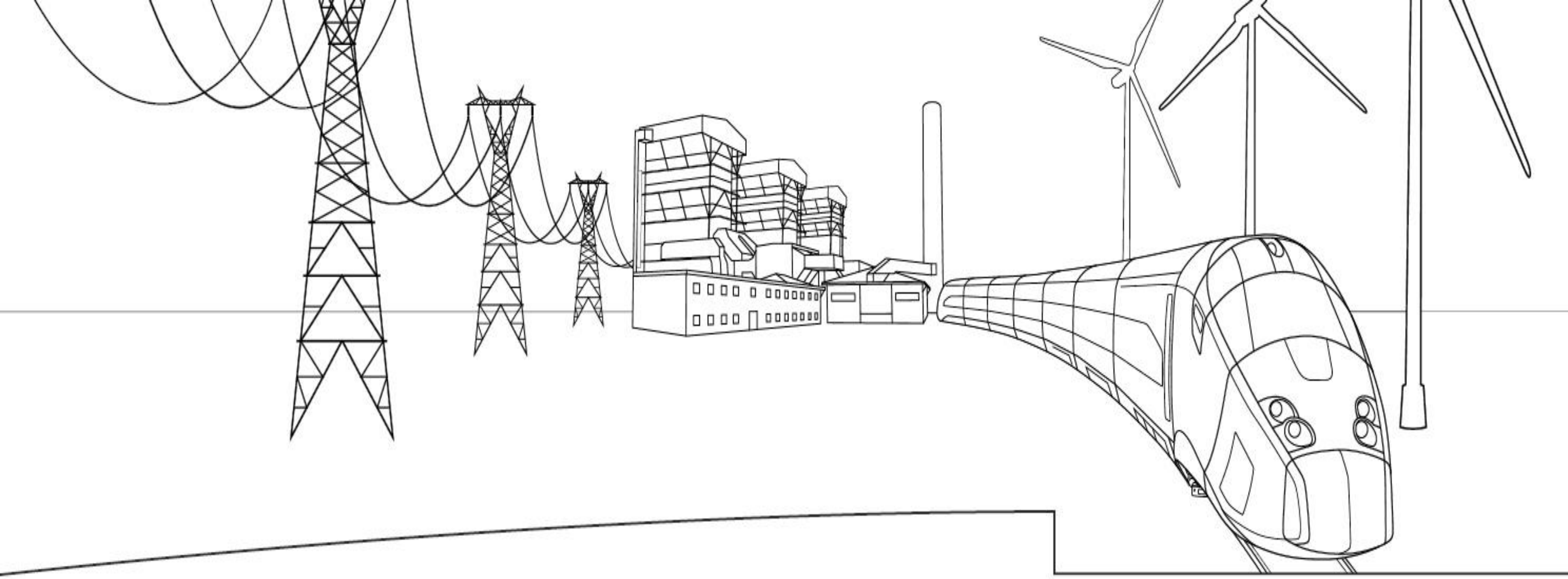

Alstom Limestone Chemical Looping System:

Experiments and Isothermal Simulation

2014 Multiphase Flow Science Conference
August 5-6, 2014

David G. Sloan, Herbert E. Andrus, Jr., and Paul J. Chapman

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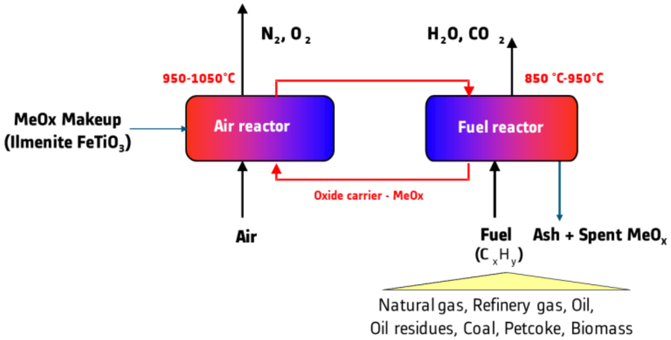
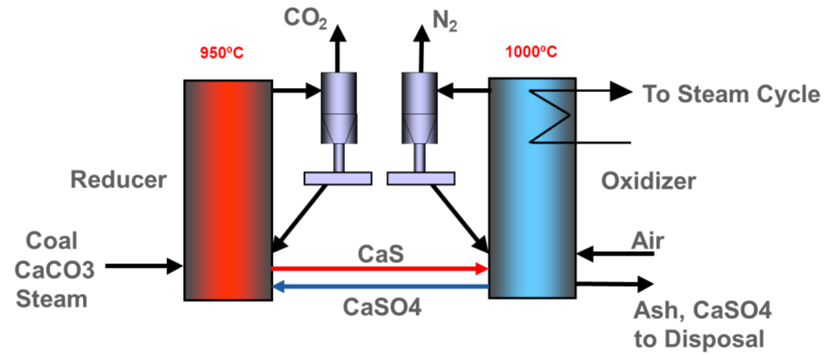
Shaping the future

Alstom's Chemical Looping Development Since Late 1990s





Metal Oxide Based (MeOx)

ÉCLAIR/ACCLAIM Programs – EU RFCS funded

Main Features:

- Metal Based Oxygen Carriers such as Fe, Mn, Cu… ores, ilmenite ($FeTiO_3$), or on substrates
- Process based on CFB solids transport
- Carbon stripper for minimizing UBC

Limestone Based (LCL™)

US-DOE funded

Main Features:

- Limestone based oxygen carrier – CaS, $CaSO_4$
- Process based on "Fast" Bed
- Sorbent reactivation for increased limestone utilization

Alstom is pursuing two different chemical looping technologies

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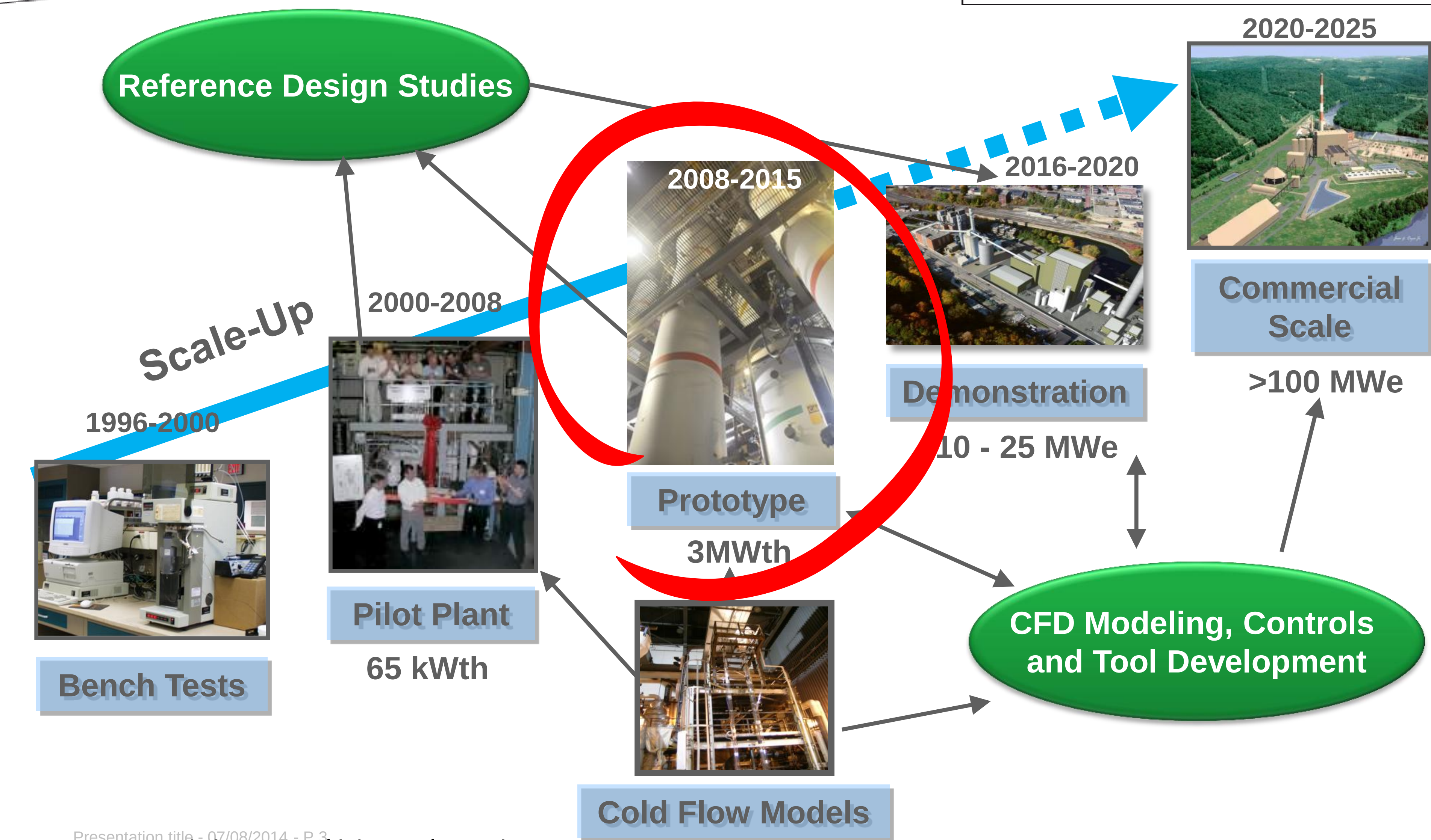
LCL-C™ Chemical Looping Process

