ALSTOM'S LIMESTONE-BASED (LCL™) CHEMICAL LOOPING PROCESS

OCC3, Ponferrada, September 12th 2013

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a-ALSTOM

b – US-DOE/NETL

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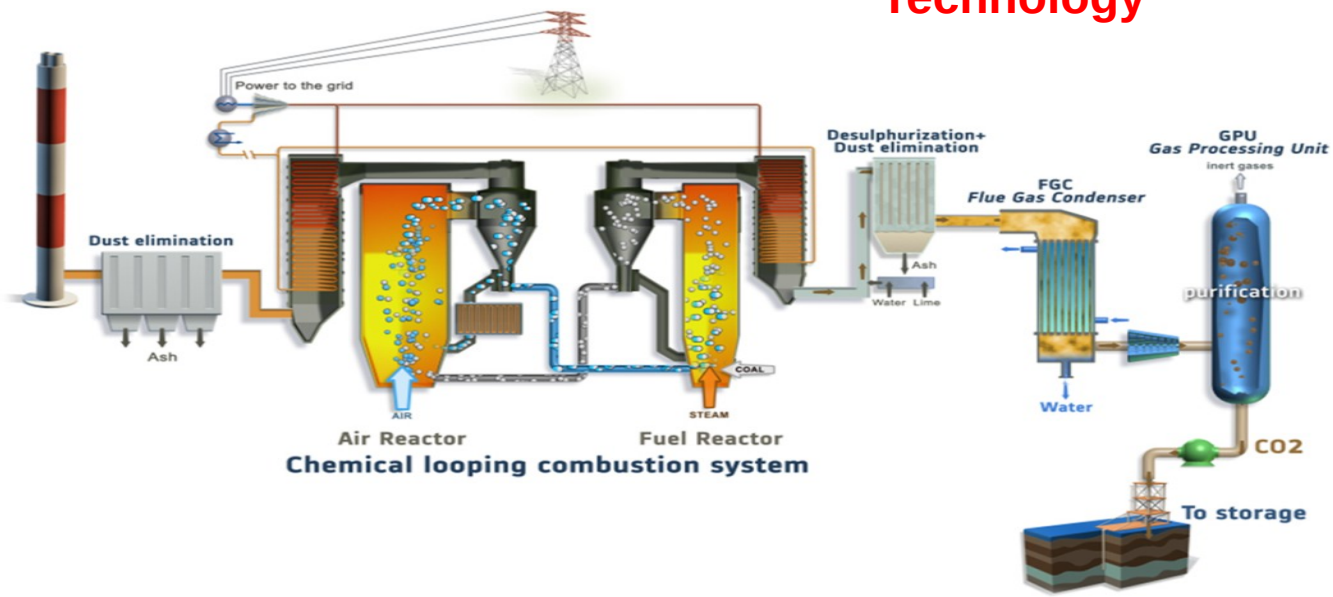
Chemical Looping

Fossil fuel Power with CCS at lower cost than alternates

"Breakthrough CCS Technology"

"Transformational Coal Power Technology"



- Alstom targets:
  - ✓ Coal power generation for electricity
  - ✓ Coal/Petcoke to liquid fuels and chemicals

CO_2 capture process in oxy-combustion using solid oxygen carriers rather than an ASU (cryogenic O_2 production), avoiding related cost & energy penalty

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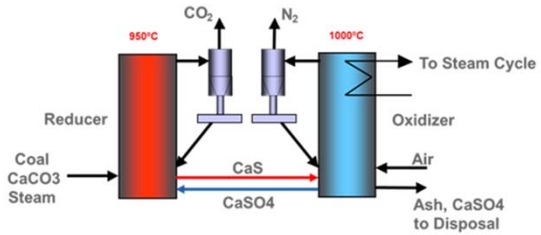
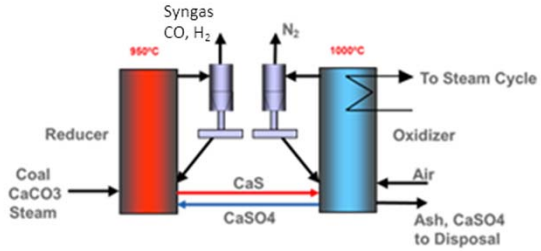
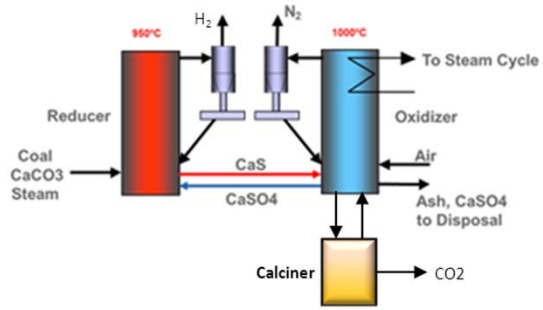
Chemical Looping Process: Options and Applications



