Techno-Economic Assessment for C_2H_4 production using OCM integrated with membrane and membrane reactor

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Summary

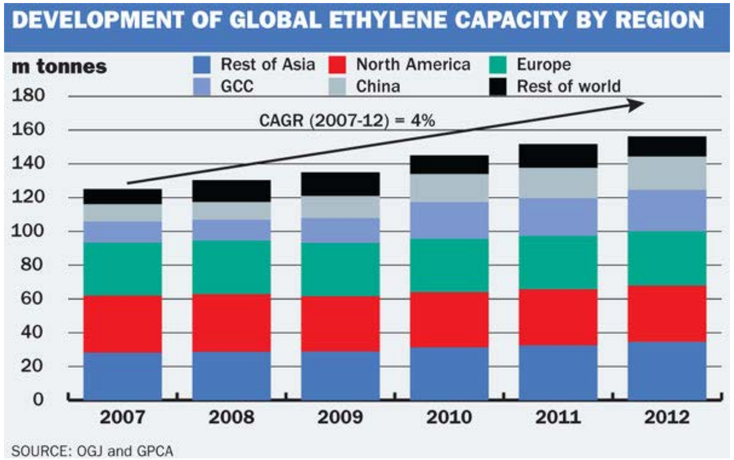
- Objectives and Motivation
- OCM technology
- Benchmark technology
- OCM plants
  - Classic OCM
  - Distributed feeding of O_2
  - MIEC membrane reactor
- Comparison
- Conclusions

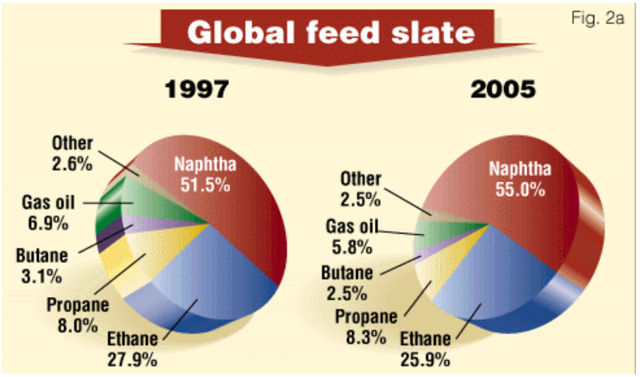
Objectives and Motivation

- Ethylene is a very important product for the petrochemical industry → *high impact process and large market share*

- The primary raw materal for the C_2H_4 production are Naphtha and Ethane (especially in Middle East and US) → *interest in feedstock cost reduction and diversification*

- From an environmentally point of view, naphtha steam cracking results in 3-4 t_{CO2}/t_{olef} → *reduce the environemental impact*

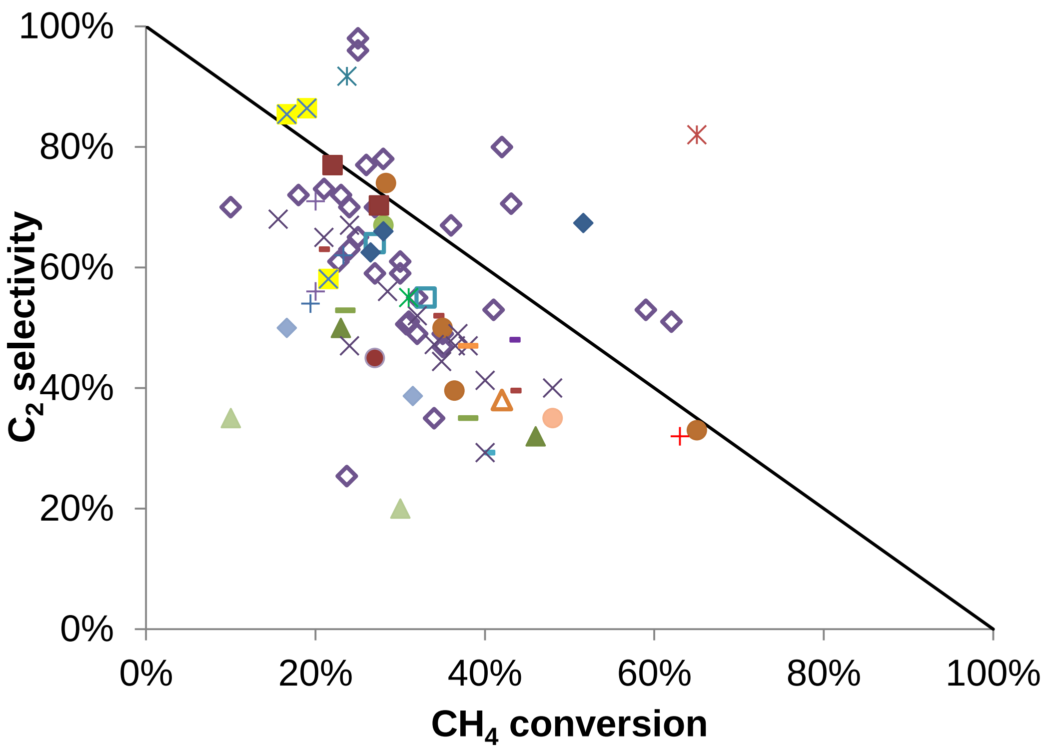




Oxidative coupling of methane process is a possible solution

$$2CH_4 + O_2 \rightarrow C_2H_4 + 2H_2O$$

Oxidative Coupling of Methane



Main reactions

$$2CH_4 + O_2 \rightarrow C_2H_4 + 2H_2O$$
$$C_2H_6 + 0.5\,O_2 \rightarrow C_2H_4 + H_2O$$

