



UNIVERSITY OF PERUGIA



*1st European Fuel Cell Technology  
& Applications Conference  
December 14-16, 2005 - Rome, Italy*

# **MCFC / Biomass energy recovery concept is technically, economically, and environmentally viable !!!**

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## OBJECTIVES



- **Propose technical analysis of integration between Molten Carbonate Fuel Cell and Gaseous Biofuels**
- **Assess the Italian potential market**
- **Compare MCFC based systems with conventional ones (ICE and GT) performing a technical, economical and environmental factors analyse**



➤ INTRODUCTION

➤ SOLID BIOMASS:

- Municipal Solid Waste (MSW)

- Assessment of Italian potential market
- Composition of landfill gas (LFG)
- Example of LFG/MCFC system
- Summary

- Agricultural, wood and agro-industrial by-products

- Assessment of Italian potential market
- Bio-Syngas
- Example of Gasifier - MCFC system
- Summary

➤ LIQUID BIOMASS:

- Wastewater and Manure

- Anaerobic Digester Gas
- Assessment of Italian potential market
- Italian Case Study (Marsciano, Perugia): System description
- Technical-economical analysis
- Multicriteria Analysis
- Summary



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## INTRODUCTION



The main advantages of Gaseous Biofuels/MCFC:

$E^3$

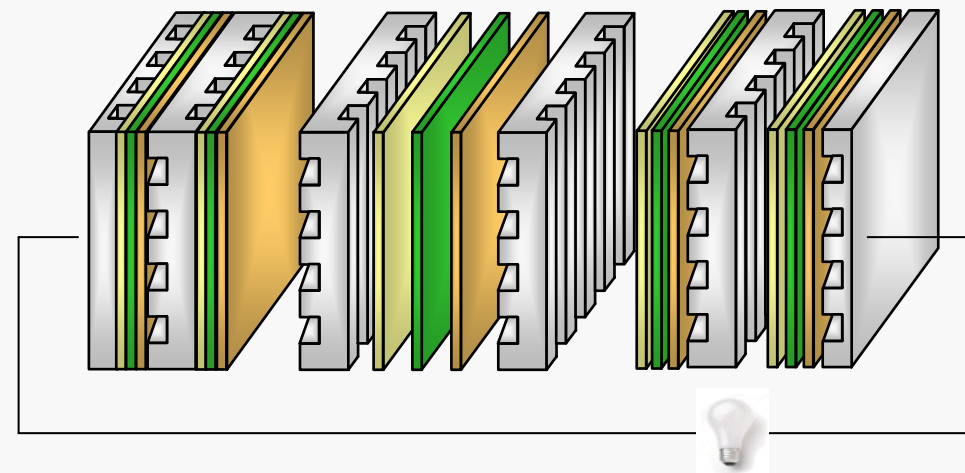
Energetic advantages

Environmental advantages

Economical advantages

## Energetic advantages

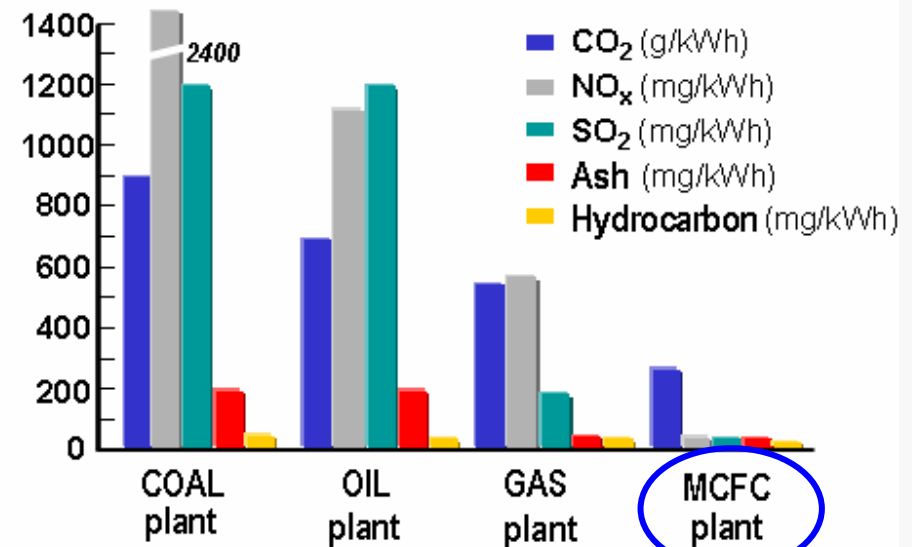
- *Reduction of dependence on primary energy sources*
- High efficiency (50 – 55%)
  - Possibility of co-generation and tri-generation
  - Size flexibility
  - Decentralization of electrical energy production for more secure and stable grid and for minimizing transfer losses





## Environmental advantages

- *Reduction of dependence on primary energy sources*
- Reduction of pollution by greenhouse gases and contaminants
- Sustainable environmental advantages by using a CO<sub>2</sub> neutral fuel combined with high efficiency





# Economical advantages

- *Reduction of dependence on primary energy sources*
- Decentralization of consumable energy production for more secure and stable energy supply reducing costs for grid stabilizing
- New income for agricultural sector
- Closing the nutrient cycle by production of valuable fertilizer solving the deposition problem of biogas-plant effluent



**Different biomasses have been analysed:**

## **SOLID BIOMASS**

- |                                                      |   |              |
|------------------------------------------------------|---|--------------|
| • Municipal Solid Waste                              | ➔ | Landfill gas |
| • Agricultural, wood and agro-industrial by-products | ➔ | Bio-syngas   |

## **LIQUID BIOMASS**

- |                         |   |        |
|-------------------------|---|--------|
| • Wastewater and Manure | ➔ | Biogas |
|-------------------------|---|--------|



## APPLIED METODOLOGY

❖ Definition of gaseous flow's features



- Composition
- Energetic Content
- Pollutant Content
- Potential Market

❖ Comparing analysis on use of gaseous flow in conventional technology and in MCFC



- Technical Feasibility
- Economical Aspects
- Environmental Aspects



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# MSW PRODUCTION IN EUROPE BY COUNTRY

