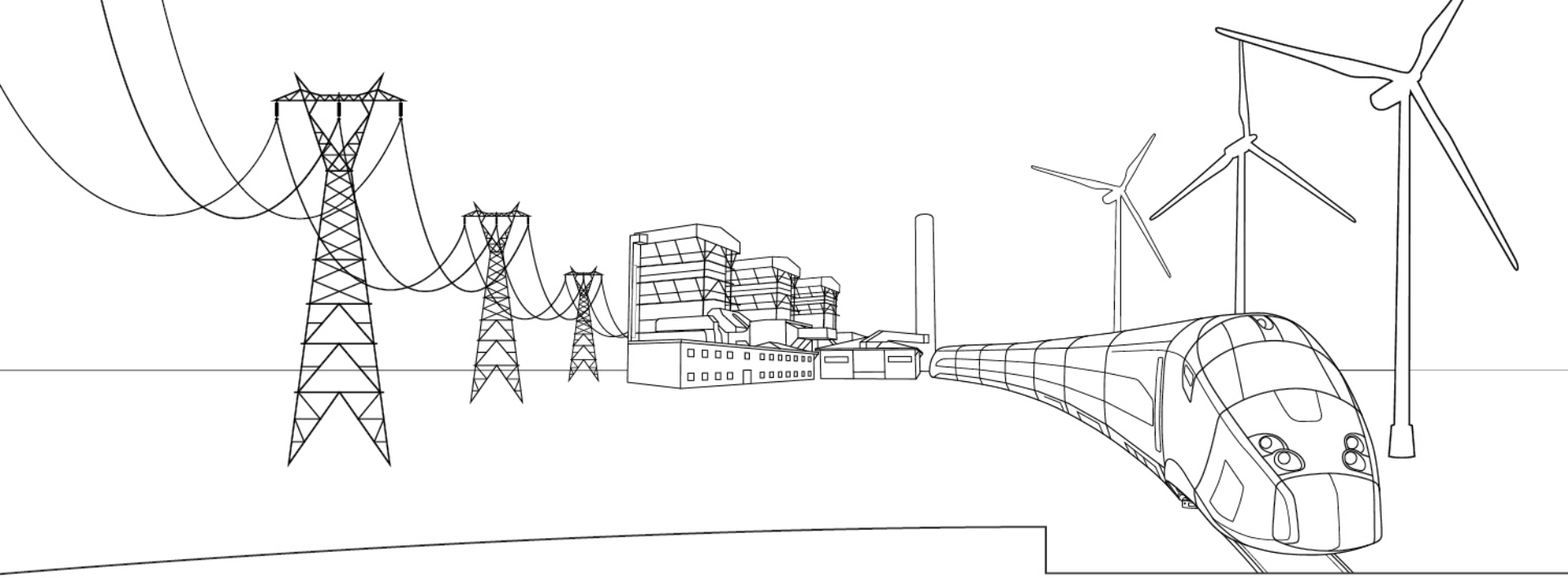

Sustainable Power Generation by "Transformational"

Chemical Looping Technology

Mr John L. Marion

Director Technology and R&D, Alstom Power Inc

Transformational Carbon Capture Technology Workshop

Arlington, Virginia

23-24 September, 2014

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Shaping the future

Agenda

- What is Chemical Looping - Concept
- Why Chemical Looping - Market and Product Vision
- Alstom Development Status
- Next Steps
- Conclusions and Challenges