Option 1 – Combustion with CO2 Capture – LCL-C™



Option 2 – Syngas with no CO2 Capture – LCL-Gas™



Option 3 – Hydrogen with CO2 Capture – LCL-H2™

Applications

- ✓ CO_2 Capture – PC Retrofit
- ✓ CO_2 Capture – CFB Retrofit
- ✓ CO_2 Capture-Ready Power Plant
- ✓ Advanced Steam Cycles with CO_2 capture

- ✓ IGCC with Down-Stream CO_2 Capture
- ✓ Industrial Syngas production
- ✓ Coal-to-Liquid Fuels

- ✓ CO_2 Capture – PC Retrofit
- ✓ CO_2 Capture – CFB Retrofit
- ✓ CO_2 Capture-Ready PC/CFB Power Plant
- ✓ Advanced Steam Cycles with CO_2 capture
- ✓ IGCC with CO_2 Capture
- ✓ Fuel Cell Cycles with CO_2 Capture
- ✓ Industrial Hydrogen with CO_2

Flexible technology with low cost

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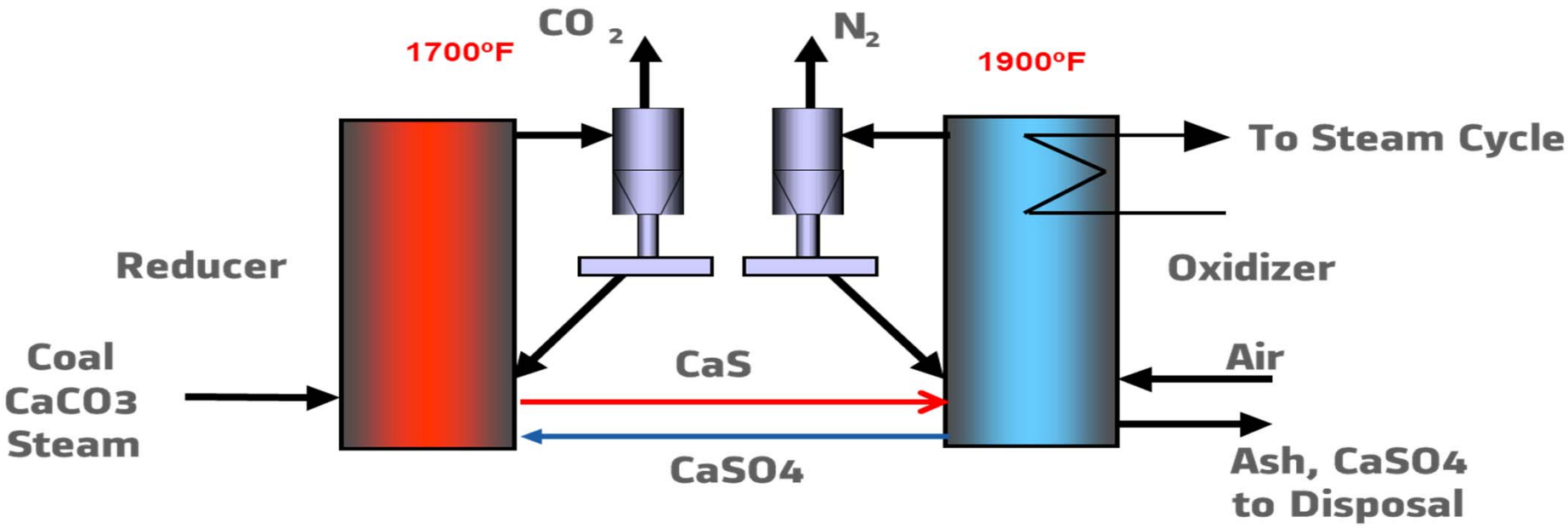
Limestone Based Chemical Looping
CaS - CaSO4 Loop in CFB Reactors



Fuel Reactor (Endothermic -Reducer)

$2\ C_{fuel} + CaSO_4 + Heat \rightarrow CaS + 2\ CO_2$

$8\ H_{fuel} + CaSO_4 + Heat \rightarrow CaS + 4H2O$

Air Reactor (Exothermic - Oxidizer)

$CaS + 2O_2 \rightarrow CaSO4 + Heat$

CaS - CaSO4 Combustion Loop in CFB Reactors
Calcium-based oxygen carrier process is suited to coal

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Alstom Targets – CLC for Coal Power with CCS

