ADVANCED COMBUSTION TECHNOLOGY: OXYFIRING TO ENABLE CO_2 CAPTURE

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ADVANCED COMBUSTION TECHNOLOGY: OXYFIRING TO ENABLE CO_2 CAPTURE

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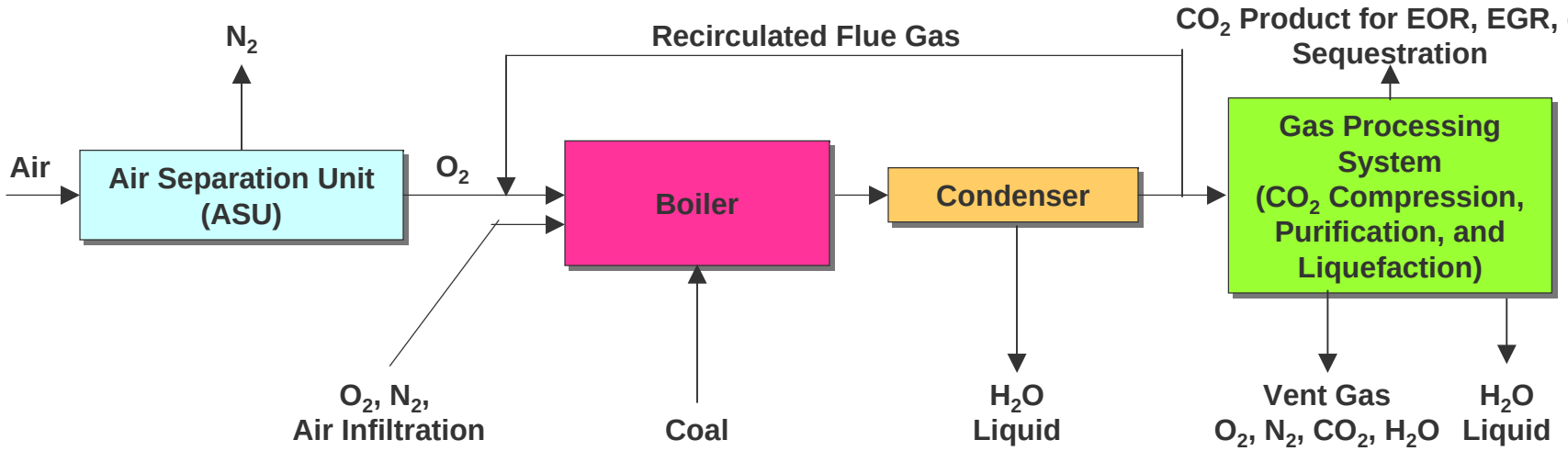
Alstom Power Boilers

Oxygen firing: Concept

Fuel is burned in a boiler in a mixture of oxygen and recirculated flue gas (principally CO_2), essentially eliminating the presence of atmospheric nitrogen in the flue gas. The resulting flue gas is comprised of primarily CO_2 and H_2O vapor along with some N_2, O_2, and trace gases like SO_2, and NO_X. Consequently:

- **The flue gas can be processed relatively easily (through rectification or distillation) to enrich the CO_2 content in the product gas to 96-99+ percent for use in enhanced oil or gas recovery (EOR or EGR), or**
- **The flue gas is simply dried and compressed for sequestration only**



Oxygen-Fired PC/CFB Technology - Motivation

- **Most near-term solution -Uses commercially available air fired PC/CFB technology and enabling technologies:**
  - **O_2 production by commercial cryogenic air separation**
  - **CO_2 capture, compression, and liquefaction**

- **Economic analysis looks viable for commercial EOR application**
  - **Electricity for sale**
  - **CO_2 sale for oil field stimulation**
  - **N_2 sale for oil field pressurization**

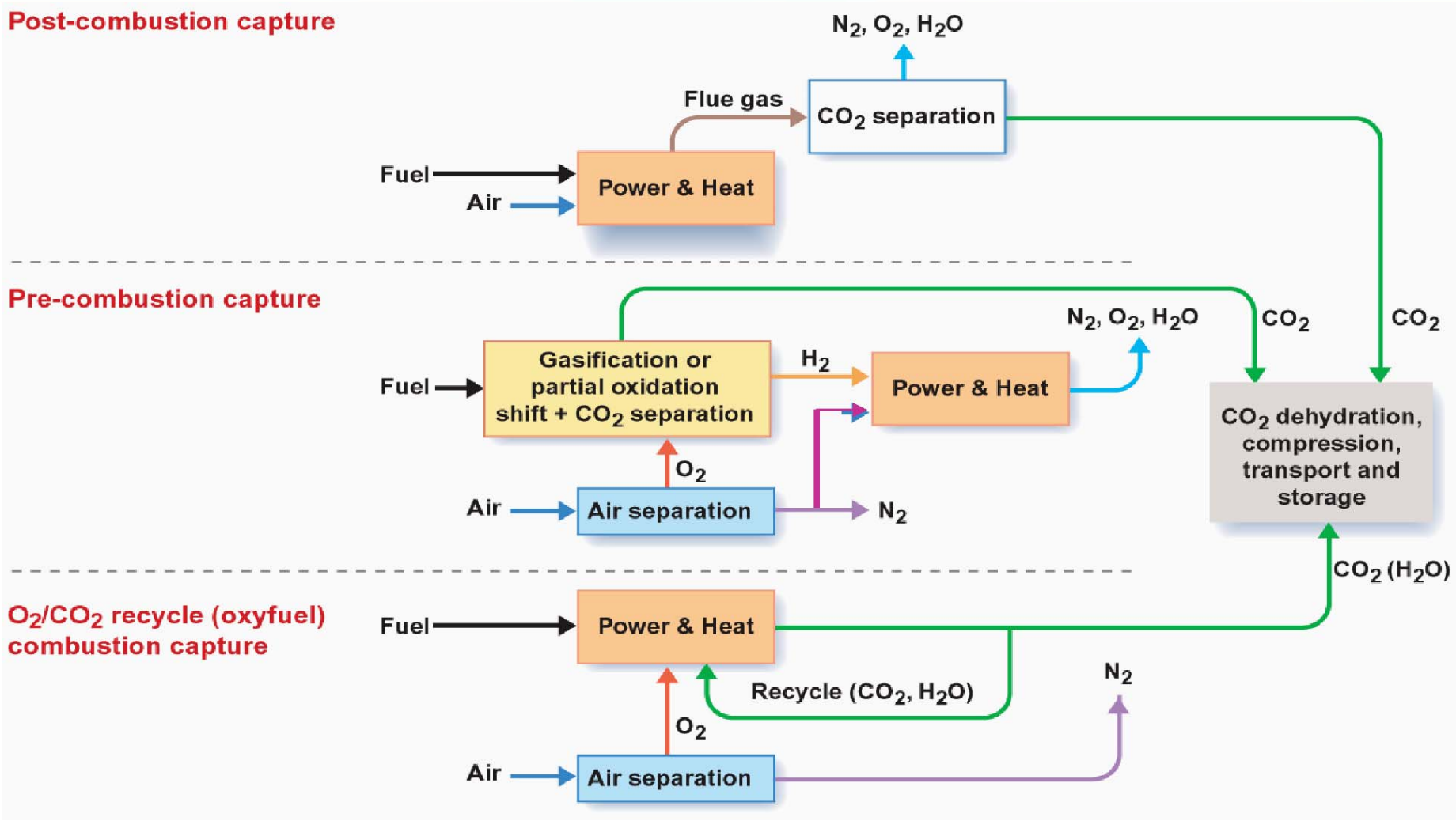
- **Required intermediate step leading to the more advanced processes, e.g.:**
  - **Oxygen Fired PC/CFB with Oxygen Transport Membrane**
  - **Chemical Looping Combustion**
  - **Chemical Looping Gasification**

Near-Term Development Horizon

Today's Discussion

- Overview
  - Conventional oxy-firing
  - Advanced concepts
  - Economics of recent studies
  - Ongoing test programs

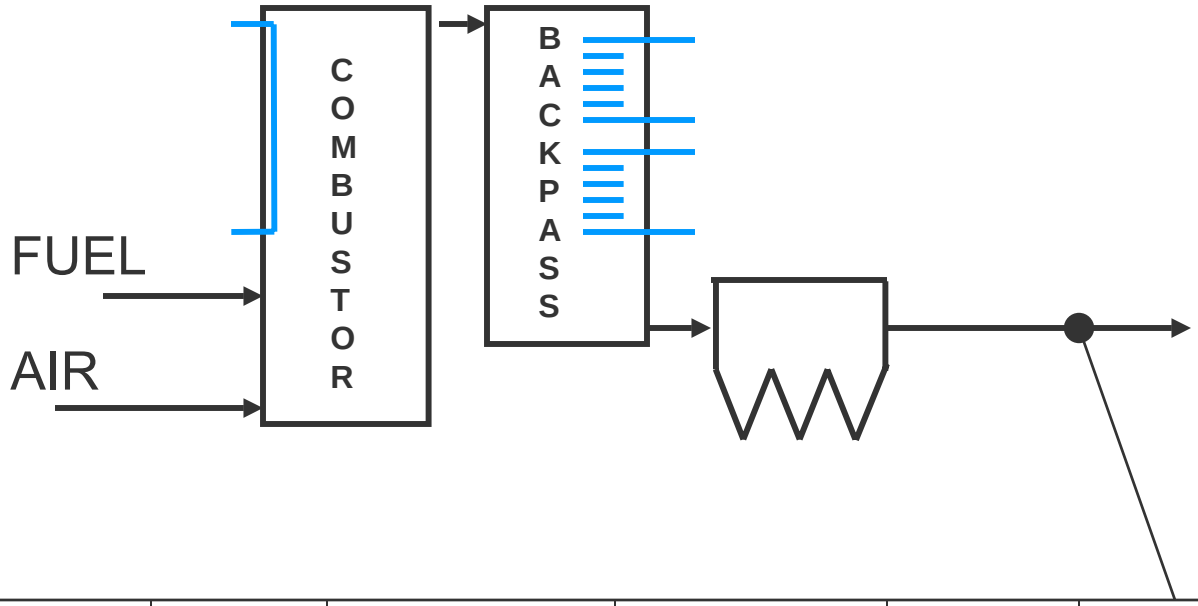
CO_2 Capture Options



CO_2 Capture Options

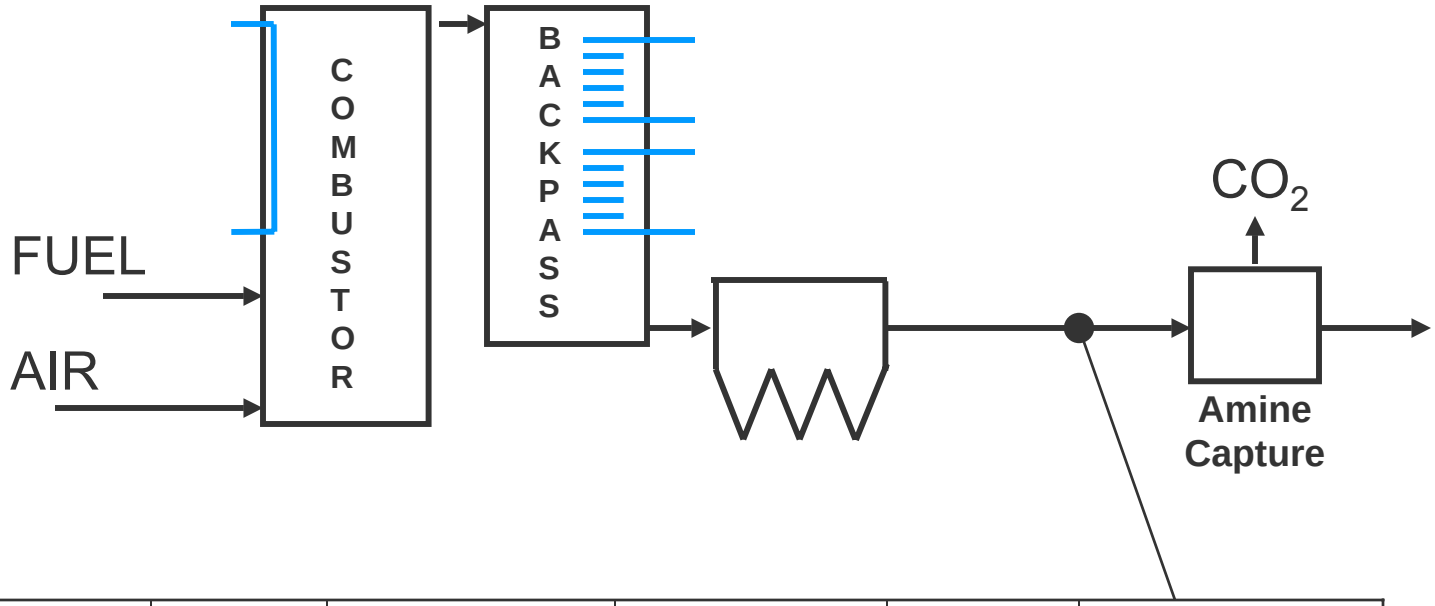
	Oxidant	CO_2 Removal
Post-combustion	**Air Fired**	**Extract from Flue Gas**
Pre-combustion	**O_2 for Gasification**	**Shift CO to CO_2**
	Air for Final Combustion	**Extract from Fuel Gas**
Oxyfiring	**O_2 for Combustion**	**Dry and Purify Flue Gas**

Conventional Firing



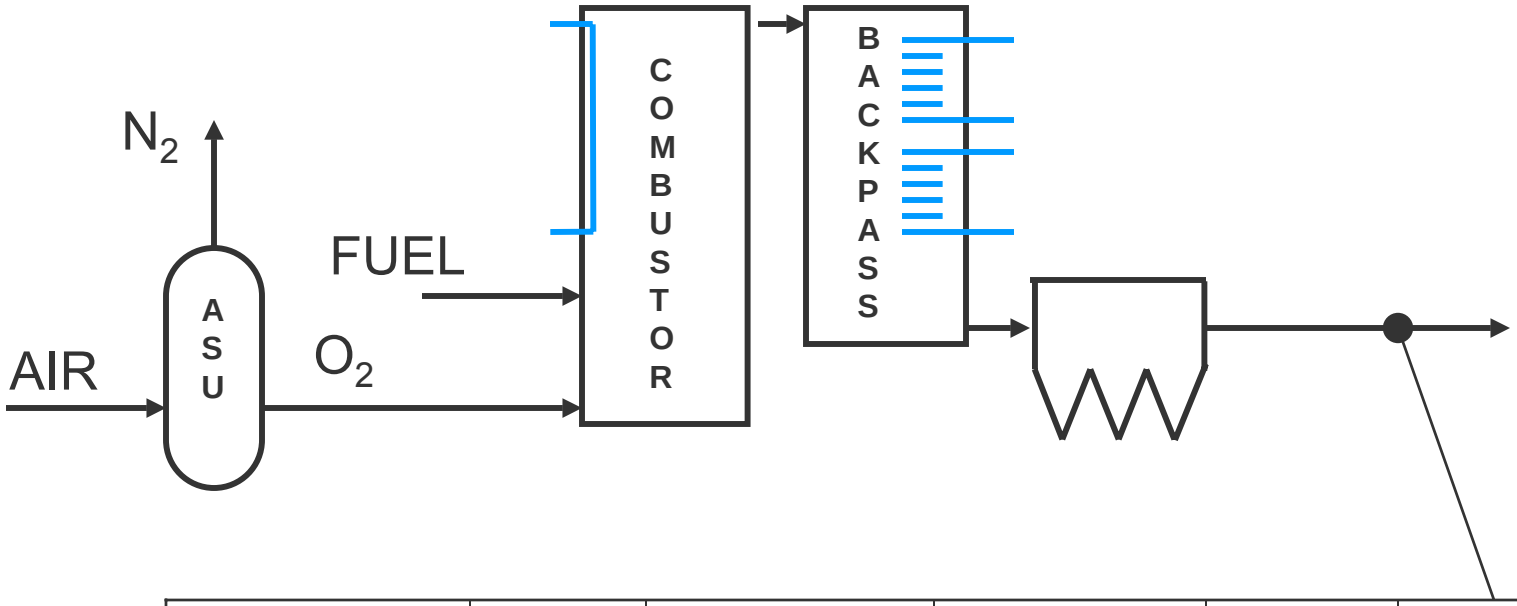
	N_2	CO_2	H_2O	O_2	Rel Vol
AIR	75	15	7	3	100

Conventional Firing with Amine Scrubbing



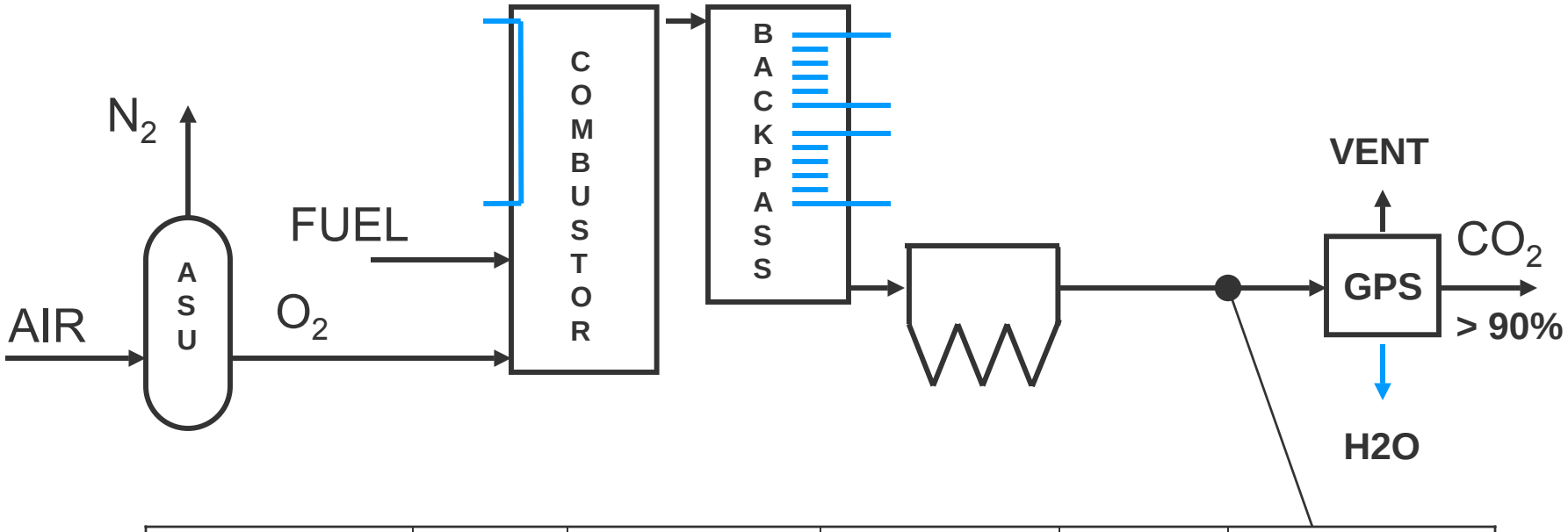
	N_2	CO_2	H_2O	O_2	Rel Vol
AIR	75	15	7	3	100

