Thermochemical Power Group

PRESSURISED SOFC HYBRID SYSTEMS FED BY PYROLYSIS SYNGAS FROM COAL

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CLEAN COAL TECHNOLOGIES 2007

TOPICS:

- Description of national FISR project “Integrated systems for production and exploitation of hydrogen in the distributed power generation”.
- Description of the experimental activities and models that will be implemented in the FISR project.
- Chance of hydrogen utilisation in SOFC Hybrid System power plants.
- Layout description of the power plants proposed.
- Comparison of thermodynamic and economic analysis of distributed generation SOFC Hybrid System power plants (1.5 MW_e) with low CO_2 emissions.

OBJECTIVES:

- Definition of systems and models for Production and Purification of syngas from coal (1th year FISR project objective)
- Development of a SOFC Hybrid System model for the distributed generation fed by pure hydrogen obtained through coal pyrolisis
- Development of a scenario of performances and costs of low CO_2 emission power plants for the distributed generation fueled by natural gas and hydrogen

FISR project:

Ricerca Scientifica e Tecnologica
Ministero dell'Istruzione dell'Università e della Ricerca

INTEGRATED SYSTEMS FOR HYDROGEN PRODUCTION AND EXPLOITATION IN THE DISTRIBUTED POWER GENERATION (Sistemi Integrati di Produzione di Idrogeno e sua Utilizzo nella Generazione Distribuita)

CRS4

Consiglio Nazionale delle Ricerche
Istituto di Ricerche sulla Combustione - Napoli

Consorzio Pisa Ricerche S.c.a r.l.

