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NEWS

PROJECT

A2UFood - Avoidable and Unavoidable Food Wastes: A Holistic Managing Approach for Urban Environments

Heraklion, Greece

TOPIC

Circular economy

EDIT 25 JULY 2022

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Bioplastics from Food Waste - ZOOM IN

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The A2UFood project proposes a holistic approach to food waste management in the Municipality of Heraklion. It includes food waste reduction (awareness raising, digital applications for the public and the hospitality sector to promote responsible shopping and consumption), food waste reuse (for humans through a 2nd opportunity restaurant for people in need, and for production of bioplastic bags), and composting (at home and neighborhood levels). So, in the context of this project, a pilot bioplastics production unit was established to produce polylactic acid (PLA) from food waste, after laboratory experiments that aimed to optimise the relevant production process as stated in the scientific literature. This zoom in focuses on the A2UFood pilot production of bioplastics from food waste, the involved people's perspectives on the issue, the science and the future prospects of bioplastics production and the A2UFood contributions to it.

1. Introduction

Increasingly, many countries and international bodies, including the European Union, are seeking to adopt circular economy principles, in an effort to address a range of environmental issues from natural resource depletion to global warming and different forms of pollution. Single use especially of long-lasting materials like plastics is of particular concern with important environmental implications. With the additional concern of food security in mind, addressing the issues of food waste and plastics use in one blow is a worthy consideration. Thus, bioplastics from food waste is a very promising and still developing field of research and innovation.

The A2UFood project of the Municipality of Heraklion has incorporated this alternative approach to food waste management in its integrative plan. This zoom-in will focus on the A2UFood pilot production of bioplastics from food waste, the involved people's perspectives on the issue, the science and the future prospects of bioplastics production and the A2UFood contributions to it.

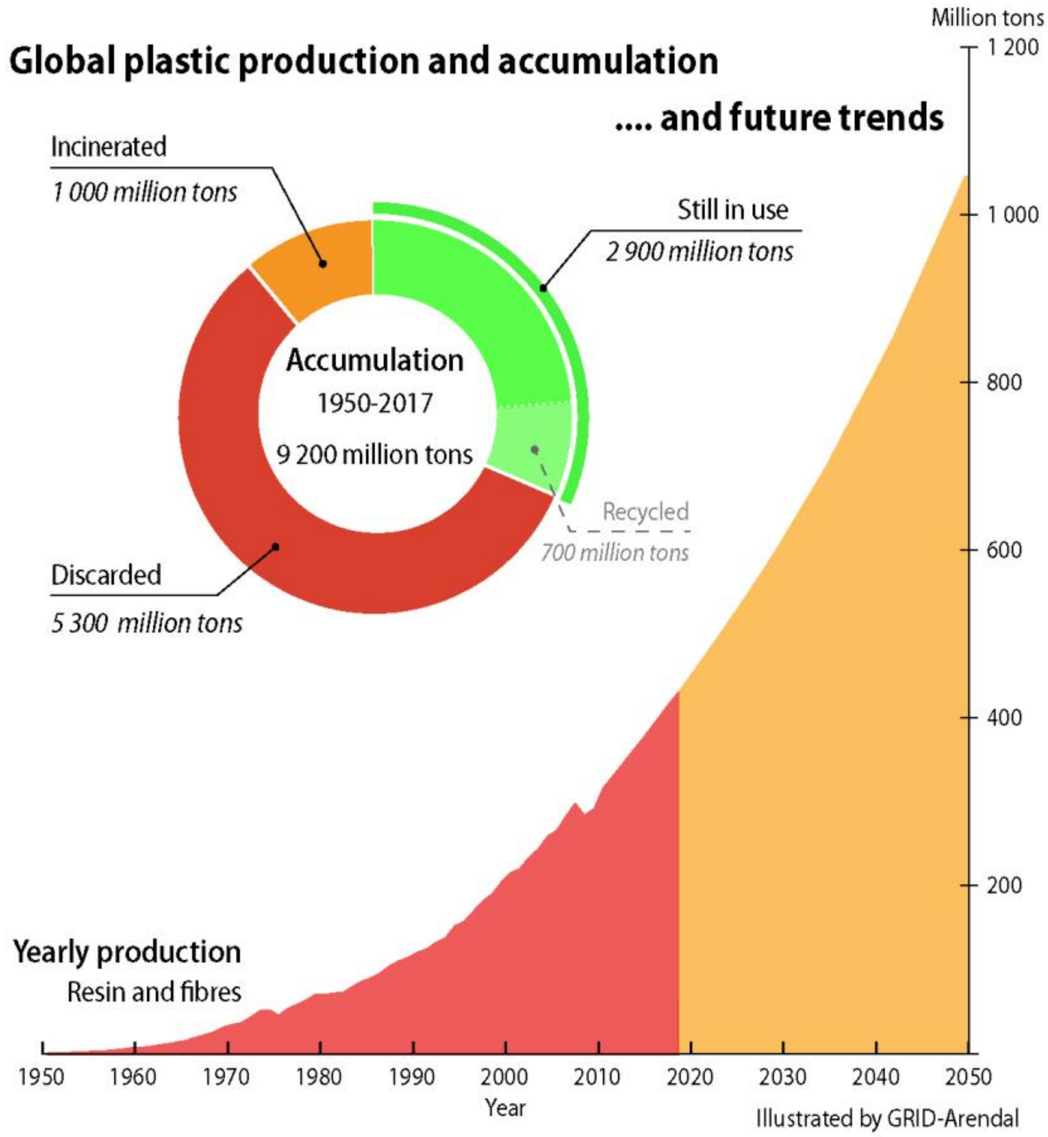
2. Bioplastics: The challenge and the opportunity