- **LCoE <30% penalty vs. Plant without CCS (stretch target < 20%)**

- **CO2 Capture Cost < 25 € /ton (stretch target < 15 € /ton)**

Targets appear to be achievable

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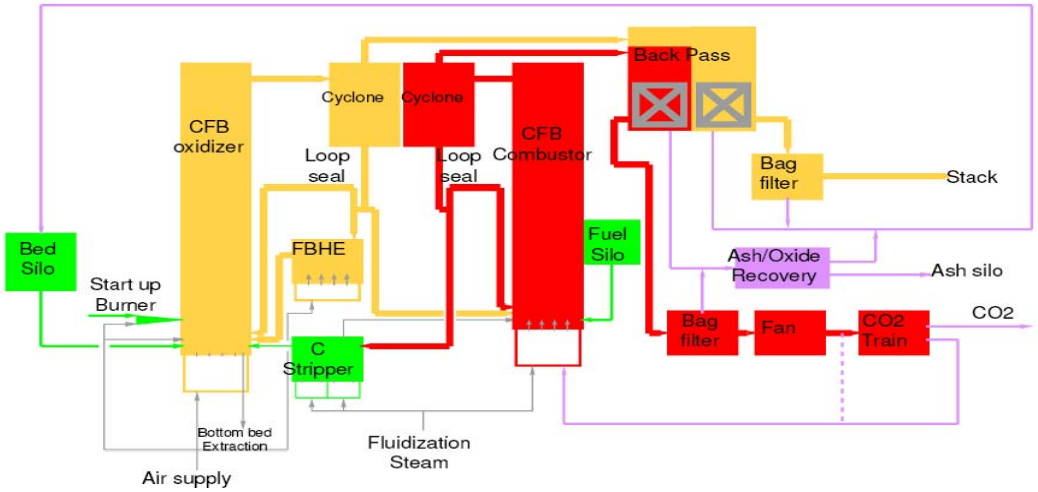
Alstom Chemical Looping Reference Studies

Reference Plant Studies		
Date	**Plant Size**	**STUDY**
2013	550 MWe	Phase 1 FOA (4 Cases Just Completed) (DOE)
2012	550 MWe	Update of 2003 Study (DOE)
2006	400 MWe	CO_2 Product Gas (Alstom)
2005	455 MWe	ENCAPco_2 (EU-FP6)
2003	220 MWe	Green House Gas Control (DOE)



Latest analysis is consistent with prior studies, that CLC has potential to be lowest LCoE for coal-based power with CCS

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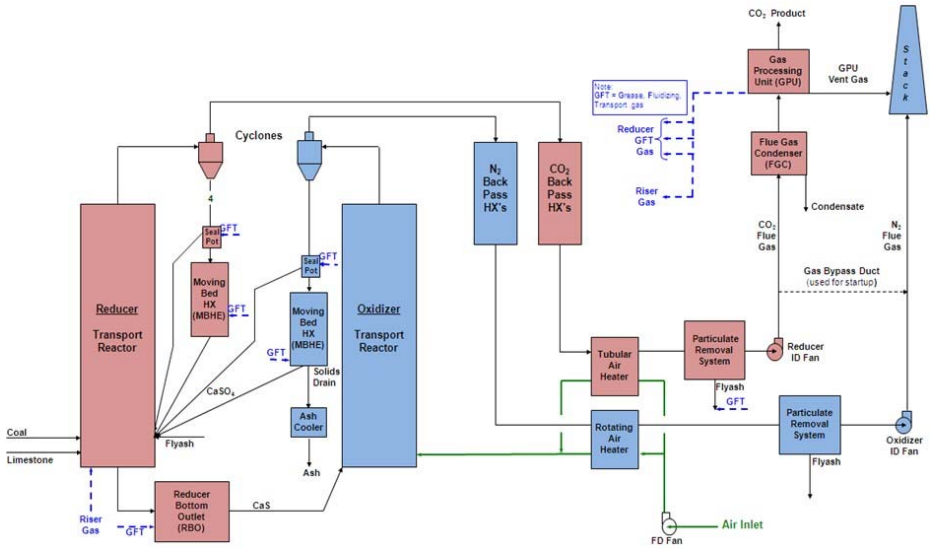
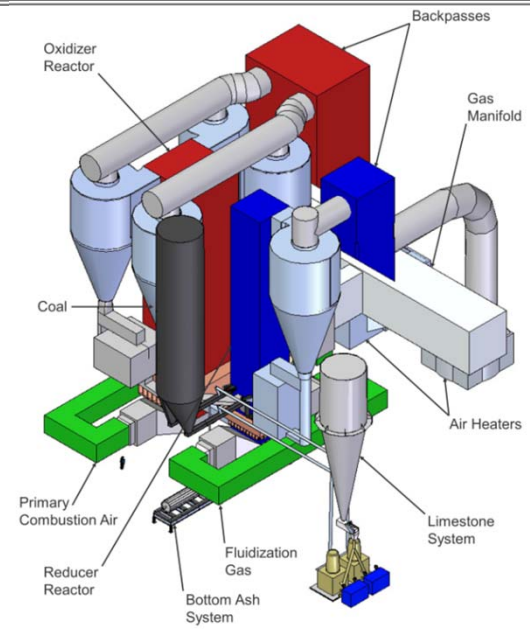
Alstom Chemical Looping Reference Studies latest analysis – completed June 2013

