Starting point of the project

The conversion of organic waste into biogas using controlled biological systems is an increasingly important waste management technology, whatever the origin of gas:

- from landfills equipped with a methane collection system to recover the biogas
- from the anaerobic digesters at agricultural, industrial or wastewater treatment plants.

Finding cleaner ways to turn biogas into electricity and heat, using more reliable equipment and at the same time reducing maintenance costs, is one of the main challenges for waste management and for the reduction of greenhouse gases emissions to atmosphere.

Conventional technologies for biogas valorisation are:

- Boilers or forced air furnaces in which biogas is directly combusted for heat generation
- Internal combustion engines, gas turbines generators or microturbines for CHP generation

The electrical efficiencies for the above mentioned CHP systems are about 27% for small scale power (< 200 kW) and gas turbines generators are economically feasible for multi-megawatts plants.

The BioSOFC project

As an alternative to these technologies, the **BioSOFC project aims** to demonstrate the use of biogas from different sources (landfill gas and digester gas) with a Solid Oxide Fuel Cell (technology designed to be used with natural gas) and to prove higher electrical efficiency with regards to existing technologies. Along with this equipment a biological biogas purification system must prove its sustainability and the ability of reaching the SOFC requirements.

The main objective in the project is divided into the following specific objectives

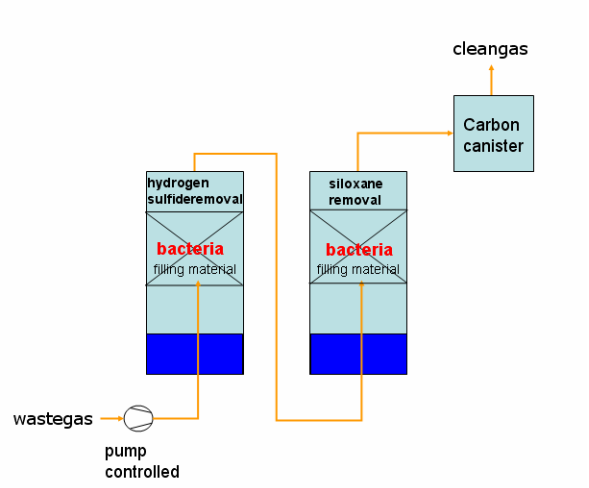
- Demonstrating the benefits (energy savings, environmental and economical) of using a CHP system based on a SOFC fed with biogas, in 3 different facilities.
- Reducing the environmental impact, while solving the problems associated with the safe, cost-effective and clean disposal of wastes in the agro-food industry, and municipal solid wastes (MSW) in the landfills
- Proving the reliability of a sustainably working filter for upgrading different biogases
- Comparing the SOFC's and the whole systems' performance, using different biogases and biogas upgrading systems.

Biotrickling Filters, to upgrade biogas

The biotrickling filter, a biotechnological method which uses different micro-organisms cultures to degrade the H2S and siloxanes, is as efficient as physical-chemical ones in the H2S removal, presents lower investment and operation costs, and avoid catalysts and formation of secondary contaminants which are the drawbacks of the physical-chemical methods

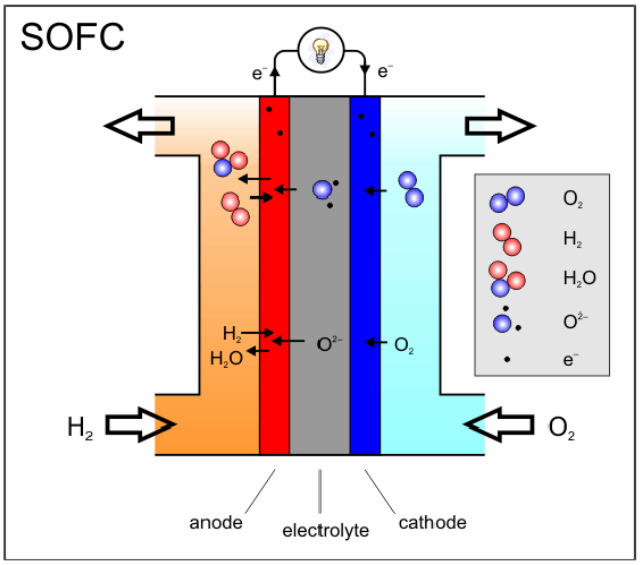
The biological cleaning system consists in principle of two biotrickling filters in series: trickling filter column one is for desulphurisation, trickling filter column two eliminates siloxanes from the biogas / landfill gas.