Managed Development and Scale-up Steps



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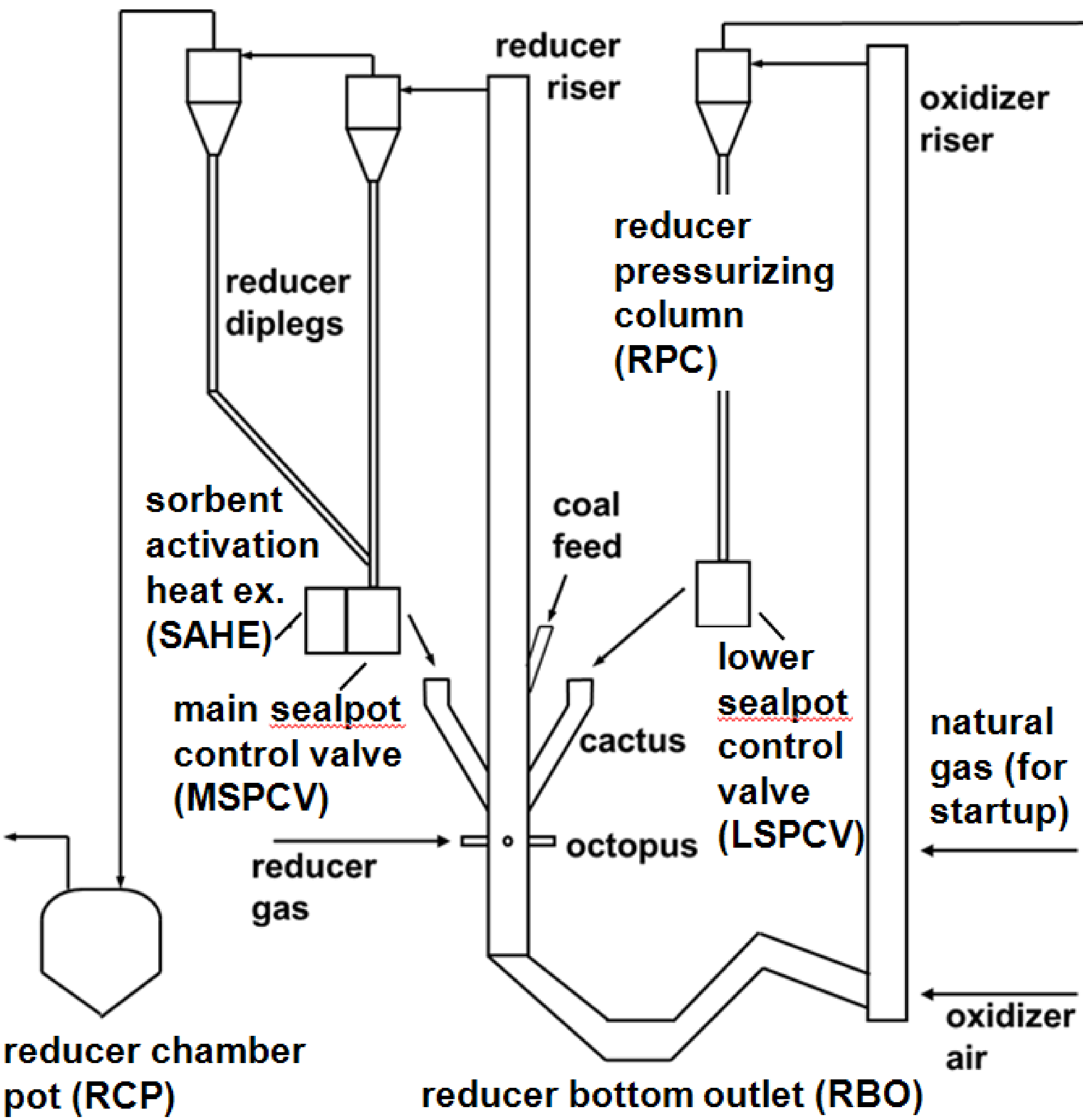
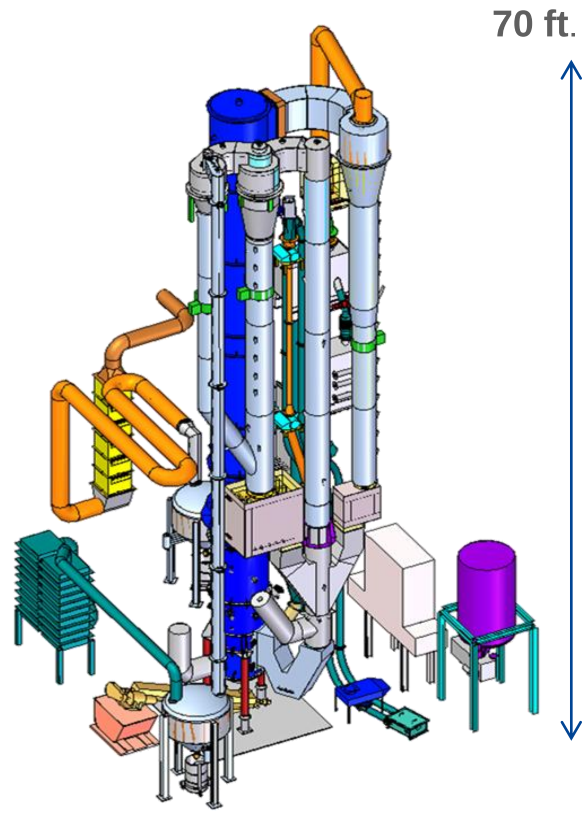
3 MWth LCL™ Prototype





3 MWth LCL™ Pilot

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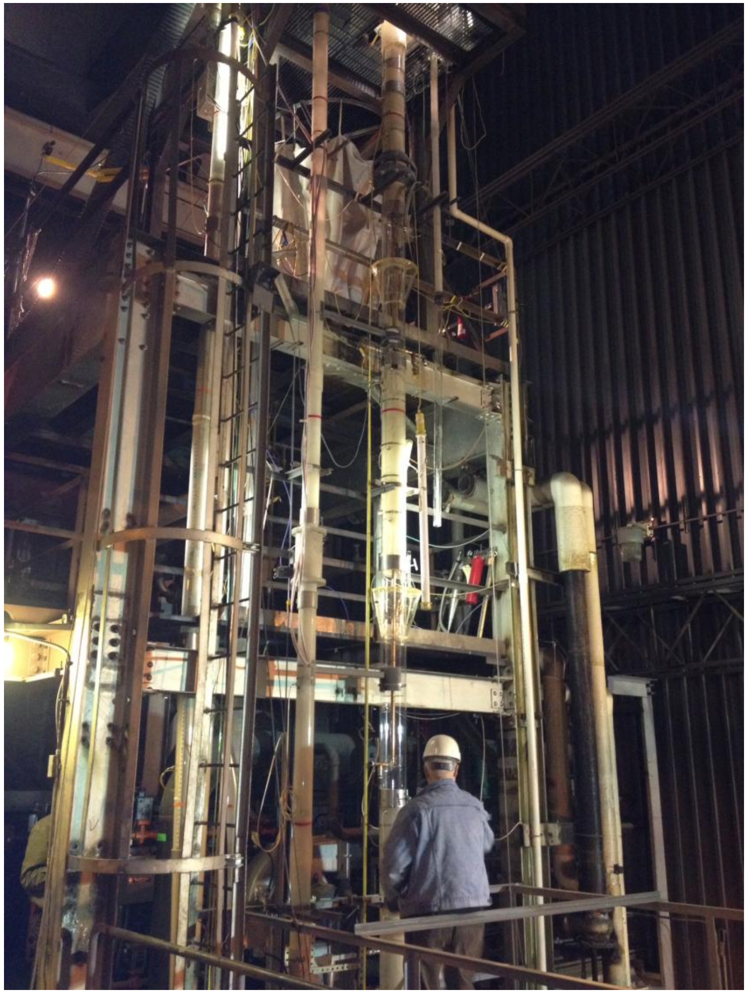
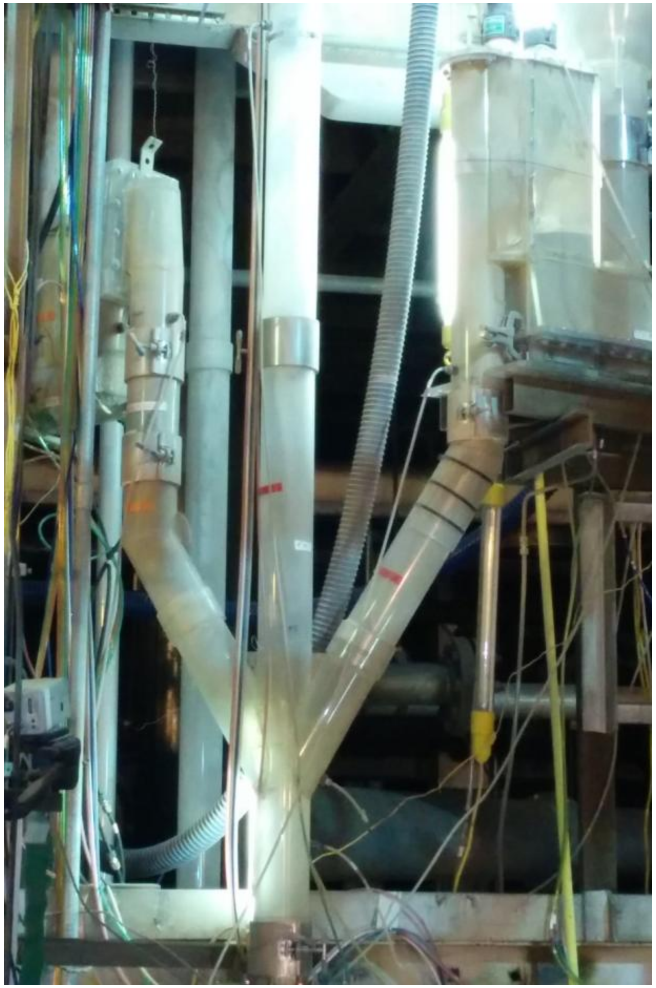
40-Foot Cold Flow Physical Model





