



Third International Conference  
On Clean Coal Technologies  
For our future

# THERMOECONOMIC ANALYSIS OF AN INNOVATIVE CO<sub>2</sub> ZERO EMISSION PROCESS FOR THE CO-PRODUCTION OF HYDROGEN AND POWER

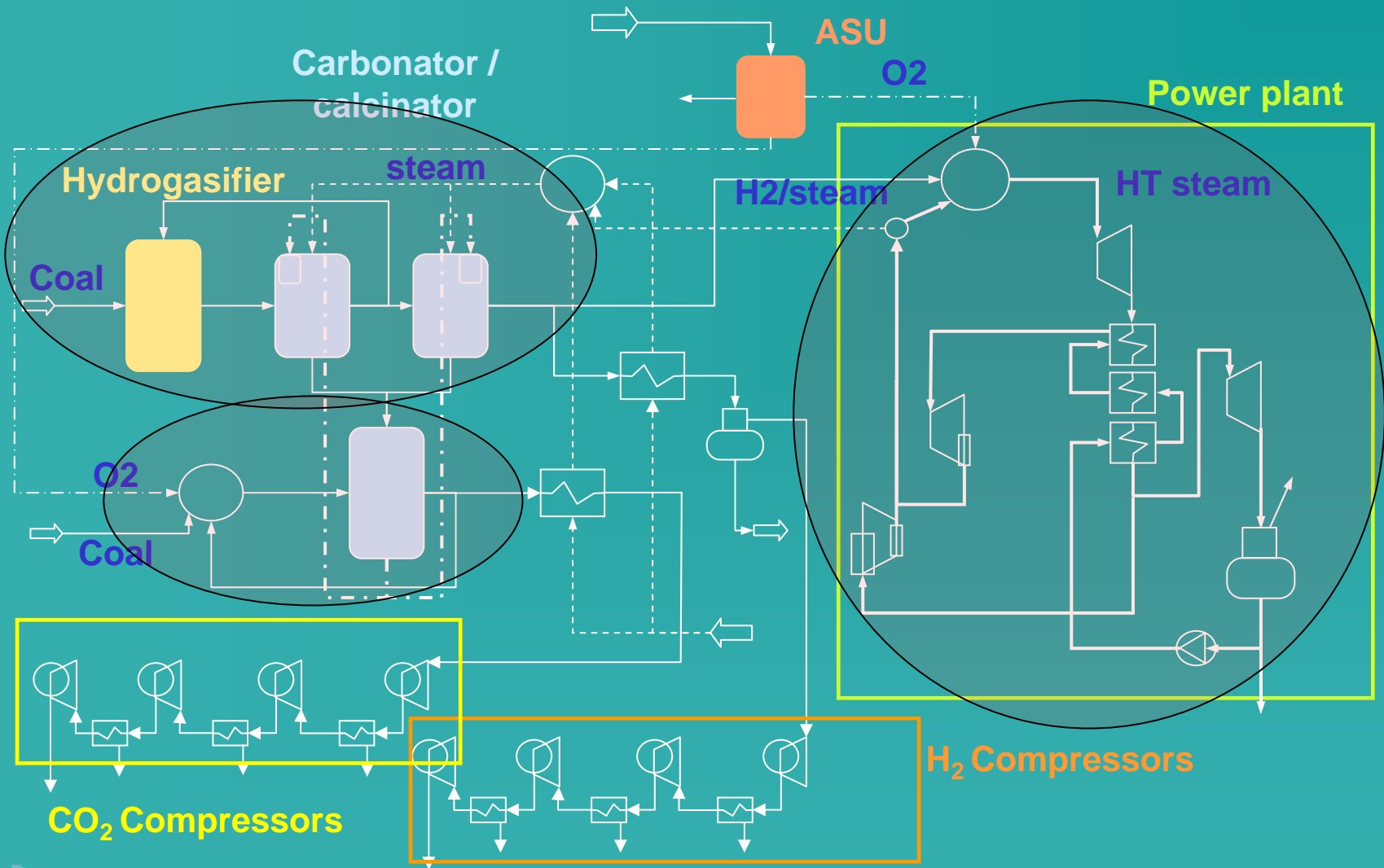
