Biogas-Conversion Renewable Process for Enhanced Hydrogen Assisted Combustion

- S. Vassiliadis[1], Z. Ziaka[2], M. Tsimpa[1]

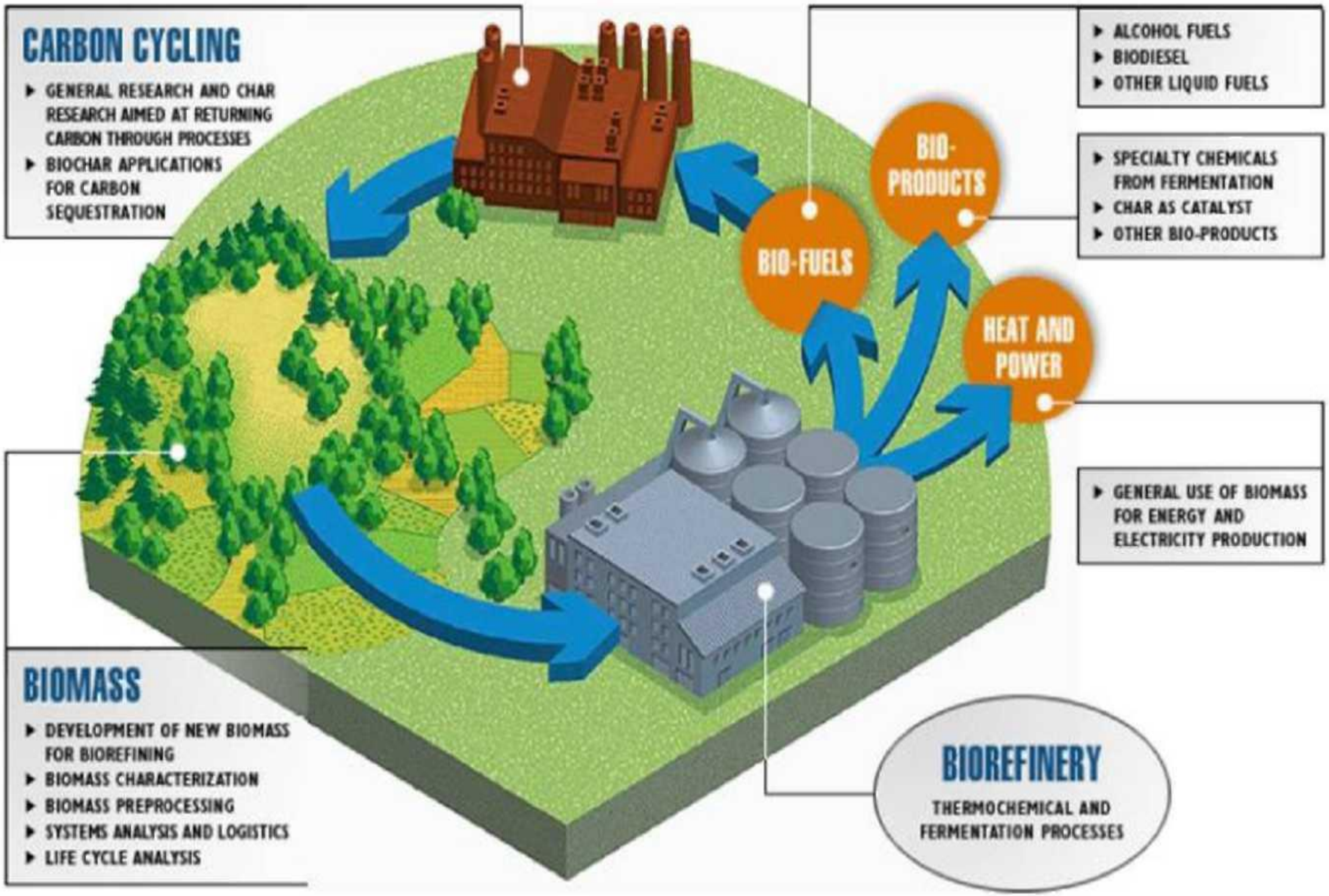
- 1. Hellenic Open University
- 2. International Hellenic University

PREVIOUS RESEARCH WORK

Description and Analysis of new findings and results on catalytic reactors/heterogeneous processors for the Steam Reforming of Methane, Natural Gas and Biogas for use in Power Generation systems and Fuel Cells [12].

