The RES URBIS Rationale

RES URBIS aims to convert several types of urban organic waste into valuable bio-based products, in an integrated biorefinery and by using one main technology chain.

- The TECHNICAL GOAL of converting organic waste into the above mentioned bioproducts will be combined to TERRITORIAL AND ECONOMIC ANALYSES in four territorial clusters.

- At the end of the project, we demonstrated the feasibility of whole RES URBIS technology chain for territorial clusters of more than 500,000 inhabitants, by involving all technical/non-technical aspects ( economical, regulatory, social and environmental).

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Rationale of RES URBIS project

Considering the strong EU commitment towards full implementation of a European circular economy, it is necessary to extend and to improve available options for resource recovery from the organic fraction of waste of urban origin, especially towards higher value products than energy and compost.

Within the urban environment, significant amounts of organic residues originate from the separate collection of urban solid waste (OFMSW) and the sludge from urban wastewater treatment plants (WWS). Although OFMSW and WWS originate from the same urban area and contain similar amount of organic carbon and of similar nature, usually these two streams are handled separately. This historical separation of treatment options creates an interesting opportunity to identify processes and strategies that allow for the effective conversion of organic carbon contained in urban wastes into useful bio-based products, while also reducing the global impacts on water and climate caused by their treatment and disposal. The integrated treatment of civil wastewater along with organic solid wastes (mostly of municipal origin, while not excluding residues from food-processing industry of comparable composition) in a novel “bio-waste biorefinery” is a key option to practically implement a synergic treatment of all relevant bio-waste streams of urban origin. Indeed, this integrated and flexible “bio-waste biorefinery approach” can present several advantages, in both environmental and economic terms, especially because it allows to achieve the critical operating capacity of the bio-waste biorefinery even in small “waste basins”.

In order to define appropriate strategies, it is thus necessary to take into account that driving forces and constraints highly depend on the territorial conditions. In other words, it is necessary to create autonomous clusters where the recovery strategies are affordable and recovery cycles can be closed within the cluster itself, e.g. without the need to transport either bio-waste or the resulting bio-based products for long distances.

Scope of RES URBIS project

Since the objective of RES URBIS project is to integrate into a single facility and to use one main technology chain for the conversion of several types of urban bio-wastes into valuable bio-based products, while also minimizing any residual or consequent waste to be disposed of, with this concern, urban bio-waste and bio-based products are the targeted substrate and outcome of a chain of biological processes.

Urban bio-waste include the organic fraction of municipal solid waste (from households, restaurants, caterers and retail premises), excess sludge from urban wastewater treatment, garden and parks waste, selected waste from food-processing (if better recycling options in the food chain are not available).

Bio-based products include polyhydroxyalkanoate (PHA) and related PHA-based bioplastics as well as ancillary productions: biosolvents (to be used in PHA extraction) and fibers (to be used for PHA-based biocomposites). Territorial and economic analyses will be done either considering the ex-novo implementation of the biowaste biorefinery or its integration into existing wastewater treatment or anaerobic digestion plants, with reference to different territorial clusters and for different production size. The economic analysis will be based on a portfolio of PHA-based bioplastics, which will be produced at pilot scale and tested for applications:

- Biodegradable commodity film
- Packaging interlayer film
- Speciality durables (such as electronics)
- Biocomposites with lignocellosic fibers
- Premium slow C-release material for ground water remediation
A consequential LCA comparing six scenarios for the management of urban organic waste (i.e. OFMSW and sewage sludge) and covering five territorial clusters (Metropolitan Area of Barcelona, Metropolitan Area of Lisbon, South Wales and the Province of Trento, and in addition the Metropolitan Area of Copenhagen) was conducted. The LCA study was to a large extent based on primary data for mass flows delivered by the clusters; data regarding the RES URBIS biorefinery were mostly generated within the RES URBIS project. Results were calculated for a range of impact categories (Climate Change, Photochemical Ozone Formation, Terrestrial Acidification, Terrestrial Eutrophication, Freshwater Eutrophication, Marine Eutrophication and Depletion of fossil resources) and as aggregated single-scores, and were presented disaggregated by waste flows and by contributing processes. The main conclusions can be summarized as follows:

- From a methodological point of view:
  - The aggregated single-score indicator shows that there is not a single impact categories that drives the results, but it is a combination of several impact categories.
  - The introduction of new technologies (as RES URBIS) needs to take into consideration also the upstream and the downstream technologies, including the pre-treatment, the extraction, the management of the residues, etc. some of these processes can in fact have a significant effect on the performance of the system.

- When comparing technologies, scenarios and clusters:
  - The environmental performance of the RES URBIS is strongly dependant on the ratio between OFMSW and sewage sludge. This ratio severely affect the amount of PHA produced in individual clusters, as well as determines the amount of sewage sludge that must be handled in the traditional way.
  - The RES URBIS biorefinery has a negative environmental burden, meaning that the energy and the material consumed for the production of PHA are less impacting than replacing the production of fossil plastic.
  - Compared to the other technologies, the RES URBIS biorefinery:
    - It is always better than the landfiling
    - It is in general better than the AD if the amount of urban organic waste handled is large enough compared to the overall amount of organic waste available in the clusters.
    - It is better than the incineration only if the residues of the biorefinery are sent to optimised treatments: the biogas from the AD needs to be upgraded and the methane emissions from the AD plant needs to be minimised.
  - The RES URBIS biorefinery is highly dependant on the utilisation of the biogas from the AD plant and from the treatment of the liquid fraction.
  - Overall, the implementation of the RES URBIS biorefinery is more beneficial within certain local conditions, i.e. when:
    - A market for high-applications for PHA is available;
    - The marginal energy mix is mostly based on renewables;
    - It contributes to diverting organic waste from landfills;
    - Organic waste generation is rather concentrated (i.e. urban areas) to minimize transportation and deliver a minimum critical mass.