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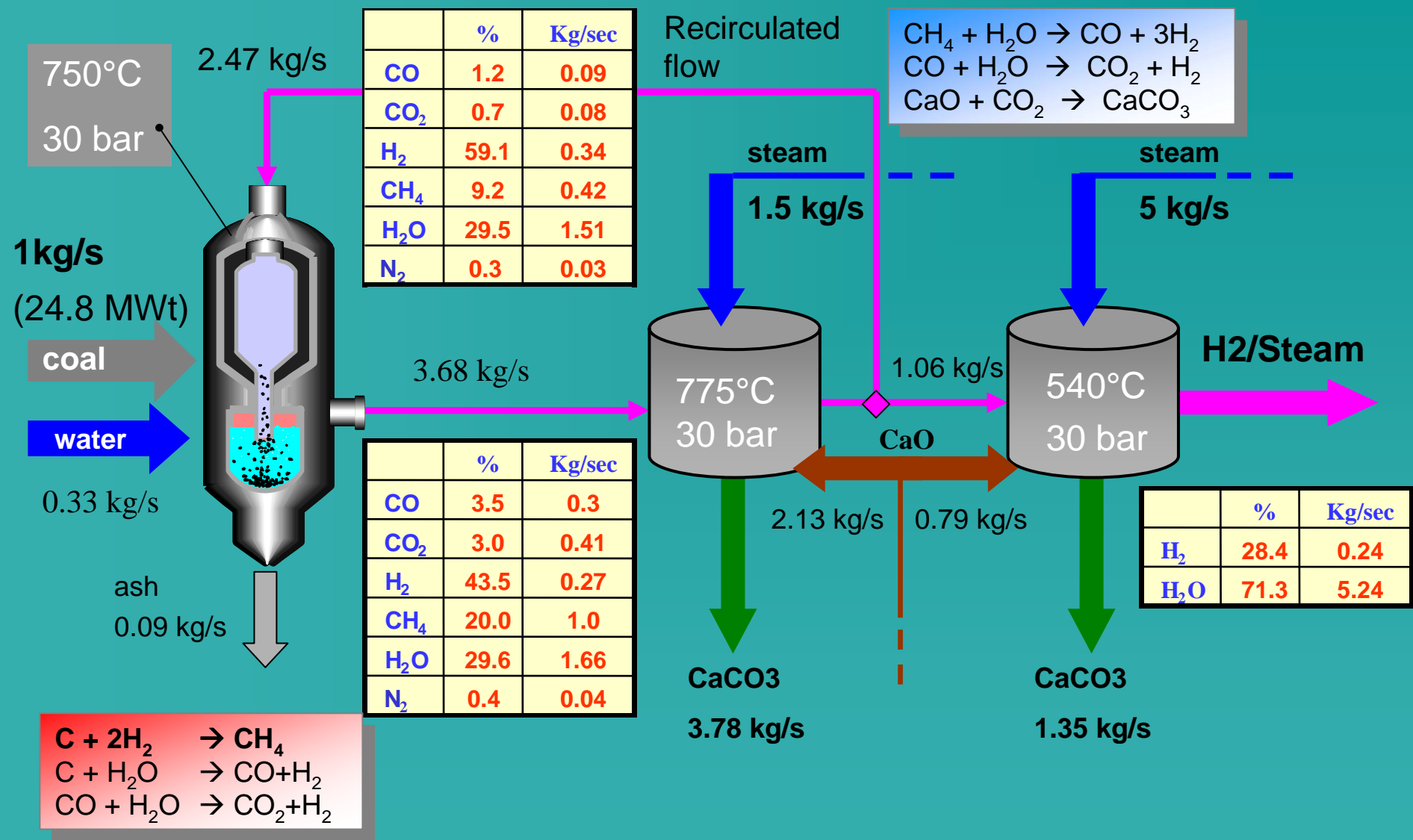
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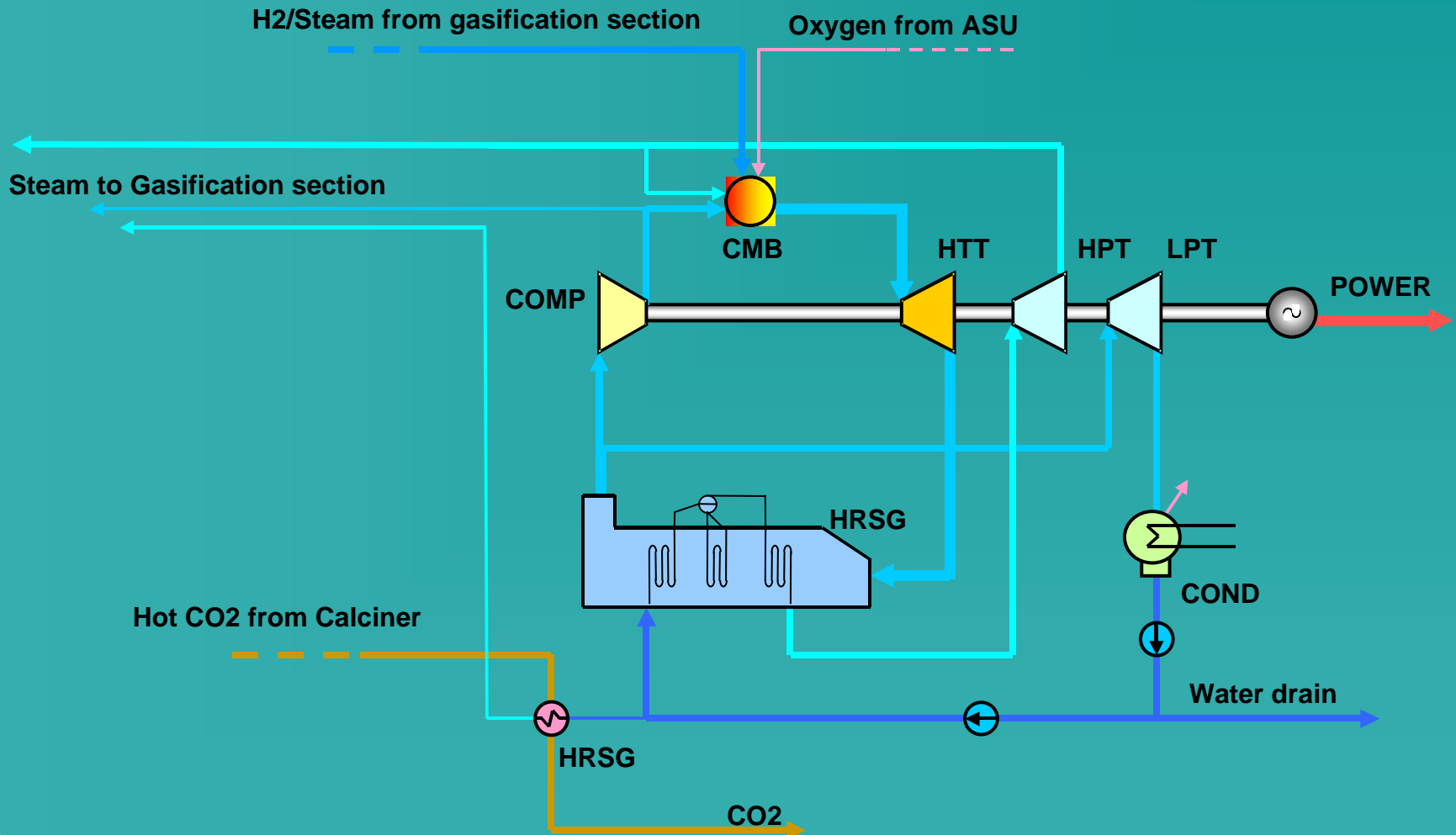
# ZECOMIX plant. Description



