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# Technology Options for Controlling CO2 Emissions from Fossil Fueled Power Plants

**presented at**

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Alexandria, VA

**Presenter:**

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ALSTOM Power Boilers

ALSTOM Power Plant Laboratories



# Who is ALSTOM ?

- We design, build, and service technologically advanced products and systems for the world's energy and transport infrastructure.
  - 14 B€ in Sales, 69,000 employees, in 70 countries



Marine  
7%



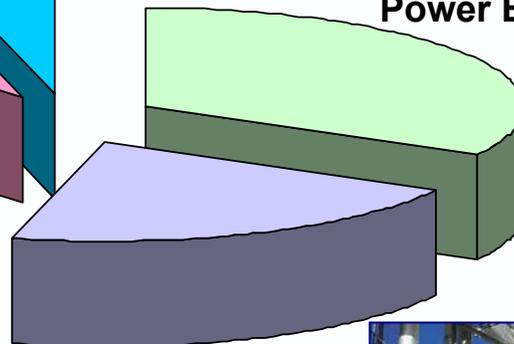
Power  
Conversion  
4%



Power Turbo-Systems /  
Power Environment  
33%



Transport  
35%



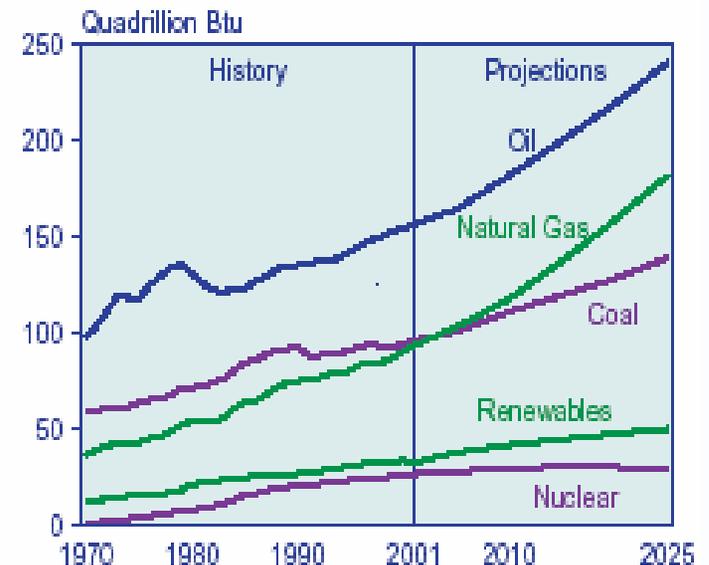
Power Service  
21%



**A global leader in infrastructure  
for Power Generation and Rail Transport**

# CO<sub>2</sub> Mitigation Options - for Power

- ▶ Conservation
- ▶ Increase efficiency
  - [ of fossil fuel energy conversion ]
- ▶ Fuel Switch
  - ▶ nuclear
  - ▶ renewables
  - ▶ natural gas
- ▶ CO<sub>2</sub> Sequestration
  - ▶ Capture
  - ▶ Sequestration



EIA 2003

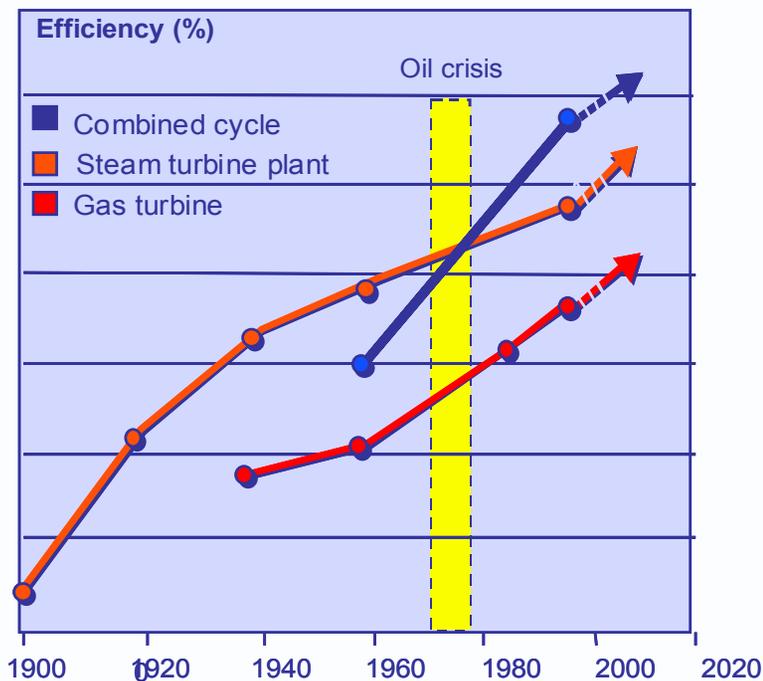
**Fossil Fuel use is projected to increase**

# CO<sub>2</sub> Mitigation Options - for Power

▶ Conservation

▶ Increase efficiency

[ of fossil fuel energy conversion ]



- Reduces emissions
- Reduces CO<sub>2</sub>
- Saves limited fuels resources

**Efficiency improvement is a “no regrets” strategy we can implement today!**

# CO<sub>2</sub> Mitigation Options - for Power

- ▶ **Conservation**
- ▶ **Increase efficiency**  
[ of fossil fuel energy conversion ]
- ▶ **Fuel Switch**
  - ▶ nuclear
  - ▶ renewables
  - ▶ natural gas



- ▶ **CO<sub>2</sub> Sequestration**
  - ▶ Capture
  - ▶ Sequestration

Needed in the long run  
if we continue to use  
fossil fuels and commit  
to CO<sub>2</sub> emissions  
stabilization

# CO<sub>2</sub> Capture Approaches - for Power

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- ▶ **Post Capture**
  - ▶ Adsorption
  - ▶ Absorption
  - ▶ Hydrate based
  - ▶ Cryogenics / Refrigeration based
- ▶ **Oxy-fuel Firing**
  - ▶ external oxygen supply
  - ▶ integrated membrane-based
  - ▶ oxygen carriers
- ▶ **Decarbonization**
  - ▶ reforming (fuel decarbonization)
  - ▶ carbonate reactions (combustion decarbonization)



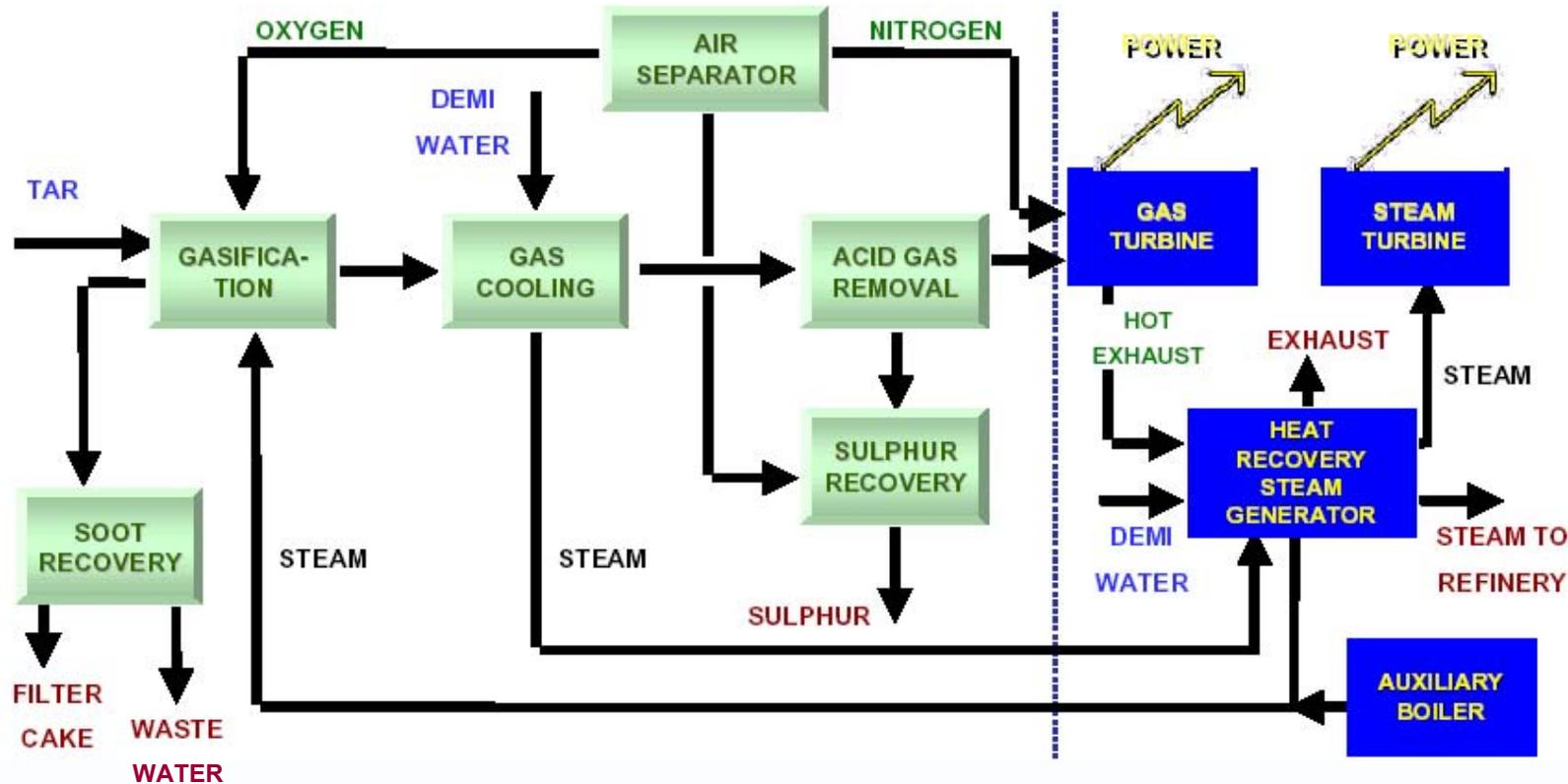
**Innovative options continue to emerge and develop**