2.1 Food waste

Food waste is a significant social and economic problem, with noteworthy environmental impacts. 1.3 billion tonnes of food are wasted every year at a global scale, which is an economic, social and environmental challenge. Food waste is responsible for approximately 8% of the anthropogenic global greenhouse gas emissions (4.4 Gt CO_2 eq per year), since methane – a potent greenhouse gas – is generated from its decomposition. It also contributes to energy and water waste, natural resource depletion, air, soil and water pollution and many more. This waste implies significant, direct, and indirect, financial losses or costs. But food waste is an ethical issue too. Although more than enough food is produced to feed the global human population (Action Against Hunger, 2022), 811 million people were hungry or undernourished in 2020, and undernourishment is on the rise (https://sdgs.un.org/goals/goal2)

2.2 Plastics

The use of plastics started in the 1950s and its use is now pervasive in practically all economic sectors and everyday life. Packaging and the building and construction sector represent the largest end-use markets of plastics (PlasticsEurope, 2020). The global production of plastics was 370 million tonnes in 2019 alone and continues to steadily increase estimating to reach 1,100 million tonnes in 2050, as figure 1 below shows (UNEP, 2021). In Europe, plastics production reached almost 58 million tonnes in 2019 (PlasticsEurope, 2020). Most of these plastics are disposed after their first use, and only a small percentage is recycled, (see Figure 1 below). 85% of marine waste is plastic materials (UNEP, 2021). Plastics have direct and significant negative impacts on the marine environment, all ecosystems and human health.



UNEP (2021). From Pollution to Solution: A global assessment of marine litter and plastic pollution. Nairobi.

Fig. 1: Global plastic production and accumulation

2.3 Bioplastics production

As a response to the serious environmental problems posed by fossil-fuel based plastics, bioplastics have been investigated in the recent decades.

The term bioplastics needs clarification. Bioplastics refers to two categories of plastic materials: bio-based plastics (i.e. plastics that are fully or partly made from biological matter) and biodegradable plastics (i.e. plastics that can be completely broken down by microbes into carbon dioxide and water, in a reasonable timeframe and under specific conditions) (Krieger, 2019). The two are not the same; some biodegrade, some do not, and some biodegrade in some environments only. You can see which bioplastic materials biodegrade and under what conditions in Figure 2 below.

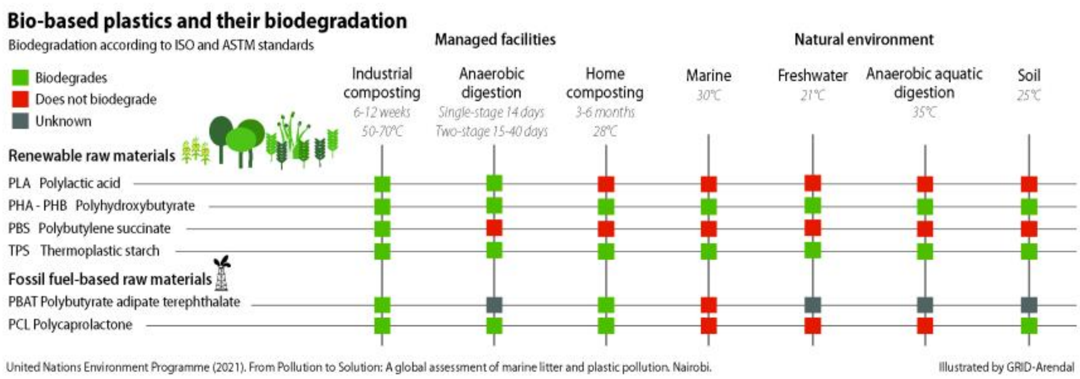


Fig.2: Bio-based plastics and their biodegradation

At present, approximately 2 million tonnes of fully bio-based polymers (plastic) are produced annually, and two thirds of these are biodegradable. They are used in a great variety of applications, including health and medicine, while their largest markets are food packaging and fast-moving consumer goods (Rosenboom, Langer, & Traverso, 2022). However, they are more expensive than fossil-fuel based plastics, and they usually get landfilled.

2.4 The A2UFood project

The A2UFood project proposes a holistic approach to food waste management in the Municipality of Heraklion. It includes food waste reduction (awareness raising, digital applications for the public and the hospitality sector to promote responsible shopping and consumption), food waste reuse (for humans through a 2nd opportunity restaurant for people in need, and for production of bioplastic bags), and composting (at home and neighbourhood levels). So, in the context of this project, a pilot bioplastics production unit was established to produce polylactic acid (PLA) from food waste, after laboratory experiments that aimed to optimise the relevant production process as stated in the scientific literature.