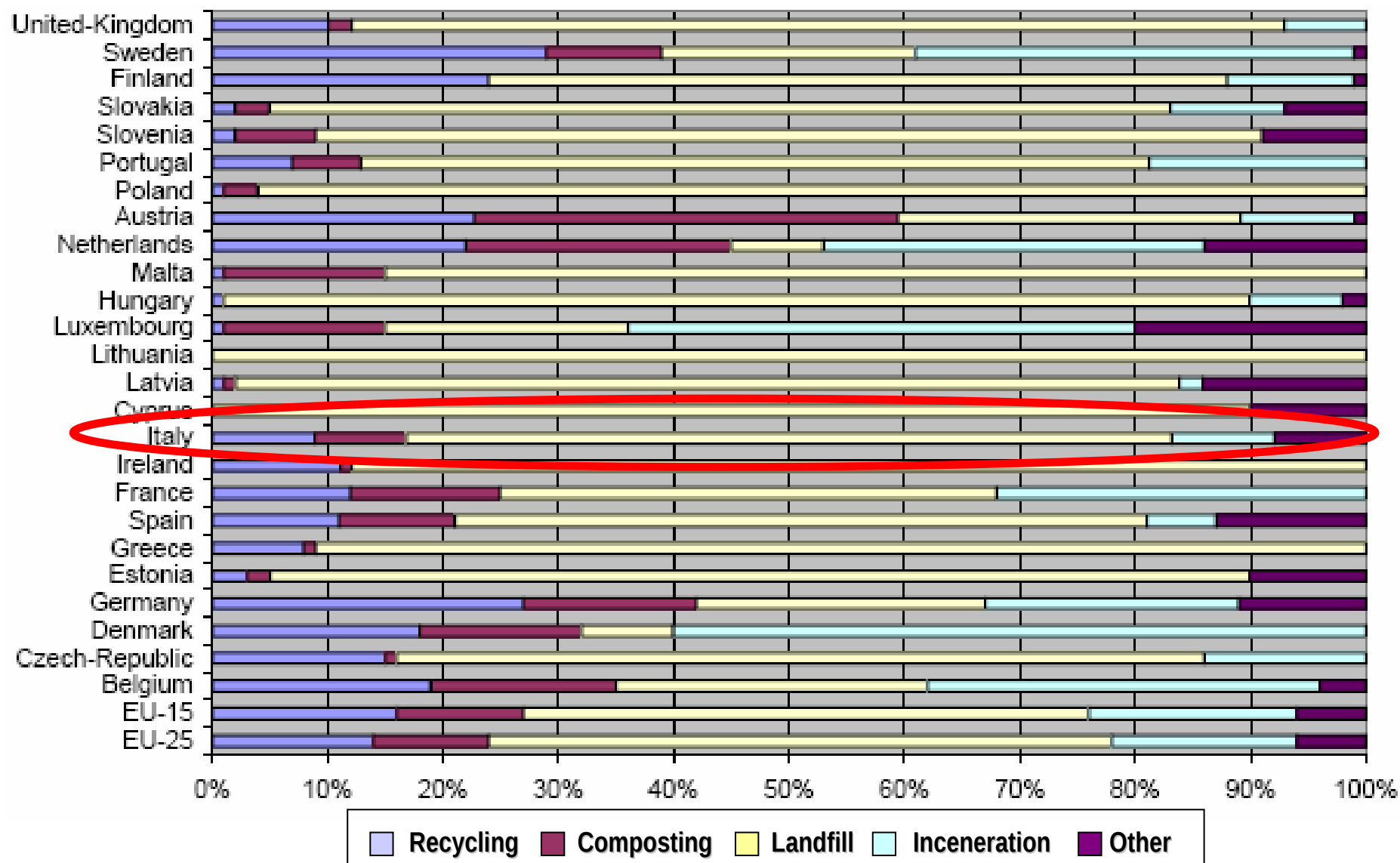




# WASTE MANAGEMENT



## European waste management

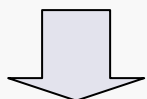




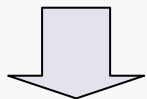
# LANDFILL GAS



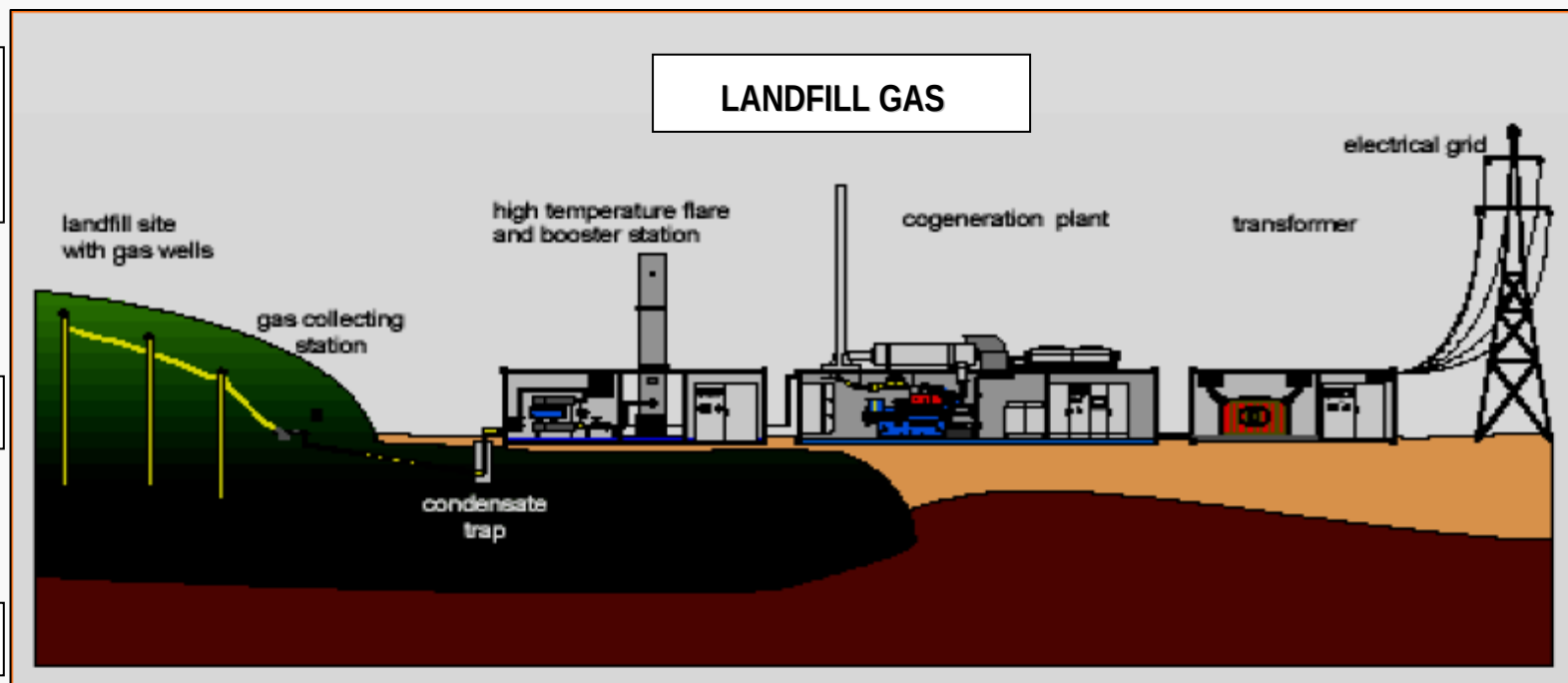
**MUNICIPAL  
SOLID  
WASTE**



**LANDFILL**



**BIOGAS**



## COMPOSITION OF LANDFILL GAS

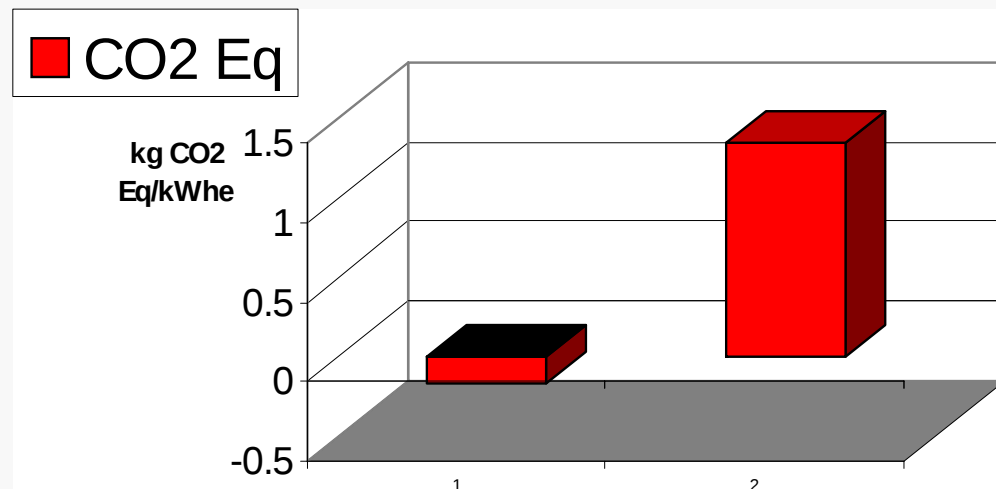
|                 | CH4<br>(%) | CO2<br>(%) | O2<br>(%) | N2<br>(%) | H2S<br>(%) | NH3<br>(%) | Others<br>(%) |
|-----------------|------------|------------|-----------|-----------|------------|------------|---------------|
| Landfill<br>gas | 45-60      | 40-60      | 0.1-1     | 2-5       | 0-1        | 0.1-1      | 0-1           |