- Case 1 [**base**] **Atm. pressure LCL-C™ system using "fast CFB" transport reactors**
- Case 2 Atm. pressure LCL-C™ system with the Reducer reactor in the CFB mode,
- Case 3 Atm. pressure LCL-C™ system of Case 1 with an AUSC steam cycle,
- Case 4 3 – 7 bar pressurized LCL-C™ system with an AUSC steam cycle





Latest analysis is consistent with prior studies, that CLC has potential to be lowest LCoE for coal-based power with CCS

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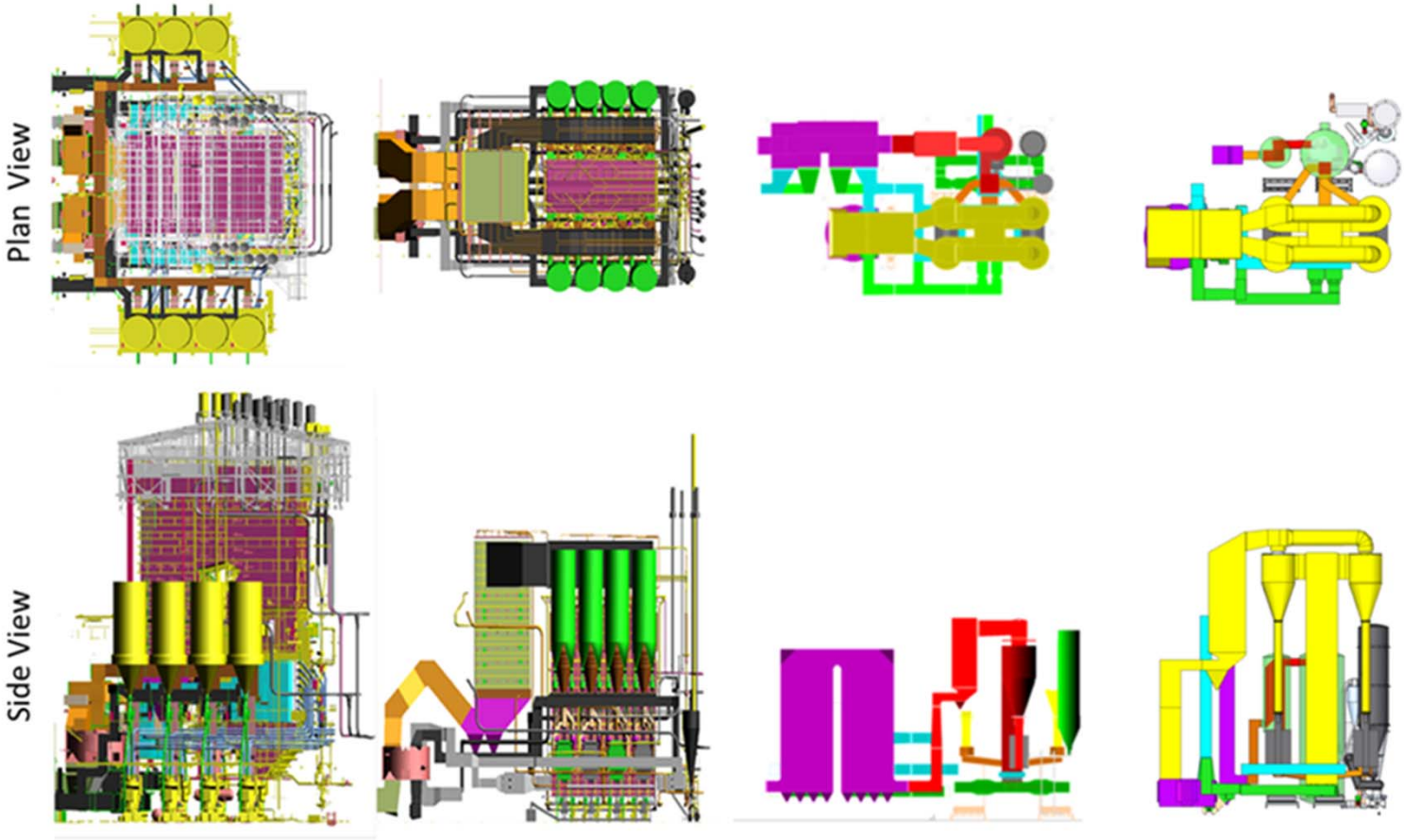
Comparison of Nominal USC-660MWe gross Boiler Plants: Oxy-PC, Oxy-CFB, and LCL™ (1 atm and 7 atm)



Oxy-PC Fired Utility Unit	Coal Fired Oxy-CFB Unit	Coal Fueled LCL™ Unit	7 atm Coal LCL™ Unit
Relative Boiler Height = 100%	80%	60%	90%

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Performance and Economic Comparison
Oxy-Combustion vs. Chemical Looping