Regarding the A2UFood initiative to turn food waste to bioplastic, the team writes: "Aiming to contribute to the reduction of food and plastic waste, we designed a pilot bio-refinery for the production of compostable bioplastic as a total material recycling process for municipal food waste following the system proposed by Sakai et al. (2003) This contribution focuses on the optimization of the polymerization step for the synthesis of poly-lactic acid (PLA) from the waste produced lactic acid." (Theodorou, et al., 2021)

3. Bioplastics from Food Waste: A2UFood - The Experience

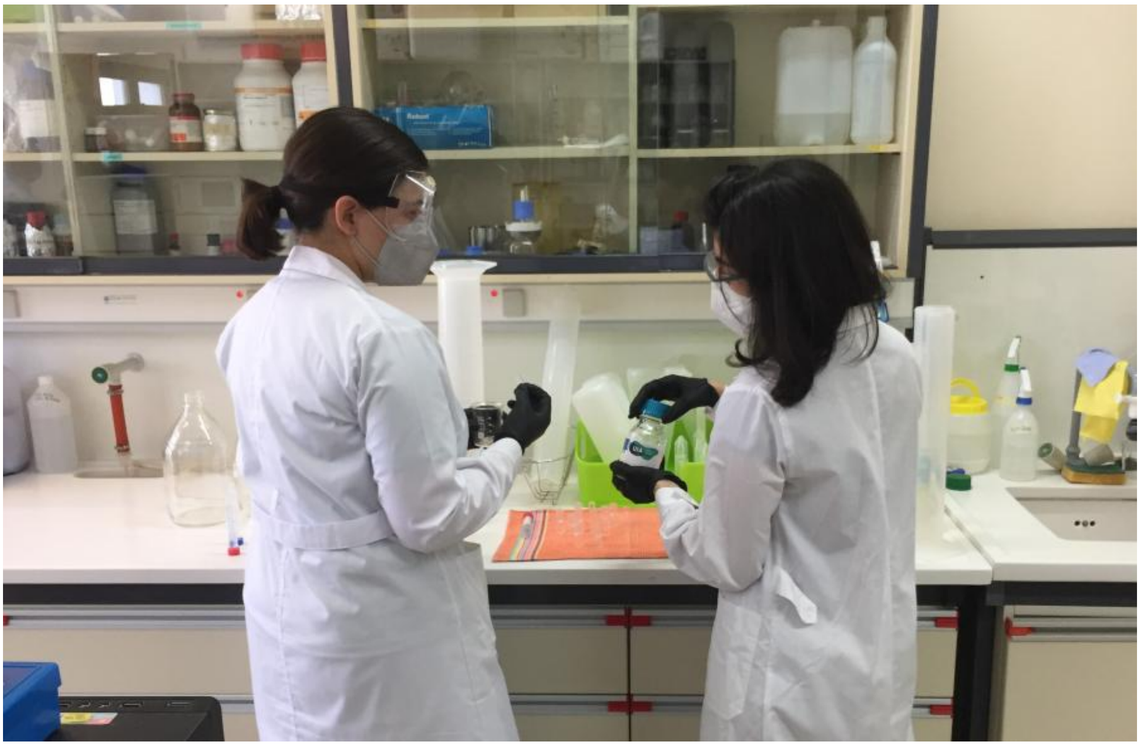
3.1 The scientific work

Stages of the PLA product in the laboratory

In the context of the A2UFood, the University of Crete team was responsible for the scientific work and supervision of the bioplastics production from food waste.

They conducted several laboratory experiments to optimise the process of bioplastics production from food waste, as this was described in the scientific literature. In their first tests, they reproduced the synthesis of Polylactic Acid (PLA), a bioplastic made from lactic acid, from a commercial lactide (monomer). After a trial of an aerobic (requiring oxygen) fermentation process which did not give the desired results, they conducted anaerobic (without oxygen) fermentation experiments for lactide production and they proceeded with the characterisation of the produced material, for standardisation purposes. For the polymerisation step – a chemical process in which smaller molecules (called monomers) are connected into larger chainlike or network molecules (PLA in this case), the team developed and optimised a more efficient and less energy demanding approach.

The UoC team also supported the implementation of the bioplastics production by cultivating the Propionic bacteria and lactobacillus, characterising and evaluating samples of the material from the pilot facility (in terms of lactic acid content, pH etc.) throughout the production process, and suggesting enhancements where necessary.



Laboratory experiments for the reproduction of biopolymer PLA

3.2 The background work

The A2UFood Bioplastics production facility

Much effort was needed to set up the bioplastics facility, involving identifying the appropriate site for the facility, licensing, designing the facility, and tendering. These tasks took a long time and faced obstacles that led to delays. But at the end, the efforts were fruitful.