**250 – 350 m<sup>3</sup>/ ton MSW**

**LHV = 16 – 22 MJ/Nm<sup>3</sup>**

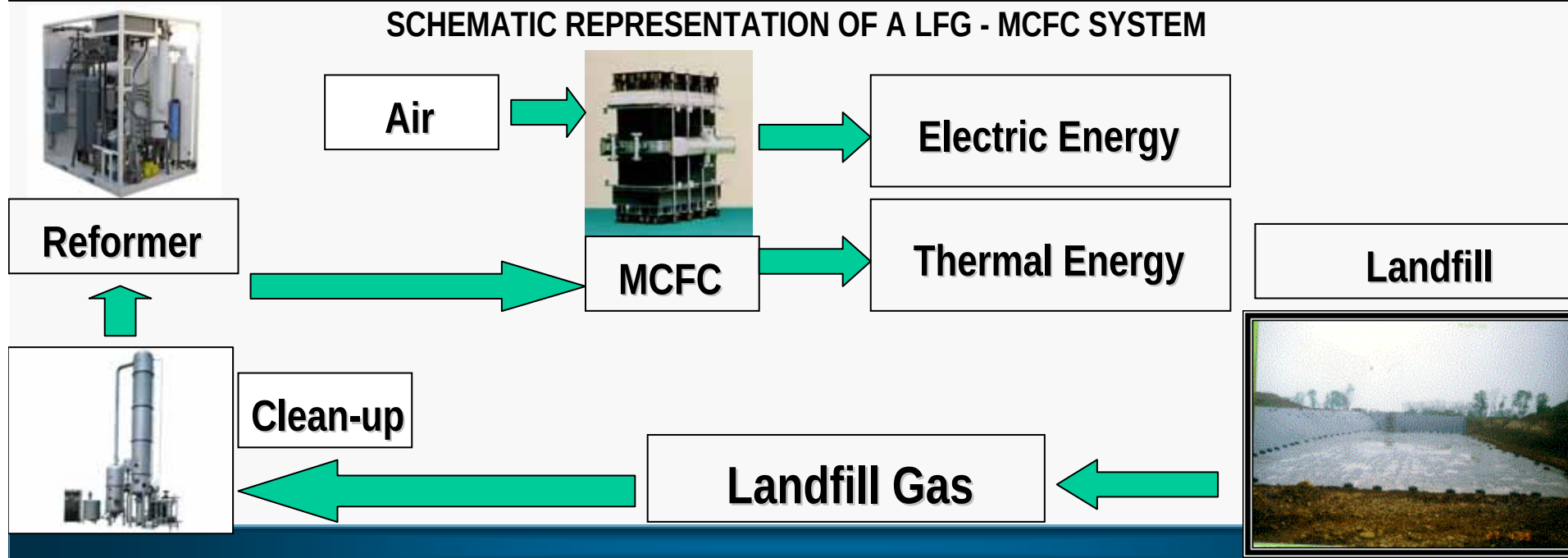


# LFG - MCFC SYSTEM



Global warming emissions comparison between LFG-MCFC and NG-MCFC

## SCHEMATIC REPRESENTATION OF A LFG - MCFC SYSTEM





## SUMMARY



- Landfill gas is very abundant in Italy;
- Comparison with traditional system shows impressive environmental benefits;

|                                            |               |               |                     |
|--------------------------------------------|---------------|---------------|---------------------|
| MSW in Italy                               | 30.000.000    |               | ton/y               |
| MSW in Landfill [65%]                      | 19.500.000    |               | ton/y               |
| Average biogas production for ton of MSW   | 250           | 350           | m <sup>3</sup> /ton |
| Average biogas production / year           | 4.875.000.000 | 6.825.000.000 | m <sup>3</sup> /y   |
| Intercepting efficiency                    | 60%           |               |                     |
| Average biogas production / year           | 2.925.000.000 | 4.095.000.000 | m <sup>3</sup> /y   |
|                                            | ICE/GT        | MCFC          |                     |
| % as regards to italian electricity demand | 1% - 2%       | 2% - 3%       |                     |
| Mton CO <sub>2</sub> avoided               | 3,5 -- 5,5    | 5,5 -- 8      |                     |
| % as regards to Kyoto goal for Italy       | 4,5% - 7%     | 7% - 10%      |                     |

- It is not possible to replace all the energy resources with LFG or to replace all the energy systems with fuel cells, a partial substitution would bring substantial emissions reduction and a decrease in resources consumption.



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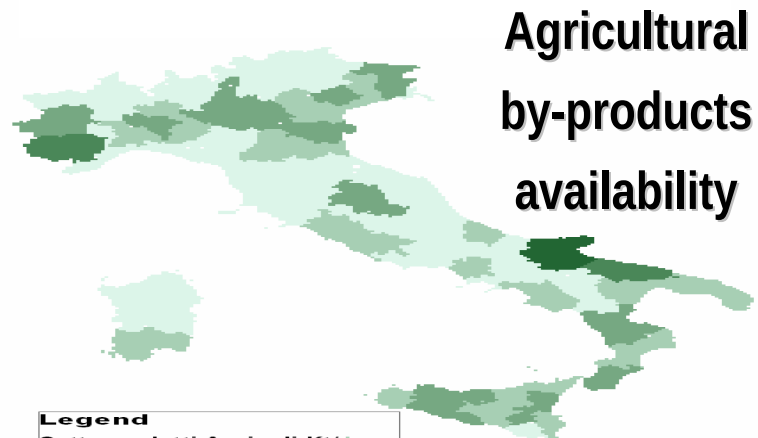
➤ **LIQUID BIOMASS:**

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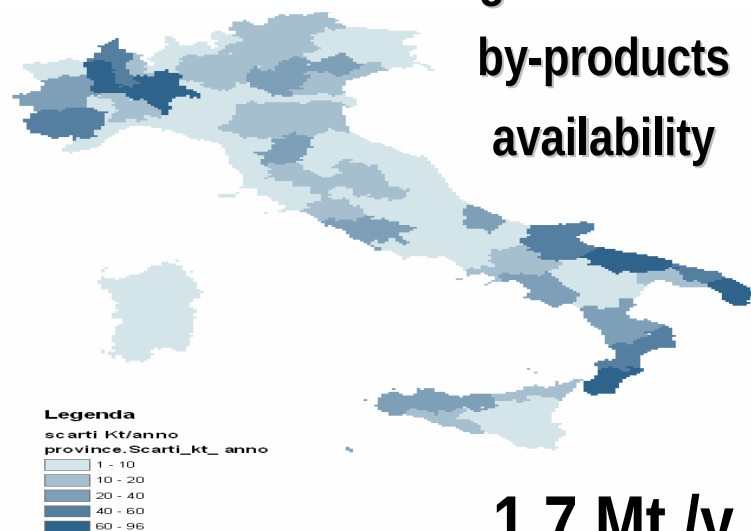
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# ITALIAN POTENTIAL MARKET



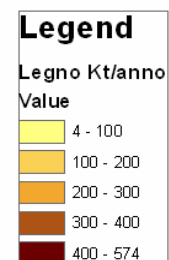
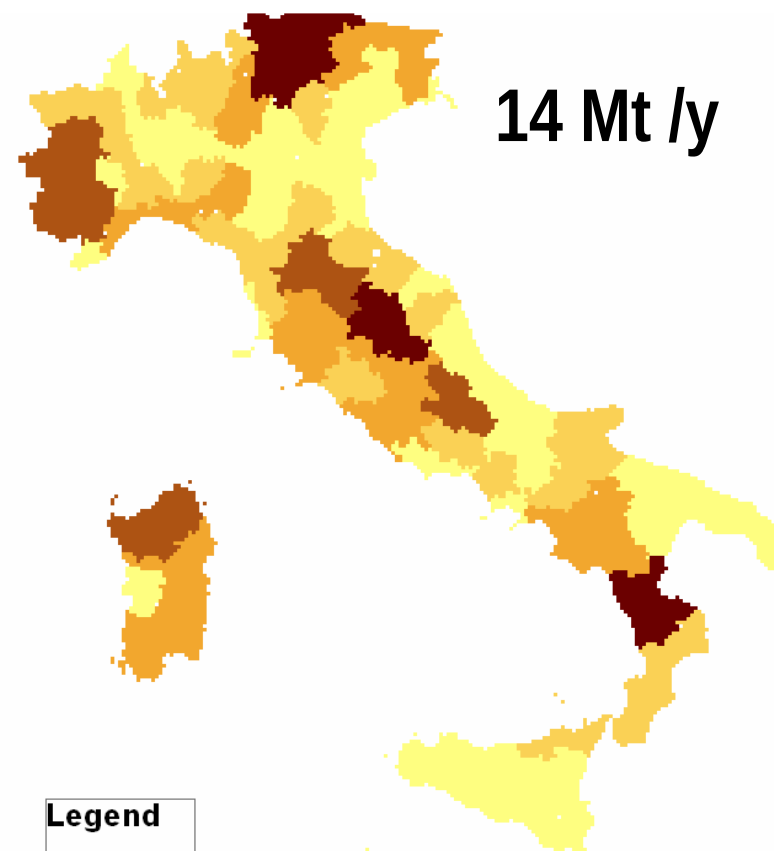
**8,9 Mt /y**