	Atm Pressure Oxy-Combustion	Case 1 LCL™ SC 1 atm
Net Plant Efficiency Change Relative to Atm. Air-Fired SCPC w/o CCS	-26%	-9%
Capital Cost Change Relative to Atm Air-Fired SCPC w/o CCS	+62%	+14%
Levelized COE Increase Relative to Atm. Air-Fired SCPC w/o CCS	53.5%	19.5%
CO_2 Capture ($/ton CO_2) [€/ton]	79.3	27.0 [20]

SCPC w/o CCS – **550 MWe** net Reference Plant Basis:

Net Plant Efficiency:	39.3% HHV	Cost of Electricity:	81.0 $/MWhr [60 €/MWhr]
Total Overnight Capital Cost :	2452 $/kW [1816 €/kW]	Fuel:	Illinois #6 bituminous coal

LCL-C™ has potential to be lowest LCoE for coal-based power with CCS

Pre-, Post-, or known "transformational technologies" such as POx, SCO2

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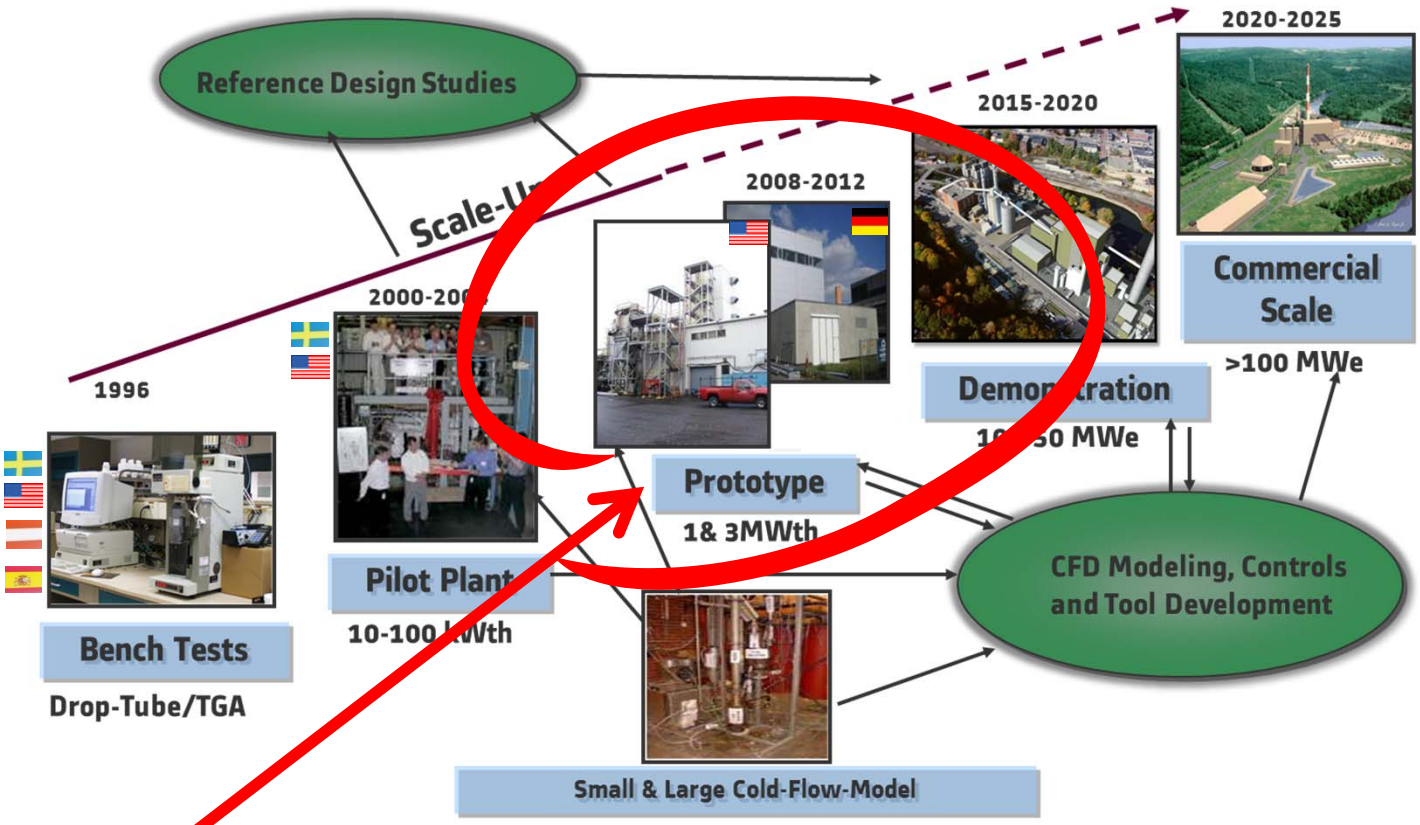
Alstom - Chemical Looping Process
Managed Development and Scale-up Steps



We are here, Significant progress made

1st Worldwide to achieve "Auto Thermal Operation"