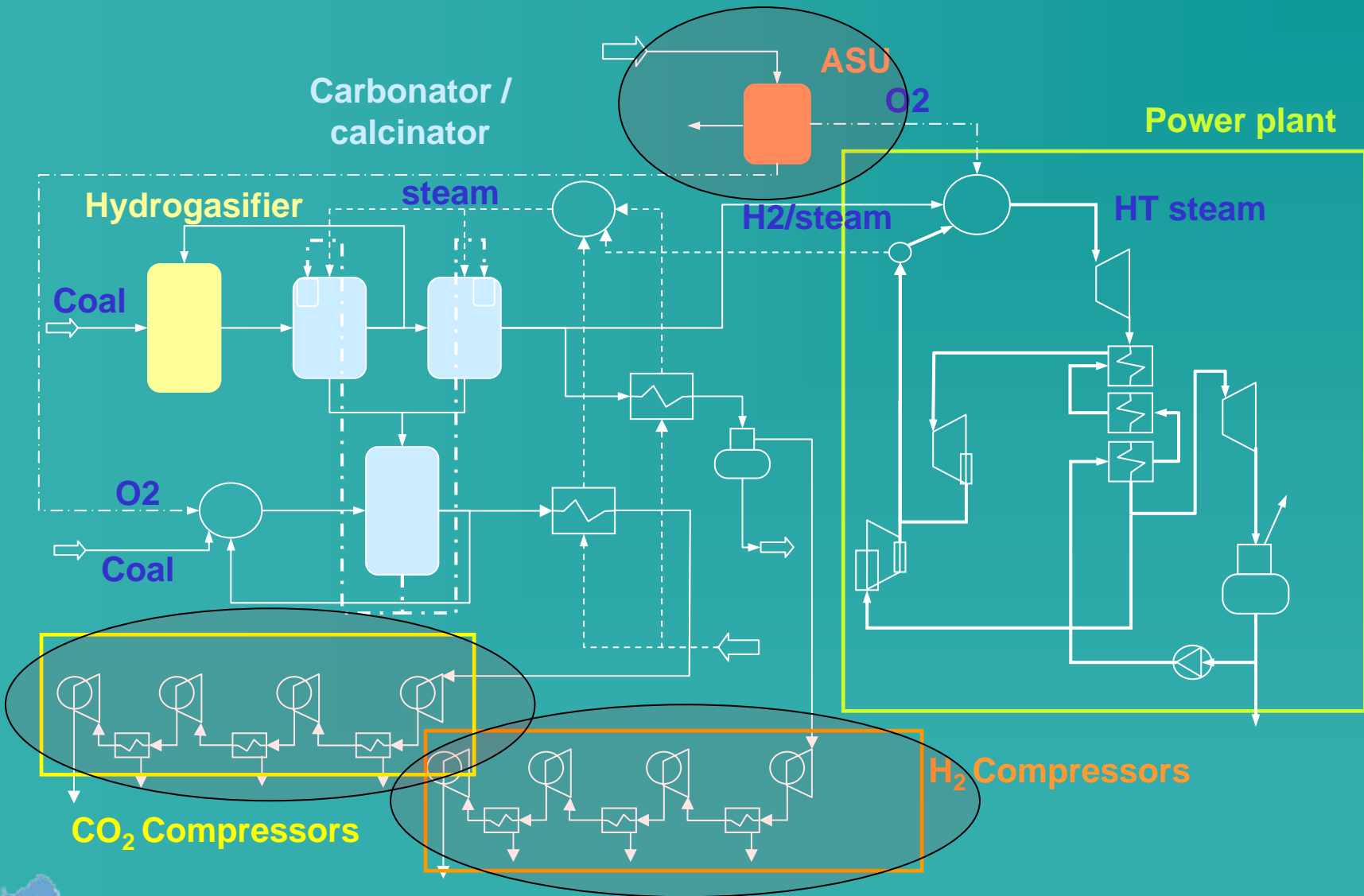
# Coal gasification & H2 production section