**1,7 Mt /y**

## Wood availability

**14 Mt /y**

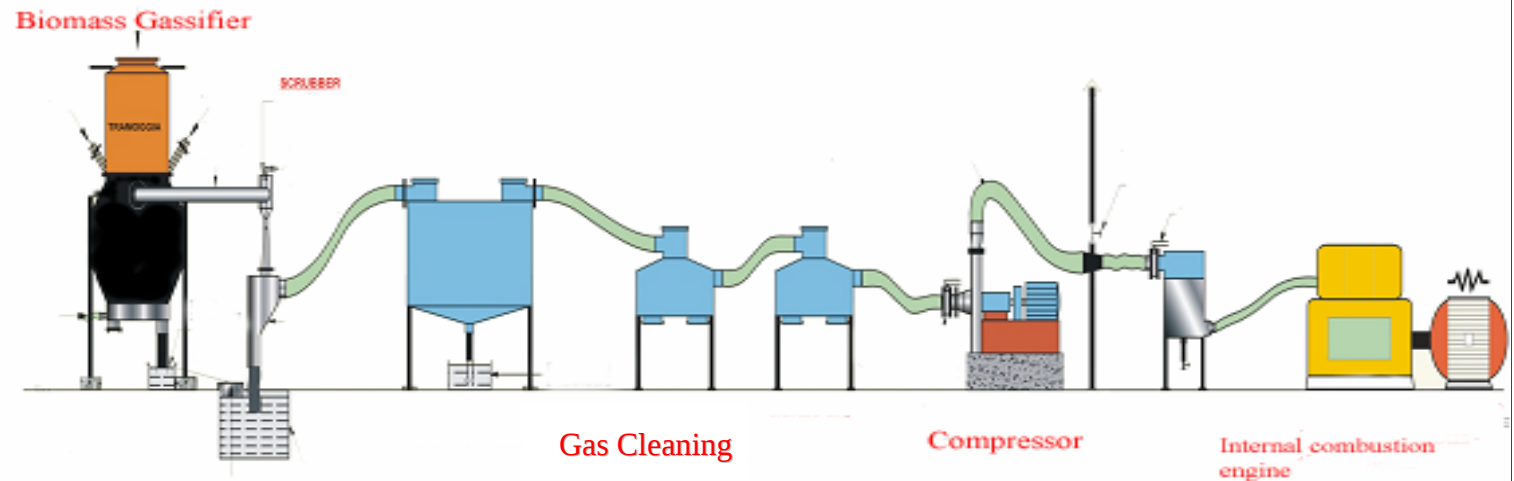




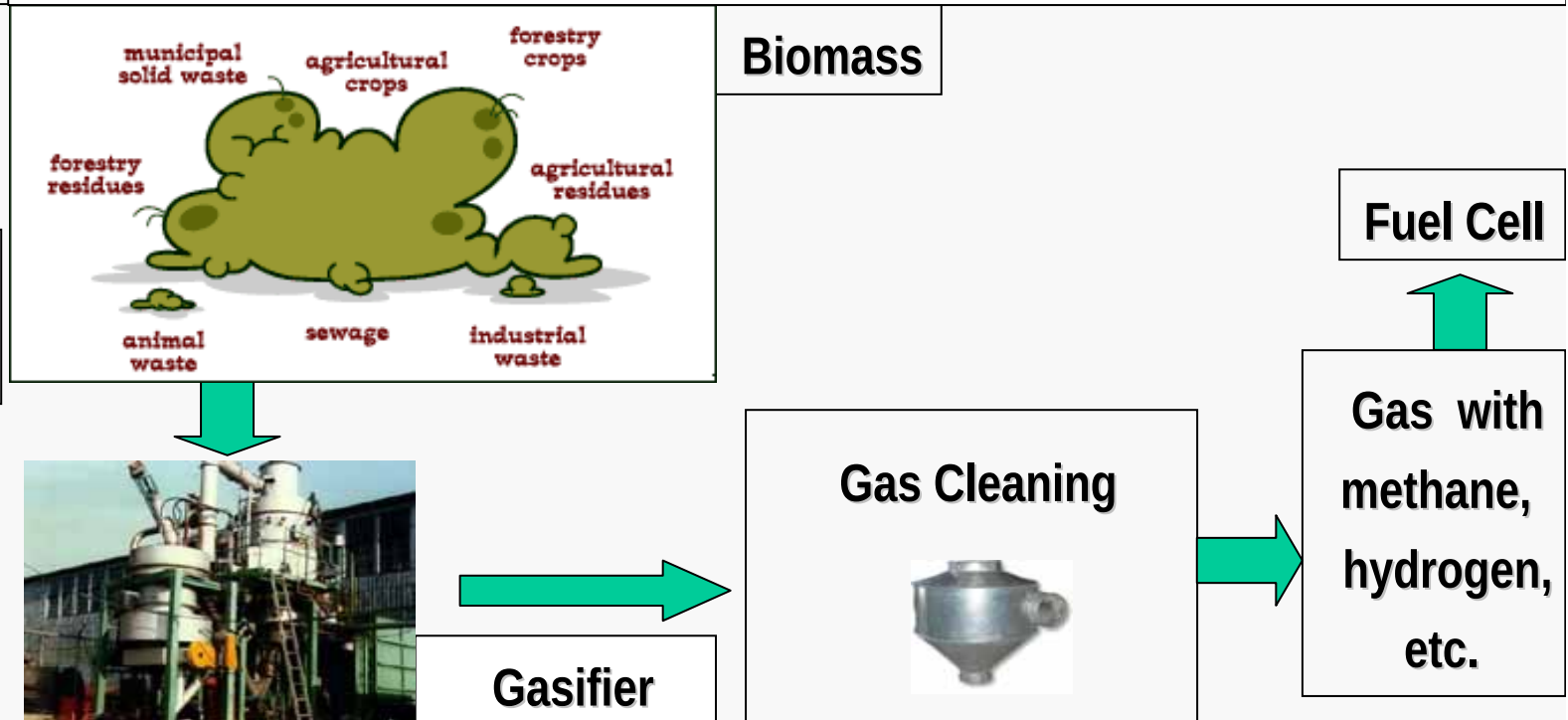
# SYNGAS FROM GASIFICATION



Typical  
schematic of  
gasifier-internal  
combustion  
engine



Schematic of  
gasifier-fuell-  
cell system





# SYNGAS FROM GASIFICATION

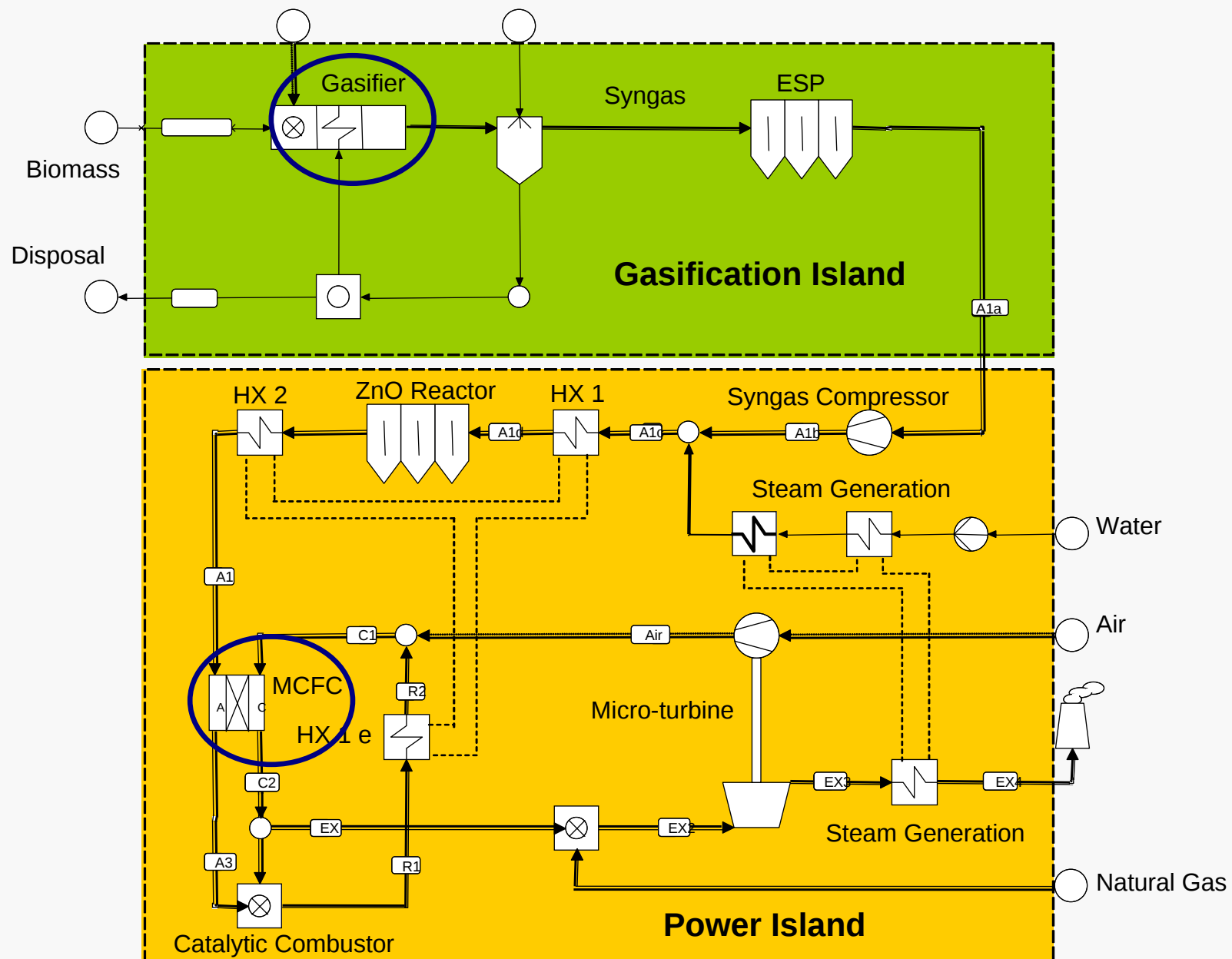


## BIO – SYNGAS COMPOSITION

| Agent for Gasification          | AIR                    | OXYGEN  |
|---------------------------------|------------------------|---------|
|                                 | <i>Typical conc. %</i> |         |
| H <sub>2</sub>                  | 10 ÷ 25                | 10 ÷ 30 |
| CO <sub>2</sub>                 | 10 ÷ 20                | 10 ÷ 20 |
| CO                              | 9 ÷ 25                 | 10 ÷ 45 |
| CH <sub>4</sub>                 | 3 ÷ 8                  | 1 ÷ 20  |
| N <sub>2</sub>                  | 30 ÷ 60                | 1 ÷ 5   |
| ASH (g/Nm <sup>3</sup> )        | 100 ÷ 200              | -       |
| <i>LHV (MJ/ Nm<sup>3</sup>)</i> | 8 ÷ 10                 | 14 ÷ 16 |