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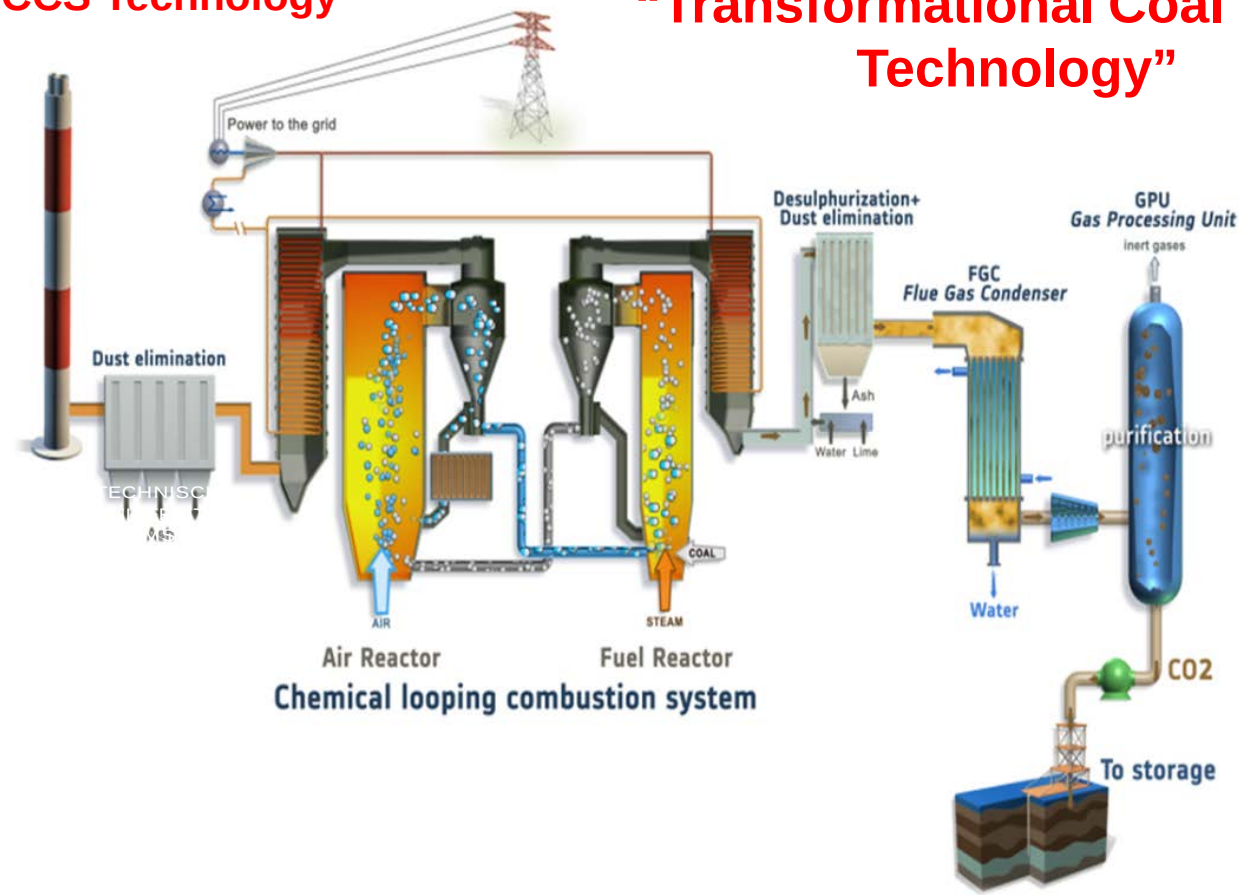
Chemical Looping –
Fossil fuel Power with CCS at lowest cost

"Breakthrough CCS Technology"

"Transformational Coal Power Technology"



CO2 capture process in oxy-combustion using solid oxygen carriers rather than an ASU (cryogenic O2 production), avoiding related cost & energy

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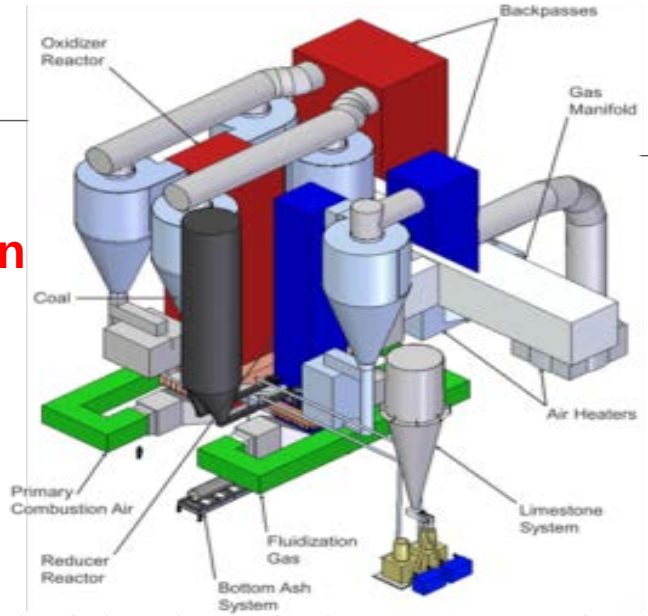
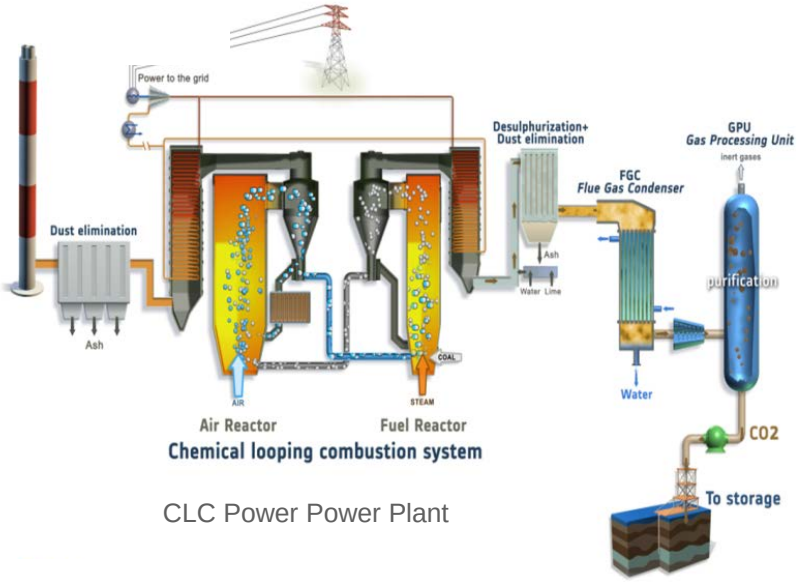
Chemical Looping Power Plant

