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Integrated Oxygen Production and CO_2 Separation through Chemical Looping Combustion with Oxygen Uncoupling

Project DE-FE0025076

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The University of Utah

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Outline

- Project overview
- Technology background
- Technical approach / project scope
- Progress and current status of project
- Future plans

Project Overview

Participants:

THE UNIVERSITY OF UTAH

Amaron Energy

Funding:

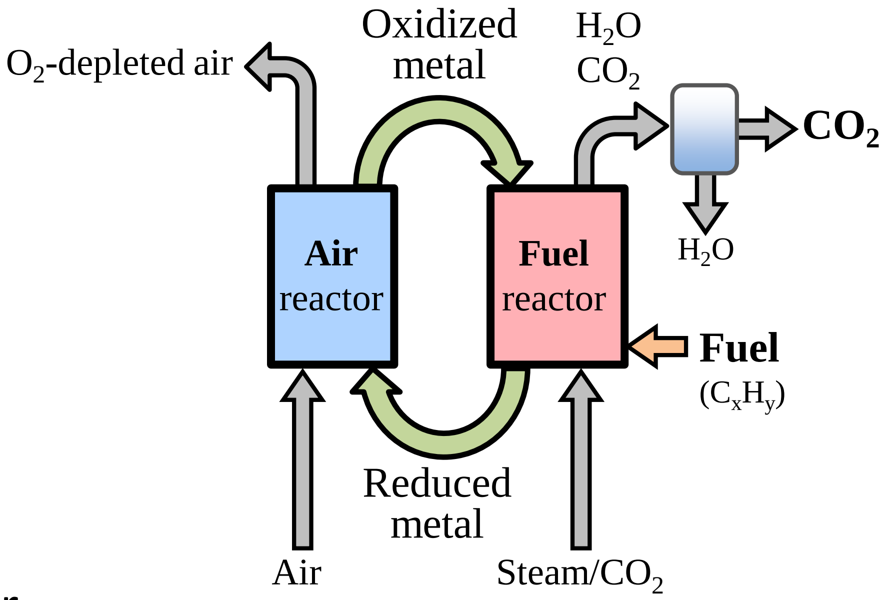
Source	University of Utah	Amaron Energy	TOTAL
DOE	$ 1,597,665	$ 282,655	$ 1,880,320
Cost share	$ 399,416	$ 70,664	$ 470,080
TOTAL	$ 1,997,081	$ 353,319	$ 2,350,400

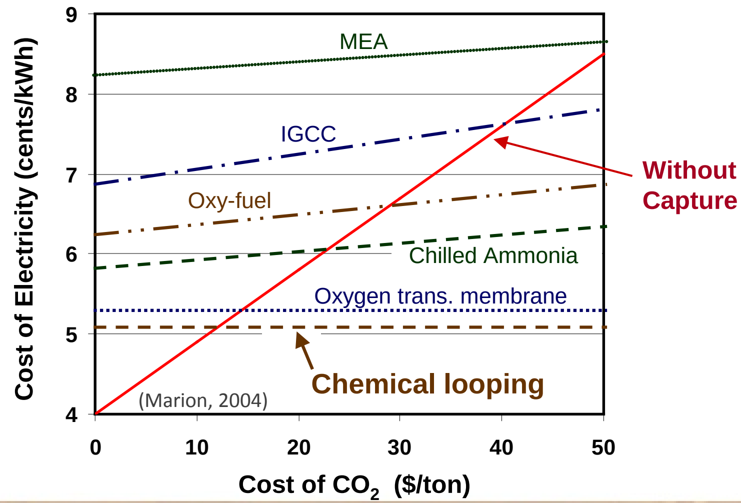
Project Dates: September 1, 2015 – August 31, 2017

Objectives: Advance chemical looping combustion with oxygen uncoupling (CLOU) technology to pilot scale (NETL TRL 5) through system scale-up, operation of a 200 kW process development unit, process modeling and reactor simulation

Technology Background: Chemical Looping Combustion

- CLC achieves *in situ* air separation by using a metal to transport oxygen from *air reactor* to *fuel reactor*
- Fuel (e.g. natural gas, coal) fed to fuel reactor is indirectly combusted by oxygen on oxidized metal
- Metal returns to reduced state in fuel reactor and "loops" back to air reactor
- Overall balance same as for conventional combustion
- Economic evaluations indicate CLC yields lowest COE of any CO_2-capture technology