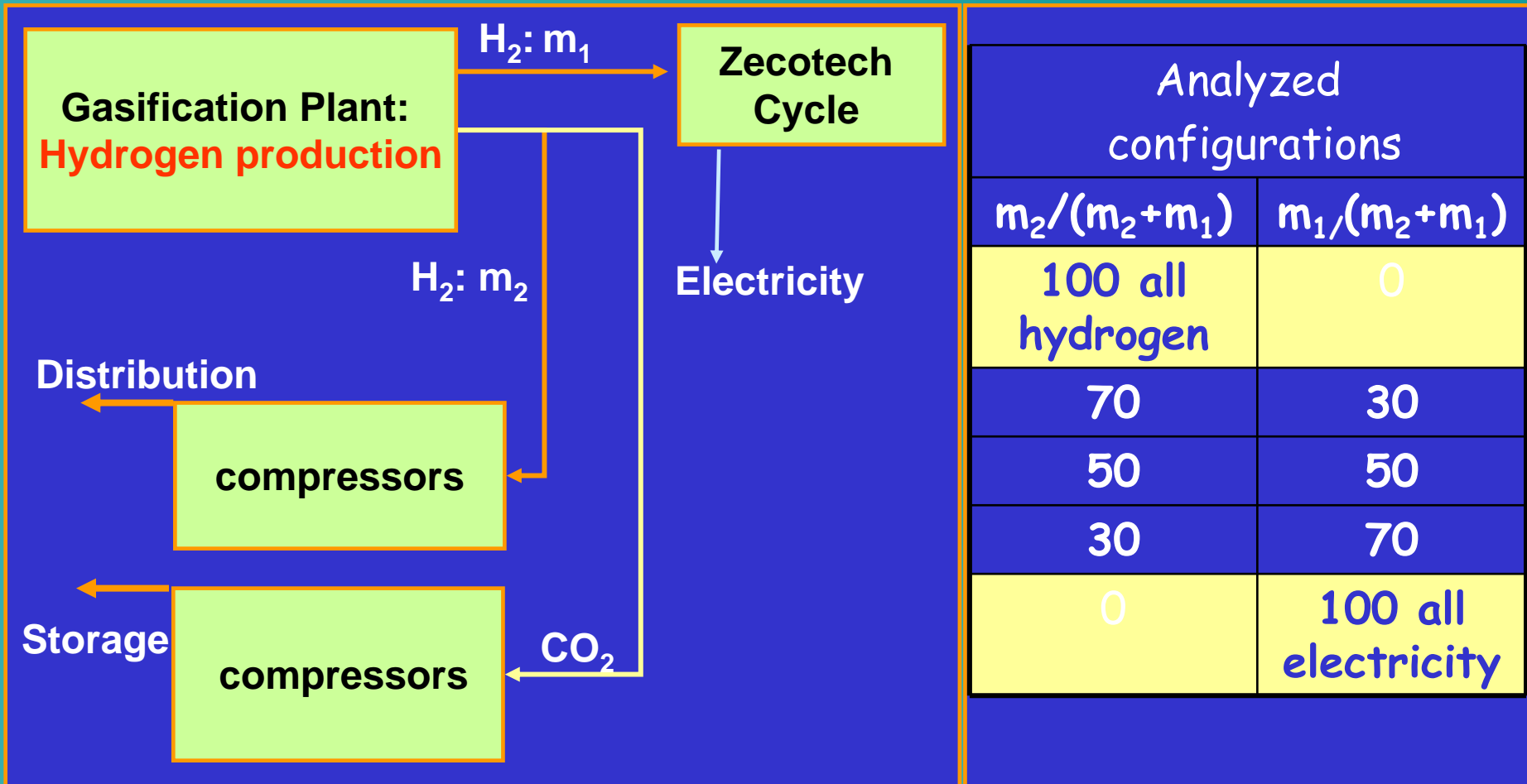
# Power Section (Zecotech cycle)



# ZECOMIX plant: net efficiency 50%



# Plant configurations in thermo-economic analysis



# Plant configurations simulation results

CR (%)	Energy Eff.	Exergy Eff.	Coal input (kg/s)		Production	
			Gasifier (A)	Calciner (C)	H2 (kg/s)	Electricity (MW)
100	78%	43%	59.1	25.4	18.7	0.0
70	66%	41%	59.1	25.4	13.7	250.0
50	62%	43%	26.9	11.6	4.4	250.0
30	56%	46%	17.4	7.5	1.7	250.0
0	50%	50%	11.4	4.9	0.0	250.0