- Further development of the RES URBIS approach:
  - The utilisation of VS, carbon and nutrients should be further optimized by increasing the conversion efficiency of different processes. As the OFMSW to sewage sludge ratio is to some extent a bottleneck, a more flexible setup that allows handling more variable feedstock would be desirable.

It appears successful the point of view of the project to focus on high purity and niche plastic market as the polyurethane. Moreover, further improvement can be expected by optimizing the PHA extraction step. These conclusions are strongly dependant on how the technology will develop on the next future: type of substrates, increasing the quantity of OFMSW compared to the sewage sludge, focusing only on OFMSW, optimisation of the extraction.
WP2: PHA Production at Pilot-scale

The Working Package 2 (WP2) deals with the technical challenges of polyhydroxyalkanoates (PHA) production process and it has the following main objectives:

- Optimization of the individual steps of the PHA production while producing PHA with a target PHA composition to be characterized and tested for planned applications (subtask 2.1 and 2.2);
- Development of a brand new process for biosolvents production from acidogenic effluents for PHA extraction (subtask 2.3);
- Development of a sustainable process for PHA extraction avoiding the use chlorinated solvents and using mild conditions (subtask 2.4);
- To gather technical data to carry out a mass balance and economical evaluation of the process (subtask 2.5).

In the scope of subtask 2.1, different partners aimed at optimizing the acidogenic fermentation of several wastes originated from urban sources and relevant pre-treatments. Namely, University of South Wales (USW) operated a 100 L bioreactor and tested the fermentation of three different wastes: garden waste, sewage sludge and food waste (FW). The fermenter integrated novel electrochemical separation and concentration strategies, designed to extract and purify volatile fatty acids (VFA) in situ (see paper 8). University of Barcelona (UB) also tested anaerobic fermentation of several wastes, including organic fraction of municipal solid waste (OFMSW), FW and manure compost. Both mixtures and single substrate were tested and compared at different operating conditions aiming at optimizing VFA production (see papers 9 and 12). University of Verona (UNIVR) used household food waste (HFW) to produce VFA. During the course of the study, sewage sludge and cotton wool (in order to simulate nappies) were mixed with HFW and operational parameters were fine tuned to improve productivity (see paper 1).

Regarding subtask 2.2, University of Rome (UNIRM) and NOVAID have focused on optimizing the subsequent steps for PHA production, while producing PHA to be used by WP3 partners. More specifically, UNIRM in cooperation with UNIVE operated at Treviso WWTP 3 pilot scale reactors with aim of producing PHA from a mixture of sewage sludge and OFMSW. During the timeframe of the project, the fractions of these feedstocks were optimized and a thermal pre-treatment of the feedstock mixture was added to the process. Centrifugation and filtration steps were also included to remove undesirable particulate matter from the fermented effluent that could negatively impact PHA extraction (see paper 7 and 10). In collaboration with CNR-IRSA, the microbial population was characterized (see paper 11). NOVAID tested several sources of waste as feedstock for PHA production: fermented fruit waste, fermented food waste and sewage sludge. While fermented FW and fermented sewage sludge were only tested at lab scale as potential feedstocks for PHA production, the fermentation of sewage sludge and the conversion of fruit waste into PHA were carried out at pilot scale. Using NIR, a model for on-line monitoring of PHA was developed. UNIRM and NOVAID produced more than 20 kg of PHA with different monomeric compositions which were extracted and purified by BIOTREND and tested by partners of the consortium.

In subtask 2.3, the objective was to produce biosolvents using VFA from fermented OFMSW. University of Bologna (UNIBO) developed a continuous flow process based on a cationic resin for VFA purification and concentration. The production of ethyl esters from VFA was optimized by CNR-IRSA (see paper 13).

The aim of subtask 2.4 was to deliver a pure PHA powder from PHA-rich biomass using chemicals, other than chlorinated solvents. BIOTREND managed to develop an extraction process using inorganic chemicals, which is able to cope with the variability of the PHA-rich biomass while keeping its high molecular weight. Good results were also obtained by using supercritical CO₂ (lab scale).

Collaboration between UNIRM and University of Venice (UNIVE) resulted in a study concerning optimization of overflows and minimization of production costs in subtask 2.5. More specifically, any overflow from the PHA production process was used to feed an anaerobic digester to produce biogas. Mass flows were measured and economical evaluation of the integrated process was carried out (see paper 6).
WP3: PHA Properties and Applications

PHA properties

The properties of produced PHA were measured by a range of techniques, including viscosimetry, GC, TGA, DSC, FTIR. Under optimised operational conditions, a set of 12 replicates of PHA samples showed a purity of 98.7% w/w (by GC, 4.8% variation coefficient), a HV content of 18.2% w/w (by GC, 5.1% VC), a decomposition temperature of 286.6 °C (Td max by TGA, 2.7% VC), and a molecular weight of 429 kD (by viscosimetry, 18.3% VC).

Moreover, the possible presence of selected microcontaminants (metals, PAHs, PCBs) was ascertained in several PHA samples, obtained from different waste and either in raw PHA-rich biomass or after extraction by different extraction methods (see paper 2). Although depending on origin and extraction method, the contaminant contents in PHA samples were generally very low, i.e. in the range between ppb and a few ppm) Although a specific regulation does not exist yet, all tested PHA types met present regulatory standards and guidelines for similar conditions and materials (e.g. limits for Cd and PAH in plastic materials based on REACH regulation, including toys; limits for PCB in Recycling Plastics from Shredder Residue, based on EPA guidelines).

PHA applications

INRA received PHBV produced at NOVAID from fruit waste and purified at Biotrend. Thermal properties of the PHBV sample suggested the possibility of processing the sample for compounding, on condition that nucleating agents are added to the formulation. Nucleated pellets were first obtained by compounding virgin powder of PHBV sample with 0.5 wt% of boron nitride. The obtained rod was white, uniform and smooth and it was easy to pelletize using an automatic pelletizer. Moreover, composite compounds by using lignocellulosic fillers (from park and garden waste) were produced with a second extrusion step. Finally, composite films displaying a thickness of 300 µm were then prepared using a heated hydraulic press from compounds previously produced by melt extrusion.

