



**Stanbridge Capital**  
Oil & Energy

**An energetic analysis of CO<sub>2</sub> capture on a gas turbine  
combining flue gas recirculation and membrane separation**

**-AIChE, Minneapolis, 21<sup>st</sup> october 2011 -**

**Bouchra Belaissaoui, Eric Favre**

LRGP (Laboratory of Reactions and Process engineering), Nancy, France

**G.Cabot, M.S Cabot**

CORIA (COMplexe de Recherche Interprofessionnel en Aérothermique), Rouen, France

**David Willson**

Stanbridge Capital, New York, USA

# Introduction : context

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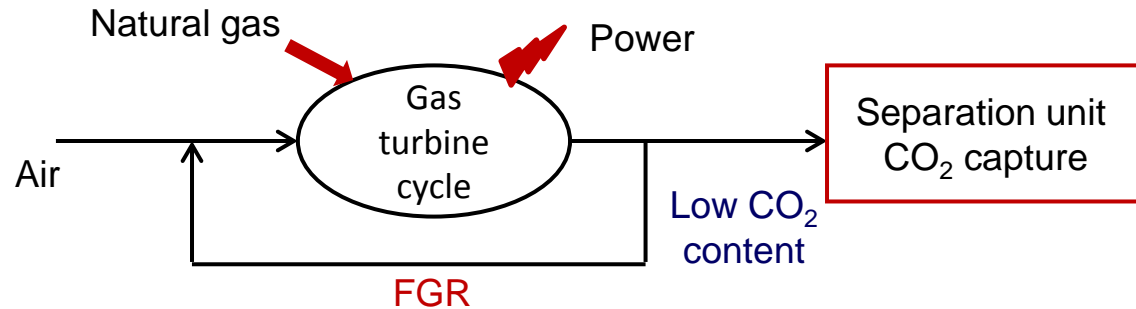
- Reduction of the cost of CO<sub>2</sub> capture on a gas turbine
- With respect of CO<sub>2</sub> capture constraints :
  - High CO<sub>2</sub> capture ratio ( $\geq 90\%$ )
  - High CO<sub>2</sub> purity ( $\geq 90\%$ )

Reference (MEA absorption) : 3.5GJ/ton of recovered CO<sub>2</sub>

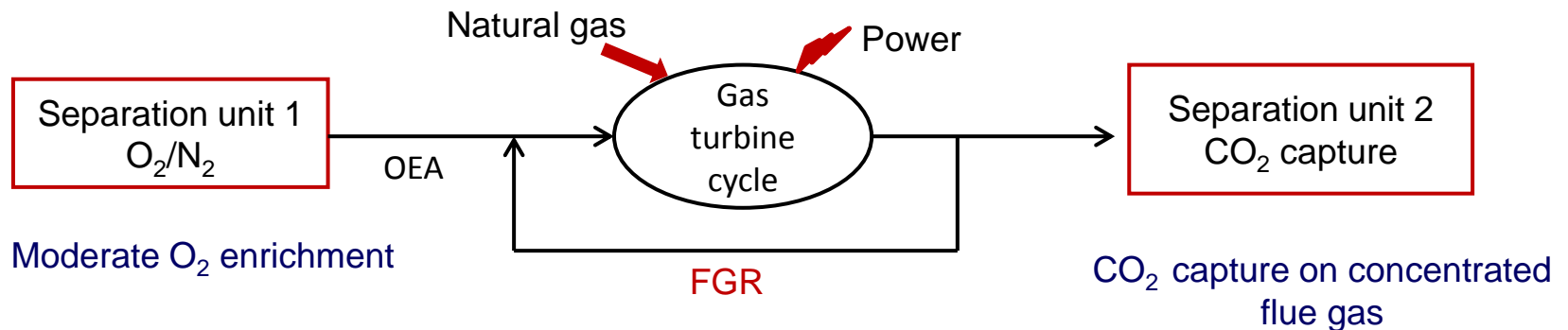
Target : 2GJ/ton of recovered CO<sub>2</sub>

# Introduction : objective

## 1- Postcombustion



## 2- Hybrid process\*



\* Favre, E. Bounaceur, R., Roizard, D.(2009),, *Sep. Purif. Technol* , 68, 30-36.