Side reactions

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$
$$CH_4 + O_2 \rightarrow CO + H_2 + H_2O$$
$$2CH_4 + 0.5O_2 \rightarrow C_2H_6 + H_2O$$
$$CO + 0.5O_2 \rightarrow CO_2$$
$$C_2H_4 + 2O_2 \rightarrow 2CO + 2H_2O$$
$$C_2H_6 \rightarrow C_2H_4 + H_2$$
$$C_2H_4 + 2H_2O \rightarrow 2CO + 4H_2O$$
$$CO + H_2O \leftrightarrow CO_2 + H_2$$

- Lower CH_4/O_2 ratio decreases the selectivity towards C_2H_4/C_2H_6 producing more CO_2 and CO
- Very esothermic reactions
- Low pressure and low temperature favors the C_2 yield

Oxidative Coupling of Methane

High temperature decreases C_2H_4 yield however lower temperature increases the heat-to-be removed

Temperature = 850˚C

Low pressure increases the C_2H_4 yield however large reactor section is required to avoid excessive Δp

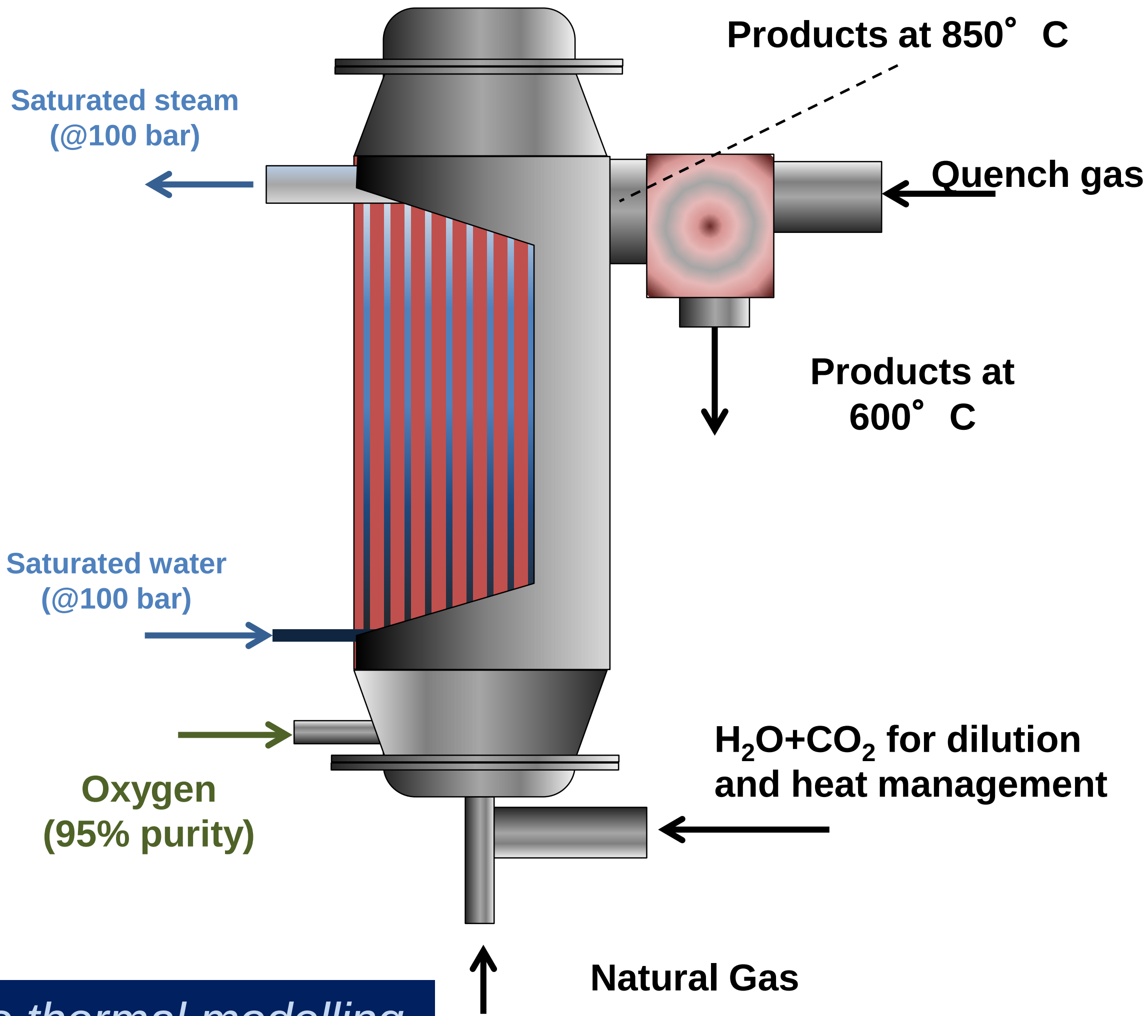
Pressure = 10 bar

Reactor heat management:

H_2O/CO_2 dilution

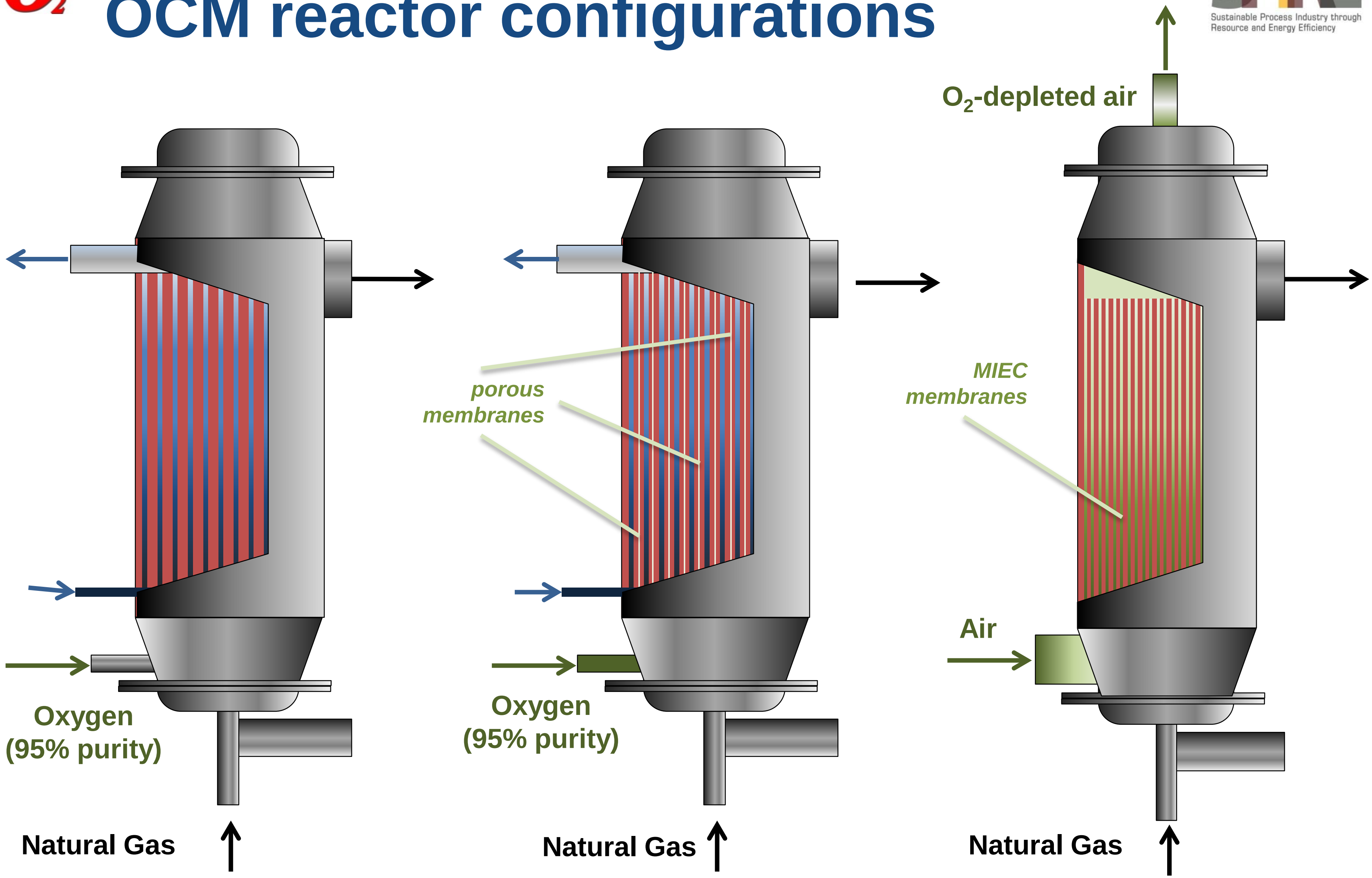
cooled reactor

Quench to stop side reactions

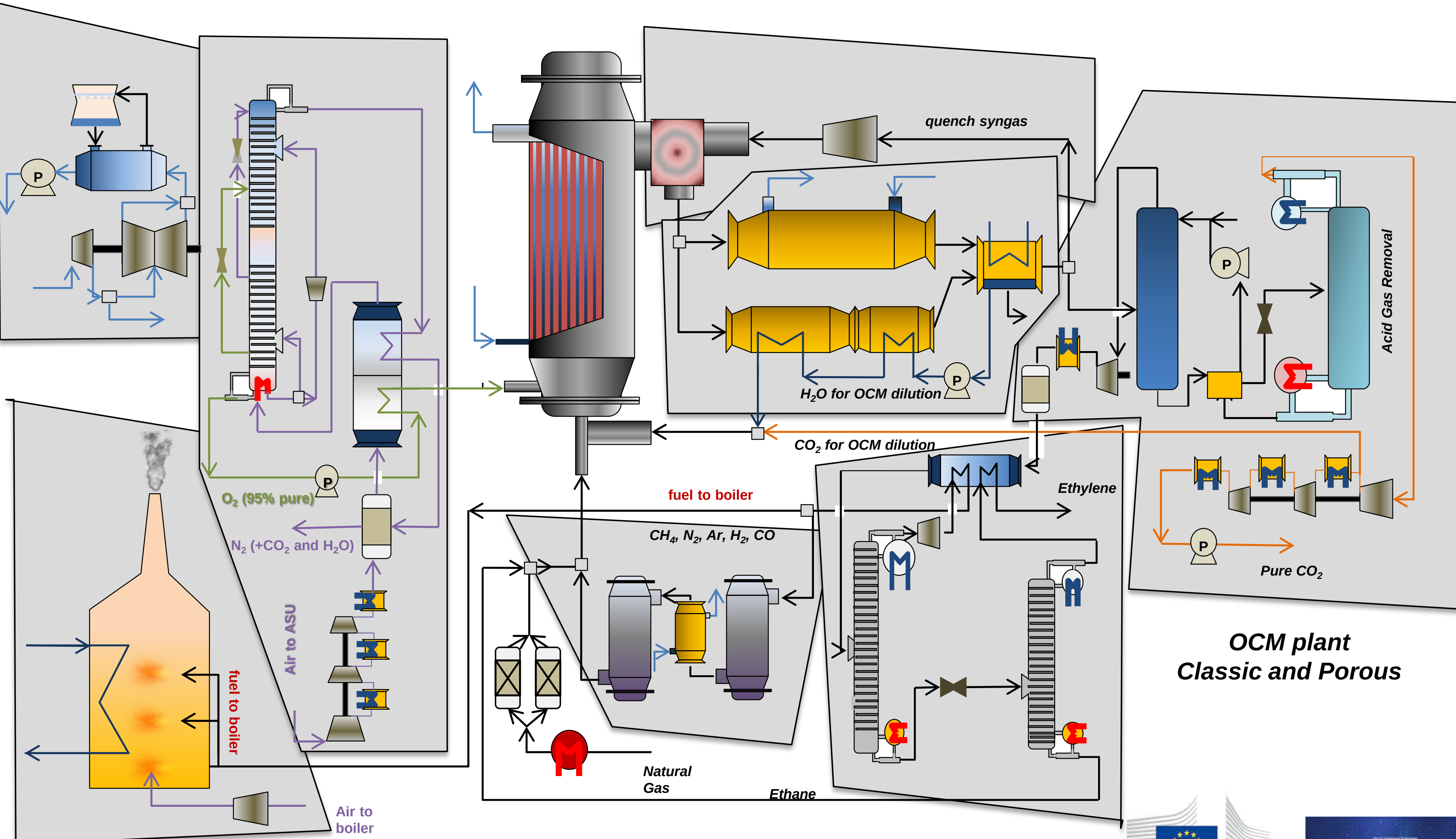


No thermal modelling of the reactor

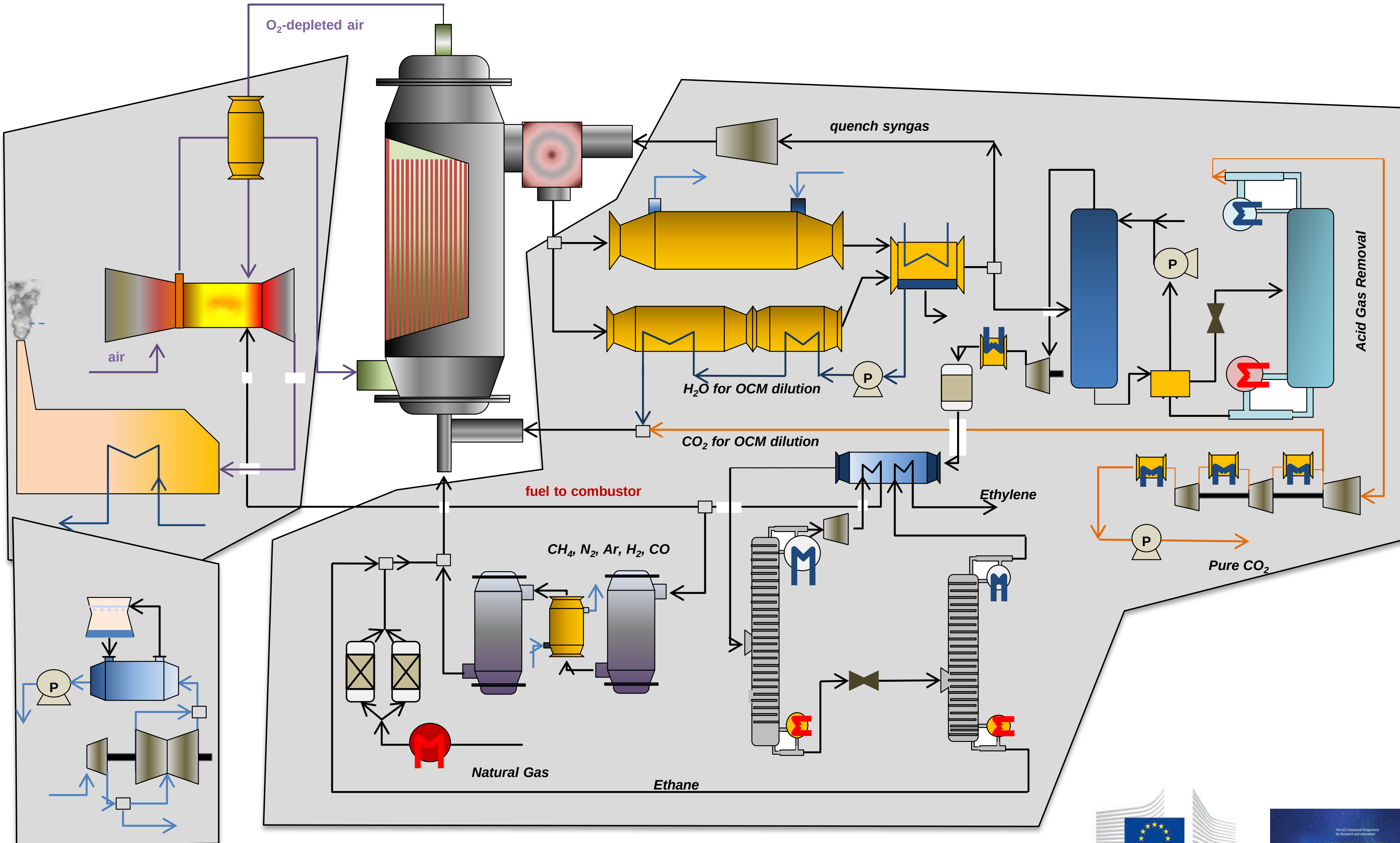
OCM reactor configurations



OCM classic and OCM porous



MIEC + OCM plant



Performance comparison

$$W_{tot} = \sum W_{chem,i} + \sum W_{EL_{IN-OUT}} + W_{TH}$$

Energy from the products (chemicals, electricity, heat)