# EXAMPLE OF GASIFIER-MCFC



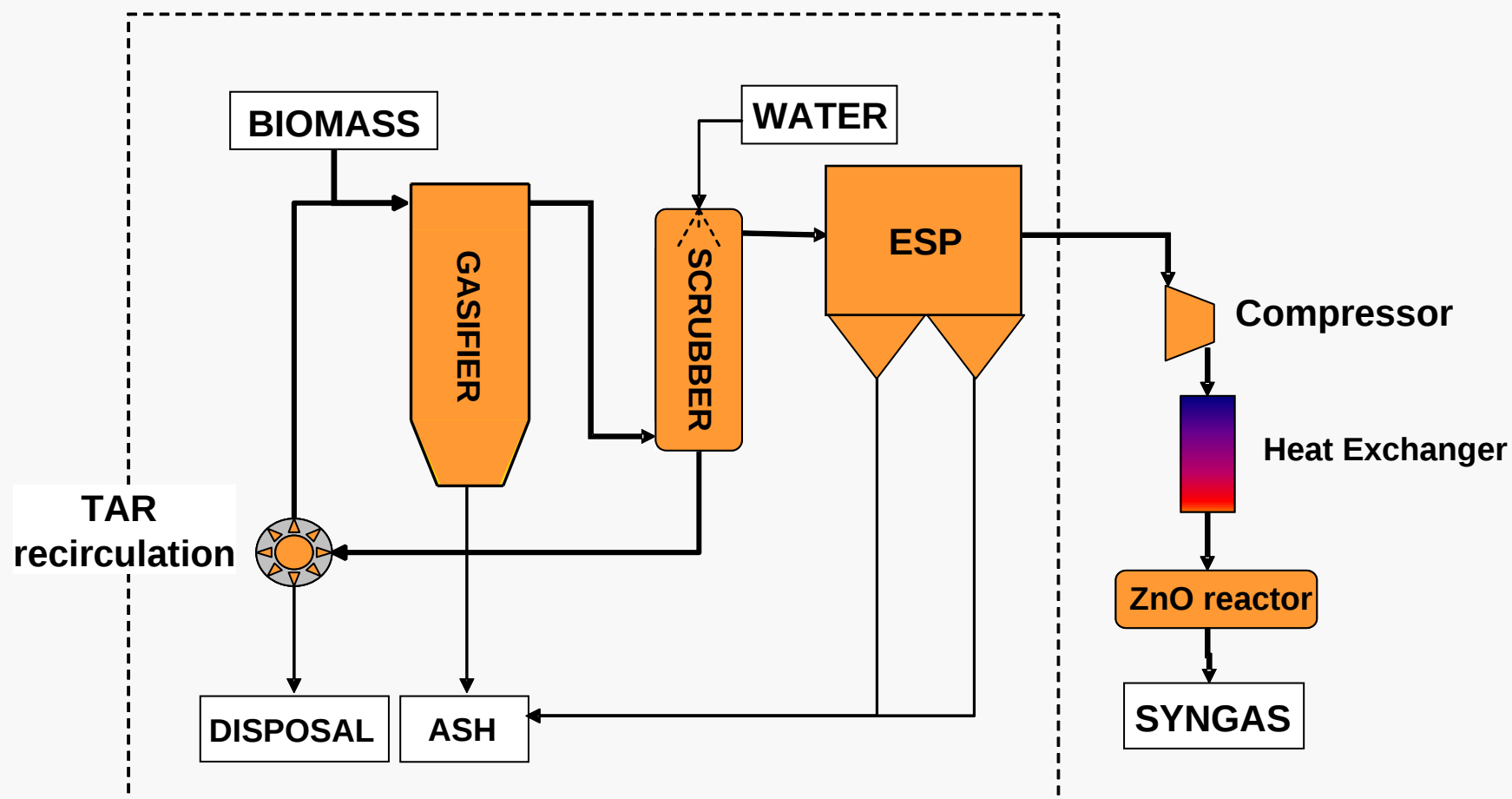


# EXAMPLE OF GASIFIER-MCFC



## Gasification Island

- *Counter-current fixed-bed gasifier*
- *Gas cleaning system*

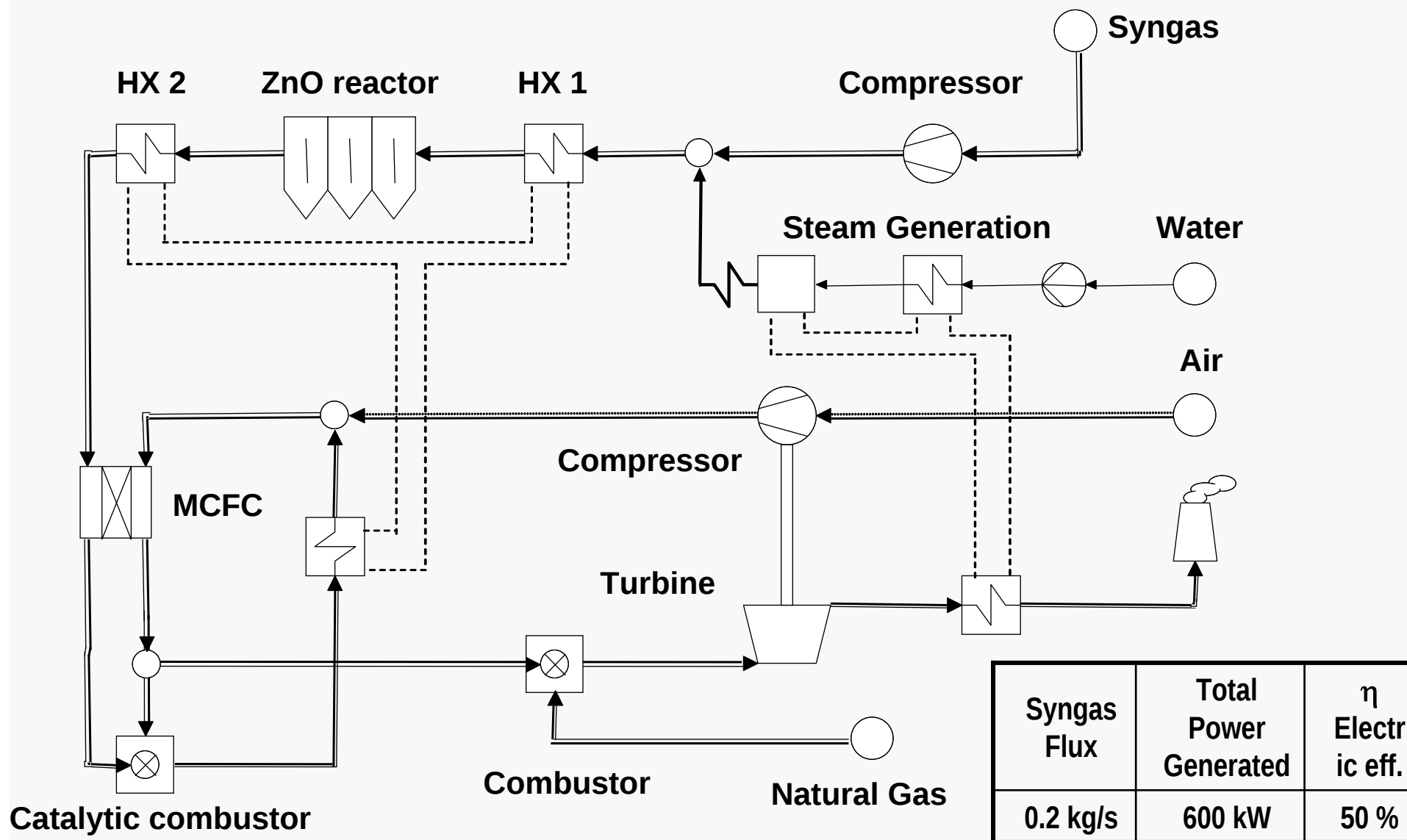




# EXAMPLE OF GASIFIER-MCFC



## Power Island





## SUMMARY



- Considering only a partial wood availability, there are significant advantages

|                                            |               |             |
|--------------------------------------------|---------------|-------------|
| WOOD availability                          | 14.000.000    | ton/y       |
| Use                                        | 30%           |             |
| Primary energy                             | 17.500        | GWh/y       |
|                                            | <b>ICE/GT</b> | <b>MCFC</b> |
| % as regards to italian electricity demand | 1% - 2%       | 2% - 3%     |
| Mton CO <sub>2</sub> avoided               | 4,0 -- 4,5    | 6,0 -- 6,5  |
| % as regards to Kyoto goal for Italy       | 5% - 6%       | 8% - 9%     |