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Limestone Based (LCL™) CLC Process
3 MWth Prototype – Windsor , CT, USA

Chemical looping – 3 MWth CaOx Prototype - Coal

Main objectives:

- Design, engineering, construction, commissioning and operation of a 3 MWth CaS prototype
- Autothermal operation of CaOx prototype
- Proof of concept – deliver data required to scale up to Demo and commercial size

50 month program

- First coal fire completed 2Q 2011
- **Autothermal Operation Achieved – July 2012**
- **40+ Hr. Autothermal Operation Achieved – May 2013**
- **Over 350+ hours of prototype operation**

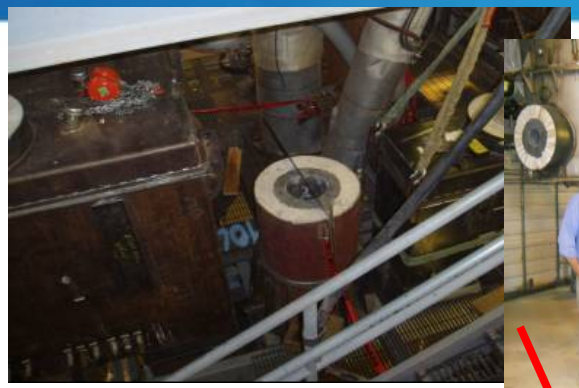
Total budget: 15 M$, cost share by US-DOE and Alstom

Partners: US-DOE/NETL & Alstom

3 MWth Prototype Model

Rear View of Prototype Building

Limestone Based (LCL™) CLC Process
3 MWth Prototype – Windsor, CT, USA

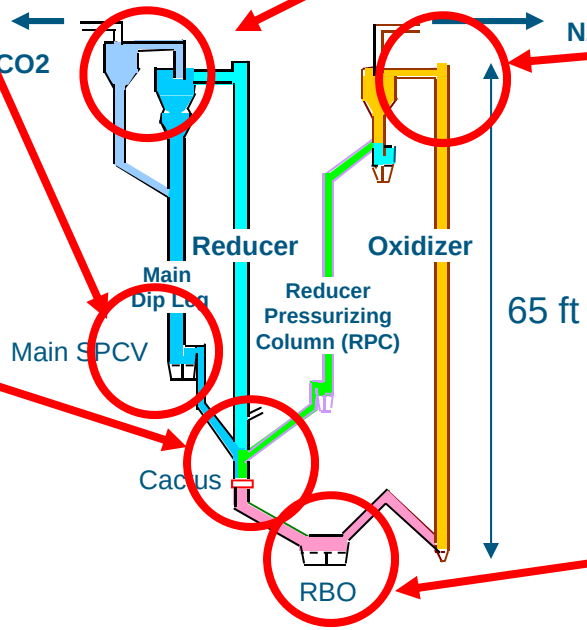


Main Sealpot Control Valve (SPCV)