Università degli studi di Genova

Enel

EniTecnologie

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

RIELLO
il clima per ogni tempo

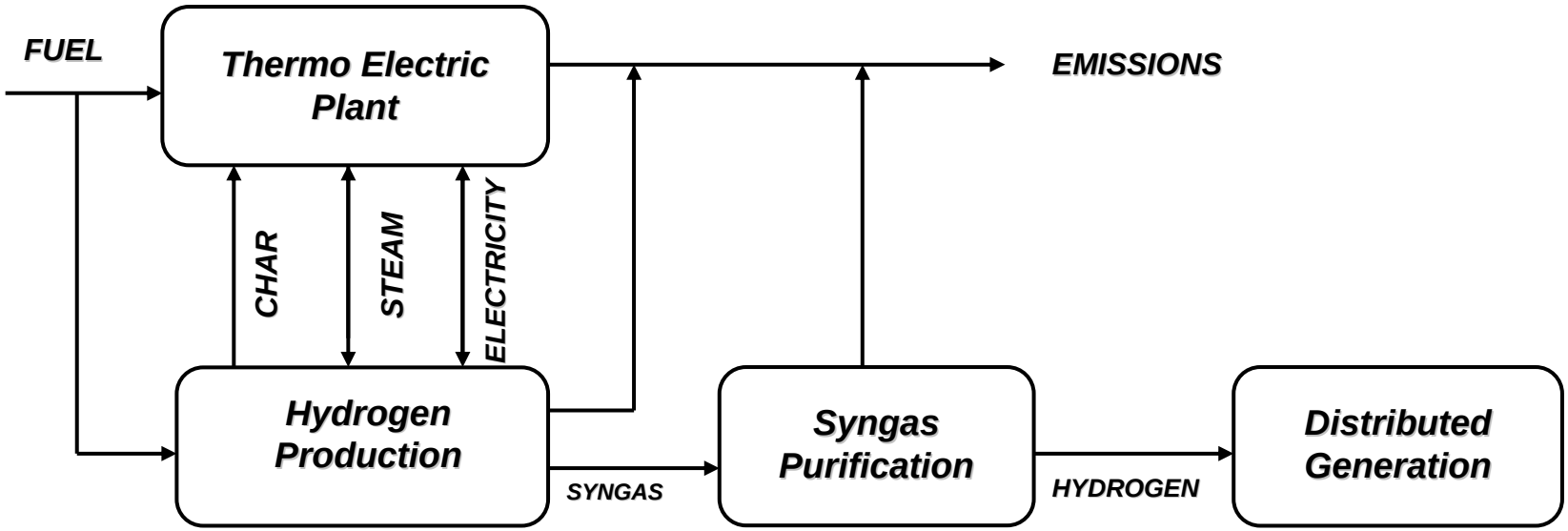
Kick Off of the Project: January 2006

Duration: 3 years

Budget of the Project: € 7.945.000

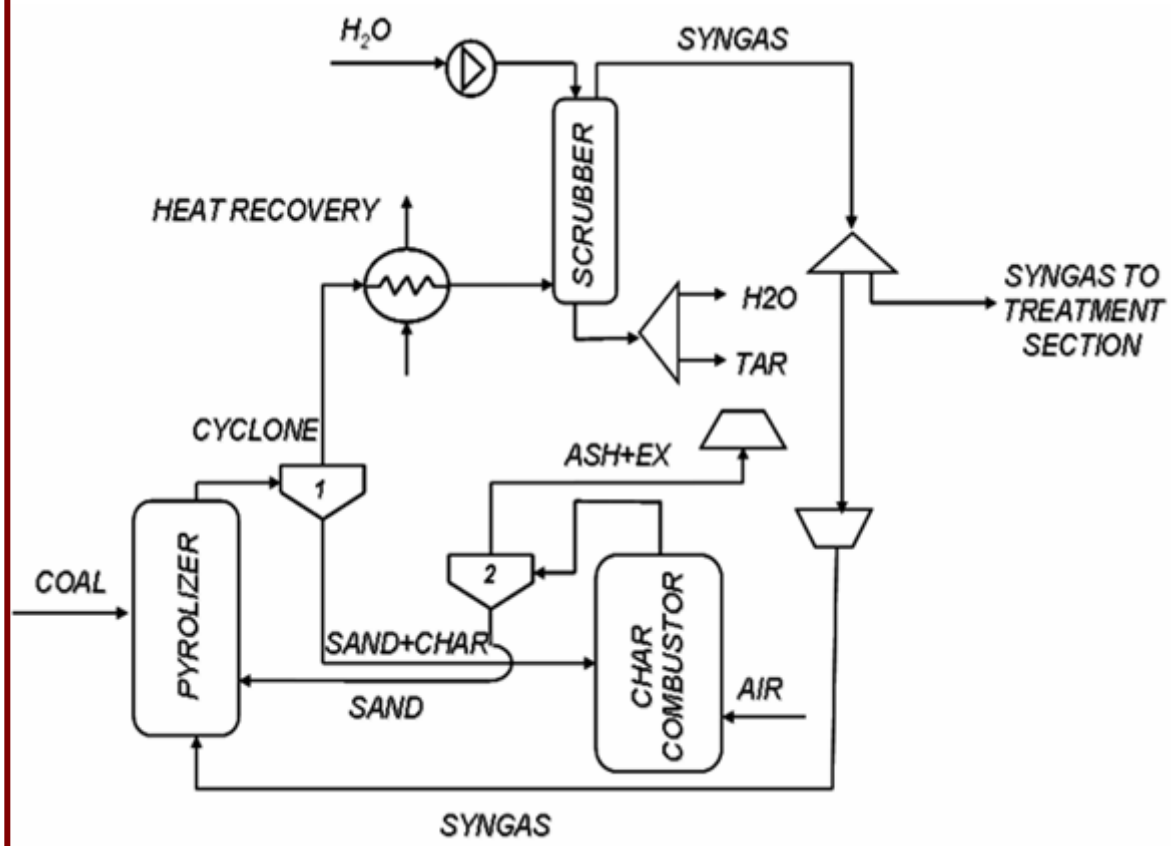
Cagliari, CCT 2007, 15th May 2007

UNIGE-TPG'S ACTIVITIES IN FISR PROJECT:



- Integration of Hydrogen production and purification into power plants and exploitation in small power generation units.
- This activity deals with the integration of the technologies for converting coal into hydrogen within existing power plants (Brindisi, Fusina).
- Experimental facilities of ENEL will be used and modified for the purposes of the project.
- The original software tool WTEMP will be employed and specifically developed for this application, with contributions from most project partners.

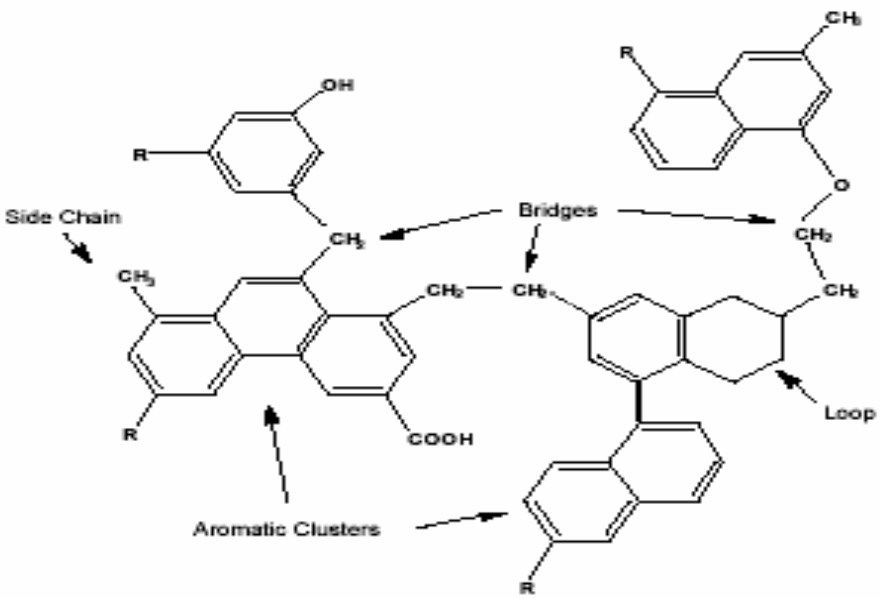
SYNGAS PRODUCTION-PYROLYZER LAYOUT:



- 800 kW_t Flash Pyrolysis Pilot Plant
- Placed in Bastardo (Perugia)
- Owner: ENEL (Italy)
- Plant Producer: ENSIS (Canada)
- Originally fed by biomass and converted for coal

KINETIC MODEL "CHEMICAL PERCOLATION DEVOLATILIZATION" FOR COAL PYROLYSIS:

- CPD-Model describes the devolatilization of coal submitted to rapid heating
- CPD-Model is based on the coal chemical structure
- CPD-Model has been developed as stand-alone code in Fortran ambient but it can be incorporated in more complex combustion code (Fluent or CFX).



SULPHUR REMOVAL MODEL:

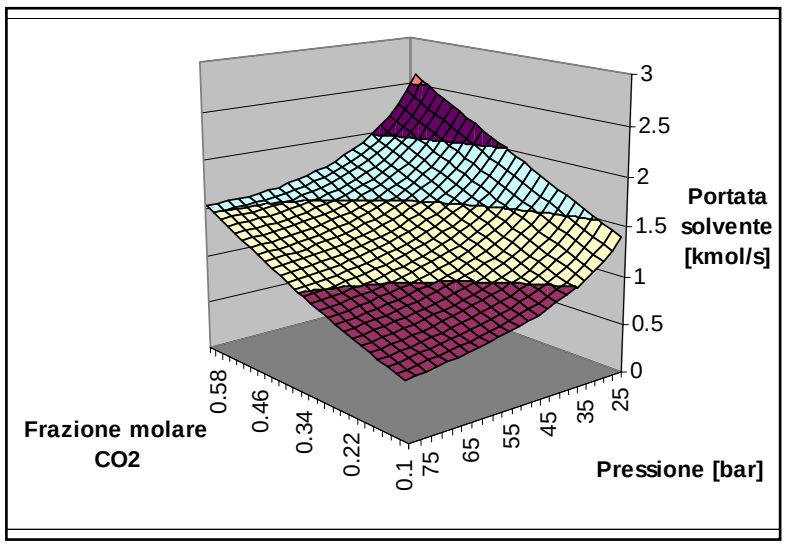
Selexol process based on phisical absorption