- **Product Attributes:**
  - **Lowest Cost option for Coal Power Generation with CCS**
  - Lowest energy penalty
  - Fuel flexible
  - Near Zero Emissions
  - Useful solid ash by-product
  - Application Flexible
    - Coal Power, Syngas, Hydrogen
  - Feasible with CFB basis

- **Targets:**
  - **Efficiency <10% CCS penality vs Plant w/out CCS**
  - **LCoE <30% increase vs. Plant without CCS (stretch target < 20%)**
  - **CO2 Capture Cost < 25 $ /ton (stretch target < 15 $ /ton)**



Chemical Looping Combustion Steam Generator (550 MWe)



CLC Power Power Plant

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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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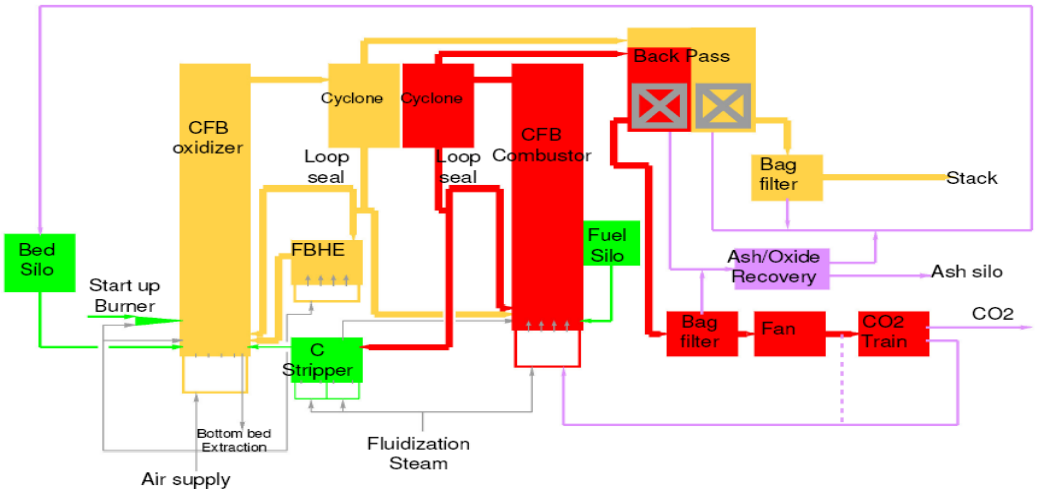
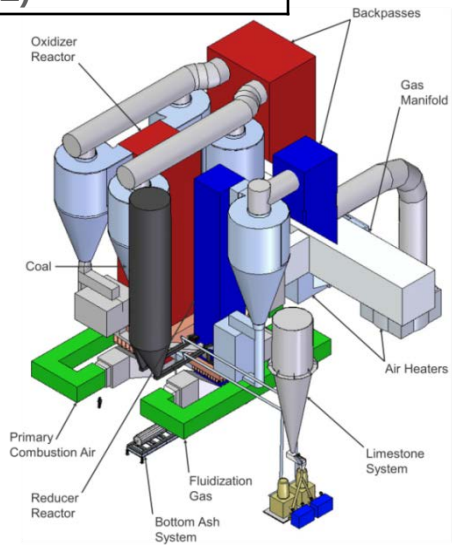
Alstom Chemical Looping Reference Studies

Reference Plant Studies		
Date	**Plant Size**	**STUDY**
2013	550 MWe	Phase 1 FOA (4 Cases 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)