Identifying an appropriate site for the pilot bioplastics facility proved a difficult task in the city of Heraklion, which has both the limitations of an urban context (e.g. limited space availability, limitations in terms of uses of space, geological considerations) and the stricter ones applying to a historic city. Licensing was also challenging, but it was overcome by achieving the application of the rules relevant to pilot projects, which are more lenient. The design of the facility was demanding, as it required a tenuous balancing act of technical, geologic, budgeting (as the foreseen budget was limited), and scheduling aspects. Finally, the pilot bioplastics facility was constructed on a site offered by the Municipal Company for Water Supply and Sewage of Heraklion (DEYAH), at the southeastern part of the city, in the last months of the project duration.

Close communication between the involved project partners and flexibility on the side of the Urban Innovative Actions initiative contributed to the successful implementation of this innovative pilot action.

Information days were also organised to promote awareness about the benefits of the production of bioplastic from food waste, and about the need for reducing and reusing food waste with alternative management methods.

Presentation of the pilot bioplastics facility to the public

3.3 The operation

The operation of the pilot unit lasted 2 months and 21 days and it involved 11 rounds of pilot operations, with approximately 65-96 kg of incoming food waste per batch. Each round of operation lasted approximately 10 days. The food waste material was received from the catering service of the Hellenic Mediterranean University. The facility worked with an on-site operator (the Joint Venture of "TH.G.LOLOS - C.TSOMBANIDIS Partnership – MEDICAL WASTE SA") and the scientific supervision of the University of Crete. Such a facility requires the continuous support of a chemistry laboratory.

The pretreatment step

The pilot implementation provided useful lessons for the enhancement of the production process of bioplastics from food waste and promising scientific insights. However, enhancements are needed. The pilot experience demonstrated that the mechanical filter was not appropriate. This filter worked well at the laboratory level but was not as effective as desired at the pilot scale operation. A new filter, based on the principle of centrifugation (i.e. centrifugal separator), should be purchased for better results. The beneficiaries are investigating the funding possibilities for such a separator. Furthermore, scientists of the partnership are doing coagulation experiments to increase the density of the produced PLA.

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4. Bioplastics from Food Waste: A2UFool - The People

4.1 Who was involved?

The implementation of the pilot bioplastics facility was the outcome of many people's intense effort. The work started with scientific experiments in the laboratories of the Department of Materials Science and Technology of the University of Crete (UoC). The UoC team, led by Dr. Kelly Velonia and involving 3 Masters students and 2 Postdoctoral Fellows, executed laboratory experiments to optimise the PLA production from food waste. At the same time, the United Association for Solid Waste Management in Crete (ESDAK) in collaboration with the Municipality of Heraklion worked hard to identify an appropriate and available site in the city for the construction of the pilot bioplastics facility. This proved challenging and contributed to delays. On the basis of the scientific findings and the selected site, ENVIROPLAN designed and redesigned the facility, including the necessary mechanical infrastructure enhancements. This was another challenging task as the budget was limited and the project time was also running out. Tendering procedures for the construction and the operation of the facility were executed by ESDAK after the tendering documents were drafted by ENVIROPLAN in collaboration with ESDAK. The University of Crete team provided the required scientific support, including laboratory checks and characterisation procedures, to the bioplastics production process. The Harokopion University of Athens (HUA) team evaluated the environmental and social impacts of the facility, via a Life Cycle Assessment, and did the initial quantitative and qualitative analysis of food waste from the participating hotels that fed the bioplastics unit. The Hellenic Mediterranean University (HMU) team and ESDAK organised open days at the facility, which aimed to inform and raise awareness among the public. Mainly educators and university students attended these events. Finally, the Municipal Authorities were involved in their decision and policy making capacity. The Hellenic Recycling Agency (EOAN) visited the project (https://esdak.gr/episkepsi-ceo-eoan-bioplastic/) and awarded ESDAK for its work (https://esdak.gr/verde-tec-vraveusi/). EOAN is the national agency responsible for ensuring "the implementation of waste prevention policies and the alternative management of product waste" in Greece (https://www.gov.gr/en/sdg/goods/recycling-and-waste-management/general/hellenic-recycling-agency-hra-eoan) . Although it is not responsible for organic waste, it has responsibility for the recycling of bioplastic bags. All these activities were of course facilitated by the coordination team. All these people were the heart and the mind behind this effort.

4.2 People's perspectives

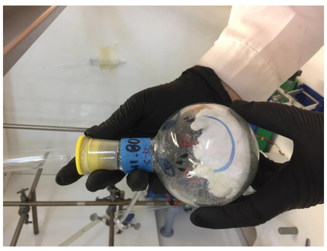
People observing the pilot unit

Twenty (20) of these people were interviewed: 4 scientists, 4 individuals involved in the implementation phase (i.e. in the establishment and operation of the facility), 2 participants of the coordination group, 8 representatives of the "lay people" – i.e. not directly involved in the project, but rather having been informed about the facility (i.e. 4 school educators, 1 HMU educator, 2 HMU students, 1 HMU staff), and 2 "policy makers" (i.e. 1 local politician and 1 representative of EOAN). Their views were collected via individual face-to-face interviews or via focus groups (especially for the "lay people"). They were asked to comment on the benefits of the production of bioplastics from food waste, and of the particular A2UFood unit; the challenges of the food waste to bioplastics production generally, locally and especially for the A2UFood initiative; their willingness to use bioplastics bags (especially relevant for the "lay people"); and the future prospects of such production. Their views are useful for shedding light on what this technological effort may mean to people and what its prospects may be.