$$W_{chem} = \dot{m_{chem}} LHV_{chem}$$

$$W_{feed} = \dot{m_{feed}} LHV_{feed}$$

Energy input to the plant

$$\eta_{FTO} = \frac{\sum W_{chem,i}}{W_{feed}} \qquad i = C_2H_4,\ C_3H_6$$

Olefins Production efficiency

$$\eta_{tot} = \frac{W_{tot}}{W_{feed}}$$

Overall energy efficiency

$$\dot{m_{CO_{2},em}} = \sum m_{CO_{2,source}}$$

absolute CO_2 emissions, kg/s

$$E_{CO_2} = \frac{m_{CO_{2,em}}}{m_{C_2H_4}}$$

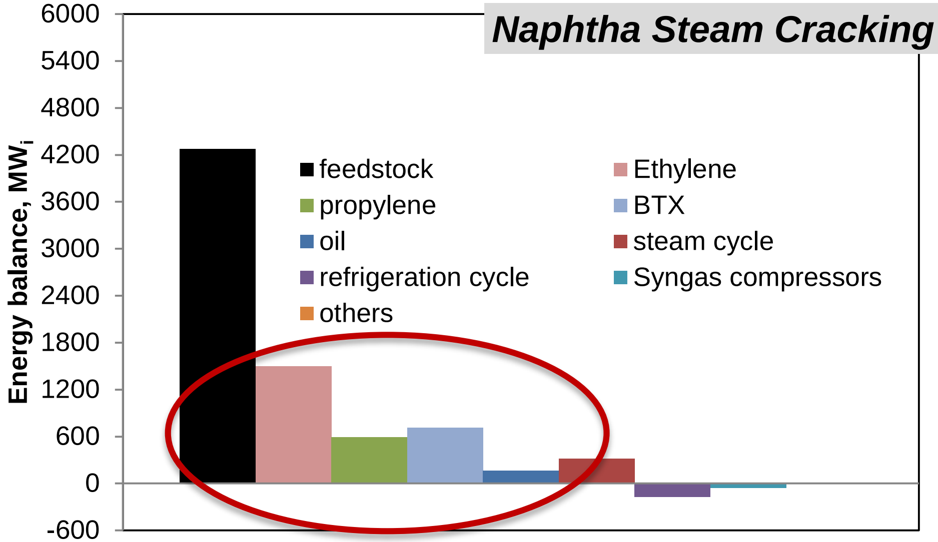
CO_2 specific emissions, ton_{CO2}/ton_{C2H4}

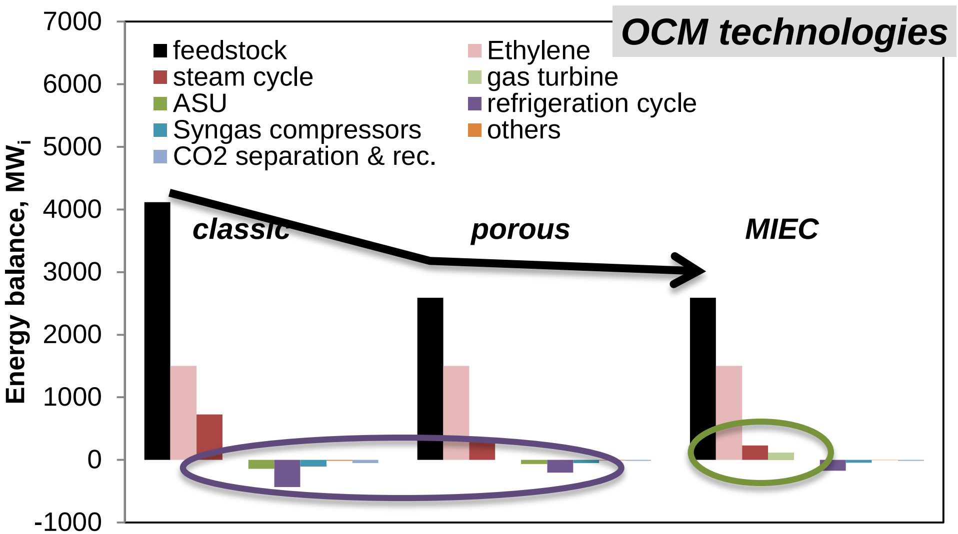
$$OPEX_{C_2H_4} = \sum \pm OPEX_{chem} + OPEX_{el} + OPEX_{O\&M}$$