Chemical Looping Based Steam Power Plant with CCS

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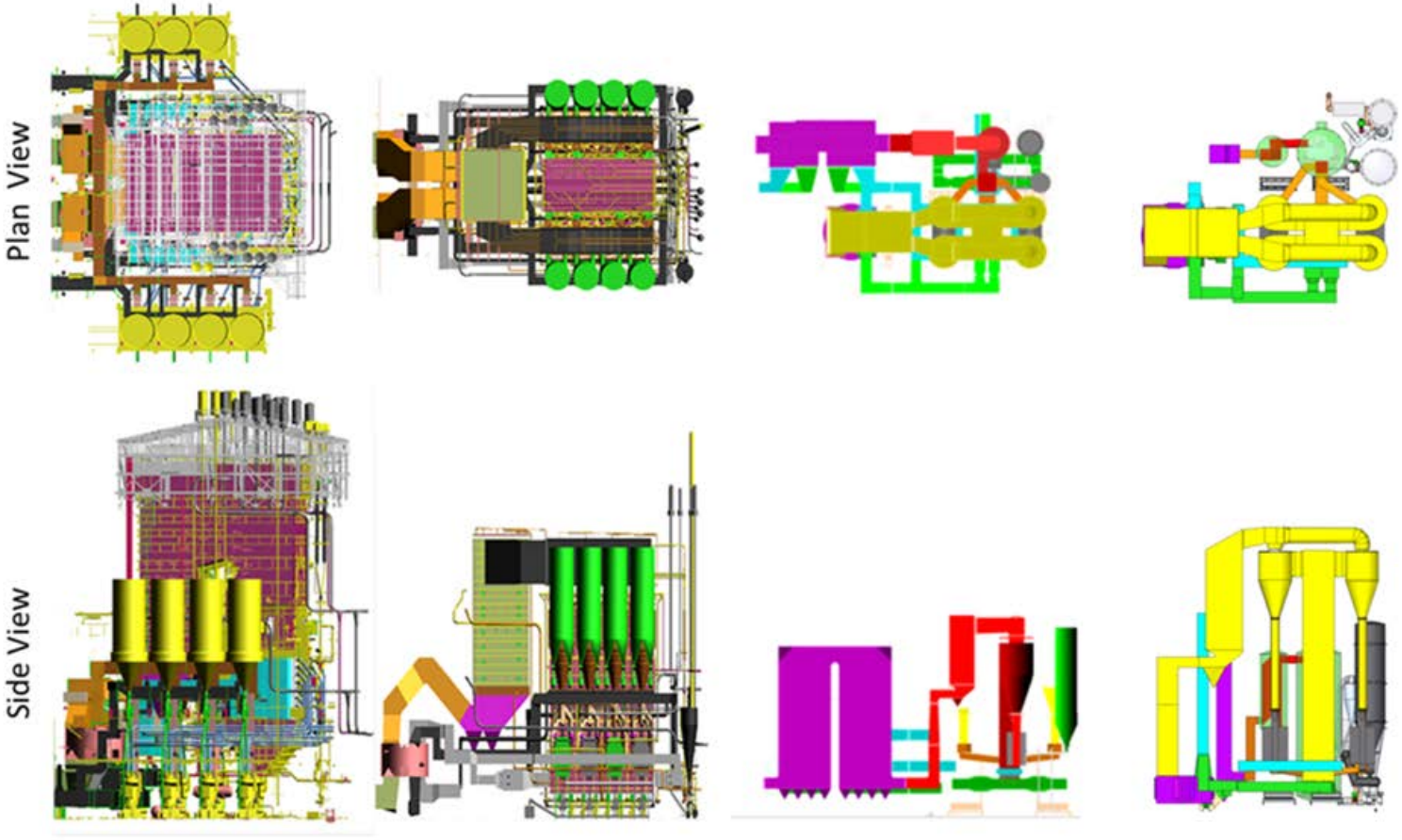
Comparison of Nominal USC-550MWe Boiler Plants:
Oxy-PC, Oxy-CFB, and LCL™



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% 29.3% HHV	-9% 35.8% HHV
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

Total Overnight Capital Cost : 2452 $/kW [1816 €/kW]

Cost of Electricity: 81.0 $/MWhr [60 €/MWhr]

