PhD School on Agriculture, Environment and Bioenergy
(http://sites.unimi.it/dottorato_aab/)

(XXXV cycle, 2019-21)

Project draft

1. Field of interest

   AGR13: biomass re-use circular economy, green chemistry.

2. Project title

   Bioplastic from organic wastes and agricultural wastes

3. Tutor (Fabrizio Adani)

   - Eventually: co-tutor/s

4. Relevance of the topic and state of the art:

The future bio-based economy will be realized by industrial biorefineries that produce sustainable biofuels and bioproducts from renewable biomass sources. The realization of an integrated biorefinery represents a strategic goal of the biogas sector towards addressing the circular economy, which would include production of high added values compounds beside biomethane (bioCH_4) for energy.
Co-producing renewable plastic precursors with technologies integrated in the waste management sector and agricultural wastes industry could potentially benefits in designing a sustainable and viable closed-loop multistage biogas based biorefinery. Plastic demand is continuously growing (e.g. 50 million Mg in Europe, in 2016). Conventional plastics require significant volumes of oil and gas every year and its impact due to its accumulation in the environment is well documented [1].

Bioplastics are the types biodegradable plastic, which are obtained from renewable biomass sources. Bioplastic started to substitute the fossil-derived plastic [2], and although it represents only the 1 % of the total plastic produced in the world, it is expected to growth from 2.05 x 10^6 Mg in 2018 to 2.44 x 10^6 Mg in 2022.
Biopolymers such as polyhydroxyalkanoate (PHA) can be the main constituent of bioplastics and are the main drivers of this growth. The global PHA market is expected to reach US$ 93.5 million by 2021, by a compound annual growth rate of 4.88% [3]. These biomaterials are polyesters synthesized under excess of C and nutrient limitation (nitrogen or phosphorous) by certain types of bacteria and stored inside their cells as intracellular carbon and energy reserves. They are attracting attention as replacements for petroleum-based plastics due to advantages, including that they (1) have mechanical properties similar to polyethylene and polypropylene; (2) are completely biodegradable; and (3) can be derived from renewable resources [3].
Conventional methods of producing these biopolymers use sugar feedstocks from plants as C source; however, sugar requires significant energy to grow, harvest, and processing [4].
Different pathways for fermentative production of PHA have been explored to find microbial species “PHA producers” that convert inexpensive substrates, in order to decrease the cost of production that greatly depends on the cost of the C source [5].
An alternative route and a promising C feedstock candidate for the development of an integrated closed-loop “cradle to cradle” system biorefinery for PHA production is the use of organic wastes via dark fermentation producing organic acid and/or using bioCH_4 from biogas [6].

5. Layout of the project (draft)

The project aims is to *establish an economically viable process to convert low cost substrates such as organic wastes and* bioCH_4 *from anaerobic digestion into PHA*. Organic wastes and CH_4-based PHA production through fermentation process will be investigated. Impact of the conversion in terms of PHA productivity, cost and energy saving aspects will be evaluated as well. With a perspective of realizing an integrated biorefinery, anaerobic fermentation producing both organic acid and biomethane as multi-process system will be considered, exploiting the biogas grid of Lombardy region, which represents 400 biogas plants fueled by bioCH_4. The idea behind this project is to establish a strong strategic organic waste biorefinery platform, integrating the innovations of converting renewable biomass to bioplastics, into the logic of a circular economy model that will contribute to sustainability improvements. This project will explore and develop bioprocesses and strategies for the valorization of inexpensive C sources such as complex substrates and solid waste streams (e.g. agro industrial waste, OFMSW, and highly productive energy crops) in order to improve the viability and economics of PHA production.

5.1.Materials & Methods:

The three-years project will be developed throughout the application of different approaches and will be divided into four tasks that will contribute to improve the conversion of organic wastes and biogas-derived CH_4 to PHAs. These tasks will be: **1)** microbiological based screening analysis of the MMC and PHA-producing bacteria selection **2)** evaluation and optimization of CH_4-based PHA production at batch and semi-continuous lab scale studies **3)** assessment the performance of full-scale case studies biogas plants in terms of yields, mass balance, extraction/recovery, physicochemical characterization of CH_4 based PHAs relative to different bioconversion scenarios such as through short-chain-carboxylates as volatile fatty acid (VFA) platform **4)** techno-economic analysis (TEA), life cycle analysis (LCA) and a comparative performance matrix on all tested CH_4 based PHA production approaches. A Gantt chart for planning the project with all the tasks is presented.

5.2. Schedule and major steps (3 years): mezza pagina max

Task 1: *Microbiological based screening analysis of the MMC and PHA-producing bacteria selection*.

In the first phase of this work, it will explored the groups of microbial populations for a preliminary estimation, screen and selection of PHA-producing MMC. Bacteria consortia selection will be checked by PHA production with a feast/famine feeding regime strategy, such as suggested previously [9,10] by using inoculum feed constituted by different sources as substrate. evaluation and the biomass selection.
Tools such as tag-pyrosequencing and amplicon sequencing methods targeting the 16S rRNA gene on the Illumina platform by outsourcing the samples will be applied to characterize and identify the difference in composition of the microbial community.

Task 2: *Evaluation and optimization of organic wastes-based and CH_4-based PHA production at batch and semi-continuous lab scale studies.*

The methanotrophic consortia established and selected from Task 1 will be used as inoculum producing PHA from organic wastes and biomethane by consolidate approaches. PHA accumulation tests will be treated in sequential separations and purifications to allow the extraction and quantification of produced PHA that can be further analyzed for its chemical and physical properties.

Task 3: *Organic wastes and CH_4-based PHA production*

PHA production by conversion of organic acid via dark fermentation and bioCH_4 from anaerobic digestion will be investigated in terms of yields, mass balance, extraction/recovery, chemical characterization of PHAs using MMC.
Performance of PHA production will be compared regard different bioconversion scenarios. In particular, we will consider fermentation from three AD selected plants treating respectively OFMSW, manure, crop energy/ non-food lignocellulosic biomass and agro-industrial wastes. The PHA yields from these scenarios will be related to those obtained from route where VFA is used as C source for MMC under anaerobic fermentative reactions applied on the same sources complex organic matter agro-waste and energy crop, by approaches previously reported [9,10].
All the information and data relevant to energy consumption, mass balance, costs, mass flow, yields in terms of CH_4 and PHA will be collected and transferred to Task 4.

Task 4: *Biorefinery evaluation and overall full-scale products estimation*

This task aims to analyze the data obtained by previous action/achievments and evaluate the economical sustainability of the process. In particular, the evaluation of the different processes will be discussed by a complete mass balance approach of biorefinery process that will estimate PHA producible amount and yields referring them to waste weight unit used.

6. Available funds (source and amount)

Fabrizio Adani Fund (consultable by DiSAA secretary).

6. Literature:

References

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