Improvement of Alstom's [GE] LCL-C^{TM} process for higher purity flue gas production (FE0025073)

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Imagination at work

Performance summary

	Commercial Goal	3 MW Prototype - Current Level	Project Success Criteria (3 MW Prototype)	100 kW PSTF – Current Level (III#6)
Carbon Conversion Performance				
Carbon Gasified in Reducer (%)	>95	40 - 50	>80	70 - 85
Unburned Carbon Loss in Ash (%)	<0.5	Up to 20	<5	3 -5
Carbon Carryover to Oxidizer (%)	1	20 - 40	<20	13 -21
Reducer Gas Oxygen Demand (% of Stoichiometry O_2)	<5	25 - 15	<10	8 -19
Sulfur Retention by Reactors				
Sulfur Capture (% of S input)	>85	Net Sulfur Loss	>70	0 - 94
Solids Transport				
Solids Circulation Rate	Design Range	Lower	Design Range	Design Range
Dipleg Flushing (Frequency)	None	Frequent	Rare	None
Solids Loss Rate Thru Cyclones (lb/MBtu- Fired)	As Req'd Stable Inventory	Up to 200	50	70 – 120

The oxygen demand of the LCL-C^{TM} process remains a technical challenge

Improvement of LCL-C Process for High Purity Flue Gas Production - Project FE0025073

Objective: To further develop a coal-fired LCL-C™ process that can produce a higher purity flue gas stream and achieve an improved overall performance while achieving greater than 90% CO_2 removal at less than 35% increase in the Levelized Cost Of Electricity (LCOE)

The Oxygen Demand (OD) targeted is:

OD < 5% (enhanced LCL-C™) and OD < 1% (polishing stage)

3 technical approaches will be followed:

- 1st technical approach: Improved LCL-C™ Oxygen Carrier
- 2nd technical approach: Oxy-combustion downstream of the reducer
- 3rd technical approach: Gas processing Unit with reducer product gas recycle

Oxygen demand definition: percentage of oxygen to be supplied to the product gas (e.g. by ASU) to achieve complete combustion of such product gas with respect to the stoichiometric oxygen required for complete combustion of the fuel