4.2.1 Benefits

All respondents recognised the ecological and social benefits of an effort to turn food waste into bioplastic. The "lay people" – educators and other people that attended the Information Days – had a general awareness of these positive impacts. The scientists had more specific knowledge, with a clearer understanding of the environmental and social benefits (i.e. bioplastic as a substitute to fossil-fuel plastics; bioplastic from food waste as better than bioplastic from food stuffs as it does not use valuable arable land, bioplastic from food waste as a socially responsible and ethical approach to food). Dr. Manios added the caveat that "what you actually do with food waste is closely related with the purity of the food waste." The people involved with the implementation also emphasised the contribution of such an approach to circular economy and to awareness raising and development of a new consciousness against the use of fossil-fuel-based plastics. The local Municipality political representative emphasised the turn to a circular economy, a vision adopted by the MoH, while EOAN focused on the concerns regarding bioplastics produced from primary food stuffs and the European Union (EU) policy turn-away from this option due to food security considerations.

Regarding specifically the pilot bioplastics facility, on the one hand, the scientists emphasised how this initiative contributed to increased awareness about food waste and plastics.



Students in the laboratory enjoyed it

Dr. Velonia indicated that this facility "challenged people to think about food waste, plastics, circular economy" and raised interest in learning more about this alternative food waste management method (e.g. she received many invitations to speak from schools) and even in getting involved (e.g. UoC students). The implementation team also emphasised the positive awareness raising outcome of this activity. This view was reinforced by the "lay people's" responses, who generally found the idea of "food waste to bioplastics" and the effort to implement it exciting and even hopeful. On the other hand, the representatives of the coordination team were torn regarding the benefits of the pilot bioplastics facility. One of them, Mr. Skarvelakis, emphasised the very small capacity of the pilot unit, which can treat a rather miniscule amount of the municipal food waste (less than 0.1%). The other one, Ms Schiza, focused on the future and highlighted that the project facilitated the MoH's adjustment to the new legal requirements regarding waste management, as it helped the Municipality to acquire valuable experience, useful tools and equipment, while awareness raising on food waste has been done. Deputy Mayor Mr. Sisamakis reiterates both of these points: "Such a project creates the right culture and desire for the reduction of the ecological footprint of the Municipality. But in practical terms, the project's impact is very small."

4.2.2 Challenges

Beyond the aforementioned benefits, the respondents identified technological/ scientific, environmental and social challenges as well in the process of turning food waste to bioplastic/PLA. EOAN highlighted that not all PLA is biodegradable, and thus, certification of biodegradability is required based on the existing standards (e.g. EN13432 which refers to industrially compostable packaging material). At present, the information that is available to the public regarding bioplastics is not clear. The scientists talked about the need for further research on PLA (and other bioplastic materials) biodegradability, and especially in the marine environment, as well as on other technological issues like the use of enzymes in this process. On more practical terms, scientists also indicated that food waste is a very sensitive primary source and effective refrigeration is required throughout the supply chain; and that food waste material is not homogeneous, while its clarity affects the effectiveness of the PLA production process and the quality of the product. In the case of this pilot unit, food waste was received from the HMU catering service, which had been well trained to separate waste efficiently. A positive aspect is that food waste is a steady source of primary material. A concern of the public regarding bioplastic bags was that they can smell like fish – "a terrible smell" as a respondent indicated; she suggested that experts need to address this issue.

Regarding the actual pilot unit and the project experience, several challenges were identified. Dr. Manios summarised the challenges as follows: "It was a pilot, involving public facilities, and a small budget. When it was implemented several years after the proposal submission, prices had increased significantly (approximately 30%); this of course was a challenge. Furthermore, due to the time public administration and bureaucracy procedures take, there were several delays." Other respondents stated the difficulties of the public administration as follows: insufficient coordination between different Municipality departments, limited staff and even more limited scientific personnel, frequently changing public procurement legislation, public budgeting, lengthy and sometimes impossible licensing procedures (e.g. the pilot bioplastics facility could have been licensed only as a pilot; otherwise, it would have been a very lengthy process). Others mentioned the constraints imposed by the pandemic. Dr. Velonia added yet another dimension: that the leap from the laboratory to the pilot scale implementation is a qualitative – not simply a quantitative – upscale; thus, unexpected problems may arise, like in the case of this pilot bioplastic unit. The mechanical filter worked very well at the laboratory level; however, it proved ineffective at the pilot scale. Consequently, it needs to be substituted with a centrifugal separator for the pilot to operate in its full capacity. Ms Georgiou of the implementation team reinforced this point and in addition, indicated that there was insufficient time for the operation of the facility (short in the proposal and further shortened due to the observed delays).