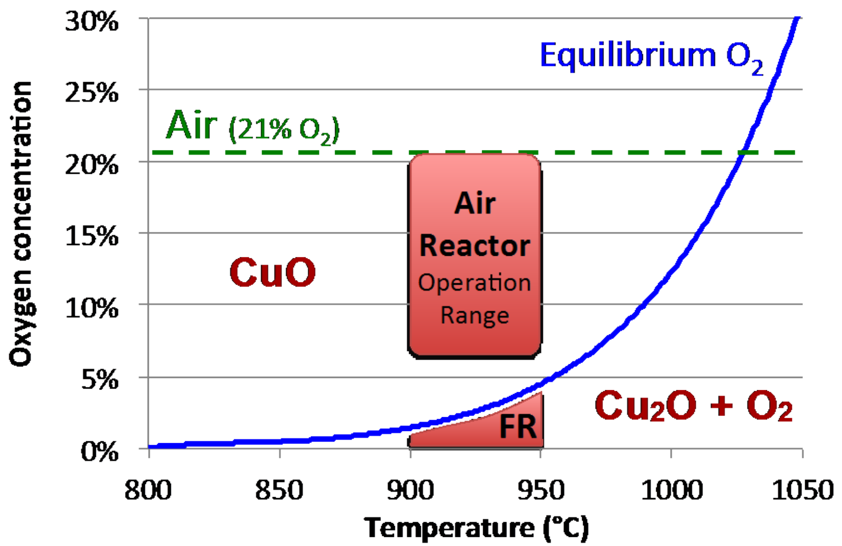


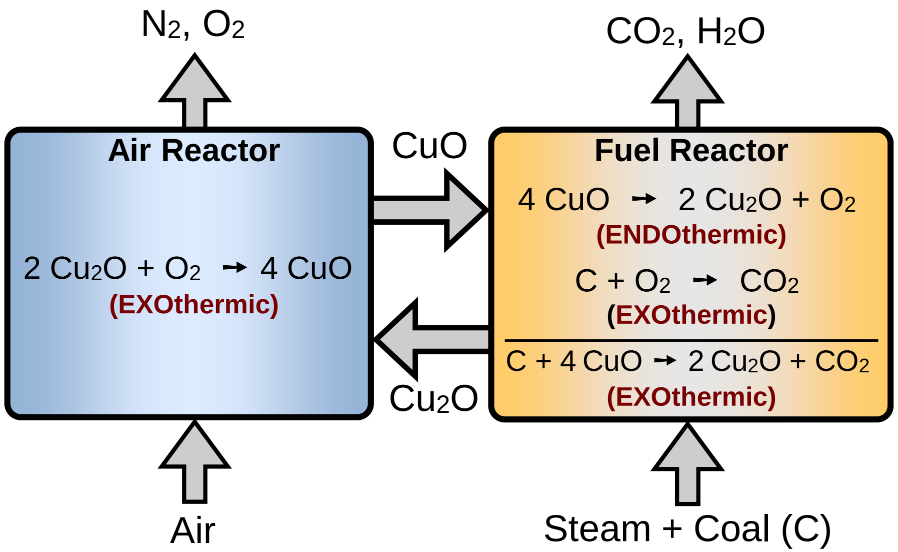


Technology Background: Chemical Looping with Oxygen Uncoupling (CLOU)

$$Cu_2O(s) + \tfrac{1}{2} O_2(g) \rightleftarrows 2\,CuO(s)$$

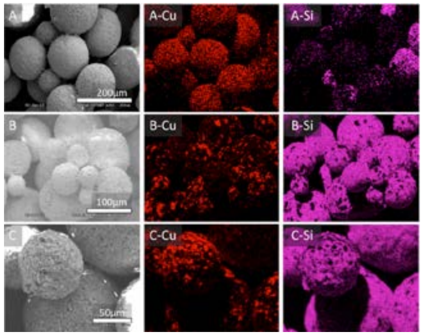
- Copper is one of few metals for which oxidation equilibrium (Cu_2O/CuO) lies within CLC operating temperatures.
- Cu_2O is oxidized in air reactor
- CuO spontaneously releases O_2 in fuel reactor due to low O_2 partial pressure
- Released O_2 reacts with solid coal char, converting more than 50x faster than with non-CLOU oxygen carriers