Identified technical approaches

1. Improved LCL-C™ oxygen carrier/process performance (syngas, volatiles)

2. Oxy-combustion downstream of reducer:

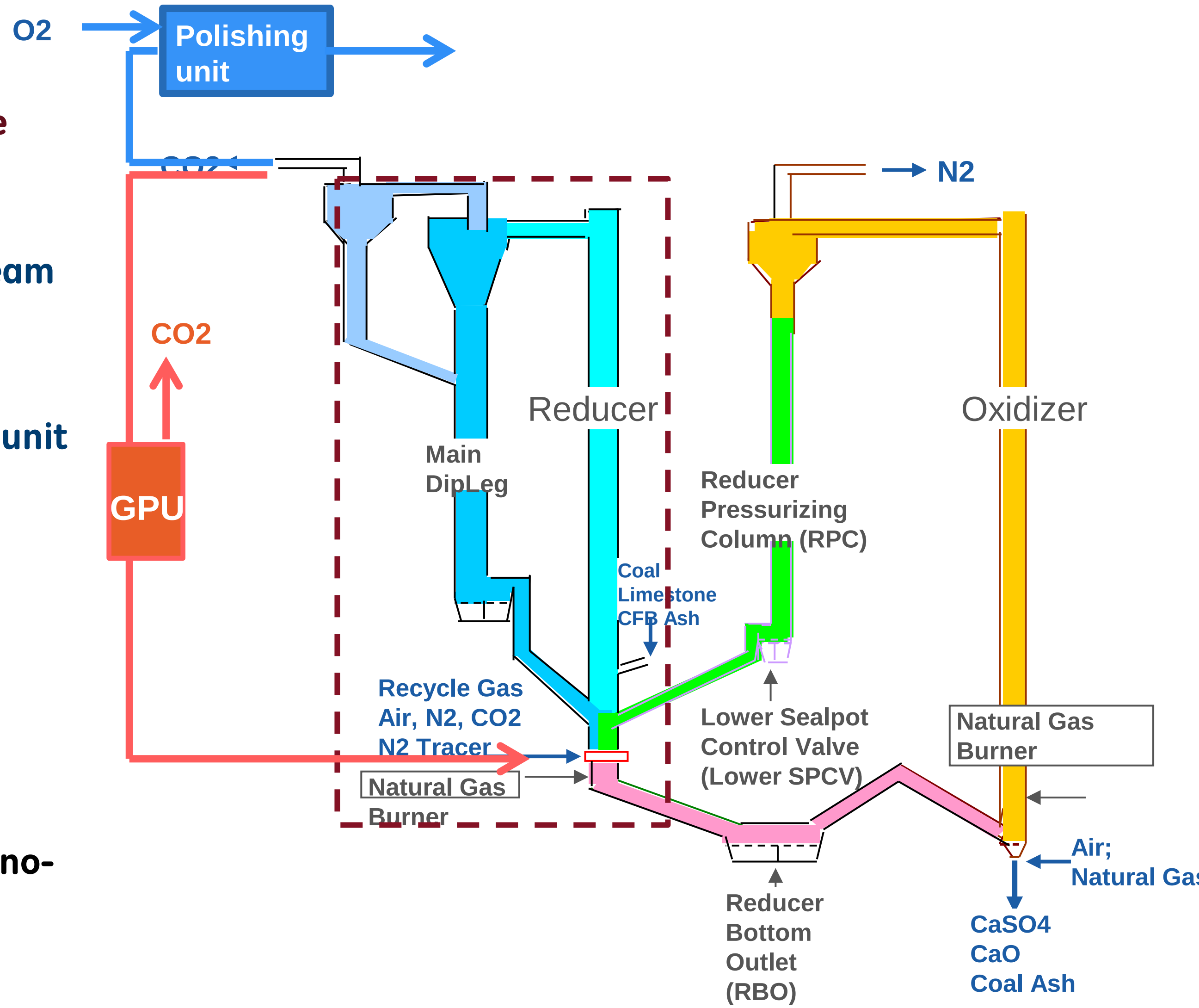
Oxygen injection

Secondary chemical looping unit (polisher)

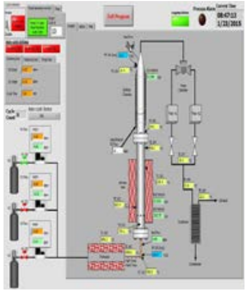
3. Gas Processing Unit with reducer gas recycling

4. Any combination of the 3 approaches above

5. Downselect based on techno-economic analysis

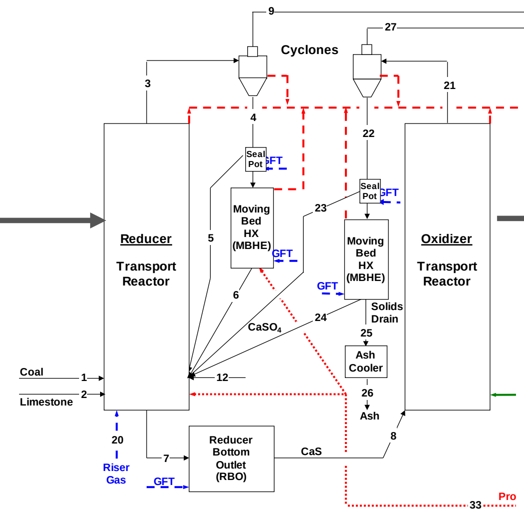


Project structure



Reaction Number	Solid Reactant Species		Reactions	Reference
		Pyrolysis		
			coal ==> char + CO + H2 + N2 + H2O + CO2 + CH4 + H2S + soot [Note 1]	Based on PC Coal Lab
		Char Decomposition		
			char ==> C + S + ash [Note 2]	
		Heterogeneous Char Reaction Rates [kmol/m/s]		
R-1	C		C + (1/ϕ) O2 ==> 2(1-1/ϕ) CO + (2/ϕ-1) CO2	Wen and Chaung [Ref. 4]
R-2	C		C + H2O ==> CO + H2	Wen and Chaung [Ref. 4]
R-3	C		C + CO2 ==> 2CO	Wen and Chaung [Ref. 4]
R-4	C		C + 2 H2 ==> CH4	Wen and Chaung [Ref. 4]
R-5	S		S + H2 ==> H2S	Derived from R-4 [Ref. 1]
R-6	S		S + O2 ==> SO2	Derived from R-1
		Homogeneous Reaction Rates [kmol/m/s]		
R-7			CO + 1/2 O2 ==> CO2	Cen, et al. [Ref. 5]
R-8			H2 + 1/2 O2 ==> H2O	Cen, et al. [Ref. 5]
R-9			CH4 + 2 O2 ==> CO2 + 2 H2O	Cen, et al. [Ref. 5]
R-10			CO + H2O ==> CO2 + H2 [Water-Gas Shift]	Wen and Chaung [Ref. 4]
R-11			CH4 + H2O ==> CO + 3 H2 [Steam Reforming]	Wen and Chaung [Ref. 4]

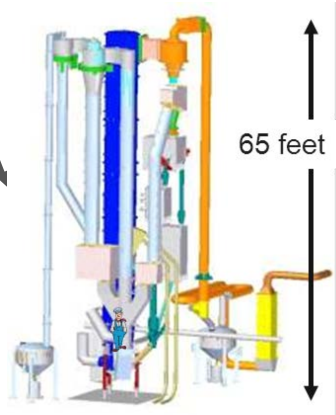
- Pilot plant data, validation effort
  - GE, CT
- Bench scale data (conversion, yield)
  - UND labs
  - GE, CT
- Advanced process models
  - GE, CT
  - GE, Vaxjo SE



Simulation platform (ASPEN) (process flowsheeting)

- GE, CT
- GE, Wiesbaden DE
- CRADA (NETL)

- Techno-economic analysis
  - GE, CT
  - GE, Wiesbaden DE
- Scale up study
  - GE, CT