The current communication, continues this research by giving emphasis in the so-called “Green Power” and “Biogas Energy” systems.

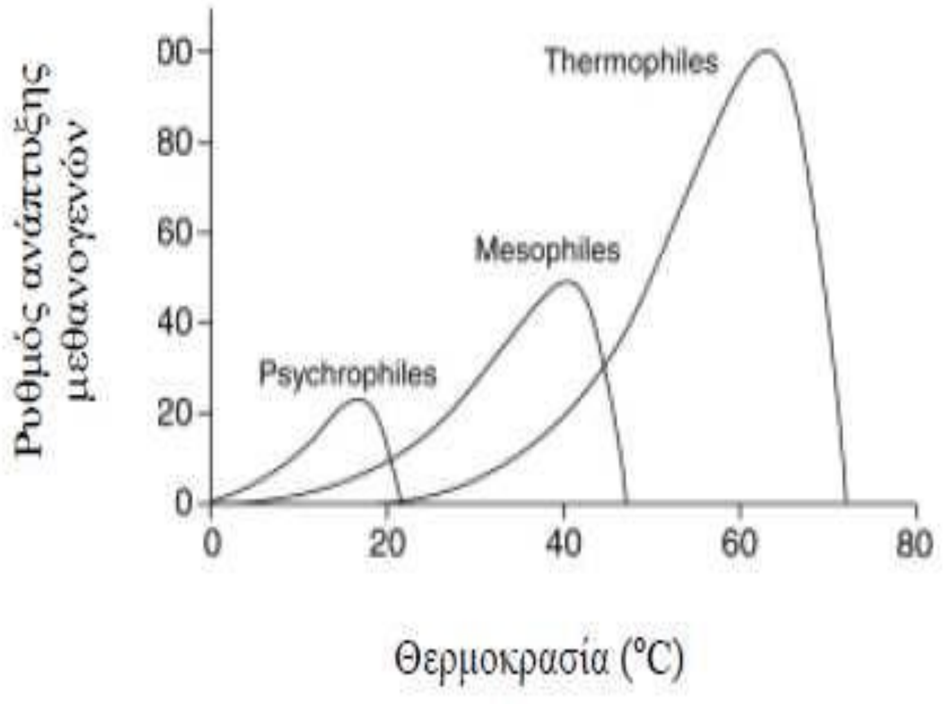
We analyze the use of Biomass gases (Biogas generating feedstocks) as sources for Power/Electricity generation via Hydrogen Assisted Enhanced Combustion (HAEC).


CARBON CYCLING
▶ GENERAL RESEARCH AND CHAR RESEARCH AIMED AT RETURNING CARBON THROUGH PROCESSES
▶ BIOCHAR APPLICATIONS FOR CARBON SEQUESTRATION
▶ ALCOHOL FUELS
▶ BIODIESEL
▶ OTHER LIQUID FUELS
BIO-PRODUCTS
▶ SPECIALTY CHEMICALS FROM FERMENTATION
▶ CHAR AS CATALYST
▶ OTHER BIO-PRODUCTS
BIO-FUELS
HEAT AND POWER
▶ GENERAL USE OF BIOMASS FOR ENERGY AND ELECTRICITY PRODUCTION
BIOMASS
▶ DEVELOPMENT OF NEW BIOMASS FOR BIOREFINING
▶ BIOMASS CHARACTERIZATION
▶ BIOMASS PREPROCESSING
▶ SYSTEMS ANALYSIS AND LOGISTICS
▶ LIFE CYCLE ANALYSIS
BIOREFINERY
THERMOCHEMICAL AND FERMENTATION PROCESSES

- There is a recent emphasis on the Development and Commercialization of such Biogas based systems for Energy and Heat/Cooling generation applications.
- Such installations exist currently mainly in the developed and developing countries.
- Fig.1 below, shows the itemized distribution and usages of biogas energy-applications which is coming from various renewable sources [2].

The effect of Temperature on the growth rate of methanogenesis bacteria

pH also affects (6.8 -7.5 best range)



- The reformer under consideration can be a fixed bed catalysis-reactor operating under plug flow conditions.
- Its outlet gas stream can be used directly as feed in the accompanied combustor-turbine system for direct electricity generation.