Conventional Firing using ASU to Produce a Stream of Oxygen



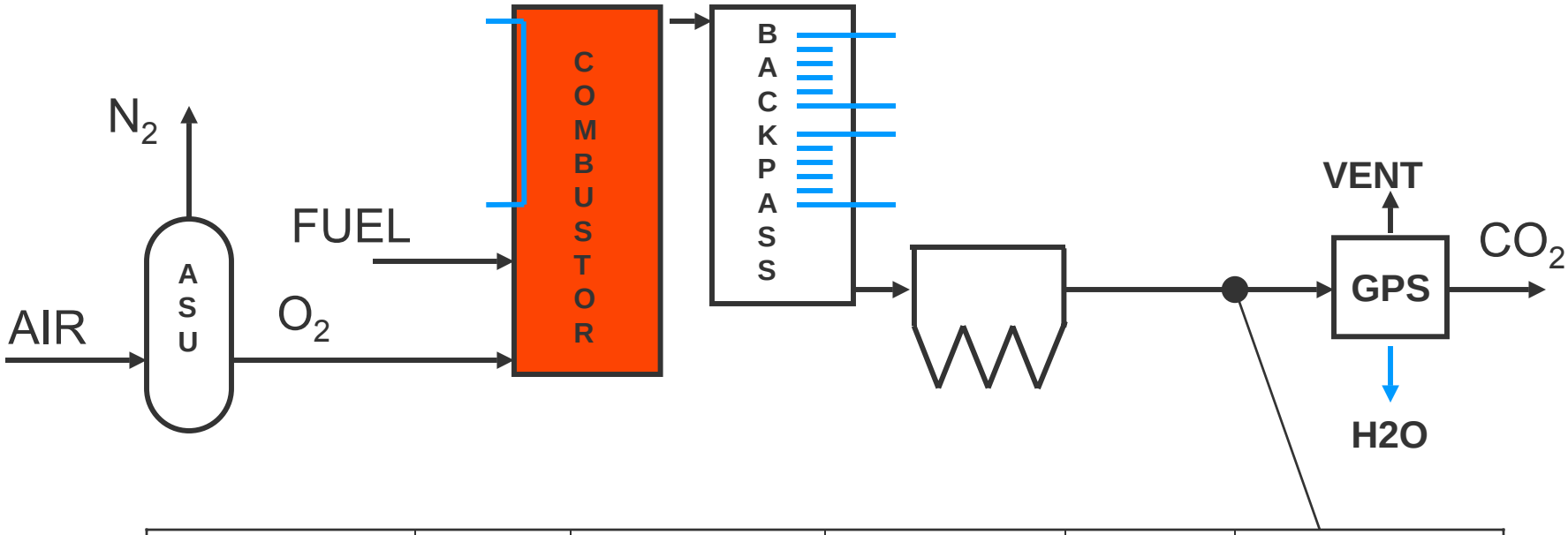
	N_2	CO_2	H_2O	O_2	Rel Vol
AIR	75	15	7	3	100
100% O_2	5	67	25	3	22

Conventional Firing with ASU and Drying to Purify the CO_2 stream



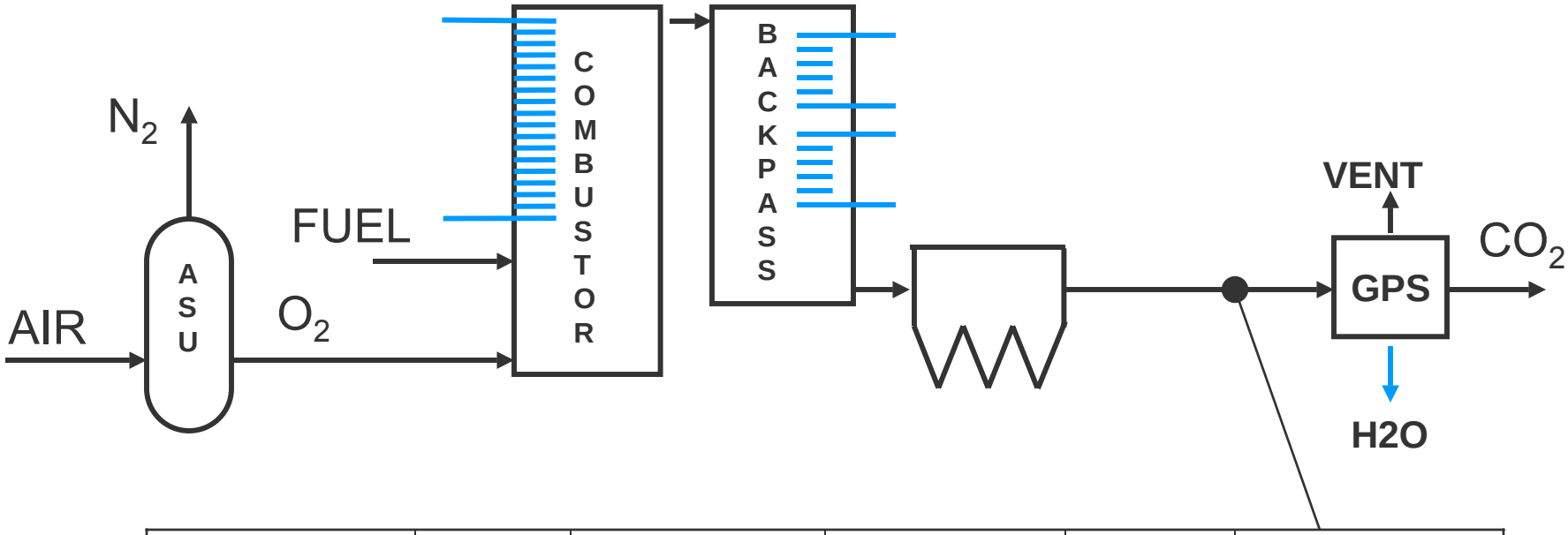
	N_2	CO_2	H_2O	O_2	Rel Vol
AIR	75	15	7	3	100
O_2	5	67	25	3	22

Conventional Firing with ASU produces high combustor temperatures



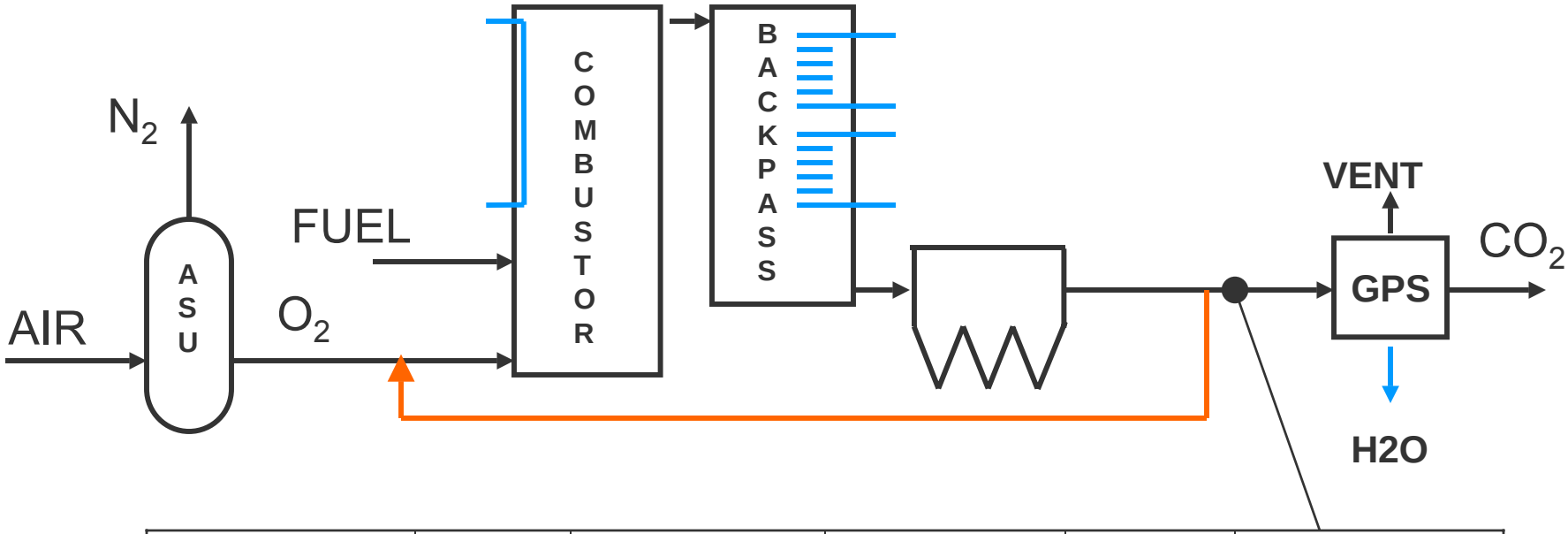
	N_2	CO_2	H_2O	O_2	Rel Vol
AIR	75	15	7	3	100
O_2	5	67	25	3	22

Combustor temperatures can be mitigated with upper furnace heat absorption



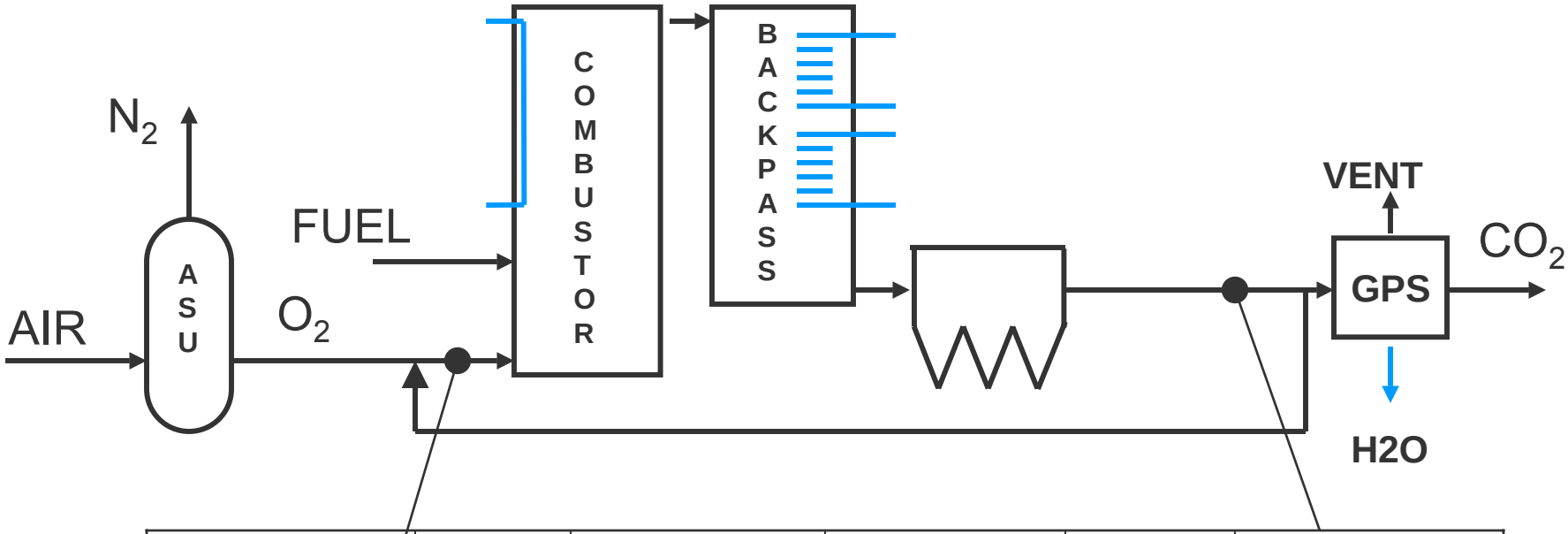
	N_2	CO_2	H_2O	O_2	Rel Vol
AIR	75	15	7	3	100
O_2	5	67	25	3	22

Combustor temperatures can be mitigated with flue gas recirculation



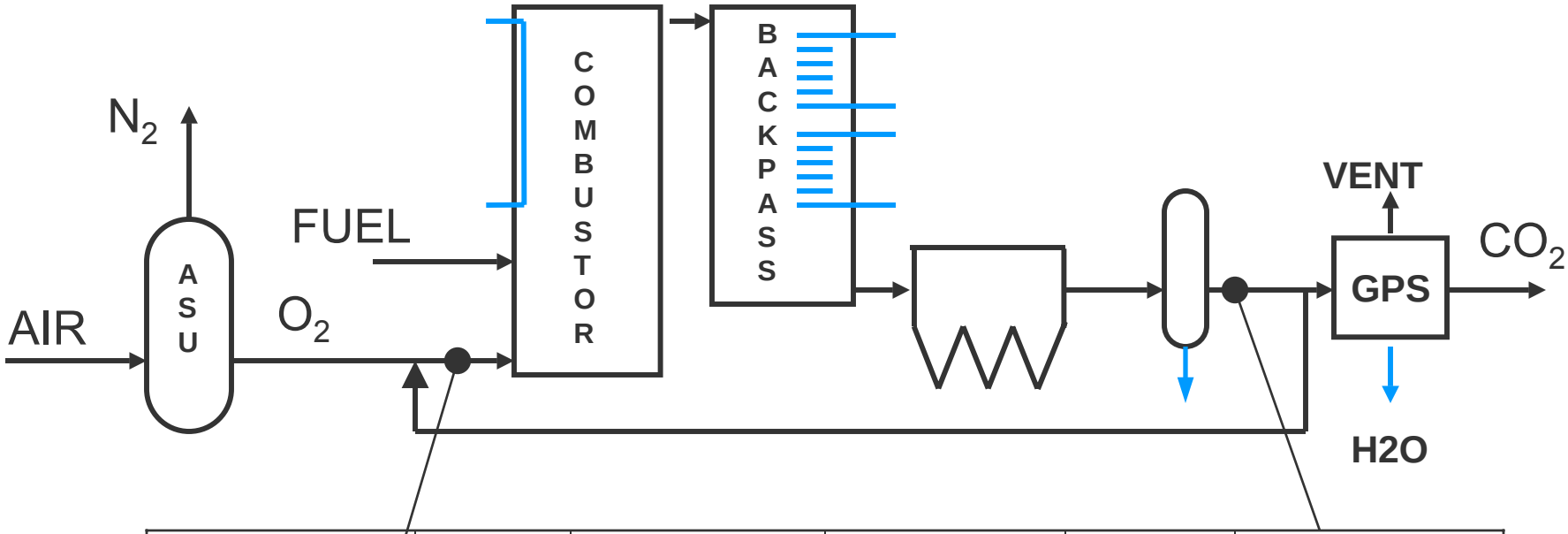
	N_2	CO_2	H_2O	O_2	Rel Vol
AIR	75	15	7	3	100
O_2	5	67	25	3	22

Retrofit option: Recirculate flue gas to a 30% O_2 blend maintains unit performance



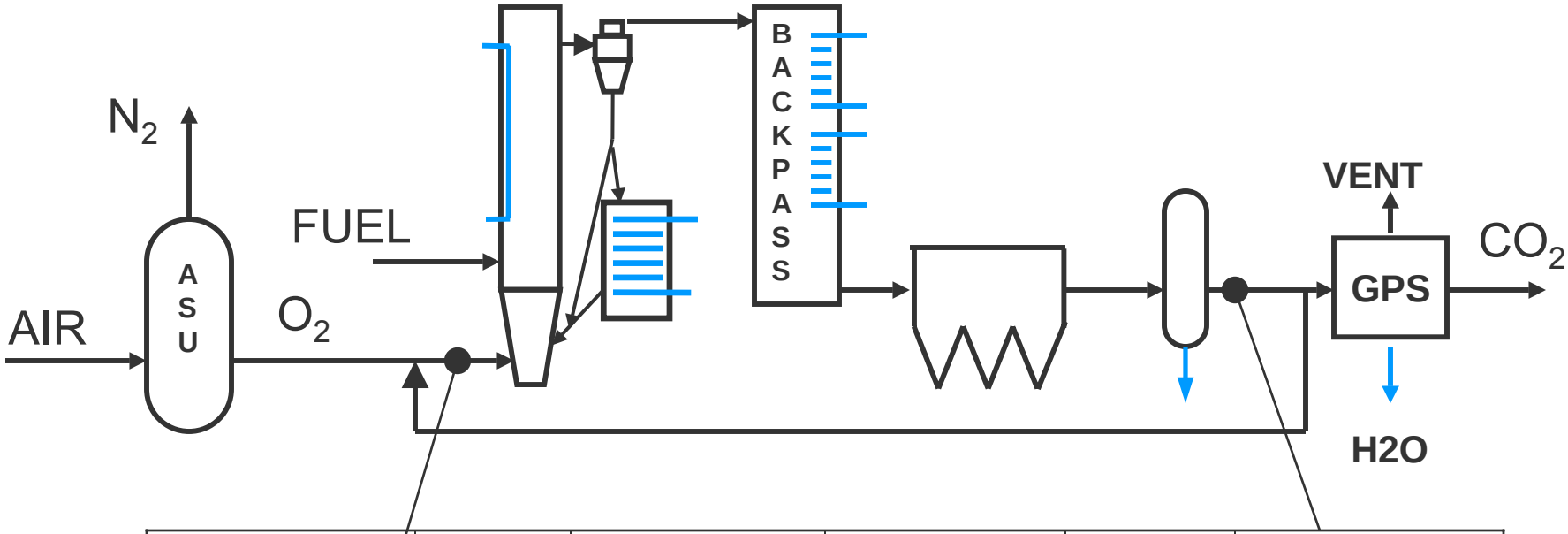
	N_2	CO_2	H_2O	O_2	Rel Vol
AIR	75	15	7	3	100
O_2	5	67	25	3	22
30% O_2	5	67	25	3	64