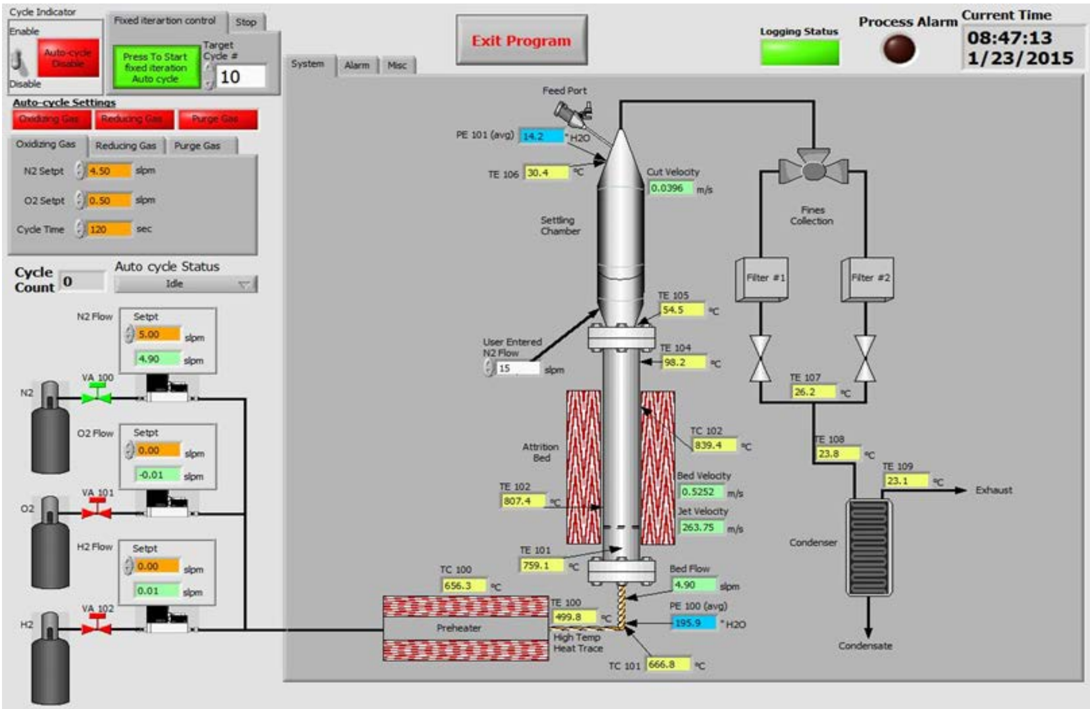
Prototype (3 MWt)

Scale-up from bench scale to 550 MWe (TEA)

Bench scale testing (1^{st} and 2^{nd} approaches)

Objective: screening of oxygen carrier blends and their performance in terms of:

Reactivity / selectivity, cyclability, attrition, physical properties, morphology



Kinetics and Attrition Testing Equipment (KATE)

at the University of North Dakota:

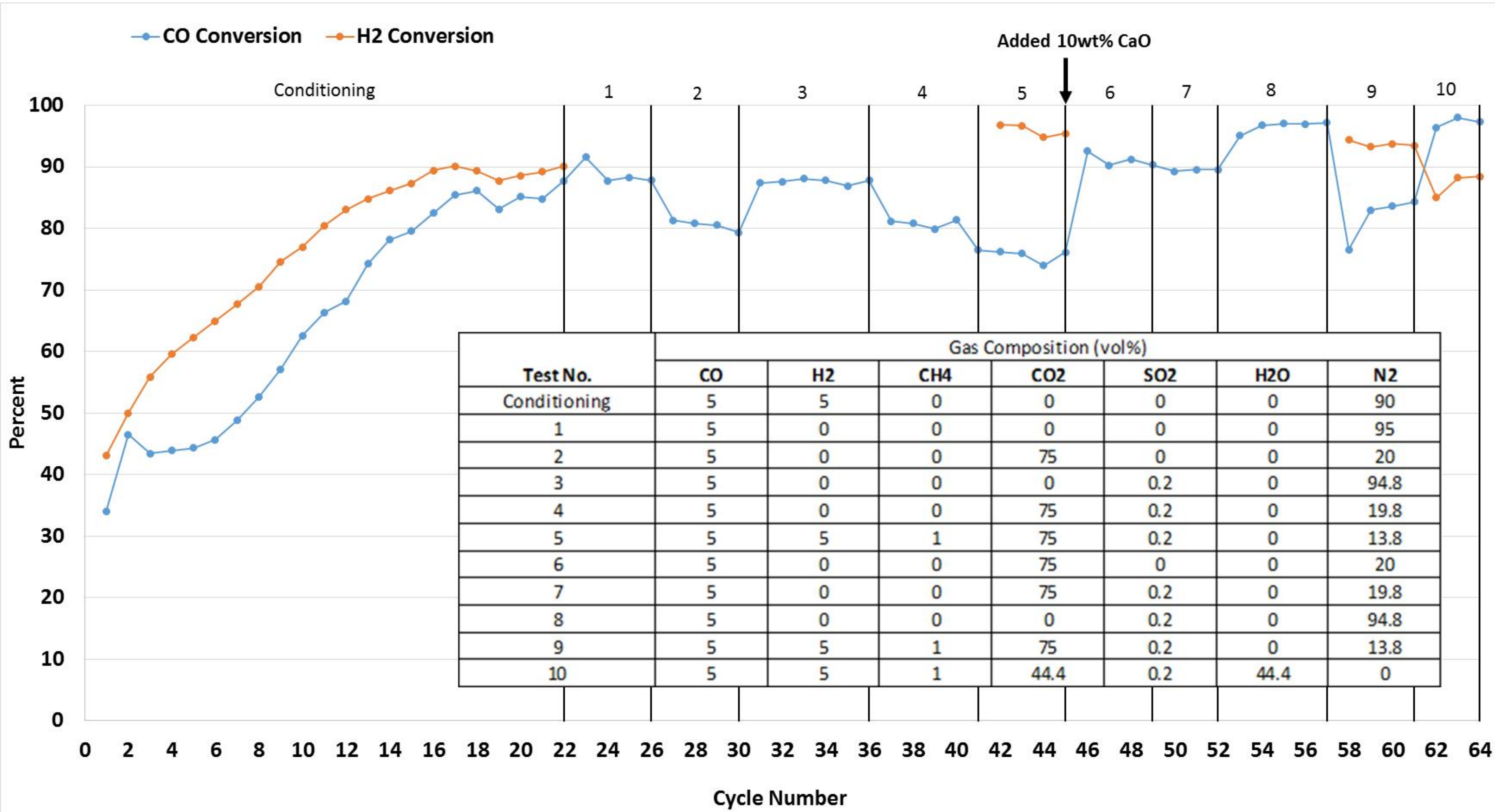
Fully automated bench scale testing facilities