# Thermoeconomic analysis

Goal: minimization of products cost



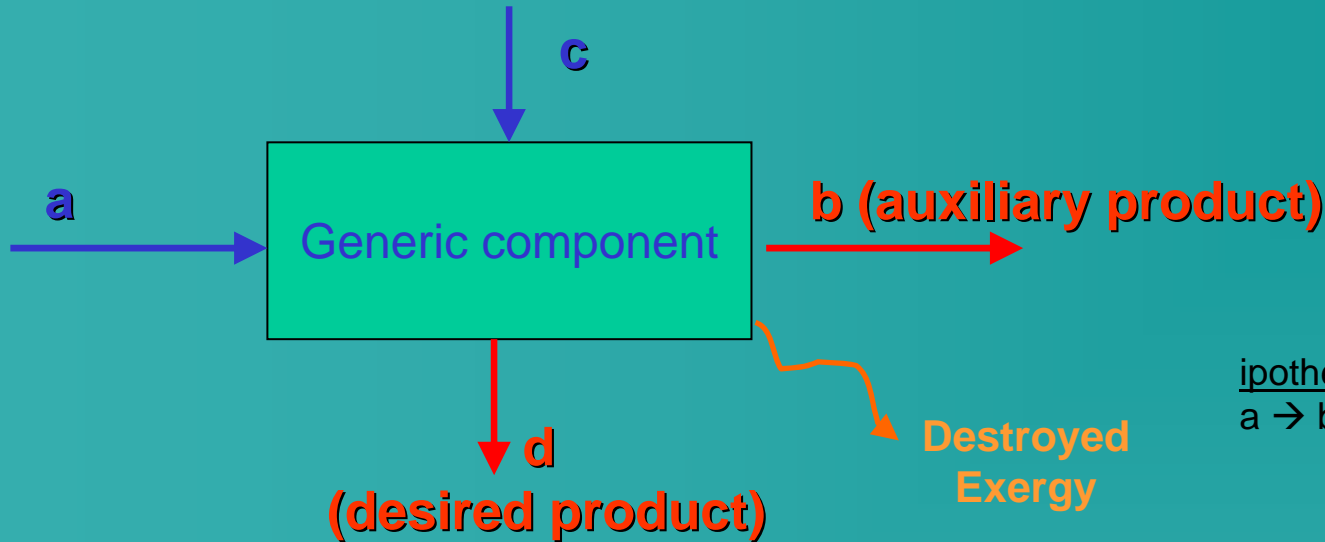
## 1) Correct Allocation of:

- *Capital costs* of each plant components
- *Operating costs* (efficiency components and primary resources)

## 2) Combination of:

- *Investment*
- *Thermodynamic analysis*

# Thermoeconomic analysis: procedure



ipotesis:  
 $a \rightarrow b$  auxiliary step  $\Rightarrow c_a = c_b$



auxiliary equation:

$$c_a = c_b$$

Cost balance equation:

$$m_a \cdot e_a \cdot c_a + m_c \cdot e_c \cdot c_c + Z = m_b \cdot e_b \cdot c_b + m_d \cdot e_d \cdot c_d$$

where:

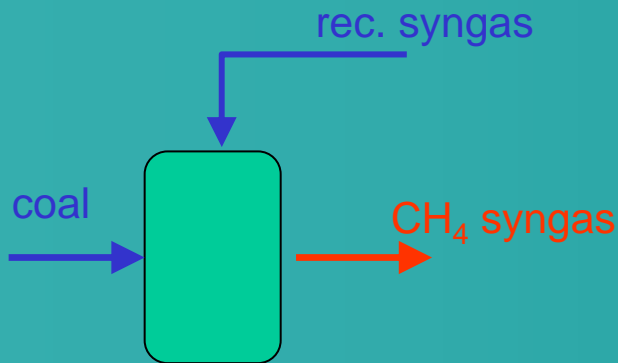
**m:** mass flow rate (kg/s)

**e:** specific exergy (kJ/kg)

**c:** exergy cost (€/kJ)

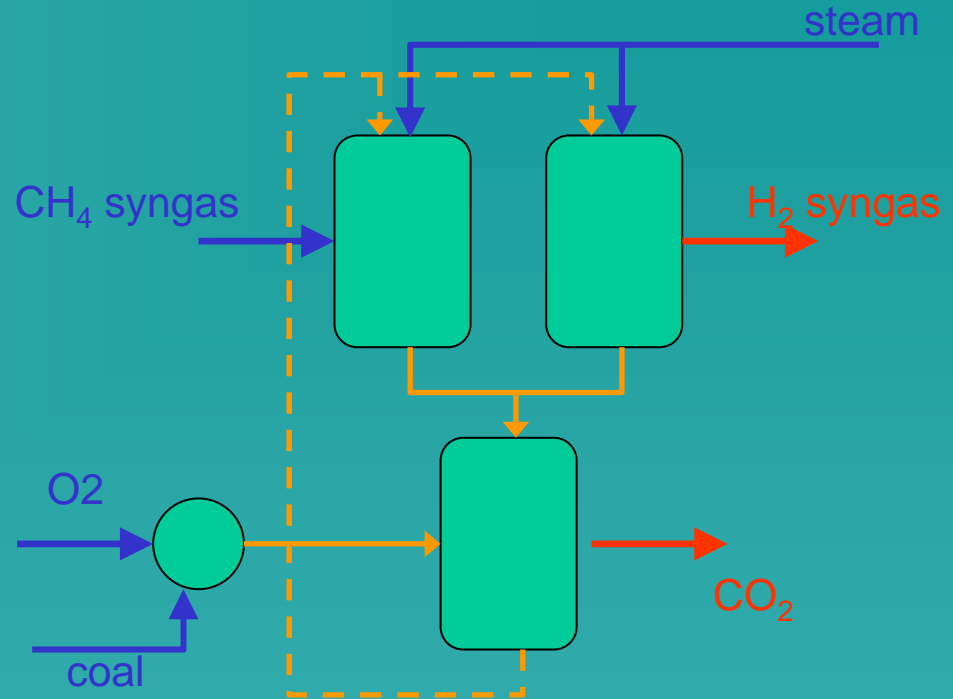
# Thermoeconomic analysis: component cost balance equation