Note: $OPEX_{el}$ are negative in case of overall electricity export

Plant size: $1MTPY_{C2H4}$

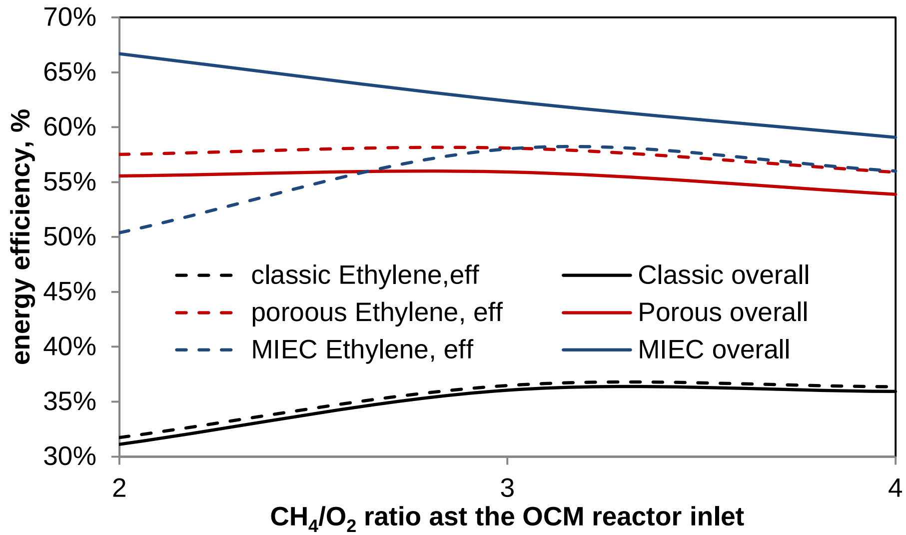
Naphtha steam cracking vs OCM

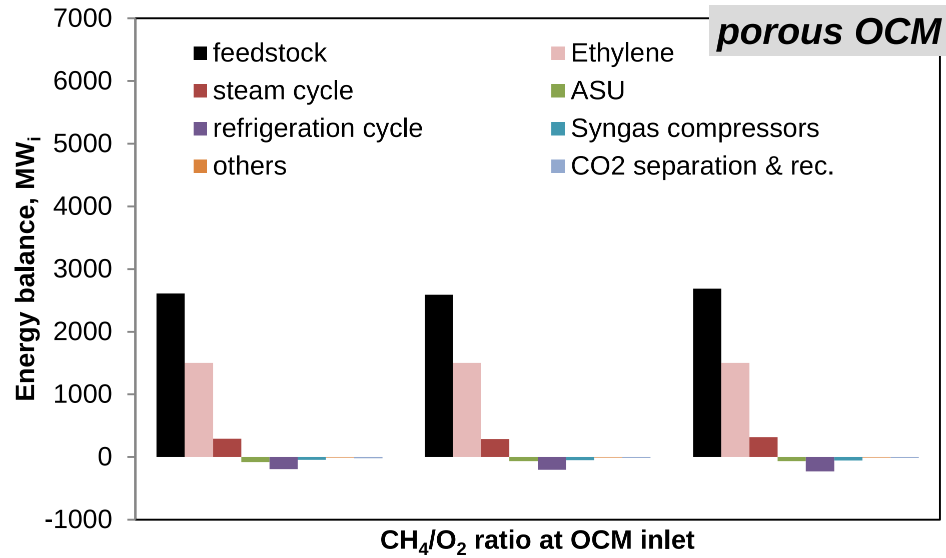


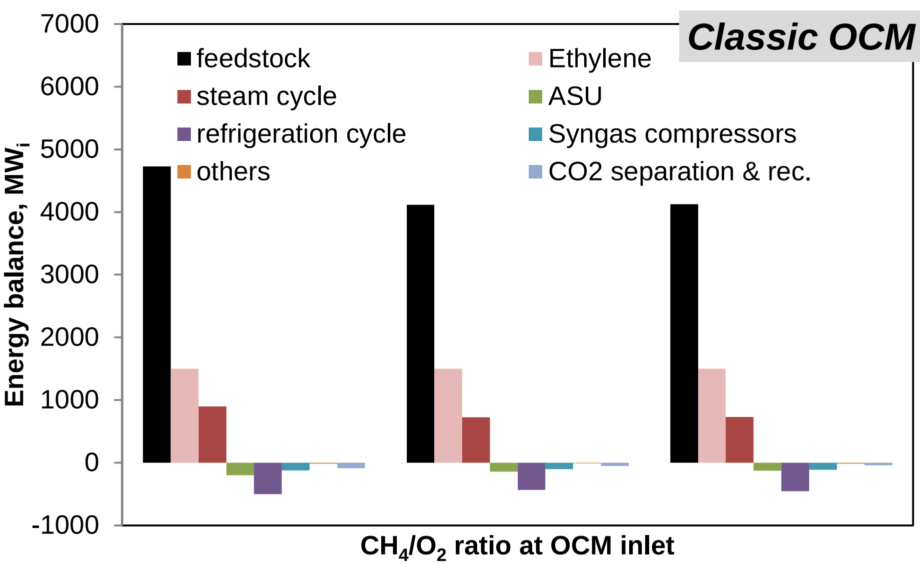


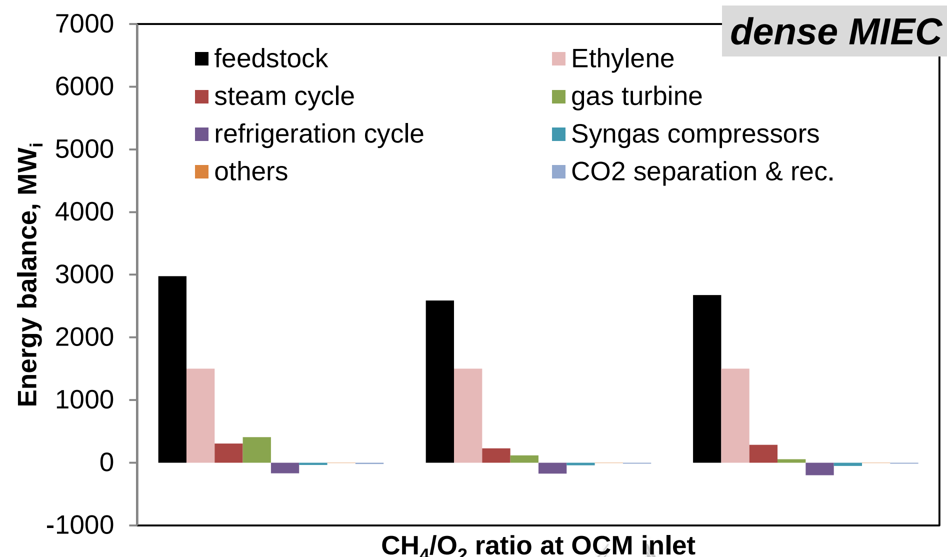
- Multi-products from NSC (C_2H_4, C_3H_6, BTX)
- The use of membranes improves the performance with respect to classic OCM reducing the feedstock required