# Outline

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I- Membrane unit for CO<sub>2</sub> capture

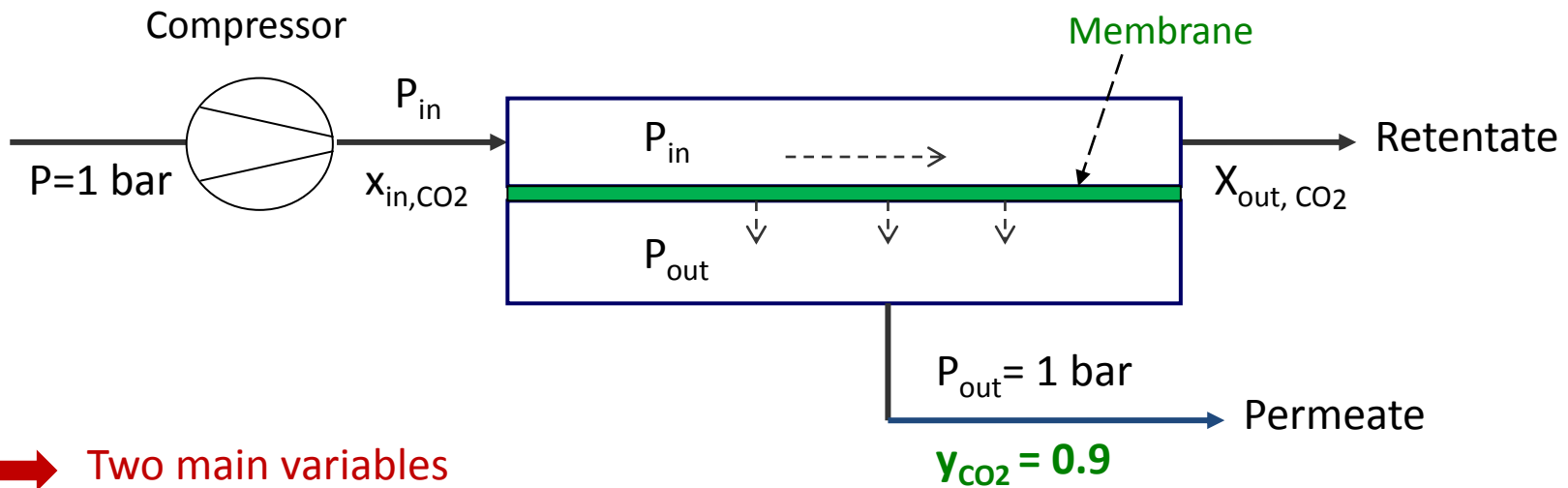
II- Performances for air feeding condition

III- Performances for OEA feeding condition

IV- Conclusion and perspectives

# I- Membrane unit for CO<sub>2</sub> capture

- A single stage membrane module - Cross flow model \*
  - Binary CO<sub>2</sub>/N<sub>2</sub> mixture -



➔ Two main variables

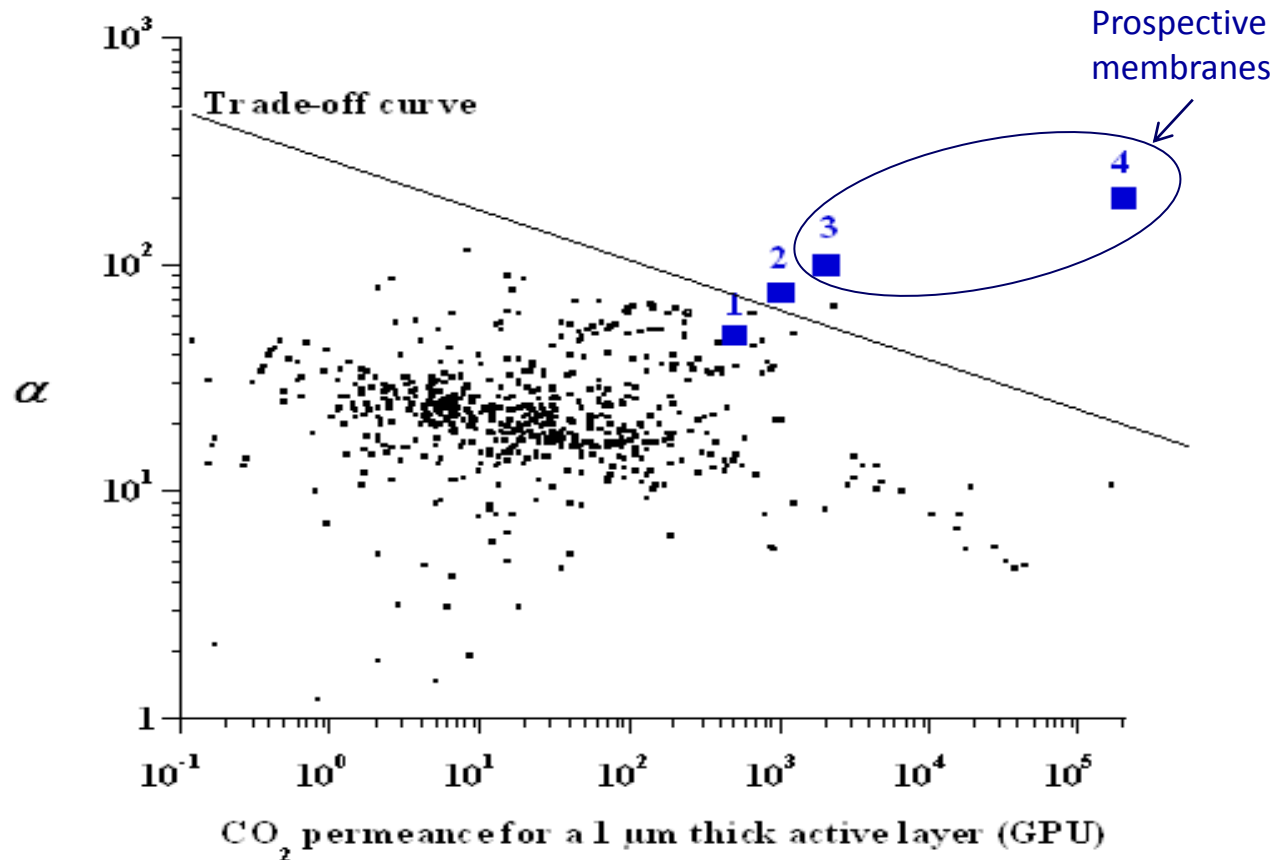
● Membrane selectivity :  $\alpha_{CO_2/N_2}$