4.2.3 People's attitudes and practices

The "lay people" that participated in the interviews expressed willingness to use bioplastic bags produced food waste, including the respondent who expressed dislike to the "fish-like" smell of some bioplastic bags. All of the respondents in this group reported that they presently throw away food waste, or when possible, they give food leftovers to animals. Some indicated that they compost as well, but when they are in a village setting. As inferred from the "lay people's" responses, in an urban context, there are fewer options for alternative food waste management that promote circularity. However, they were willing to separate food waste and reuse it more frequently in one way or another, if appropriate structures (e.g. brown bins in close proximity) allowed such choices. Regarding their use of plastic bags, they reported that plastics are still in everyone's life. They use biodegradable bags when these are provided by the shops they visit, while small shops tend to still use plastic bags. A respondent indicated that she tries to use reusable bags too.

5. Bioplastics from food waste: The Science

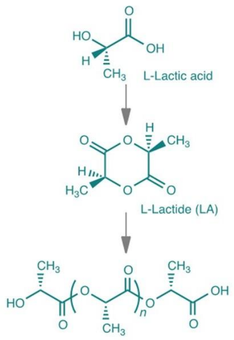
5.1 The science of bioplastics production

Polylactic acid (PLA), which is of interest in our case, is a biobased aliphatic polyester; a very versatile, biodegradable and easily hydrolysable polymer (Drumright, Gruber & Henton, 2000). As shown in figure 2 in section 2.3 above, PLA biodegrades under specifically controlled industrial conditions but does not biodegrade in the natural environment or a landfill. At present, it is most frequently produced from edible plant sugars from corn, sugar beets or cassava (de Albuquerque et al., 2021).

There are several techniques to produce PLA: either from lactic acid as the precursor, such as polycondensation of free lactic acids via fermentation of sugars or polymerisation by ring-opening of lactides (the cyclic dimer of lactic acid), or directly from lactic acid, such as azeotropic dehydration or enzymatic polymerisation (de Albuquerque et al., 2021; Rosenboom et al., 2022). Strict control of the operational conditions (i.e. pH, temperature and pressure) is required in several of these production methods, throughout the process. The physicochemical characteristics of the PLA, like molecular weight, degree of crystallinity, morphology, and rate of water diffusion, affect its mechanical characteristics and are thus important for its appropriateness for different uses (DeStefano, Khan & Tabada, 2020).

More recently, and in line with the promotion of circular economy, food waste as a source for PLA production has been investigated (Ramadan & Handayani, 2020). It has been suggested by several researchers that food waste is a promising material for the development of environmentally friendly bioplastics.

5.2 The A2UFood bioplastics production process



A2UFood Bioplastics production process

Schematically, the bioplastics production process involves 3 stages: pre-treatment, extraction, and characterisation of material (Ramadan et al., 2020).

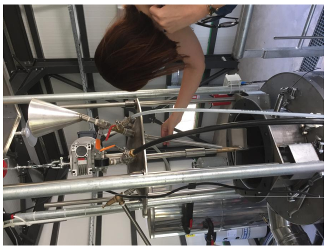
In the A2UFood pilot bioplastics facility, which can process 120 kg of food waste at a time, PLA was synthesised via first fermentations and then a tin (II) 2-ethylhexanoate optimised azeotropic polycondensation of lactic acid (Theodorou et al., 2021). More specifically, the process involves the following steps:

1st step at the sorting line – Pre-treatment and preparation of the material:

When food waste arrives to the facility, it enters a short hand-sorting line. The sorted material then passes through a shredder and a pulveriser, while water is fed into the system. Then, a pump directs the pulp to the 1st reactor.

2nd step in the 1st reactor – Fermentation:

In the 1st reactor, the fermentation of sugars takes place. The 1st reactor is supported by a gas boiler, which sends hot air to the walls (heating zones) of the reactor in order to increase the temperature in it, propane containers and a heat exchange pump for the later-needed cooling and stabilisation of temperature.



A member of the team checking reactor 1

After a *sterilisation* process, lasting approximately 2.5 hours, where the material is kept at 120oC for 30 minutes, the fermentation of sugars takes place. Fermentation is achieved with the addition of anaerobic bacteria (*Propionibacterium freudenreichii*), of *Saccazyme/Glucoamylase*, and finally of *Lactobacillus rhamnosus*, an aerobic microorganism which produces lactic acid from sugars. The fermentation stage lasts more than 3 days, with continuous pH regulation and analysis of samples. Two are the products of this step: a liquid-phase material (80%) and a solid one (20%, used for composting in Autonomous Composting Units).

Conditions need to be carefully controlled throughout the process. With the use of the heat exchange pump, the temperature is controlled (e.g. kept stable at 37oC during the fermentation process and increased as needed). The pH needs to be regularly checked and controlled as well, as it is changing continuously during the process.