# IGCC - Hydrogen from Coal?

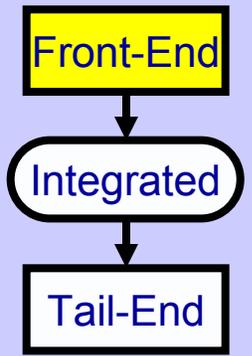


## Syngas Manufacturing Process Plant

## Combined Cycle Power Plant

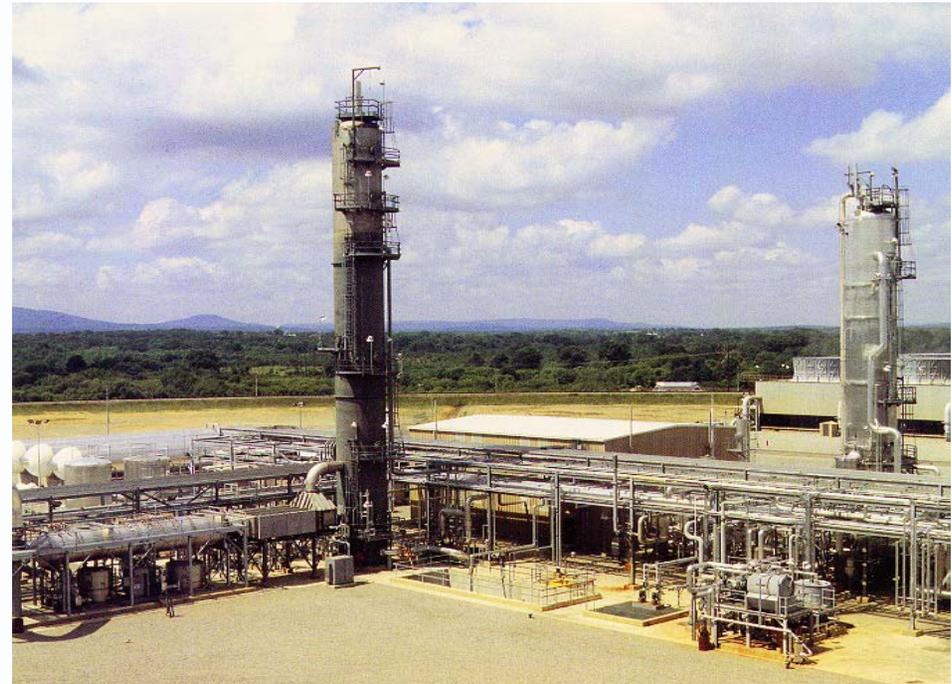
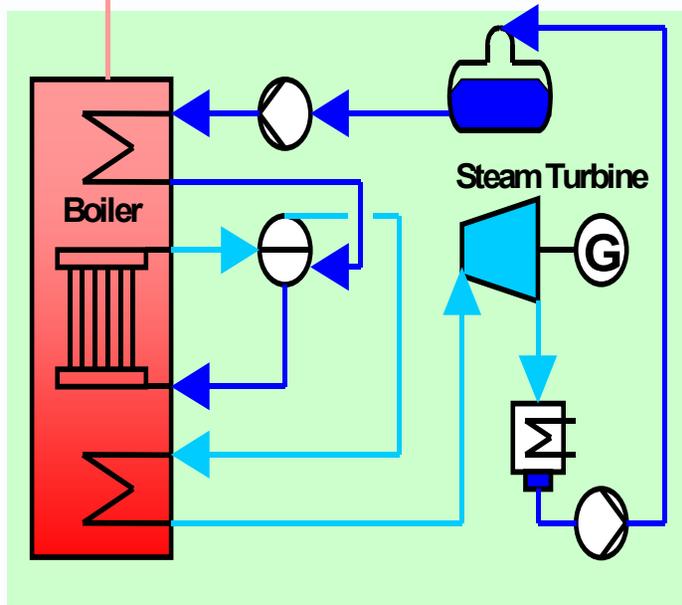
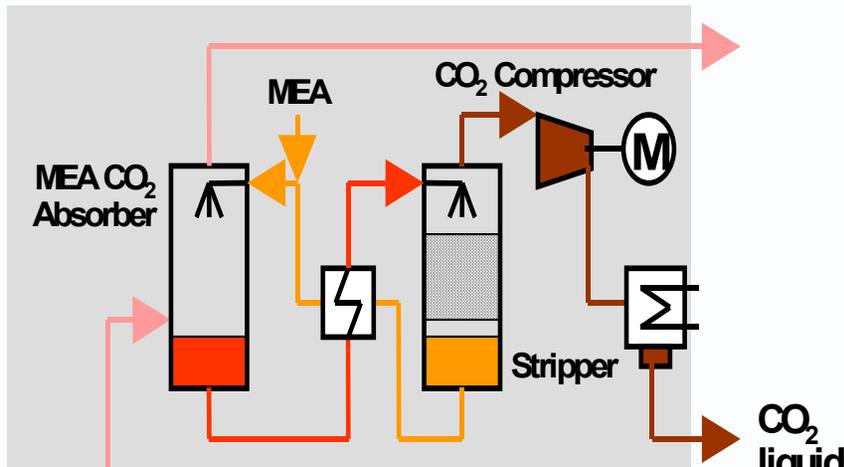


**THE ONLY OPTION?**



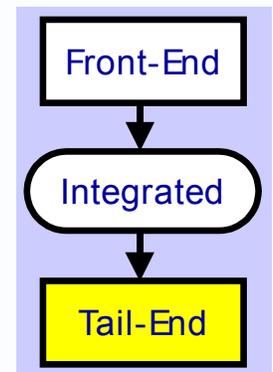
**Open issues: cost, reliability, fuel flexibility**

# Amine-Based Absorption - Stripping CO2 Capture



SHADY POINT,  
OKLAHOMA, USA

an ALSTOM built CFB power plant with  
ABB Lummus MEA CO2 separation



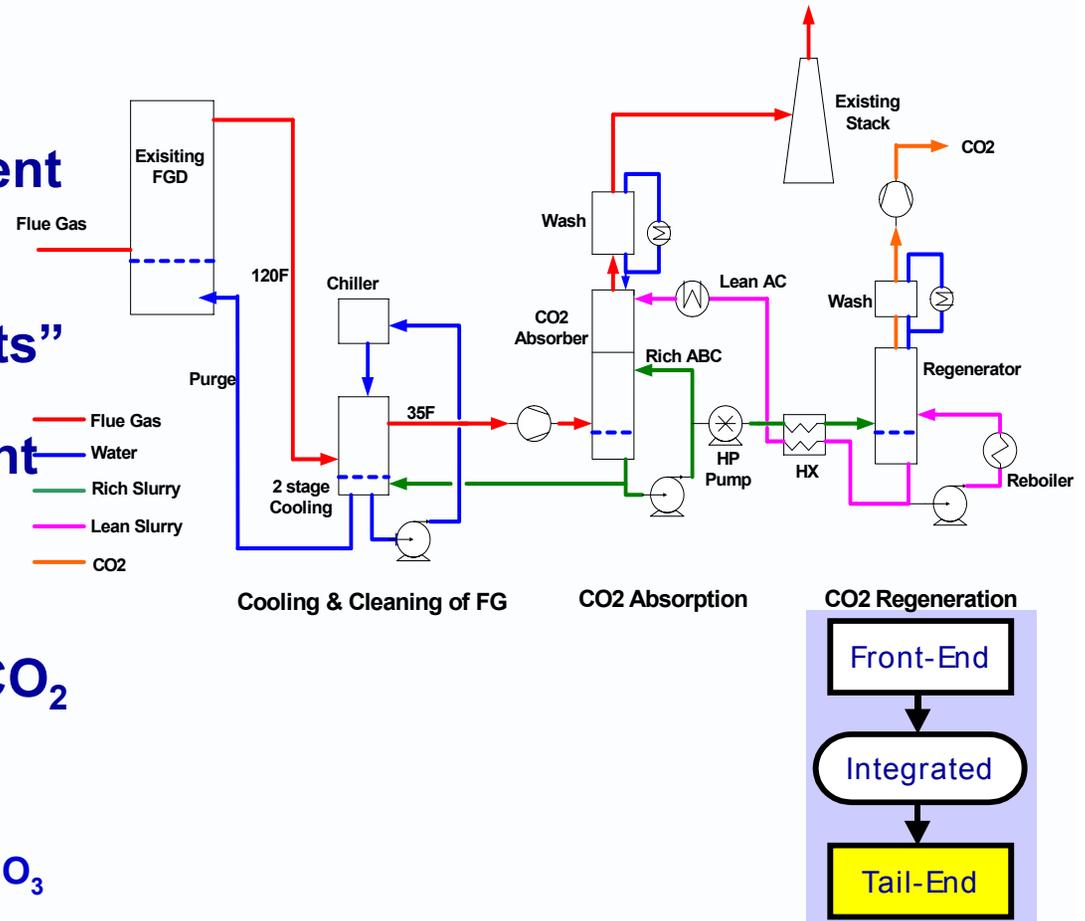
The "MEA" concept

# Absorption - Stripping CO2 Capture

## Current Developments:

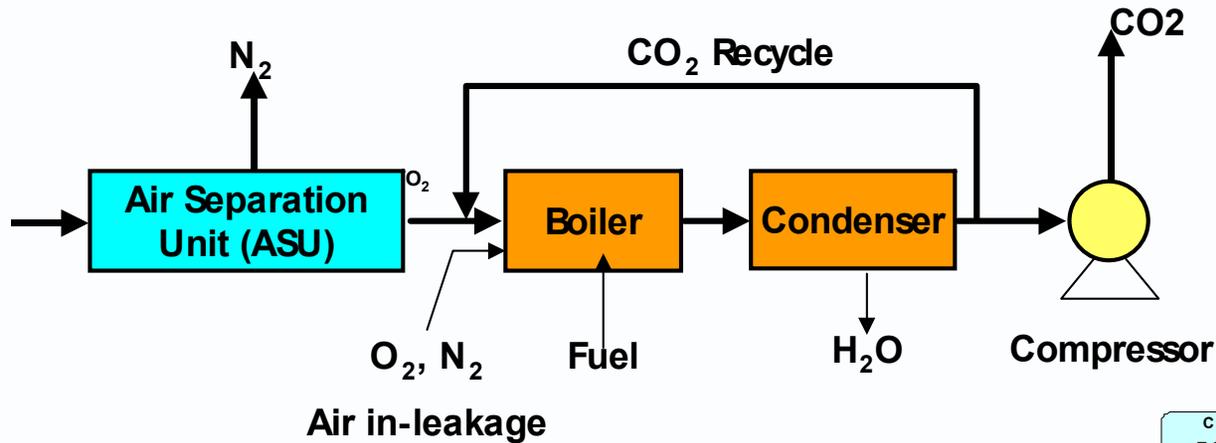
- Process integration/improvement driven cost to 40 \$/ton CO<sub>2</sub>
- Ionic Liquids “designer solvents”
- “Piprozene” - alternative solvent
- Membrane enhanced
- Aqueous ammonia < 20 \$/ton CO<sub>2</sub>
  - $2\text{NH}_3 + \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons (\text{NH}_4)_2\text{CO}_3$
  - $\text{NH}_3 + \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{NH}_4\text{HCO}_3$
  - $(\text{NH}_4)_2\text{CO}_3 + \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons 2\text{NH}_4\text{HCO}_3$