● Pressure ratio :  $\psi = \frac{P_{out}}{P_{in}}$

\* Bounaceur R. et al, (2006) *Energy*, 31, 2556-2570.

# I- Membrane unit for CO<sub>2</sub> capture

## ● Membrane unit performances



1- Merkel, T.C., Lin, H., Wei, X., Baker, R., 2009. , *J. Membrane Sci*

2- S.J. Metz, M.H.V. Mulder, M. Wessling,, *Macromolecules*, 37 (2004) 4590-4597.

3- L. Deng, T.-J. Kim and M.-B. Hagg,, *J. Membrane Sci.*, 340 (2009) 154-163.

3 - Xomeritakis, G., Tsai, C.Y., Brinker, C.J., *Sep. Purif. Technol.*, 42 (2005) 249-257.

4- Krishna, R., van Baten, J.M., *J. Membrane Sci* 360 (2010) 323-333.

# Outline

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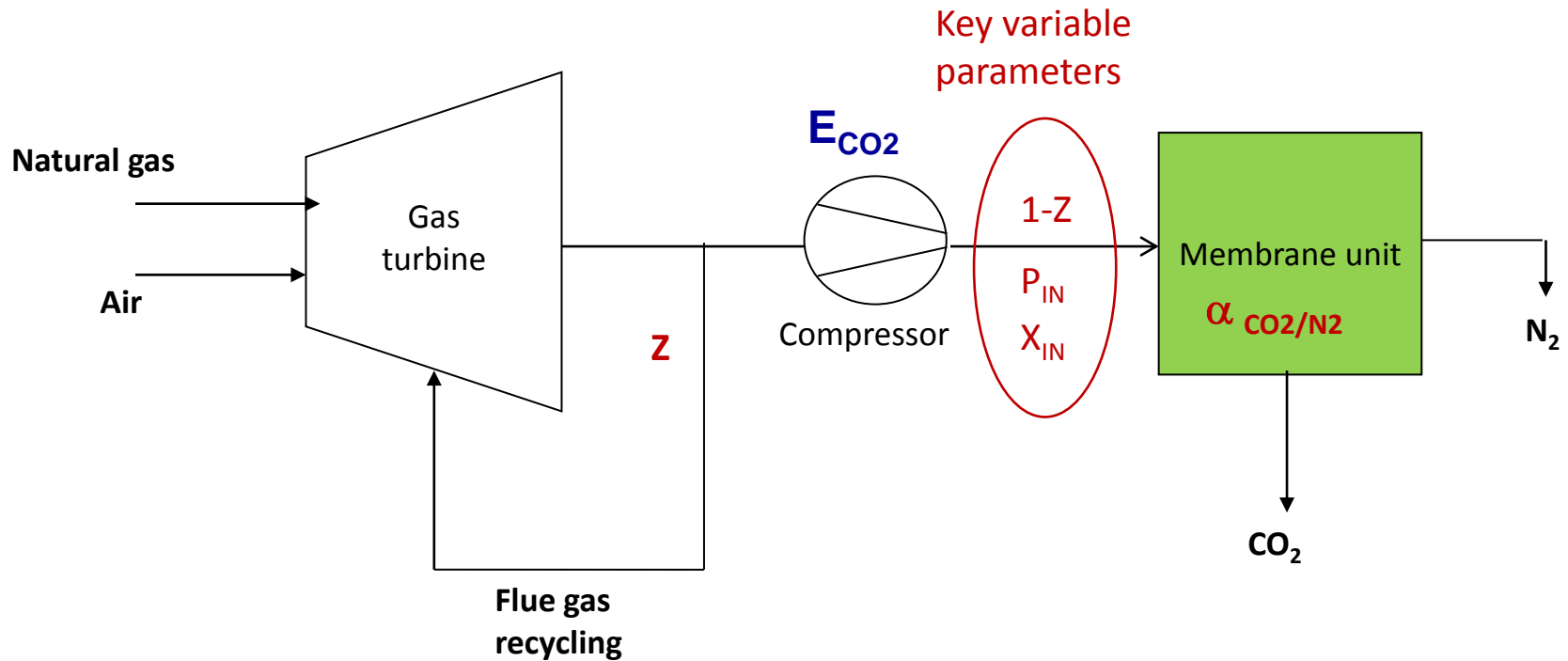
I- Membrane unit for CO<sub>2</sub> capture