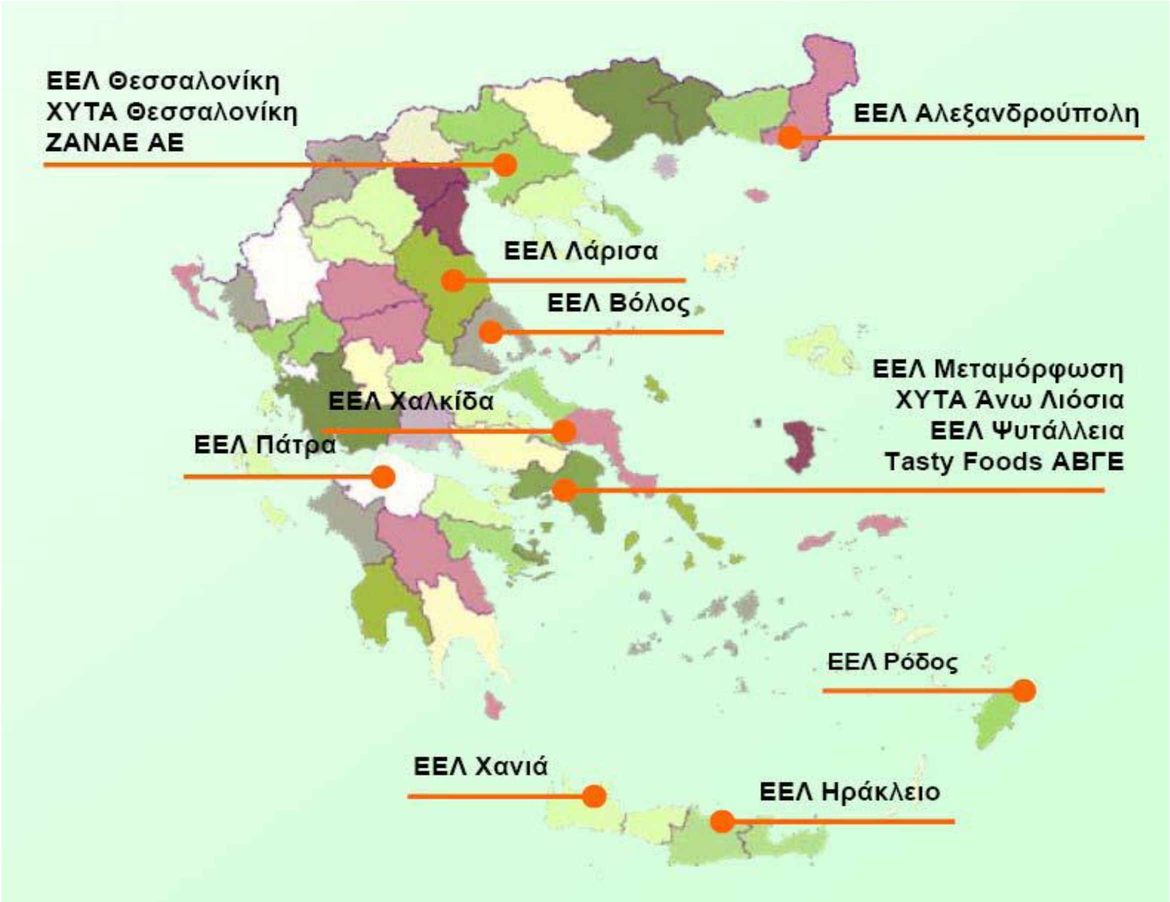
- The Outlet Stream is rich in hydrogen, carbon monoxide, and methane (and possibly some CO_2) and consists the proper mixture for enhanced hydrogen assisted combustion.
- It is moreover beneficial, to operate the reactor at a lower temperature regime for increasing the reactor and catalyst life times and for reducing the endothermic heating load (Btu/hr) of the endothermic reformer [8].

USE OF BIOGAS FOR ELECTRICITY AND HEAT

The combined biogas cycle plant for electricity and heat (CBCP) is a typical use of biogas in many developed countries for energy generation.

APPLICATIONS OF BIOGAS UNITS IN GREECE

In 2007, there were about 15 biogas units in Greece at various cities. Most of those units were constructed in Landfills and Garbage Processing Places. But mostly there were absent the animal/agricultural type biogas plants.