Schematic of Ammonia-based CO2 Capture System

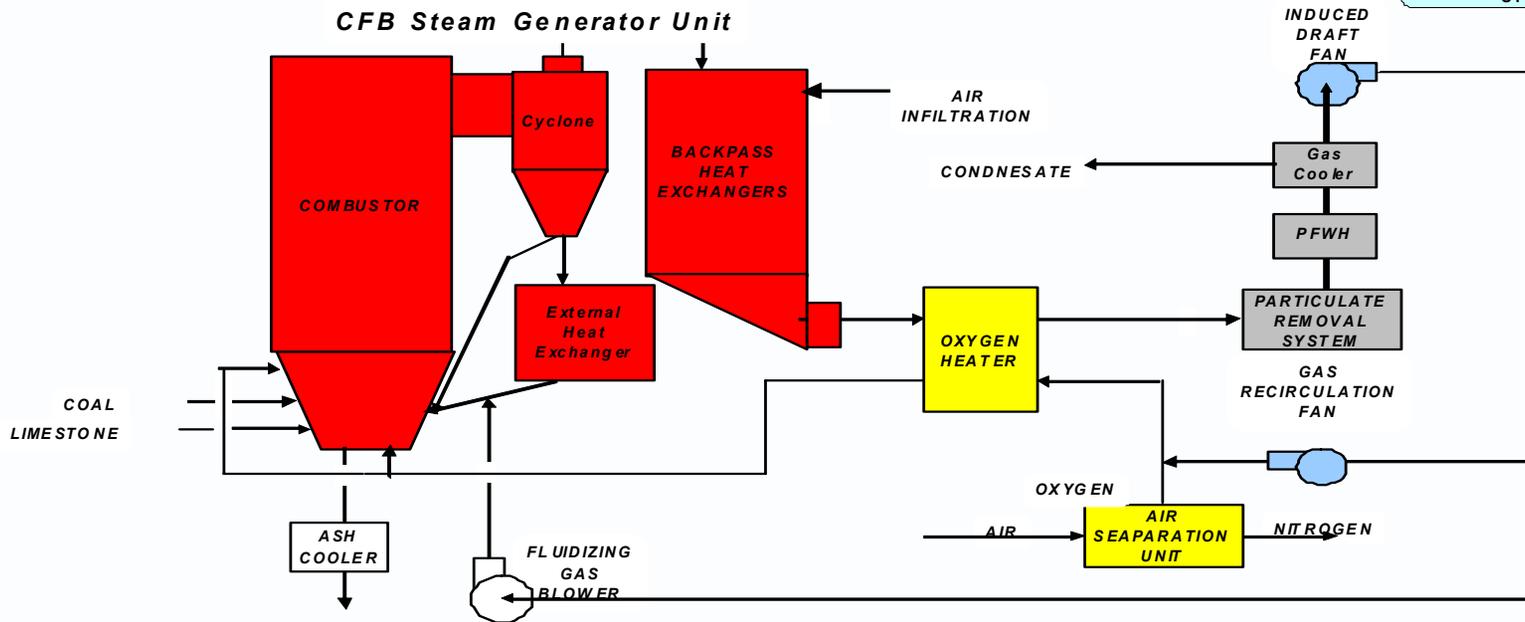


**CO2 scrubbing continues to develop and is a retrofit solution**

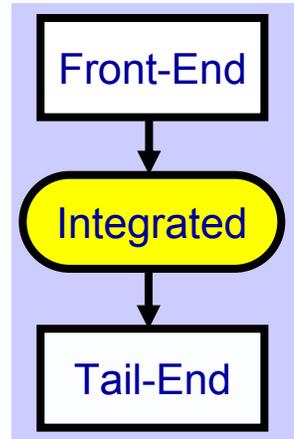
# Oxygen Firing to produce concentrated CO<sub>2</sub> stream



3 MWt pilot CFB



CO<sub>2</sub>-RICH PRODUCT TO GAS PROCESSING SYSTEM



## The "Oxy-fuel" concept

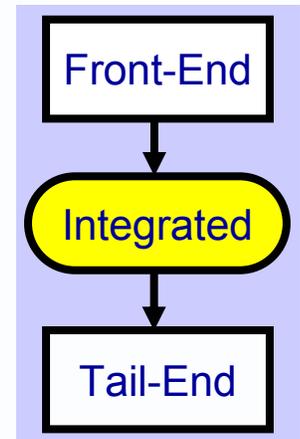
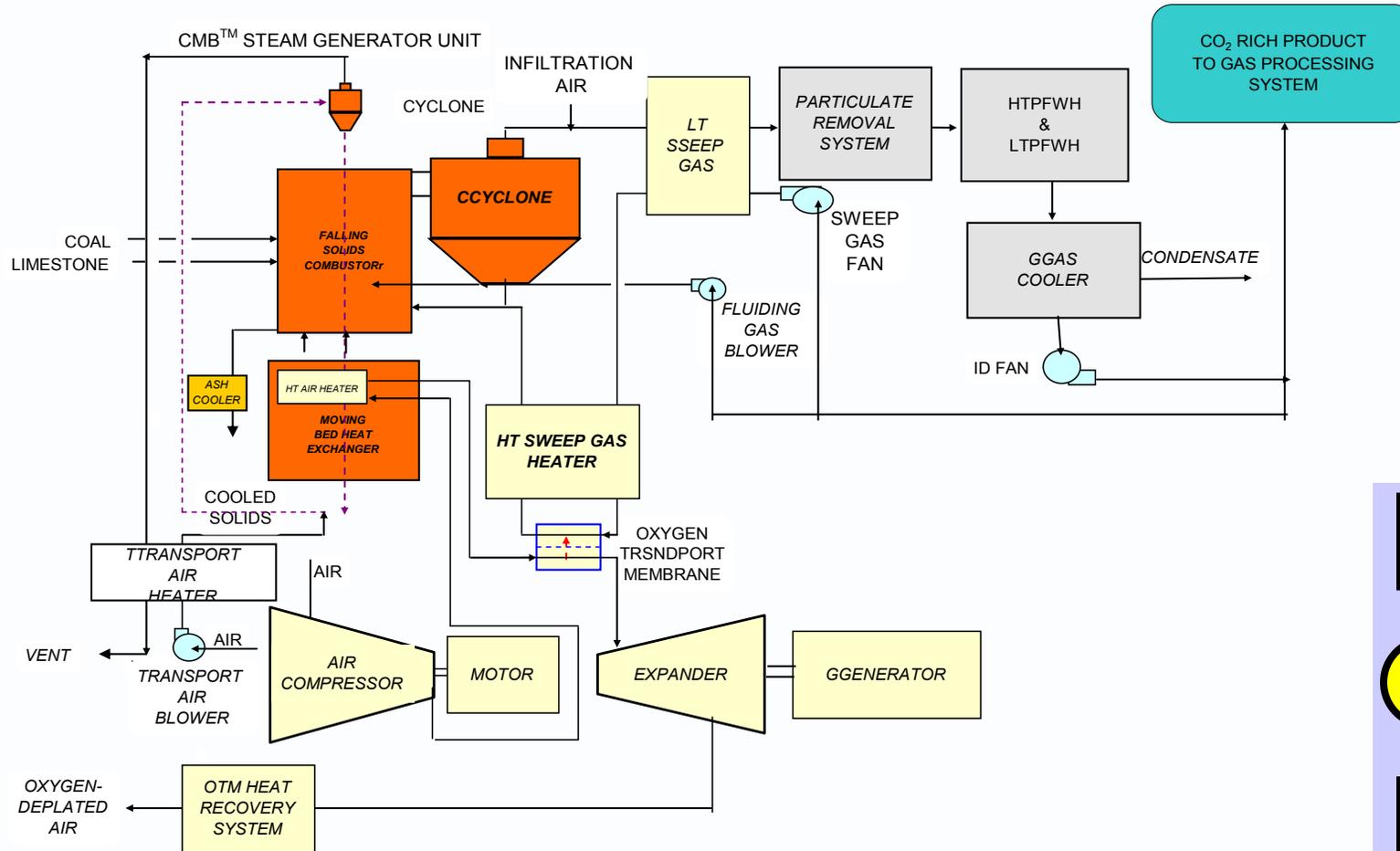
# 30 MW<sub>th</sub> Oxy-fuel PF Pilot Plant - Vattenfall

Location of pilot plant in the Industrial Park Schwarze Pumpe



Development Steps	Scale-up Factor	Objective	Com	Partners
Laboratory Tests 10 / 55 kW <sub>th</sub>		Fundamentals of oxyfuel combustion	2004 2005	Universities (Stuttgart, Chalmers, Dresden) Vattenfall, ALSTOM..
Test Plant 500 kW <sub>th</sub>	1:50	Fundamentals of oxyfuel combustion with flue gas recirculation	2005	CEBra, BTU Cottbus, Vattenfall, ALSTOM
Pilot Plant 30 MW <sub>th</sub>	1:60	Test of the oxyfuel process chain	2008	Vattenfall..., ALSTOM, others
Demo Plant 600 MW <sub>th</sub>	1:20	Realisation with CO <sub>2</sub> sequestration,	2015	
Commercial Plant approx. 1000 MW <sub>el</sub>	approx. 4-5		2020	