Hydrogasifier



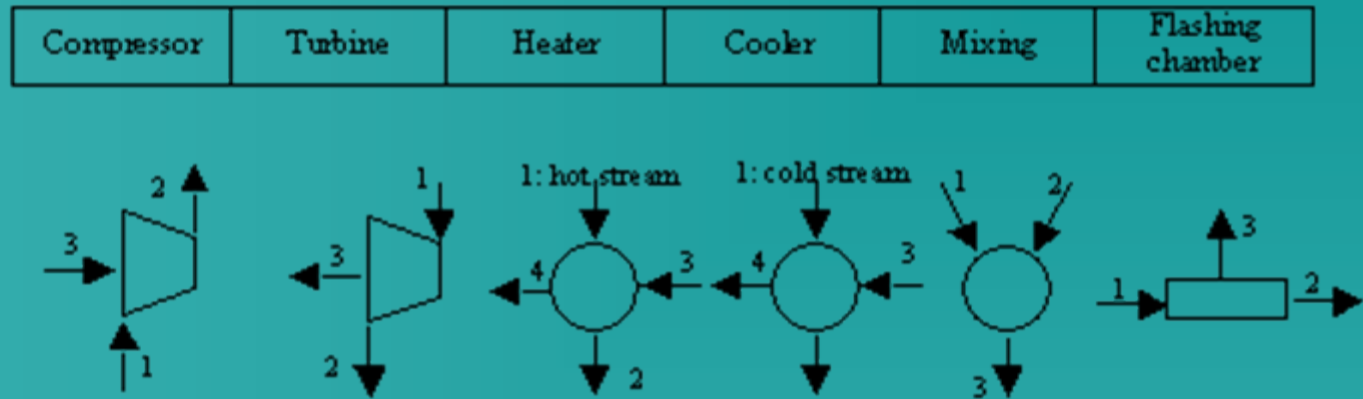
$$m_{\text{coal}} * e_{\text{coal}} * c_{\text{coal}} + m_{\text{rec}} * e_{\text{rec}} * c_{\text{rec}} + Z = m_{\text{ch4}} * e_{\text{ch4}} * c_{\text{ch4}}$$

CO2 capture section:



$$m_{\text{coal}} * e_{\text{coal}} * c_{\text{coal}} + m_{\text{o2}} * e_{\text{o2}} * c_{\text{o2}} + m_{\text{steam}} * e_{\text{steam}} * c_{\text{steam}} + m_{\text{ch4}} * e_{\text{ch4}} * c_{\text{ch4}} + Z = m_{\text{h2}} * e_{\text{h2}} * c_{\text{h2}} + m_{\text{co2}} * e_{\text{co2}} * c_{\text{co2}}$$

# Thermoeconomic analysis: component cost balance equation



Auxiliary equation	NONE	$c_1=c_2$	$c_1=c_2$	$c_1=c_2$	NONE	$c_1=c_2$
Product	2	3	4	4	3	3

# Cost assignment

R&D component:  $C = C_0 * \left(\frac{x}{x_0}\right)^\alpha$

Conventional component:  $C = f(x_1, x_2, \dots, x_n)$

Conventional component outside allowable range:  $C = f(x_1, x_2, x_3) * \left(\frac{x}{x_0}\right)^\alpha$

x: representative size parameter

C0: known cost of component with x=x0

α: depends on component type

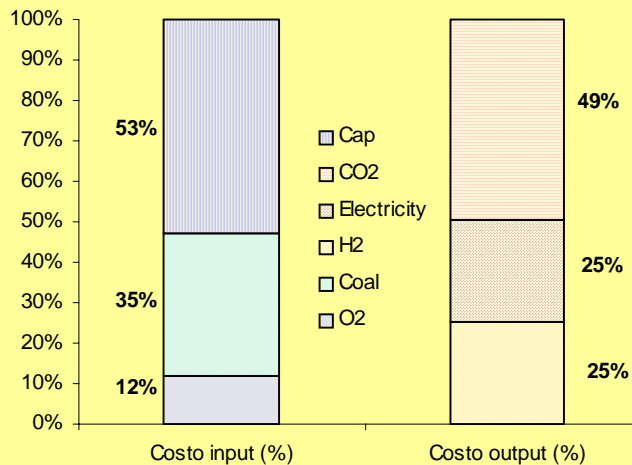
Investment parameters	
Time frame investment	20 years
Interest rate	5%;
Plant load factor	85%.