- In addition , it should be noticed that by a first estimation of the avoided CO<sub>2</sub> with plant fuelled with available biomass, this value is between 37 and 45 Mt CO<sub>2</sub>, 30% as regards to Kyoto goal for Italy.



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# ANAEROBIC DIGESTER GAS



Wastewater:  Anaerobic digestion of sludge in wastewater treatment plant

Wastewater can come by different producers: municipal liquid wastes, swine and bovine wastes, industrial wastes, etc.



Biogas as a by-product of the process

|                  | Typical conc, % |
|------------------|-----------------|
| CH <sub>4</sub>  | 55 ÷ 75         |
| CO <sub>2</sub>  | 25 ÷ 45         |
| H <sub>2</sub> S | 0,01 ÷ 1        |
| N <sub>2</sub>   | 2 ÷ 6           |
| O <sub>2</sub>   | 0,2 ÷ 1         |
| H <sub>2</sub>   | 0,1 ÷ 2         |

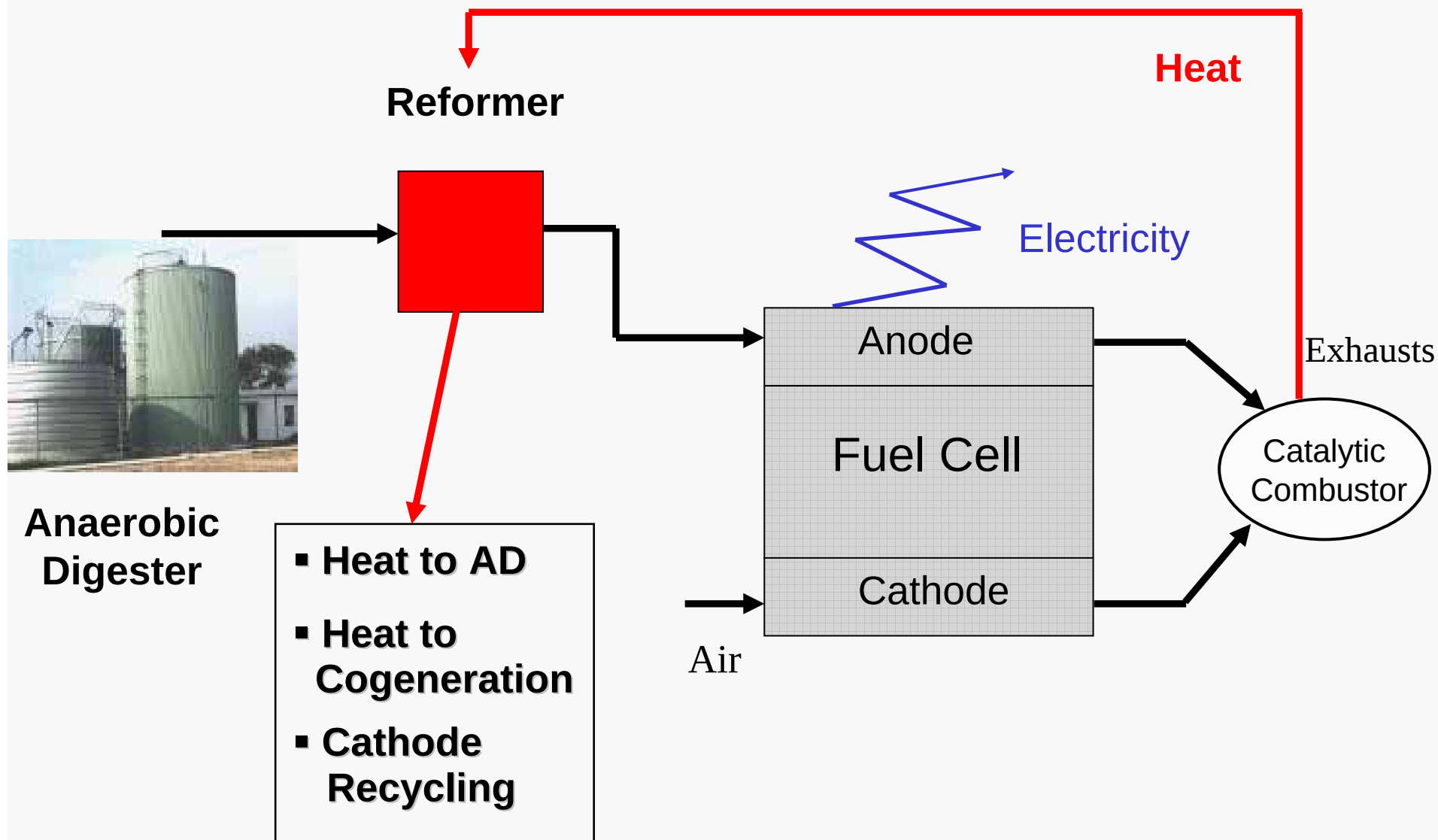
LHV  
20 – 27 MJ/Nm<sup>3</sup>



REFORMED BIOGAS  
after pretreatment and  
steam-reforming  
⇒ H<sub>2</sub>S < 1 ppm



# ANAEROBIC DIGESTER – MCFC SYSTEM





# MANURE: ITALIAN POTENTIAL MARKET



## BOVINE ANIMALS



**6.781.000** Number of animals  
**71%** in farms with more than 50 Bovines

Min Biogas production

**0,5 m<sup>3</sup>/d.bovine**

Range considered



Max Biogas production

**1,5 m<sup>3</sup>/d.bovine**

## SWINES



**9.196.000** Number of animals  
**93%** in farms with more than 100 Swines

Min Biogas production

**0,1 m<sup>3</sup>/d.swine**

Range considered



Max Biogas production

**0,2 m<sup>3</sup>/d.swine**

Min

Max

Biogas available [m<sup>3</sup>/y]

840.629.836

65% CH<sub>4</sub>

2.269.222.263

Italian Electricity Demand

320.658,4

GWh<sub>el</sub>/y

CO<sub>2</sub> Emissions in Europe

600

kg/MWh<sub>el</sub>

CO<sub>2</sub> Emissions in Europe

200

kg/MWh<sub>th</sub>

Kyoto goal for Italy

77,9

MtCO<sub>2</sub>eq



## Comparison among ICE, GT, MCFC

- Electric Energy produced [GWh/a]
- % as regards to italian electricity demand
- ktep saved considering  $\eta \approx 39\%$
- Termic energy transfered [GWhth/y]
- Mton CO2 avoided
- % as regards to Kyoto goal for Italy

| ICE                |                     | GT                 |                     | MCFC               |                     |
|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|
| $\eta_{el} = 33\%$ | $\eta_{th} = 30\%$  | $\eta_{el} = 24\%$ | $\eta_{th} = 48\%$  | $\eta_{el} = 50\%$ | $\eta_{th} = 40\%$  |
| f.u.i. = 0,8       | $\eta_{CHP} = 90\%$ | f.u.i. = 0,8       | $\eta_{CHP} = 90\%$ | f.u.i. = 0,9       | $\eta_{CHP} = 90\%$ |
| Min                | Max                 | Min                | Max                 | Min                | Max                 |
| 1.438              | 3.882               | 1.046              | 2.823               | 2.451              | 6.618               |
| 0,45               | 1,21                | 0,33               | 0,88                | 0,76               | 2,06                |
| 317                | 856                 | 231                | 623                 | 540                | 1.459               |
| 1.177              | 3.176               | 1.883              | 5.082               | 1.765              | 4.765               |
| 1,10               | 2,96                | 1,00               | 2,71                | 1,82               | 4,92                |
| 1,41               | 3,81                | 1,29               | 3,48                | 2,34               | 6,32                |



# ITALIAN CASE STUDY: MARSCIANO (PG)



AN. DIG.+FER.