Drawbacks for the Development of Biogas Plants in Greece

- Market type drawbacks (Energy, Agricultural)
- Economical and loan obstacles
- Other types of drawbacks (administrative, legislative, approval)
- Variation of the cost of electrical energy (sale price)
- Cost of the Investment

- Such Biogas based power systems require the development, use and commercialization of an effective catalytic reformer utilizing active metals such as Ni, Rh, and Cr, or bimetallic combinations of those.
- Enrichment of the catalyst with earth metals, such as Ca, Mg, and K promotes the catalyst stability on stream and minimizes the deactivation from carbon deposition, especially at the reactor inlet.

- The following reactions take place in the reformer by adding steam as the oxidant in the biogas-feedstock, as shown below:

- $CH4 + H2O = CO + 3H2$ $(\Delta H^o_{298} = +206.1\ kJ/mol)$
- (biogas - steam reforming reaction) **(1)**

- $CO + H2O = CO2 + H2$ $(\Delta H^o_{298} = -41.15\ kJ/mol)$

- (possibly a parallel water gas shift reaction) **(2)**

- Mathematical modeling for a steady-state biogas-steam reformer under plug-flow conditions includes the following:
- $dX_A/dz = (\pi\, d_T^{2} / 4n_{Ao})\, \rho_B\, R_A$ (3)
- Species A can be any of the reactants and products of the reactions (1) and (2) above.
- With: $R_{CH4} = - R1$
- $R_{CO2} = R2$, $R_{CO} = R1 - R2$,
- $R_{H2} = 3R1 + R2$, $R_{H2O} = - R1 - R2$,
- Where R_1 and R_2 are the descriptive heterogeneous reaction rates of the reactions (1) and (2) given above.

The thermal balance in a non-isothermal reformer is given as follows:

- $dT_T/dz = (\pi\, d_T^{2} /4)\, (1/m'c_p)\, \{ \rho_B\, [(-\Delta H_r^{1})\, R_1 +$
- $(-\Delta H_r^{2})\, R_2] – 4(U/d_T)(T_T-T_S) \}$ (4)
- The reformer pressure balance along the fixed bed of catalyst particles is given as follows:
- $- dP_T/dz = (2\, f\, \rho_g\, u_s^{2} / g_c\, d_p)$ (5)

- The initial conditions are shown below:
- at z=0 (reactor inlet) , $X_{\boldsymbol{A}} = 0$, $T_T=T_o$, $P_T = P_{To}$

- Computational modeling of the described reformers in this paper was also performed which shows performance measures (biogas-reactant conversion, products yield, **H_2** rich gas composition) versus the variation of intrinsic model parameters (reactor space time, reaction temperature and pressure, feed composition, space velocity).
- The models also analyze and show performance measures under new operating conditions which are of interest to new biogas-energy process and project applications

- The interconnected or integrated combustion system is fed directly by the fuel-gas generated by the described reformers.
- The focus of our studies includes solutions in a number of problems associated with the installation, operation, and mass, energy conservation of the entire reformer-combustion unit.

- The solutions focus into the operative improvement of the combined reactor-combustion unit and include catalysts and reformer internal and wall materials optimization, and feedstock specifications.
- Catalysis studies focus to install improved catalysts with minimal deactivation on stream for continuous reliable reactor and turbine operation on a long term basis.
- Materials studies focus to improve on the life and constant activity of materials including catalysts and internal components of the reformer and turbine systems.
- Design and process studies focus on system integration, efficient operation, increased power output (kW/m^3), and adaptability to different biogas-based feedstocks.