**II- Performances for air feeding condition**

III- Performances for OEA feeding condition

IV- Conclusion and perspectives

## II- Performances for air feeding condition

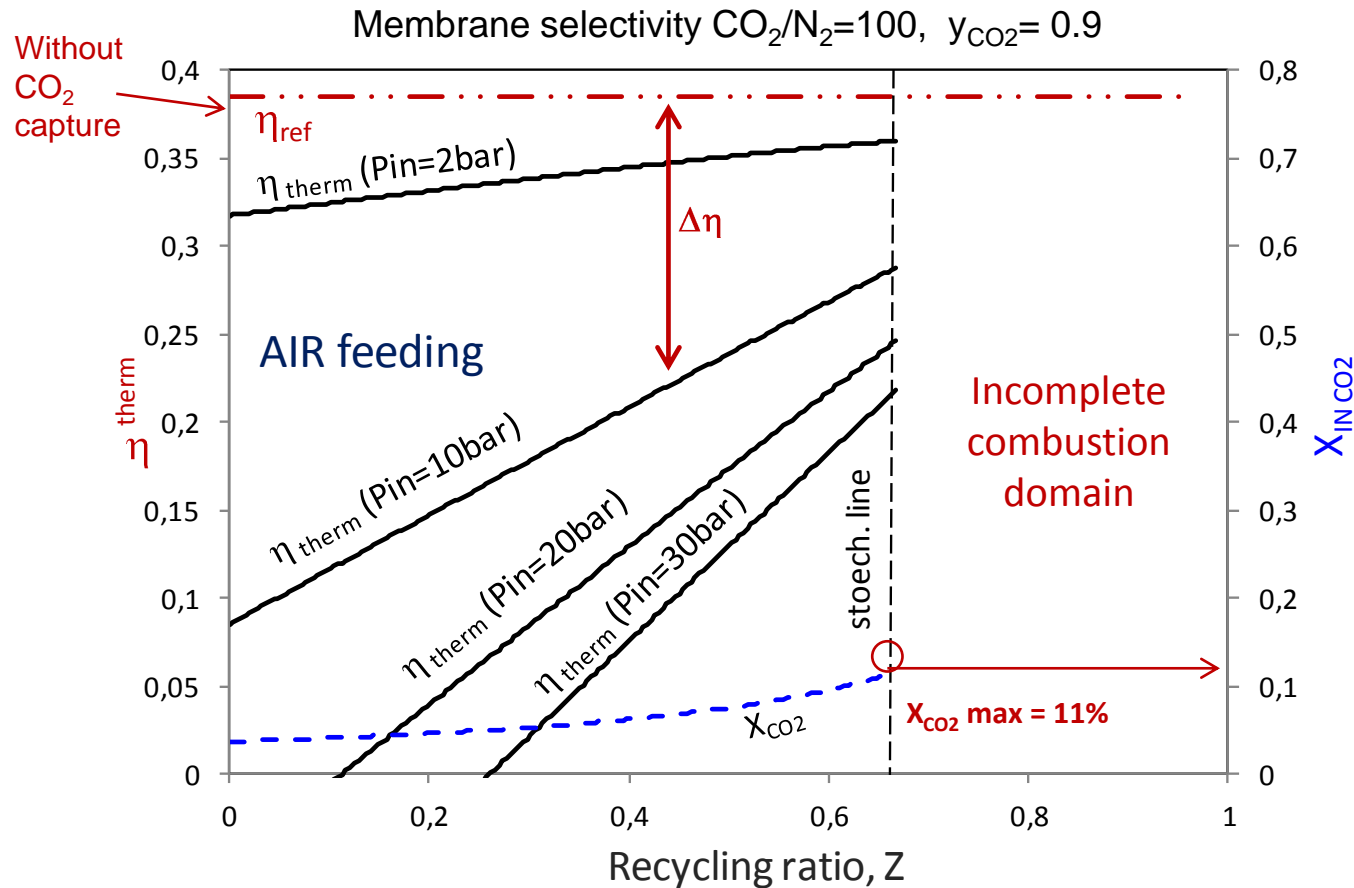