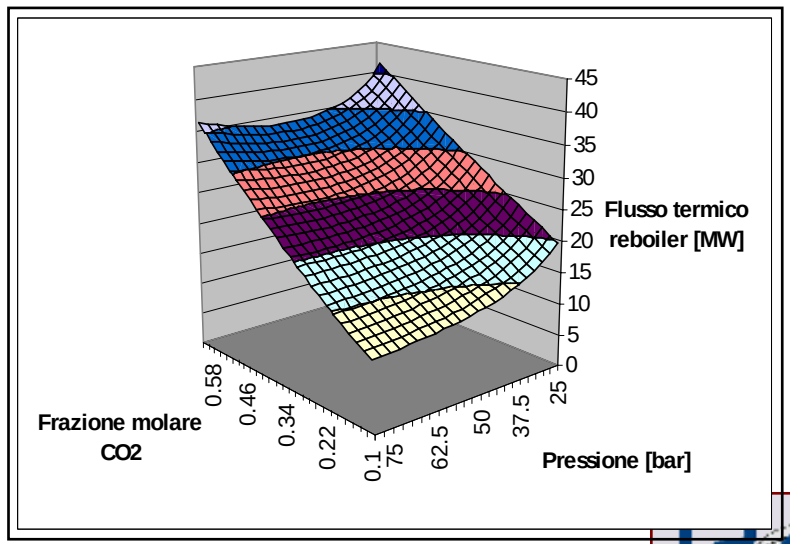
- Theoretical set up of the problem for the estimation of the number plats of the absorbment
- Simulation of the whole plant section utilizing commercial code ®Provision
- Map of the performances of the plant section for the W-TEMP simulation

Variability field considered

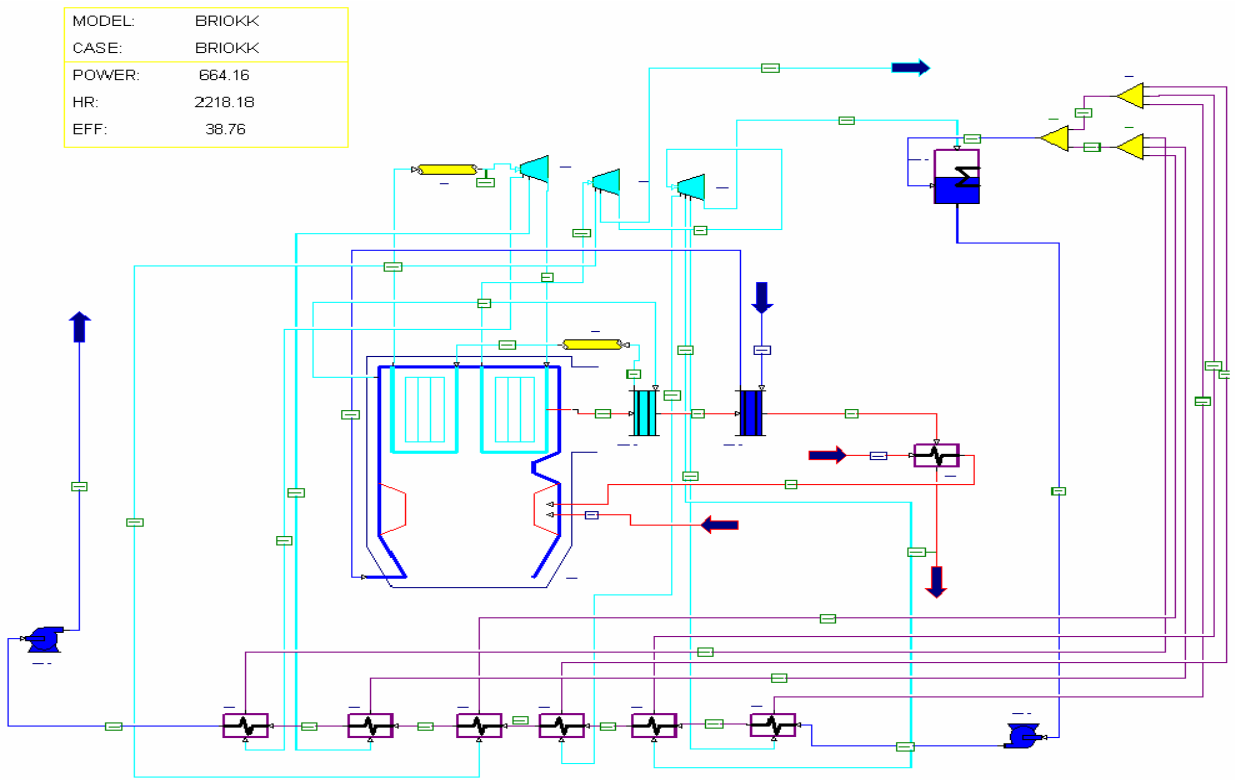
- Molar Fraction H_2S 0.1%-2%, step 0.1%
- Molar Fraction CO_2 10%-60%, step 2%
- Pressure 25 bar-80 bar, step 2.5 bar