Biocinia and their third party CSIC have been working with PHBV samples from both fruit waste and urban waste, which were successfully processed by electrospinning. The resultant electrospun PHBV mats were subjected to annealing. The morphologies of the electrospun PHBV fibers and resultant films were observed by scanning electron microscopy (SEM), which indicated the uniformity of the samples. The mechanical properties of the samples were also tested at room, where the PHBV from fruit waste seemed tougher than the one from urban waste. Similarly, the tensile modulus was higher from the PHBV from urban waste. Finally, the permeability was also measured, with respect to water vapor, oxygen, and limonene. By looking at the data, the PHBV from urban waste had better barrier capabilities against oxygen and limonene, whilst PHBV from fruit seemed to be more optimal for water vapour (see paper 4).

As for the partner SABIO, they performed a melt test on 12 PHA samples. The tests showed that none of the specimens suffered from a change of color and no smell was released while melting. Conversely melt behavior showed the largest differences between the specimens, in spite their molecular weight was high enough (in the range between 350 and 650 kD). In one case it was possible to appreciate a rheological behavior that meets the needs of plastic industry. The application of the polymer for films was carried out bio MI-PLAST. Preliminary, PHBV-based films were obtained via direct extrusion by using commercially available PHBV. Two bio-polymer/bio-polyester miscible with PHBV were selected taking into consideration rheology, physical and temperature properties:

- PBAT/PLA - partially biobased polymer from BASF (Ecovio)
- bioPBS - biobased polymer from MCCP.

MiPlast obtained films via direct extrusion, up to high PHBV content ratio of 50% in the final products, although they would rather limit ratio at 20%-25% due to extrusion process and purpose of the films (packaging applications). Higher PHBV ratio would be possible but only for rigid films - trays for food packaging. Blends of PHBV+PBS showed significantly better behaviour during extrusion and better physical properties.

UNIROMA worked with PHBV samples from both fruit waste and urban waste, which were tested for their biodegradability under anaerobic conditions, in view of their use as electron donors for groundwater remediation for contamination by chlorinated solvents. Additionally, non-extracted PHA-rich biomass from urban waste was also used. All PHA samples behaved well for the purpose, by slowly degrading and steadily releasing volatile fatty acids.
WP4: Proposal for End of Waste Criteria

The production of poly-hydroxy-alkanoates (PHA) from biowaste and wastewater sludge is adapted from the Circular Economy concept which was announced by the European Union in 2015. Concerning this scenario, Pardo and Schweitzer (2018) reported in their analysis regarding a long-term strategy for the European circular economy that a series of barriers currently prevent to shift from a linear to a circular economy model. In particular, regulatory barriers, such as the lack of a harmonized definition of end of waste criteria at global level, makes it difficult to determine precisely when waste ceases to be waste to become a resource (Sadhukan and Hernandez, 2017).

Presently, there are no end of waste (EoW) criteria for the whole process of PHA production and its final end-product in any EU country, which is not surprising, being the technology still under development. During the project life, sufficient information was gathered to define a preliminary proposal of EoW for PHA originated from separately collected organic wastes and municipal wastewater sludge. Data on one type of food processing waste (fruit waste) were also collected. This proposal consists of three distinct sections: one dedicated to the characteristics of the original waste, one dedicated to the production process and the “new” product characteristics and the third one dedicated to the market definition for the new product. As a summary we can report here that:

✔ Proposed organic waste for PHA production are typically the organic fraction from municipal solid waste and the sludge from municipal wastewater treatment, whose quantity and characteristics are typically well defined at territorial level. Based on local conditions, food processing waste can be also included.

✔ Characteristics of obtained PHA can be easily determined (monomer composition, purity, ashes), and PHA meet regulatory standards or guidelines for the allowable presence of relevant contaminants as well. Exemption/compliance for REACH/ECHA regulation has to be checked case by case.

✔ There is a clear market demand for bioplastics in several sectors and a first estimation of at least 1 million ton per year worldwide can be considered. (see also WP5). Because all market segments are well ruled, there’s a general provision that PHA use complies with existing regulations, guidelines and technical specifications for the relevant sector.

Besides of regulatory constraints, social perception was also investigated through an experimental study based on a representative sample of respondents. In particular the study aimed at understanding consumers’ intentions to purchase, pay for, and switch to bio-based products (see paper 5).

Moreover, INAIL investigated the occupational risk for the workers who are involved in the production process of PHA from bio-waste. The assessment included biological risk, chemical risk and potentially explosive atmospheres, and recommendations how to decrease and control these risks were given.

WP5: Cost-benefit Analysis for PHA Production

Market analysis

The portfolio of RES URBIS was successfully analysed based on initial assumptions, technical work done by WP3 and desktop work done in WP5 in order to obtain a finalized integrated portfolio for RES URBIS. We refer to Portfolio as this term is generally understood in the chemical industry, as a set of products /chemicals /materials that are offered by a company and it is good praxis to base the offer on a strategy.

The market and competitive scan performed in this study has shown that there is unmet need for PHA among biodegradable plastics and the global capacity is still far from sufficient to match demand, therefore there is a potential market space for PHAs produced by RES URBIS technology.

The three initial application areas of consumable packaging, split into interlayer specialty film and commodity film, environmental remediation and durables, interior furniture have been reviewed based on market assessment and performance assessment; it has emerged that so far the specialty packaging interlayer film and environmental remediation have demonstrated to provide a good fit between requirements for the application and properties of the polymer, and also shown in the tests.

Commodity films and durable interior furniture are still under tests, however there are concerns due to Molecular Weight (MW)
potential required for those application. Based on performances of interlayer film and the related adhesive market, so called “adjacent” for marketing analysis purposes, in particular those applications currently covered by ether based polyurethanes (PUs) have been scanned in terms of market potential as potential extension for RES URBIS integrated portfolio.