Cactus, Reducer Riser, and Sealpot

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Assessment of CFD Software for Data / Design Analysis of CL:
Summary

Potential program scope to identify appropriate use and limitations of current CFD tools <u>for CL development</u>:

1. CFD software prediction accuracy (hierarchical approaches and V&V/UQ)
2. CFD software run time
3. Convergence recognition during dynamic upsets and severe oscillations
4. Grid independence
5. System dimensional scaling
6. Solids transport flow regimes
7. Particle size distribution (PSD) and particle densities
8. Gas density and viscosity
9. Effects of gas generation
10. Others?

Alstom needs continued support from the DOE to solve these problems.
Cooperative and collaborative efforts / FOAs encouraged, as appropriate.
Alstom is interested in continued participation.

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Assessment of CFD Software for Data / Design Analysis of CL:

Effects of Gas Generation

$$CaSO_4 + 4\,CO \Leftrightarrow CaS + 4\,CO2$$
$$4\,C(coal) + 4\,CO2 \Leftrightarrow 8\,CO$$
$$CaSO4 + 4\,C(coal) \Leftrightarrow CaS + 4\,CO$$

- Chemical looping systems generate various amounts of gas <u>at all points</u> within the reducer (fuel reactor) system.
- Events in the dipleg and sealpot regions can fluidize the dipleg and cause the dipleg to flush, inducing a transfer of the dipleg solids into the return leg.
- The secondary cyclone can be compromised, inducing solids loss.
- Physical cold flow modeling:
  - Experimental impact could be checked with strategic lance or gas injection in regions of sealpot and dipleg, etc.
  - Results could be compared with corresponding CFD runs
- Reacting systems:
  - May use gas drains in dipleg, etc., to measure gas generation.
  - Gas tracer techniques to quantify gas generation along riser.

CFD needs to account for gas generation everywhere and capture flushing.

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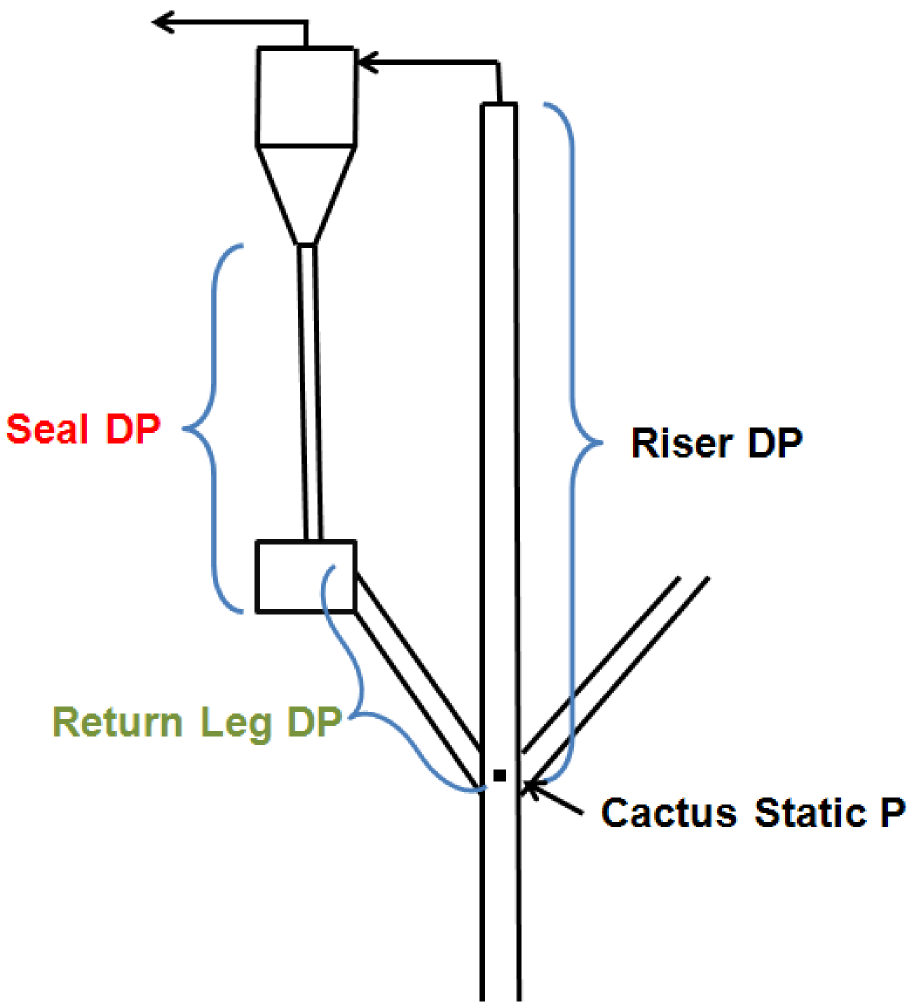
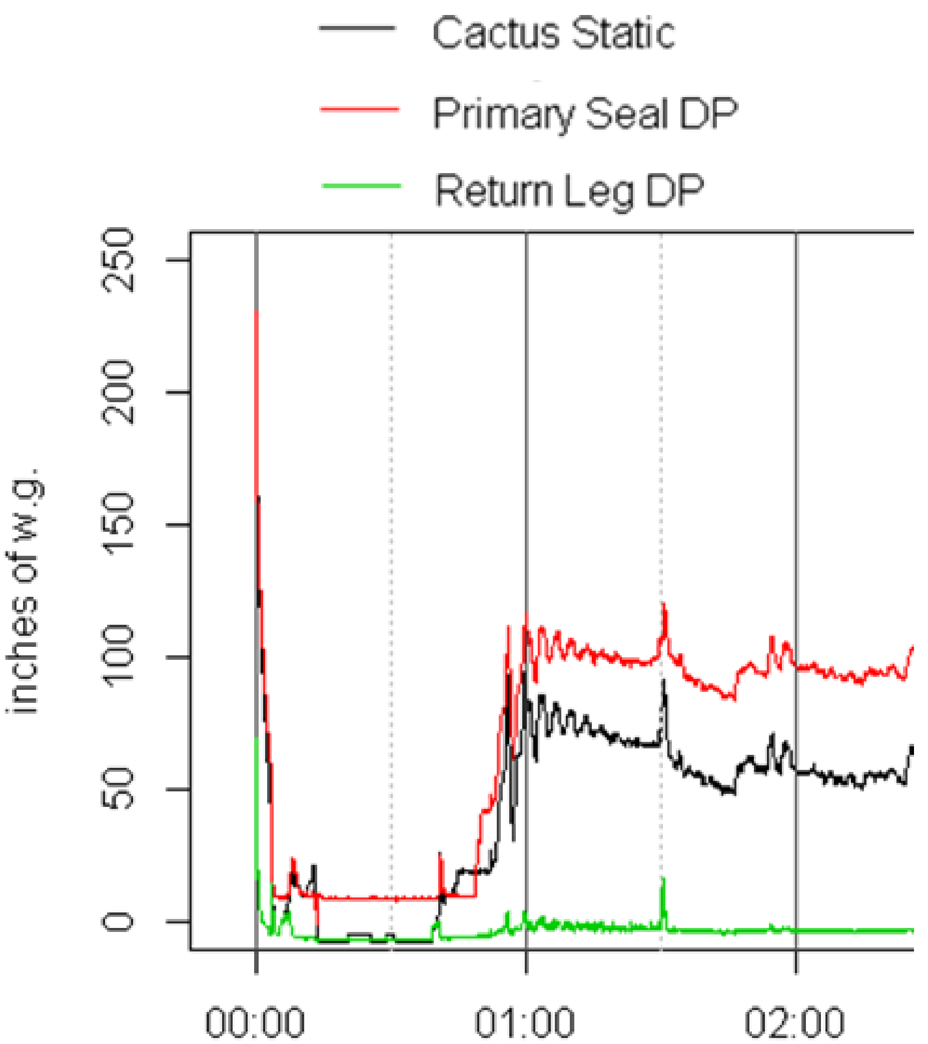
3 MWth LCL™ Prototype
Pressure Trace Definitions