Retrofit option: Recirculate flue gas to a 30% O_2 blend maintains unit performance



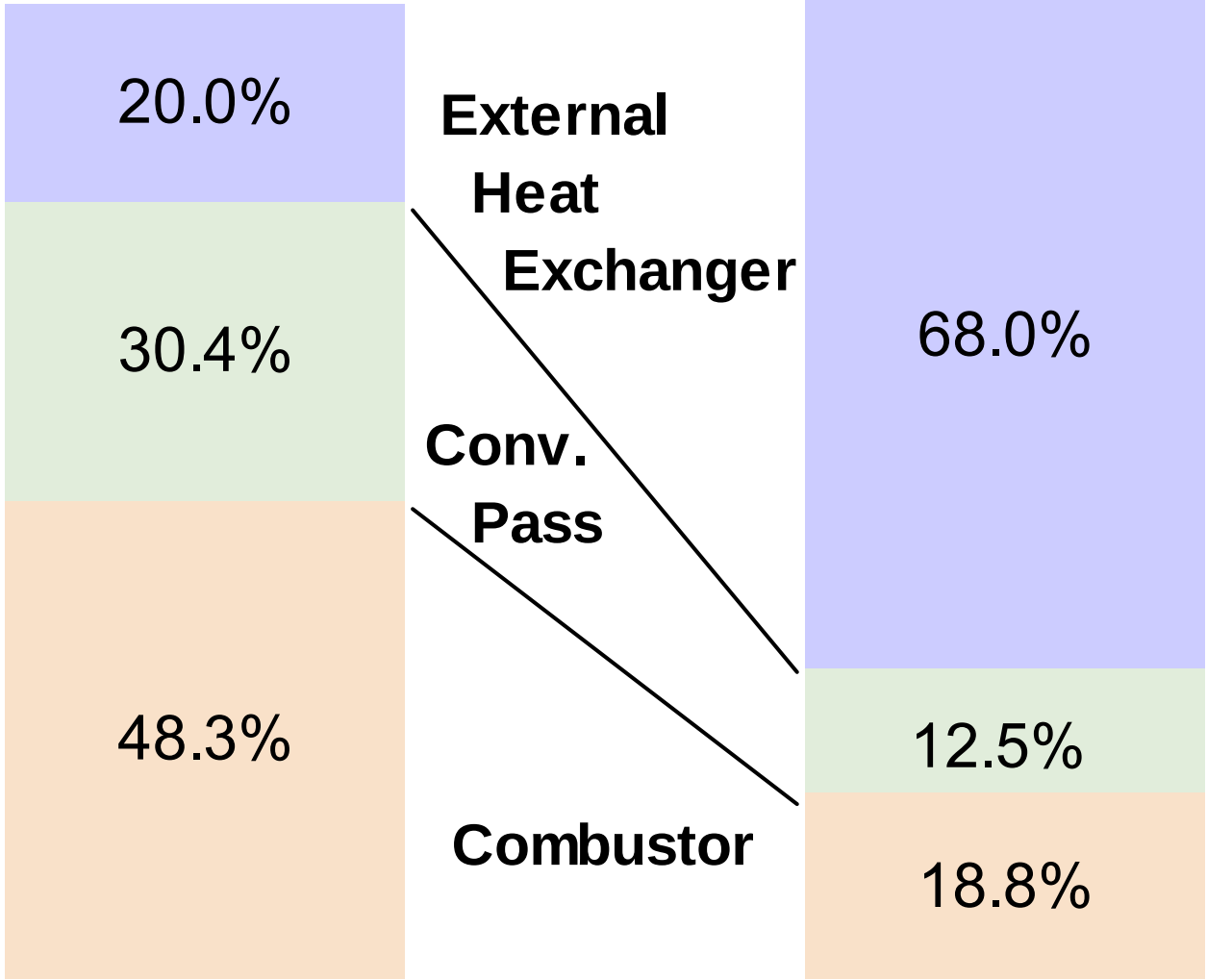
	N_2	CO_2	H_2O	O_2	Rel Vol
AIR	75	15	7	3	100
O_2	5	67	25	3	22
30% O_2	6	83.5	7	3.5	65

Greenfield option: Circulating Fluidized Bed reduces recirculation of flue gas



	N_2	CO_2	H_2O	O_2	Rel Vol
AIR	75	15	7	3	100
O_2	5	67	25	3	22
70% O_2	6	83.5	7	3.5	28

CFB Heat Duties for Air and Oxy fired systems



Overview of ALSTOM Studies

Developments Related to Oxy-firing for CO_2 Capture

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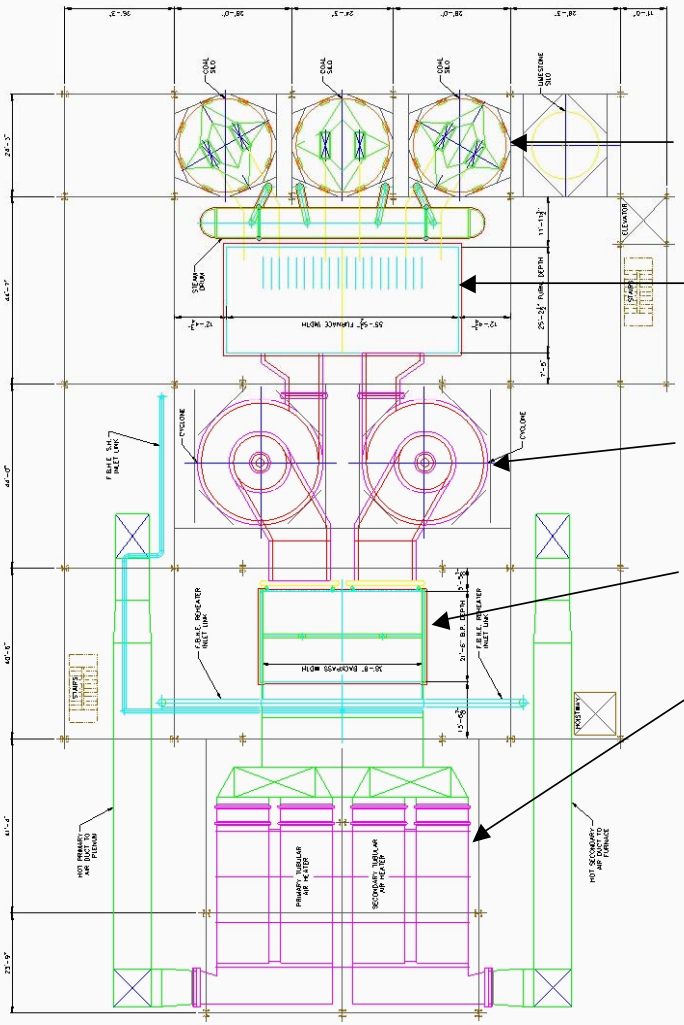
ALSTOM CO_2 Capture Efforts

1998	ALSTOM	Technical Feasibility of a CO_2/O_2 Combustion Retrofit to an Existing Coal-Fired Bolier for CO_2 Extraction
1999	TransAlta	Preliminary Design and Costing of a CO_2/O_2 Combustion Retrofit to an Existing Coal-Fired Bolier for CO_2 Extraction
1999	ABB	Investigation of Ceramic Oxygen Transport Membrane Processes with Coal Fired Power Plants
2000	Suncor	CFB Boiler Integrated with 300 Tonnes per Day CO_2 Removal System for Suncor Thermal Solvent Process Project
2000		eneration CO_2 Capture,
2001		centage for Amine-
1999 - 2001	OCDO / DOE / ALSTOM	Engineering Feasibilty and Economics of CO_2 Capture on an Existing Coal-Fired Power Plant
2001 - 2004	DOE / ALSTOM	Greenhouse Gas Emissions Control by Oxygen Firing in Circulating Fluidized Bed Boilers
2002 - 2003	EU	GRACE – Chemical Looping Combustion – Feasibility Study
2003 - 2004	ADEME / ALSTOM	CO_2 Capture – (cascade cryogenics) – ECS/BUB
2003 - 2004	ADEME / ALSTOM	CO_2 Capture - Calcium Cycle
2003 - 2005	DOE / ALSTOM	Hybrid Combustion Gasification Chemical Looping Coal Power
2003 - 2005	ADEME	EDF - 2015
2003 - 2006	EU	ENCAP
2004	EU / IPFP6	ENCAP (Oxyfiring – Chemical Looping)
2004 - 2006	DOE / ALSTOM	Commercialization Development of O_2-Fired CFB for Greenhouse Gas Control
2005 - 2006	DOE	CO_2 Capture from Existing Fleet Feasibility Study
2006 – 2009	DOE / BOC / ALSTOM	Pilot Scale Demonstration of CAR Technology on Oxygen Boilers

12 of 18 CO_2 studies focused on O_2 firing: a variety of partners EU, DOE, State agencies and utilities

Advanced O_2 Technologies

Comparison of plant layouts: 210MWe Gross



Air Fired

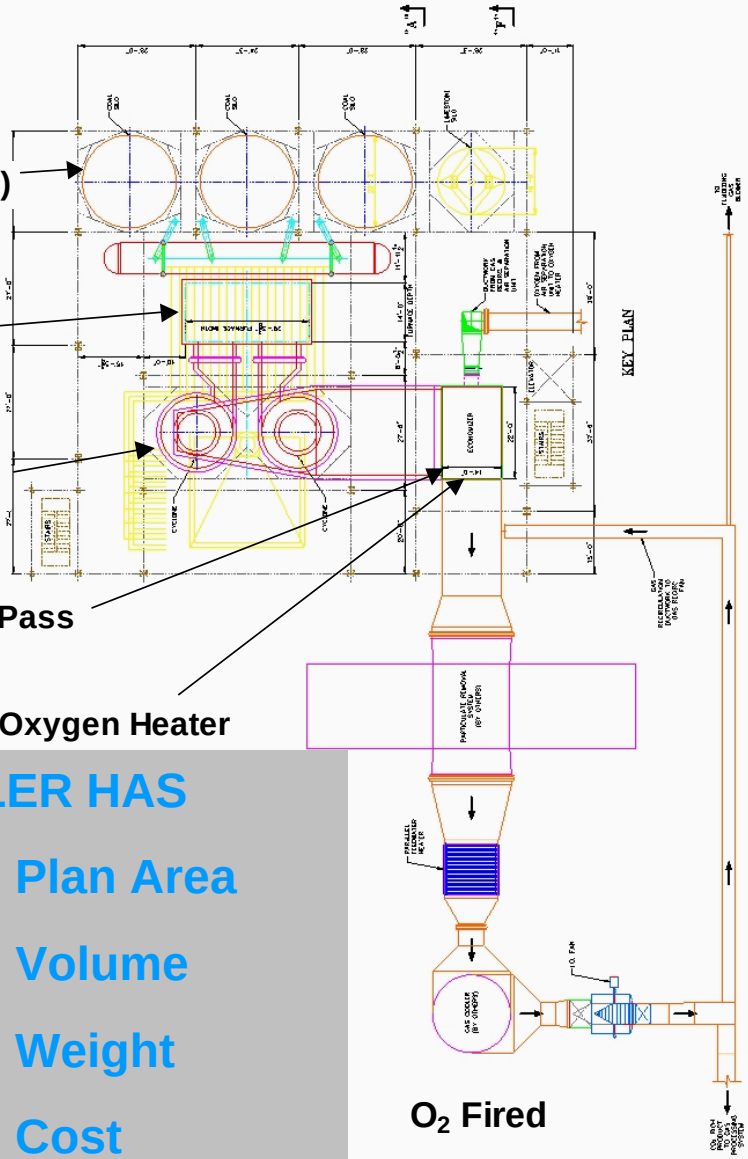
Coal Silos (3)

Furnace

Cyclones (2)