In the columns filling inert material is introduced in whose surface the bacteria grows forming a biofilm. In the start up of the system, the columns must be inoculated with bacteria, so that the pollutants of the gas passing through the column diffuse into the biofilm and are degraded by the microbial activity. Nutrient solutions are also needed to breed and feed the bacteria. At the end of the biological cleaning system the gas is led additionally through an activated charcoal filter (police filter). The activated charcoal filter also ensures a cleaning of the fermentation gas in cases of emergency, maintenance and reparations



SOFC Technology to convert biogas into electricity and heat

A solid oxide fuel cell is an electrochemical device that converts hydrogen from fuels directly into electricity and heat (exothermic reaction). The process is driven by the flow of oxygen ions from a cathode to an anode through an electrolyte. These ions combine with hydrogen from the fuel at the anode producing water, releasing electrons to an external circuit. This reaction occurs at the cell at a voltage of 1V approximately, so you need to connect cells in series to reach a convenient voltage for the inverter (electronic device for converting the DC power from the stack into AC). This is called a stack. It's possible also to connect in parallel to increase the intensity. The cells are connected in series and parallel until you reach the desired voltage and intensity.



The project implementation

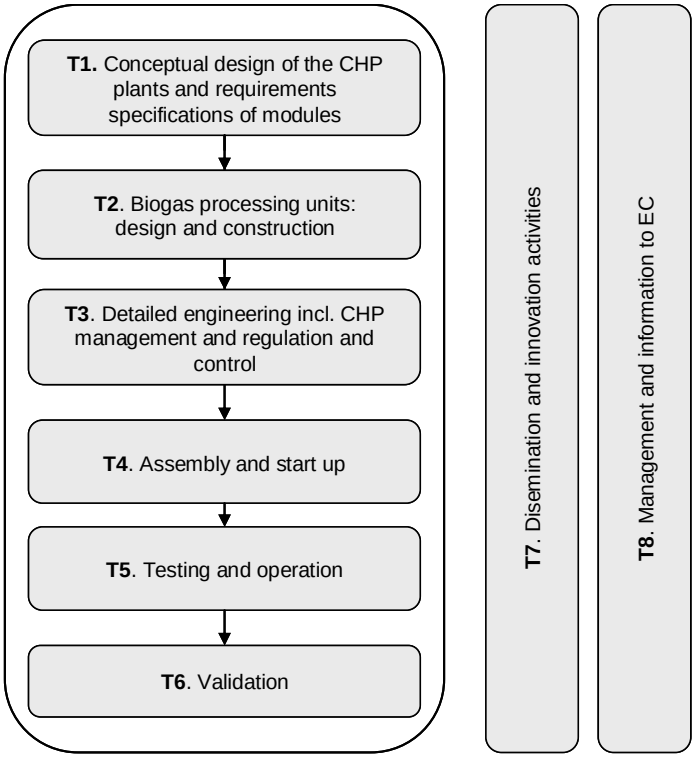
Within the project 2 innovative CHP systems based in SOFC, fed with landfill gas and digester gas, have been designed and built. Every unit comprises: (i) a biogas conditioning and purification system with a security AC filter which will be specifically designed and constructed for the characteristics of the biogas from the plant and the gas requirements of the fuel cell, (ii) combined heat and power generation with a SOFC, including the power conditioning and thermal and electrical energy recovery, (iii) the regulation control system of the equipment. All this will lead to a better waste management, as biogas will be used as fuel to generate heat and electricity for the plants processes.

The first 3 phases in the project aimed at the **conceptual design** of which plant and module, the definition of the requirements according to the characteristics of every gas and every plant, the **planning of the detailed engineering**, P&I diagrams, regulation and control system, and the **construction** of the individual modules plus the purchase of the 2 SOFC prototypes.

