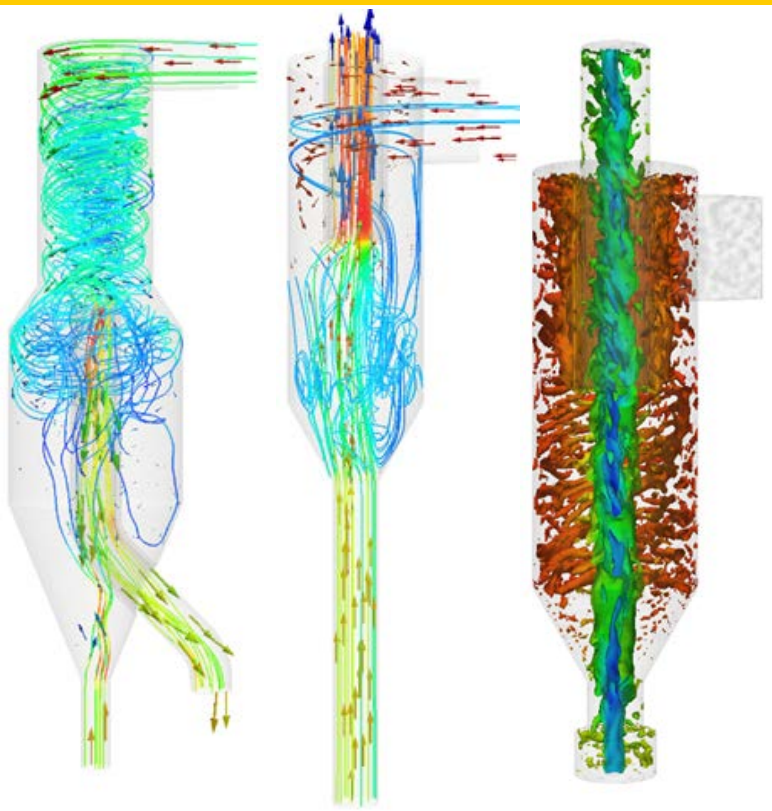
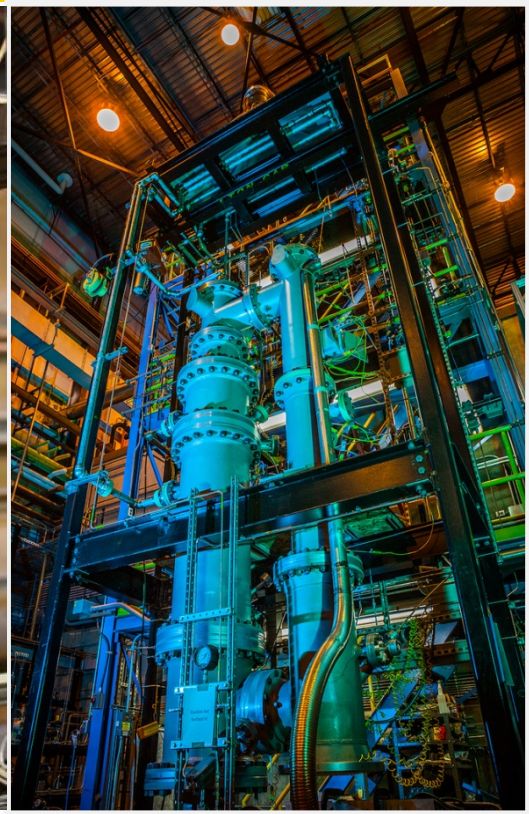
Driving Innovation ♦ Delivering Results





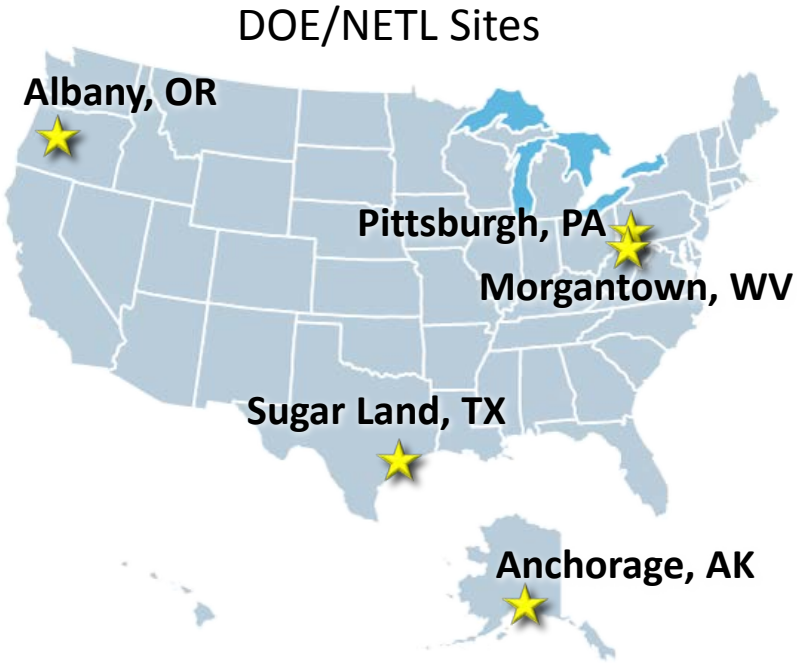
NETL's 50kW Circulating Chemical Looping Combustion Test Facility and Operating Experiences

Doug Straub, Justin Weber, and Dr. Jim Spenik

November 11, 2015

Presentation Outline

- **Motivation/Background**
  - Why is there interest in chemical looping combustion?
- **Test facility description**
  - Background
  - Operating modes
- **Preliminary test results**
- **Conclusions and future work**



Motivation for this work

- **Presidential GHG reduction goals**
- **Domestic importance of fossil fuels**
  - Need fossil fuel options to reduce GHGs
- **CLC technology has "potential" to achieve DOE goals**

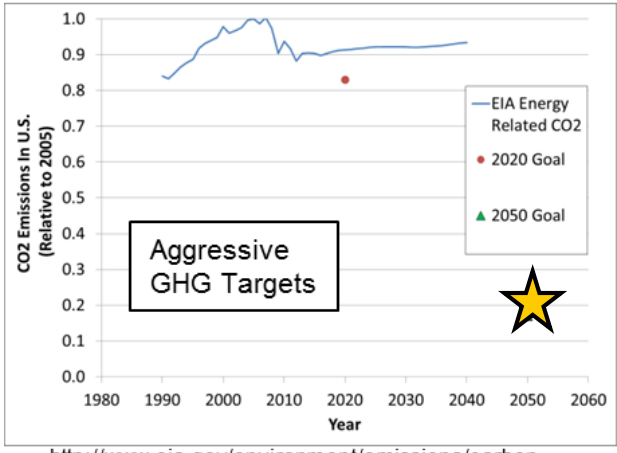
Exhibit ES-3 Cost of electricity breakdown comparison