2014 NETL Workshop on Multiphase Flow Science

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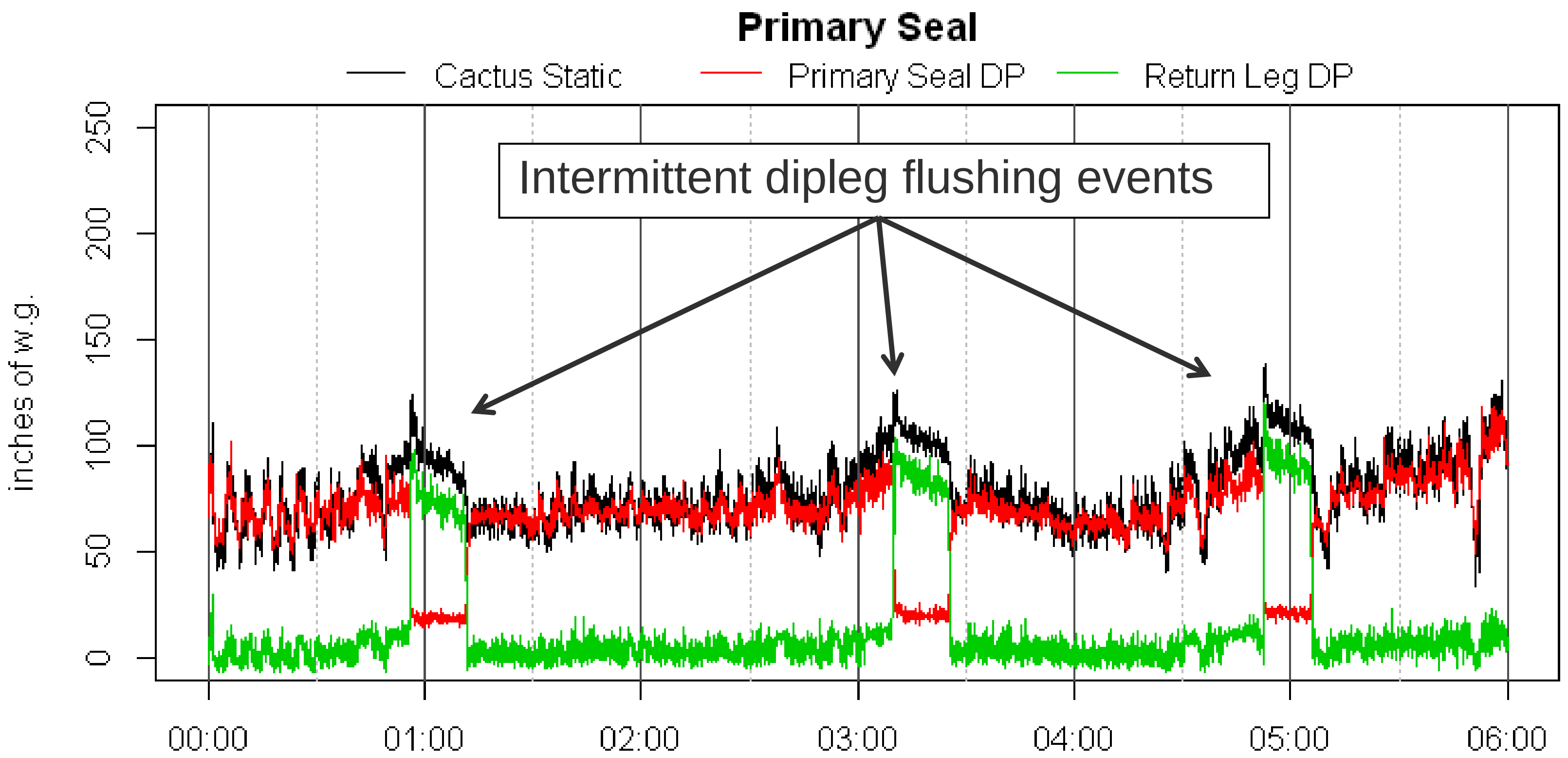
Prototype Coal Firing – Primary Dipleg Flushing

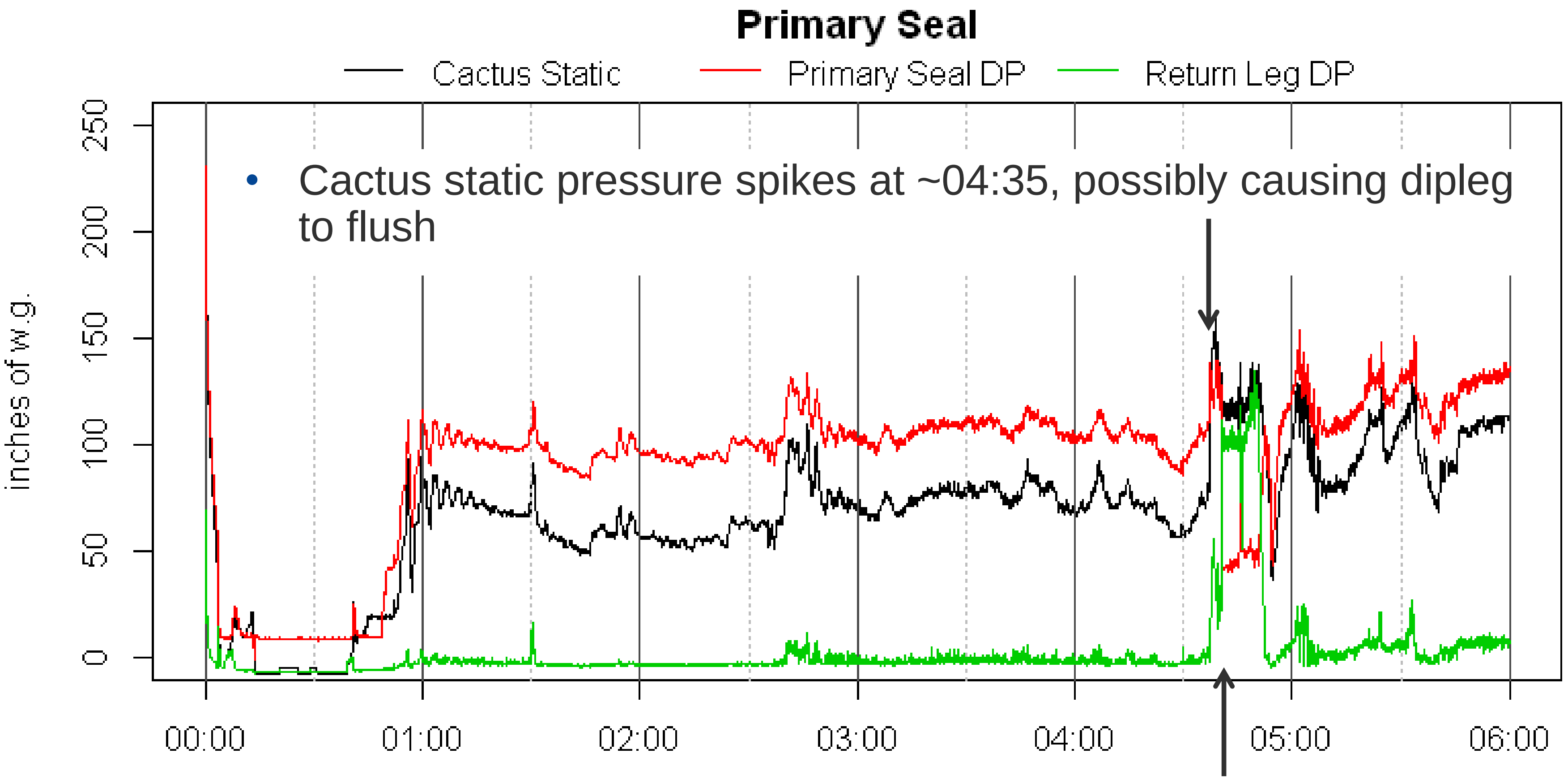
Example of Flushing Events in Dipleg and Sealpot



- CFD must be able to capture the intermittent upsets / instabilities.
- If CFD misses the instabilities/flushing, then the dipleg and seal will not be designed with proper margins.

