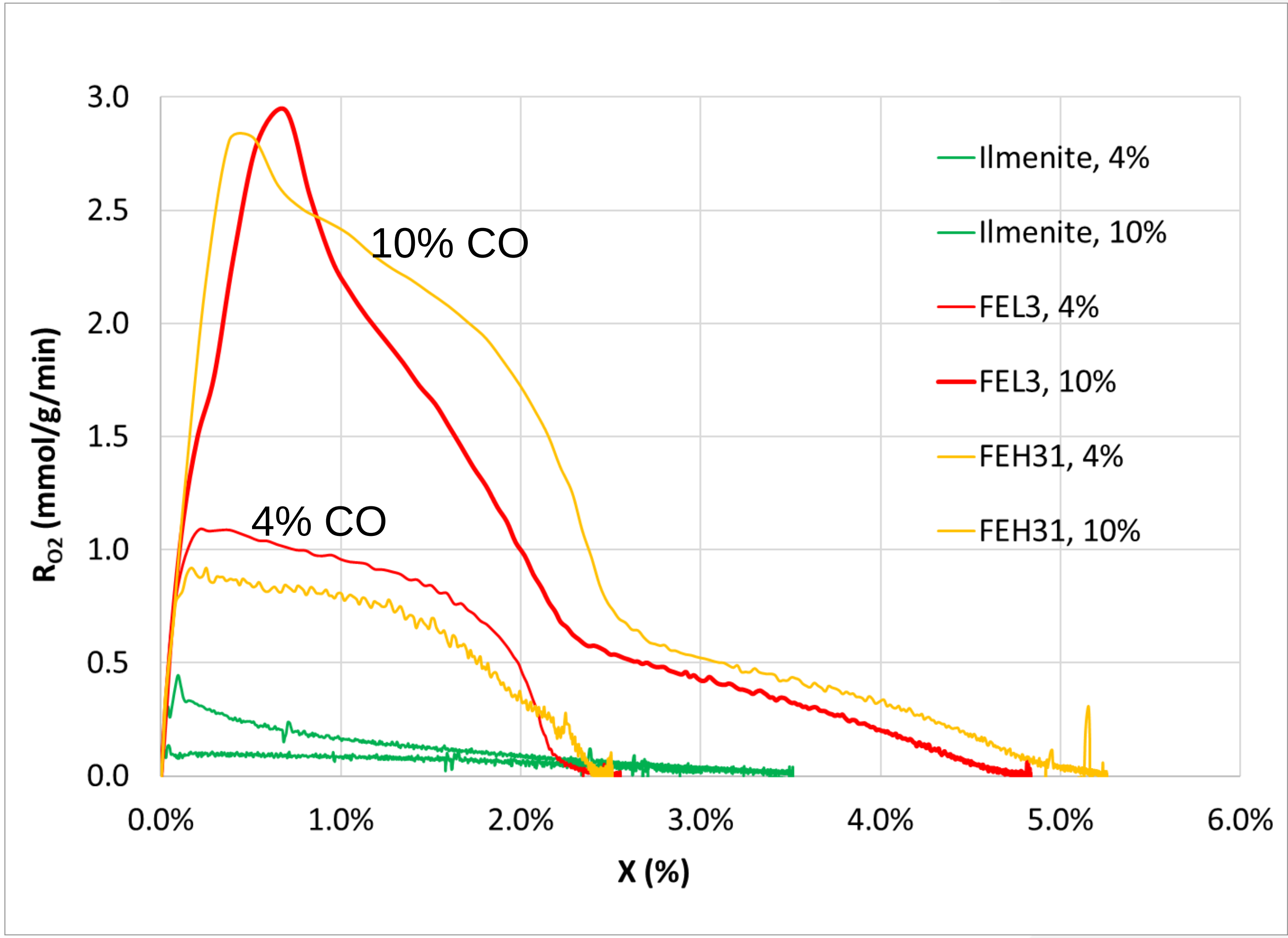
Oxygen Carrier Benchmarking - Reactivity