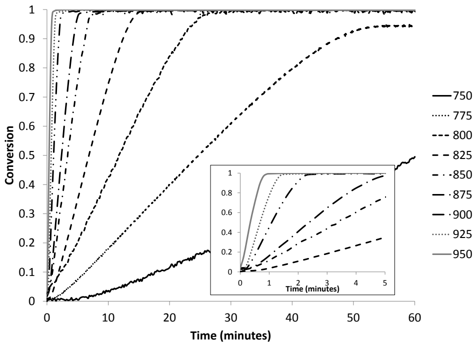


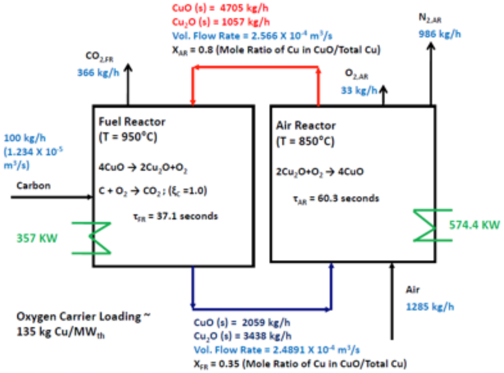


Technology Background: Previous Research and Development

- **CLC intensively researched worldwide**
  - UofU researching since 2007
  - 10 projects totaling $5.2 million
- **Oxygen carrier development**
  - Focus on <u>inexpensive</u> copper-based carriers with <u>scalable</u> production
  - Dozens of alternatives tested
  - Current focus is CuO-on-SiC
- **Reactor and process development**
  - Fundamental studies of CLOU reaction kinetics
  - Lab-scale experiments of coal conversion
  - Design and initial construction of 200 kW PDU
- **Process modeling and reactor simulation**
  - Aspen Plus modeling of CLC system
  - Barracuda VR® modeling of integrated fluidized bed system







Technical Approach

- **Three major research areas**
  1. Scale up of CLOU oxygen carrier production
  2. CLOU Experiments
     - 200 kW PDU
     - 10 kW bench-scale
  3. System modeling and reactor simulation