# Advanced CFB with O2 Membrane

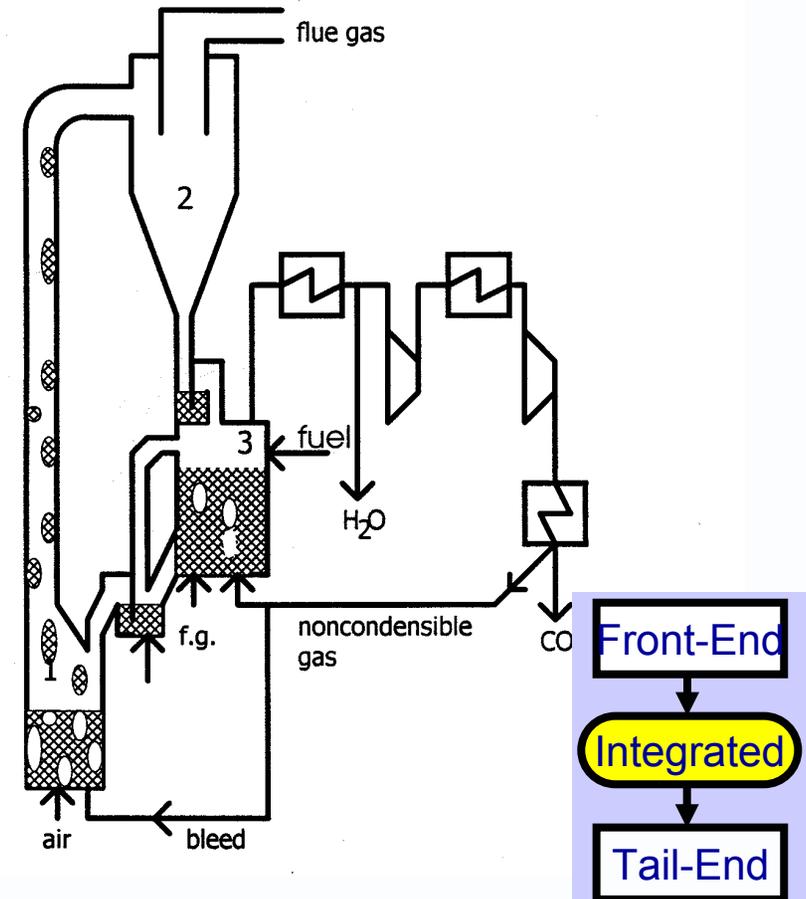
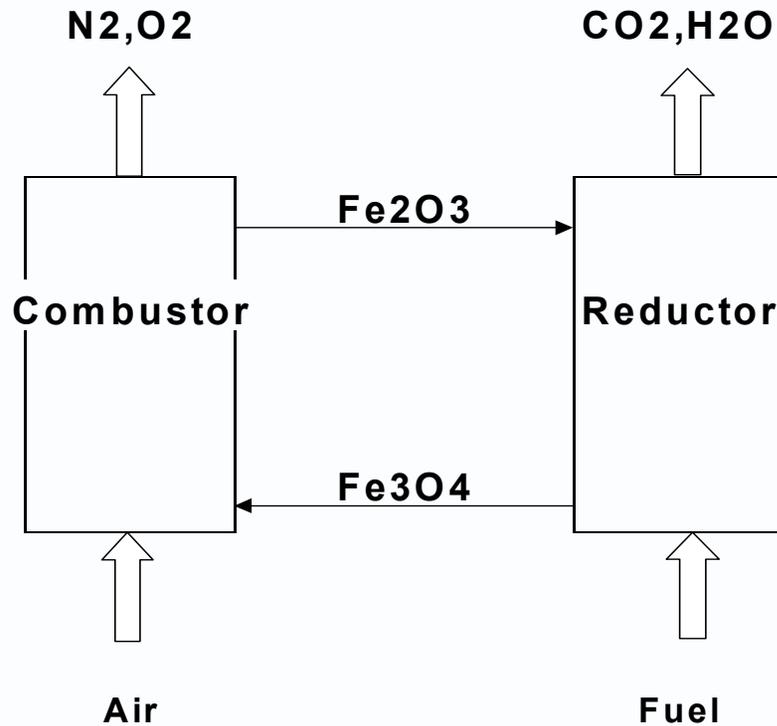