Prototype Cold Flow Testing – Primary Dipleg Flushing

Reducer Side



- Cactus static pressure spikes at ~04:35, possibly causing dipleg to flush
- Dipleg flushes at ~04:40

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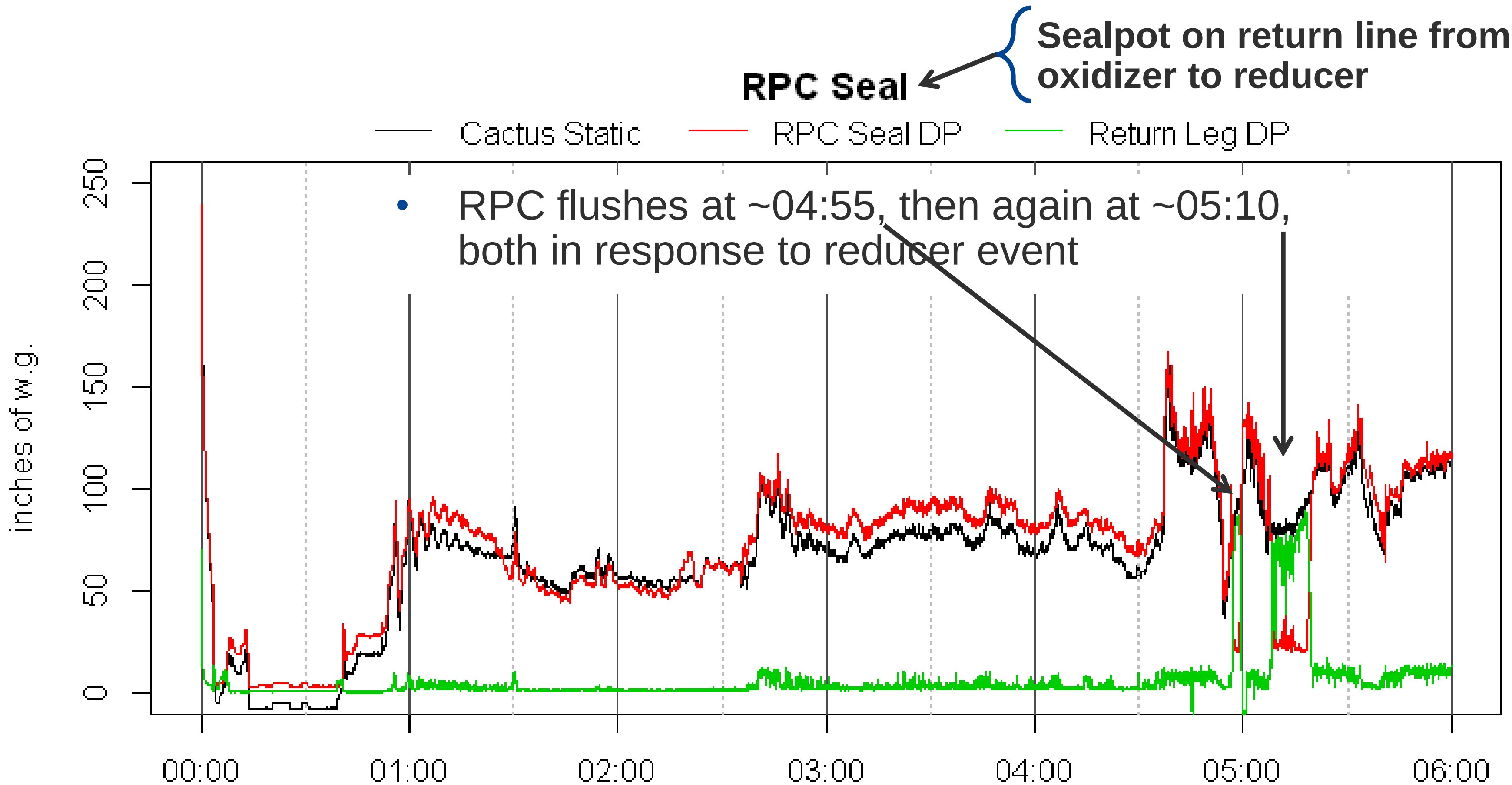
Prototype Cold Flow Testing – RPC Flushing

Reducer Event Propagates to Oxidizer Side and Induces Response



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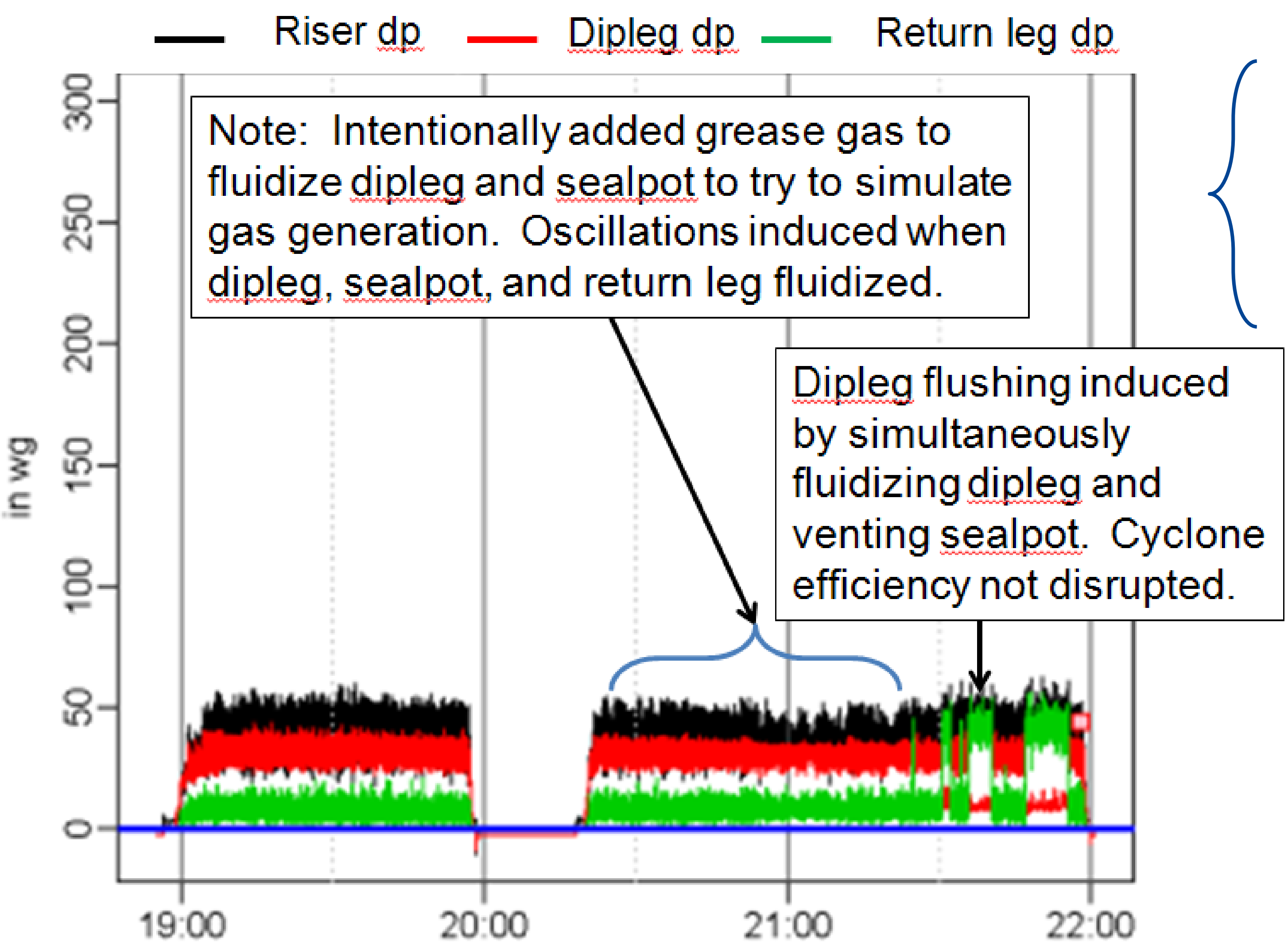
40-Foot Cold Flow Test Results – Small Dipleg Height



Movie of oscillations in cactus region of 40-foot cold flow model

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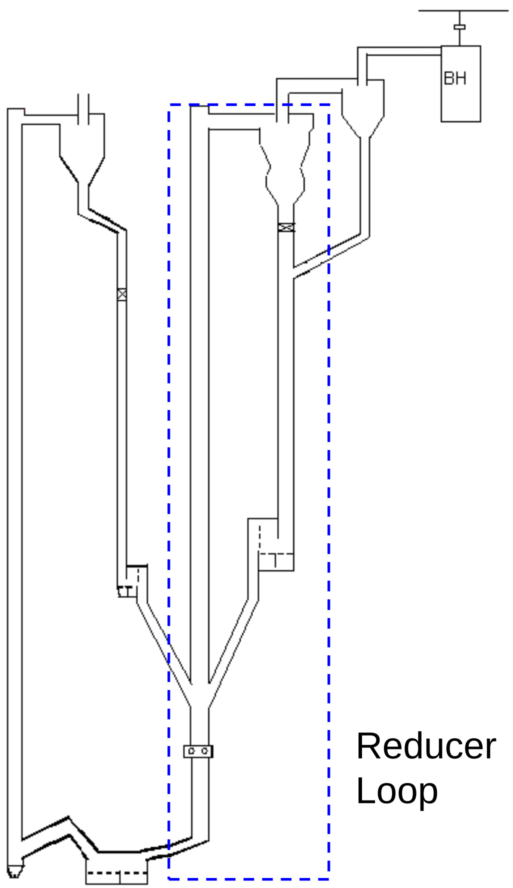
Cold Flow Modeling Example: Single Loop Operation