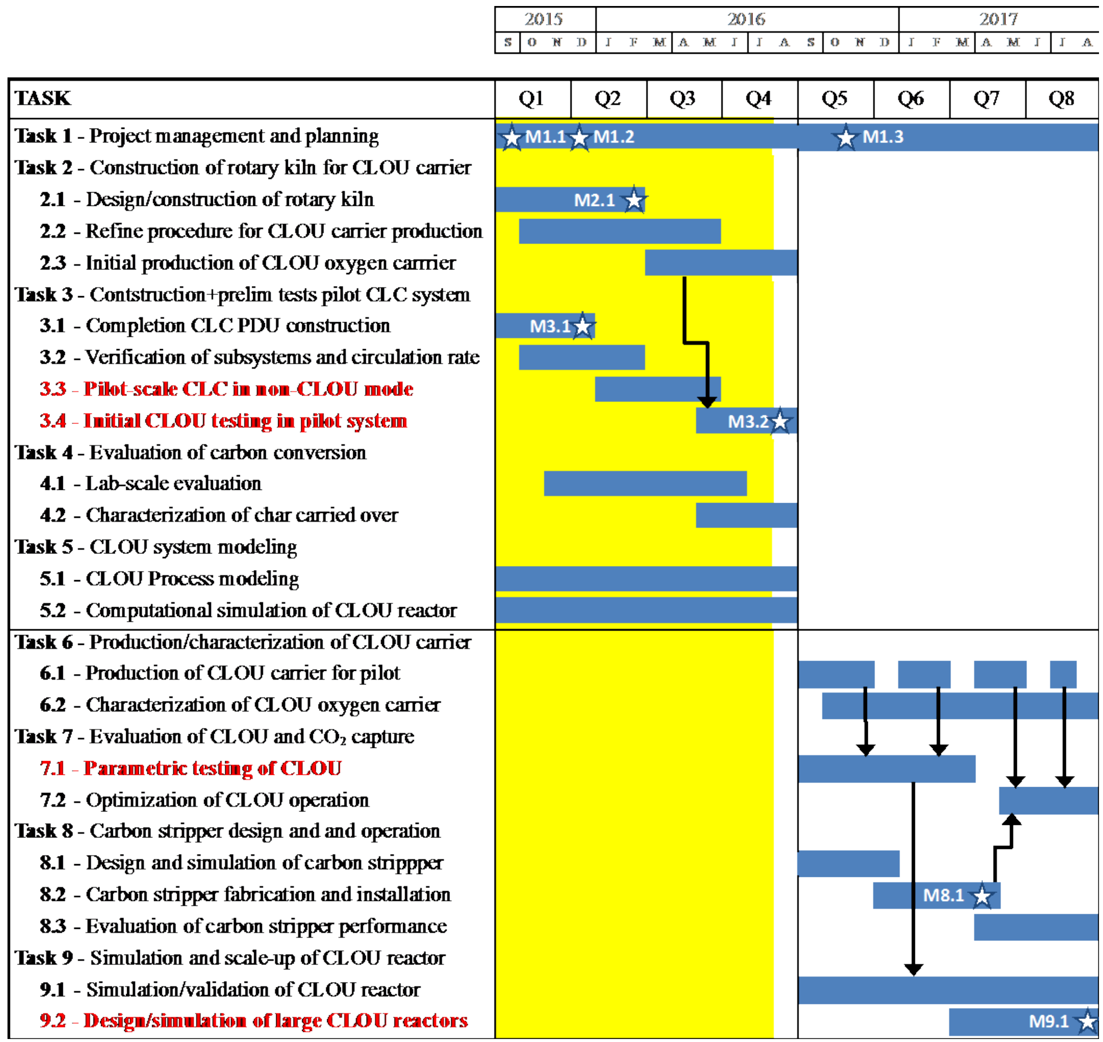
- **Performance targets**
  - CO_2 capture (target min. 90%)
  - CO_2 purity (target min. 95%)
  - Coal conversion (target min. 99%)

Work plan / Tasks

1. Project management
2. Construction of pilot-scale rotary kiln for carrier production
3. Complete construction/initial testing of pilot-scale CLC system
4. Evaluation of carbon conversion in CLOU environment
5. CLOU system modeling
6. Production and characterization of CLOU carrier particles
7. Evaluation of CLOU performance and CO_2 capture at pilot scale
8. Carbon stripper design and operation
9. Design of pilot/demo scale CLOU reactors

Project Scope (Project Management Plan)

- **Technical milestones**
  - 2.1 Complete pilot rotary kiln
  - 3.1 Complete CLC PDU
  - 3.2 Start CLOU testing
  - 8.1 Carbon stripper installed
  - 9.1 Large CLC system design
- **Success criteria** focused on pilot system
  - Key operation steps (tasks in red) require that specific performance can be achieved
- **Technical risks**
  - CLOU carrier unsuitable
    - Target lower Cu loading
  - Inadequate pilot performance
    - Component redesign
  - Excessive carrier attrition/loss
    - Reduce velocity, produce more carrier, find alternates



Progress and Current Status:
Scale-up of CLOU Oxygen Carrier Production

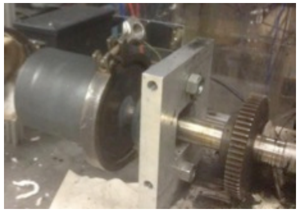
Procedure

- Incipient wetness with copper nitrate
- Current support: SiC
  - Best based on previous screening
- Research focuses on identifying optimum production "recipe"
  - $Cu(NO_3)_2$ concentration
  - Number of additions
  - Calcining time
  - Solvent
  - Support pretreat

Equipment

- Rotary evaporator for screening
- Three scales of rotary kiln
  - 1 kg lab scale
  - 10 kg bench scale
  - 100 kg pilot built by Amaron Energy