In task 4 both plants were **assembled and started up** at the site planned. Previously the needed permit for the plant operation had to be requested and the technical pack documents ready for the start up protocol, operation and maintenance.

Task 5 meant the **operation and the testing period** of the plants in order to analyse the results of the operation considering all the variables, and finally the **validation** task in which the results from the testing lead to the improvement of the plants.

One of the SOFCs was tested with natural gas in Asturias, and the biofilter in CyL, using the biogas generated by the anaerobic digestion of livestock manure. The other one has been tested in 2 different plants: a landfill site in Barcelona, and a landfill site in Galicia. Therefore more valuable data, due to the different biogas quality and conditions, was acquired to assess the performance of the system in different conditions.



Dissemination

The partners in the project have been very active in attending congresses and related fairs in order to disseminate the progress of the project. The major event was the organisation of a workshop at the end of the project to present the BioSOFC results and the perspectives for biogas and its valorisations with the title ”Biogas as renewable energy source. Innovative valorisations”. Operators of waste treatment plants, renewable energy engineering companies, agricultural associations, scientist from universities and research institutes and administration representative participated.

Main Results

The testing of the SOFC with a 75% methane content biogas resulted in an electrical and thermal efficiency of 29% and 24,5% respectively, showing that, despite the fact of operating a SOFC designed for natural gas, the operation with biogas in the landfills did not have an appreciable impact on the fuel cell performance.

Further test at the other landfill site showed that lower than 50% methane content is not sufficient power input to be able to operate the SOFC.

The biogas composition must be analysed carefully before joining both technologies, as SOFC requirements are very demanding and additional security filter must be considered; also the flow and methane content in the biogas must be as steady as possible. One fact resulting from operation is that very little amounts of other sulphur compound than H2S degraded the stack of the SOFC in a very short time. Therefore this lead to the conclusion that landfills are not a suitable location for the implementation of the SOFC technology: the biogas composition and supply is unsteady and the removal of harmful compounds may be difficult and too costly.

The efficiency of the biological treatment (biotricklling filter) achieved in the 4 sites tested (with 80-100 to 2.500 H2S ppms) varied from 90% up to 100% in the removal of H_2S, operating steadily. The reliability of this cost-effective technology working with different gases has been proved, although the time reaction of bacteria when fed with very variable H_2S concentrations must be taken into consideration.

Environmental benefits

The principal benefit of SOFC technology fed with biogas is the saving in overall CO_2 output, coming from 3 fronts: the equivalent CO_2 value of the methane converted, the equivalent CO_2 saved from generating electricity and the equivalent CO_2 saved from generating heat. A 250 kWe SOFC contributes to the reduction of over 9.000 CO2 tonnes/year higher than a conventional technology of the same power which presents lower efficiency.

As for the biotrickling filter, it does not generate secondary contaminants and the energy demand is minimum when compared with physical-chemical methods.

The BioSOFC technology has negligible NOx and SOx emissions which prevent from the effect of those compounds such as eco-toxicity, human toxicity, smog, acidification and acid rain.

Cost-benefit discussion on the results

The high capital cost of the technology is a current barrier since it is still a technology under development with many issues to be improved: lifetime must be increased, durability of the stack, robustness, size of the system and also the availability of the system itself comparable to today's systems.

Even if the operational costs are minimum and the incomes via electricity selling and savings by the use of the heat generated are included in the calculations, the technology does not reach the point of being feasible economically.

Although technological advances, particularly in fuel cell materials and construction, will reduce costs, the reduction necessary to become competitive requires *unit mass production*.

SOFC has a niche market in the small scale applications, i.e for domestic and residential use, hotels, etc. Under 65 kW there is no competing technologies as microturbines or internal combustion engines, therefore the use of SOFC would be an alternative once the barriers of the capital costs and the size of the equipment are overcame. For higher power, conventional technologies, although not as environmentally friendly, are economically feasible.

Transferability of project results

At present it is of much importance to transfer the results of the project and the experience gained to coming demonstration projects in order to spur future activities, help to avoid the repetition of the experienced difficulties in the future and adapt the experience to other high temperature level

For a marketable product further co-financed projects – RTD and demonstration -have to be carried out in the near future.

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