Convective Pass

Tubular Air/ Oxygen Heater



O_2 Fired

O_2 BOILER HAS

51% Plan Area

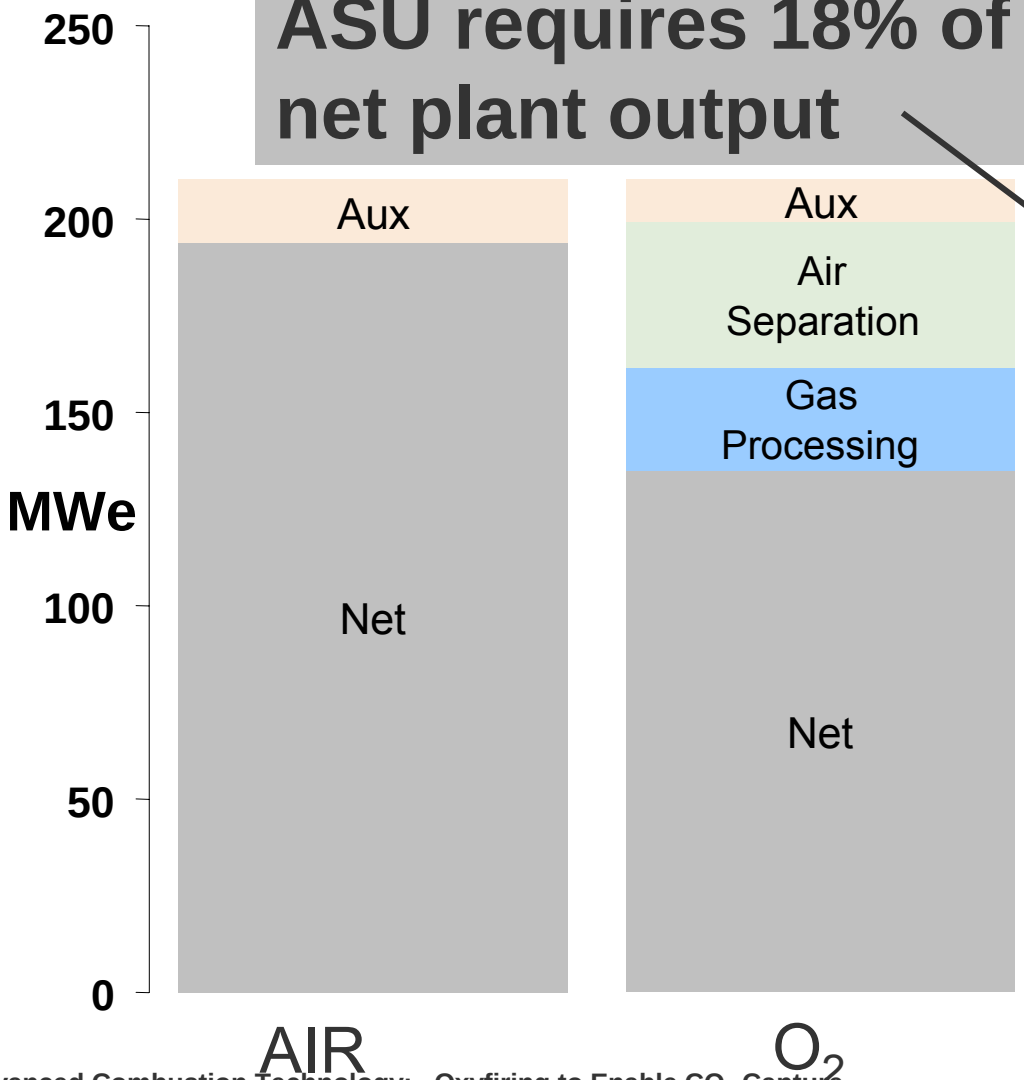
56% Volume

65% Weight

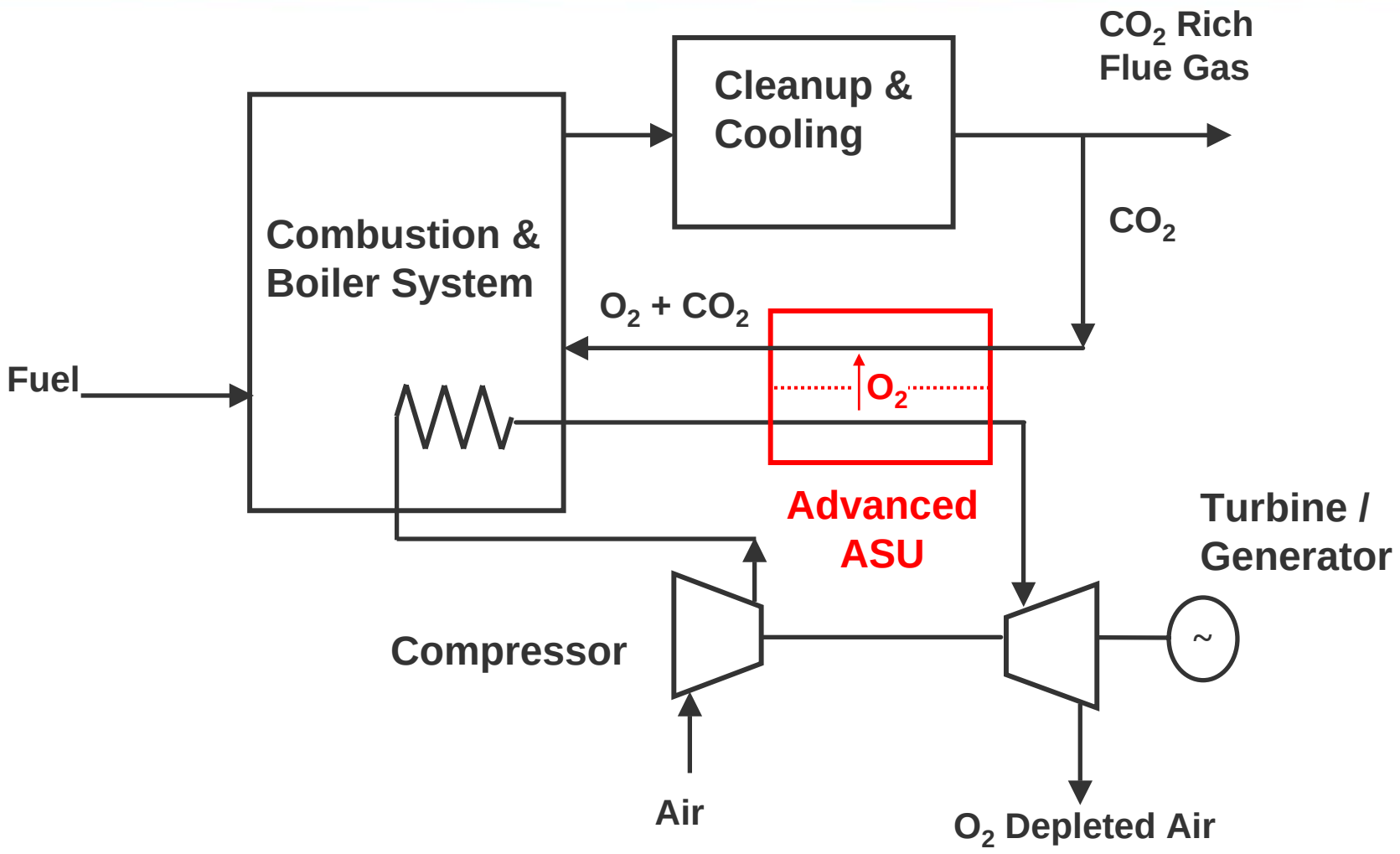
68% Cost

Comparison of plant power output: 210MWe Gross

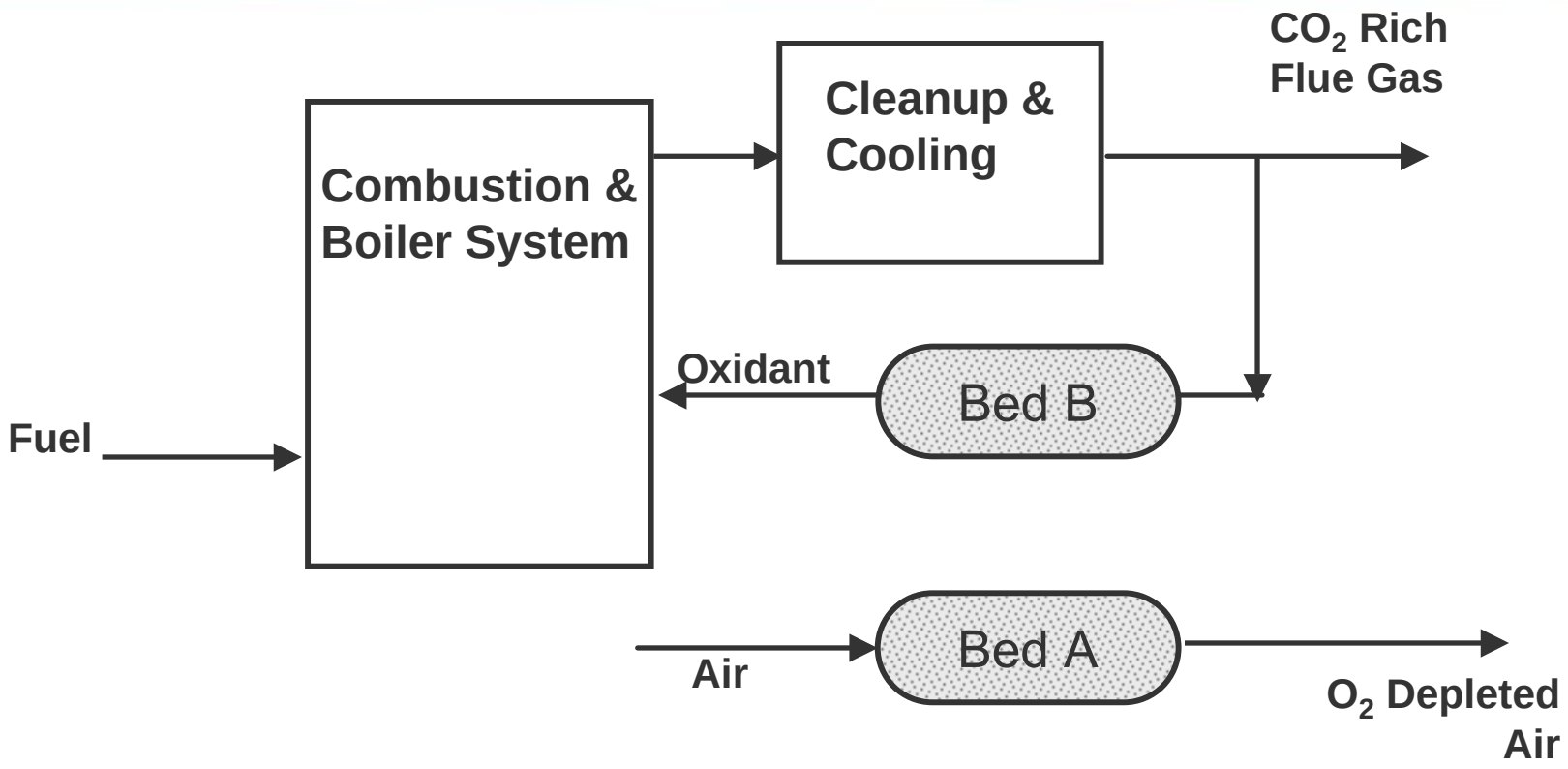
ASU requires 18% of net plant output



Evaluation of Advanced Oxygen Separation

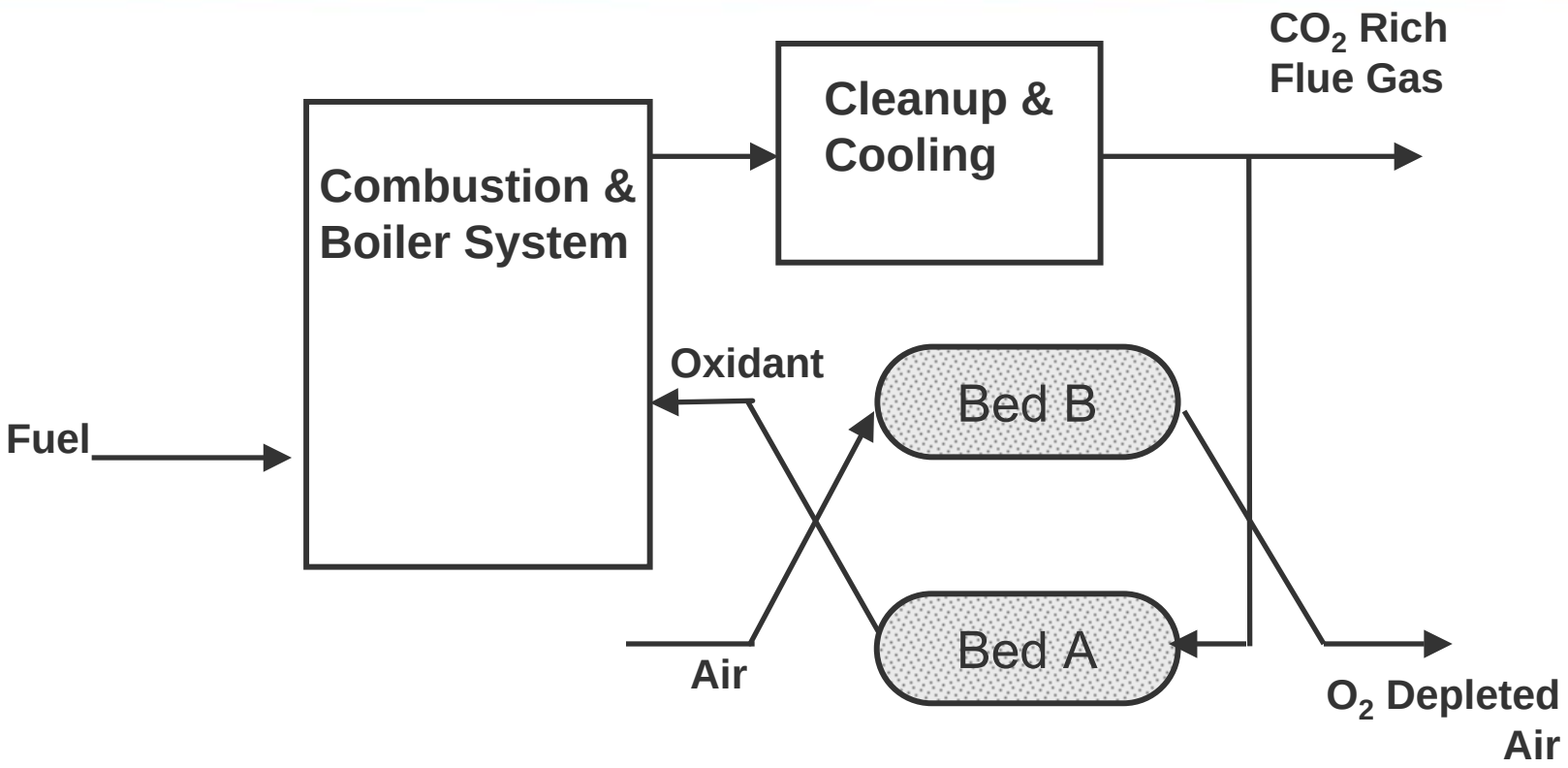


Evaluation of Ceramic Autothermal Recovery



Perovskite materials have the capacity to absorb oxygen from air

Evaluation of Ceramic Autothermal Recovery



Cycle the valves to recharge Bed B while Bed A is used.

Advanced *vs.* Cryogenic ASU

	AIR	CRYOGENIC ASU	ADVANCED ASU
Total Aux Power, % of Gross	8	36	20
Plant Efficiency, % HHV	35	25	30
Capital Cost*, $/kW	1300	2500	2400
COE*, ¢/kWh	4.5	8.0	7.0

Summary from DOE Phase I Study

* in 2003 dollars

ALSTOM Economic Studies

CO_2 Capture with Coal Power

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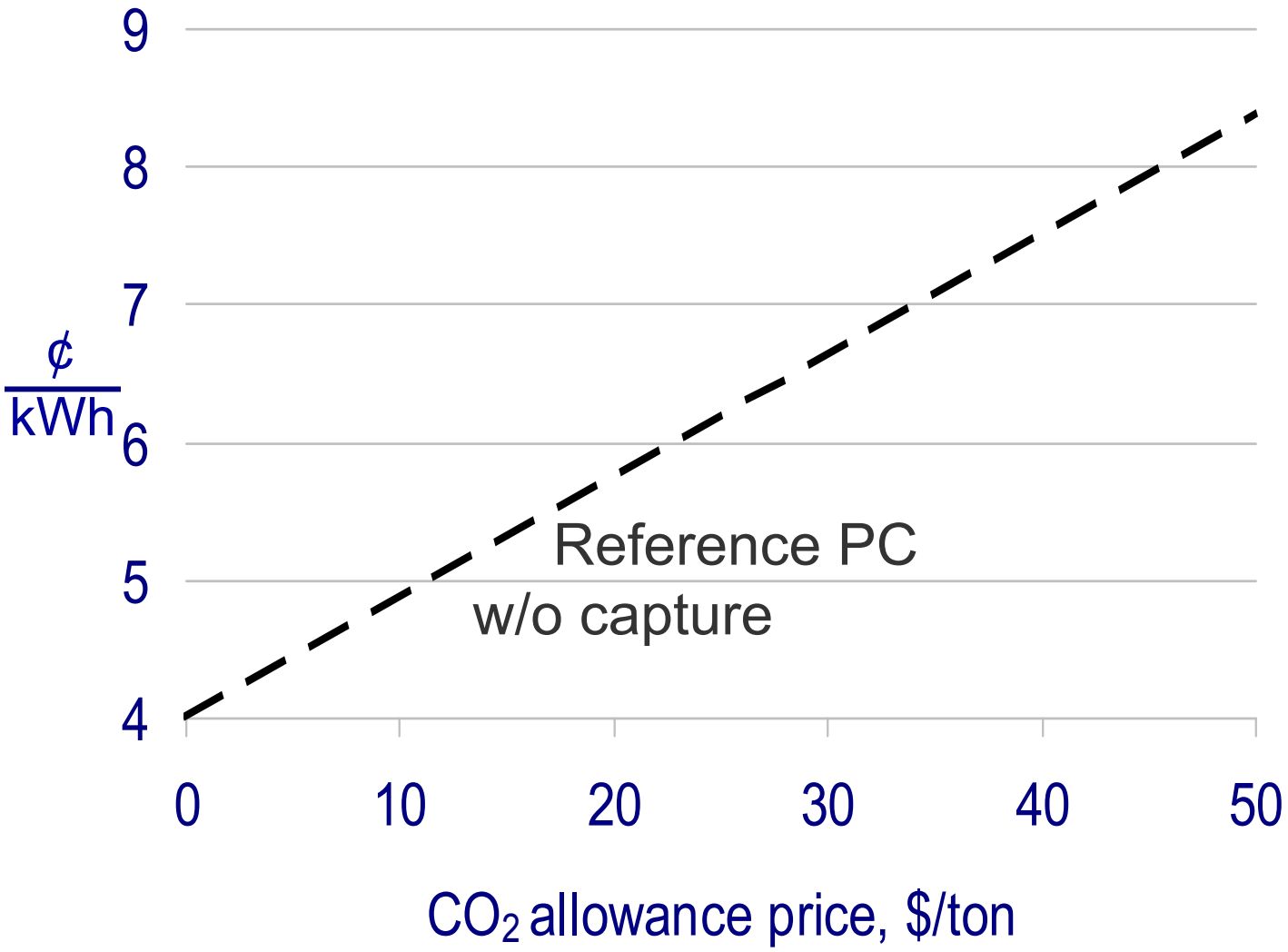
ALSTOM CO_2 Capture for Power Studies:

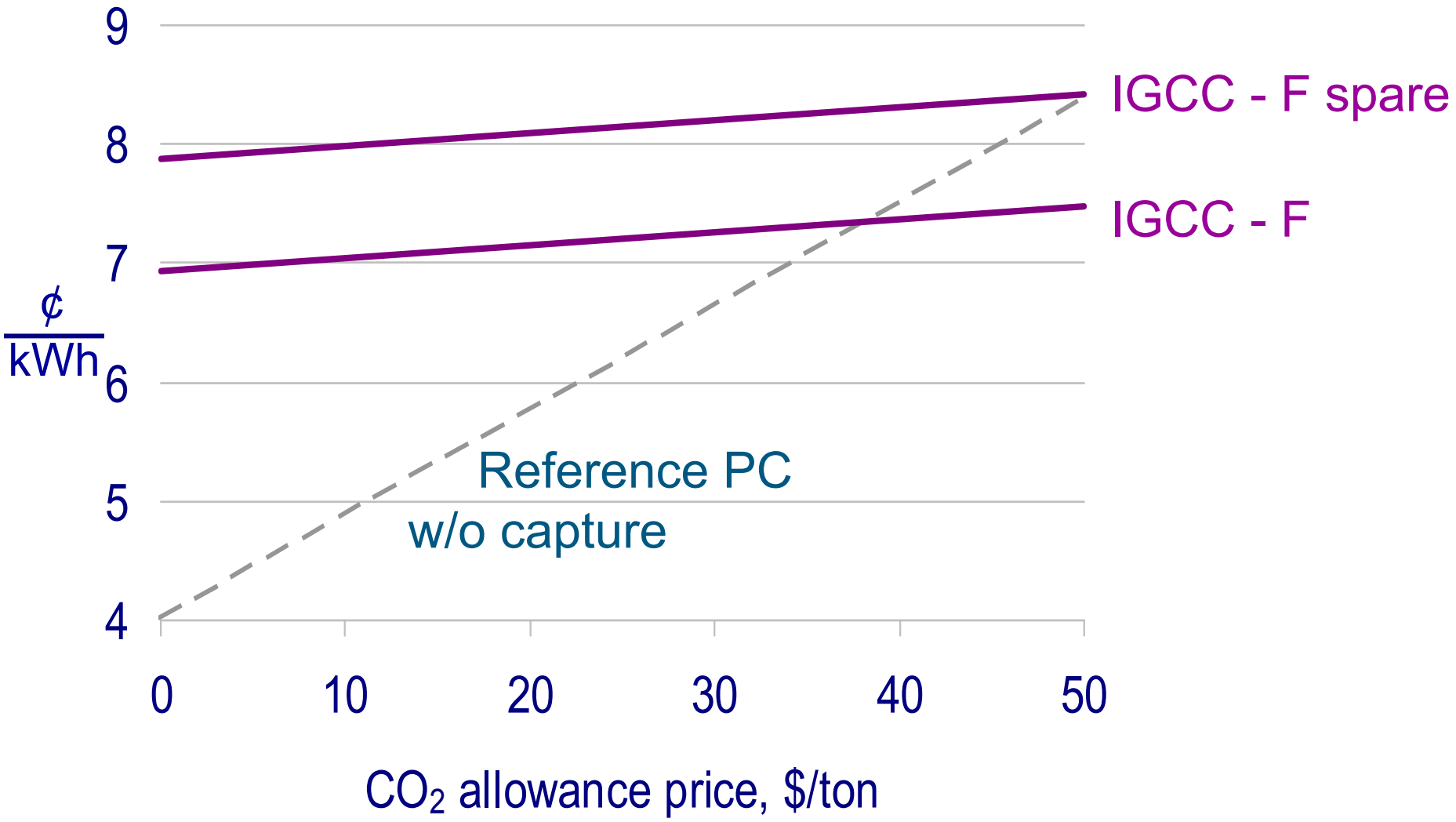
#	Project Name	Sponsors	Years
1	Technical Feasibility of a CO_2/O_2 Combustion Retrofit to an Existing Coal-Fired Boiler for CO_2 Extraction	ABB	1998
2	Preliminary Design and Costing of a CO_2/O_2 Combustion Retrofit to an Existing Coal-Fired Boiler for CO_2 Extraction	TransAlta Corp.	1999
3	Integration of Ceramic Oxygen Transport Membrane Processes with Coal Fired Power Plants	ABB	1999
4	CFB Bo Suncor		2000
5	CO_2 Ca Project f Sequestration		2000
6	CO_2 Capture in a Coal-Fired Boiler: Economic and Performance Sensitivity to CO_2 Capture Percentage for Amine-Based Processes	ALSTOM Power Inc.	2001
7	Engineering Feasibility and Economics of CO_2 Capture on an Existing Coal-Fired Power Plant	OCDO/DOE NETL	1999-2001
8	Greenhouse Gas Emissions Control by Oxygen Firing in Circulating Fluidized Bed Boilers	DOE NETL	2001-2004
9	GRACE - Chemical Looping Combustion - Feasability study	EU	2002 - 2003
10	CO2 capture (cascade cryogenics) - ECS/BUB	ADEME	2003 - 2004
11	CO2 Capture - Calcium cycle	ADEME	2003 - 2004
12	EDF - 2015	ADEME	2003 - 2005
13	ENCAP (Oxyfiring - Chemical Looping)	EU / IPFP6	2004
14	EnCap	EU	2003 - 2006

Fourteen economic studies from 1998 – 2006 with a variety of partners: DOE, EU and utilities