Cost	Fe_2O_3 ($/MWh)	$CaSO_4$ ($/MWh)	Conventional PC BBR Case 12
Capital	49.6	53.4	73.1
Fixed	11.3	12.2	15.7
Variable	25.7	8.4	13.2
Maintenance materials	3.2	3.5	4.7
Water	0.4	0.4	0.9
Oxygen carrier makeup *	18.7	1.1	N/A
Other chemicals & catalyst	1.9	1.7	6.4
Waste disposal	1.4	1.7	1.3
Fuel	28.4	30.8	35.3
Total	115.1	104.7	137.3

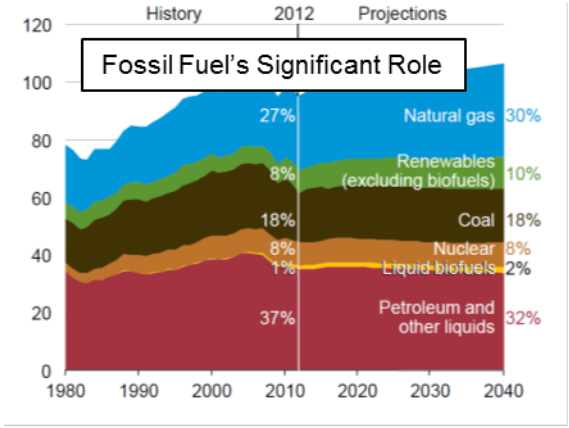
*Fe_2O_3 oxygen carrier makeup: 132 tons/day @ $2,000 per ton; Limestone carrier makeup: 439 tons/day @ $33.5 per ton

Ref: U.S. Department of Energy (DOE), National Energy Technology Laboratory (NETL). Guidance for NETL's Oxycombustion R&D Program: Chemical Looping Combustion Reference Plant Designs and Sensitivity Studies. Pittsburgh : s.n., 2014. DOE/NETL-2014/1643

Presidential Energy-Related GHG Targets



http://www.eia.gov/environment/emissions/carbon



AEO2014 – Early Release

NETL/ORD's Chemical Looping Combustion

What is our end goal?

- **Determine if CLC is a feasible technology for FE and worthy of additional investment/development**

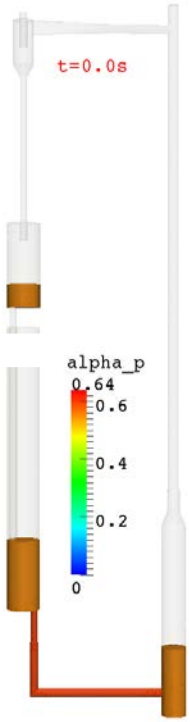
  → Data and information for strategic decision making

- **If it is feasible, THEN**
  - Help developers overcome technical issues
  - Help technology be successful
  - Ultimately commercialization