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

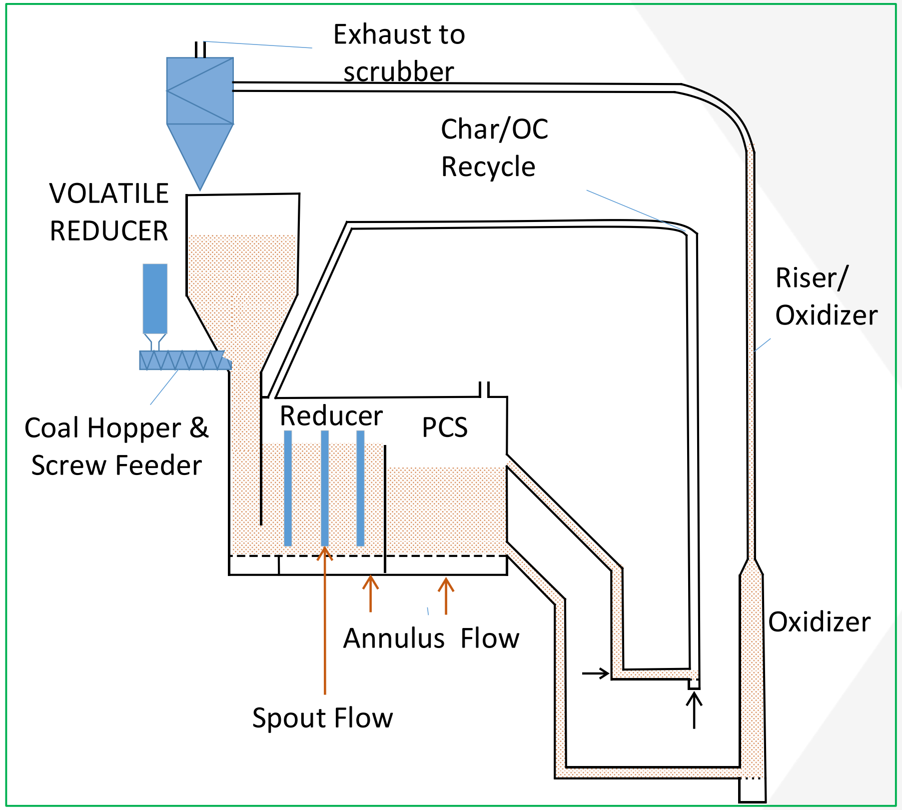
- Scaled-up manufacturing of FEL3
  - Produce **1000 lbs**
  - Procured **Jet mill** for communition step (top picture)
  - Negotiating lease of **micro-pelletizer** for making pellets. In discussion with Lancaster Products for lease of a micro-pelletizer
  - **Rotary kiln** for curing step (bottom picture)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

Project Update

- **Project Objectives:**
    - Develop low cost, low attrition and "recyclable" oxygen-carrier
    - **Develop a 10 kW unit that:**
        - **Use unique hydrodynamics of spouted fluid bed (SFB) to improve coal char reduction**
        - **Incorporate particle char separator (PCS) technology to improve char conversion**
        - **90% CO2 Capture (90% fuel conversion)**