Characterization of the component in wide range field



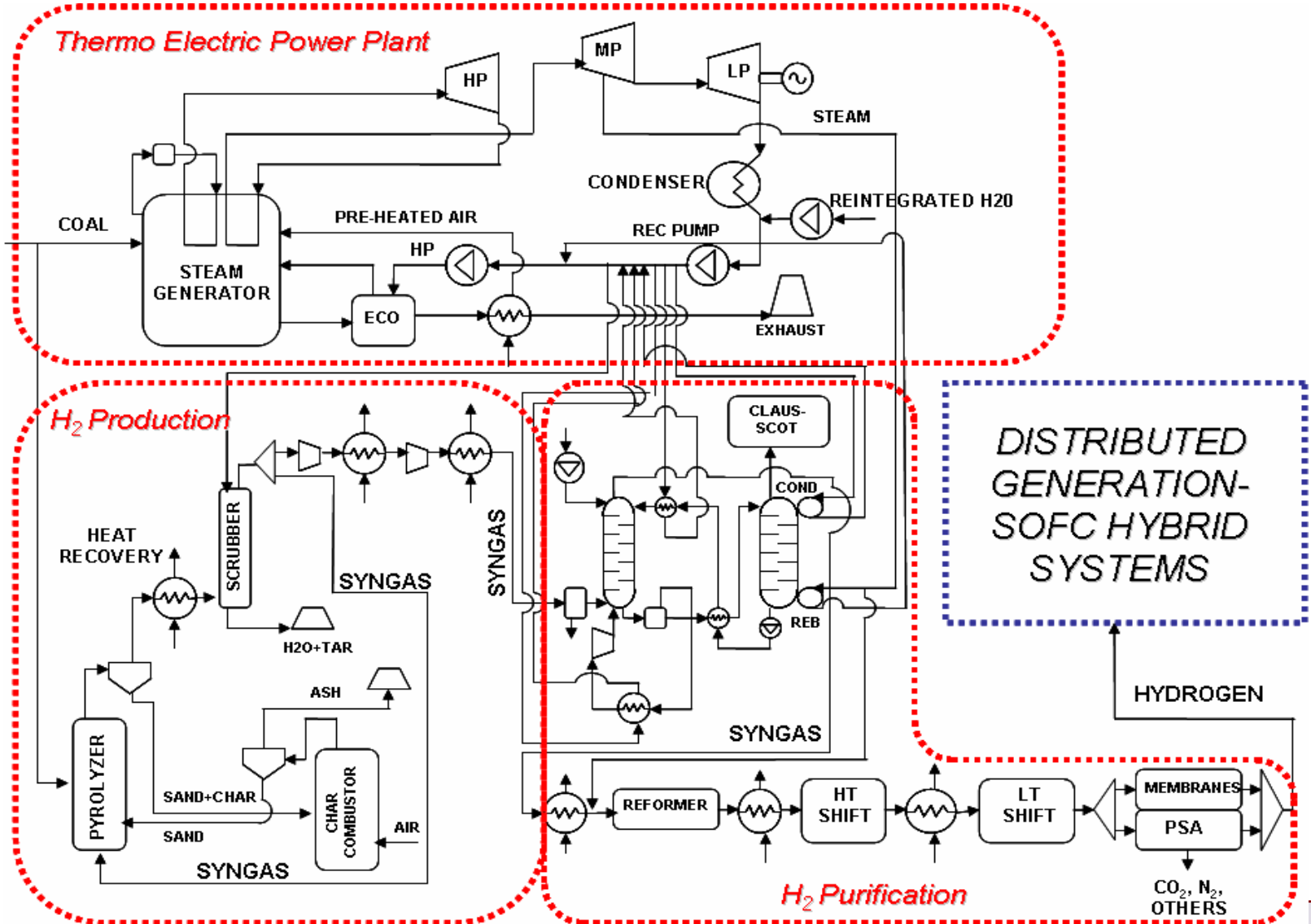


ENEL POWER PLANT MODELS (BRINDISI, FUSINA):



- Coal Power Plant 3 LP
- Net Power: 660 MW_e, 330 MW_e
- Net Efficiency: ~ 39%
- Developed with Gate-Cycle code for Off-Design analisys

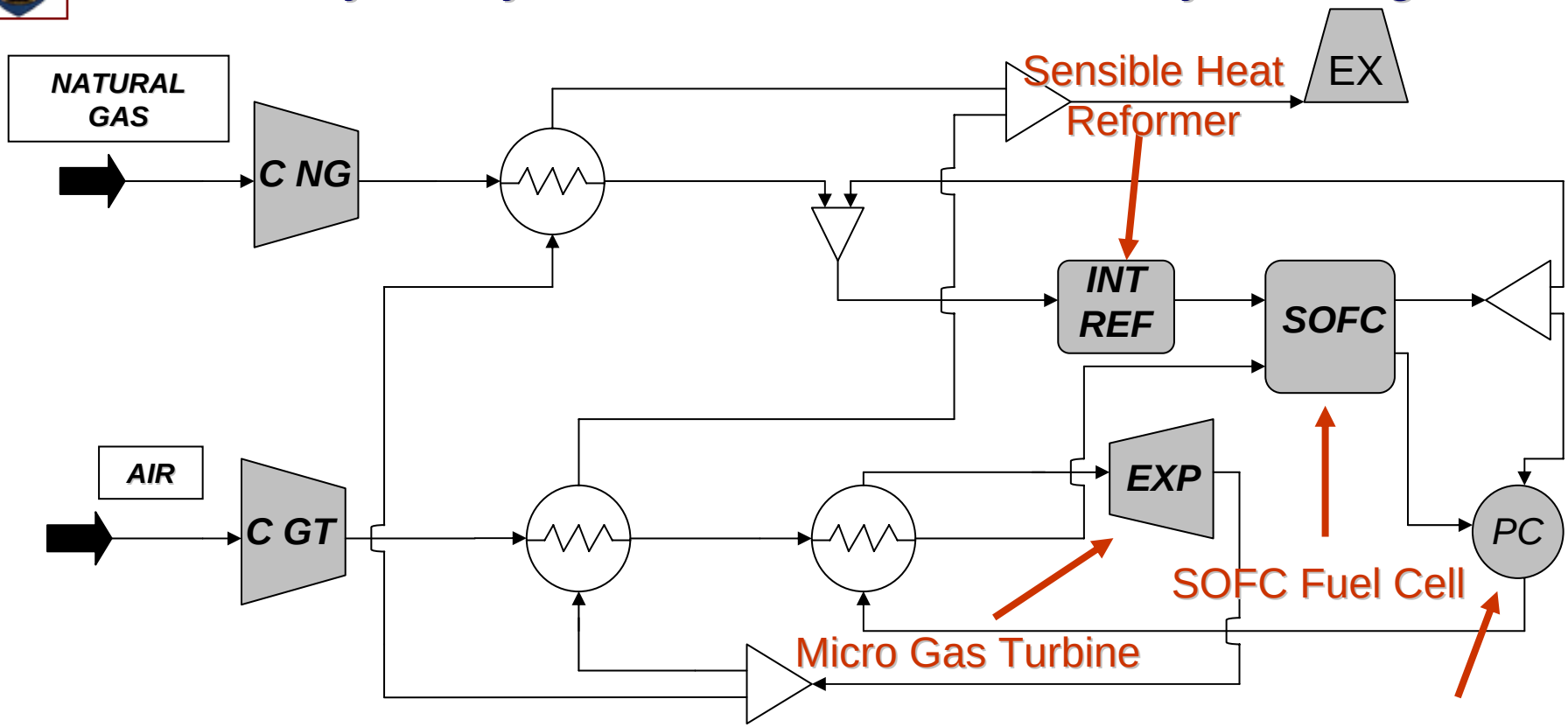
INTEGRATED SYSTEM:



SCENARIO OF LOW CO_2 EMISSION SOFC HYBRID SYSTEM POWER PLANTS (1.5 MW_e) FUELED BY PURE HYDROGEN AND NATURAL GAS

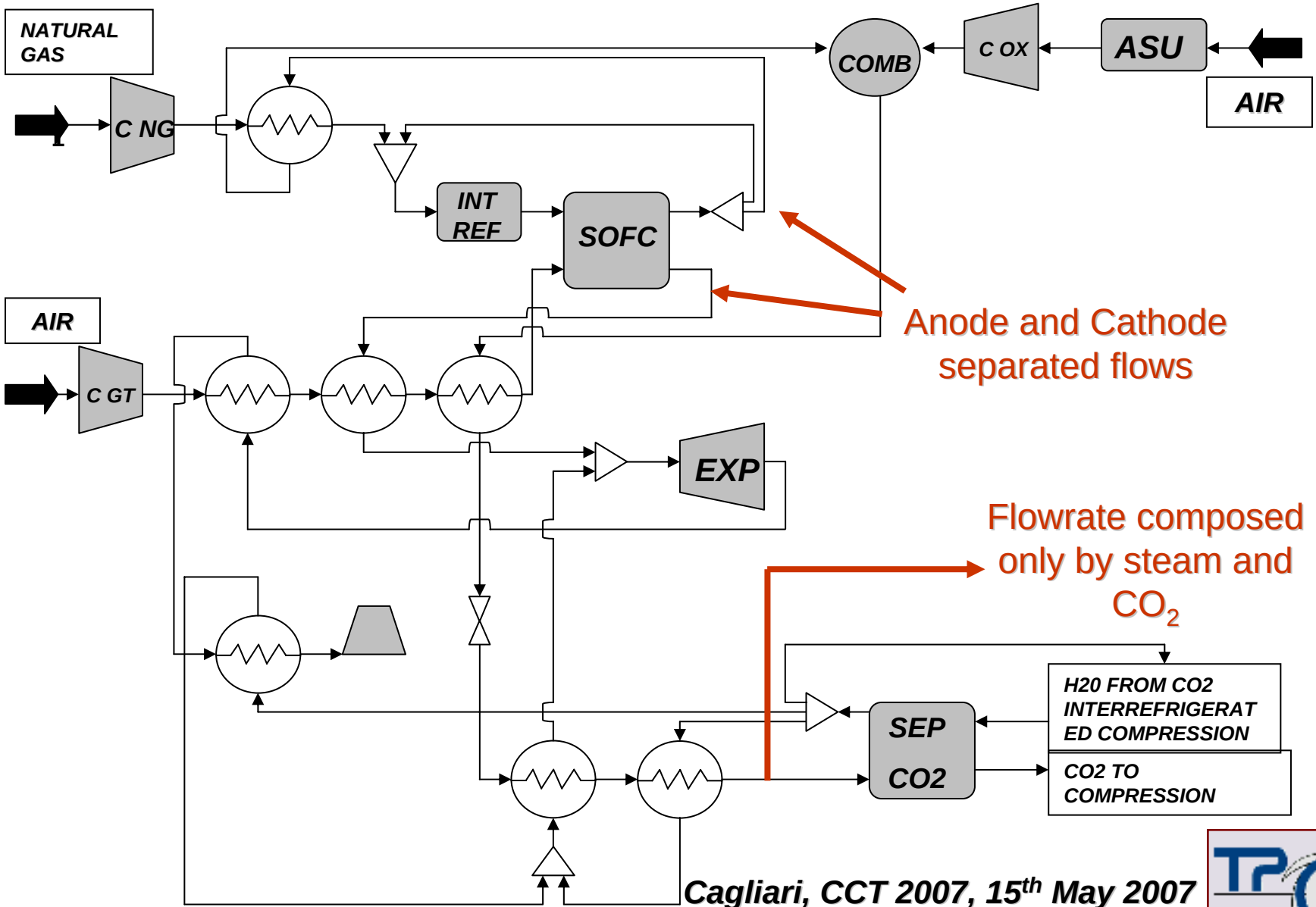
- Case 1-Hybrid System with tubular SOFC fed by natural gas (Magistri, Ph. D. thesis, 2003)
- Case 2-Anode/Cathode separeted Hybrid System with CO_2 separation for steam condensation
- Case 3-Hybrid System with tubular SOFC fed by pure hydrogen

Case 1-Hybrid System with tubular SOFC fed by natural gas



Microturbine TIT	940 [°C]
Air Compressor Pressure Ratio	4.5
Ceramic Exchanger Effectiveness	0.3
Gas side pressure drop	3 %
Current Density	4000 [A/m^2]
Utilization Factor [$H_{2,conv}/H_{2,in}$]	0.85

Case 2-Anode/Cathode separeted Hybrid System with CO_2 separation for steam condensation