USE OF BIOGAS FOR ELECTRICITY, HEAT, and COOLING

(Several such pilot plants are under development today),

Income distribution of a typical combined biogas cycle plant (CBCP),

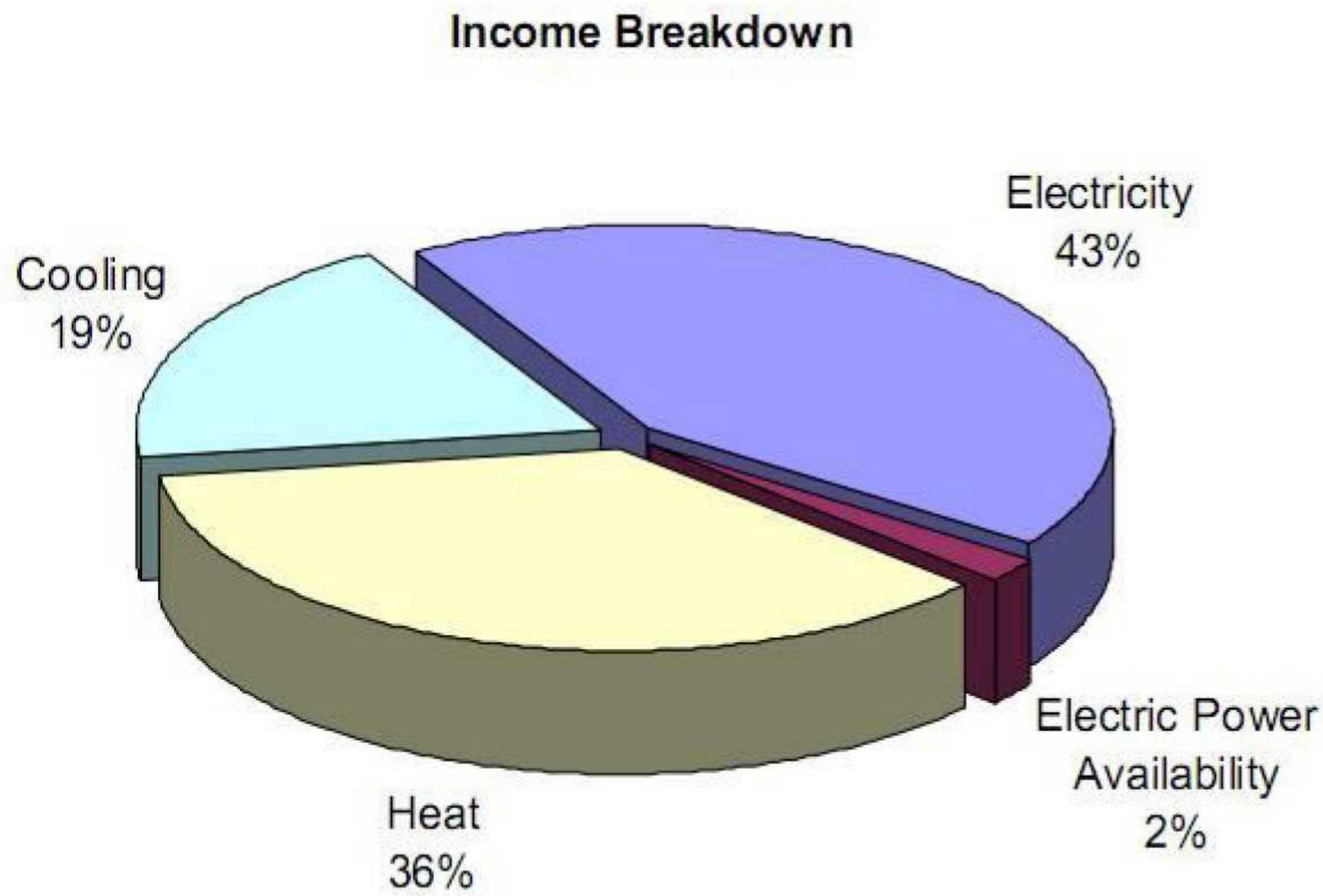


Fig.1. Percentage of income from the direct utilization of biogas coming from agricultural and farm-animal wastes