## The "OTM" boiler concept

Oxygen production breakthroughs improve oxy-firing performance and economics

# Chemical Looping Combustion

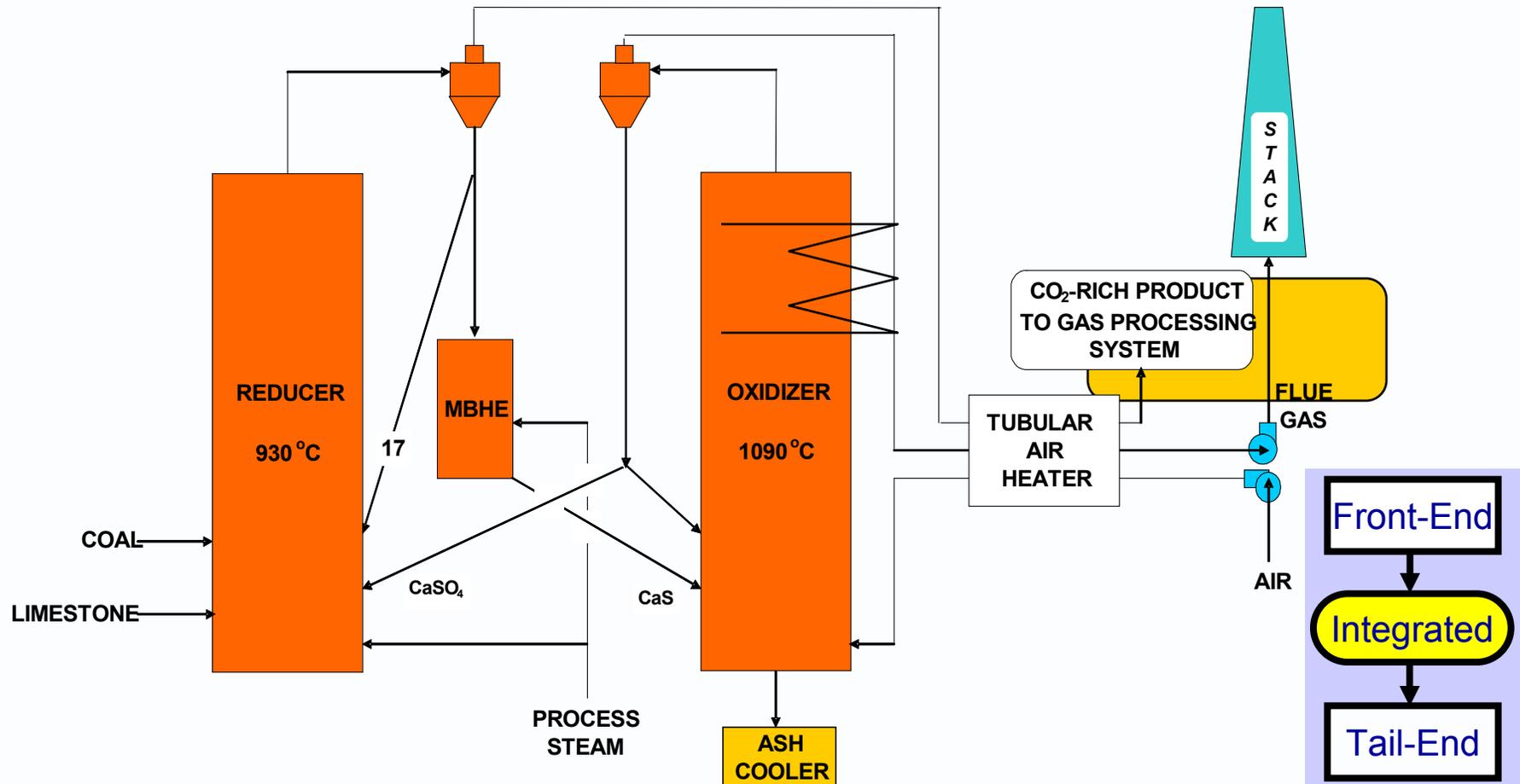
## Metal Oxides in Connected CFB's



**Chemical Looping is a potential breakthrough technology**

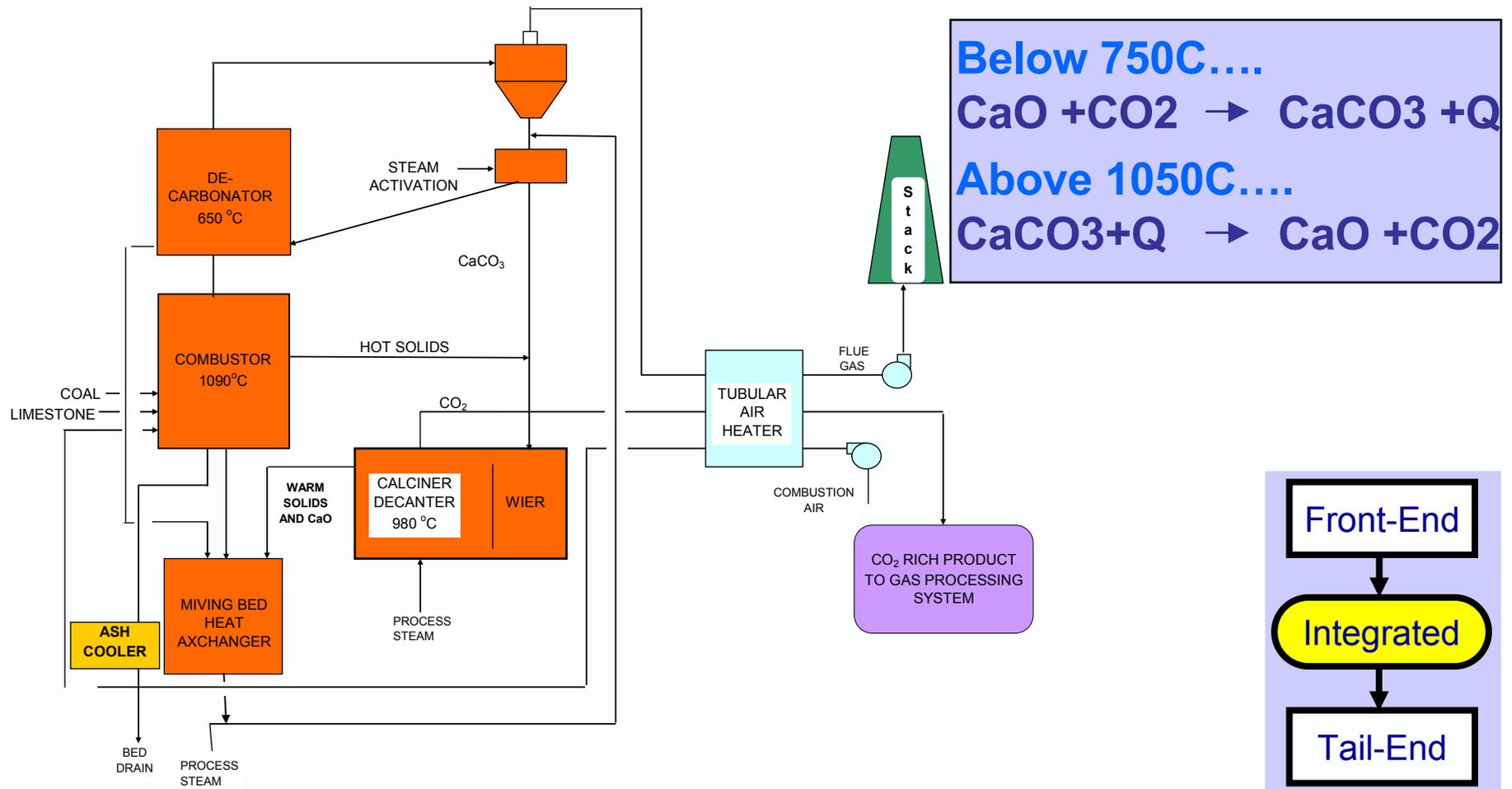
# Chemical Looping Combustion

## CaS - CaSO<sub>4</sub> loop in CFB reactors



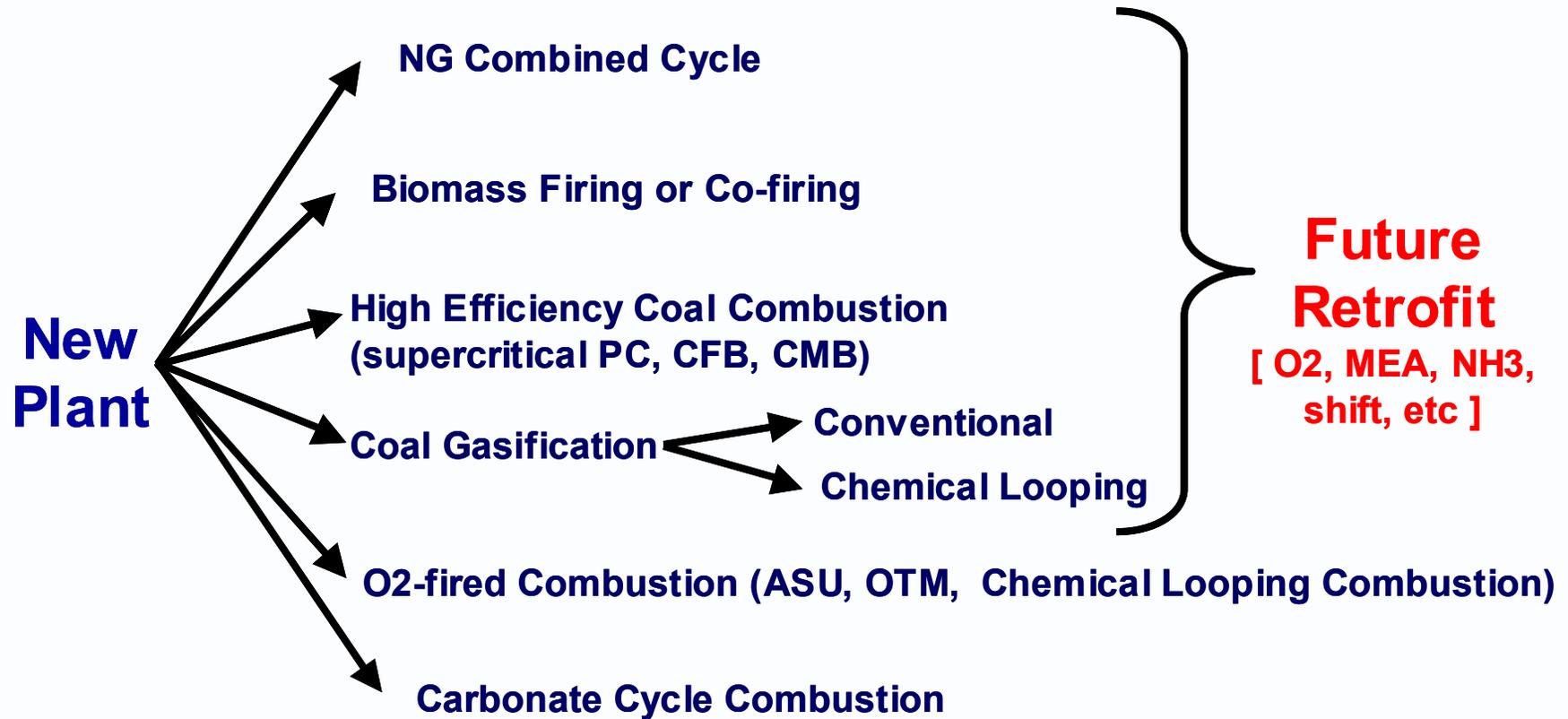
**Calcium-based CLC process is suited to coal**

# Carbonate Absorption - Stripping



**Zero thermodynamic impact due to high temperature process**

# New Power Plant Options



**Many Options for New and Retrofit CO<sub>2</sub> Mitigation**

# Economics of Electricity Production with Carbon Values

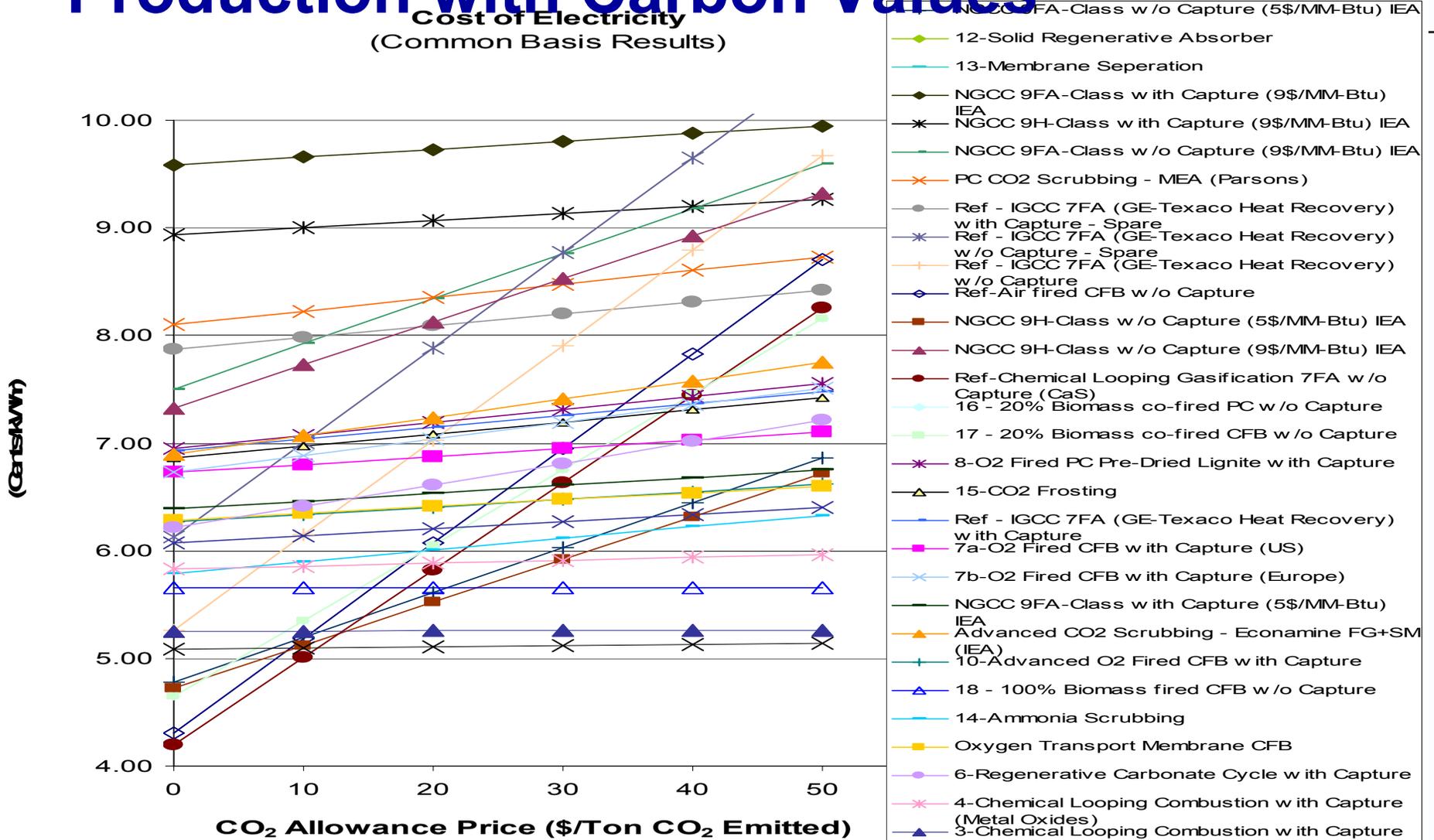


## Economic Assumptions

- **Coal Cost** 1.50 (\$/MM-Btu)
- **Natural Gas Cost** Range: 5.0 - 9.0 (\$/MM-Btu)
  
- **Capacity Factor** 80% - 7,008 (hrs/yr)
  
- **Performance (thermal efficiency)** Taken from referenced studies
- **Investment Costs (\$/kW)** Taken from referenced studies
- **Annual Capital Charge Rate** 13.5% of investment cost
- **Operating & Maintenance Costs** Taken from referenced studies
  
- **CO<sub>2</sub> allowance price** Range: 0-50 (\$/Ton of CO<sub>2</sub>)

