



**Politecnico
di Torino**

ScuDo

Scuola di Dottorato ~ Doctoral School

WHAT YOU ARE, TAKES YOU FAR

Doctoral Dissertation
Doctoral Program in Chemical Engineering (38th Cycle)

Production of biofuels and biochemicals from waste biomass

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Summary

In recent years, climate change has opened our eyes to the importance of energy transition and waste management. These two issues have become intertwined with the development of new sustainable technologies and the production of biofuels to address ecological challenges that we can no longer ignore. On the one hand, the growing production of plastic materials, including those labelled as biodegradable, raises questions about their effective compatibility with existing biological treatment systems: some of them do not degrade within the timeframes and under the conditions typical of anaerobic digestion plants (according to ISPRA data, 67% of Italian organic waste ends up in anaerobic and mixed treatment plants), creating inefficiencies and accumulating residues. According to Legislative Decree 28/2011, waste biomass is “biodegradable components of products, waste and residues of biological origin from agriculture, forestry, fishing and related industries,” including municipal solid organic waste that arrives at composting and anaerobic digestion plants. Such biogenic waste is an excellent source of renewable energy because it is not and will not be subject to depletion as long as humans exist on Earth. Indeed, as the global population grows, waste management is becoming an increasingly pressing issue that requires space, facilities, and investment. What if we changed the paradigm so that these investments were not only made to manage waste but also to benefit from it? In my PhD research, I sought to answer this very question by studying and testing the potential of different types of biomass, from agricultural to urban waste (both organic and non-organic) to obtain biomolecules for the formulation of biofuels and, at the same time, to valorise the non-recyclable plastic component, which is now an integral part of organic fraction of municipal solid wastes (OFMSW) but still separated and mostly sent to landfill due to a lack of suitable treatment facilities.

Traditional non-biodegradable plastics, and even worse microplastics, are found everywhere: from the soil to the marine environment, even finishing up in the food

we consume and therefore in our bodies. And if finding an alternative is no longer an option but an imperative, we must also understand how to make the most of all the plastic waste that already exists. This is where the waste problem can itself become the solution to our dependence on non-renewable fossil fuels. If properly pre-treated, plastics can be integrated into biological processes such as anaerobic digestion, whose gaseous product, biogas, can be converted into biomethane and used as a biofuel. Despite plausible doubts about biofuels being the ultimate solution to decarbonization, in some sectors, they still appear to be the only option in the short to medium timeframe. Although electrification is now widespread in the road transport sector, the aviation and shipping sectors, which jointly account for almost 10% of global greenhouse gas emissions remain difficult to electrify. These sectors require high-energy-density liquid fuels that cannot be replaced by electricity or solid fuels. This study focused on this issue, combining biological and thermochemical processes using agricultural and organic wastes and by products. This PhD route aims to contribute to solving today's environmental and energy challenges by taking a holistic approach to waste management and fuel production. In a nutshell it involves optimising and combining innovative approaches to the valorisation of second and third generation streams, with the ultimate aim of converting them into value.

The first study concerns the anaerobic digestion of biodegradable polymers, previously treated biologically and chemically, to accelerate the degradation of PBAT within the conventional timeframes required for the management of organic municipal solid waste (OFMSW), obtaining the three constituent elements: adipic acid, terephthalic acid, and 1,4-butanediol. On a pilot scale, 24% polymer degradation was achieved after 24 hours of enzymatic pre-treatment with esterase and amylase, and 97% in terms of weight loss after 55 days of anaerobic digestion. The second chapter examines the synergistic effect of anaerobic digestion in combination with the hydrothermal carbonization (HTC) process for the non-biological fraction of OFMSW. Hydrothermal treatment produces a liquid and a solid fraction, which, when added up to a maximum of 40% v/v and 10% w/w, respectively, increase biogas production and decrease H₂S production.

Finally, the third chapter compares different techniques for extracting triglycerides (TAGs) obtained from a two-step fermentation process using syngas produced from the gasification of biogenic residues. The final yield of the process is 26.5% of extracted TAGs.