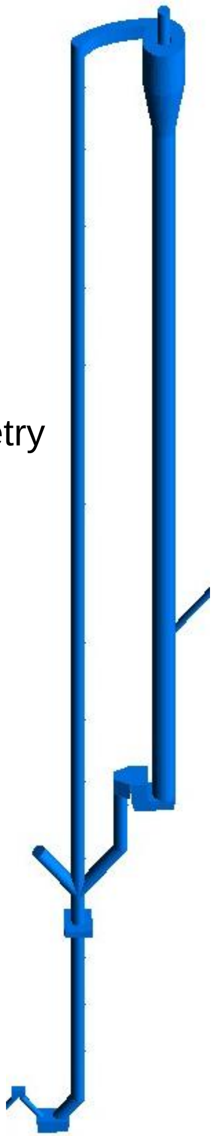
- Setup riser, sealpot and grease air flows.
- Include tracer gas species at 3 locations.
- Run simulation for 200s with Barracuda
- Compare predictions to measurements



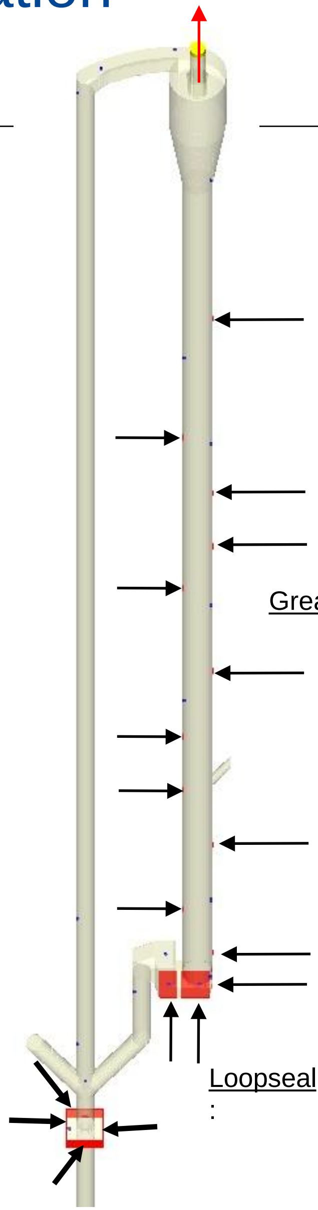
Oxidizer Loop

Reducer Loop

CAD Geometry



Flow Inputs:

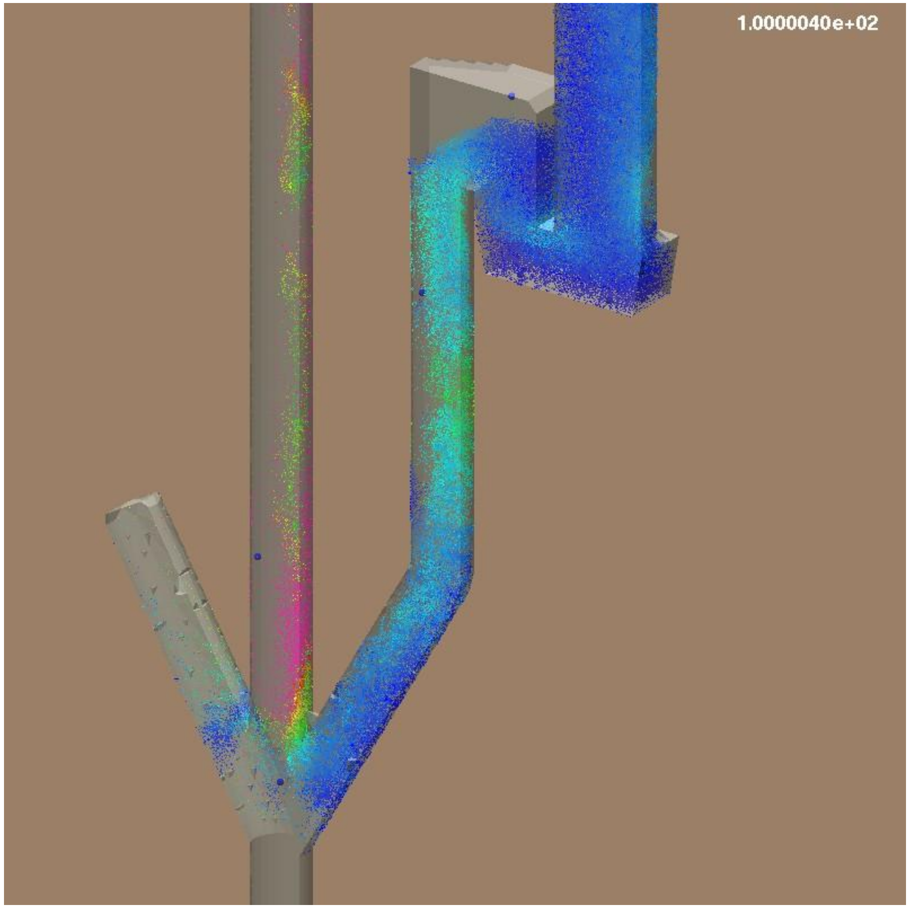


Grease:

Loopseal:

Riser: The Major flow source…

Qualitative Comparison: Physical Flow Model and CFD (Picture)



Particle velocity from 0 to 3 m/s. Velocities above 3 m/s in riser are clipped and are not shown.

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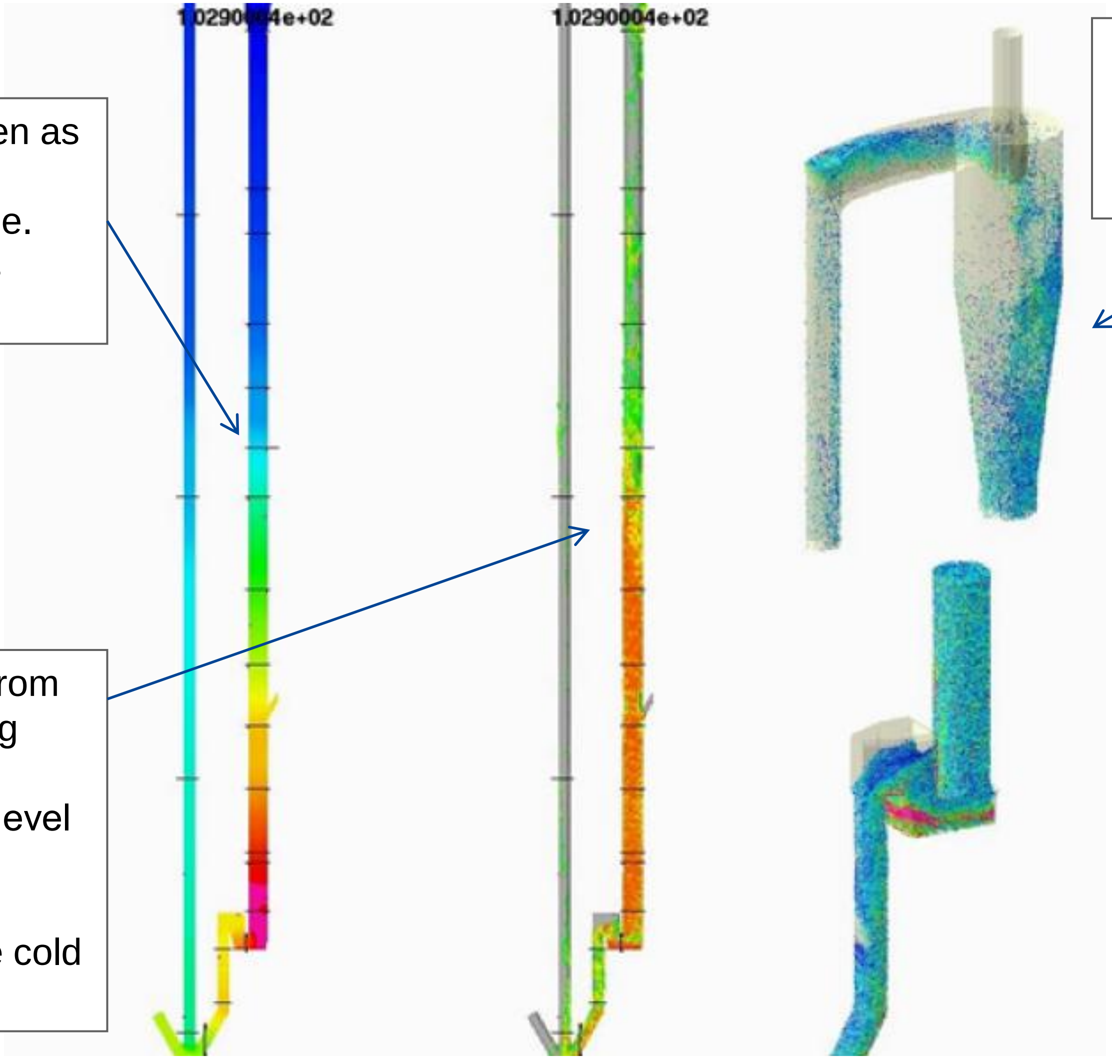
Summary of Simulation: Pressure, Solids, Localized Flows (Picture)

- Pressure pulsations driven as solids enter the reducer column in the cactus zone.
- Time step in animation is about 0.1 sec.



- Flow of particles colored by size

- Solids volume fractions from 0.3 to the defined packing limit of 0.65.
- Determining the “solids” level in the dipleg is difficult
- Level in the simulation is slightly higher than in the cold flow model.