Bench-scale testing: achievements to date

- Equipment design and upgrades for enhanced LCL-C™ testing:
  - Upgraded for H_2O, SO_2, H_2S injection
  - Coal-injection (batch) capable
  - Temperature up to 2000°F
  - Material selection for reduced wall effects and corrosion resistance while cycling in the presence of S-containing species

- Preliminary results on limestone and limestone/metal oxide blends
  - >95% reduction in oxygen demand demonstrated on synthetic gas
  - Co-separation of SO_2 feasible under process conditions relevant to LCL-C™
  - Chemical Looping Oxygen Uncoupling for LCL-C™ identified and sourced with the collaboration of Chalmers University

Performance under cyclic conditions

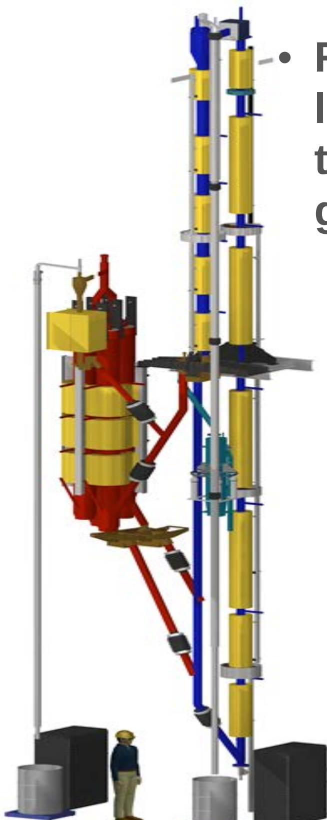


Test No.	Gas Composition (vol%)						
	CO	H2	CH4	CO2	SO2	H2O	N2
Conditioning	5	5	0	0	0	0	90
1	5	0	0	0	0	0	95
2	5	0	0	75	0	0	20
3	5	0	0	0	0.2	0	94.8
4	5	0	0	75	0.2	0	19.8
5	5	5	1	75	0.2	0	13.8
6	5	0	0	75	0	0	20
7	5	0	0	75	0.2	0	19.8
8	5	0	0	0	0.2	0	94.8
9	5	5	1	75	0.2	0	13.8
10	5	5	1	44.4	0.2	44.4	0

Fast screening of oxygen carrier/process conditions under redox cycles

Pilot scale testing (2nd approach)

Objective: modify existing pilot plant to demonstrate process/oxygen carrier performance/stability under polishing process conditions

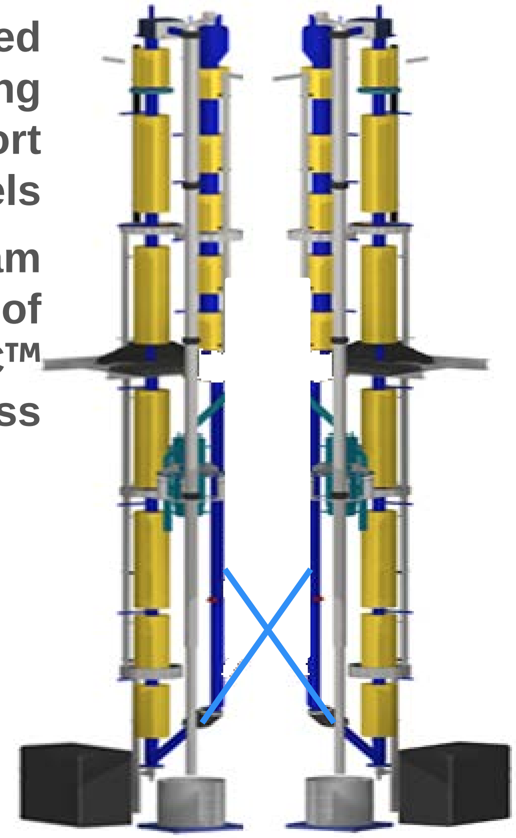


- Reducer box for longer residence time required for gasification

Enhanced LCL-C™ (solid fuel configuration)