## Plant construction contingencies as percentage of total components cost

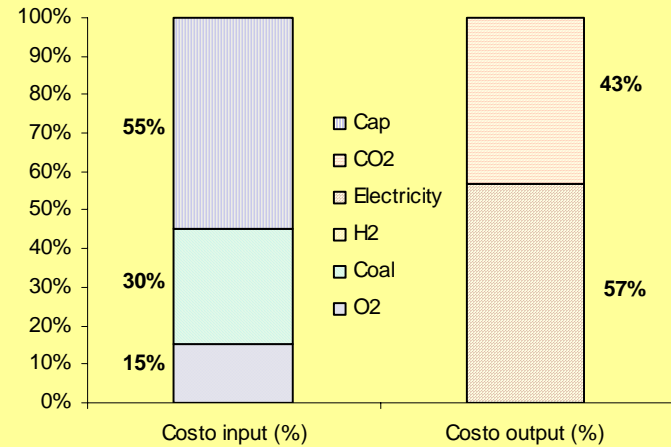
Instrumentation and control	5%
Land	5%
Buildings	15%
site preparation	5%
Civil works	15%
Electronics	15%
Piping	20%
Engineering	20%
Building interest	8%
project contingency fees	10%
start up	5%
Auxiliaries	14%
Coal Pre-treatment	5%

# Results of analysis: cost distribution

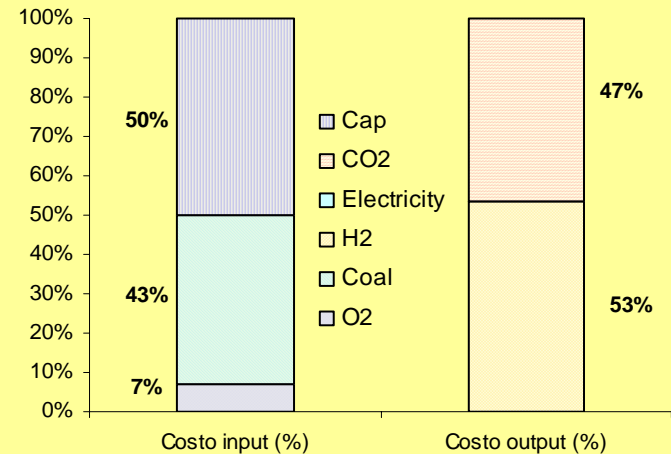
Cost distribution (50% H2 - 50% Elec)



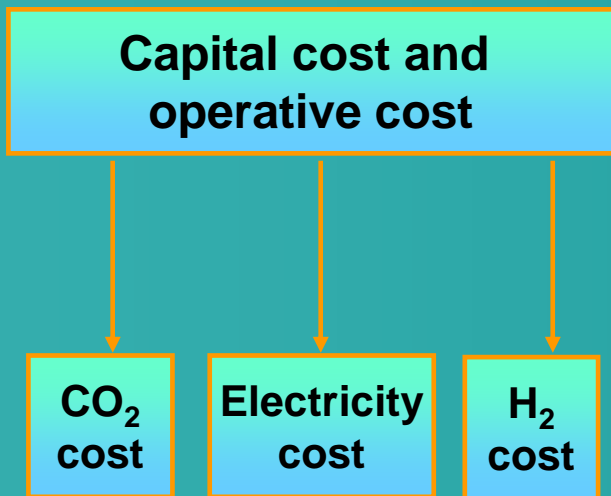
Cost distribution (0% H2 - 100% Elec)



Cost distribution (100% H2 - 0% Elec)



# Results of analysis: products specific cost



**H<sub>2</sub> cost:**

- Gasifyer capital cost
- Coal consumption
- Compression
- Oxygen consumption

**Electricity cost;**

- Power plant capital cost
- Syngas consumption
- Oxygen consumption

**CO<sub>2</sub> cost:**

- Decarbonator/calcinator capital cost
- CO<sub>2</sub> compression
- Calcination coal consumption

CR (%)	CO2 cost (€/ton)	Electricity cost (c€/kWh)	H2 (€/GJ)
100	21,8	0,0	3,2
70	25,1	2,0	3,0
50	25,9	2,0	3,2
30	26,8	2,0	3,1
0	30,0	2,5	0,0

# Results of analysis: hydrogen and electricity cost

CR (%)	$\eta=1$		$\eta=0.55$		Overall Exergy cost (€/GJ)**
	Cost electricity (c€/kWh)*	H2 (€/GJ)*	Cost electricity (c€/kWh)**	H2 (€/GJ)**	
100	0.00	5.9	0.00	5.9	10.8
70	3.18	6.8	3.92	6.4	11.4
50	3.29	7.4	3.84	6.4	11.2
30	3.50	7.7	3.85	6.2	10.8
0	4.36	0.0	4.36	0.0	12.1

