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ANAEROBIC FERMENTATION: BIOGAS FROM WASTE THE BASIC SCIENCE

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Abstract
In this lecture the Basic Science for the Anaerobic Fermentation process leading to the production of Biogas from organic waste will be discussed. The different phases that drive the conversion of non-cellulosic vegetal materials, sludge or monomeric organics into biogas will be described and the role of a number of microorganisms and enzymes will be detailed. The production of methane from acids and CO_2 will be presented.

Introduction
Non-cellulosic vegetal materials (the so called Fruit-Vegetal-Garden-FVG residues) and sludge have such a high water content that discourages their thermal treatment that would result economically and energetically disadvantageous. Conversely, such organic waste, as well as monomeric organics, are suitable for the generation of energy products like methane and/or other biofuels (alcohol, oil, biodiesel): such practice is expanding worldwide with steadily growing intensity. The energetic valorisation of waste contributes to avoiding landfilling, that is under strict limitation in many countries, reduces water and soil pollution, allows water recovery and re-utilization while producing usable energy that would otherwise be lost.

Discussion
FVGs, industrial organic residual compounds and sludge, can be treated either by "aerobic" or "anaerobic" digestion. In the former process, the cost of which depends on the aeration frequency [1], the degradable fraction is converted without energy recovery. The latter technology, instead, allows to convert organic carbon into "biogas", i.e. a mixture of methane and CO_2, from which the energy rich species methane can be separated, even if with moderate efficiency (30-50%) due to

the low biodegradability of parts of the solid fraction (see below) and the long retention times (20-30 days) [2]. Biogas technology is being continuously improved by optimizing the process parameters and the reactor geometry [3] and with integration in other waste treatment plants. Methane can be used for thermal or electric energy production.
The “anaerobic” metabolism does not require oxygen and is suitable for treating FVG or organics. The main theoretical limits to the application of an anaerobic process are:

- incomplete conversion of the substrate: often more than 50% of the organic material (the polymeric fraction) is not degraded;
- medium-or long-retention time;
- formation and persistence of some acids that may be polluting agents;
- bacteria may need some nutrients that are not available in the original substrate. Their growth may be slow because of the scarce energy available;
- permanence of ammonia (NH_3) and other N-compounds.

Some of these problems have already found a solution at the industrial scale plant, others need further studies and research.
The FVG biomass conversion into biogas encompasses a number of phases, namely: i) depolymerization, ii) acidogenesis, iii) acetate formation, iv) methanogenesis, and v) methanation of CO_2, each of which requires different bacterial communities and a complex metabolic food chain [4-6]. In the whole process, H_2 and organic carboxylic acids, such as acetic acid, are key intermediates: it is important to maintain a low H_2 partial pressure as key biological reactions may occur that for thermodynamic reasons do not take place under high H_2 pressure [4]. The anaerobic digestion of fatty acids, alcohols and organic compounds is accomplished through a syntrophy between H_2-producing and H_2-consuming methanogenic archea [6] that favour the best use of the energy content of primary substrate [7].
In this lecture, the foundamental science at the basis of methane production is discussed, while technologies for methane production will be presented in another lecture. In particular, the enzymes involved in the biogas production process are described here and the role of iron, nickel and cobalt during the anaerobic digestion of a sludge is elucidated. The above metals play a key role in anaerobic metabolism during the methanogenic digestion [8].

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Acknowledgements

The research leading to this publication has received funding from the European Union Seventh Framework Programme [FP7/2007-2013] under grant agreement n° 241718 EuroBioRef.