3rd step – Filtration:

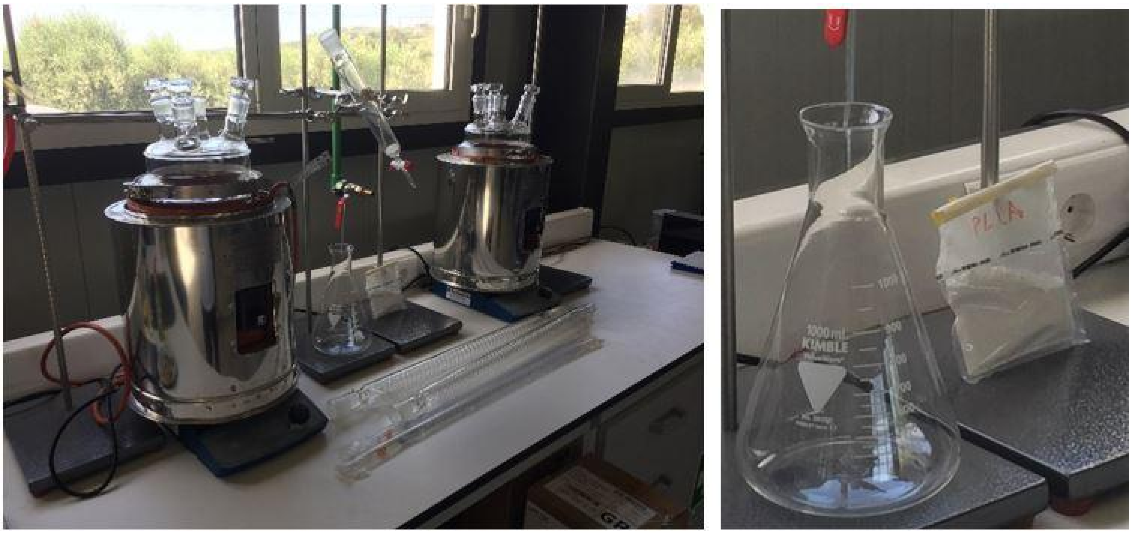
At this step, the liquid material is filtered, as all solids need to be removed before the material can enter the 2nd reactor. A mechanical filter was used in this facility, which separated solids from liquids through shaking.

4th step in the 2nd reactor – Esterification:

Esterification, which is done in the 2nd reactor, aims to achieve a higher concentration (40% condensation) of lactic acid per liter. This step lasts about 8 hours and involves the use of butanol and the application of higher temperature for the extraction of water. Following the esterification, hydrolysis of butyl lactate is necessary to isolate the lactic acid. The final product is approximately 10 lt, about 10% of the incoming amount of food waste.

5th step at the polymerisation unit – Polymerisation:

The last step is the *polymerisation* stage, which is done in anhydrous toluene. In order for this process to be effective, all water is removed from the incoming material through azeotropic distillation. The temperature is increased up to 170oC and the material becomes more viscous and finally solid. Depending on the water content, this step might last 7 to 10 days. The final PLA product (PLLA) is a white powder, and its weight is similar to the incoming lactic acid (approximately 10 kg).



Pic.9: The polymerisation unit and the PLA product

Samples of the material and the final product were regularly received and characterised by UOC, using the developed characterisation protocols.

5.3 A2UFood contributions to the science of bioplastics production

The A2UFood project made several useful contributions to the science of PLA production that can support practical initiatives to turn food waste to bioplastics, as Dr. Velonia of the University of Crete indicated.

- Firstly, they managed to decrease the required temperatures for PLA production, in comparison to those indicated in the scientific literature. This implies energy savings and decrease of the carbon footprint of such a facility.
- Secondly, with the stimulus of the limited budget, they did experiments in order to limit the needed equipment. Consequently, they avoided the costly stage of crystallisation; this resulted to the decrease of the energy footprint of the PLA production process in the pilot unit.
- Finally, they optimised the protocols for the characterisation of the PLA product (e.g. in terms of amount of lactic acid, sugars, etc.), so that they can now support such a production unit with simple measurements.

At the laboratory, the research team developed very good quality bioplastic (i.e. PLA with a longer molecular chain). Very effective removal of water is required. Such laboratory developments promise the possibility of further enhancement of the PLA production process.

6. Bioplastics from food waste: The future

6.1 The policy context

In response to the problematic and unsustainable use of plastic bags, the European Union passed the Plastic Bags Directive (Directive (EU) 2015/720), which aimed to limit the use of lightweight plastic bags and set the following targets: reduction of the use plastic bags to 90 bags/person/yr by 2020, and 50 bags/person/yr by 2025. In 2021, the Directive on Single-Use Plastics (Directive (EU) 2019/904) was adopted; it bans single-use plastics for which there are alternatives.

Following the Plastic Bags Directive, Greece also imposed a fee on lightweight plastic bags in 2018, which was later increased in 2019. Greece, however, missed the 2020 target; 110 bags (only for thin bags)/person/yr were used in 2020 in the country. Thus, a new law (Law 4736/2020) was passed, which foresees a fee for all plastic bags (irrespective of weight), with the exception of those used in open markets and kiosks (continued from before) and of biodegradable/compostable bags. This is a promising policy development which is expected to further limit the use of plastic bags and support the transition to bioplastic ones. However, this legal requirement presupposes certification of bioplastic bags according to EN 13432 standard (industrially-compostable bags) and then clear information dissemination to the public.