- Interconnected circulating fluidized/transport beds for gas fuels

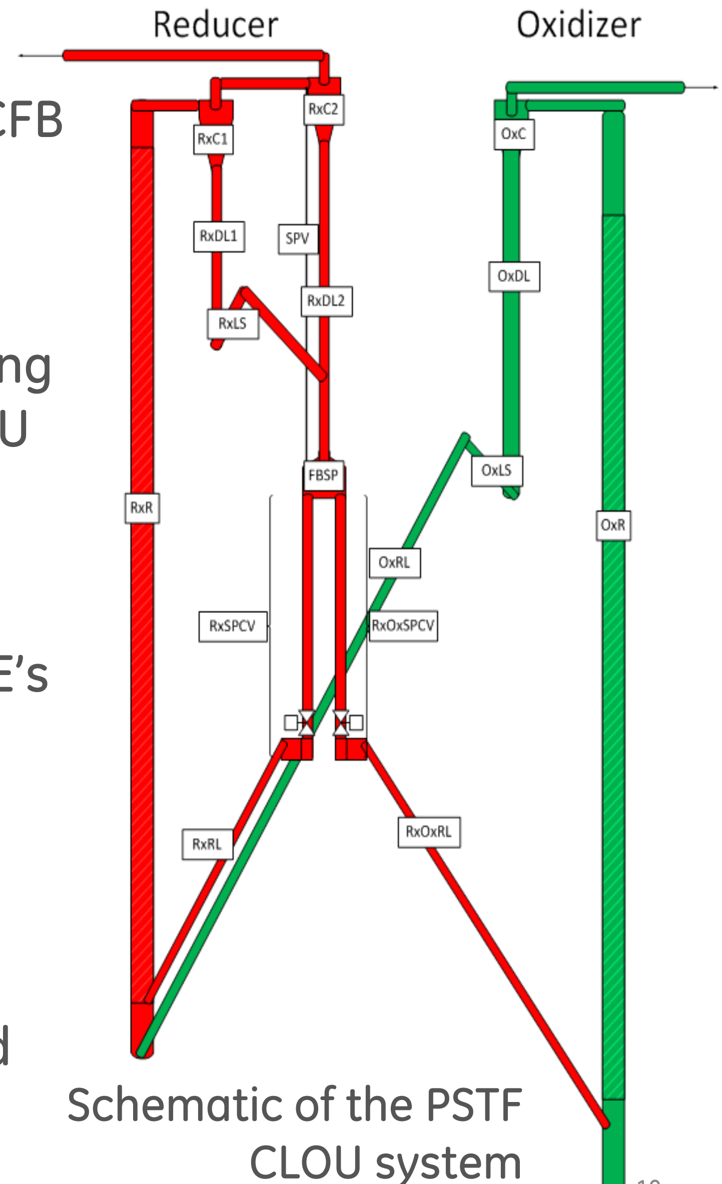
=> Downstream configuration of existing LCL-C™ process



Enhanced LCL-C™ (gas fuel configuration)

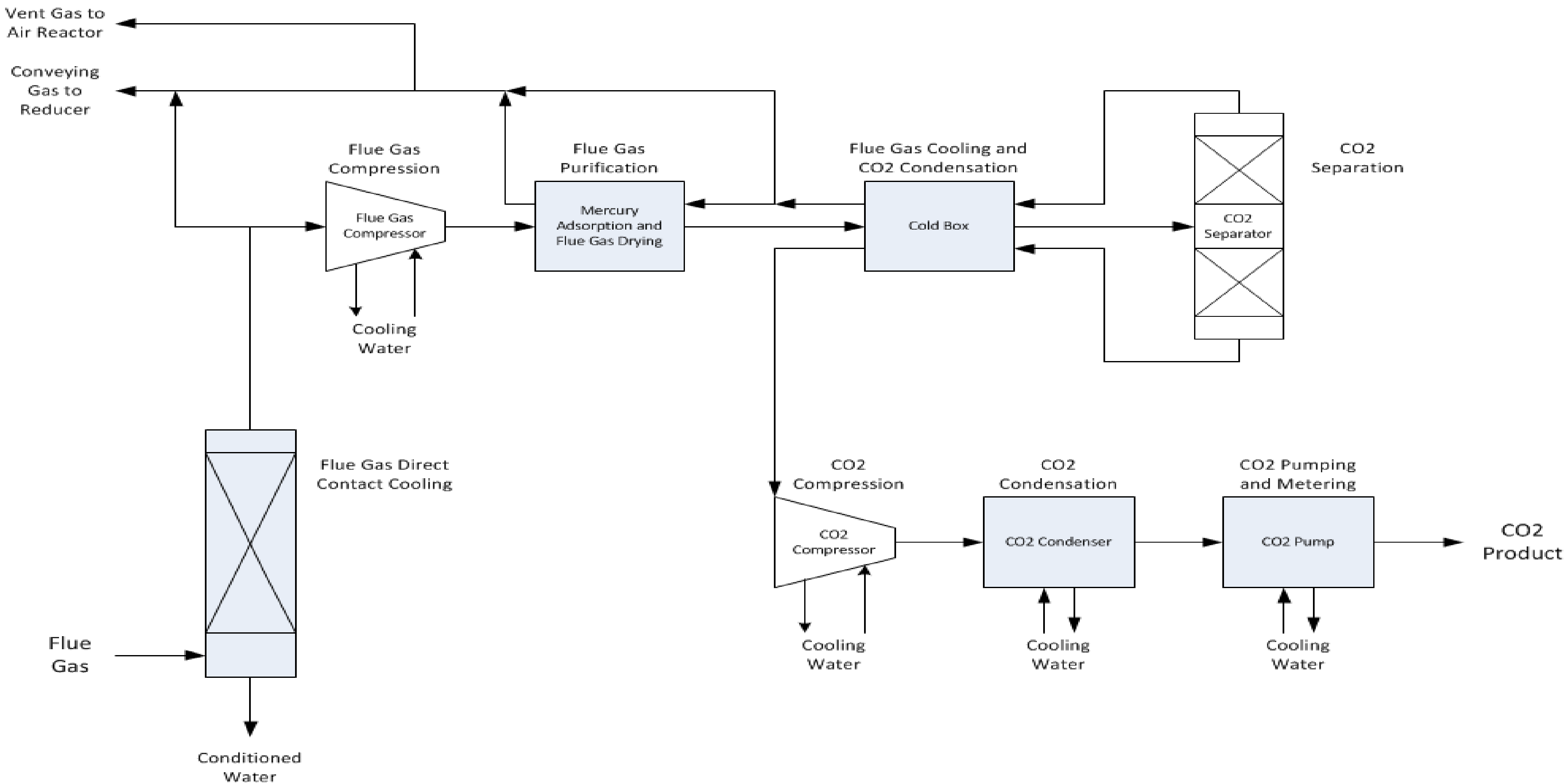
Pilot scale testing: achievements to date