System	Type	Capacity	Heating	Max T	Length	Diam
RV-1	Rotary evap	1 kg	Water bath	95°C	n/a	0.15 m
RK-1	Rotary kiln	1 kg	Elec Inductive	800°C	0.15 m	0.1 m
RK-10	Rotary kiln	10 kg	Elec radiative	350°C	0.8 m	0.2 m
RK-100	Rotary kiln	100 kg	Natural gas	500°C	1.4 m	0.4 m


RK-1 lab-scale induction kiln

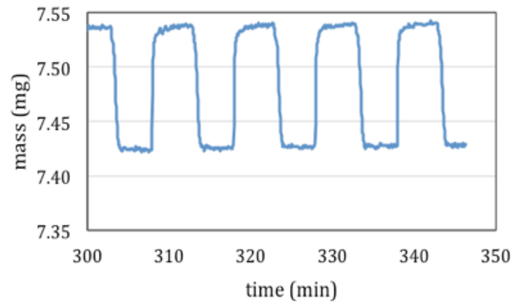

RK-10 bench-scale rotary kiln


RK-100 oxygen carrier production kiln

Progress and Current Status: Scale-up of CLOU Oxygen Carrier Production (2)

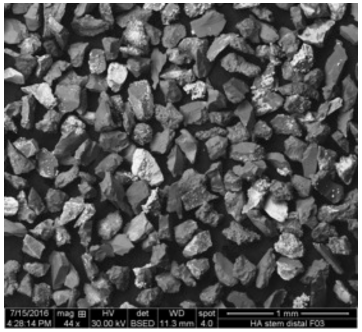
- **Characterization**
  - TGA for oxygen loading/rates
  - BET for available surface area
  - SEM for morphology
  - Crush strength
  - Lab-scale fluidized bed for long-term performance in a cycling fluidized bed reactor
- **Current Status**
  - Over 35 different carriers produced and characterized
  - Test batch of 50 kg CuO-on-SiC successfully produced in RK-100 pilot kiln

TGA for oxygen capacity and rate tests



Sustained cyclability of UofU carrier

BET surface area analyzer



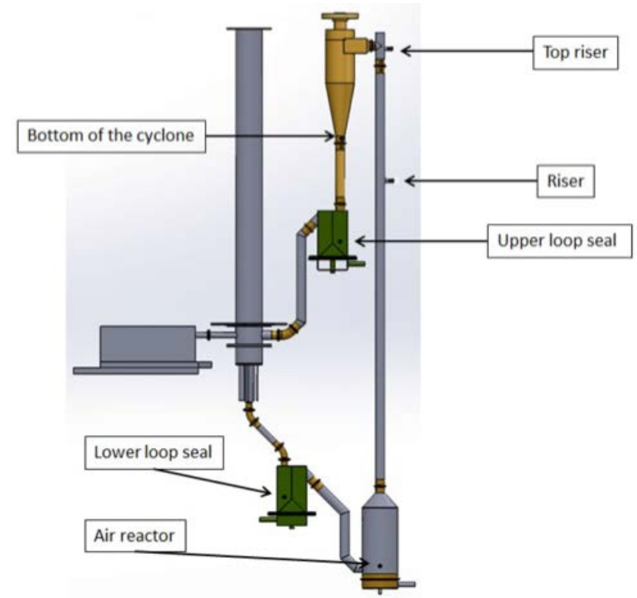
CuO-on-SiC oxygen carrier

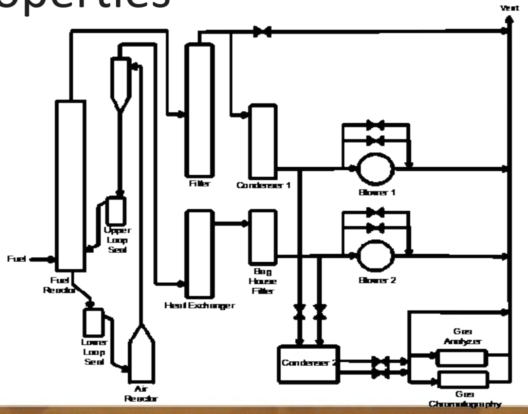
Lab-scale fluidized bed system

Progress and Current Status:
CLOU Experiments and Process Development

- **Two primary chemical looping reactor systems**
  - 10 kW bench-scale
  - 200 kW semi-pilot scale