One more challenge for the future of bioplastics in Greece, is that at the moment, there is no clarity on how to handle biodegradable bags: should they be recycled? Composted? Home or industrially composted? Is it ok to throw them in the landfill? Thus, although they have the potential to feed the circular economy, they are improperly disposed most of the times.

6.2 People's perspectives

As the interviewed scientists indicated, at global level, there is no proven technology for the production of bioplastics from food waste at large scale. More research is needed to address issues of biodegradability, cost and other concerns in order to make the production of bioplastics feasible. However, the scientists are hopeful and believe that in the future, the use of bioplastics will expand in the market. Dr. Manios indicated that "Source separation which is now promoted will need biodegradable bags. We need to be able to produce them. And it is advisable to look for local solutions." So, there is a market. However, it was also reported that the plastics industry at the national level is sceptical about the prospects of bioplastics in the market. EOAN highlighted the need to generate interest in the bioplastics market. The "lay people" repeatedly stated that awareness raising and education regarding alternative methods of food waste management and bioplastics are needed, but they also highlighted that the Municipality's stance and the practical alternatives it offers to the public regarding food waste management and plastic bags are also important. One respondent proposed the usefulness of incentives. Several of the "lay people" indicated that other alternative uses, higher in the waste hierarchy (i.e. use for people and animals) are also worth investigating.

Locally, the scientists saw great prospects for bioplastics production from food waste in Crete as the tourist industry in the area both produces significant amounts of food waste and uses many plastic containers. Furthermore, there is a plastics production company in Crete which can and is reported to be interested in the prospect of bioplastics production, as long as the quality of the product is assured. Thus, there is a potential local market for the establishment of a bioplastics production unit in Crete, which would certainly render the bioplastics production more cost effective and environmentally friendly. Dr. Daliakopoulos indicated that he is "waiting for the cost-benefit analysis and awaiting to see what the Municipality will do [with the facility]", thus highlighting the significance of financial feasibility and political will as well.

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7. Concluding remarks

The A2UFood project made some significant contributions in the science of bioplastics production from food waste: the food waste to PLA production process was optimised, limiting cost, energy and equipment demands; simple characterization protocols were developed; and through the implemented pilot demonstration, the challenges of the transfer from the laboratory to the pilot scale were revealed. However, further optimisation of the pilot facility is still needed, which requires funding that is not presently available to ESDAK. At subsequent stages, a systematic evaluation of environmental impacts and a cost-benefit analysis are also required.

In addition, the project set the ground for the Municipality to adjust to the new requirements for waste management, as they have acquired valuable experience, tools and equipment, while some awareness raising regarding reduction and reuse options for food waste has been done. The prospect for a bioplastic production unit in Crete, due to the high touristic activity which generates significant food waste and uses much plastic packaging, seems promising as there is the primary source, a market for bioplastic bags, as well as a plastic production company regionally. Funding is always an issue for such alternative waste management methods; however, the possibility for a public – private collaboration exists in the region and may be a good option to consider.

Finally, the public seems open, even positive, to the use of bioplastic bags produced from food waste, although people can easily get disheartened from faults in the product or the organisation supporting such an alternative option. It appears that awareness raising with the use of experiential approaches (e.g. visits to the facility, properly planned and supported with visual materials) can support the reduction of food waste and the promotion of circularity in the food system in the area, with the production of bioplastic bags from food waste as well. However, the appropriate structures (e.g. brown bins conveniently located) and organisation to cultivate trust in the authorities (e.g. regular and proper pick up) are also required to incite new practices.

There is a future for the production of bioplastics from food waste. Progress has been made but considerable work is still needed.

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7. References

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Videos of the A2UFood project (in Greek):

1. https://1drv.ms/u/s!AqdJbN1hmHRTn_p737VWB1T7FTj57w?e=MU1Hdf (whole project)
2. https://onedrive.live.com/?authkey=%21AN%2D1VgdU%2DxU4%2De8&cid=53749861DD6C49A7&id=53749861DD6C49A7%21523647&parId=53749861DD6C49A7%21523656&o=OneUp (bioplastic pilot)
3. https://onedrive.live.com/?authkey=%21AN%2D1VgdU%2DxU4%2De8&cid=53749861DD6C49A7&id=53749861DD6C49A7%21523646&parId=53749861DD6C49A7%21523656&o=OneUp (bioplastic)

Photos were taken by the project team and by Christina Marouli, A2UFood expert.

List of abbreviations

A2UFood	A2UFood - Avoidable and Unavoidable Food Wastes: A Holistic Managing Approach for Urban Environments
EOAN	Hellenic Recycling Agency
ESDAK	United Association for Solid Waste Management in Crete
EU	European Union
HMU	Hellenic Mediterranean University
HUA	Harokopion University of Athens
MoH	Municipality of Heraklion
PLA	Polylactic acid
UoC	University of Crete, Department of Materials Science and Technology

Circular economy

See on UIA website