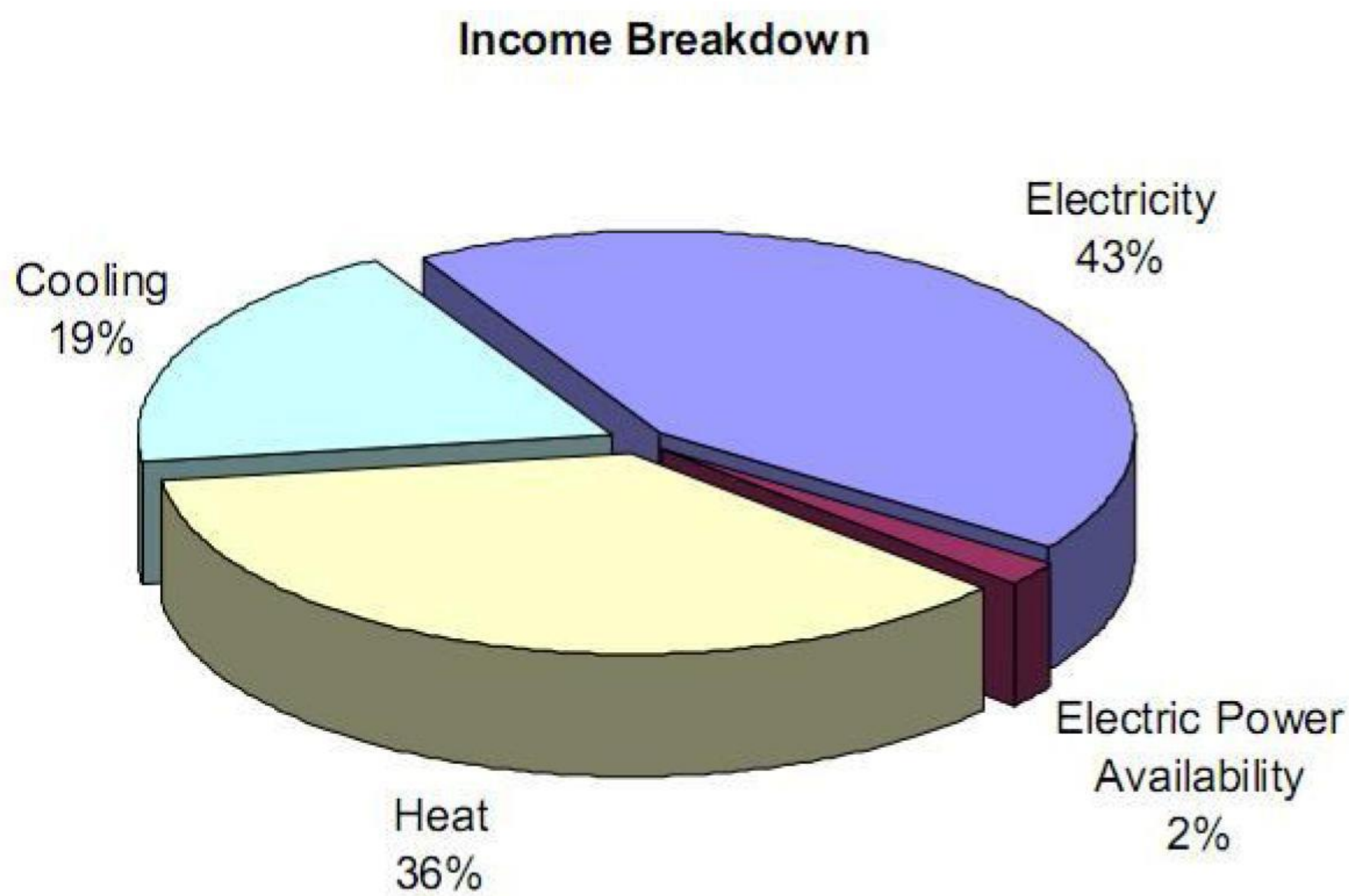


Fig.2.Experimental and modeling data/results of a biogas-steam reformer in a plug flow mode of operation. Methane conversion data at various space times and temperatures