- Energy consumptions in OCM is represented by LT refrigeration cycle and O_2 production
- In MIEC configuration an extra electricity production is obtained by the Gas Turbine and ASU consumptions

OCM technologies

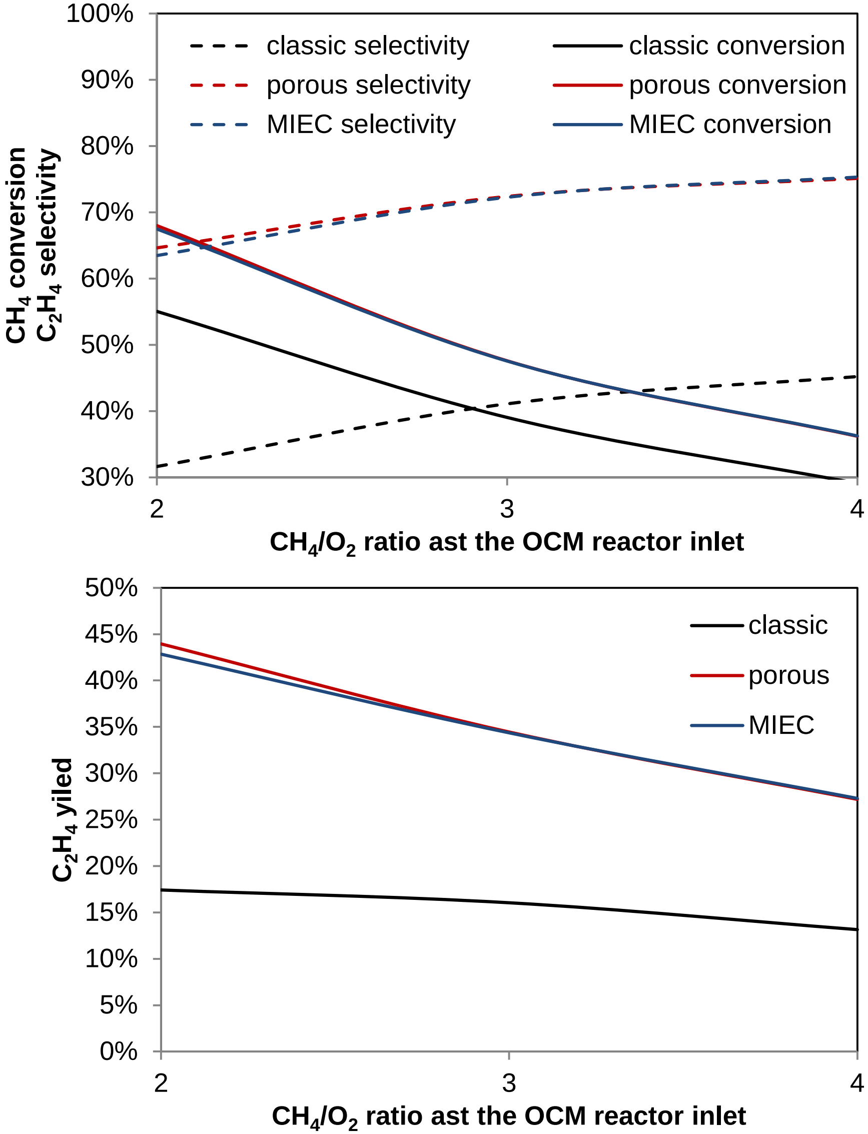








OCM reactor



- The use of OCM membranes increases both selectivity and conversion

→ C_2H_4 yields 2 to 2.7 higher

- The impact in the reactror design and assembling of porous membrane (compared to classic OCM) is minimal