The total market opportunity for RES URBIS integrated portfolio exceeds € 30 billion, therefore it allows large room to play in this landscape even assuming a small initial share, e.g. 1%.

**Technical-economic analysis**

Moreover, specific models have been developed and applied here in order to assess both Costs and Benefits deriving from the utilization of the technology in a projected full scale environment. A synergy with biogas existing value chain rather than a competition has been sought and scenarios in which RES URBIS technology is integrated with existing AD facilities have been designed and analyzed, with reference to RES URBIS Territorial Clusters: Barcelona, Lisbon, South Wales, Province of Trento, and Copenhagen. For this reason, the specific needs by clusters along with current AD framework have been mapped and the RES URBIS scenarios have been designed to address the needs and infrastructure of each cluster.

The Cost- Benefit analysis has been performed at cluster level in particular covering the part of the value chain impacted by RES URBIS adoption, thus based on specific AD plants to be converted into PHA factories through the RES URBIS technology concept. We considered here the sale of PHA equal to 3 € per kg, which is realistic considering a distributor as intermediary, thus avoiding to build the infrastructure for marketing and sale of the biopolymers. The result of this study is that PHA integration into AD facilities increases resilience of AD plants in case of volatility of bio-waste treatment prices. Moreover, it decouples the economic performances of the AD plants from price of waste treatment, which could be critical in case of removing incentives for biogas.

The integration with AD plants allows an easy entry point to PHA, since the synergy between biogas and PHA has a large potential especially because reducing OPEX specific for PHA (except material costs).

Overall, the integration of RES URBIS technology in existing AD plants of the RES URBIS territorial clusters would lead to 6.5-7 KTA PHA per annum and total additional bio-waste treatment of 270 KTA, with over 6 million m³ additional biogas generated. The gross economic value is comprised between 21 and 49 million € per annum. Considering the mid case of 35 m € gross value per annum, we estimate 100 -120 new jobs will be created, not only within the plant but also related to the entire value chain.

We assume that the average size for debottleneck project is 1 KTA PHA which is linked to €5-8 million annual gross value and 15 new jobs. The average investment ranges between € 5 and 10 million depending on the pre-existing AD plant set up.

A replication in 80-100 clusters is a reasonable perspective for the mid-term 2025-2030, in the European landscape. This would represent € 0.5-0.8 billion gross annual value and 1200- 1500 new green jobs to be created in Europe through RES URBIS Technology.

**WP6: Dissemination and Communication Activities**

The 6th RES URBIS meeting took place recently in Valencia, Spain between 9th and 11th of July 2019. This meeting started with updates of WP1, WP2, WP8 and WP6 on the first day. Also, in this meeting, there was an open session with stakeholders where the WP leaders introduced RES URBIS project and its progress. This was followed by some presentations performed by international experts. There was a visit, after the open session, to BIONICIA facilities where layer film is made from bioplastics. In the third day, joint-WP meetings and voting session too place, drawing the ending of the 6th general meeting.

The final meeting of Res Urbis, December 2019, will take place in Rome and a large Stakeholder Meeting is planned, with some 80 participants.

Dissemination and communication activities were firstly planned during the kick-off meeting and the communication and dissemination plan (CDP) was released as in March 2017. A first version of RES URBIS posters and leaflets was designed during the first few months in order to start the dissemination activities as soon as possible. A second version of poster was published in the end of 2018 to update the status of progress of the project within first two years. This leaflet
was translated to six different languages and it is available for download on RES URBIS website.

**WP7: Project Advancement**

So far, the advancement of the project has been monitored through several instruments:

- General Meetings (6 meetings, at approximately 6 month intervals)
- Strategic Committee Meetings (at each General Meeting plus intermediate ones, at approximately 3 month intervals)
- Internal Technical Reports (each 6 months approximately)
- Mid-term (month 18) Interim Report to the EU

In a general point of view, RES URBIS project is proceeding well and with good alignment to plans and expectations. 21 Deliverables have been produced in the first half of the project and regularly submitted to the EU as well as 9 Milestones were positively checked. The abstract of Deliverable is published on the website ([www.resurbis.eu](http://www.resurbis.eu)). The full text may be available upon request (unless confidential).

Currently, there are no strong risks which can jeopardize the execution of the project as planned and at the moment, the check of the project advancement is positive.

**WP8: Ethical Issues**

In general, the procedures established through the Project Management Plan (PMP) and those specifically related to Ethical issues were considered to be appropriate and were evaluated as very good in the Reviewers evaluation of the mid-term Interim Report. In the frame of the update of the PMP based on the regulatory prescriptions introduced by the GDPR (entered into force on May 25th 2018), the established rules about Human Participation have been checked against the new regulation and were found to be consistent. However, the Deliverable 8.2 has been updated in the frame of revision of PMP by inserting a new paragraph which is dedicated to the implementation of the GDPR.

More in detail, the aim of the GDPR is to protect all EU citizens from privacy and data breaches in an increasingly data-driven world that is vastly different from the time in which the 1995 directive was established. Although the key principles of data privacy still hold true to the previous directive, many changes have been proposed to the regulatory policies. Regarding the context of interest of RES URBIS project, the main changes introduced by GDPR are related to informed consent and deal with right to access, right to be forgotten and data portability.

For what concerns issues related both to environmental protection (D8.3) and work safety and health protection (D8.4), relevant national rules and guidelines were collected. On the base of the feedback from reviewers’ evaluation of the interim Report, further analysis is being performed on the Consortium members’ differences in national and, especially, internal regulations and guidelines, and the evaluation of possible mutual learning activity.

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**Find us on social media**

Frequent updates of the latest news related to bioplastics can be found on our channels. Follow us by just a simple click on the icons.