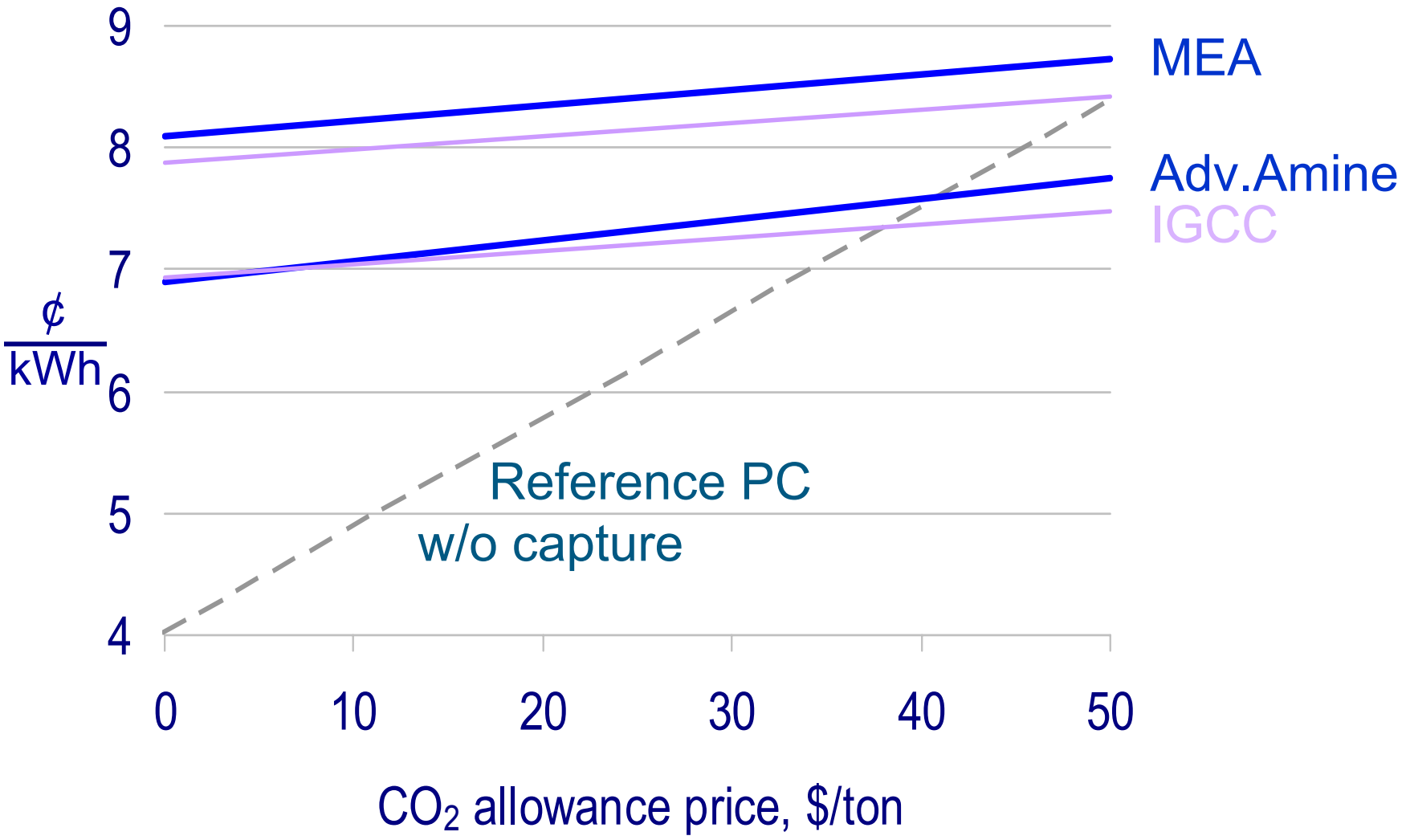
Levelized COE



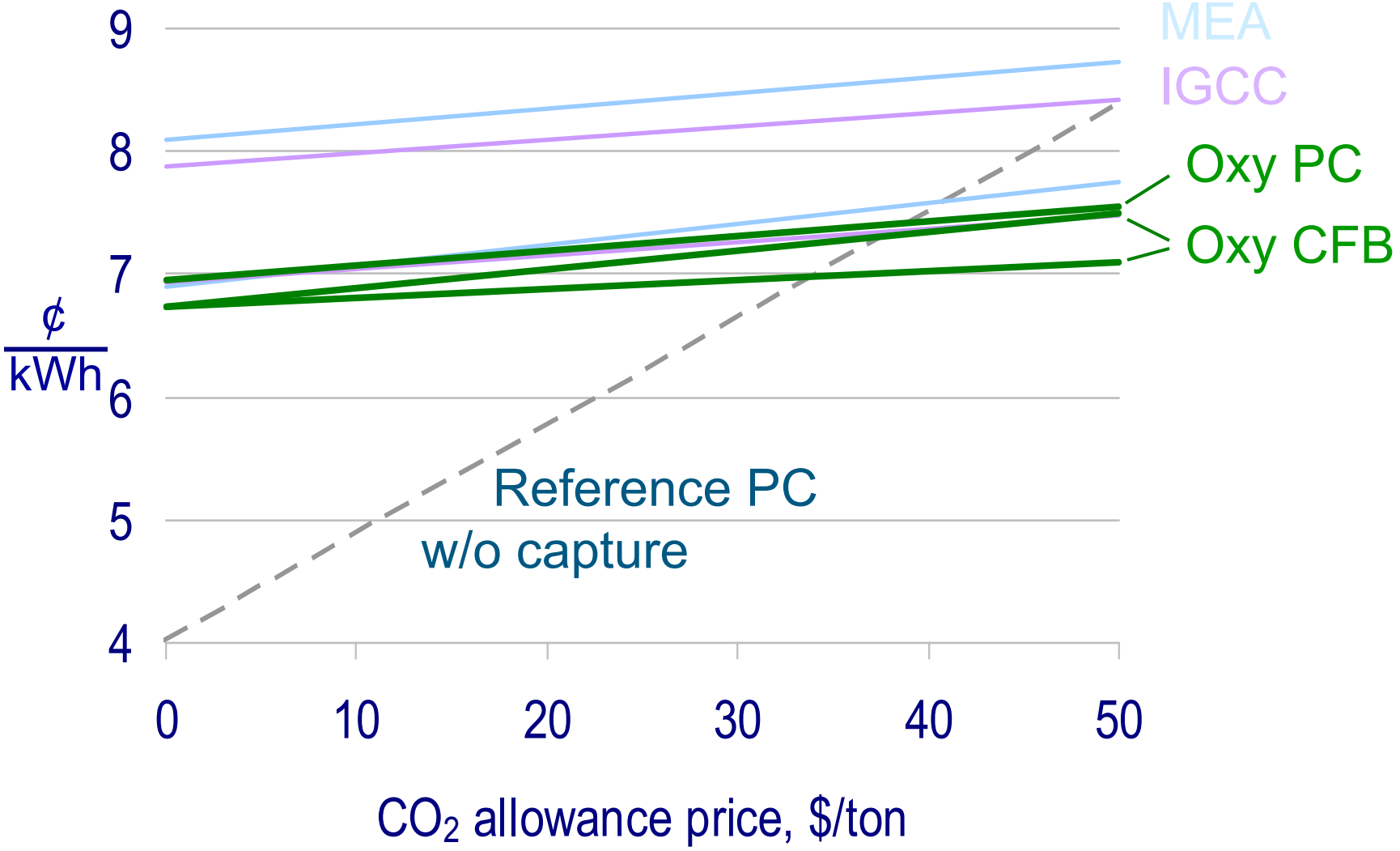
Levelized COE



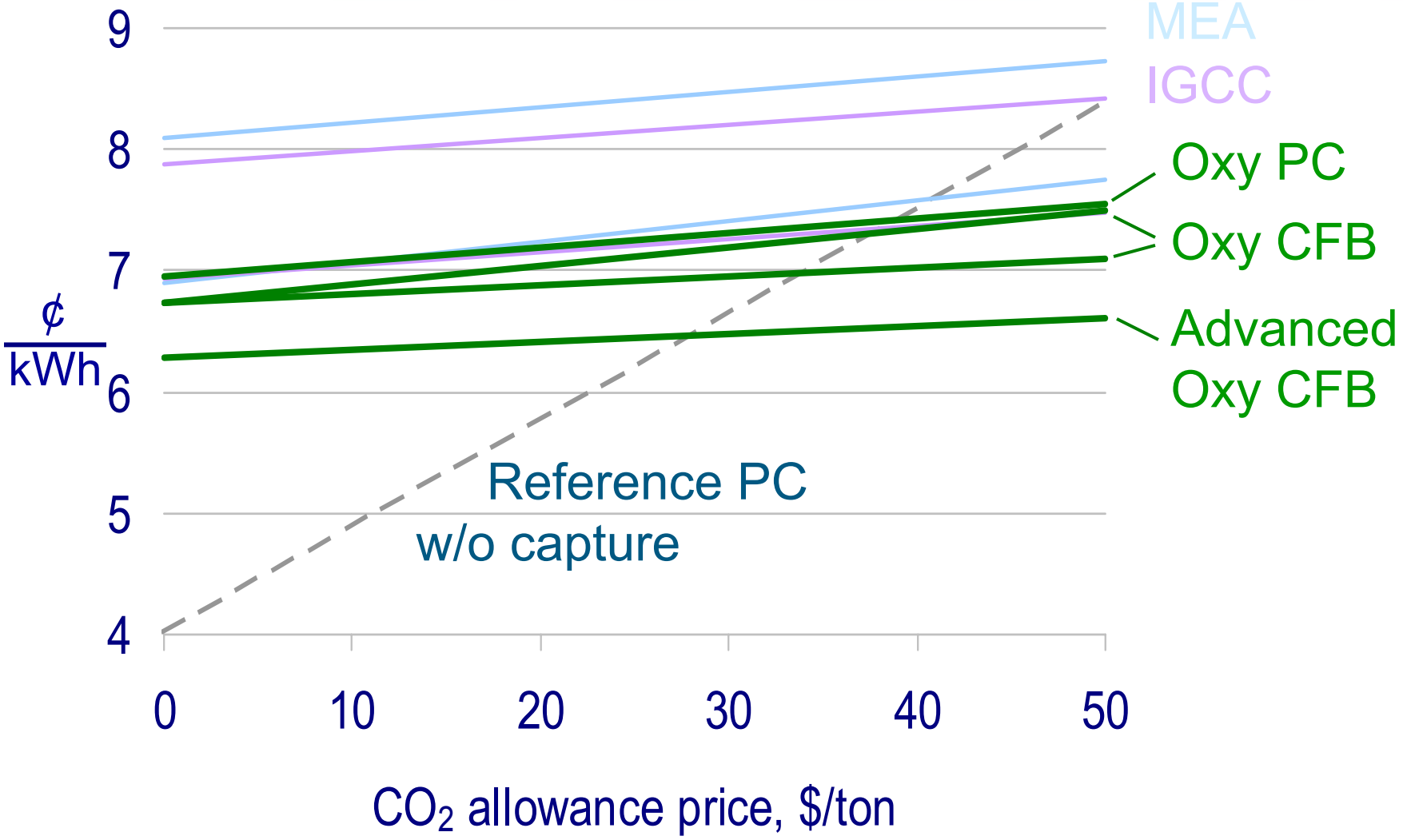
Levelized COE



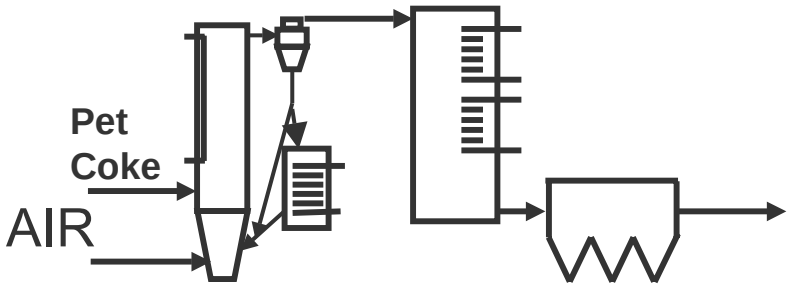
Levelized COE



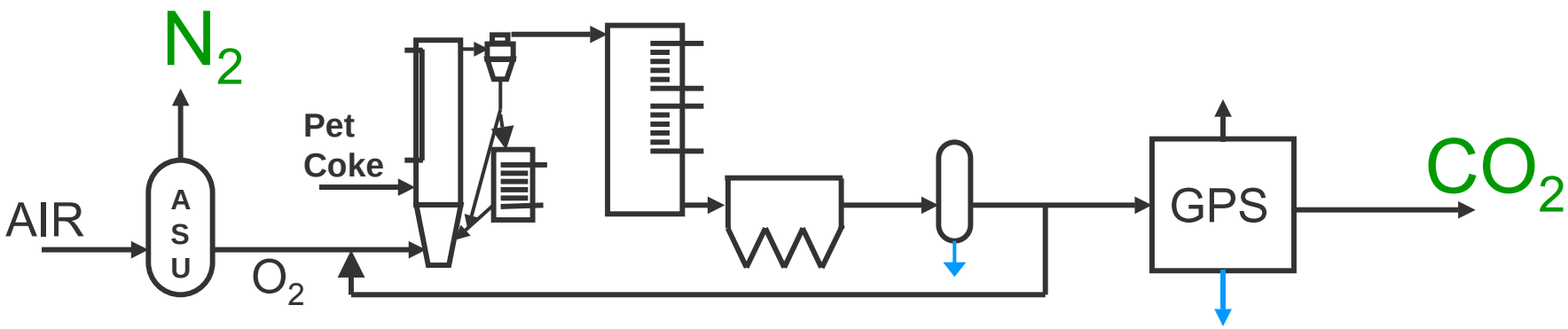
Levelized COE



CFB Greenfield/Retrofit for EOR



CFB Greenfield/Retrofit for EOR

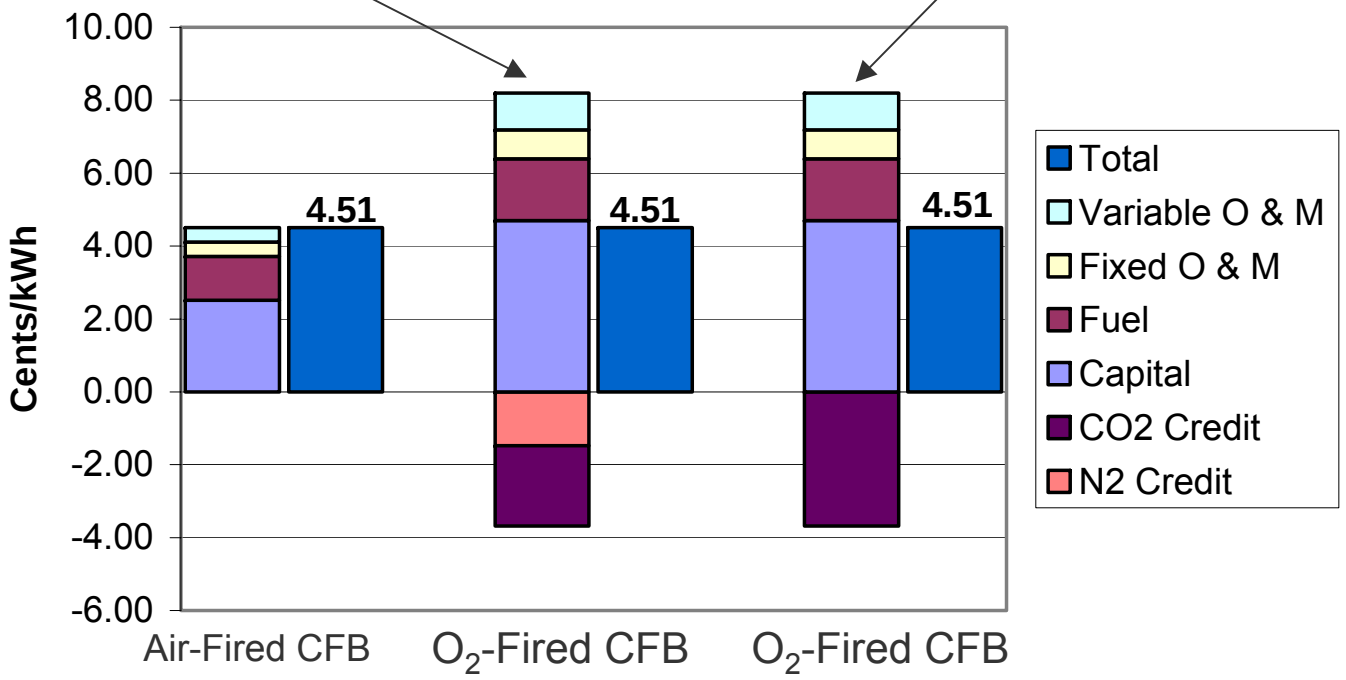


Use CO_2 and N_2 for Enhanced Oil Recovery

EOR Economics (210 MWe Gross, Greenfield)