BIOGAS



CLEAN-UP

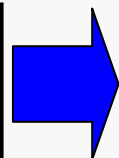


MCFC

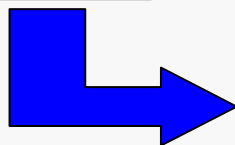


|                           | CH4<br>(%) | CO2<br>(%) | H2S<br>(%) |
|---------------------------|------------|------------|------------|
| Marsciano<br>(Pig Manure) | 58         | 38         | 0,4        |

MARSCIANO (PG)  
Real Case

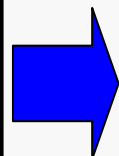


TECHNICAL – ECONOMICAL ANALYSIS



MULTICRITERIA ANALYSIS

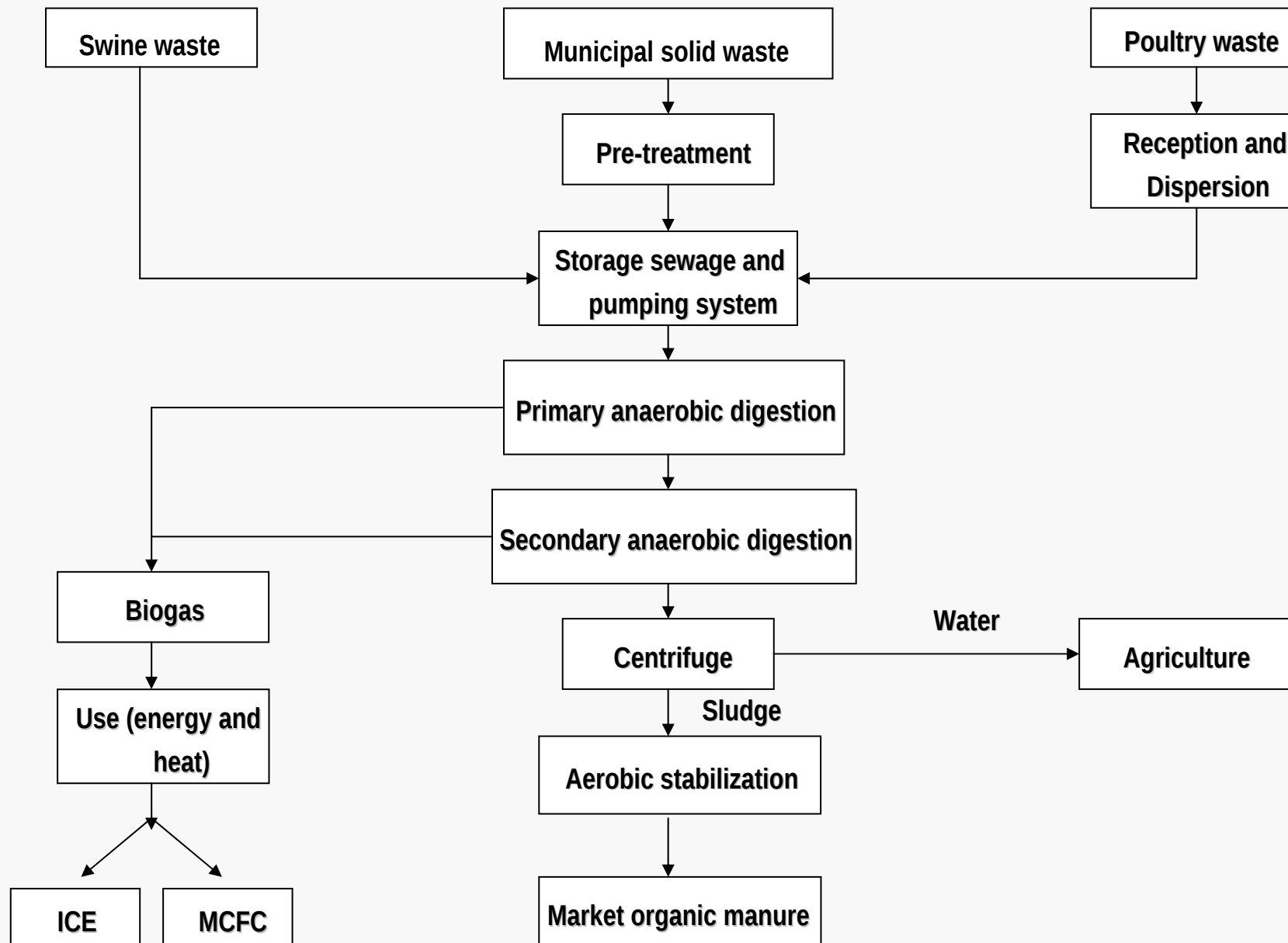
MCFC and ICE  
Comparison



NPV = FLOWS MONEY UPDATE-INITIAL INV.



# MARSCIANO: SYSTEM DESCRIPTION



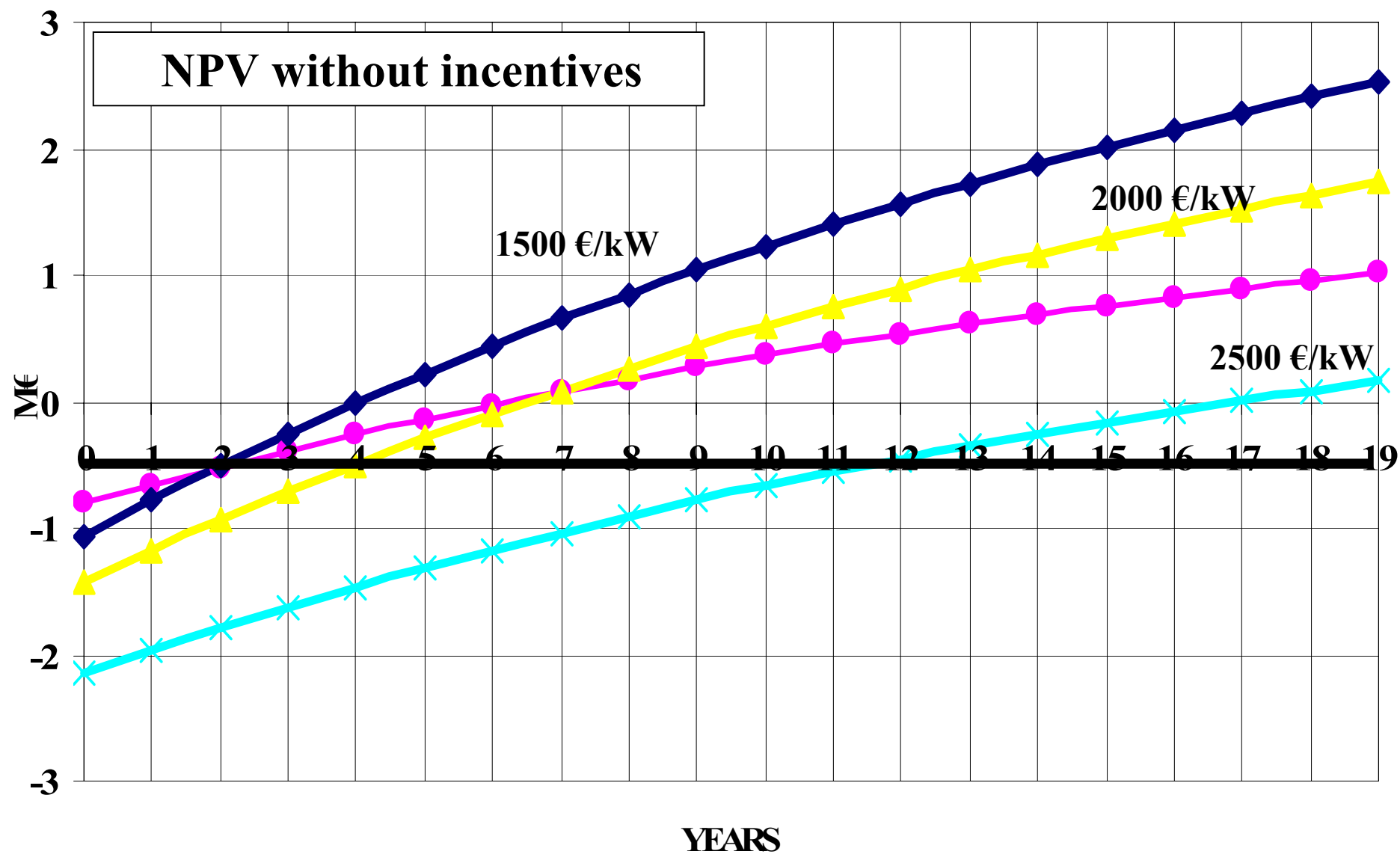


## MARSCIANO: TEC. – EC. ANALYSIS



- 1.INTEREST RATE: 5%;
- 2.INFLATION RATE: 2%;
- 3.COST ELETTRIC AND THERMAL POWER;
- 4.MAINTENANCE: 10% INITIAL INV.;
- 5.AVERAGE COST FOR EMPLOYEE;
- 6.FACTOR FOR USE THERMAL ENERGY: 90%;
- 7.DISCOUNT RATE:  $F = 1 / (1 + I/100)^{\text{year}}$ .