What is the penalty of CO<sub>2</sub> capture on the thermal efficiency of the turbine cycle ?



## II- Performances for air feeding condition

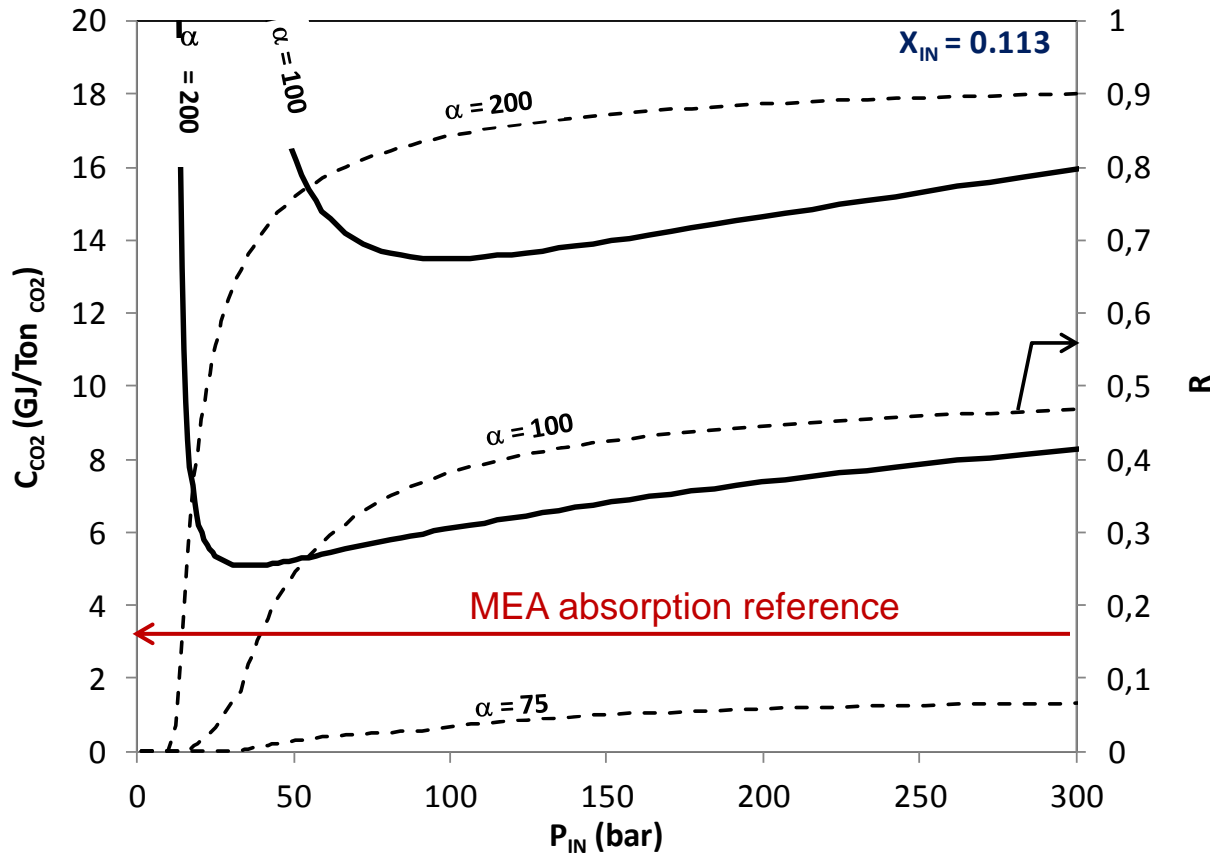
### 1- Gaz turbine efficiency – complete combustion