Reducer Primary Cyclones

Top of Oxidizer

Main SPCV and Reducer Cactus



Oxidizer, Startup Burner & RBO

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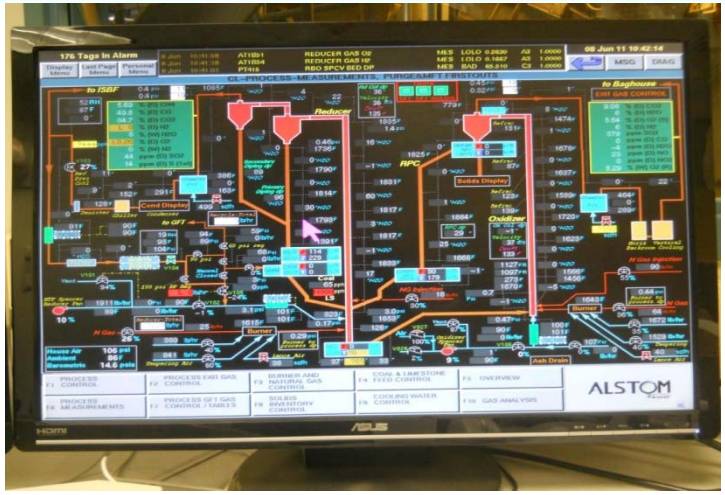
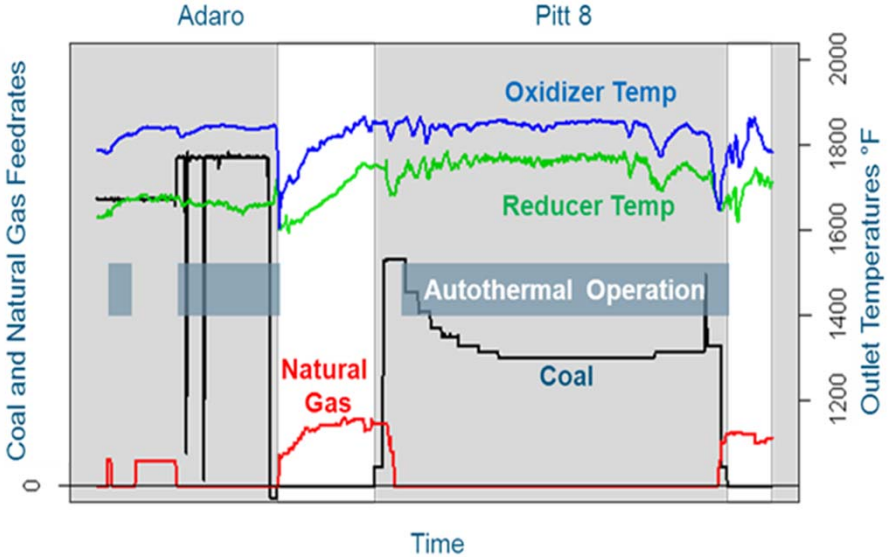
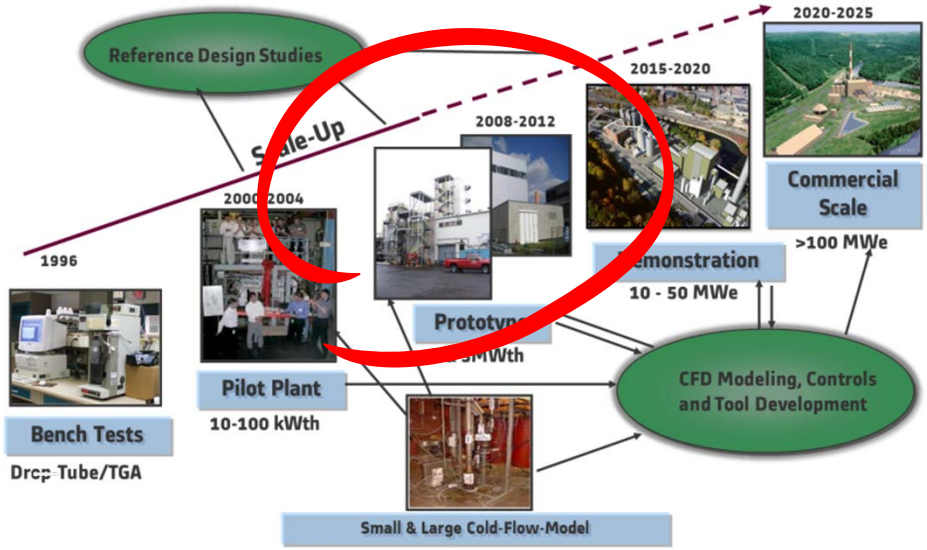
3MWt LCL™ Prototype Results to Date



3 MWth Prototype Autothermal Operation





Achievements to date:

1. 3 MWt prototype achieved sustained reactions or so called "auto-thermal" operation in July 2012 First in the World for chemical looping technology.
2. Total of 52 hours of autothermal operation and over 350 hrs of cumulative facility operation as of June 2013.