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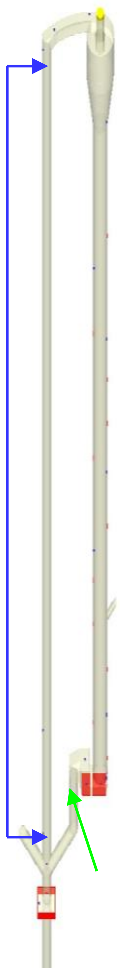
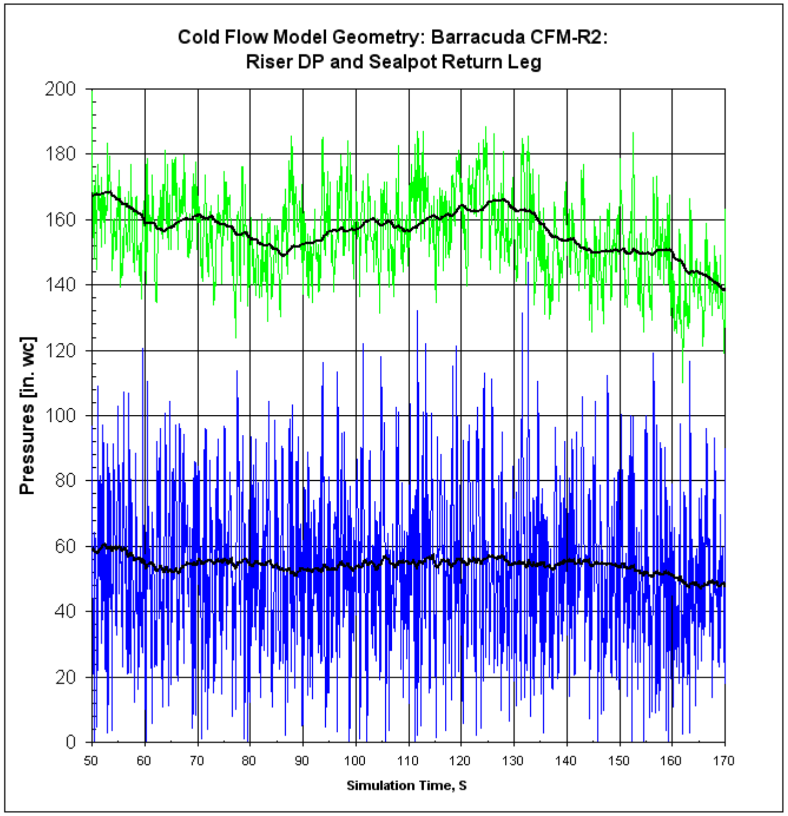
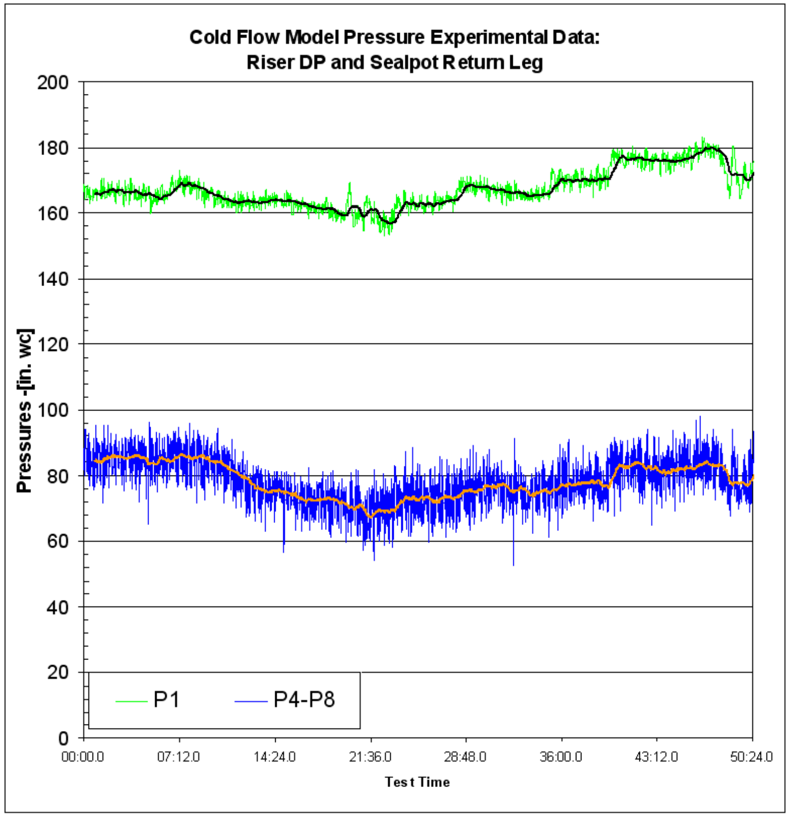
Comparison of Predictions: Solids Return Pressure and Riser DP



Predicted

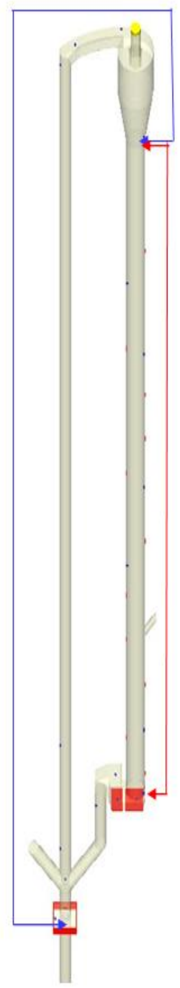


Measured

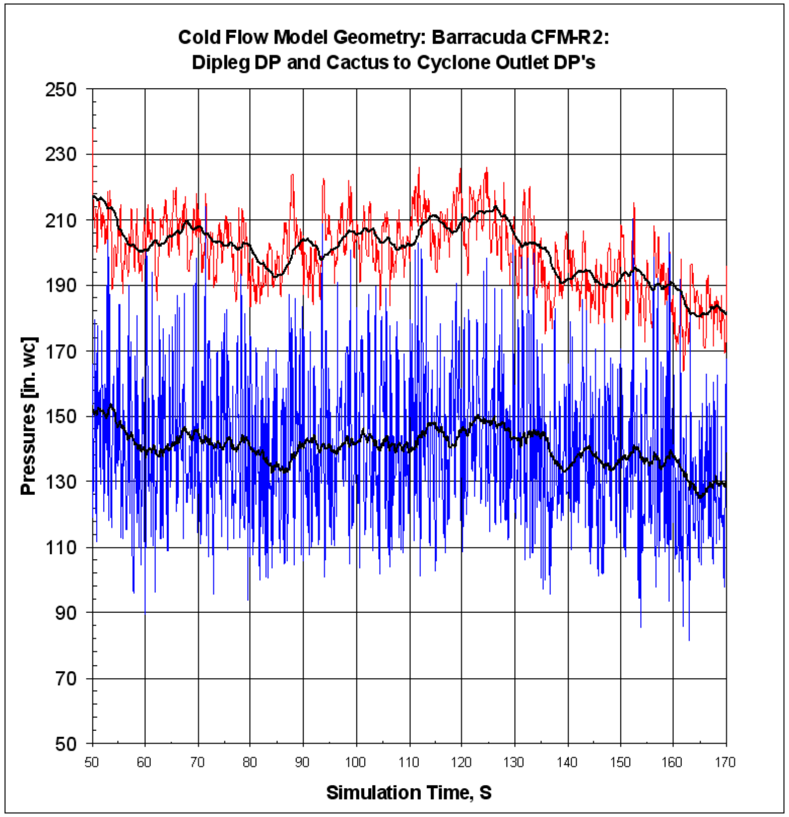


- Slow-response, low-frequency, pressure cells (logged on a 1 sec interval)

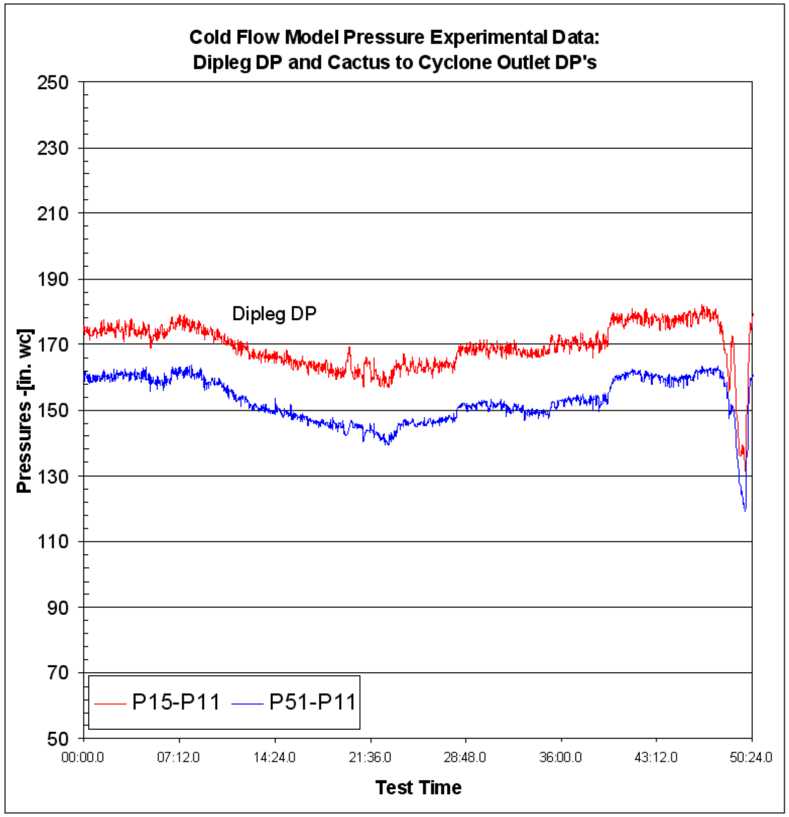
Comparison of Predictions: Dipleg DP and Cactus to Cyclone Outlet