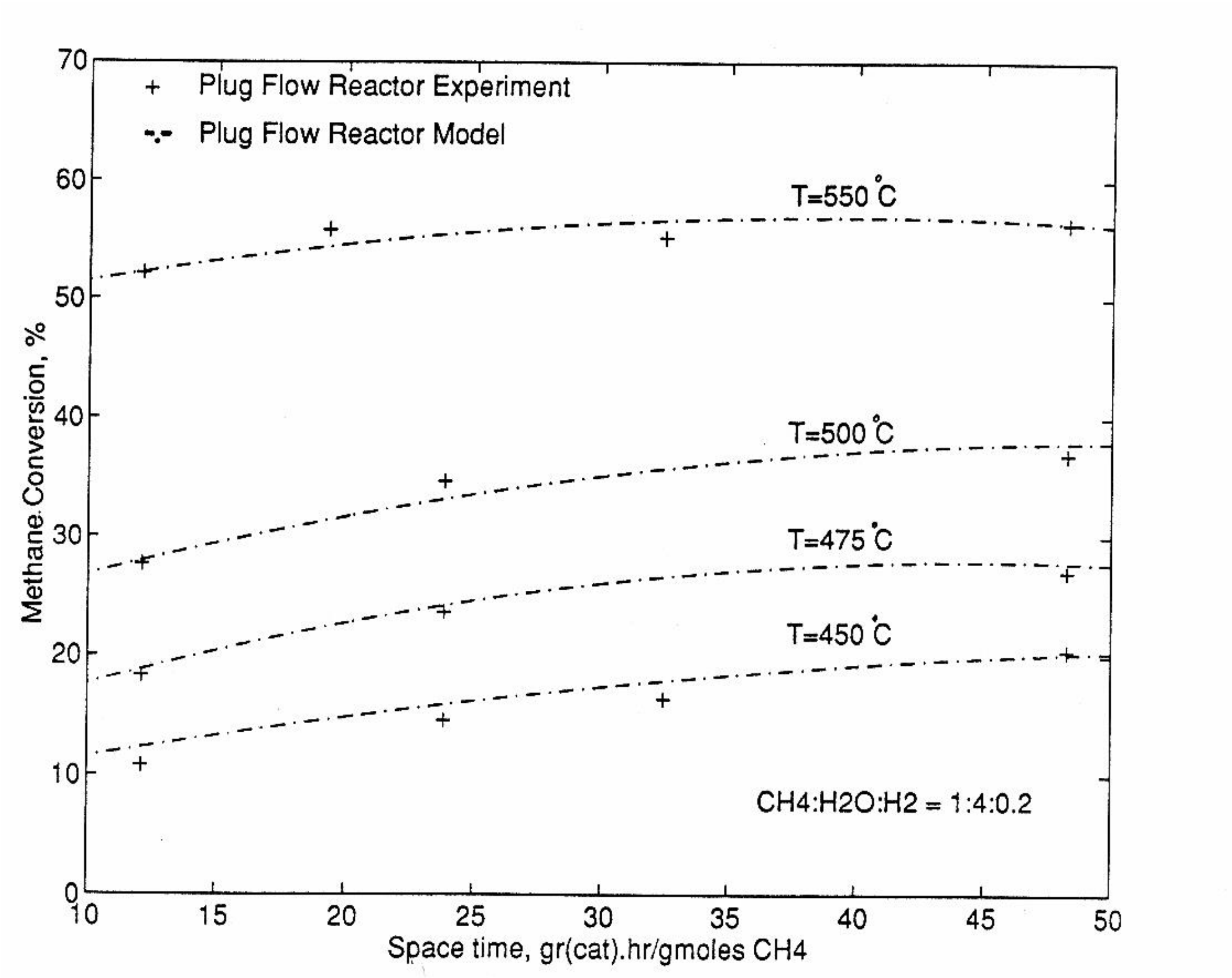
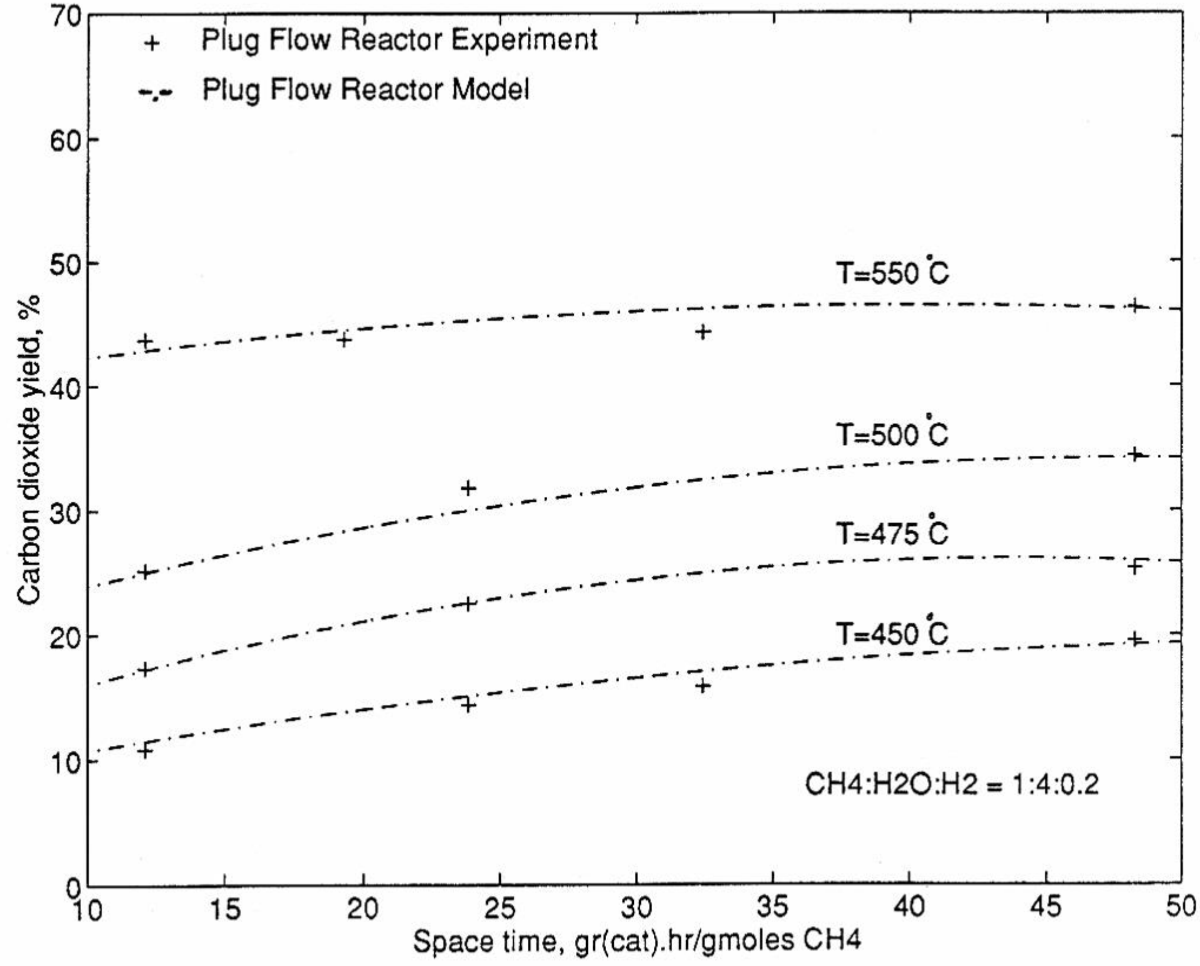