|                                             |        | ICE        |             | MCFC       |             |
|---------------------------------------------|--------|------------|-------------|------------|-------------|
| Initial Investment                          | €      | 796.500    |             | 1.069.385  |             |
| Total cost for maintenance                  | €/year | 132.500    |             | 109.141    |             |
| Total cost per person                       | €/year | 21.450     |             | 1.778      |             |
| Total costs                                 | €/year | 153.950    |             | 110.919    |             |
| Income for electric and thermal energy sale |        | year 1 - 8 | year 9 - 20 | year 1 - 8 | year 9 - 20 |
|                                             | €/year | 509.600    | 386.400     | 665.489    | 492.372     |



ICE

MCFC Investment 2000 €/kW

MCFC Investment 1500 €/kW

MCFC Investment 2500 €/kW



# MARSCIANO: MULTICRITERIA ANALYSIS



THIS ANALYSIS LEADS TO A CHOICE AMONG SEVERAL ALTERNATIVES, EVALUATED ON THE BASIS OF DIFFERENT CRITERIA.

1. ECONOMICAL ASPECTS
- INITIAL INVESTMENT
  - NET PRESENT VALUE
  - PAYBACK TIME

2. ENVIRONMENTAL ASPECTS
- NO<sub>x</sub>, • CO<sub>2</sub> REDUCTION

| Alternatives                               | <i>ICE</i><br>669 kW | <i>GT</i><br>399 kW | <i>MCFC</i><br>713 kW | <i>Weight</i><br>(%) |
|--------------------------------------------|----------------------|---------------------|-----------------------|----------------------|
| Criteria                                   |                      |                     |                       |                      |
| <i>Initial Investment</i><br>(Euro)        | € 796.500            | € 519.008           | € 1.069.385           | 15                   |
| <i>Net Present Value</i><br>(Euro)         | € 4.614.295          | € 3.828.457         | € 7.581.052           | 45                   |
| <i>Payback Time</i><br>(years)             | 2,2                  | 1,9                 | 1,9                   | 25                   |
| <i>NO<sub>x</sub> emissions</i><br>(ton/y) | 10,692               | 1,944               | 0,017                 | 5                    |
| <i>CO<sub>2</sub> avoided</i><br>(ton/y)   | 3.120                | 2.578               | 4.182                 | 10                   |

EVALUATION  
MATRIX

|                       | <i>IC</i> | <i>ID</i> | <i>IT=IC-ID</i> |
|-----------------------|-----------|-----------|-----------------|
| <i>ICE</i><br>669 kW  | -0,60     | 1,41      | -2,01           |
| <i>GT</i><br>399 kW   | -0,30     | 0,04      | -0,34           |
| <i>MCFC</i><br>713 kW | 0,90      | -1,46     | 2,36            |

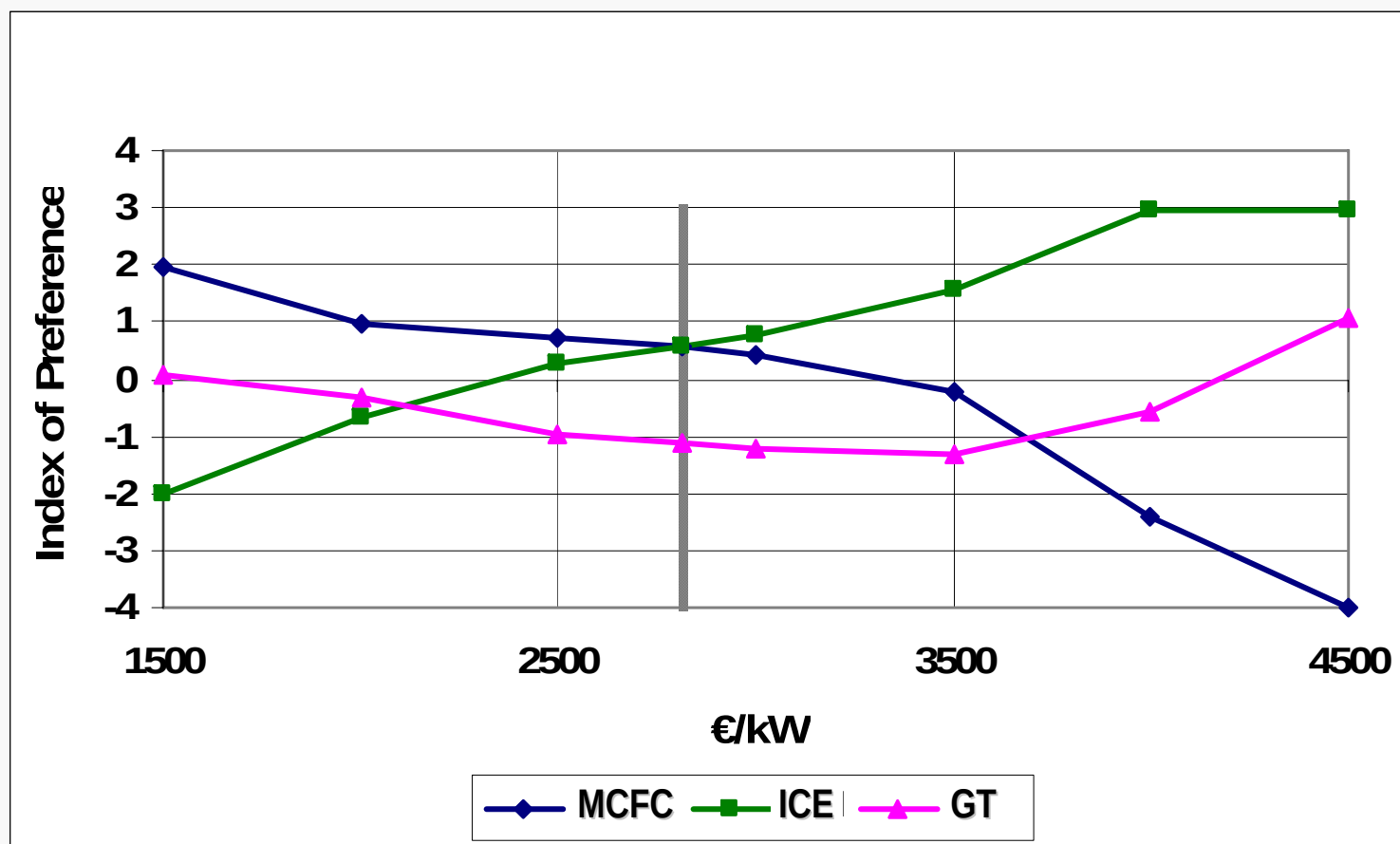
FINAL LIST

IT: Index of Preference



Target cost for MCFC

2800 €/kW





## SUMMARY



- MCFCs represent an interesting opportunity for exploiting Anaerobic Digester Biogas and could be installed in several plants, of different sizes, offering new solutions and a renewable source of energy;
- Regarding the Marsciano case study:

### ❖ ONLY ECONOMICAL ASPECTS

- ✓ With economical incentives, the MCFC investment cost as high as 2500 €/kW makes the MCFC solution economically advantageous, even if thermal power is not exploited (no cogeneration)
- ✓ Without any economical incentives, the MCFC investment cost needs to be lower than 2000 €/kW. Cogeneration is economically crucial in this scenario for both technologies

### ❖ ECONOMICAL AND ENVIRONMENTAL ASPECTS

- ✓ The MCFC solution is economically advantageous with an investment cost of 2800 €/kW.



# CONCLUSIONS



**MCFC / Biomass energy recovery concept can be technically, economically, and environmentally viable**

## Energetic aspects

Biogas and Bio-syngas-fueled operation of MCFC-stacks has been demonstrated (MTU, Ansaldo, University of Perugia, etc)

MCFCs represent the solution with higher gaseous biofuels energy conversion efficiency

## Environmental aspects

Biomass:  
CO<sub>2</sub> neutral  
fuel

MCFCs represent the solution with lower pollutants emissions

Very low NO<sub>x</sub> production

## Economical aspects

Market introduction of MCFC systems is strongly influenced by the installation cost (€/kW)

Crucial factors:

- Co-generation
- Governmental incentives
- Environmental and sustainability factors



**THANK YOU  
FOR YOUR  
KIND ATTENTION**