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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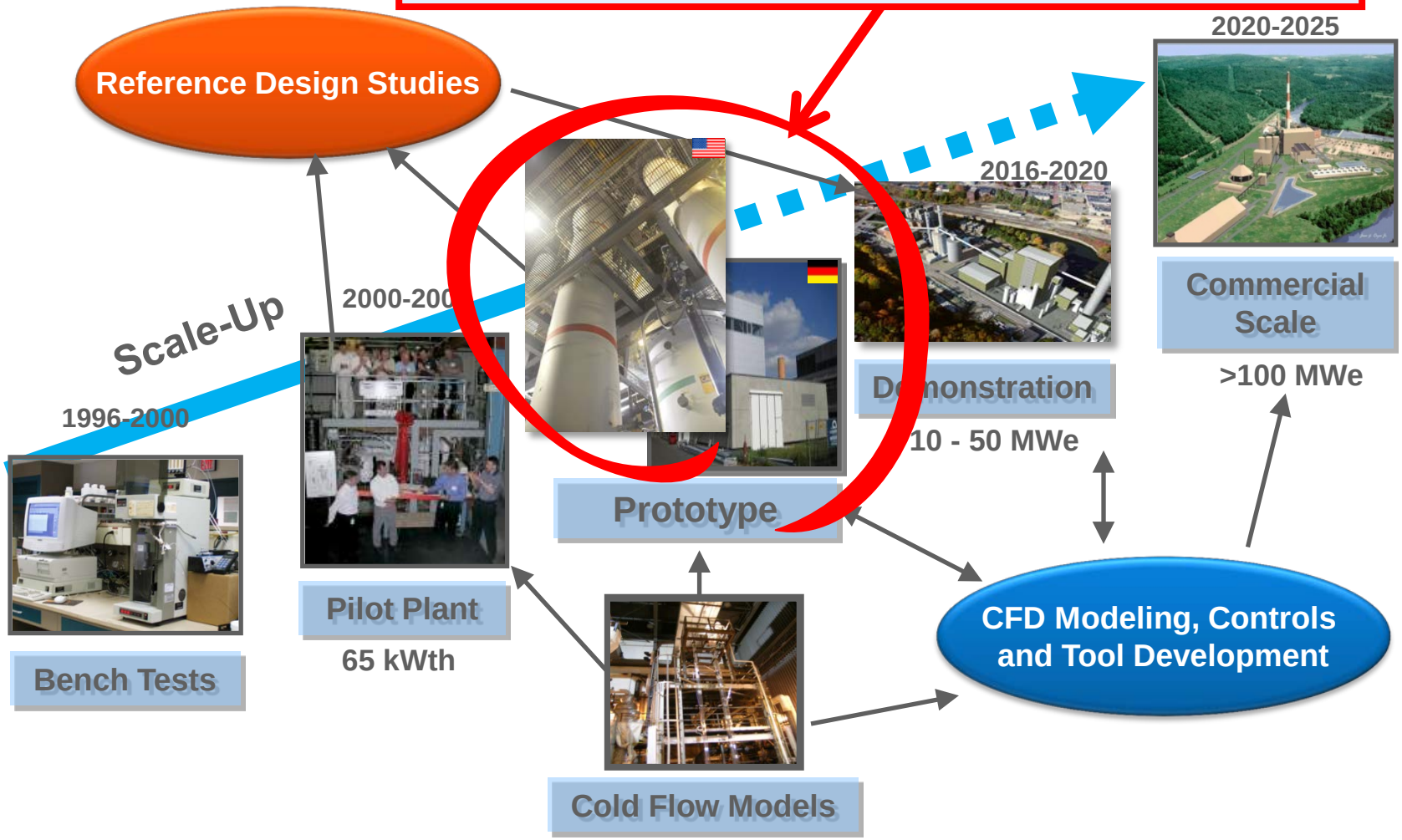
Alstom - Chemical Looping Process

Managed Development and Scale-up Steps

We are here, Significant progress made

1st Worldwide to achieve "Auto Thermal Operation"



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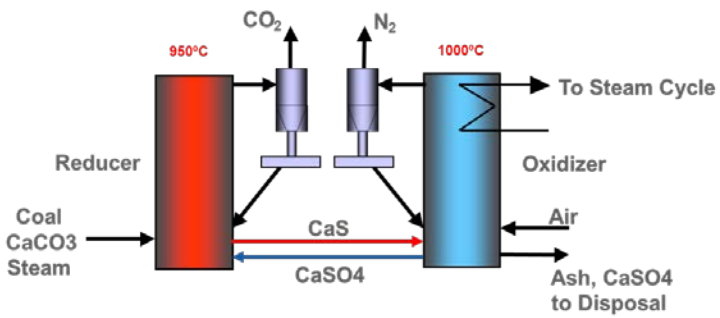
Alstom's Chemical Looping Development
Two different oxygen carrier approaches

Limestone based (LCL™)

US-DOE co-funded

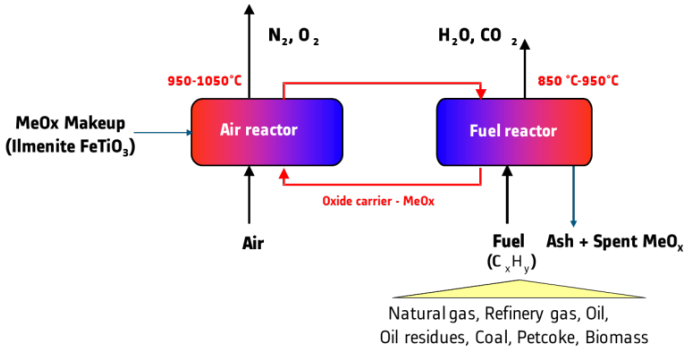
- Limestone based oxygen carrier - $CaS/CaSO_4$
- "Fast" CFB solids transport
- Same materials in commercial CFBs
- Suitable for solid fuels - coal, petcoke, biomass