\*H<sub>2</sub> exergy as is

\*\* H<sub>2</sub> processed in a plant with 0.55 exergy conversion efficiency

**Hydrogen cost = 5.9 €/GJ (7.1 \$/GJ)**  
**Electricity cost 4.36 c€/kWh (5.23 c\$/kWh)**

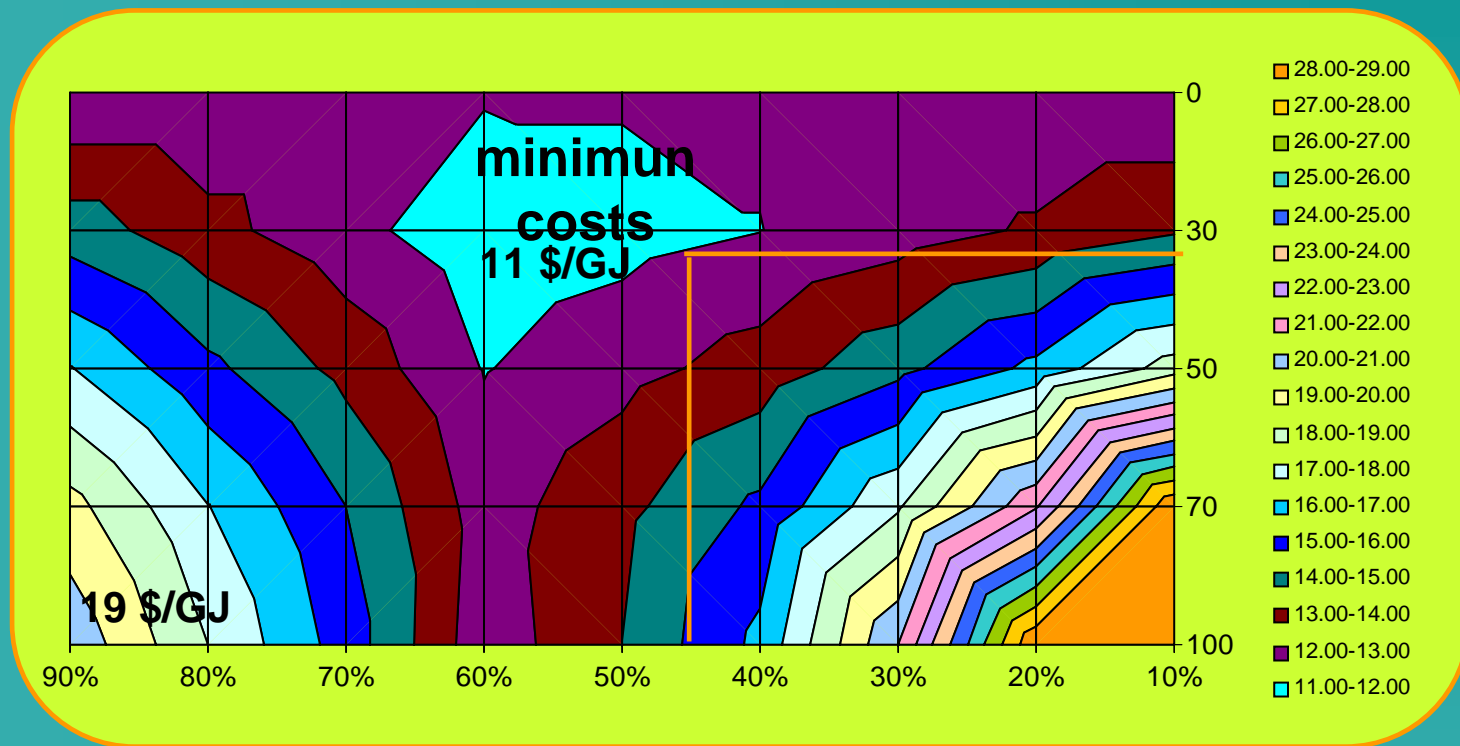
# Comparison with published data (CR = 0)

	No-CO <sub>2</sub> capture			CO <sub>2</sub> capture		
	Capital cost (\$/kW)	Elec. cost (c\$/kWh)	Eff	Capital cost (\$/kW)	Elec. cost (c\$/kWh)	Eff
<b>Entrained flow Gasifier IGCC plant</b> (Pre -Combustion Capture)	1.371	4,8	43%	1.860	6,3	35%
<b>Entrained flow Gasifier IGCC plant</b> (precombustion CO <sub>2</sub> capture)	1.187	4,5	38%	1.495	5,6	32%
<b>Supercritical pulverized coal plant</b> (post combustion capture )	1.222	4,4	44%	1.755	6,2	33%
<b>Supercritical pulverized coal plant</b> (post combustion capture )	1.171	4,3	44%	1.858	6,3	35%
<b>Oxy-fuel capture on advanced supercritical</b> Pulverized coal plant	1.513	4,9	44%	2.342	7,28	35%
<b>Oxy-fuel capture on advanced supercritical</b> Pulverized coal plant ( )	1.171	4,3	44%	1.858	6,3	35%
<b>ZECOMIX</b> <b>(CR0 configuraion -all power configuration)</b>	-	-	-	<b>2.716</b>	<b>5,2</b>	<b>50%</b>

# Cost and efficiency conversion of hydrogen final conversion devices

Plant type	Capital cost k€/kW	Conversion Efficiency
Fuel cells*	4.0	90%
Fuel cells *	3.0	80%
Fuel cells *	2.0	70%
Combined Plant (NGCC)*	0.7	60%
Combined Plant (NGCC)*	0.6	50%
Turbo gas	0.4	40%
Turbo gas	0.3	30%
Otto Engine*	0.2	20%
Otto Engine*	0.1	10%
<p>Approximation of +/- 30% has to be considered in plant capital cost</p> <p>* Several levels of costs and efficiencies have been considered for the same technology</p>		

# Analysis of the cogenerative ratio



High efficiency,  
high costs

Low efficiencies, low costs

# Conclusions

Zecomix Plant capital costs account for more than 50% of the total, the CO<sub>2</sub> capture process ought to be charged with more than 40% of the whole plant cost (operative + capital)

Several plant configurations have been analyzed, each of them characterized by different co-production ratios. The estimated product costs for the “all power” and “all hydrogen” configurations are respectively 4.36 c€/kWh and 5.9 €/GJ and confirm the validity of the proposed solution

A method for the choice of most convenient co-production ratio has been developed and applied.



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Thank you for the attention



ENEA Test Platform

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