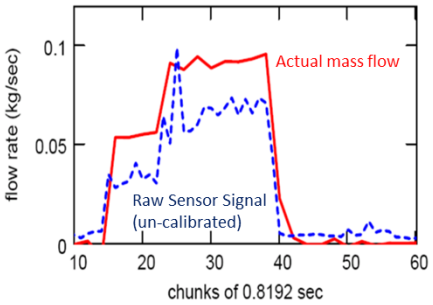
  → jobs and growth

NETL/ORD – Key Components of CLC Effort

CFD tools: Technology scaling



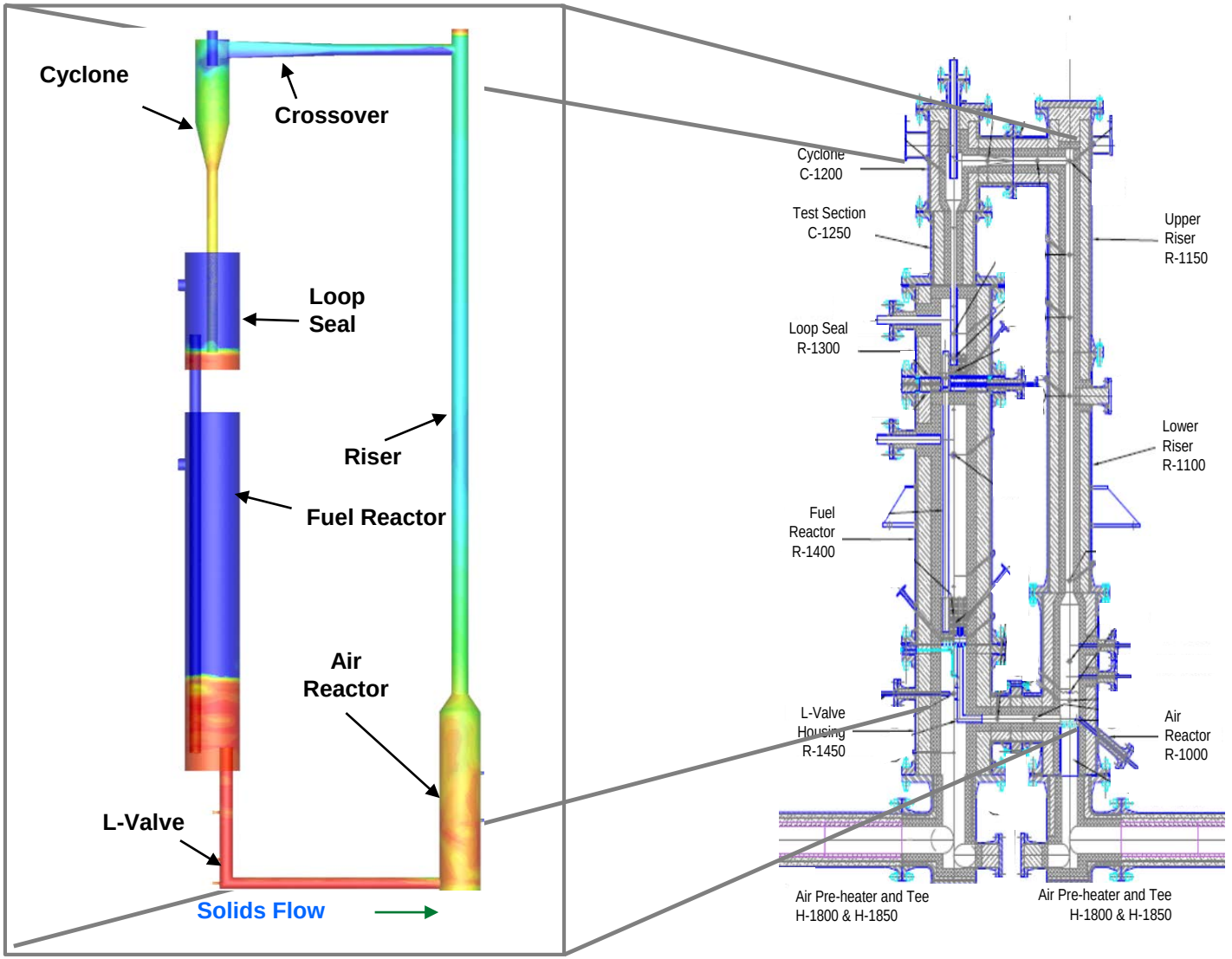
Sensors: Enable reliable systems



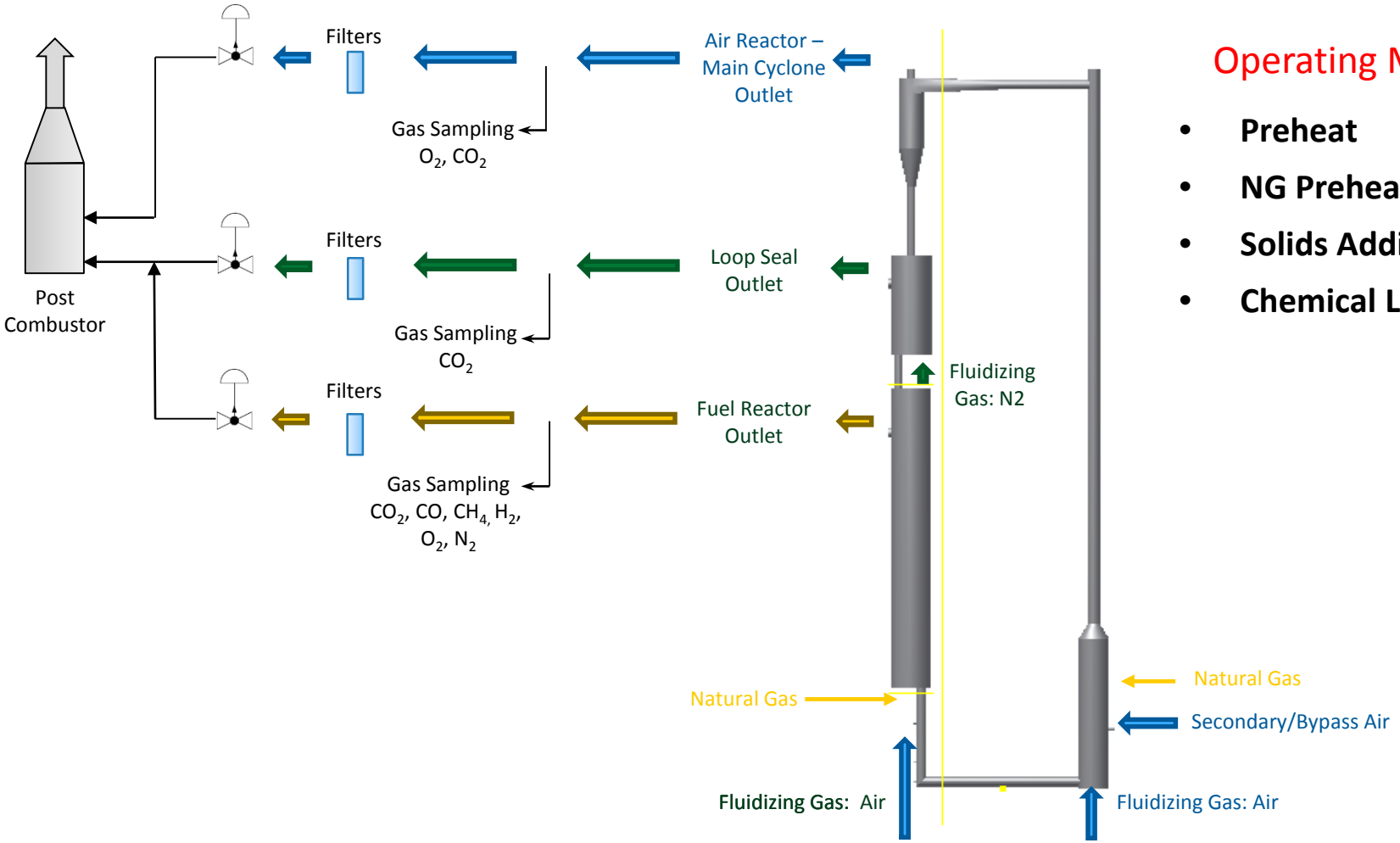
Carrier materials: Durability, cost, performance

NETL-CLC facilities: Expertise and benchmarking

Nomenclature For NETL's 50kW Test Facility



Chemical Looping Flow Diagram

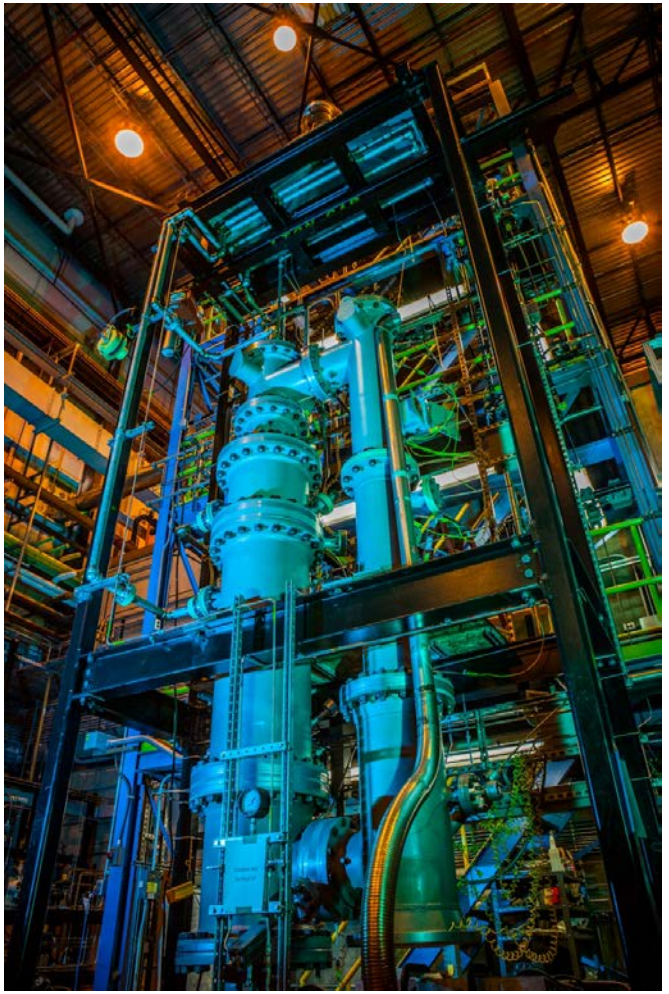


Operating Modes

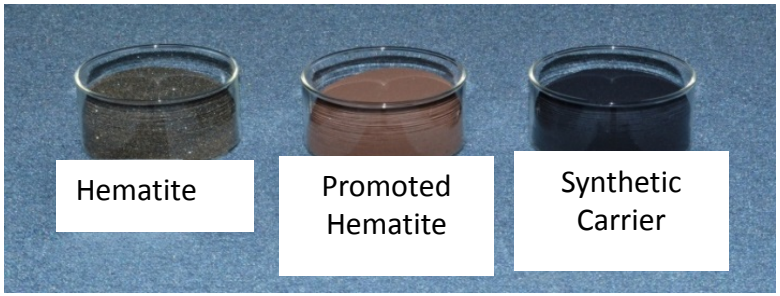
- **Preheat**
- **NG Preheat**
- **Solids Addition**
- **Chemical Looping**