Predicted



Measured



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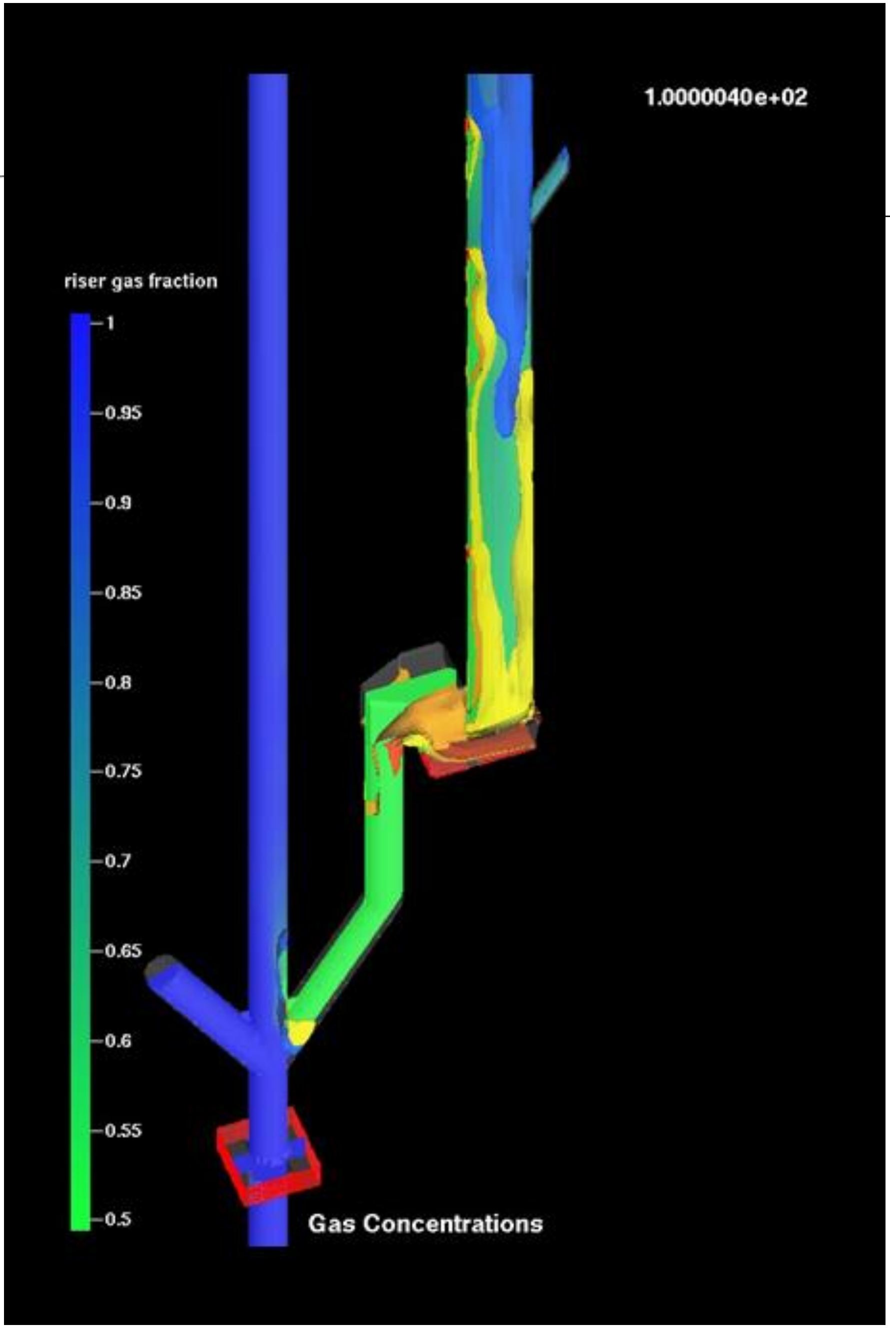
Visualization: Tracer Gases [Picture]

Centerline Slice: Contour Plot of
Reducer Gas Mass Fraction

Sealpot Flow Isosurface – Red

Grease Air Concentration Isosurfaces:
Yellow and Orange



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Summary:

- Simulation work in combination with cold flow experiments are proving beneficial.
- Some areas of reasonable alignment with measurements observed.
- Several areas where the comparison of the pressure calculations with the pressure measurements appear to be off.
- Improvements to CFD modeling accuracy and speed are ongoing.
- Use of CFD for larger scale geometries are planned for future studies.

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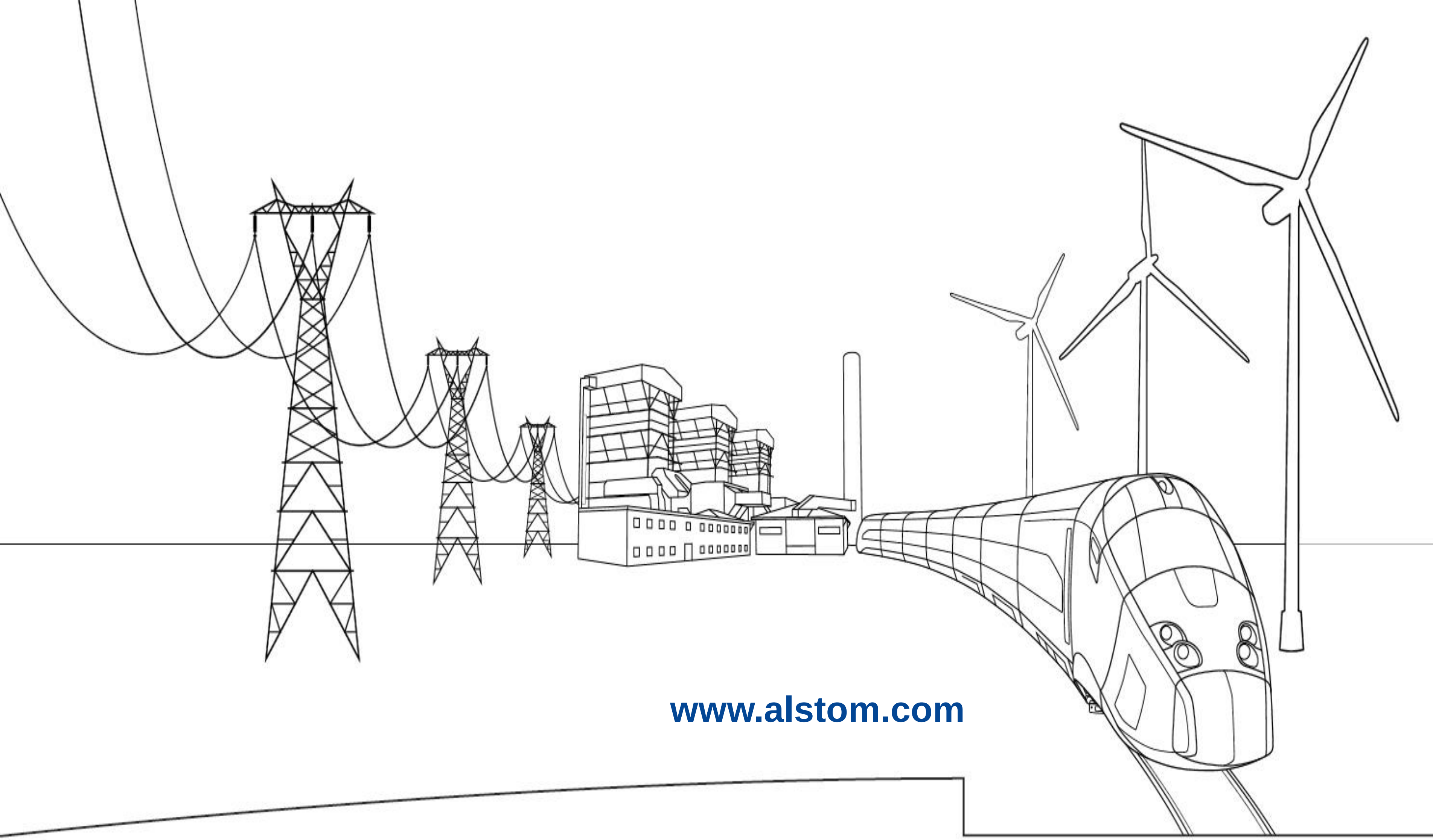

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