Breakeven COE met with credits
- **CO_2 : 17 $/ton**
- **N_2 : 4 $/ton**

Breakeven COE met with credits
- **CO_2 : 28 $/ton**



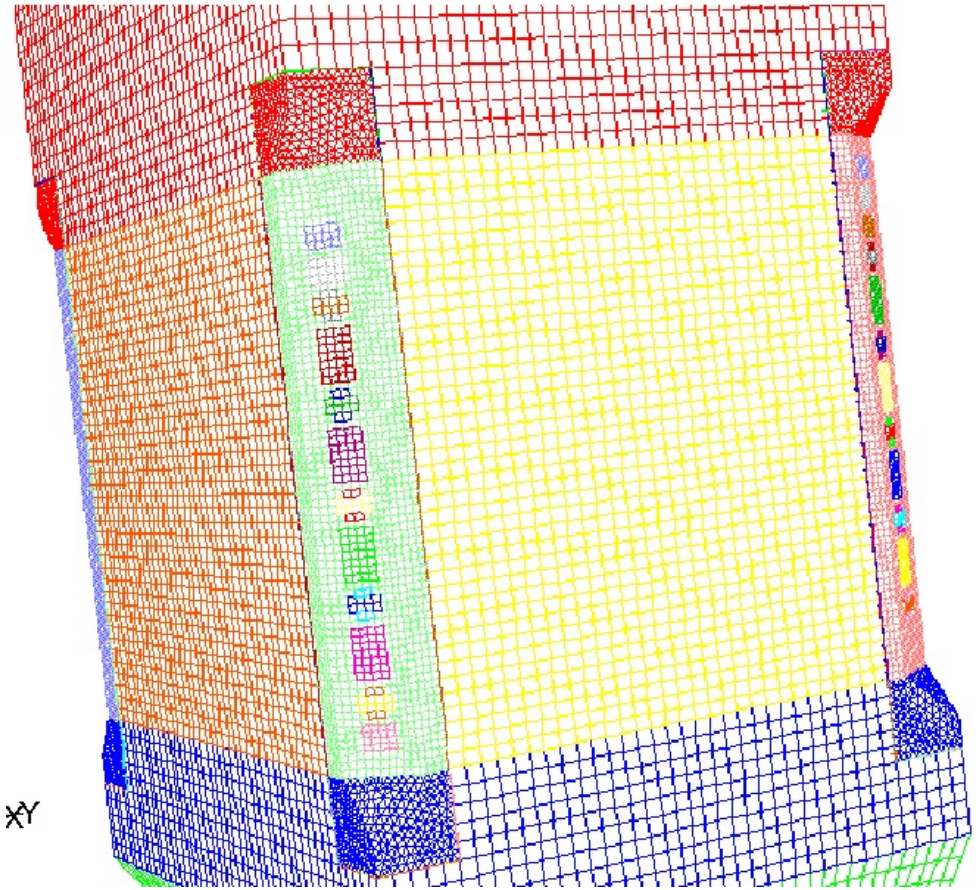
CFD Evaluation

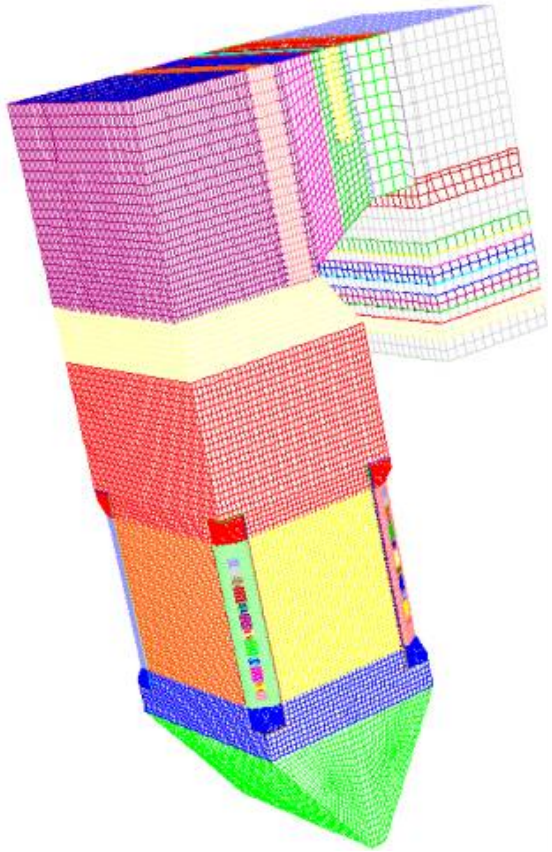
- **Objective:** **Simulation studies with Fluent™ of Conesville #5 to evaluate water-wall heat flux distribution and overall heat transfer in the furnace.**

- **Approach:**
  - (1) Calibrate ALSTOM Power Inc.'s version of Fluent™ CFD code with a baseline Conesville #5 coal combustion case
  - (2) Use calibrated code to evaluate impact of the same coal combustion in various CO_2/O_2 ratios.

- **Outputs:**
  - **Relative radiation heat fluxes**
  - **Heat transfer**
  - **Furnace outlet temperature**
  - **Unburned carbon**
  - **NO_X emissions.**

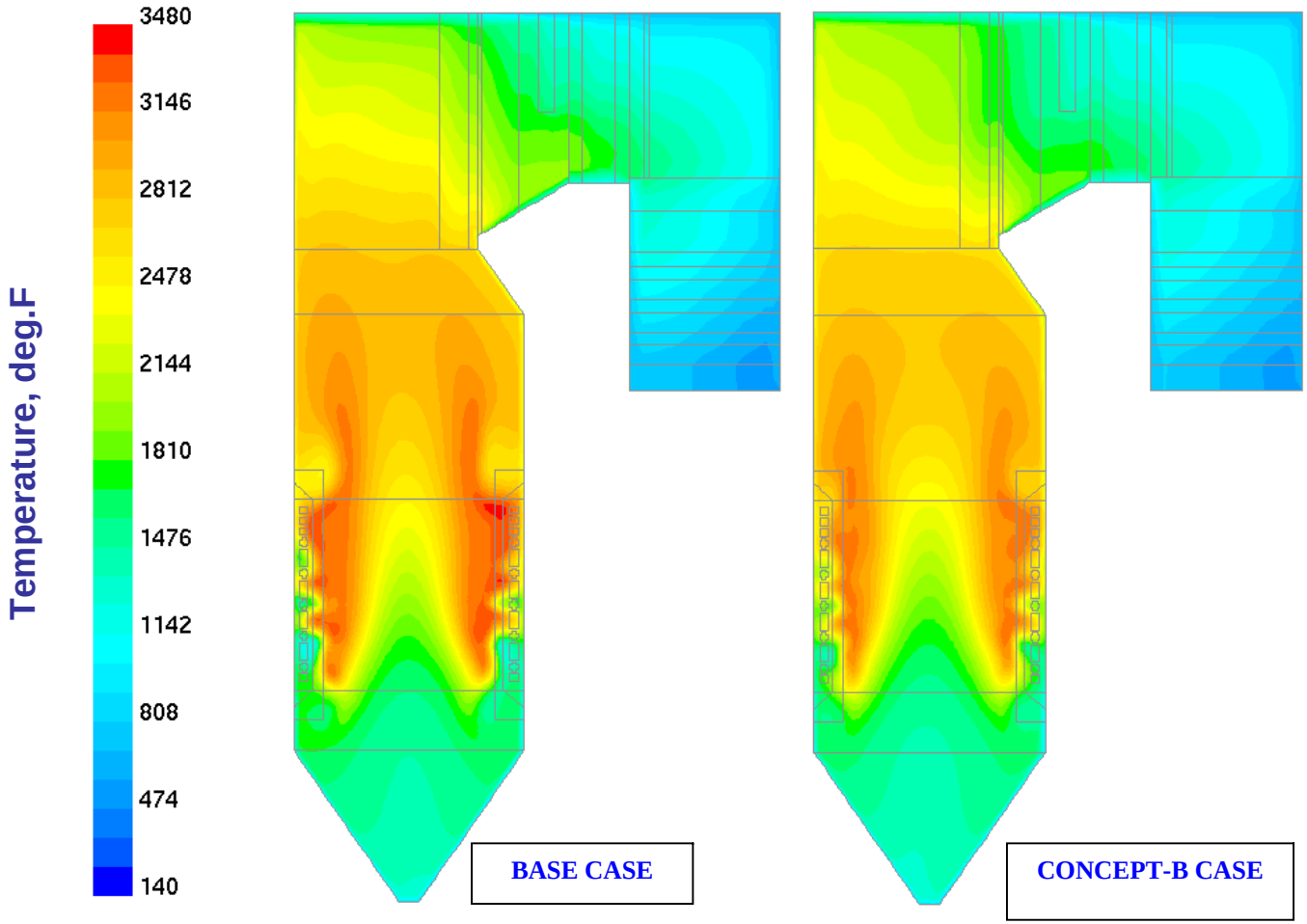
Conesville #5: Base Case CFD Grid



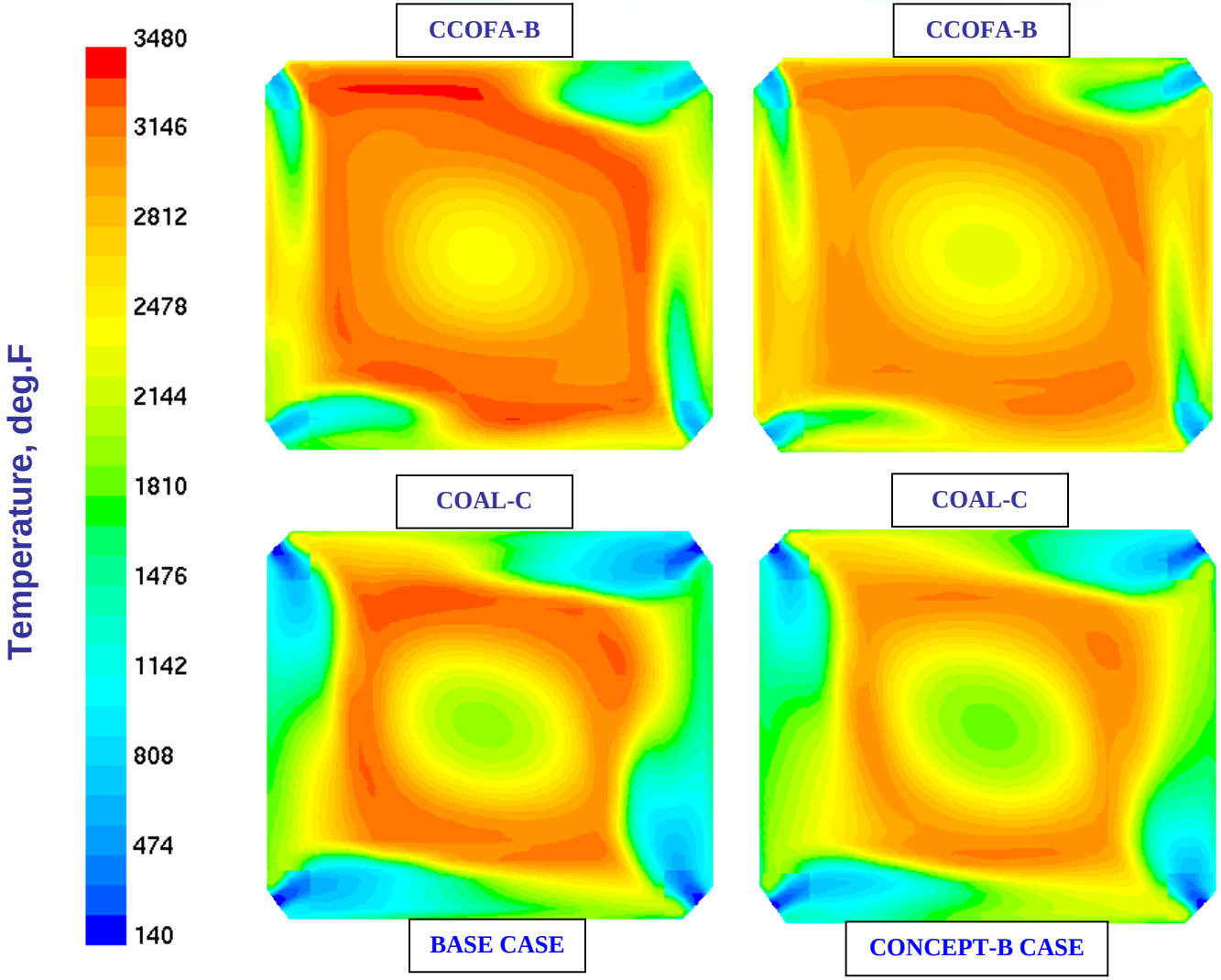


315,000 Cells (Unstructured Mesh)

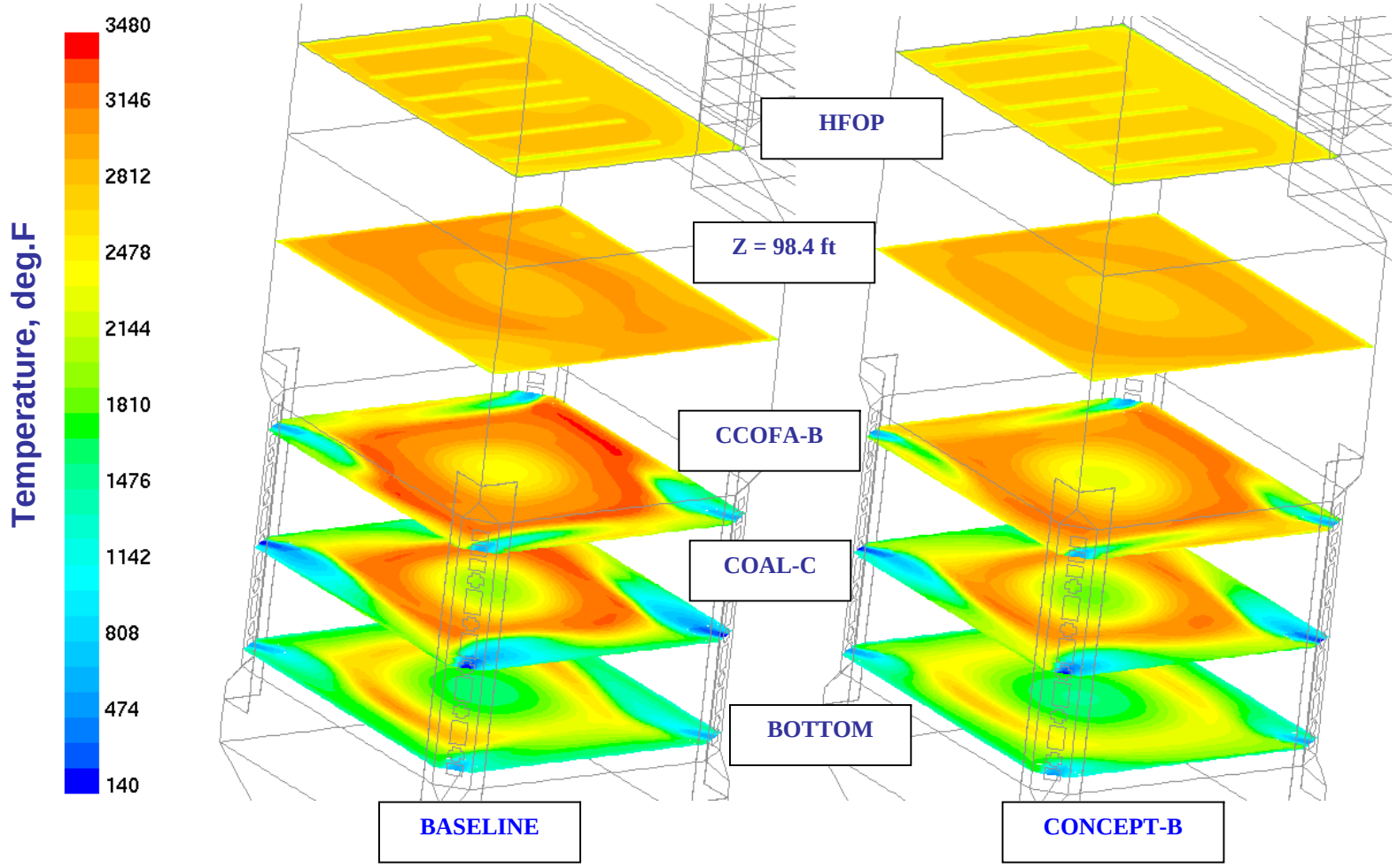
Conesville #5: Base Case Temperature Contours



Conesville #5: Temperature Contours



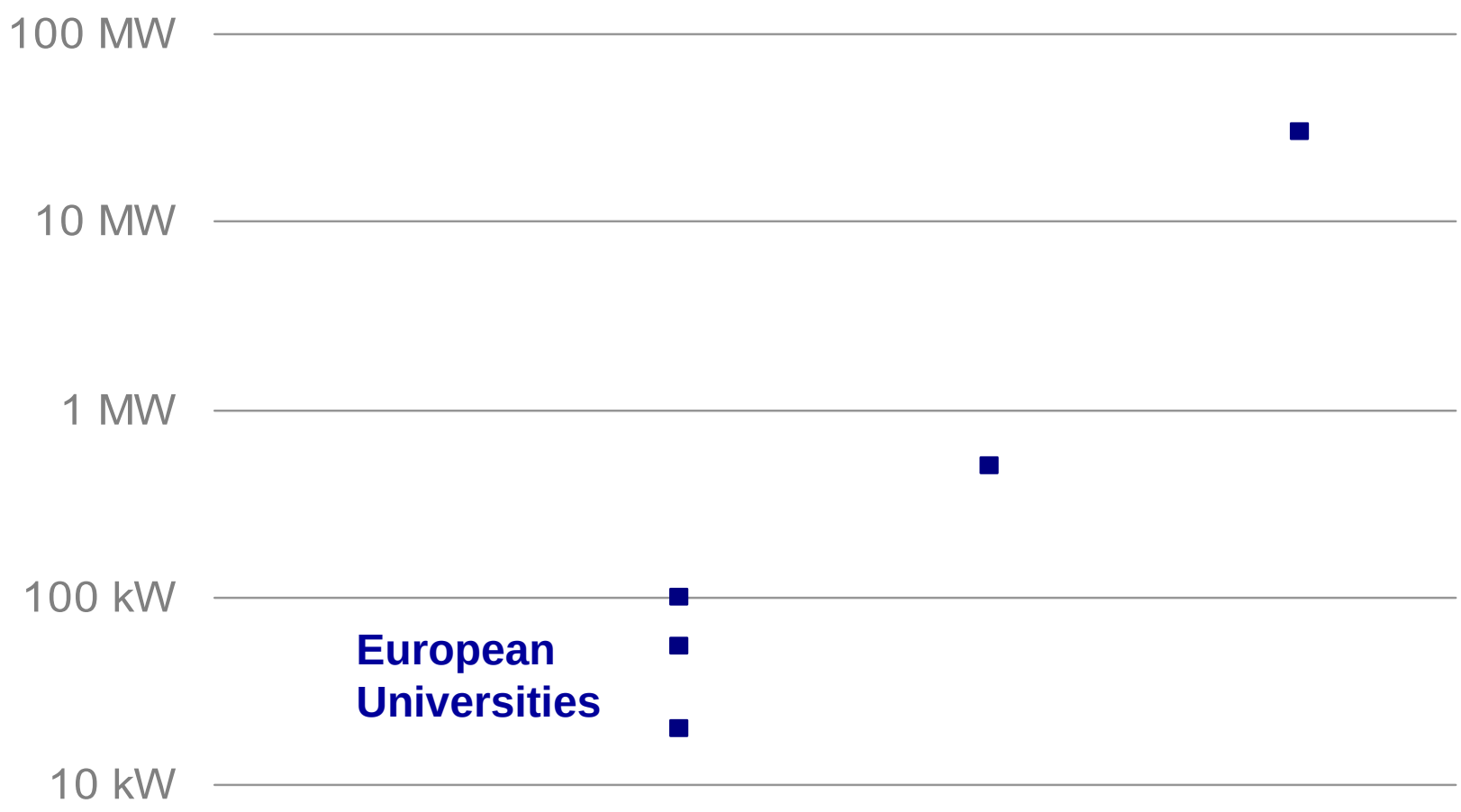
Conesville #5: Temperature Contours at elevations