LCL™ process optimization at prototype scale (3 MWt) is on-going

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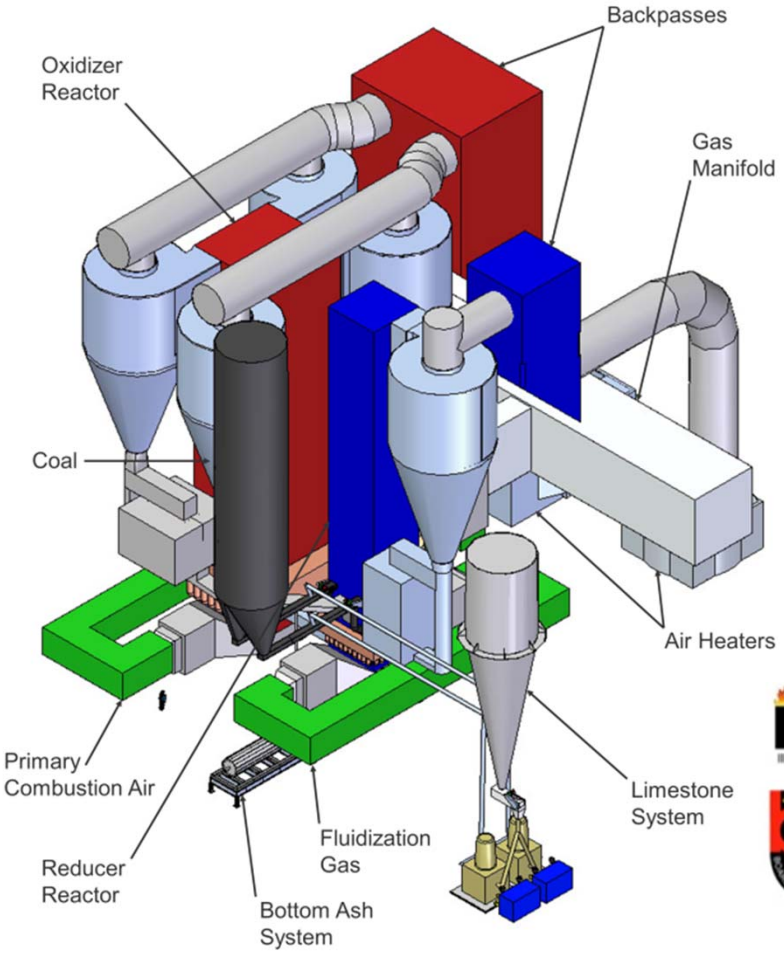
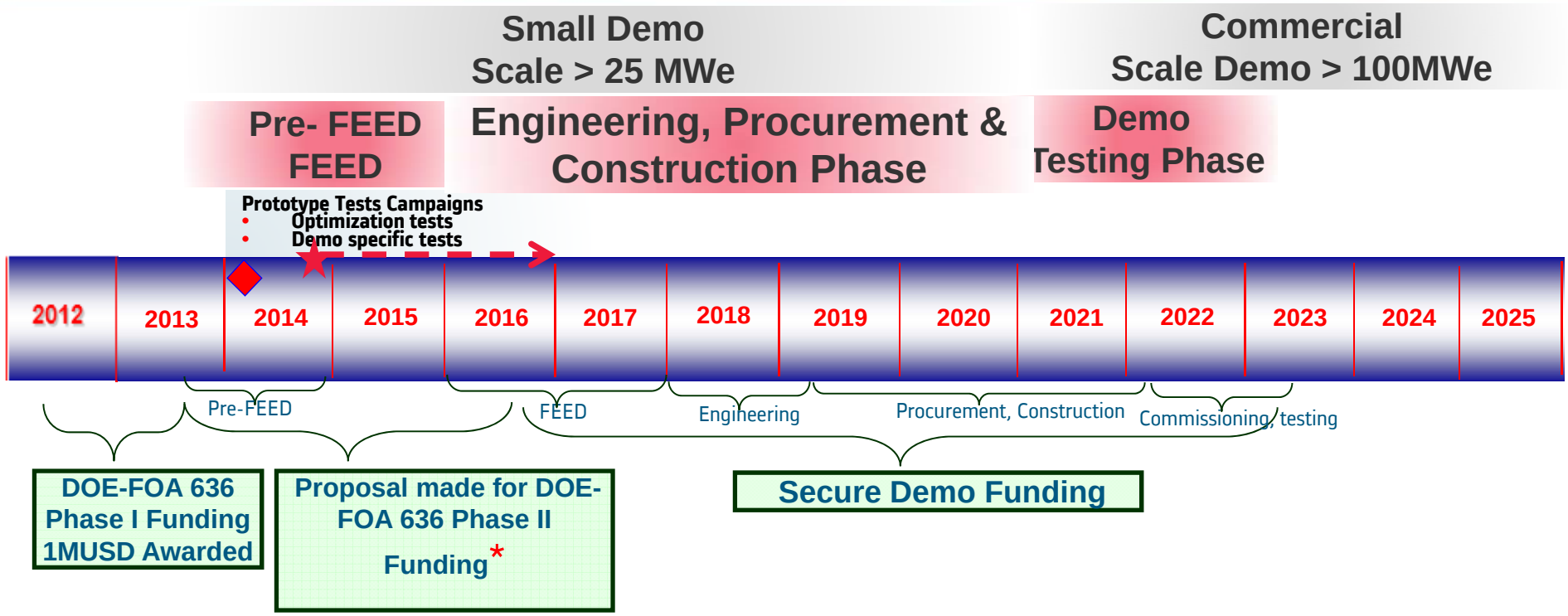
Limestone Chemical Looping (LCL™) Development
Advanced Oxy Combustion – Next Steps proposed



- **Continued testing on the 3MWth prototype**
  - Modify Prototype based on lessons learned
  - Parametric process optimization tests
- **Pre-FEED and FEED Study of a small scale demonstration plant**
  - Develop project with host and partners
  - Develop project & product specifications
  - Develop LCL™ island design
  - Complete pro-forma of the demonstration unit

Paving the road to a commercial product

Next Steps: Development & Commercialization - Timeline



* pre-FEED + partial FEED Demo related Studies

★ Resume testing at 3 MWt pilot

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Summary

- CLC is a break-through technology in terms of efficiency and economics, and has the potential of being the lowest cost CO_2 capture option
- CLC is a flexible technology that can be configured in a new or retrofit application to produce Syngas, hydrogen or power
- DOE, ÉCLAIR & ACCLAIM programs are validating Limestone based (LCL™) and MeOx Chemical Looping Combustion at 1-3 MWth prototype scale
- Next step before a large commercial unit will be a demonstration steam generator unit ~10-50 MWe scale

Alstom is Committed to Chemical Looping Development

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Thank you for your attention!

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