- A maximum  $\text{CO}_2$  fraction of only 11% is obtained
- A OEA combustion is needed if  $Z$  larger than 0.669 is wanted

# I- Performances for air feeding condition

2- Cost of CO<sub>2</sub> Capture = Cost of feed compression



$E = 8$  GJ/ton CO<sub>2</sub> → Need to enhance the efficiency of the cycle  
→ increase  $x_{in,CO_2}$

# Outline

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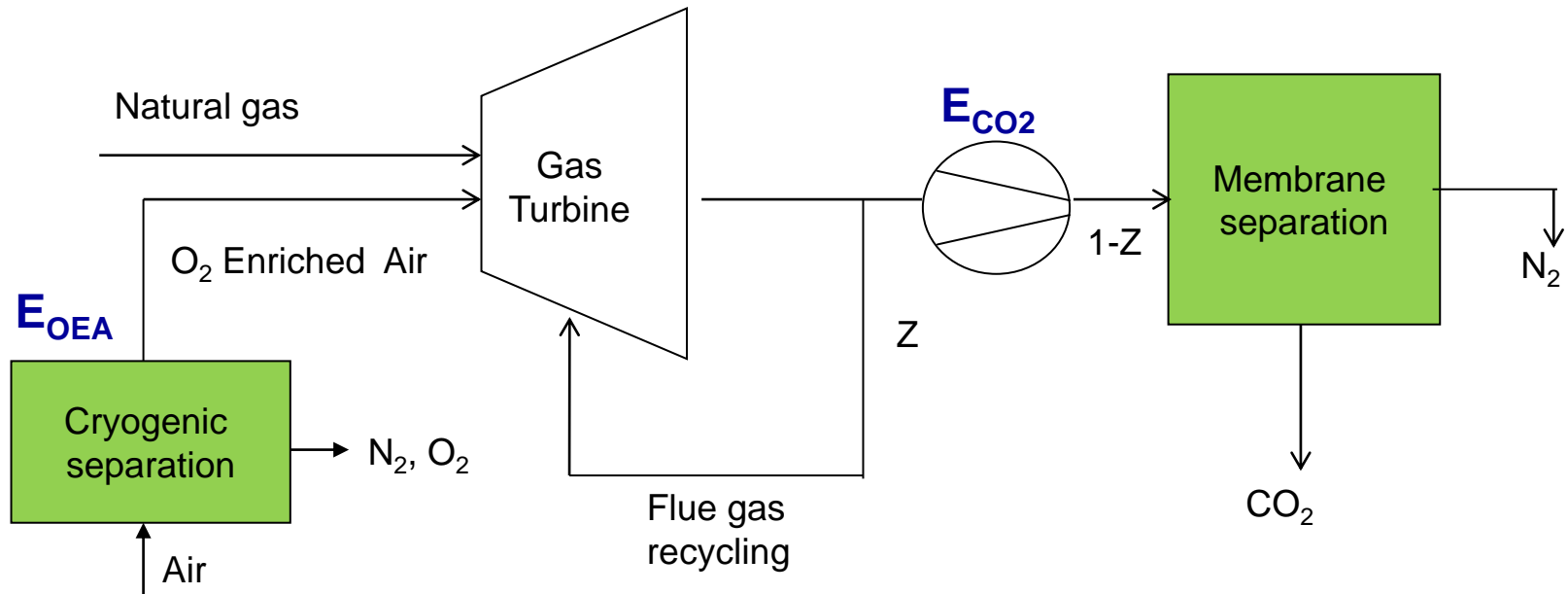
I- Membrane unit for CO<sub>2</sub> capture

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### III- Performances for OEA feeding condition



What is the overall thermal efficiency of the turbine cycle ? What is the total capture cost in GJ/ton CO<sub>2</sub> ?