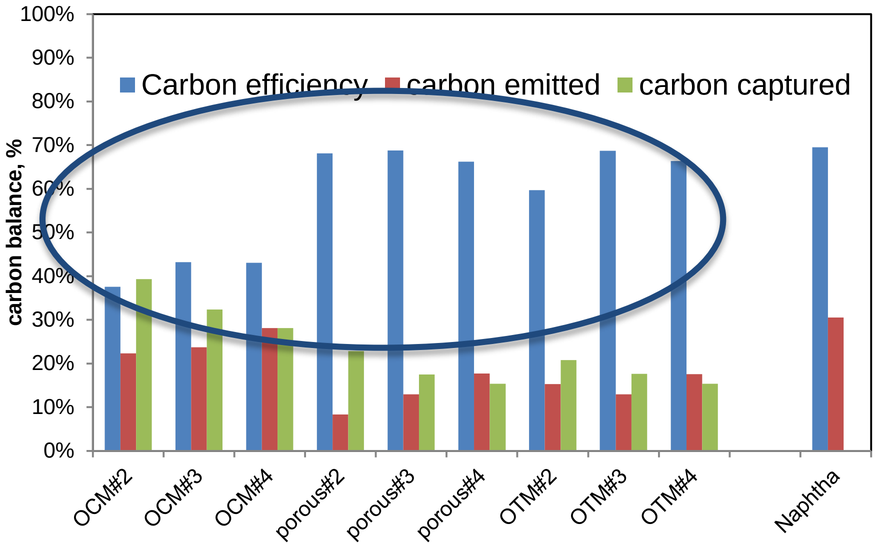
→ the membrane tubes required are 10 to 50 times lower than tubes for reactor cooling (overall around 2-7% of the reactor volume is occupied by tubes)

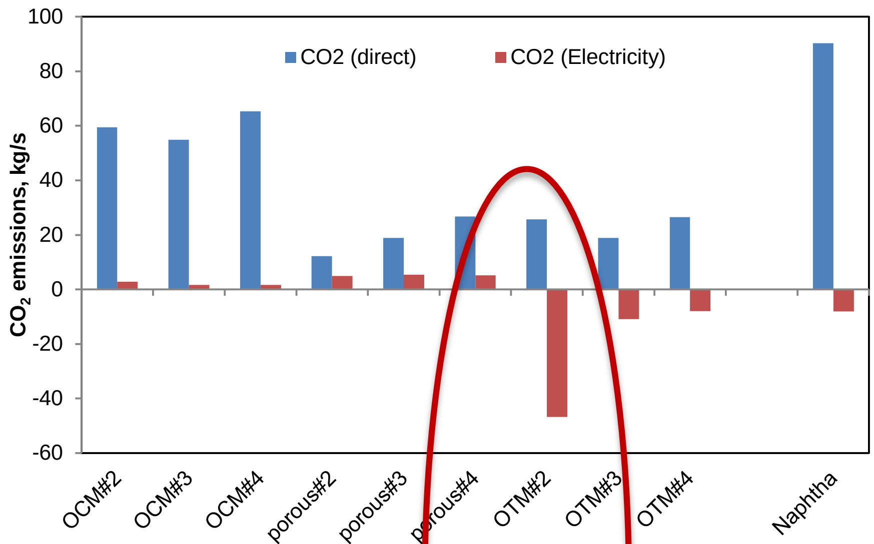
- *In case of MIEC membranes the membrane area required is very high*

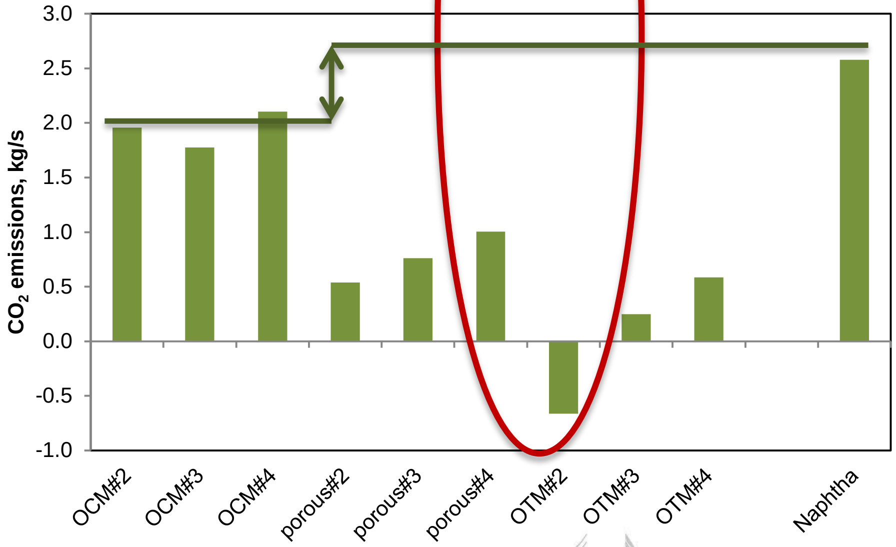
→ 750-1000 $m^2_{area}/(kg/s_{C2H4})$ (25-35x10^3 m^2 required)

→ membrane area (MIEC) is 100 times higher than heat transfer area required (in OCM classic/porous)

Environmental Performance







Apart from classic OCM, most of the carbon is converted to C_2H_4 (C_2y increases)

In case of net electricity production, the CO_2 emissions decreases (becoming negative (OTM#2)

From an environmental point of view the fuel switching represent already a -20% CO_2 emissions reduction (worst case scenario)

Conclusions

- Conventional OCM is not convenient compared to established Naphtha Steam Cracking
- OCM integrated with membranes and membrane reactor can results advantageous due to the higher CH_4 to C_2H_4 conversion
- In case of MIEC, electricity production is higher than the cost of compression and refrigeration and it re`resents a products of the plant ($3\%<\eta_{el}<16\%$)
- The emissions results from $-0.65<t_{CO2}/t_{C2H4}<1$ compared to 2.5-3t_{CO2}/t_{C2H4} of Naphtha
- The integration of MIEC in OCM reactor required a deep engineering of membrae to increase (significantly) the membrane_area/mebrane_volume ratio

Thank you for your attention

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MEthane activation via integrated MEmbrane REactors