Recently, the activities on the social media (Task 6.3) were increasing, not only directly related to RES URBIS project, but also with some relevant news or events which raise the awareness of public about the importance of recycling and the concept of circular economy.
Paper publication is considered an important part of dissemination for scientific and technical audiences where experimental results are presented in peer-reviewed journals. Being the last version of Newsletter for RES URBIS project, all published papers and their abstracts are shown in this section according to their publication date.

1) Volatile Fatty Acids Production from Household Food Waste

Natalia Herrero Garcia, Giuseppe Strazzera, Nicola Frison, David Bolzonella. https://doi.org/10.3303/CET1864018

Abstract: The present study aims at determining key factors and current constrains of household food waste (HFW) fermentation process and its large-scale implementation within the frame of biorefinery concept. The production of Volatile Fatty Acids (VFA) from HFW by a mixed microbial culture fermentation (MMC) was studied in both, batch and semi-continuous scale reactors.

Results from batch scale trials without pH control pointed out that highest conversion yield obtained, 111 ± 20 mg of chemical oxygen demand, as VFA, per gram of volatile solids fed to the system, was reached after 6-7 days of fermentation. Moreover, during semi-continuous fermentation at uncontrolled pH and hydraulic retention time (HRT) of 6 d, was observed a VFA production of 3.3 ± 0.8 g·L−1 on average, being increased up to a maximum of 30.1 g·L−1 when pH was controlled at pH 5.5.

In light of the results obtained, HFW should be considered a promising feedstock for the production of chemical intermediates like carboxylic acids and platform chemicals in general. Nevertheless, best optimal operational conditions have not been still properly deciphered and further research must be done to foster economic viability of VFA production in future urban biorefineries.

2) Extraction of polycyclic aromatic hydrocarbons from polyhydroxyalkanoates before gas chromatography/mass spectrometry analysis

Chiara Cavaliere, Carmela Maria Montone, Anna Laura Capriotti, Giorgia La Barbera, Susy Piovesana, Mauro Rotatori, Francesco Valentino, Aldo Laganà. https://doi.org/10.1016/j.talanta.2018.06.038

Abstract: Among the organic contaminants that could pass from waste to polyhydroxyalkanoates (PHAs), there are the polycyclic aromatic hydrocarbons (PAHs). For this reason, we developed a rapid analytical method for the determination of sixteen PAHs in PHAs. PAHs were extracted by n-hexane, after matrix dispersion and crumbling into sand; the extract was purified by solid phase extraction using florisil as adsorbent. Recoveries in the range of 89–101% were obtained for the deuterated analytes, except for the two with the lowest molecular weight. Trueness between 92% and 108% and within-laboratory precision (expressed as relative standard deviation) ≤18% were estimated for all the analytes. Gas chromatography/mass spectrometry was used for analyte determination. Method limits of quantification were suitable to assure that PAH presence in PHA biopolymers is much below the limits set by European law for plastic materials. Indeed, analysis of two different PHA samples showed that contamination is limited to few compounds at non-concerning levels.

3) Preparation and Characterization of Electrospun Food Biopackaging Films of Poly(3-hydroxybutyrate-co-3-hydroxyvalerate) Derived From Fruit Pulp Biowaste


Abstract: In the present study, circular economy based and potentially low-cost poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV) was produced by mixed microbial cultures derived from fruit pulp, an industrial by-product of the juice industry. Three different chemical routes, namely non-extraction, extraction with sodium hypochlorite (NaClO), and extraction with chloroform, in combination with filtering and centrifugation, were explored to purify the biopolymer and find the most optimal solution for its processing via electrospinning. The resultant ultrathin fiber mats of the different extracted PHBV materials were thermally post-processed at different temperatures in order to obtain continuous films adequate for food packaging applications. The resultant films were characterized in terms of morphology, crystallinity as well as thermal, mechanical, and barrier properties. The results showed that extraction with both chloroform and NaClO with a post-treatment of filtering and centrifugation of the PHBV-containing biomass were necessary refining steps to allow its processing by electrospinning. In particular, the PHBV extracted with chloroform presented the highest degree of purity, resulting in more transparent films with lower wettability and higher flexibility. The here-formulated electrospun films made of biodegradable produced from biowaste exhibit great potential as interlayers or coatings for food biopackaging applications.

4) Volatile fatty acids production from food wastes for biorefinery platforms: A review

Abstract: Volatile fatty acids (VFAs) are a class of largely used compounds in the chemical industry, serving as starting molecules for bioenergy production and for the synthesis of a variety of products, such as biopolymers, reduced chemicals and derivatives. Because of the huge amounts of food waste generated from household and processing industry, 47 and 17 million tons per year respectively only in the EU-28 Countries, food wastes can be the right candidate for volatile fatty acids production. This review investigates all the major topics involved in the optimization of VFAs production from food wastes. Regarding the best operative conditions for the anaerobic fermenter controlled pH in the neutral range (6.0–7.0), short HRT (lower than 10 days), thermophilic temperatures and an organic loading rate of about 10 kgm⁻³d⁻¹, allowed for an increase in the VFAs concentration between 10 and 25%. It was also found that additions of mineral acids, from 0.5 to 3.0%, and thermal pretreatment in the range 140–170 °C increase the organic matter solubilisation. Applications of VFAs considered in this study were biofuels and bioplastics production as well as nutrients removal in biological wastewater treatment processes.