### III- Performances for OEA feeding condition

1- Total cost of CO<sub>2</sub> capture on the gas turbine in GJ/ton of recovered CO<sub>2</sub>

$$C_{CO_2} = \frac{\overset{\text{GJ/kg CH}_4}{LHV} \times (\eta_{ref} - \overset{\text{with CO}_2 \text{ capture}}{\eta_{therm}})}{\underbrace{CO_2^0 \times R}_{\text{ton CO}_2 \text{ captured /kg CH}_4}} + \frac{\overset{\text{OEA unit cost}}{\overbrace{(1+e) \times O_2^0 \times C^*}_{\text{Ton O}_2 \text{ /kg CH}_4}}}{CO_2^0 \times R} \quad \text{GJ/ton O}_2$$

e : excess of oxygen (e=0.1)

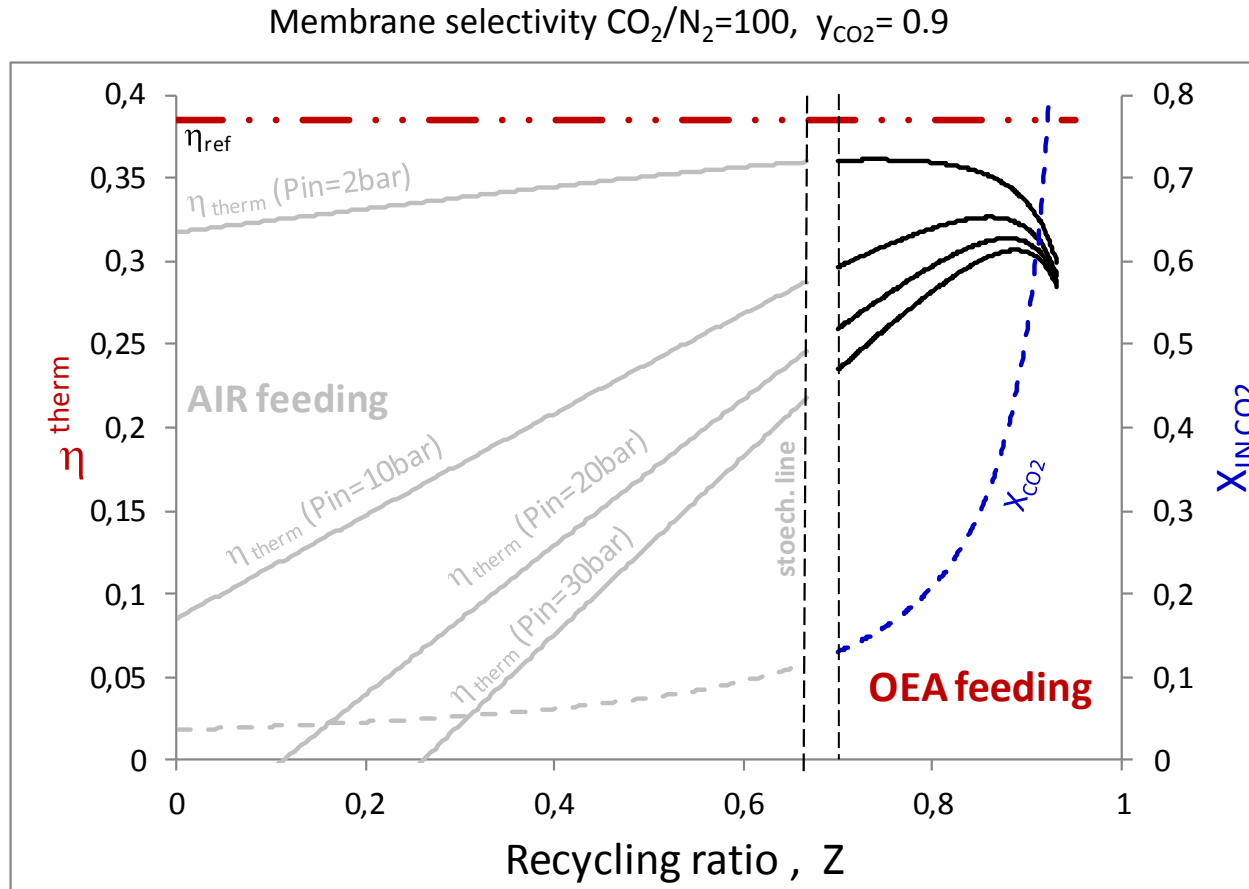
R : CO<sub>2</sub> capture ratio

CO<sub>2</sub><sup>0</sup> : 3.67Kg CO<sub>2</sub>/Kg CH<sub>4</sub>

\* Göttlicher, G. The energetics of carbon dioxide capture in power plants, US Department of Energy, National Energy Technology Laboratory, 2004.