Metal oxide based (MeOx)

EU–RFCS co-funded

- Metal-based Oxygen Carriers ilmenite ($FeTiO_3$) – iron-titanium ore
- Process based on CFB solids transport
- Carbon stripper for minimizing UBC
- Suitable for gaseous fuels – natural gas



Pursuing two different chemical looping technologies

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Alstom MeOx Testing Program
Metal Oxide-based Process

ÉCLAIR & ACCLAIM Programs: 1MW$_{th}$ MeOx Prototype in Darmstadt:

- Goals:
  - Design and operation of a 1 MWth CLC with coal
  - Assess technical, environmental, economical potential
  - Improve conversion efficiency
- Results:
  - Gasification conditions achieved 4Q2012
  - Autothermal combustion targeted for 3Q2014
- Partners:

CHALMERS Fuel reactor - Reducer

MeOx Supporting Tests:

- 100 kWth pilot and cold flow model at Chalmers Univ.
- Goals:
  - Validation of solids circulation on cold flow model
  - Parametric test on the 100 kWth
- Path Forward:
  - Tests planned with alternative oxygen carriers (iron ore) to improve conversion efficiency

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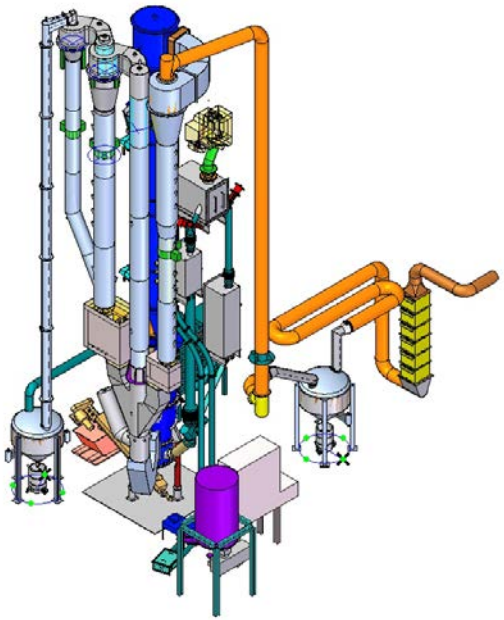
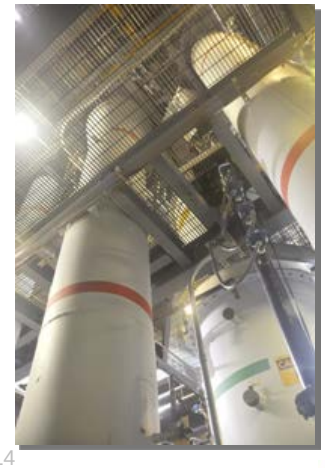
Alstom LCL™ Testing Program
Limestone-based Process

- Main objectives:
  - Autothermal operation of 3-MWth prototype in combustion mode – CT, USA
  - Address technical gaps through prototype testing
  - Obtain info to design, build and operate a demo plant
- Achievement:
  - First autothermal operation achieved in July 2012; 40 hrs in May 2013
  - As of Nov 2013, 350+ hrs of operation and 75+ hrs in autothermal mode
- Next steps:
  - Relocate 3-MWth pilot in 2015
  - Further develop LCL™ process



Largest chemical looping facility in the world, and only one operated in autothermal mode so far



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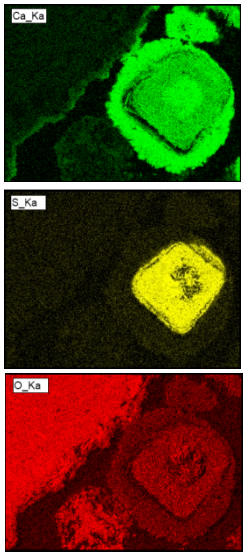
LCL™ Development
Two Complementary DOE-sponsored Programs

LCL-C™ Development:

- 3-year program started October 2013
- Objectives:
  - Address technology gaps through 3-MWth prototype tests along with CFM, CFD and 100 mm PSTF tests and studies
  - Develop a design of commercial-scale LCL-C™ plants
- Tasks
  - Prototype engineering, modification and testing
  - Process refinement and prototype testing support
  - Update techno-economic analysis



LCL-G™ Development:

- 2.5-year program started October 2014
- Main objectives:
  - Develop LCL-G™ process for high-H_2 syngas (H_2 and CO) from coal for liquid fuel production
  - Conduct techno-economic analysis