ALSTOM Oxy-firing Testing

ALSTOM Oxyfuel Testing

PC Firing

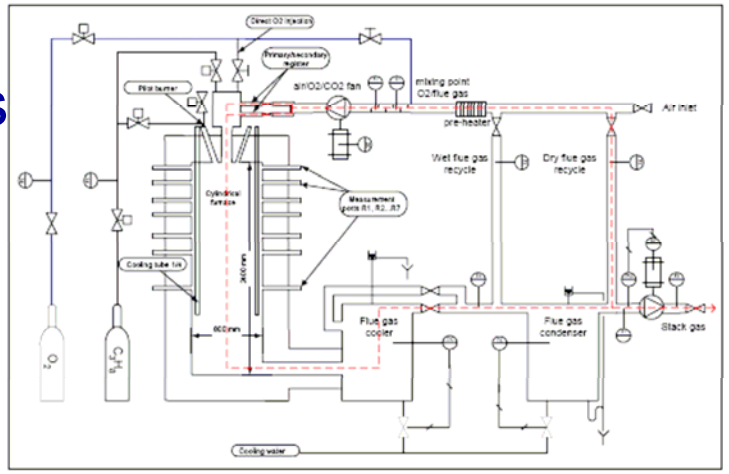


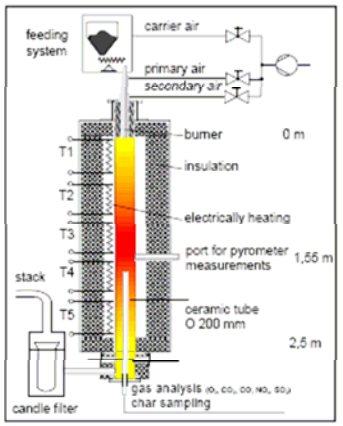
ALSTOM Oxyfuel Testing

Small Scale Test Results

Test facilities in WP 3.1

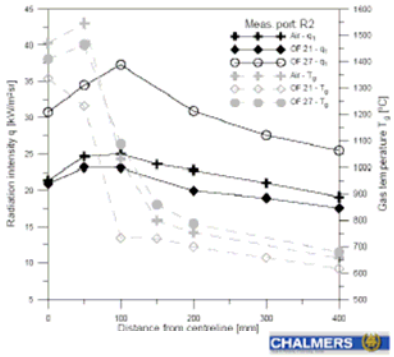
Gas Emissions
Concentration Profiles
Ignition and Burnout
Ash Characterization
Temperature Profiles
Radiation Intensity





100 kW oxyfuel test rig at Chalmers

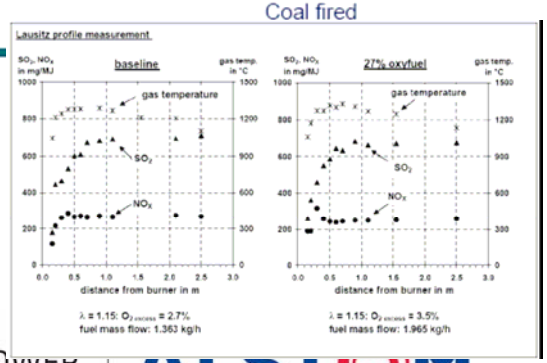
Gas and coal fired



encapco2

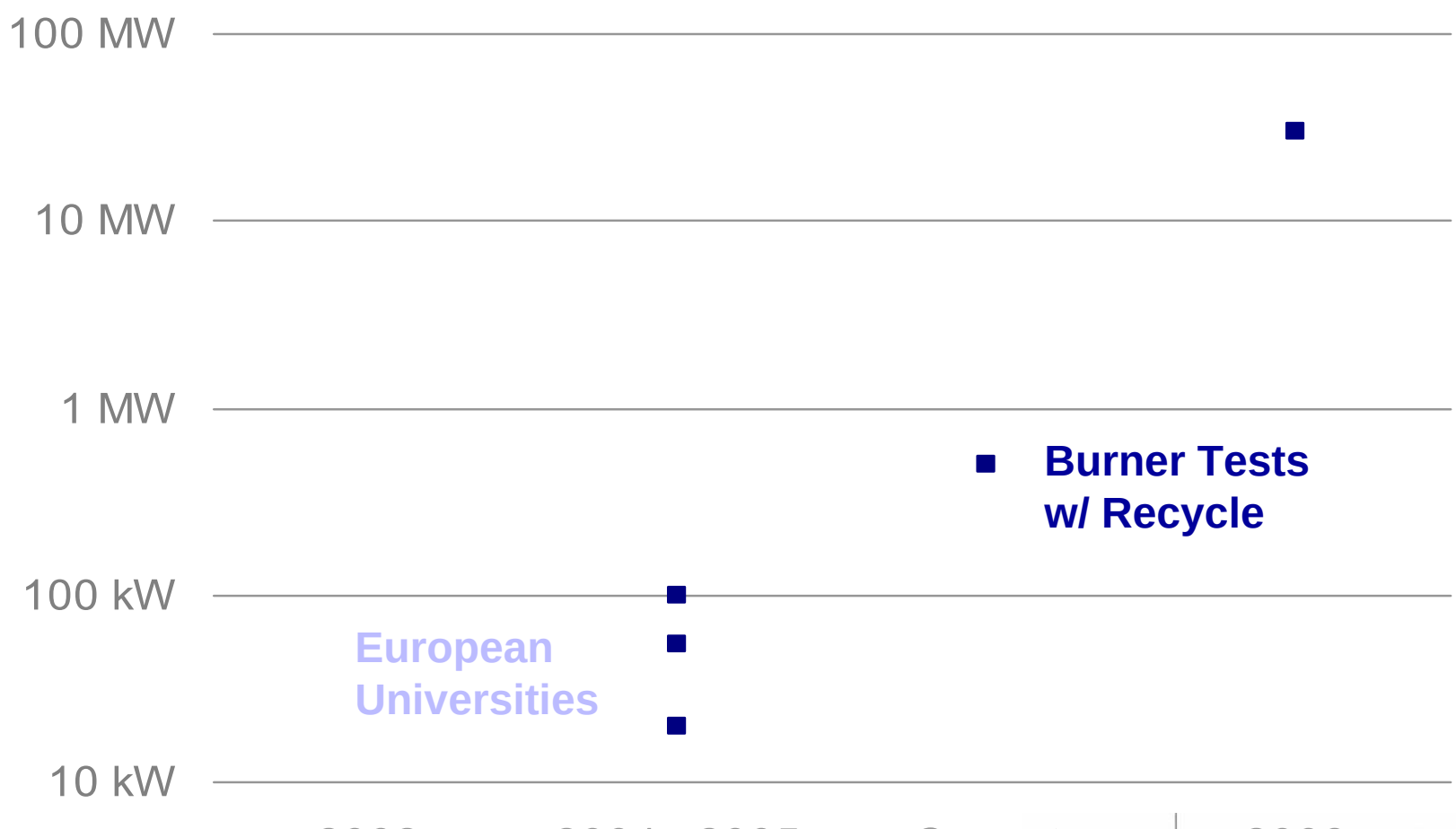
20 kW test rig at U. Stuttgart

Coal fired



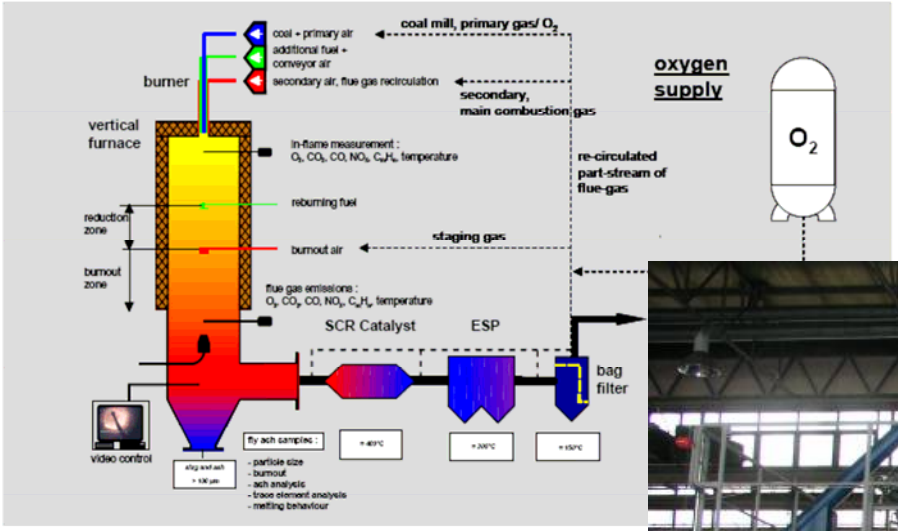
ALSTOM Oxyfuel Testing

PC Firing



ALSTOM Oxyfuel Testing

500 kW test facility at U. Stuttgart



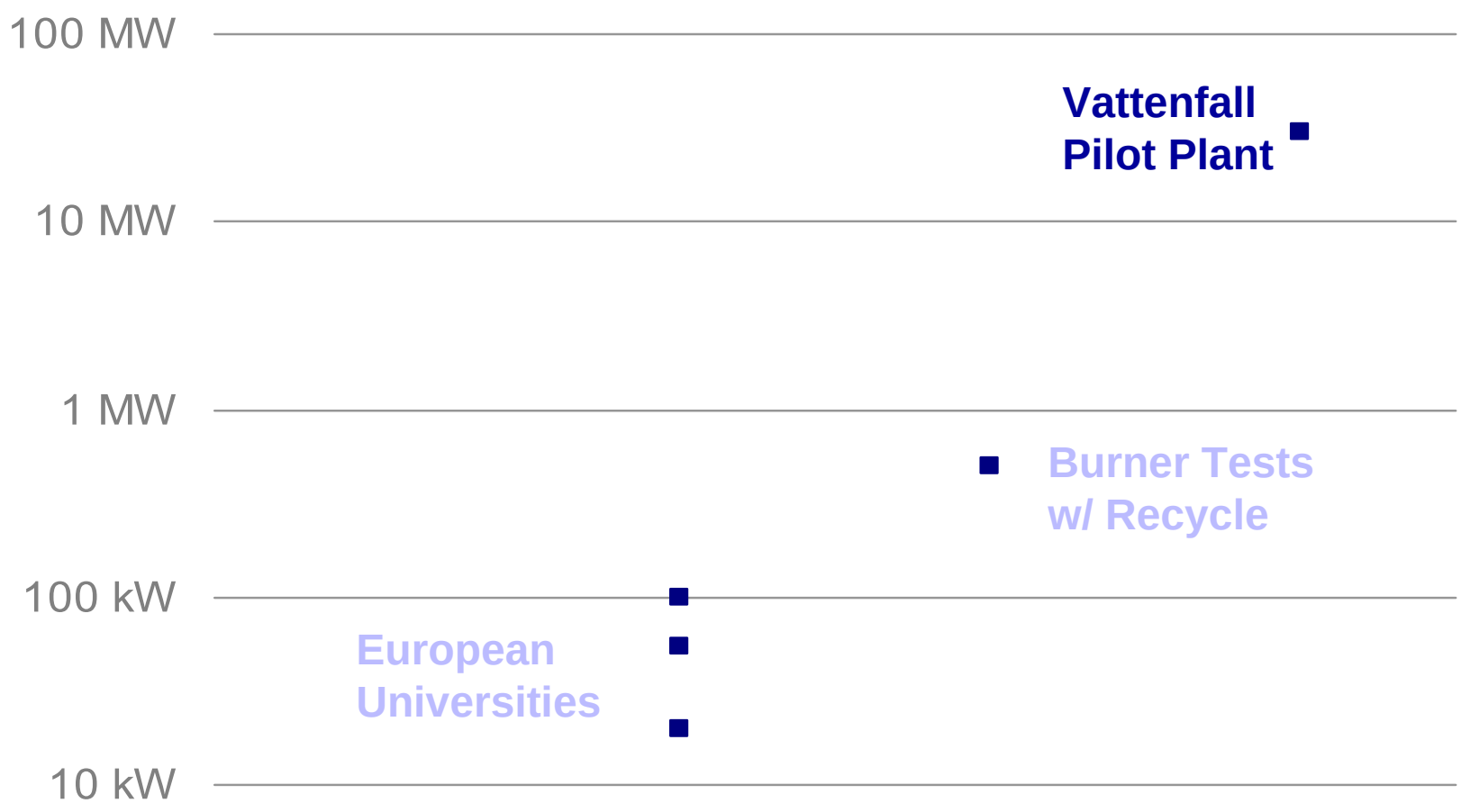
Burner Development with Flue Gas Recirculation

encapco2

500 kW_{th} at both Cottbus and Stuttgart Universities with ALSTOM participation

ALSTOM Oxyfuel Testing

PC Firing



Vattenfall 30 MW_{th} PC

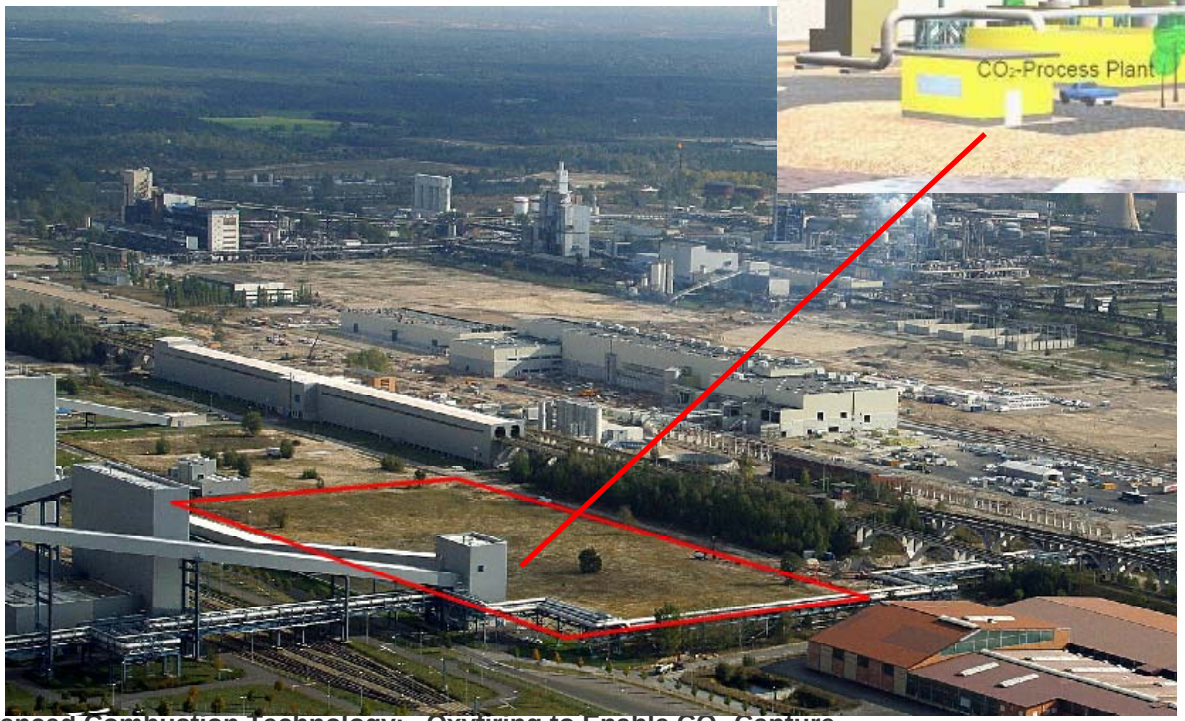
Schwarze Pumpe Power Station

Brandenburg, Germany

Alstom boiler and firing systems supplier

Vattenfall 30 MW_{th} PC

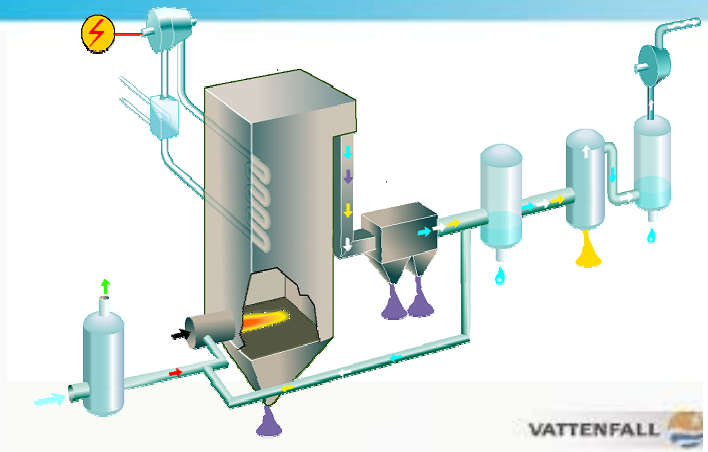
Complete Oxy-Fired Pilot Plant Startup in 2008