**COE vs CO<sub>2</sub> Value**

# Economics of Electricity Production with Carbon Values

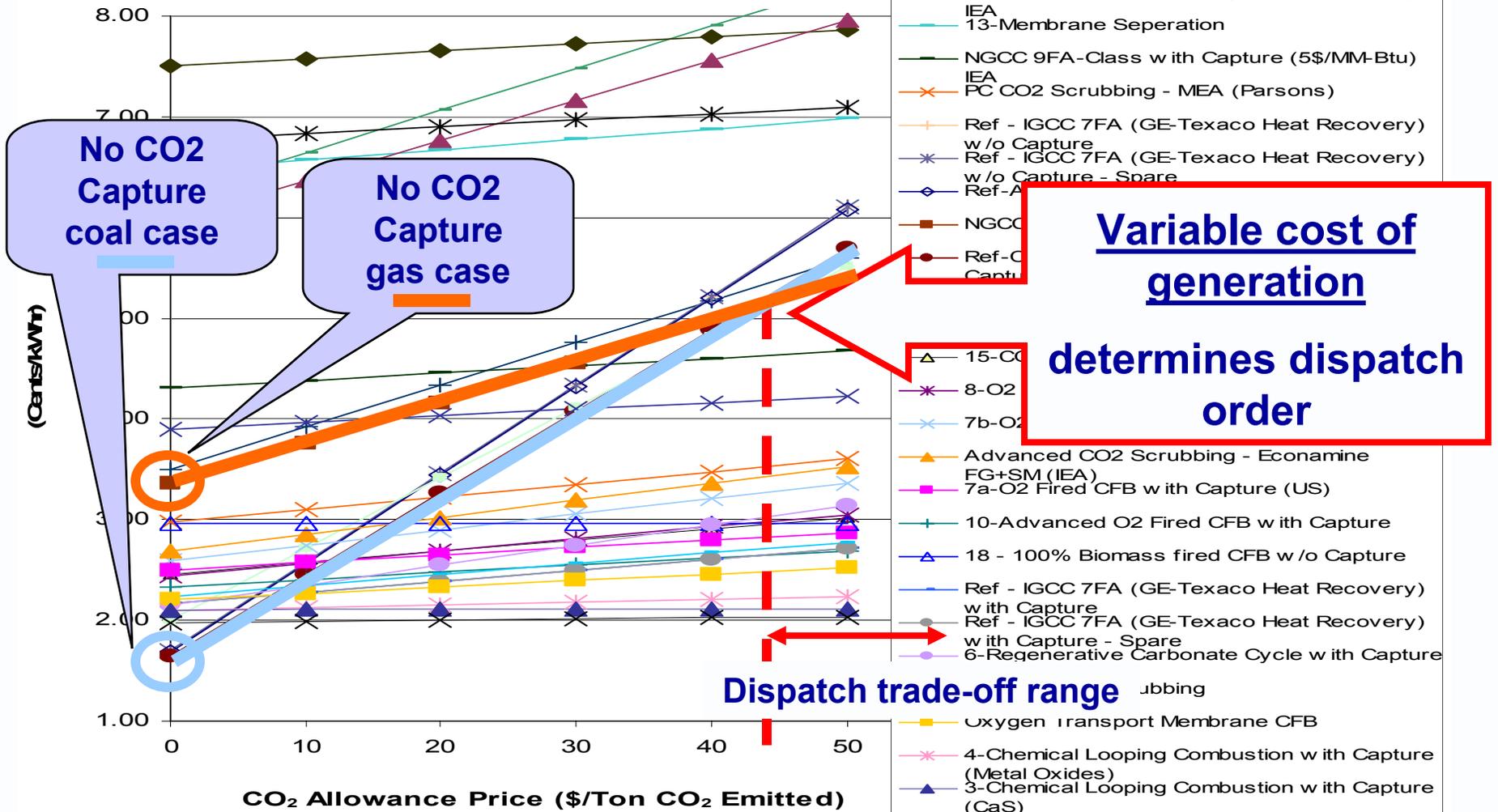


**Many cases – look at Dispatch then COE vs CO2 values**

# Economics of Electricity Production with Carbon Values

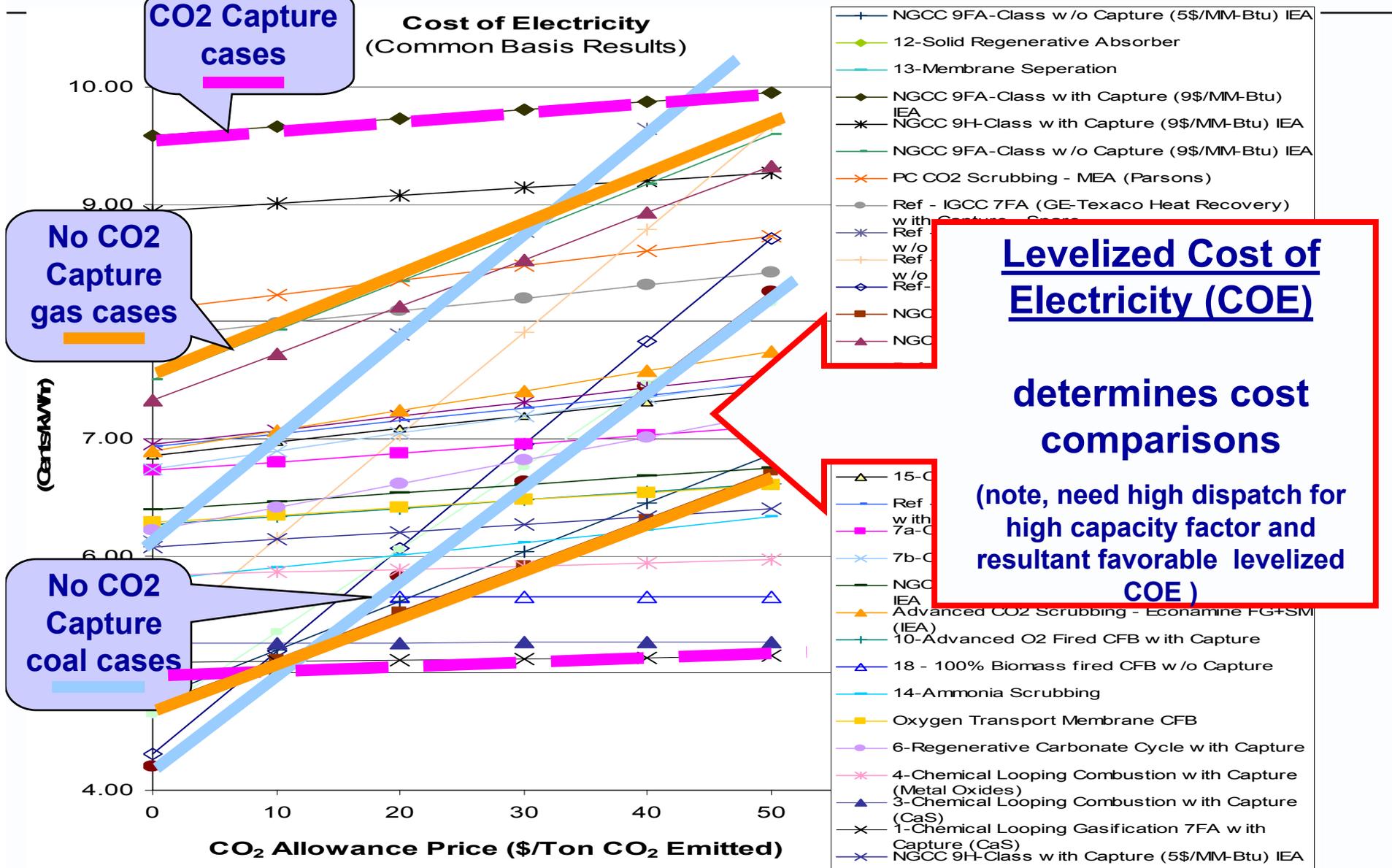


**Variable Cost of Generation - Dispatch Cost**  
(Common Basis Results)

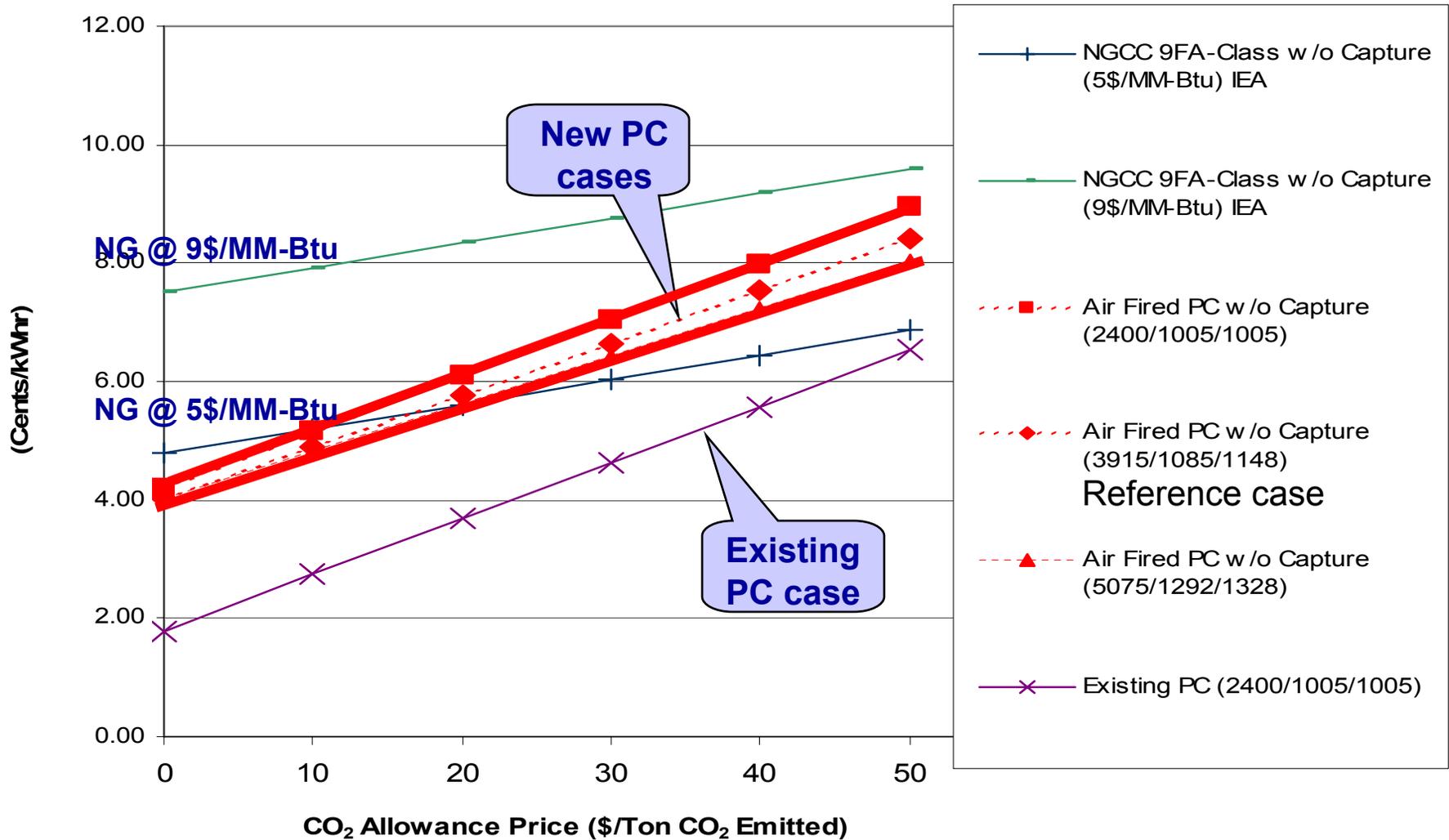


**Example: PC dispatches before NGCC**  
**This also affects Capacity Factor which affects COE**

# Economics of Electricity Production with Carbon Values

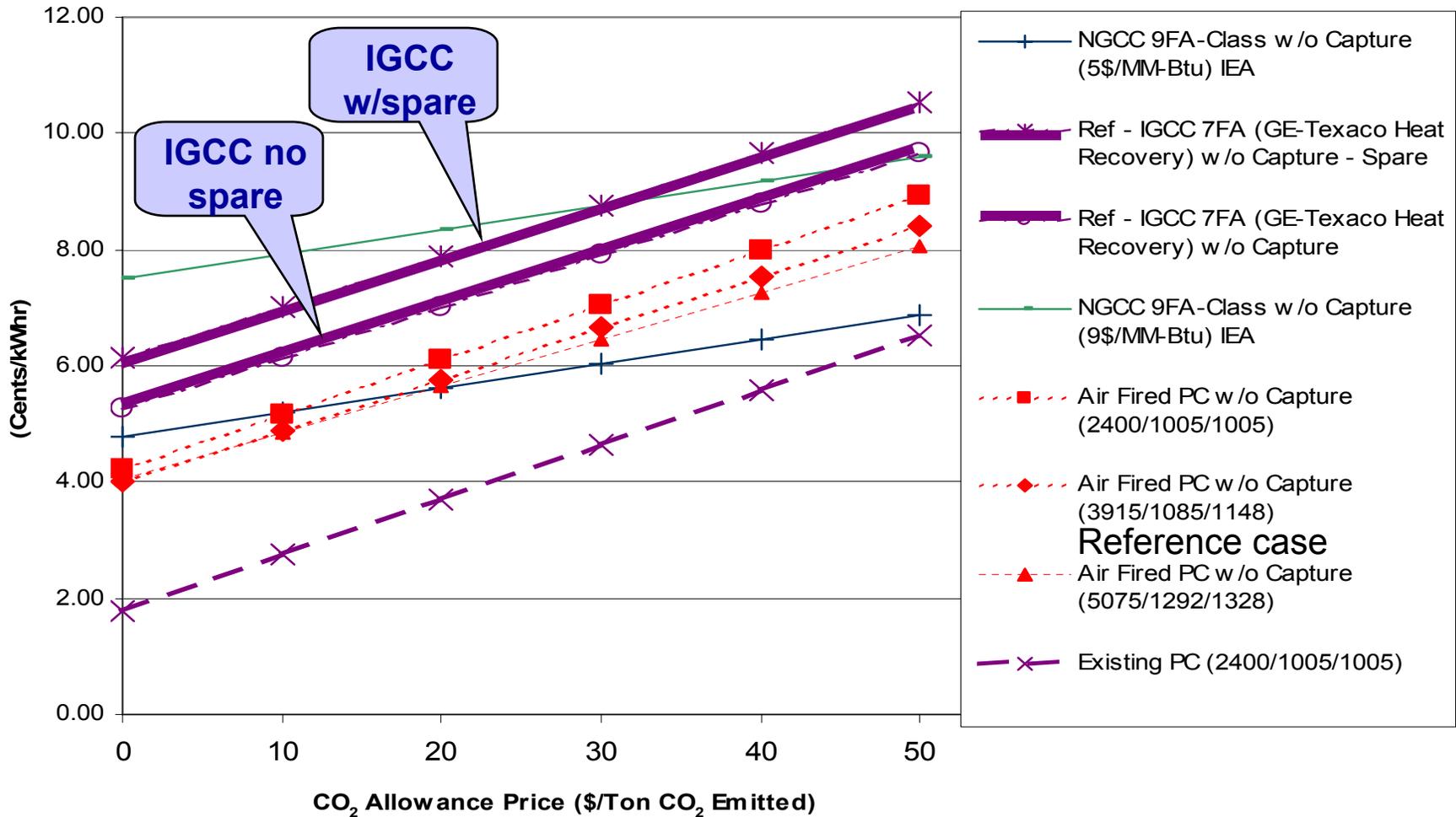


# No Capture Cases in Power Plants



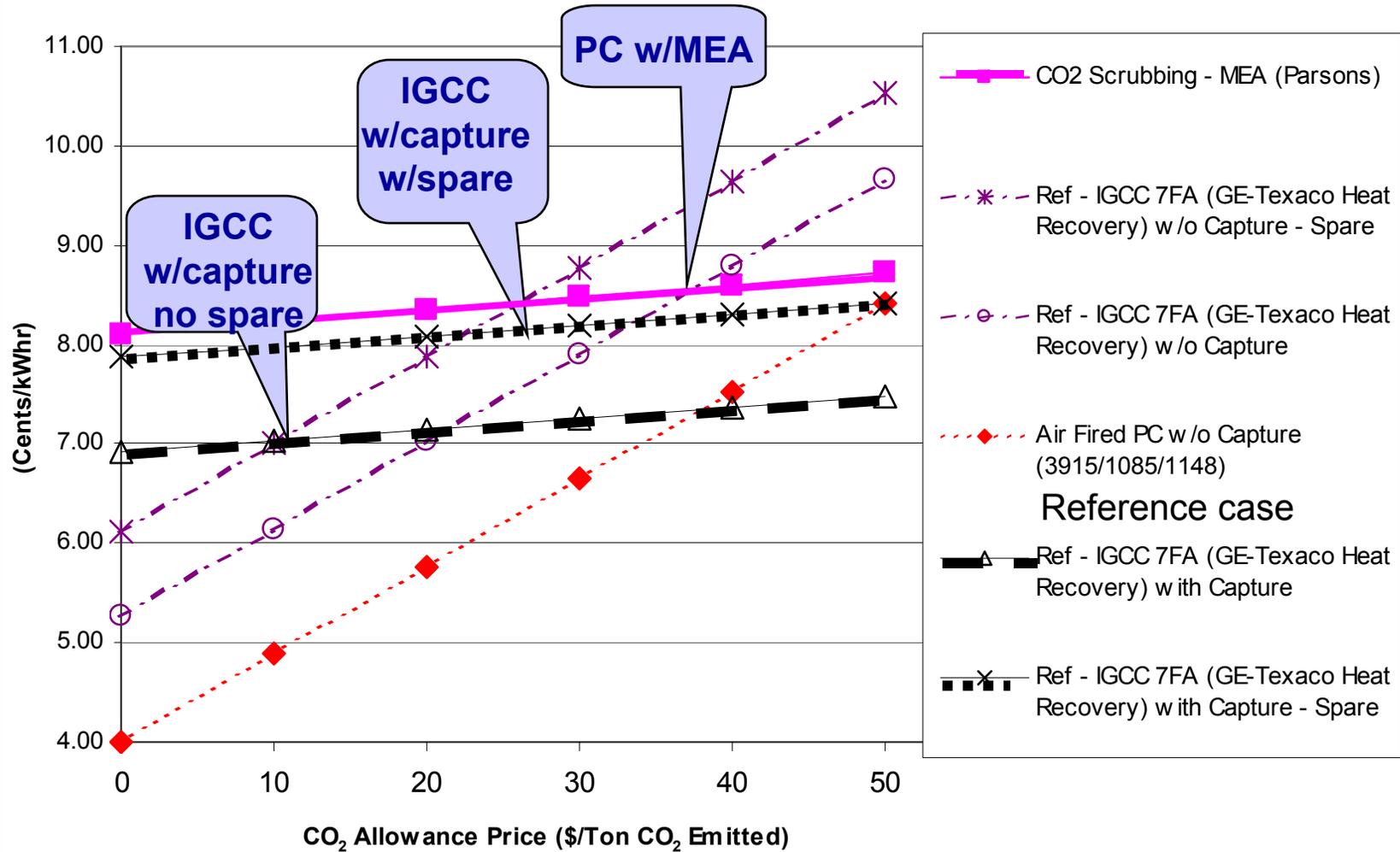
**COE - NGCC vs PC new and existing**

# No Capture cases in Power Plants



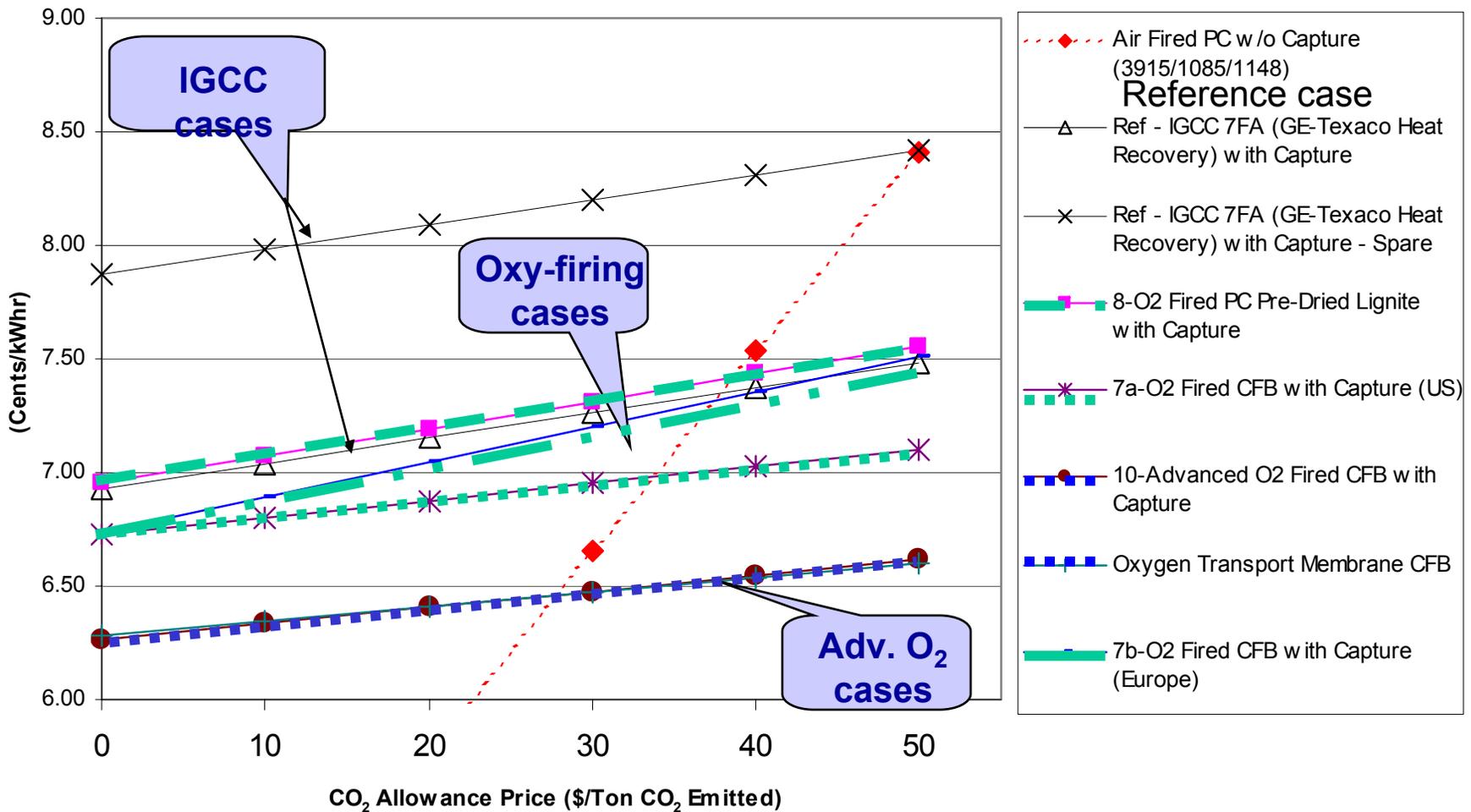
**NGCC vs PC vs IGCC**

# CO2 Capture in Power Plants



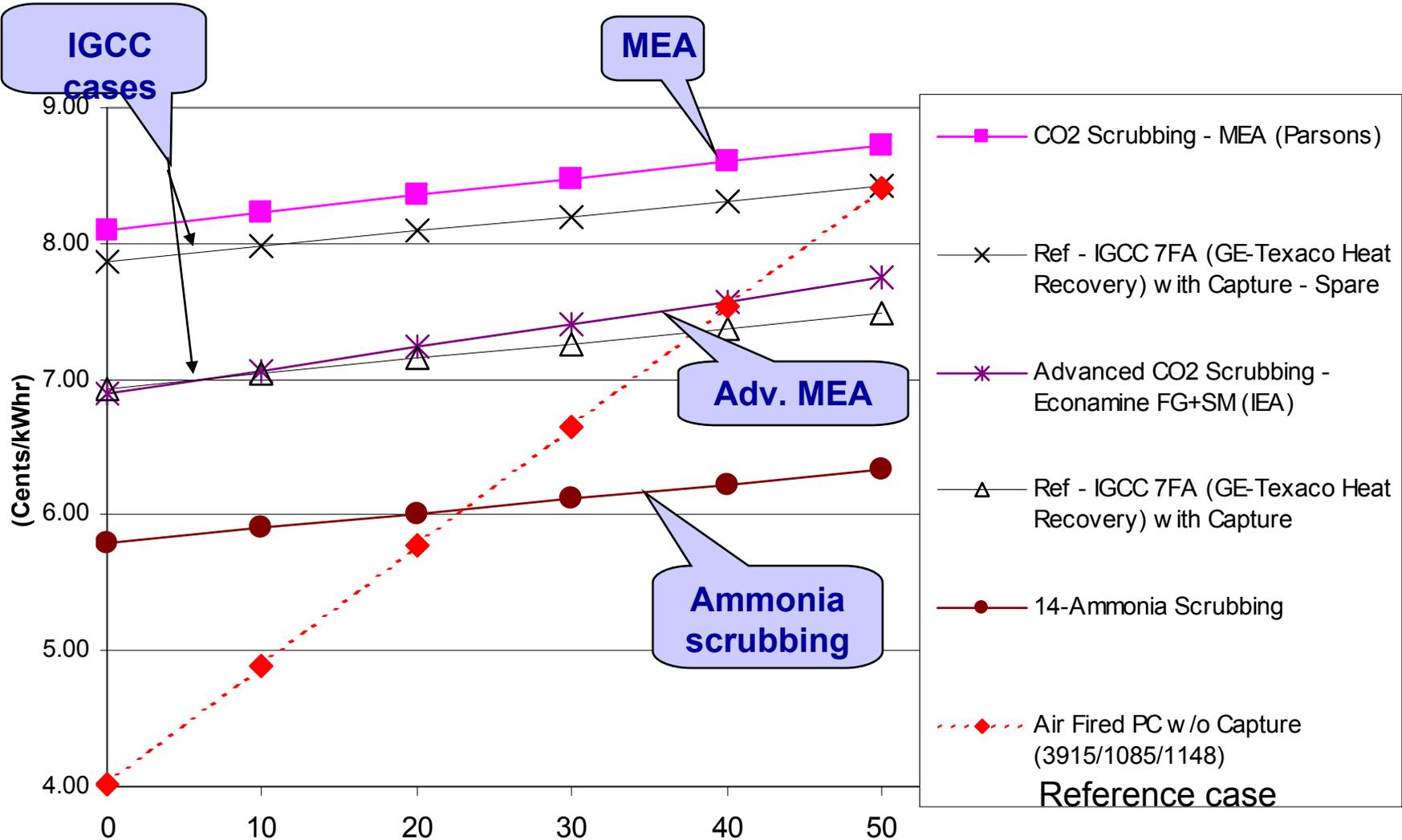
**IGCC w/capture better COE than PC with MEA**

# CO<sub>2</sub> Capture in Power Plants



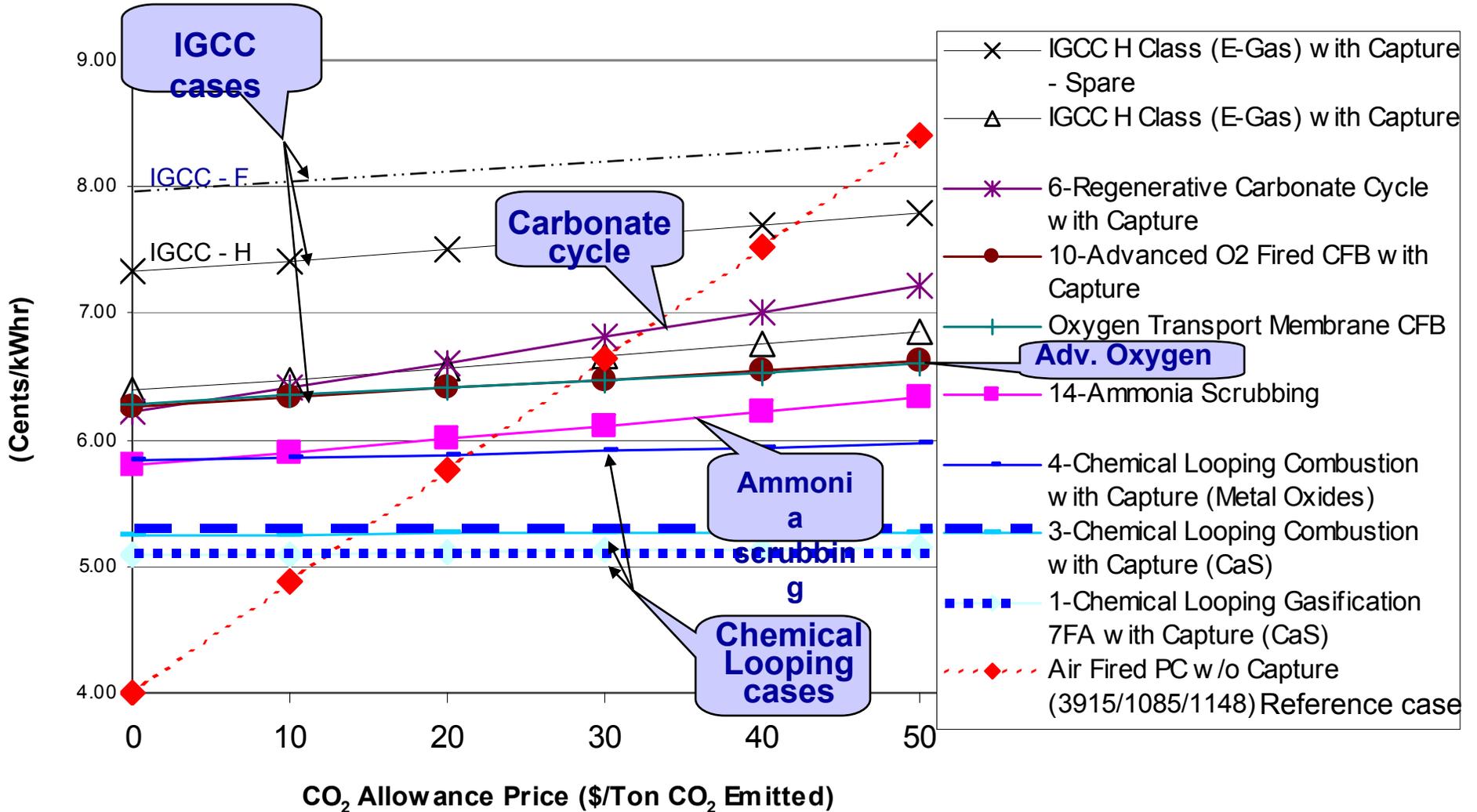