- 2 interconnected CFBs, follows conventional CFB best design practices
- Sizing done in collaboration with and leveraging the knowledge of Chalmers University on CLOU material performance
- Leveraging extensive cold flow testing and GE's expertise in material selection and solid transport (non-mechanical solids control devices)
- Flexible design with internal recycles reviewed by external experts in the field (PSRI, Inc.)



Schematic of the PSTF CLOU system

GPU for LCL-C™ (3rd approach)



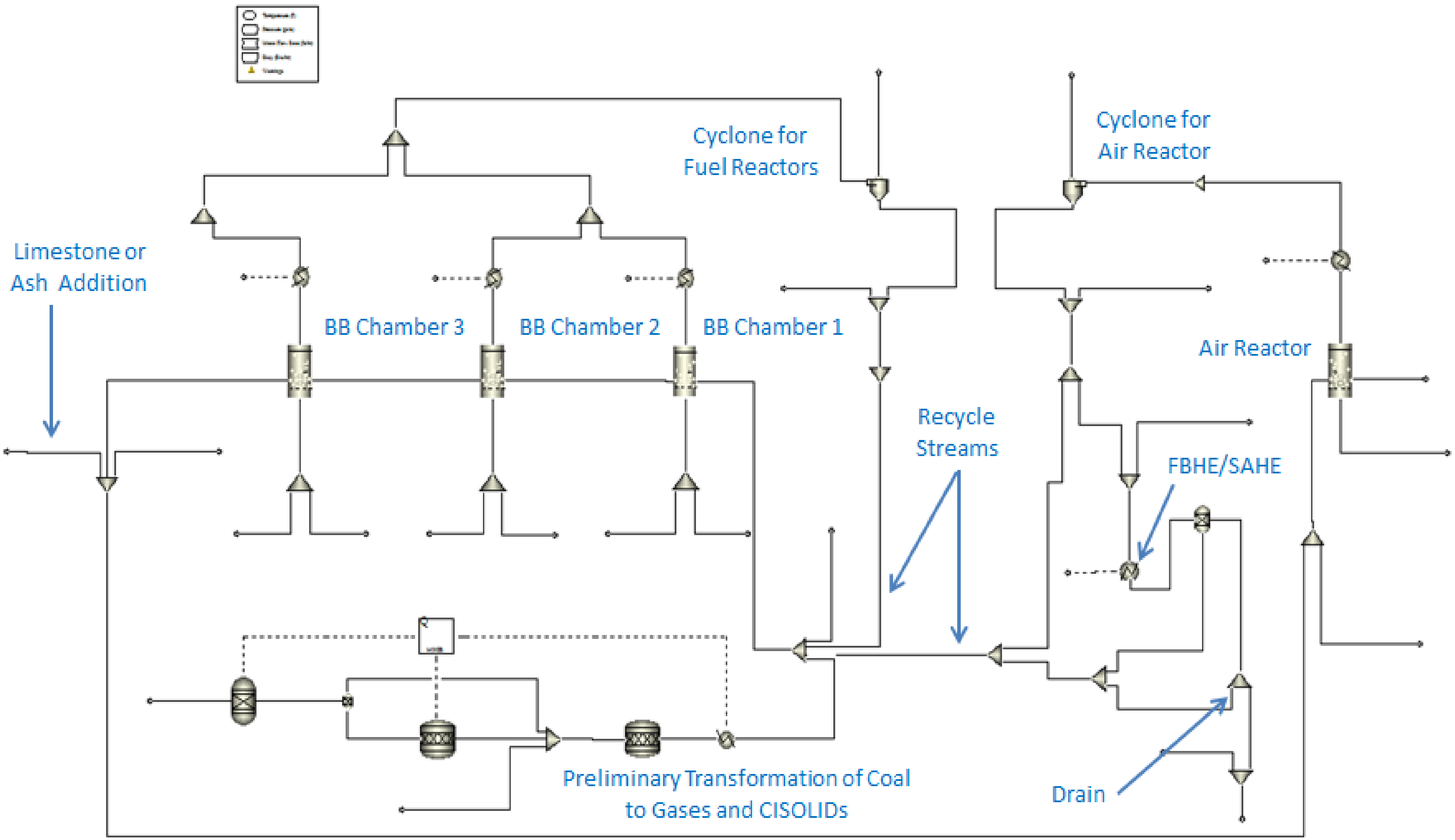
OXY-GPU process adapted to LCL-C™:

new gas separation (CO, H_2, CH_4, H_2S, C_{2+})