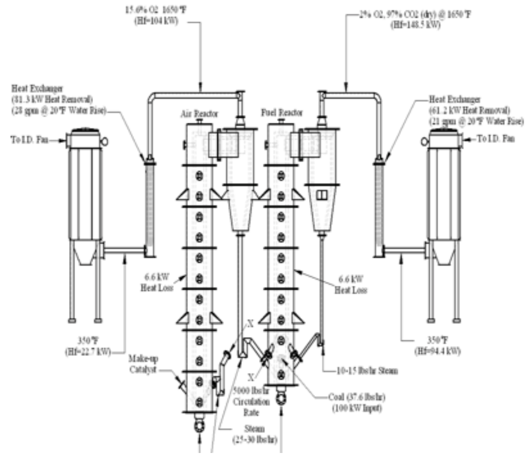
- **10 kW_{th} bench-scale system**
  - Electrically heated
  - 1.5 kg/hr coal feed rate
  - Bubbling bed fuel reactor
  - Bubbling bed air reactor
  - Riser to lift particles to cyclone
  - Used for testing carrier and char properties

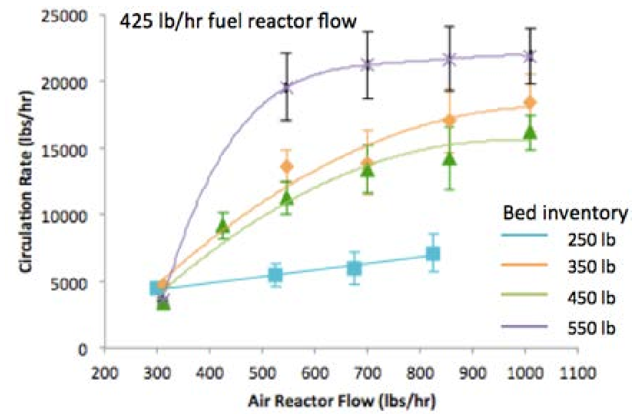




Progress and Current Status: 200 kW_{th} Process Development Unit

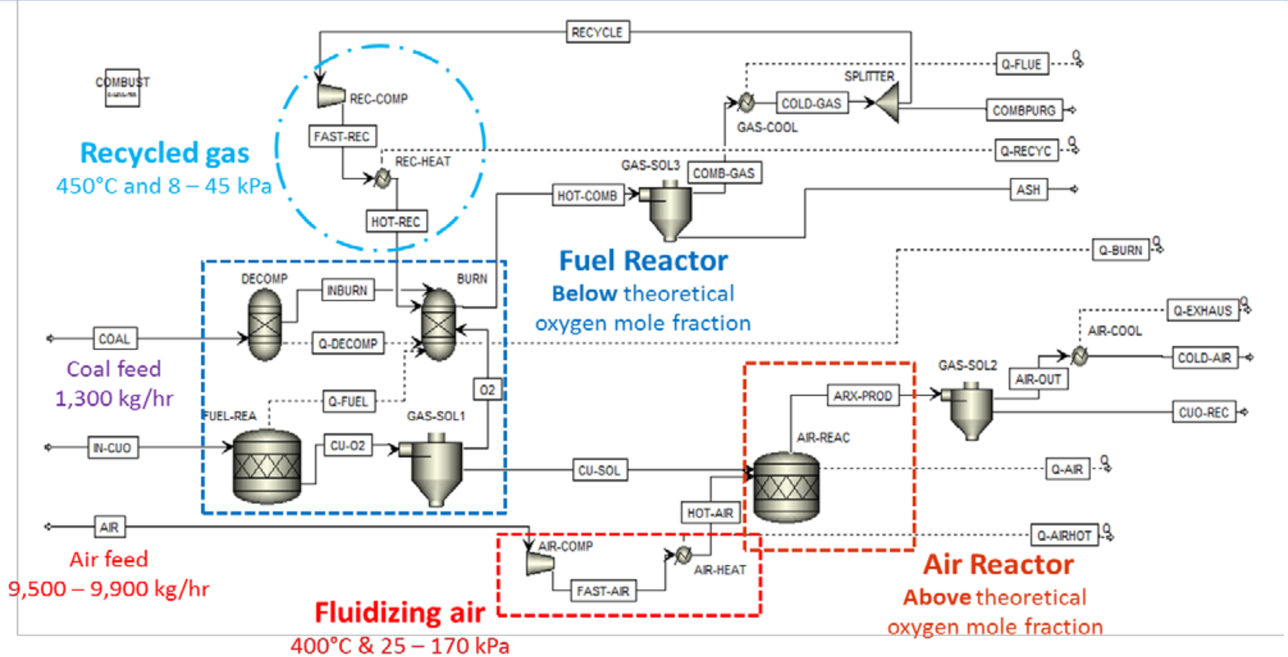
- **PDU Design**
  - Two interconnected CFBs
  - Refractory-lined
  - Electric + gas air/steam preheat
  - Approx. 175 kg bed inventory
- **Status**
  - Construction complete
    - Some rebuilds/repairs were necessary
  - Function of subsystems has been confirmed
  - Oxygen carrier circulation rates to 12 tons/hr ilmenite achieved
  - CLC testing with gas in progress; coal starting soon