Operating Modes

- **Electric preheat**
  - Room temperature → Auto-ignition temperature
- **Natural gas augmented preheat**
  - 1200F to 2000F
  - Gas phase combustion in both reactors
- **Carrier addition**
  - Reduce gas flows
  - Add carrier in batches via lockhopper
- **Chemical looping combustion**
  - Transition from air to N2 as fluidizing gas in FR
  - Adjust natural gas flow for CLC

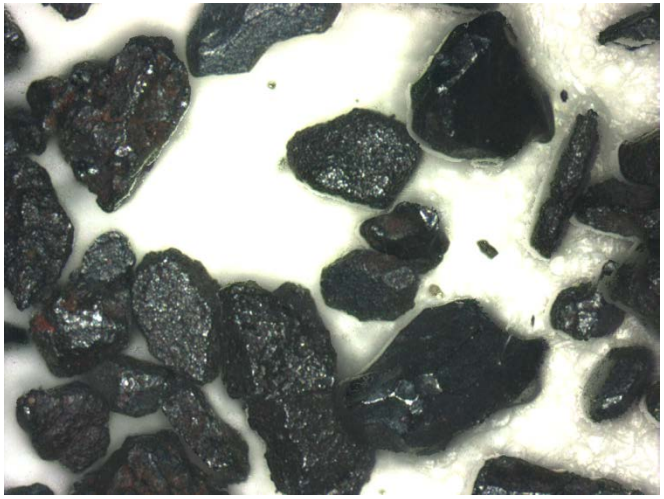


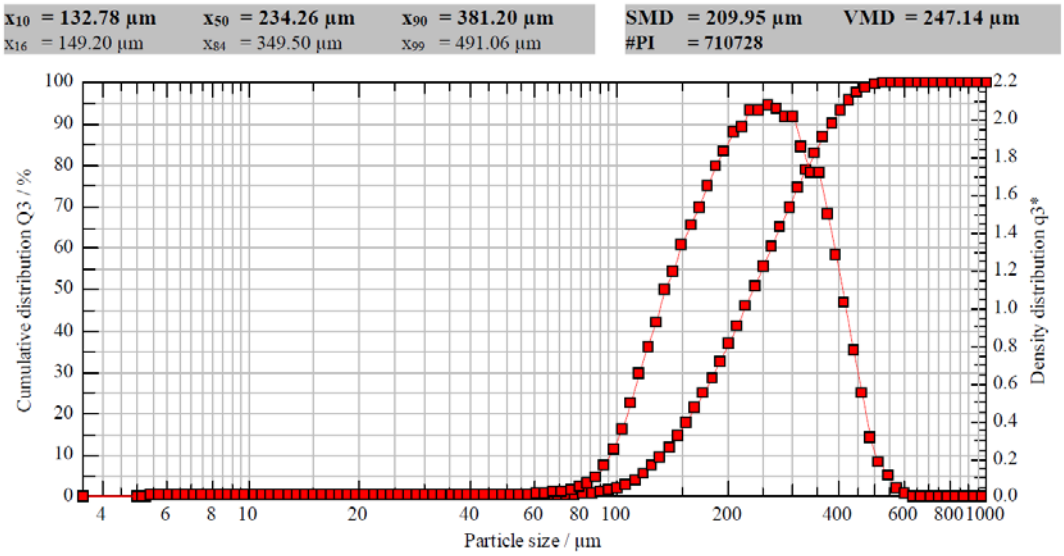
Oxygen Carrier Materials