GPU development: achievements to date

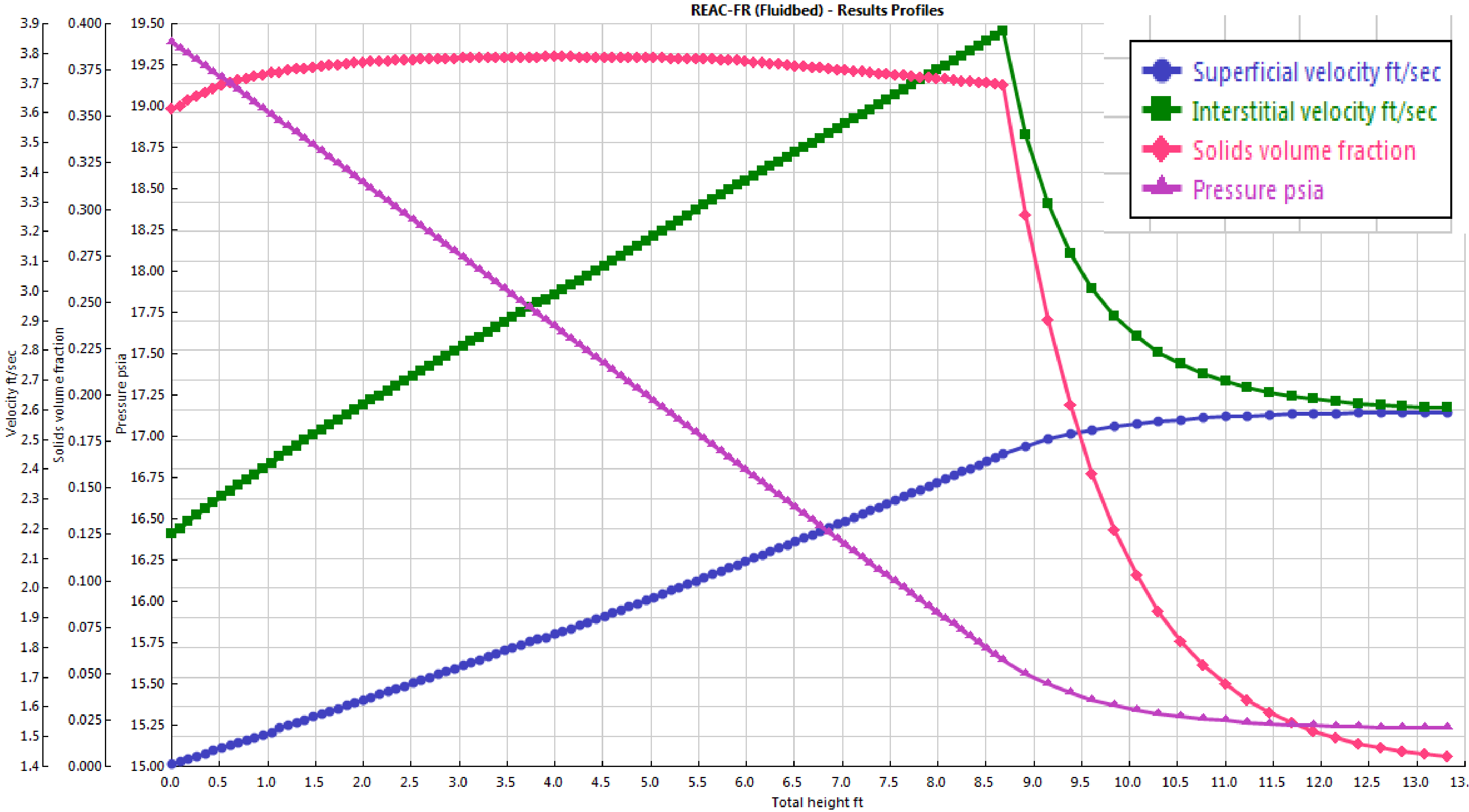
- Thermodynamics packages upgrade
- Conceptual design completed (interfaces with LCL-C^{TM}, recycle loops)
- Operating envelopes determined
- Simulated process performance and sensitivity analysis to LCL-C^{TM} oxygen demand
- Cost estimation completed
  - H&MB
  - Equipment List
  - Auxiliary Power Requirements
  - Interfaces with Plant (integration opportunities)
  - Capital Costs - Erected (material/equipment, labor costs)
  - O&M Costs (Fixed and Variable)

GPU - LCL-C^{TM} integration in Aspen Plus



Process simulation platform is being developed and will be validated at different scales over the duration of the development (here 100kW scale)