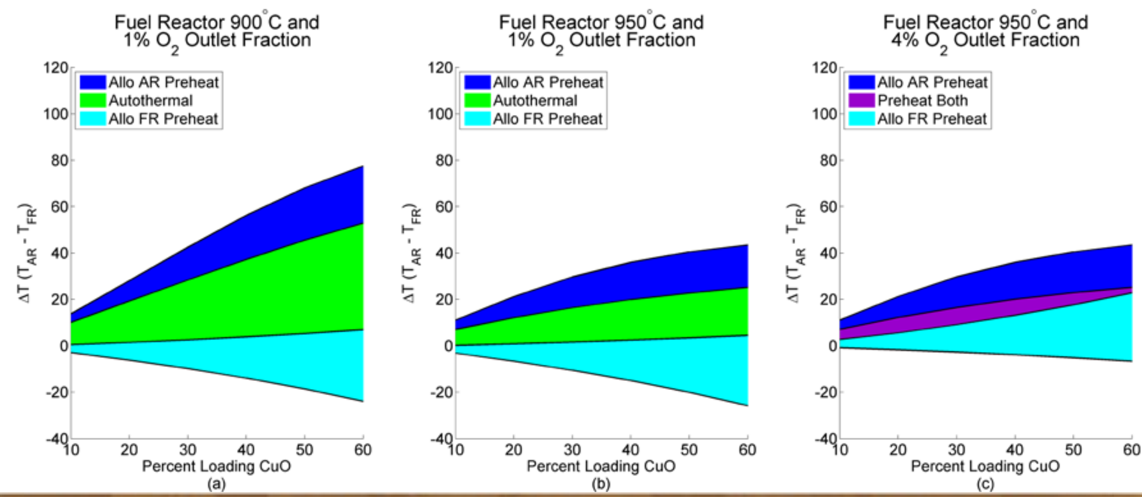




Progress and Current Status: Chemical Looping Process Modeling

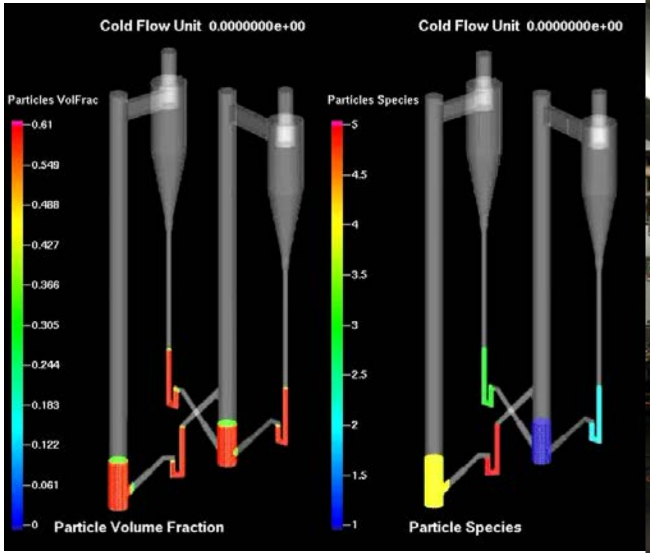
- Autothermal: Both reactors are exothermic. Energy transferred from:
  - Reactions
  - Oxygen carrier heat capacity
  - Heating gases
- Allothermal: At least one reactor requires external heating (e.g. preheating the fluidizing gas)