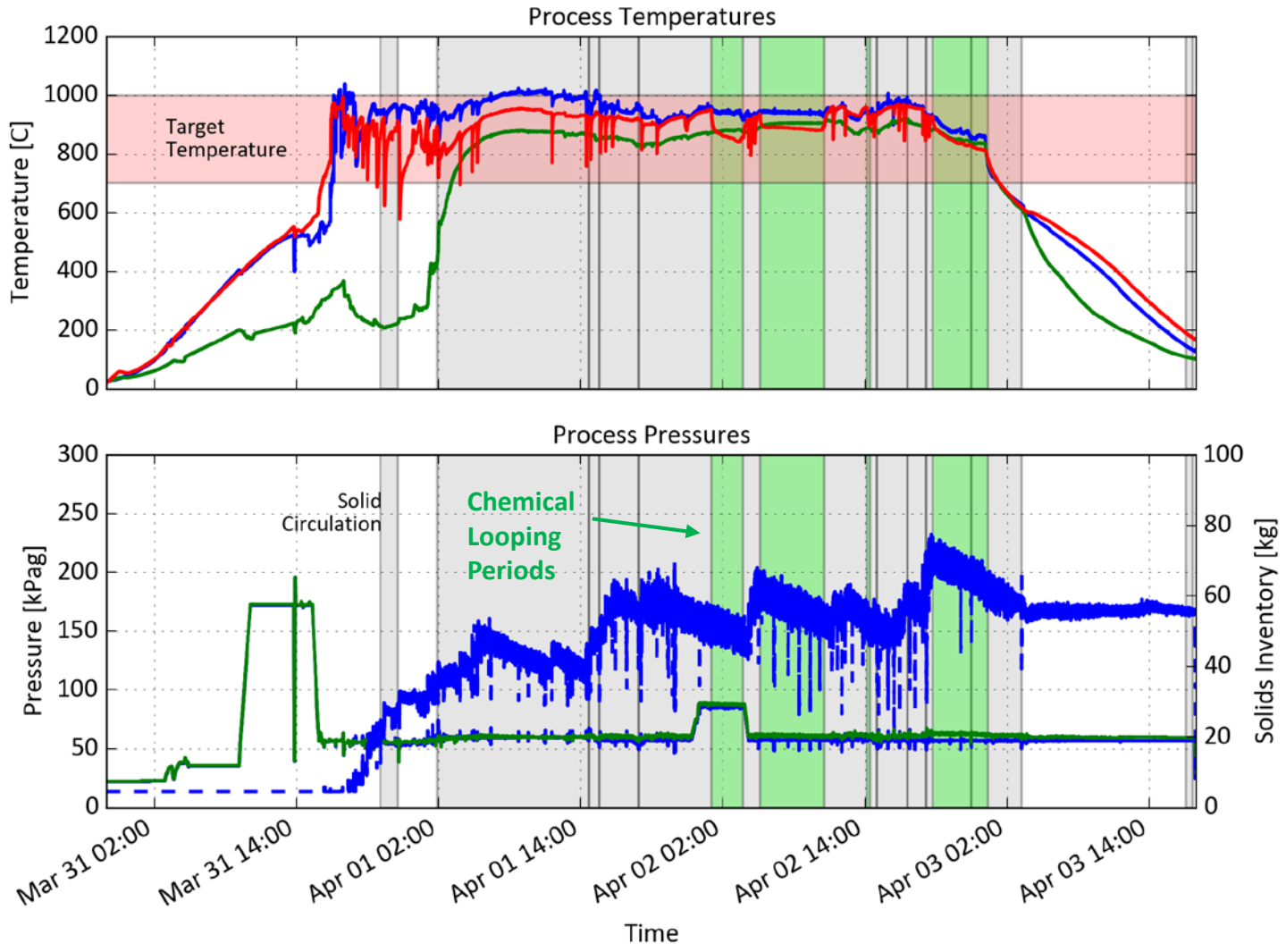
Pre-Test

Post-Test



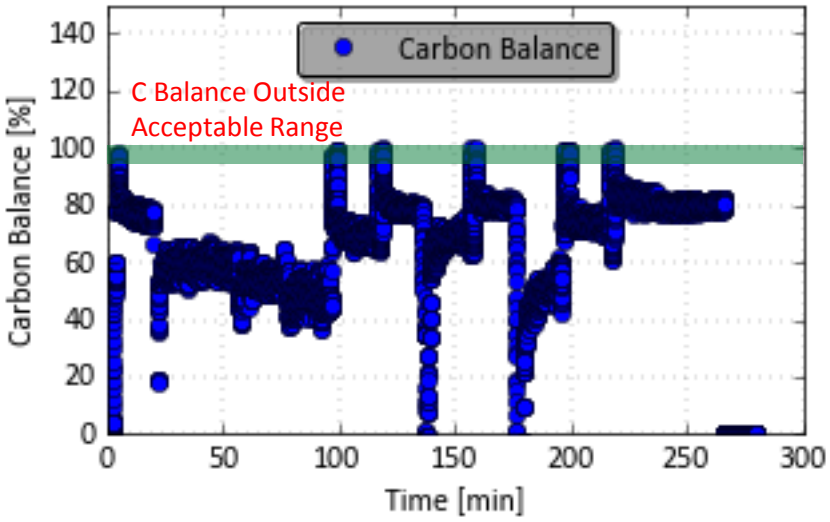


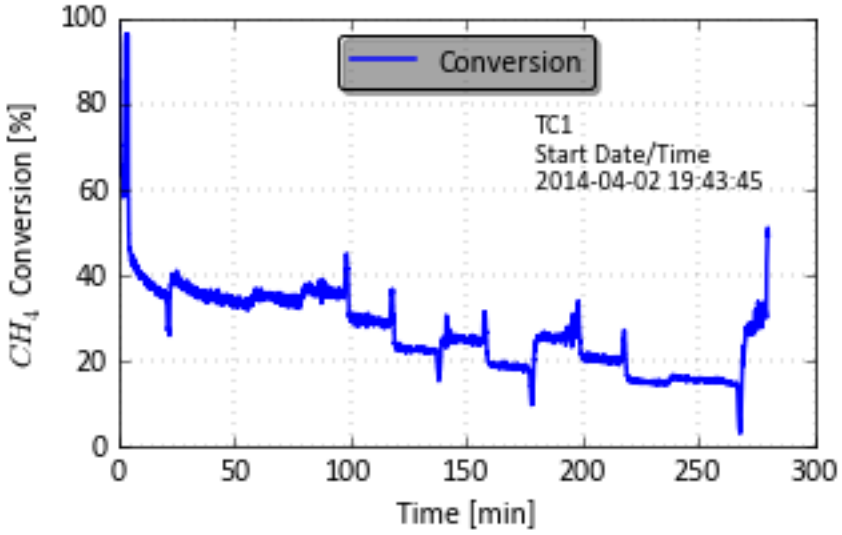
Process Data from NETL Unit – Promoted Hematite Carrier – 1st Test



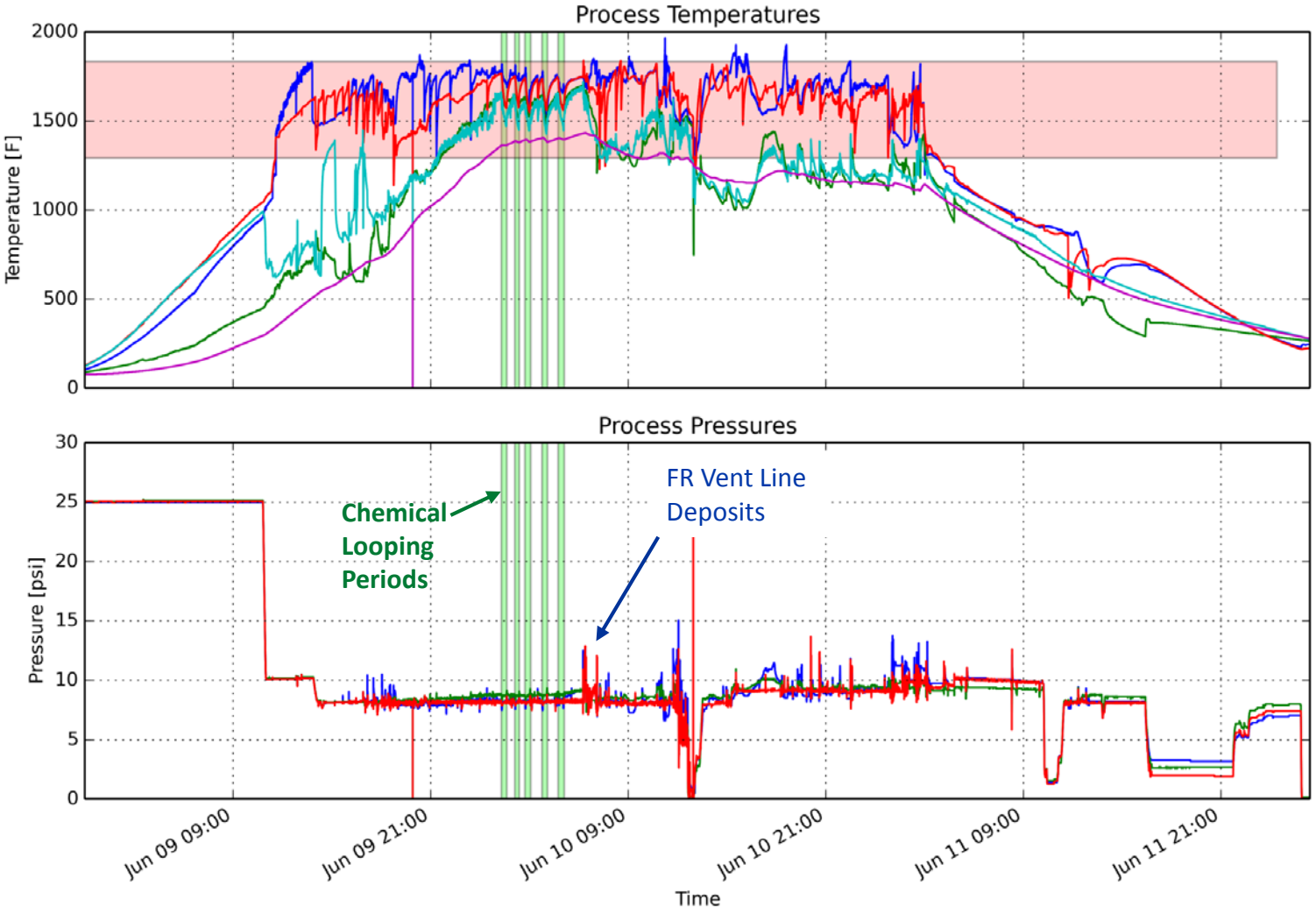
Promoted Hematite – 1st Test

- **Over 12 hours of CL operation**
- **No significant process upsets**
- **Carbon balance was less than 90%**
  - Internal leakage through refractory in L-valve region
- **Fuel conversion typically less than 50%**