5) From trash to treasure: The impact of consumer perception of bio-waste products in closed-loop supply chains

Ivan Russo, Ilenia Confente, Daniele Scarpi, Benjamin T. Hazen. https://doi.org/10.1016/j.ijclepro.2019.02.044

Abstract: Increasing efforts are made to convert waste into new materials for replacing “traditional” ones. In particular urban bio-waste represents a primary source of concern for both government and society. A new type of polyhydroxyalkanoates (PHA) has been very recently developed to convert food waste into a biodegradable multifunctional raw material to help solving the plastic waste problem. However, little is known about consumers’ reactions to products made from PHA. Hence, this study aims at understanding consumers’ intentions to purchase, pay for, and switch to those bio-based products. Both multivariate analyses of variance and mediation analyses are run, addressing product involvement, consumer values, expertise and demographics within an experimental study based on a representative sample of UK respondents. Findings reveal no effects for product involvement and gender on the dependent variables, but for green self-identity, attitude towards bio-based product, age and past purchase experience of ecofriendly products. Results can help the adoption of PHA-based bioplastics to solve the pressing problem of the disposal of bio-waste. In particular, understanding the drivers of consumers’ acceptance of biobased products poses opportunities to build new closed loop system and for successfully marketing the reuse of urban food-waste. Theoretical and managerial implications are addressed.

6) Novel routes for urban bio-waste management: A combined acidic fermentation and anaerobic digestion process for platform chemicals and biogas production

Francesco Valentino, Giulia Moretto, Marco

Abstract: A combined acidic fermentation and anaerobic digestion (AD) treatment has been developed on pilot scale for urban bio-waste conversion into volatile fatty acid (VFA) and biogas. The specific waste mixture was composed by the pretreated organic fraction of municipal solid waste (OFMSW) and waste activated sludge (WAS), both produced inside the Treviso (northeast Italy) municipality. The effect of temperature (37 °C and 55 °C) was investigated in both steps. Only the mesophilic fermentation process provided a VFA-rich stream (19.5 g CODVFA/L) with stable physical-chemical features, with no need of chemicals addition for pH control. The sludge buffering capacity made this step technically feasible. The AD step was performed on the solid-rich fraction of fermented bio-waste, after dilution with excess WAS. No relevant differences were observed under the two investigated temperature: in the steady state (organic loading rate of 2.5 kg VS/m³ d), the specific biogas production was 0.40 and 0.45m³/kg VS at 37 °C and 55 °C respectively, with similar CH₄ content (63-64% v/v). The scaled-up version of the system (in an average urban municipality of 170,000 Person Equivalent) revealed that the whole process is thermally sustainable if both reactors are operated at mesophilic temperature: 36% of surplus thermal energy and 13,03 MWh/d of produced electricity, which corresponds to a revenue of 609,605 €/year. In addition, 2,262 kg CODVFA/d are available for parallel purposes, such as the synthesis of bio-products with higher added value than bio-methane (e.g. biopolymers).

7) Optimization of urban waste fermentation for volatile fatty acids production

Giulia Moretto, Francesco Valentino, Paolo Pavan, Mauro Majone, David Bolzonella. https://doi.org/10.1016/j.wasman.2019.05.010

Abstract: The problem of waste disposal has recently focused on practices for waste recycling and bio-resources valorization. Organic waste produced in urban context together with biological sludge produced in wastewater treatment plants (WWTPs) can be used as renewable feedstock for the production of building blocks of different products, from biopolymers to methyl esters. This paper deals with the optimization of the fermentation process in order to transform urban organic waste (a mixture of pre-treated food waste and biological sludge) into added-value volatile fatty acid (VFA) rich stream, useful for biotechnological processes within a biorefinery technology chain. Different temperatures, pH, hydraulic retention times (HRTs) and organic loading rates (OLRs) were tested both in batch and continuous trials. Batch tests showed the best working conditions at 37 °C and pH 9, using the bio-waste feedstock thermally pretreated (76 h at 72 °C). These conditions were applied in continuous process, where higher HRT (6.0 d) and lower OLR [7.7 kg VS/m⁴ d¹] gave the best performances in terms of process yield and maximum VFA level achieved: 0.77 CODVFA/VS₀ and 39 g CODVFA/L. An optimized fermentation process is crucial to a biorefinery perspective since it has to give a final stream of constant composition or tailored products suitable for further applications.
8) A novel method for increasing biohydrogen production from food waste using electrodialysis


Abstract: The impact of continuous removal of volatile fatty acids on fermentative hydrogen production from food waste (FW) in a Continuously Stirred Tank Reactor (CSTR) was evaluated. Two experimental phases were conducted, a control phase and one in which volatile fatty acids were removed continuously from the reactor for the first time by electrodialysis (ED). Hydrogen yields were 64.7 cm³ H₂/g VS and 227.3 cm³ H₂/g VS for control phase, and ED phase respectively. Continuous removal of volatile fatty acids during fermentation not only increased H₂ yields but increased the production of volatile fatty acids (a valuable chemical feedstock) from 0.14 g/g VS to 0.34 g/g VS.

9) Volatile fatty acid production from mesophilic acidogenic fermentation of organic fraction of municipal solid waste and food waste under acidic and alkaline pH

Yen-Keong Cheah, Carme Vidal-Antich, Joan Dosta and Joan Mata-Álvarez. https://doi.org/10.1007/s11356-019-05394-6

Abstract: This study is focused on the effects of pH on the production of volatile fatty acids (VFAs) and their distribution through the acidogenic fermentation of source-sorted organic fraction of municipal solid waste (OFMSW) from a mechanical-biological treatment (MBT) plant, and food waste (FW) from a university canteen. In semi-continuous lab-scale digesters using OFMSW at a hydraulic retention time (HRT) of 3.5 days under acidic conditions (pH 6.0), the VFA concentration in the effluent increased to 9.8–11.5 g L⁻¹ (VS content of the feedstock between 4.2 and 5.2% w/w), while its individual VFA profiling was similar to the influent which was already prefermented (namely, C₂ 35–41%, C₃ 18–22%, C₄ 17–21%, and C₅ 9–12%). When working with the same conditions but using FW as feedstock, an effluent with a VFA concentration up to 11.5 g VFA L⁻¹ (FW with a VS content of 5.5% w/w) and a stable distribution of C₂ and C₄ acids (up to 60.3% and 12.9%, respectively) but with very low quantities of C₃ and C₅ acids (lower than 1.8 and 2.7%, respectively) was obtained. Anaerobic batch tests using FW revealed that alkaline pH near 9 could lead to higher VFA production with high acetic acid content when compared to pH 6. In the semi-continuous fermenters working at alkaline conditions (pH 9.5–10) using OFMSW and FW, an enhanced solubilization of organic matter was registered with respect to the fermenters working under acidic conditions. This fact was not reflected in a higher VFA production when using OFMSW as feedstock, probably due to free ammonia inhibition, since OFMSW was mixed in the MBT plant with supernatant from anaerobic digestion of this biowaste. However, when using FW, alkaline conditions lead to an enhanced VFA production with respect to the reactor working under acidic conditions, being acetic acid the predominant product, which represented up to 91% of the VFA spectrum obtained.