Alstom is pursuing both LCL-C™ and LCL-G™ options

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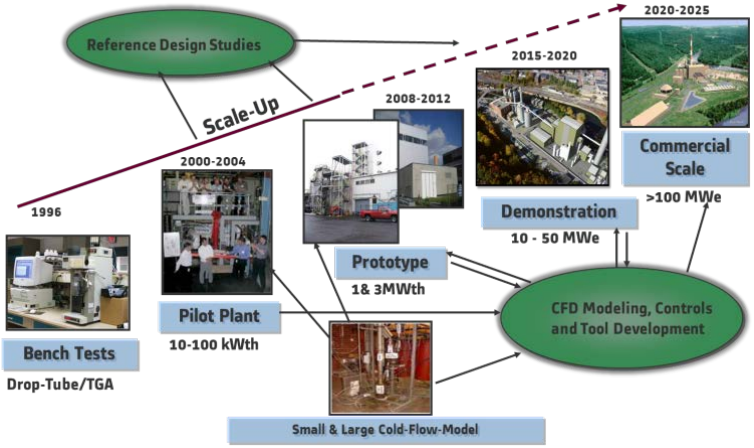
Chemical Looping Combustion Power Plant

- **Timeline** :
  - **Current:** pilot **(3 MW**th**)** testing at Alstom Connecticut
  - **2017-20:** large pilot **[10 - 50 MW**e**]**
  - **2025** : small scale power plants **[100 – 150 MW**e]
  - **2030/35** : large commercial size/ultra-supercritical [**600 MW**e]

CLC Pilot at Alstom Clean Energy Center, Connecticut, USA

- **Next Steps**
  - Complete pilot plant testing to address technology gaps
    - Combustion application
    - Syngas/Hydrogen application
  - Perform Optimization of Process to meet goals
  - Develop large pilot scale tests facility through testing, pre-FEED and FEED studies
  - Potential "showcase" at 3 MWth pilot



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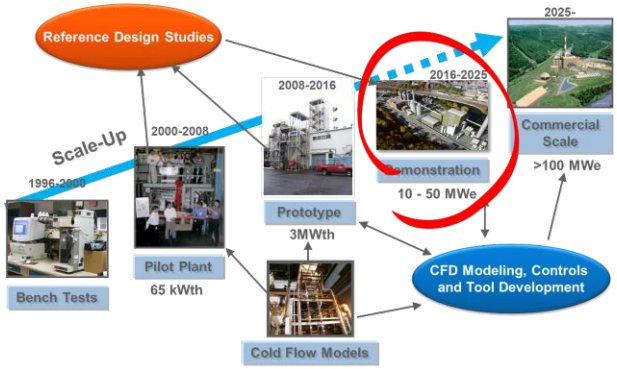
Chemical Looping Demonstration Project Options

- **Demo unit size range of <u>10 to 50 MWe</u>**
- Demo plant target – **<u>steam generator</u> for power or industrial steam**
- Hosted by either a utility, chemical industry, oil/gas/ petrochemical industry
- New or retrofit/repower application
- Pure CO_2 production for either sequestration or EOR
- **<u>Also</u> demo <u>syngas</u> mode at petrochemical plant for liquid fuel production [30 – 100 MWth eqv.]**
- **Potential "showcase" CLC power with CCUS at 3 MWth pilot** to aide demo development

Alstom's Chemical Looping Roadmap



Secure host partners and actions for funding

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Alstom Chemical Looping
Summary

- A breakthrough technology (efficiency & economics)
  - Lowest LCoE of all known coal power with CCS options
  - Based on proven CFB boiler and steam power plant technology
- A flexible technology (new or retrofit) to produce syngas, hydrogen or power
- Chemical Looping Combustion (MeOx and Limestone-based) being validated at 1 to 3 MWth prototype scale
- Alstom has made significant progress
- Technical challenges remain, which are being addressed at pilot scale
- Before large scale commercialization, a demonstration steam generator unit ~10-50 MWe scale is needed

Alstom is committed to Chemical Looping Development

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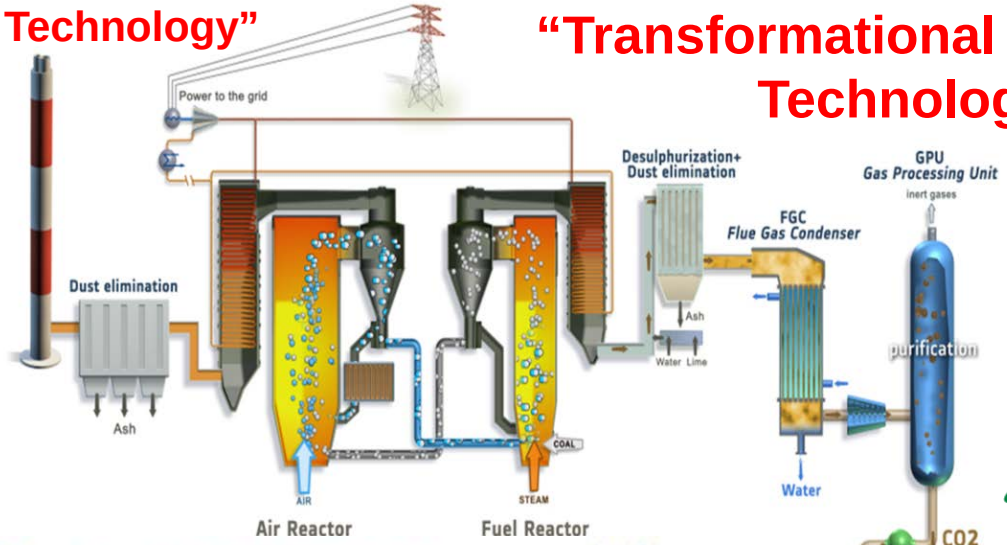
"Breakthrough CCS Technology"