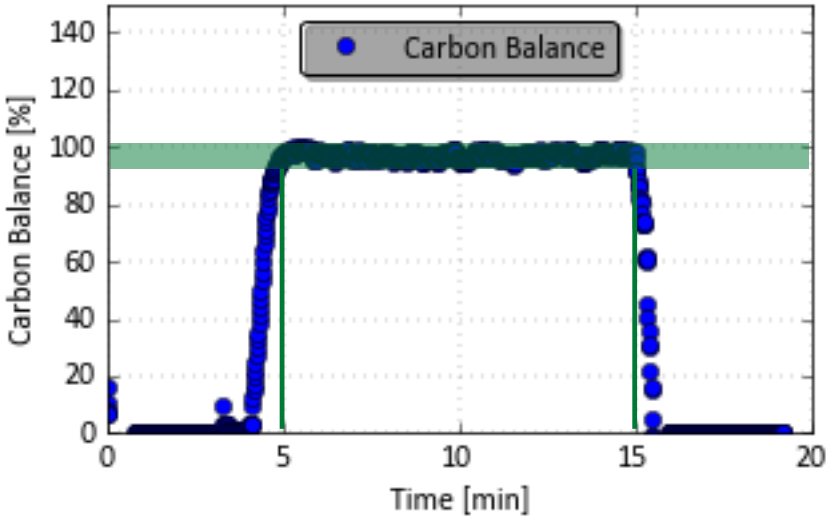


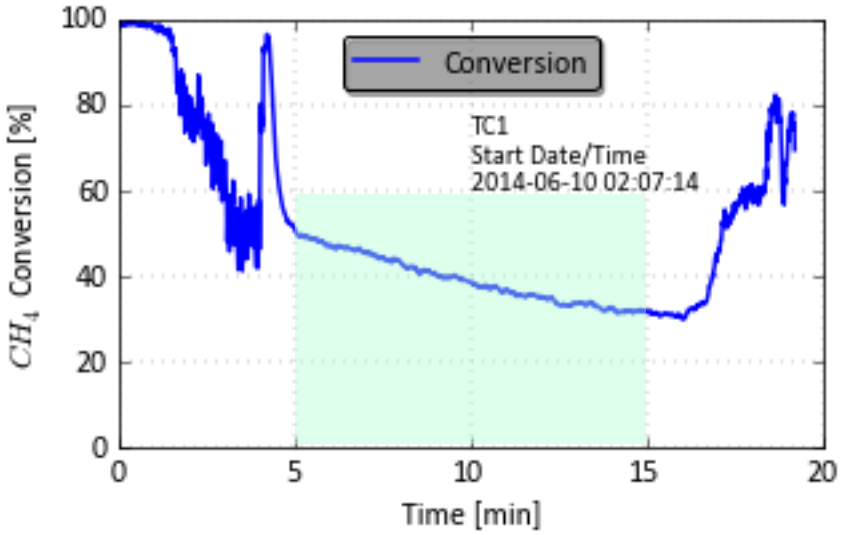
Process Data from NETL Unit – Promoted Hematite Carrier – 2nd Test



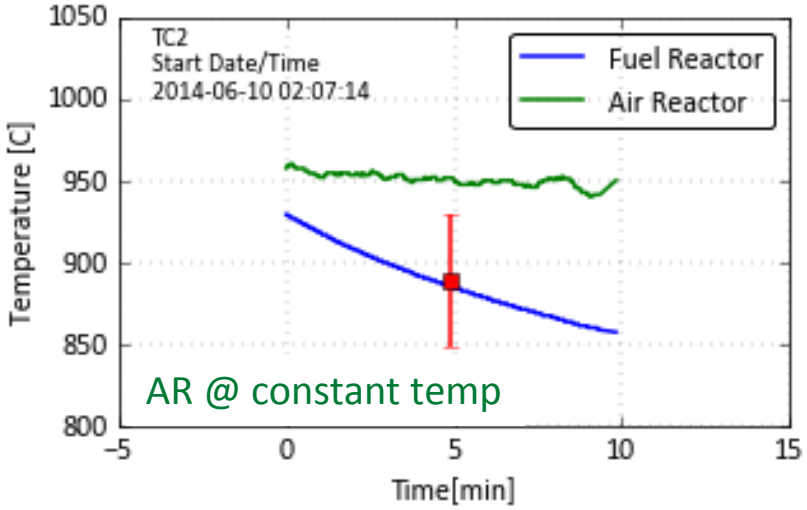
Promoted Hematite – 2nd Test

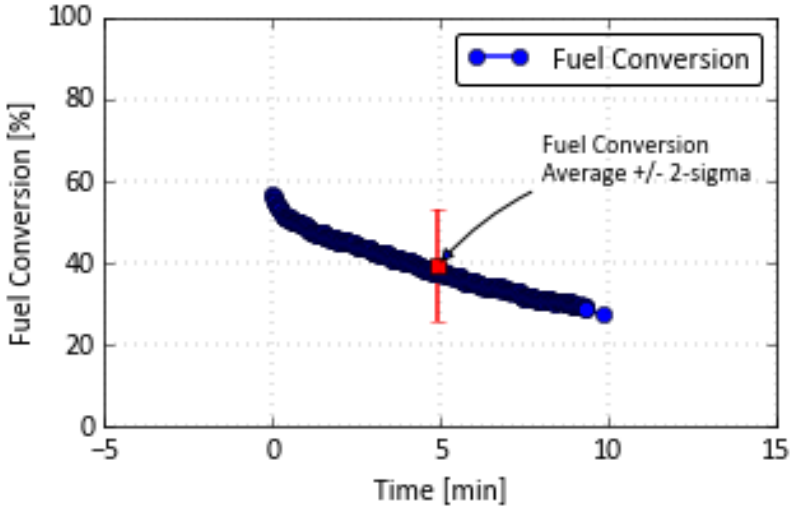
- **Carbon balance was significantly improved**
  - Greater than 90%
- **Fuel conversion still typically less than 50%**
- **Short duration test periods**
- **Operational issues encountered**