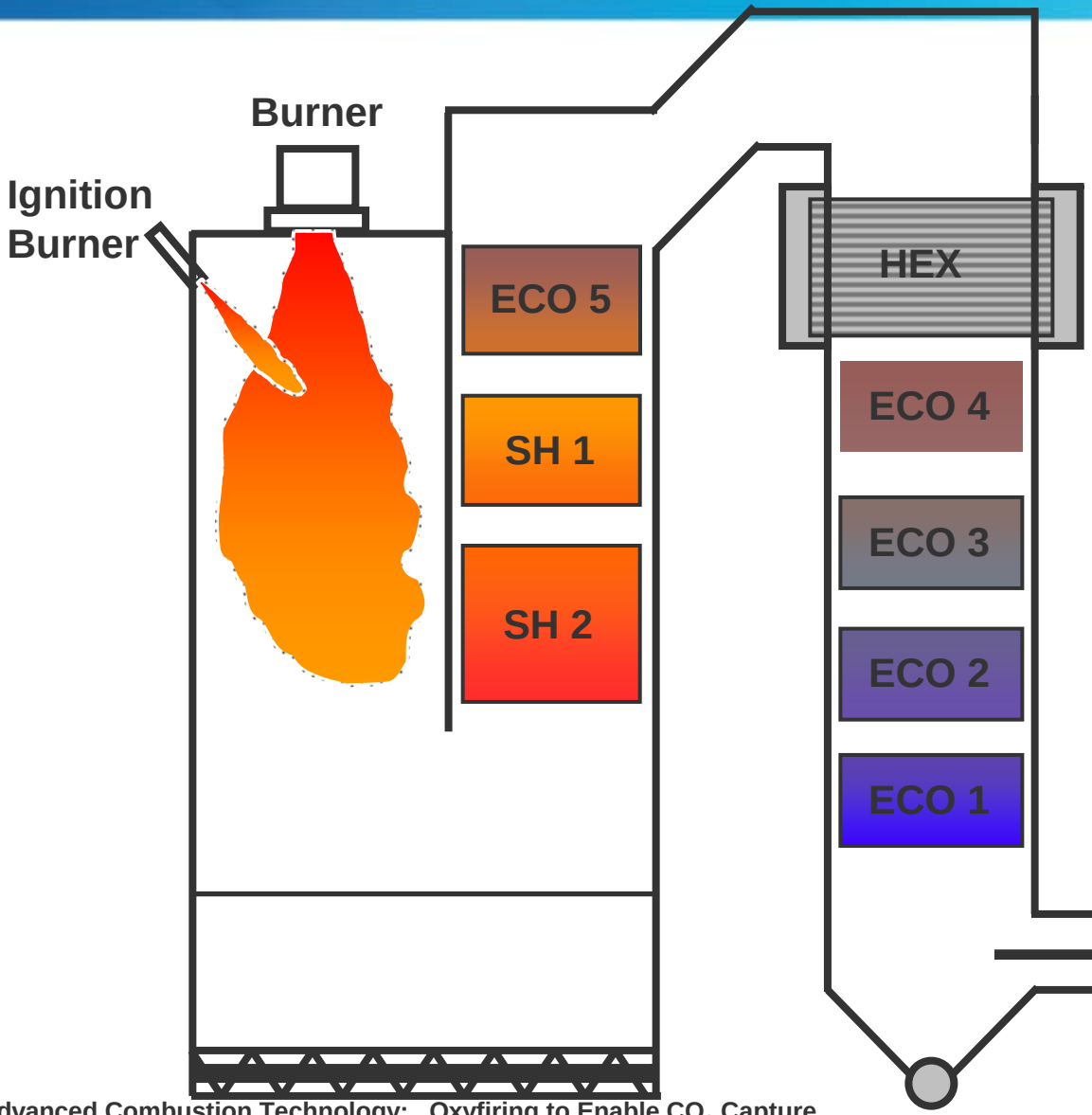
POWER | ALSTOM

Vattenfall 30 MW_{th} PC

Pre-Dried Lignite and Bituminous
Air Blown Reference Operation
21-39% Overall Oxygen Enrichment
Staged Combustion with Varying Enrichments
Load Changes and Dynamic Interactions
CO_2 Compression *vs.* Inert Levels



Vattenfall 30 MW_{th} PC



Flame Characteristics

Gaseous Emissions

Heat Transfer

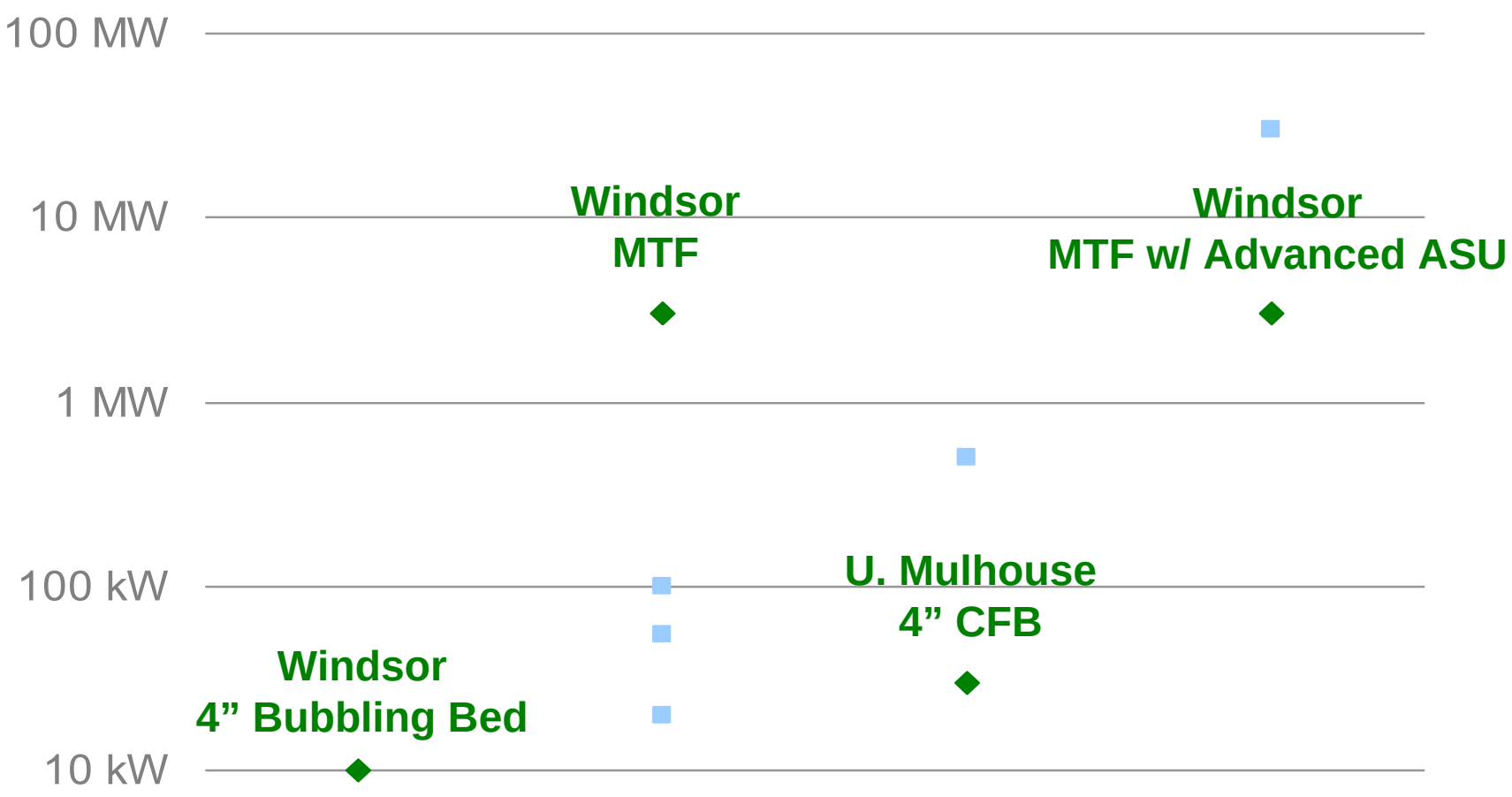
Slagging and Fouling

Materials Analysis

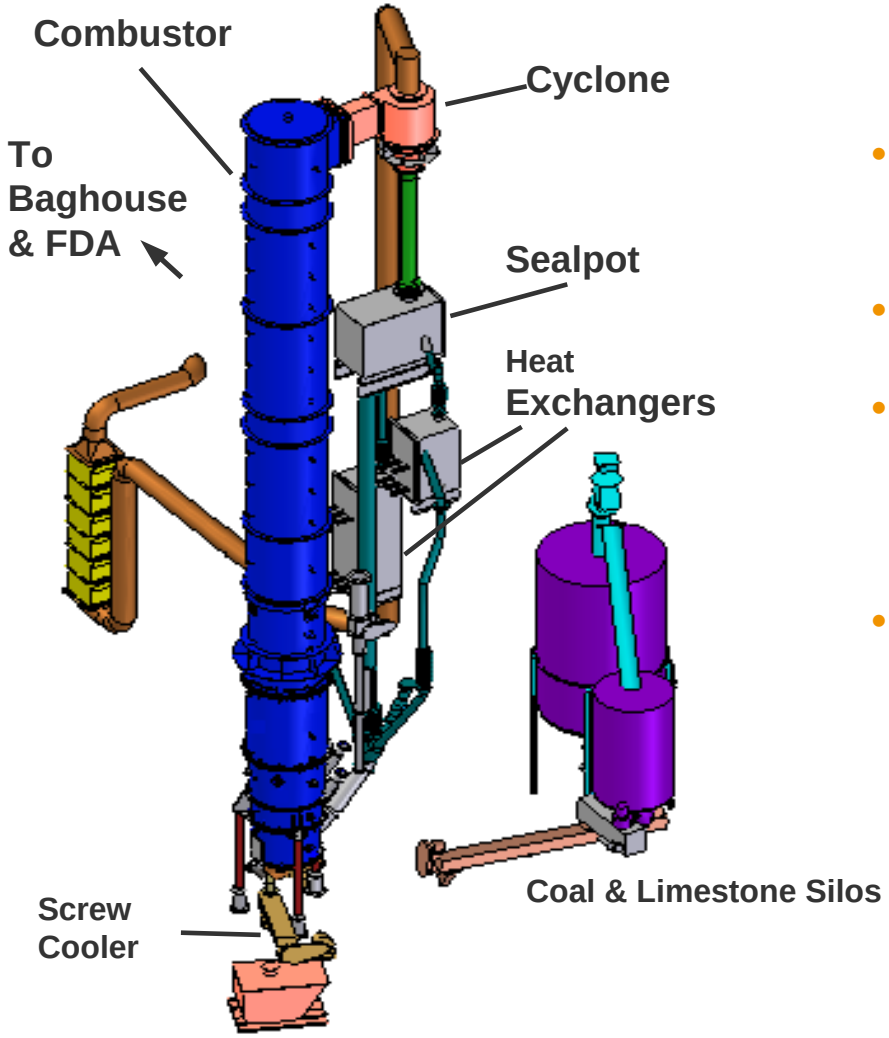
In-leakage

ALSTOM Oxyfuel Testing

Fluidized Bed

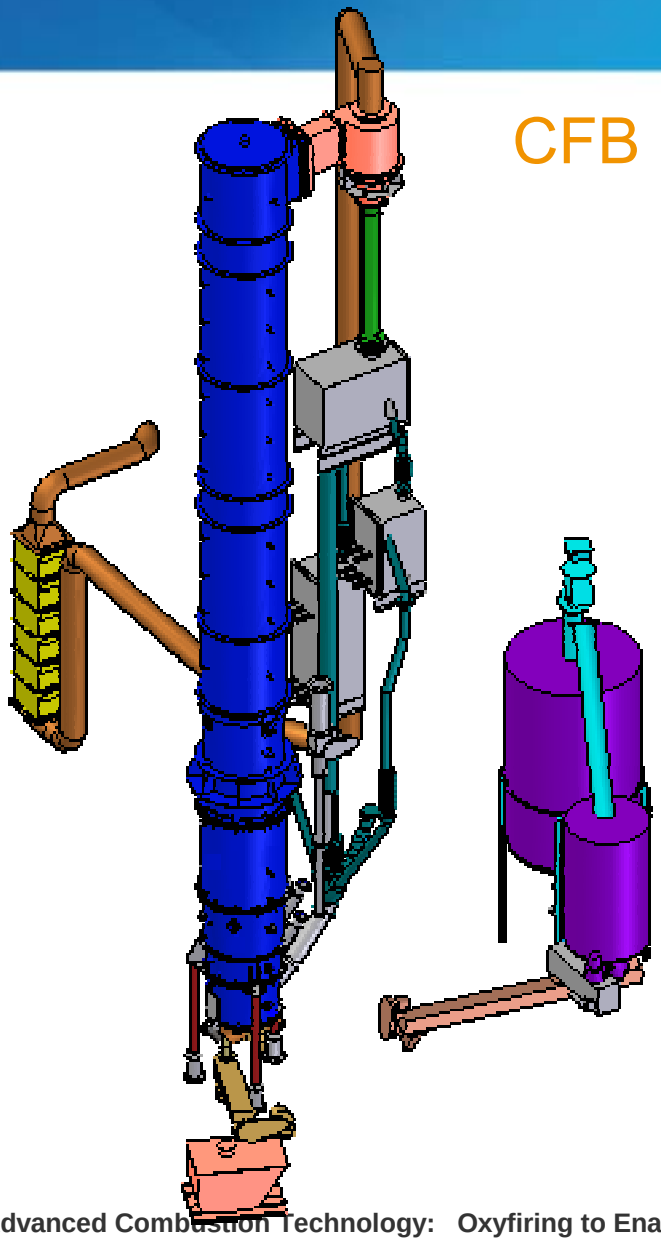


3 MWth Multiuse Test Facility



- MTF Located at Power Plant Labs
  Windsor, Connecticut
- 9.9 MM-Btu/hr (2.9 MW_{th})
- Furnace:
  60 feet (18 m) tall
  40 inch (1 m) I.D.
- 42 Test Campaigns since 1998

3 MWth Multiuse Test Facility



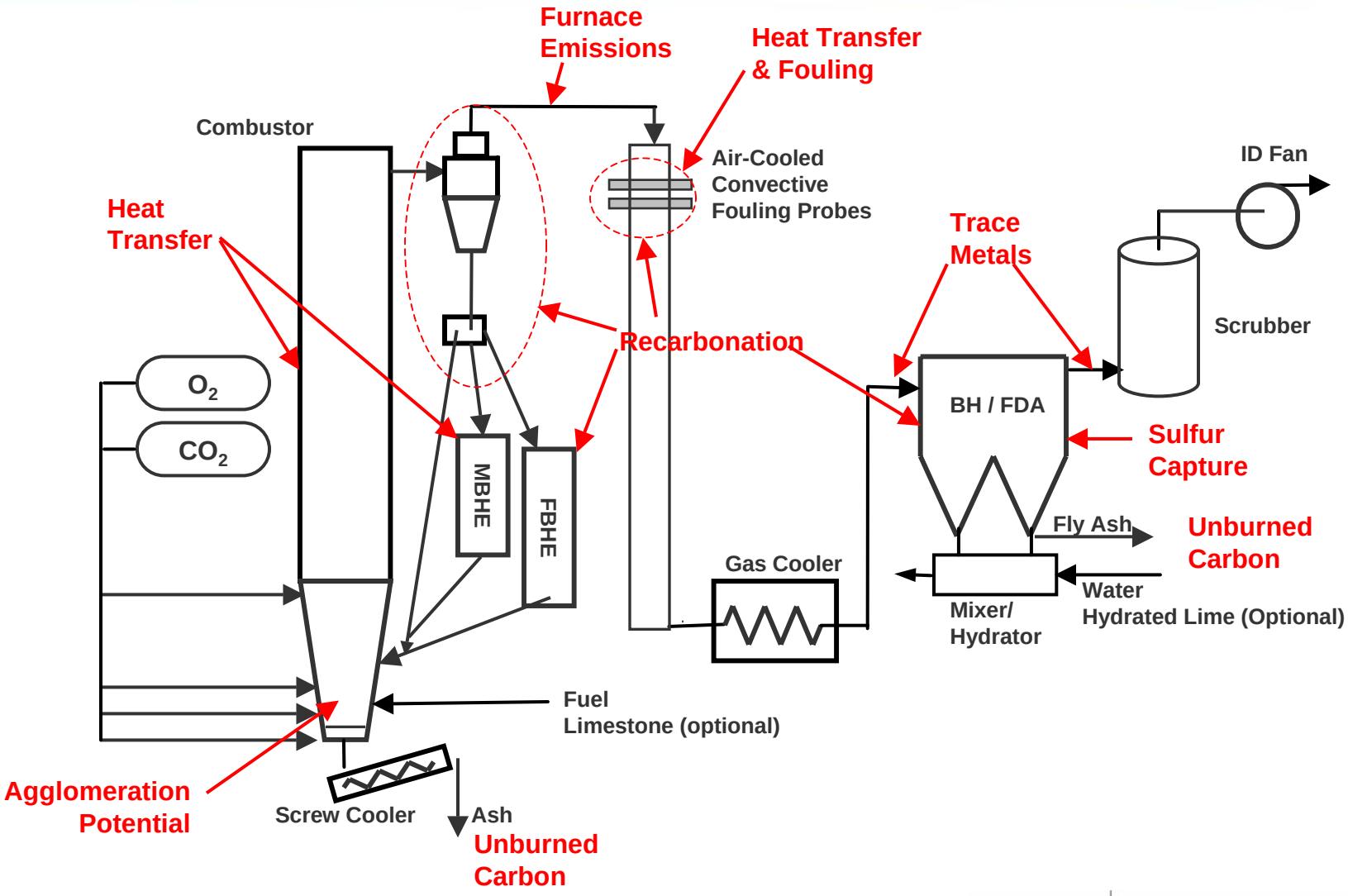
CFB Modified for Oxygen firing in 2004 & 2005

Summary of Concept Validation/Testing – DOE Greenhouse Gas Program

Year	April 2004	June 2004	June 2005
Fuel	Medium Volatile Bituminous Coal	Medium Volatile Bituminous Coal and Petcoke	Medium Volatile Bituminous Coal and Petcoke
Sorbent	Limestone	Aragonite	Lime Limestone Aragonite
Firing Rate	2.2 - 4.8 MM-Btu/hr (0.64 – 1.41 MW_{th})	4.2 - 7.9 MM-Btu/hr (1.23 – 2.32 MW_{th})	9.9 MM-Btu/hr (2.9 MW_{th})
Combustion Medium	Air and 20 - 30% O_2 CO_2 Balance	40 - 50% O_2 CO_2 Balance	Air and 30% O_2 70 % CO_2 Balance

Two fuels and three sorbents evaluated in air and O_2/CO_2 mixtures of up to 70% O_2 (by vol.)

Issues Addressed



Test Results: no show stoppers

- Heat transfer as expected
- No bed agglomeration
- Emissions (SOx, NOx, CO HC and trace monitored)
- NOx lower
- CO somewhat higher

.... Next Steps

- Future
  - **Oxyfiring**
    - **ALSTOM plans to demo PC/CFB technologies**
    - **Vattenfall a 200 MWe PC by 2015**
    - **ALSTOM scaling CFB technology for demo**
  - **Post combustion technologies**
    - **Ammonia scrubbing**

- Conclusion
  - **Oxy-firing is a relatively near term and cost competitive approach built on current technology**

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