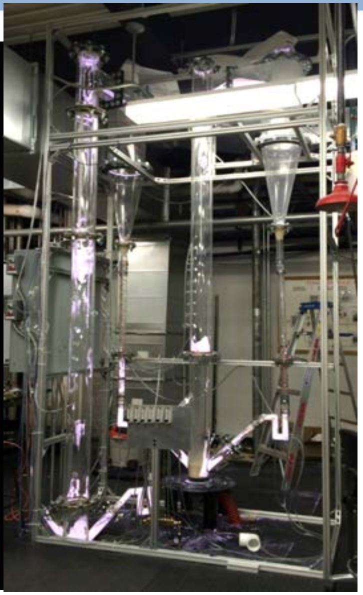




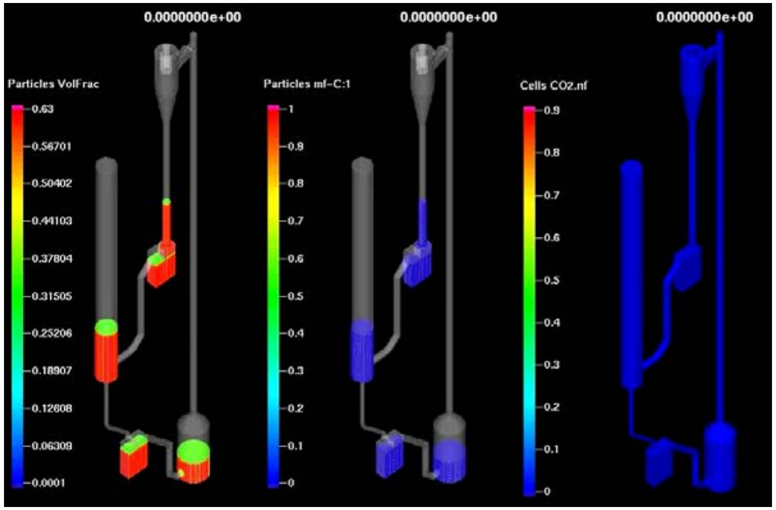
Progress and Current Status: Chemical Looping Reactor Simulation

- Using CPFD Barracuda VR®
- Models of 10 kW bench-scale, 200 kW pilot-scale reactors, and cold-flow unit
- Simulations include
  - hydrodynamics
  - heat transfer
  - Oxygen carrier chemistry/kinetics
  - Coal combustion chemistry/kinetics
- Plexiglas cold-flow model of UofU PDU to help validation
- Understanding from simulations has been valuable in starting up and interpreting behavior of pilot-scale system





Cold-flow model of UofU PDU



Progress and Current Status: Significant Accomplishments

- **Successful scale-up of CLOU oxygen carrier production**
  - Can now produce enough material for PDU operation
  - Initial batches of well-performing carrier to 20% CuO loading produced
- **Successful commissioning of 200 kW PDU**
  - All systems now function properly
  - Measured oxygen carrier circulation rates exceed design
  - Already 200+ hours of hot operation with circulation
- **Successful development of PDU simulation model**
  - Incorporation of kinetics for oxygen carrier reactions
  - Incorporation and improvement of coal combustion reaction kinetics
  - Over 20 different conditions have been simulated, each with at least 60 seconds of operation

Future Plans

- **This project**
  - Produce CuO-based CLOU carrier for PDU testing
    - Initial batch targets 20% CuO to ensure no agglomeration
    - Eventually target 40-45% CuO to increase load
  - Parametric testing of PDU with CuO (CLOU) carrier and coal
    - Vary coal, coal particle size, air reactor flow rate (circulation rate),
    - Measure CO_2 capture, CO_2 purity, fuel conversion, overall performance
    - Design, install and test carbon stripper to improve coal conversion and CO_2 capture.
  - Advance computational simulation
    - Validate simulation of PDU with operational data
    - Simulate larger (e.g. 10 and 100 MW) reactors
- **Future development**
  - Continued operation and experience with PDU
  - Pursue opportunities for larger pilot (3-10 MW) system

Acknowledgments

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