10 kW Construction

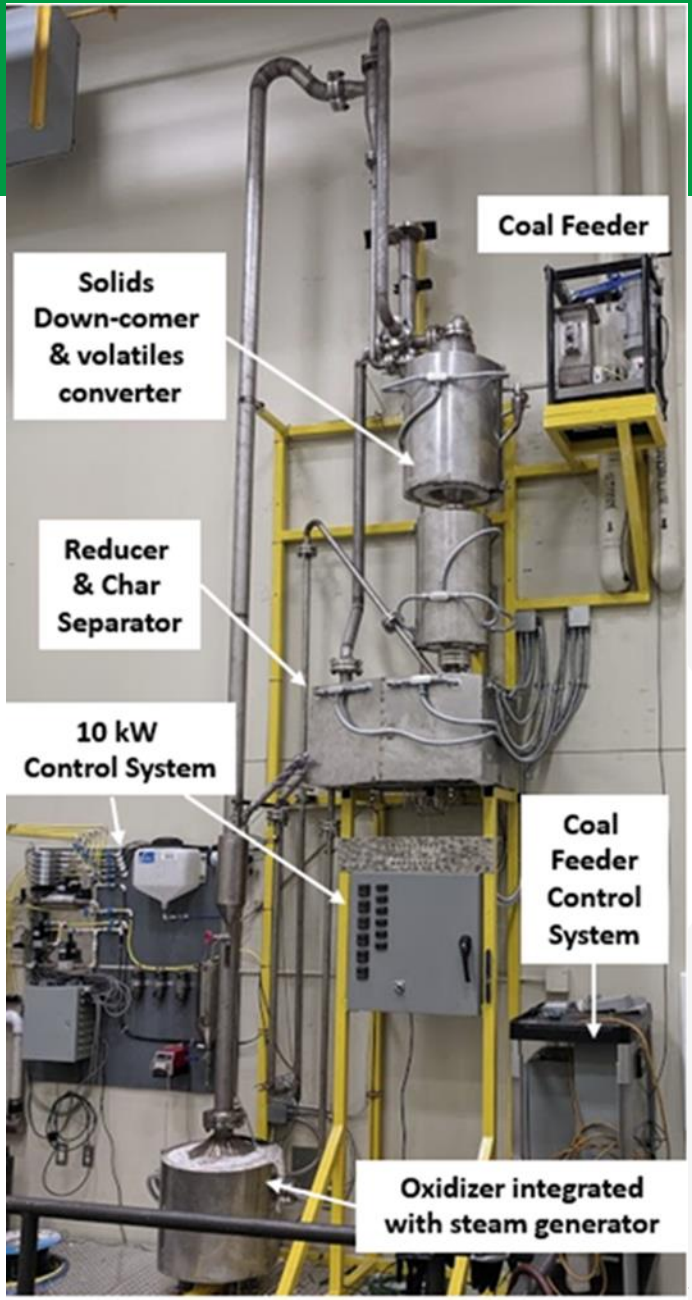
- **Reducer Design** – Spout Fluid Bed design[1]
- **Char Stripper** – Particle Char separator[2]
- **Volatile reducer** – moving bed; coal feed location



1. Van der Watt, J. G. et al. (2018) J. Energy Resour. Technol., 140 (11), 112002
2. Nasah, J. et al. (2019) Int. J. of Greenhouse Gas Control, 88, 361-370