Case 3-Hybrid System with tubular SOFC fed by pure hydrogen

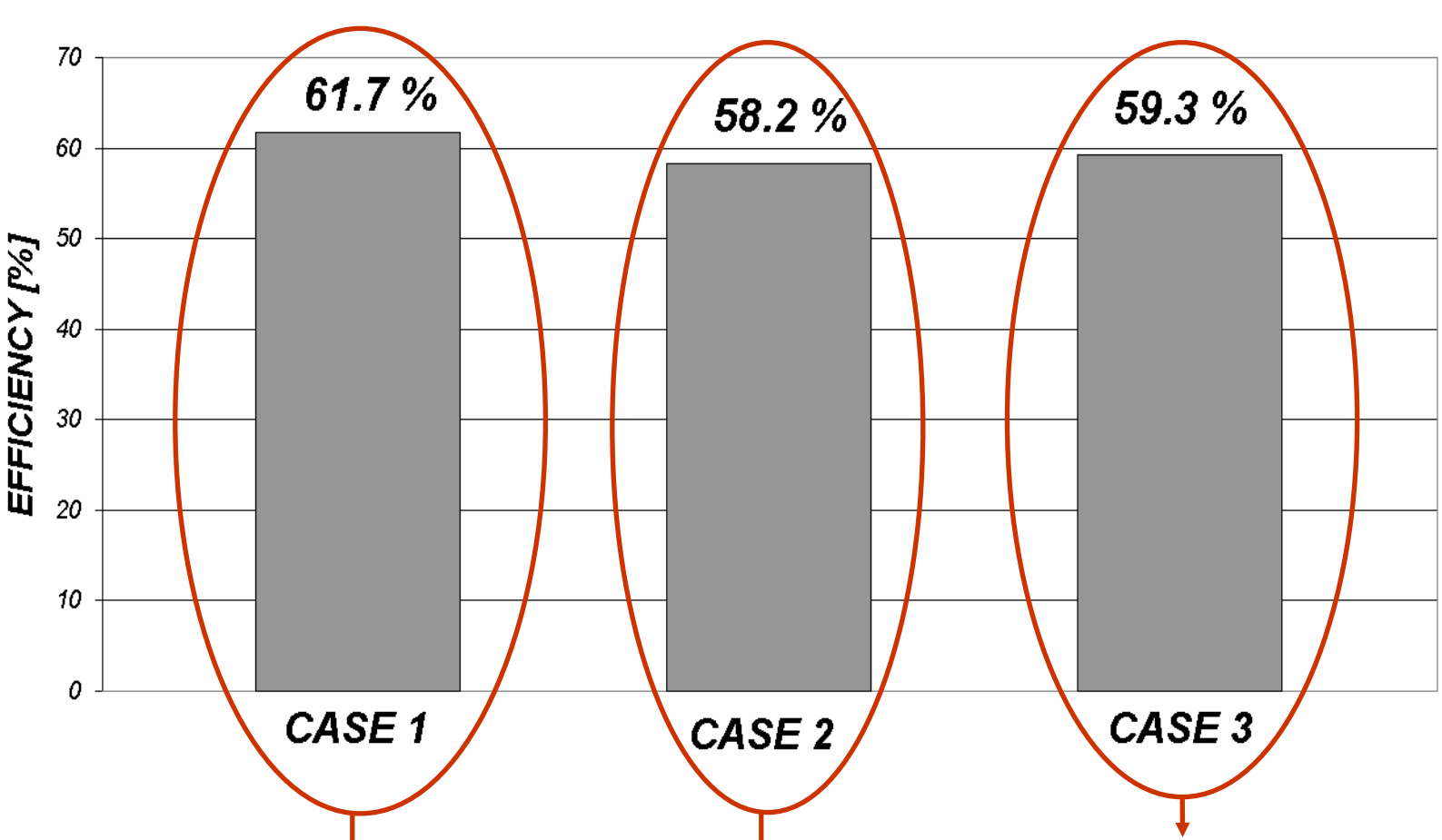
1-Similar to the one fed by natural gas.

2-Absence of the internal reformer due to the absence of hydrocarbons.

3-The presence of an anodic recirculation (that recirculate mainly steam and hydrogen) is desirable for different reasons:

- Reduction of thermal stress in the fuel cell stack by increasing the temperature of inlet fuel gases
- Performance of a high overall fuel utilization factor by retaining a lower single-pass utilization factor
- Reduction of hydrogen partial pressure at stack inlet (100% hydrogen would clearly damage the first cells causing unacceptable overvoltages).

THERMODYNAMIC RESULTS:



Hybrid System with tubular SOFC feed by pure hydrogen

Hybrid System with tubular Anode/Cathode SOFC

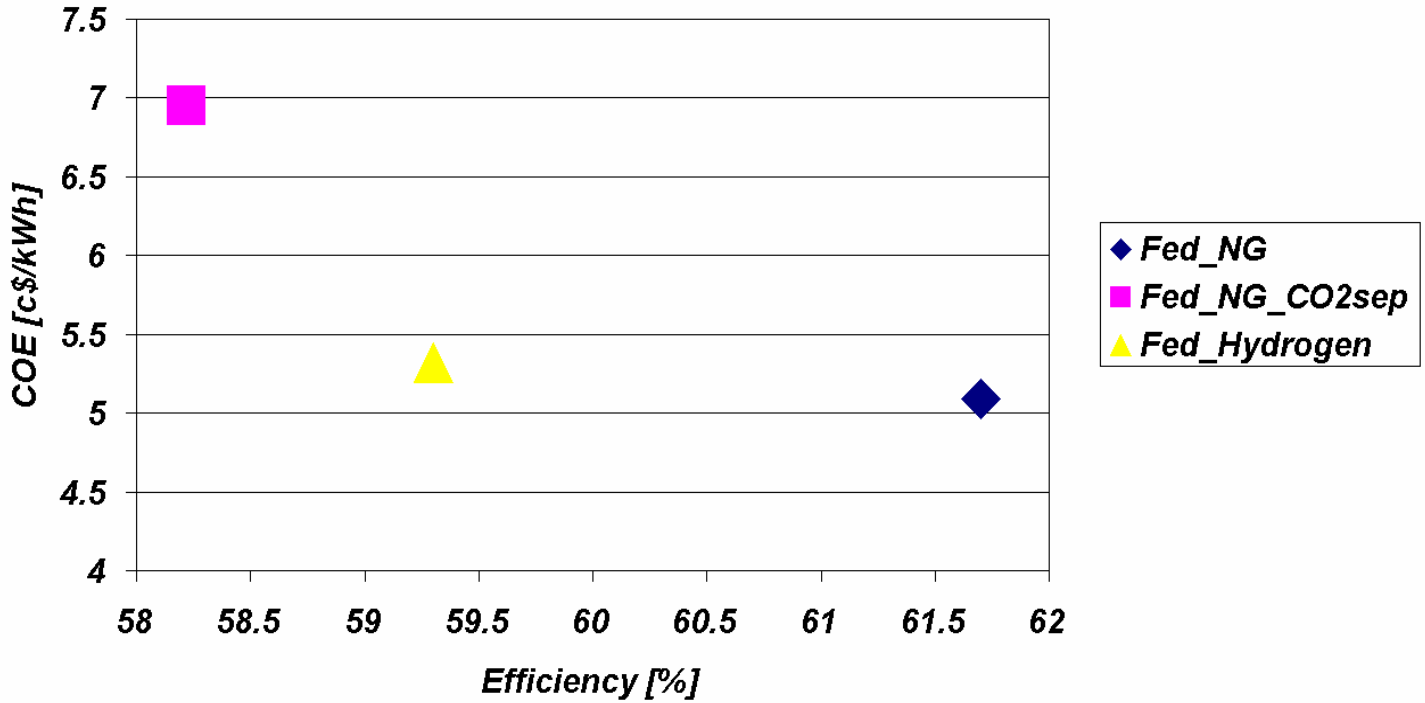
Separeted Hybrid System with CO_2 separation for steam condensation

THERMOECONOMIC ANALYSIS:

THERMOECONOMIC ASSUMPTIONS	
Inflation	3.0 %
Nominal escalation rate of PEC	3.0 %
Nominal escalation of Fuel and other supplies	3.0 %
Construction time	1 years
Plant Economic Life	15 years
Plant Life for tax purposes	10 years
Fuel price (natural gas)	6.5e-6 $/kJ
Sale Price of Electric Power	3.05e-5 $/kJ
Equivalent operating hours at nominal load	4000

- W-TEMP code is provided with “cost/costing equations” that evaluate single component capital costs on the basis of the thermodynamic and physical parameters
- The main approximation regards the fuel cell stack system, whose capital cost was assumed to be equal 400 $/kW

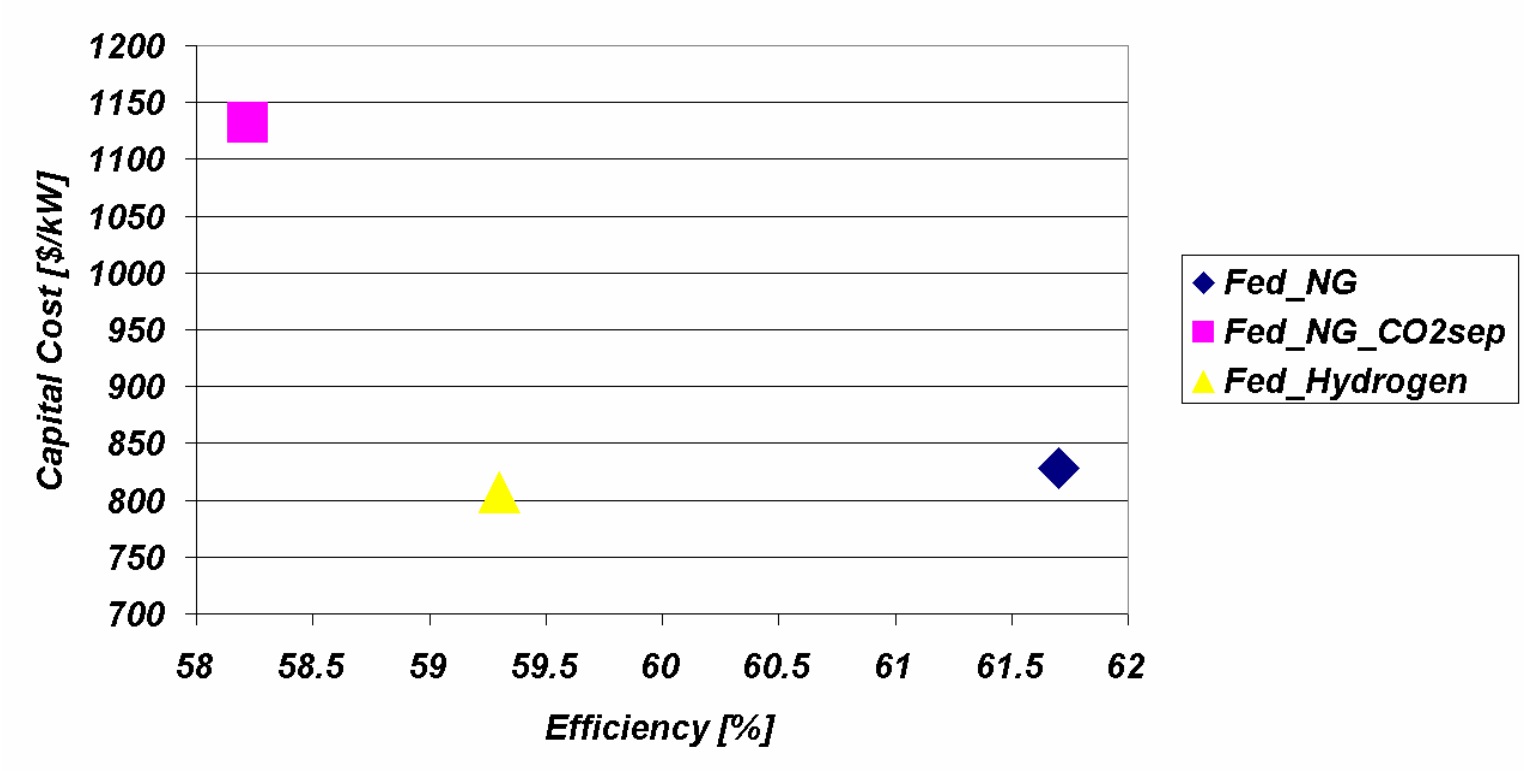
Costs of Electricity:



- The range of costs is relatively compact: the costs are between 5 and 7 c$/kWh.