**Oxy-firing with conventional or advanced O<sub>2</sub> generally lower COE than IGCC**

# CO2 Capture in Power Plants



**Advanced MEA and Ammonia scrubbing have potential and are retrofitable**

# CO<sub>2</sub> Capture in Power Plants



**Advanced concepts have great potential**

# Conclusions



- 
- New coal fired power plants shall be designed for highest efficiency to minimize CO<sub>2</sub> + other emissions
  - Several technologies for CO<sub>2</sub> capture are currently available, several are actively being developed, and many more are emerging
  - Including --- Retrofit technologies for CO<sub>2</sub> capture for Combustion-based Power
  - Cost Attractive Options are needed and should actively supported, particularly:
    - Breakthroughs ( example: chemical looping & adv. oxygen )
    - Retrofitable ( example: ammonia scrubbing )
  - There is no single technology answer

# What's ALSTOM doing about CO2?



- ALSTOM is a world-leading supplier of power generation equipment, turnkey power plants and services, and is an industry leader in providing modern, high-efficiency clean power generation equipment and energy solutions
- ALSTOM believes that providing a diverse mix of technologies for power generation is a critical element in providing affordable, reliable, and environmentally sound energy.
- There is no single, all-encompassing, long-term technological option for greenhouse gas mitigation; rather, there will be a variety of options that will be needed.
- ALSTOM continues to focus its major R&D investments in the demonstration of cost effective and practical power generation systems aimed at both improved efficiency and emissions control (including capture). Through these principles, ALSTOM is committed to the continuous improvement of its technology portfolio in order to meet the present and future needs of its customers.

The ALSTOM logo is centered on a white semi-circular background. The letters 'ALSTOM' are in a bold, sans-serif font. 'ALST' and 'M' are dark blue, while the 'O' is red and stylized as a circle with a gap. The background features a large red arc on the left and a blue background with vertical stripes and white curved lines on the right.

**ALSTOM**

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