10 kW Construction

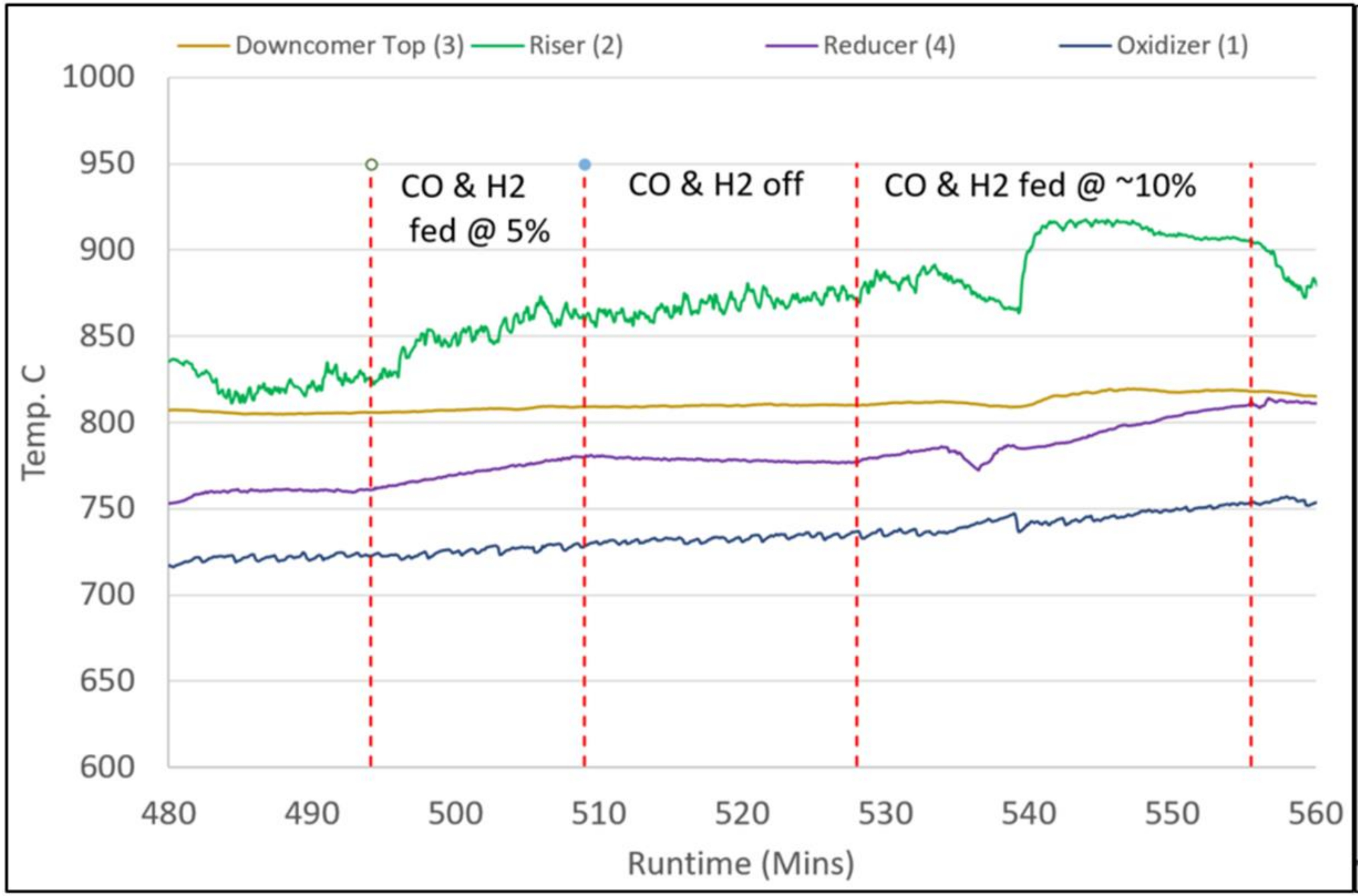
- **Cold flow model** (left) to verify solid circulation
- **10 kW unit** (right) constructed
- **Propane burner** (not shown) added to oxidizer to minimize heat loss

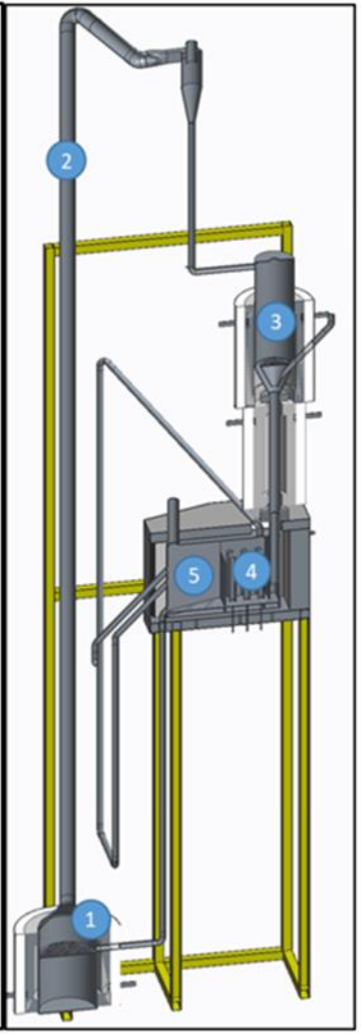


10 kW Operation

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

New
42” Tall

Propane
burner port

Old
6” Tall

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.

Future Work

- 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?