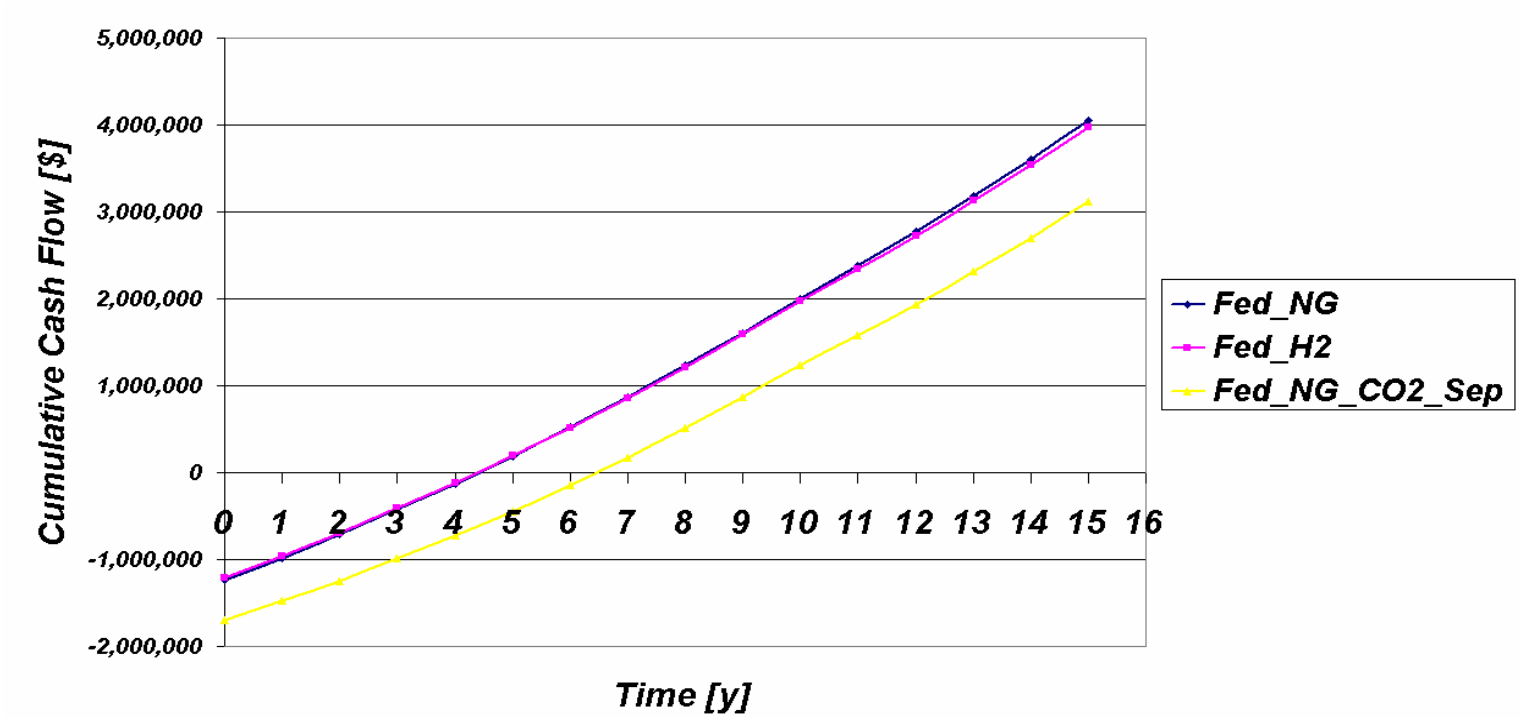
- The system fed by hydrogen seems to be more attractive in terms of costs of electricity: this is due basically from the complexity of the system fed by NG with CO_2 separation.

Capital Costs:



- The cost of "traditional system" fed by NG passes from 828 $/kW to 1131 $/kW with CO_2 separation.
- The SOFC-Hybrid System fed by hydrogen is competitive in terms of capital cost because of the simplicity of the system and in particular because of the absence of the reformer section (due to the absence of hydrocarbons).

Cash Flows:



- PBP of the "traditional" system fed by natural gas overlaps with the system fed by hydrogen. This is due basically by the assumption made in terms of fuel cost and electrical Revenue.
- The only difference between the systems is the presence in the system fed by natural gas of the sensible heat reformer that justify the reduced difference between the curves.
- The system that realize CO2 separation through water condensation shows a PBP closed to 6.5 years instead of 4.2 years of the others cases: this is due to the complexity of the system and consequently the capital costs of the components.

CONCLUSIONS:

- The preliminary definition of the integrated system that represents the objective of first year in FISR project has been realised.
- The comparison with traditional HS fed by natural gas with low CO_2 emissions and hydrogen have been investigated to carry out thermodynamic efficiencies and costs.
- These results encourage the research in the field of production of hydrogen: the main objective corresponds to the assumption of hydrogen cost from coal that is the same of natural gas (LHV basis).
- This goal should permit to dispose of low CO_2 emission system based on SOFC fuel cell technology with similar thermodynamic behaviour and costs: a loss in energy and economic terms is noticed with CO_2 separation for steam condensation.
- Carbon Taxes equal to 0.23 \$/kgCO_2 (in terms of PBP) and 0.071 \$/kgCO_2 (in terms of COE) would be necessary to make the plant with CO_2 separation competitive respect to the traditional SOFC-Hybrid System.
- Many companies are nowadays investing and working intensely on HS fed by natural gas with internal reformers: technical aspects need to be investigated as the absence of the integrated reformer on the SOFC stack.

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