GPU - LCL-C™ integration in Aspen Plus

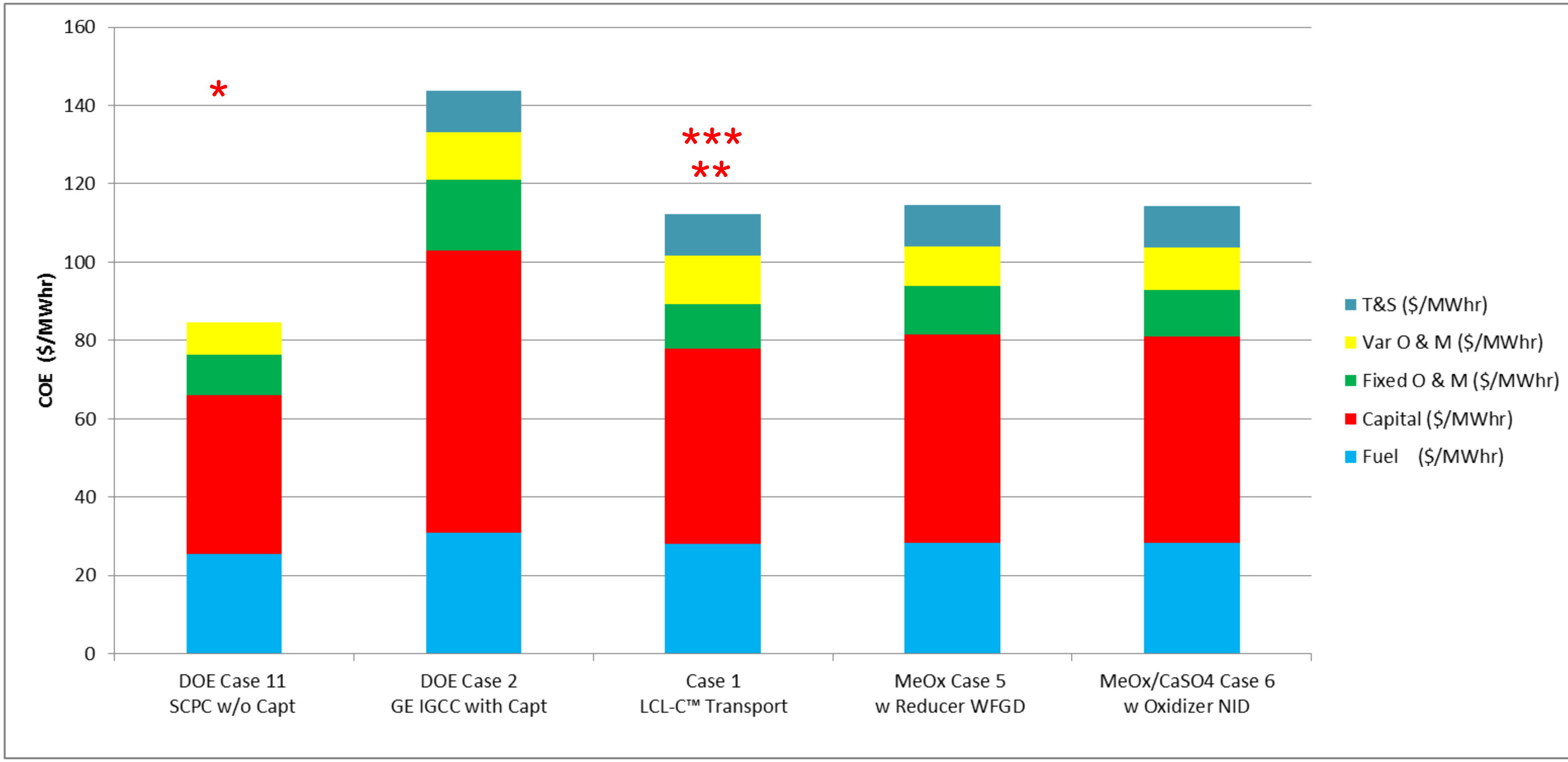


An optimization and sizing tool for scale-up

LCL-C™ Techno-Economic Analysis
Scope and Methodology

- A TEA update of the LCL-C™ process will be conducted based on three cases:
  - Improved LCL-C™ Oxygen Carrier
  - Oxy-Combustion Downstream of the Reducer
  - Gas Processing Unit with Reducer Product Gas Recycle
- The TEA will follow DOE TEA methodology and be compared to prior studies
  - All cases designed for 550MW_e and use a 3500psig/1100F/1100F steam cycle
  - All cases compared with LCL-C™ Case 1 and SCPC w/o CCS (DOE Case 11)
- The Process Modelling Environment will use both Aspen Plus and Thermoflex
  - Used together to develop the heat & material balances and plant performance
  - They will be linked through an Excel interface
  - Aspen Plus used for process modelling of the LCL-C™ process island and for the GPU
  - Thermoflex will be used for modelling of the steam cycle

COE Breakdown – GE Chemical Looping



* = SCPC w CCS

** = LCL-C™ w 5% O_2 Demand, O_2 injection to burn combustibles

*** = LCL-C™ w 10% O_2 Demand, O_2 injection to burn combustibles

Enhanced LCL-C™ with improved oxygen demand: Summary

- Several technical approaches are being followed (with a planned down select) to achieve a higher purity product gas for LCL-C™
- The OXY-GPU process and simulation tool was adapted to the chemistry of the product gas for LCL-C™ and corresponding inputs for a techno-economic analysis have been obtained
- Down select and sourcing of oxygen carriers blends have been completed leveraging Chalmers University's expertise in metal oxides and CLOU material
- The 100 kW design upgrade for mixed sorbents and CLOU material testing is complete and is entering the engineering/procurement phase
- Aspen Plus LCL-C™ process modelling has progressed: developing a validated, scale up/sizing tool
- Ultimately, this effort will culminate with a 500MWe LCL-C™ TEA update

Acknowledgements and Disclaimer

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Disclaimer