10) Pilot-Scale Polyhydroxyalkanoate Production from Combined Treatment of Organic Fraction of Municipal Solid Waste and Sewage Sludge

Francesco Valentino, Giulia Moretto, Laura Lorini, David Bolzonella, Paolo Pavan, and Mauro Majone. https://doi.org/10.1021/acs.iecr.9b01831

Abstract: Although the organic fraction of municipal solid waste (OFMSW) and sewage sludge (SS) originate from the same urban area and contain similar organic matter, they are collected separately and handled with different technologies. In this work, a combined treatment of OFMSW–SS mixture was investigated at pilot scale, by using a three-step mixed microbial culture (MMC) process in order to produce polyhydroxyalkanoate (PHA) as final high value biobased product. Biomass selection efficiency was quantified by PHA-specific storage rate that was 258 mg CODPHA/g COD XY/h under the optimized process condition. In fed-batch tests, PHA-storing MMC was able to accumulate up to 46 wt % PHA. In the perspective of a full-scale application and taking into account the mass flows in each process step, an overall yield of 65 g PHA/kg TVS was estimated.

11) Microbiome dynamics and phaC synthase genes selected in a pilot plant producing polyhydroxyalkanoate from the organic fraction of urban waste

Simona Crognale, Barbara Tonanzi, Francesco Valentino, Mauro Majone, Simona Rossetti. https://doi.org/10.1016/j.scitotenv.2019.06.491

Abstract: This study analyses the bacterial population dynamics of a mixed microbial community (MMC) selected in a pilot plant producing polyhydroxyalkanoate (PHA) from the fermentation of the organic fraction of urban waste (OFMSW) and sewage sludge (SS). 16S rRNA gene high-throughput sequencing revealed the occurrence of a variety of PHA accumulating bacteria that ensured a stable PHA production in an open system operating with real substrates and without temperature control. The Volatile Fatty Acids (VFA) changes in the feed and the temperature variation affected the dynamics of the PHA-accumulating bacteria over the plant operation. Remarkably, the higher PHA content was associated to a MMC largely comprising of Hydrogenophaga species during the operation at higher working temperature. The involvement of a heterogeneous PHA-accumulating MMC was associated with a high phaC synthase genes biodiversity confirming the occurrence of a functional redundancy.
Abstract: Food waste (FW) collected from a university canteen was treated in aciogenic fermenters to produce volatile fatty acids (VFA) under biological pretreatment with mature compost. Batch assays working at pH 6 revealed an increment of 9.0%, 7.9%, and 4.1% (on COD basis) of VFA concentration when adding 2.5%, 3.5%, and 4.5% w/w of mature compost, respectively, even though the volatile solids (VS) concentration of food waste was lower in the tests with increasing doses of mature compost. For batch tests at pH 7, this VFA generation improvement was lower, even though enhanced COD solubilization was recorded. Operating in semi-continuous conditions at 35 °C, pH of 6, and hydraulic retention time (HRT) of 3.5 days, the addition of 2.5% w/w of mature compost led to a VFA concentration up to 51.2 ± 12.3% more (on VS basis) when compared to a reference reactor without compost addition. Moreover, the percentage of butyric acid on VS basis in the fermentation broth working at a pH of 6 increased from up to 12.2 ± 1.9% (0% compost addition) to up to 23.5 ± 2.7% (2.5% compost addition). The VFA production was not improved when a higher percentage of mature compost was used (3.5% instead of 2.5% w/w), and it slightly decreased when mature compost addition was lowered to 1.5% w/w. When working at a pH of 7 in the semi-continuous fermenters with the addition of 2.5% w/w mature compost at an HRT of 3.5 days, an improvement of 79% and 104% of the VFA concentration (on VS basis) were recorded as compared to fermenters working at a pH of 6 with 2.5% and 0% w/w of mature compost addition, respectively. At a pH of 7, higher production of propionic and valeric acids was found with respect to the reactor working at a pH of 6. The effect of pH on VFA generation was estimated to have greater contribution than that of only biological pretreatment using mature compost. At a pH of 7, the VFA yield was higher for the fermenter working with 2.5% w/w mature compost but at a pH of 7 and HRT of 5 days, the effect of mature compost on VFA production improvement was lower than that obtained at a pH of 6. Moreover, higher solubilization in terms of soluble chemical oxygen demand and total ammonium was detected when biological pretreatment using mature compost was applied at both a pH of 6 and a pH of 7, which indicates enhanced hydrolysis in both conditions.

13) Process intensification for the production of the ethyl esters of volatile fatty acids using aluminium chloride hexahydrate as a catalyst

Luigi di Bitonto, Sandro Menegatti, Carlo Pastore.
https://doi.org/10.1016/j.jclepro.2019.118122

Abstract: A new process for obtaining the ethyl esters of volatile fatty acids with ethanol by using aluminium chloride hexahydrate as a catalyst is proposed. Aluminium chloride not only exhibits good activity, composition equilibrium is achieved within 3–4 h at 343 K, but also induces a phase separation with a convenient distribution of the components. In fact, more than 99 %wt of the ethyl esters, together with most of the unreacted acid and ethanol, were found in the upper layer, which was well separated from the bottom phase, which contained the co-formed water and over 97.8 %wt of the catalyst. The intensification of this reaction and separation was thoroughly investigated and the operational conditions optimised. The effects of this separation on the purification of the final ethyl esters is fully investigated. A new configuration of unit operations is designed for the specific production of ethyl acetate, simulated through Aspen Plus V9® and compared with the current industrial process based on sulfuric acid catalysis. The overall production and purification of ethyl acetate is economically competitive, reduces the energy requirements by more than 50%, and is potentially a zero-waste process, resulting in cleaner production.