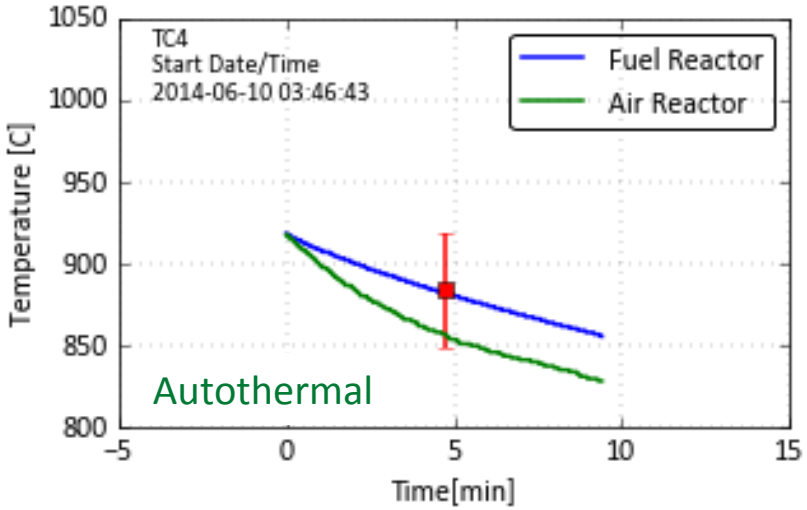


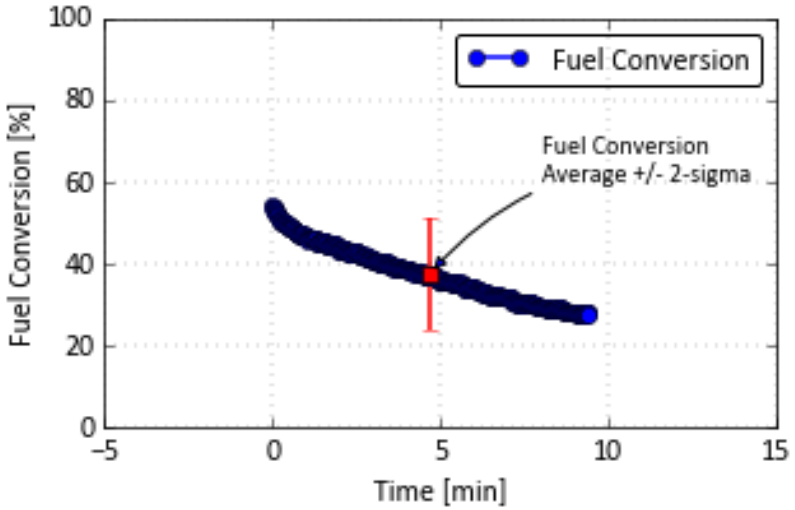


Promoted Hematite – 2nd Test





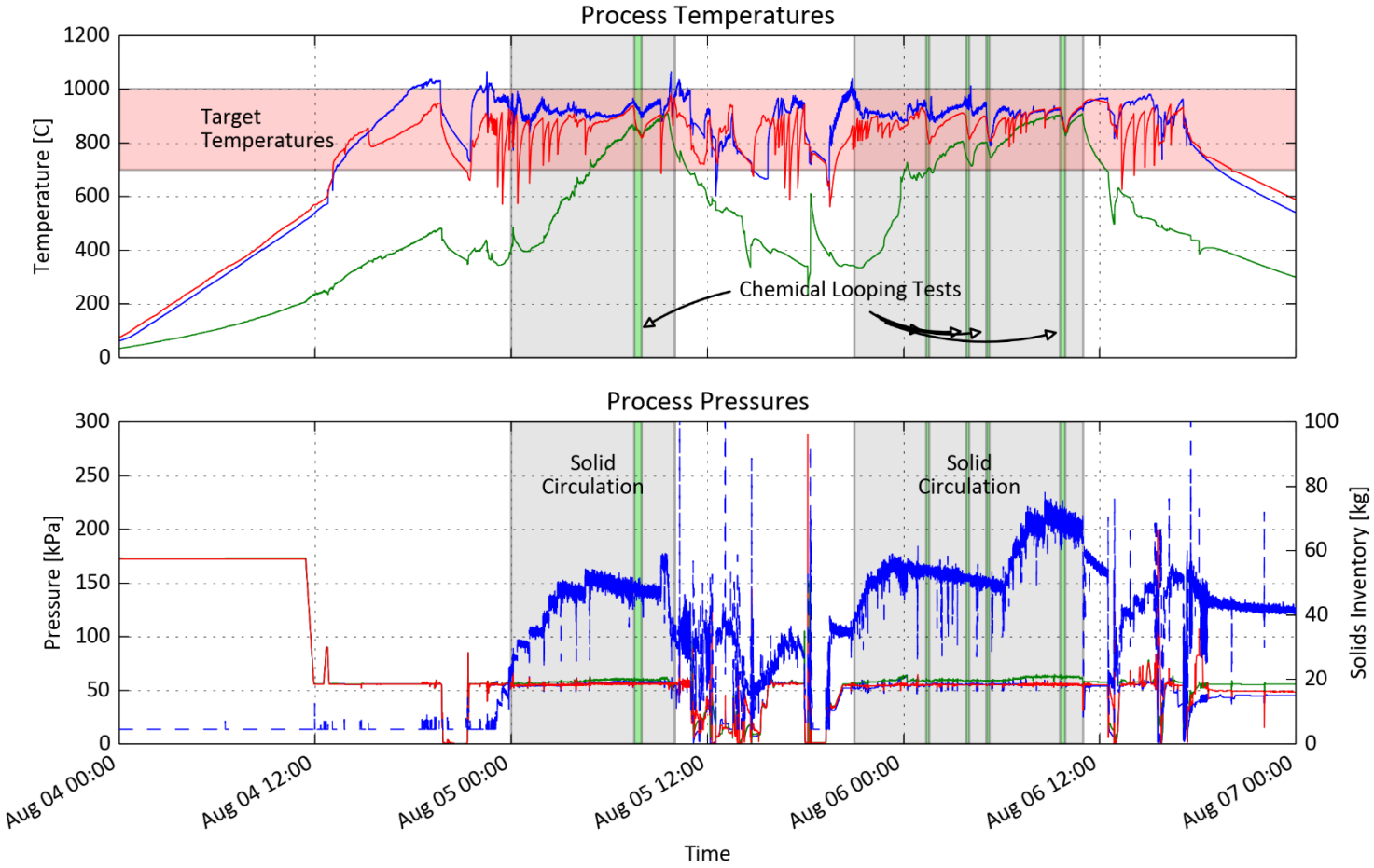




Source of Operational Issues

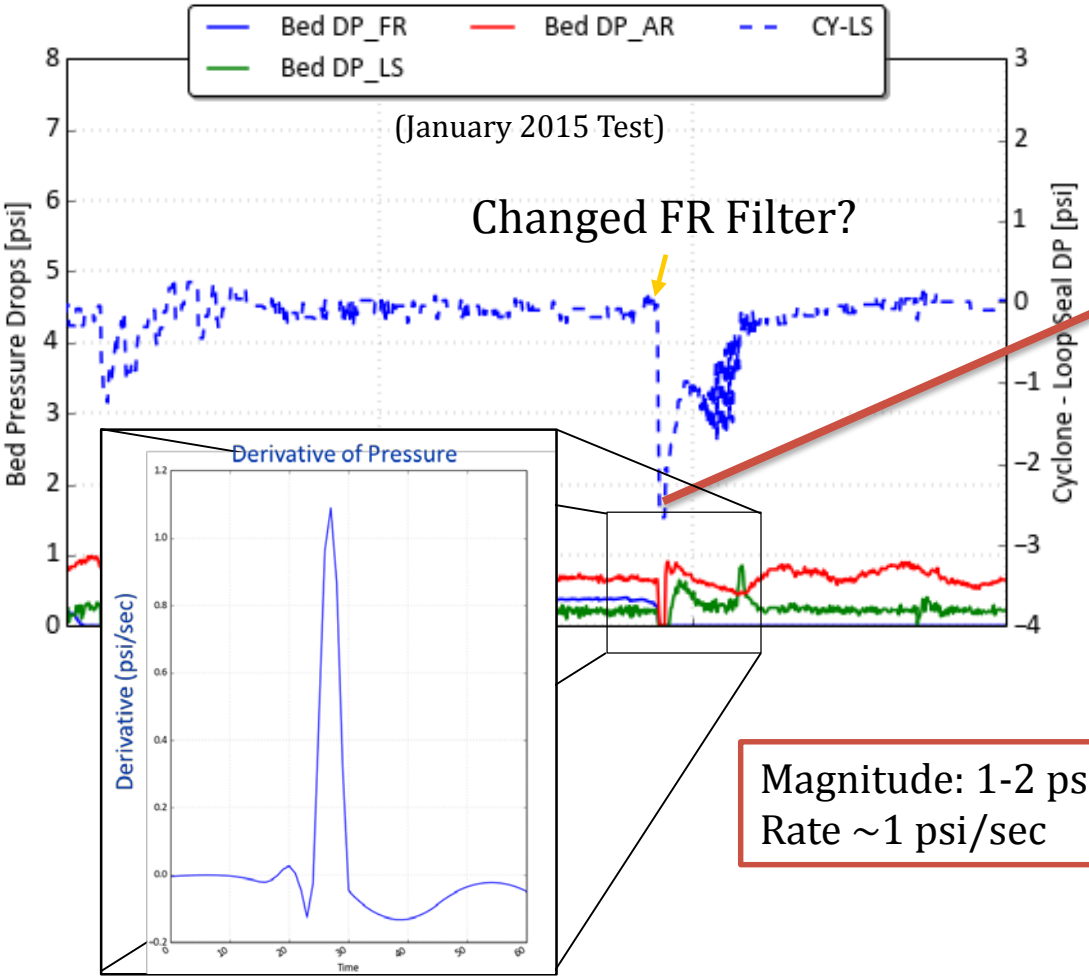
- **Cake-like deposits have been seen in tests with MgO promoted hematite carrier**
  - Deposits only in the FR vent lines (reducing environment)
  - Downstream/lower temperature components
- **Produced enough backpressure to affect pressure balance and control**

Data from Hematite – 1st Test

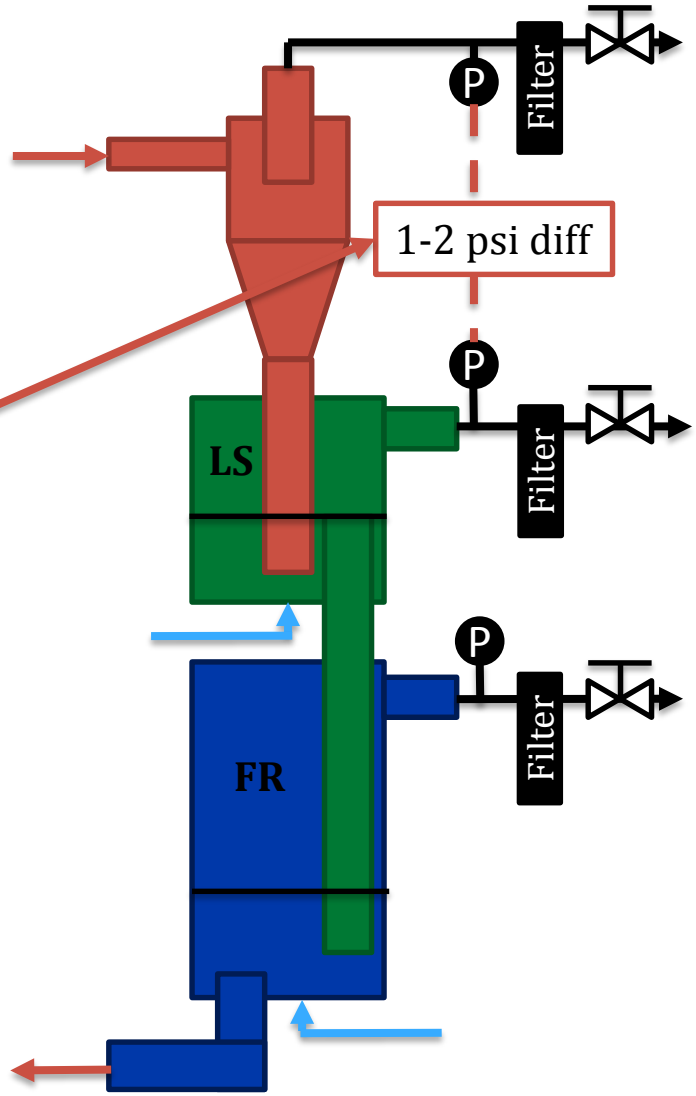


Operational issues and process upsets were encountered

Process Upset → Sudden Loss of Solids



Magnitude: 1-2 psi
Rate ~1 psi/sec



Summary

- **CLC technology has "potential" to achieve cost-effective reduction in GHG emissions from fossil-fueled combustion**
- **NETL's 50kW$_{th}$ CLC test facility**
  - Bubbling fluidized bed fuel reactor
  - Bubbling/turbulent fluidized bed air reactor
- **Tested several different oxygen carriers**
  - Hematite (Wabush Mine; Wabush, Newfoundland and Labrador, Canada)
  - MgO promoted hematite
- **Findings**
  - Mg promoted carrier materials produced coatings/cake in downstream lower temperature piping components
  - Operational pressure upsets have resulted in high rates of oxygen carrier loss
    - Pressure perturbations of 1-2 psi at rates of 1 psi/second have been recorded

Future Efforts

- **Establish baseline carrier loss/make-up requirements for this test rig**
  - Sensitivity studies have shown this to be a critical performance parameter
  - Need better solids mass closure
- **High temperature microwave doppler solids circulation sensor**
- **Collaborations on oxygen carrier testing are encouraged**
  - NETL attrition test unit would be used to screen materials
  - Quantity should be in the 100-150 kg range for one test

In memory of James Spenik, Co-author, Colleague and Friend

It’s All About a Clean, Affordable Energy Future

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