"Transformational Coal Power Technology"



Significant Progress Thanks to These Contributions

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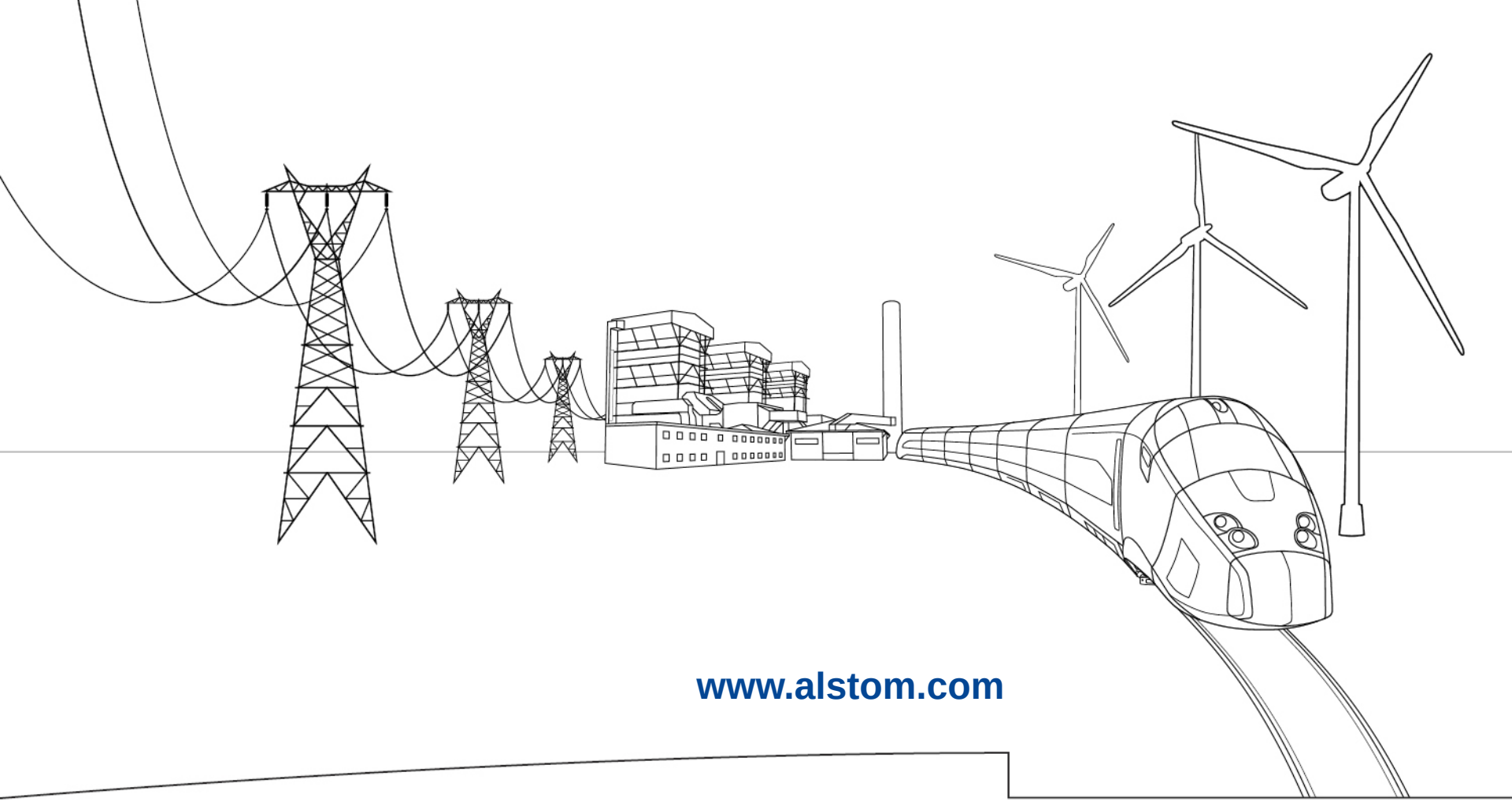

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