Fig.3. Experimental and modeling data/results of a biogas-steam reformer in a plug flow mode of operation. Carbon dioxide yield data at various space times and operation temperatures.



- **<u>Table 1.</u> Specifications and details of a biogas processing plant, for electricity and heat cogeneration from farm-animal wastes, (Northern Greece area), [3]**
- Biogas production volume:3600 m3/day
- (70% methane in biogas)
- ____
- Total number of farm animals : 2210
- (swines)
- Methane production volume: 2520 m3 CH4/day
- Total energy generation: 26100 kWh/day
- Electricity generation
- (35% min): 9100 kWh/day
- Heat generation
- (45% min): 11745 kWh/day
- Waste heat
- (about 20%): 5255 kWh/day
- Annual Electricity
- Generation: <u>3000-3300</u>
- MWh/year
- Sale price per MWh **73 Euro/MWh**
- (to DEH, Greek Electricity Authority),
- about <u>**241000**Euro/year</u>
- Annual Heat generation: <u>4200-4300</u>
- MWh/year
- Equivalent Oil capacity <u>363 m3/year</u>
- (Annual)
- Oil sale price: about 1100 Euro/m3

Conclusions

- Hydrogen Assisted Combustion Process (HACP) can be coupled with reforming operations of biomass based gases.
- The specific electricity and heat generation system can operate in series or integrated with a catalytic reformer which converts biogas feedstocks at various operating conditions.
- These biogases are rich in CH_4 and are converted into a H_2 ,CO, and CO_2 rich mixture suitable for the continuous operation of the turbine-combustion unit.
- Our reformers have been also simulated by computational models which account for the reactions taking place within the reformers.
- Several flexible operating conditions in the reformers have been tested via these models and results have been derived.

Conclusions

- Useful distributed power generation within a wider power grid can be accomplished with this operation, which can cover the local needs of municipal and remote areas rich in biogas sources.
- Final power output relates to the reformer conversion and the efficient utilization of the syngas by the turbine system. The waste heat from the conversion of syngas to electricity can be possibly reduced through the hydrogen assisted enhanced operation and higher overall efficiencies can be achieved.
- Hydrogen enhanced combustion from biogas, in a continuous operation mode offer as well pollution minimization (specifically NOx reduction), higher power density and increased efficiency (reduced waste heat) in comparison with conventional power systems.