14) Marketing a new generation of bio-plastics products for a circular economy: The role of green self-identity, self-congruity, and perceived value

Ilenia Contene, Daniele Scarpi, Ivan Russo
https://doi.org/10.1016/j.jbusres.2019.10.030

Abstract: Bioplastics represent an innovation for replacing materials obtained from fossil fuels and could provide significant benefits to the environment. A new generation of bioplastic from urban waste is now technically feasible. This paper is among the first to assume the perspective of the consumers rather than the manufacturers in addressing what could lead to the market acceptance of this particular type of bioplastic. A conceptual model is developed addressing psychological drivers that could encourage consumers’ transition from a linear to a circular economy, with the purpose of better understanding what drives consumers’ intentions to switch to and purchase products obtained from organic waste. Specifically, we find that green self-identity positively impacts perceived value, leading to higher behavioral intention. In addition, the relationship is moderated by self-congruity but not by differences in product involvement.
The main idea to carry out dissemination through scientific/technical conference, local or international congress and workshop is to spread the concept of circular economy with practical issues where specific communities (scientific/technical audiences) can involve directly and/or indirectly. During the third year (M25-M34), RES URBIS dissemination has been carried out in 14 technical events, using different modalities, in accordance with:

- 15 oral presentations
- 1 poster presentations
- 5 leaflets distributions

Here are some examples of the many events partners have attended.

### Technical Workshop on Sludge at SMAGUA

5-7 Feb. 2019
Zaragoza

### Conference Life Anadry (26 Feb. 2019, Murcia)

### BIOVOICES Regional Mobilization and Mutual Learning (MML) Workshop (13-14 Nov. 2018, Rome)


### VII Conference of Membrane Bioreactors 16 May 2019
Barcelona

### Conception of the WWTP within the Framework of a Circular Economy (28 May 2019, Barcelona)
LIFE Green Sewer Seminar (29 May 2019, Barcelona)

IV Conference of Youth Researchers of Institute of Water Research (l'IdRA) (3 June 2019, Barcelona)

Strategic Innovation Workshop (11 June 2019, Venice)

Anaerobic Digestion Conference AD16 23-27 June 2019 Delft

7th International Conference on Sustainable Solid Waste Management (26-29 June 2019, Crete)

ISWA World Congress 2019 (7-9 Oct. 2019, Bilbao)
Packaging made from wood and plant waste, which can be fed to bacteria and turned into new plastic again. Circular Material Challenge winner

Full Cycle Bioplastics, Elk Packaging, and Associated Labels and Packaging have been awarded for their compostable high-performance material from renewable materials, agricultural by-products and food waste to pack a broad range of products from granola bars and crisps to laundry detergent. This multi-layer packaging film is made using compostable PHA (a naturally occurring biopolymer) together with cellulose-based materials. Because the PHA is made from organic waste, composting the material after use can effectively provide the raw material for making new plastic, providing an innovative solution to close the resource cycle. Full article is here.

**Why 2019 may be a Promising Year for PHA?**

Manufacturers and suppliers have already spent years considering the environmental impact of petrochemical plastics and invested considerable resources in developing eco-friendly alternatives. The prospects for such materials have risen and fallen as the industry seeks a way to create resins that will reliably biodegrade at the end of their lifecycle without sacrificing the durability of traditional plastic. However, the industry has remained steadfast in its dedication to solving this challenge, and 2018 has produced several promising advances in biodegradable plastics. This has been the case particularly with polyhydroxyalkanoate (PHA) products. There have been several developments around the capabilities and production of PHA in 2018, and they will likely have a great impact on the industry going into 2019. Original news can be found here.

Nestlé and Danimer Scientific to develop biodegradable water bottle

Nestlé and Danimer Scientific, a leading developer and manufacturer of biodegradable plastic products, today announced a global partnership to develop biodegradable bottles. Nestlé and Danimer Scientific will collaborate to design and manufacture bio-based resins for Nestlé’s water business using Danimer Scientific’s PHA polymer Nodax™. In 2018, the University of Georgia (U.S.A.) confirmed in a study that Nodax™ is an effective biodegradable alternative to petrochemical plastics. PepsiCo, an existing partner of Danimer, may also gain access to the resins developed under this collaboration. News obtained here.

What you need to know about plant-based plastics

Bioplastic simply refers to plastic made from plant or other biological material instead of petroleum. It is also often called bio-based plastic. It can either be made by extracting sugar from plants like corn and sugarcane to convert into polylactic acids (PLAs), or it can be made from polyhydroxyalkanoates (PHAs) engineered from microorganisms. PLA plastic is commonly used in food packaging, while PHA is often used in medical devices like sutures and cardiovascular patches. Read the full article here.

Circular economy: consumer attitudes to products made from urban bio-waste

“Biodegradable waste, or bio-waste, from urban areas is being used to produce a bio-based material to replace plastic — this is relevant to the sustainable development of a circular economy (CE), which requires the innovative use of waste materials. Understanding public attitudes to such materials, and the drivers influencing their uptake, is key to their viability. This study explores how consumers respond to products made from regenerated bio-waste.” This statement was mentioned by Science for Environment Policy in a news entitled with 'Circular economy: consumer attitudes to products made from urban bio-waste’ which is based on a scientific paper produced by Ivan Russo and his colleagues under RES URBIS. Read the full paper here.