# III- Performances for OEA feeding condition

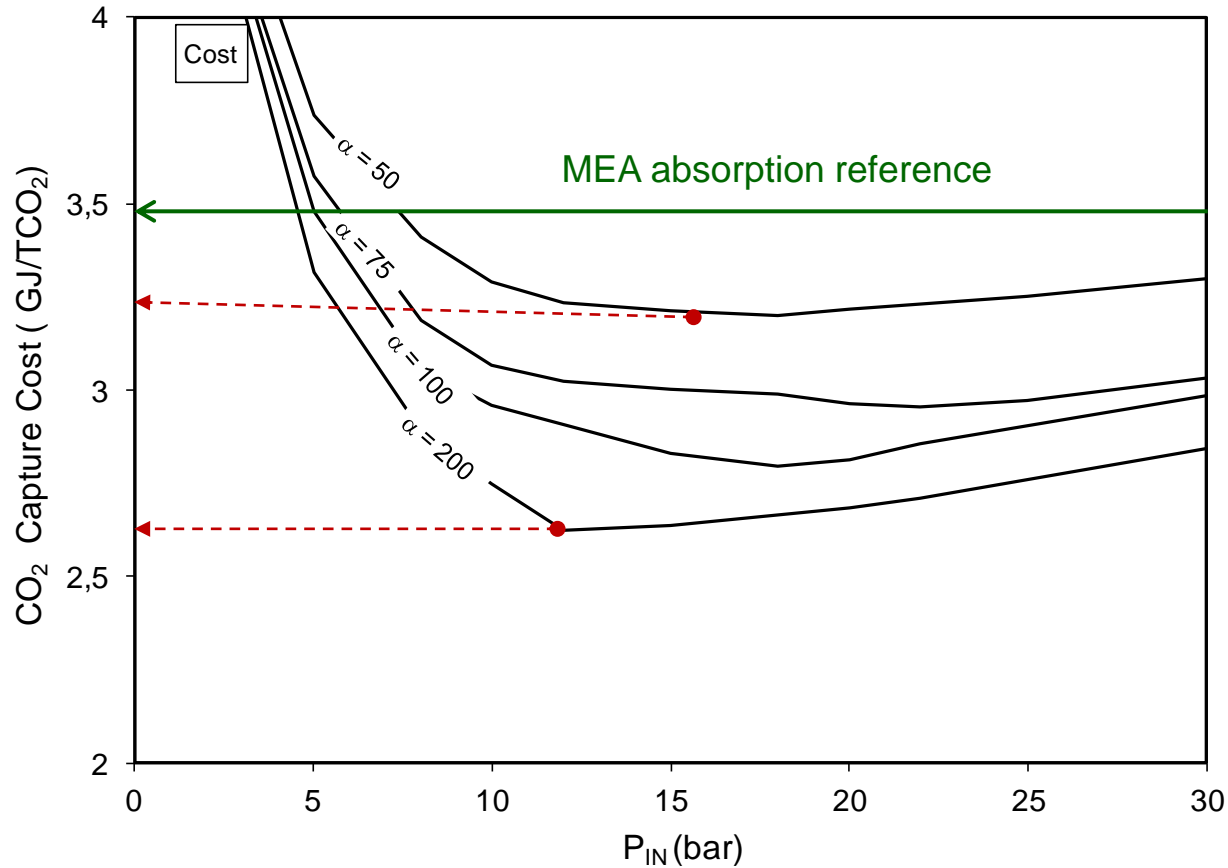
## 2- Gas turbine efficiency



- The thermal efficiency passes through a maximum value as  $Z$  increases.
- Concentrated  $\text{CO}_2$  in the flue gas can be obtained ( $x_{\text{in, CO}_2} > 0.2$ )

# III- Performances for OEA feeding condition

## 3- Process optimisation : Minimum CO<sub>2</sub> capture cost



- For  $\alpha = 50$ ,  $E_{min} = 3.2$  GJ/ton (close to MEA absorption process)
- For  $\alpha = 200$ ,  $E_{min} = 2.6$  GJ/ton

# III- Conclusion and perspectives

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## Conclusion

- For combustion in air with FGR, unacceptable energy requirement is obtained, even with membrane selectivity of 200
- For combustion in OEA, energy requirement down to 2.6 GJ/ton can be attained.

## Perspectives

- An energy recovery system on the retentate (high pressure side) could lower the capture cost
- For medium oxygen purity production, alternative technology (PSA, membrane air separation) could be investigated
- Technico-economical analysis to better evaluate the potential of the concept
- Simulation of the hybrid process for multicomponent mixture ( $O_2, NO_x, \dots$ )



# Thank you for your attention

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