An urban biorefinery for food waste and biological sludge conversion into polyhydroxyalkanoates and biogas

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EN Horizon 2020 Work Programme 2016 - 2017
17. Cross-cutting activities - Focus Areas

CIRC-05-2016: Unlocking the potential of urban organic waste
Research and Innovation Actions (RIA)

REsources from URban Blo-waSte
RES URBIS
(in latin: things, goods, or affairs of the city)

3-year project, started January 1°, 2017
20 partners, 8 countries

Project coordinator: M. Majone
Research Centre for Protection of Environment and Cultural Heritage
University of Rome “La Sapienza”, Italy
Website: www.resurbis.eu
Project Rationale: developing an urban bio-waste biorefinery

To integrate the treatment of most relevant bio-waste of urban origin

To develop an urban bio-waste biorefinery towards bio-based products

Also taking care of...

<table>
<thead>
<tr>
<th>the whole technology chain</th>
<th>Different industrial sectors to be linked each other, each one having its own business targets, needs and specifications.</th>
</tr>
</thead>
<tbody>
<tr>
<td>territorial conditions</td>
<td>Defining territorial clusters: different waste production and management systems</td>
</tr>
<tr>
<td>technical and non technical constraints</td>
<td>Regulatory (e.g. “end of waste”), environmental, and social constraints, as function of local, regional and national conditions</td>
</tr>
</tbody>
</table>
Circular economy: from waste to resource

Organic waste recycling in Treviso province = 85.3% (ARPAV, 2017)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean ± st.dev</th>
<th>Max</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS (g/kg)</td>
<td>153 ± 52</td>
<td>211</td>
<td>33</td>
</tr>
<tr>
<td>VS (g/kg)</td>
<td>113 ± 44</td>
<td>178</td>
<td>25</td>
</tr>
<tr>
<td>VS/TS (%)</td>
<td>84 ± 3</td>
<td>97</td>
<td>75</td>
</tr>
</tbody>
</table>
Recovery biodegradable carbon from urban organic waste

**Organic fraction of municipal solid waste (OF-MSW)** especially from source-sorted collection

**Municipal wastewater** major COD portion is then concentrated in primary and excess sludge (WWS)

**Park/garden waste** not easily biodegradable and more variable with season

**Agro- and food-industry wastewater and waste** often produced in proximity to urban areas

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**Slurry (squeezed OFMSW - thickened sludge)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean ± st.dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS (g/kg)</td>
<td>56 ± 3</td>
</tr>
<tr>
<td>VS (g/kg)</td>
<td>44 ± 3</td>
</tr>
<tr>
<td>COD (g/kg TS)</td>
<td>835 ± 24</td>
</tr>
<tr>
<td>TKN (g N/kg TS)</td>
<td>25 ± 3</td>
</tr>
<tr>
<td>P (g P/kg TS)</td>
<td>2.3 ± 0.1</td>
</tr>
</tbody>
</table>
The organic fraction of municipal solid waste (OFMSW)

Primary and excess sludge from municipal wastewater treatment (WWS)

THE URBAN BIOREFINERY

Bio-based Products
• polyhydroxyalkanoate (PHA), biodegradable natural biopolymer
• related PHA-based bioplastics (e.g. blends)
• fibers (for PHA-based biocomposites)
• bio-based solvents (for PHA extraction)
Bioplastics portfolio

- Bioplastics based on bio-based feedstock
  - Bio-PE (PP/PVS), biobased PET
  - Biopolymers starch blends, PLA, PHA

- Bioplastics based on bio-based feedstock and biodegradability
  - PBAT, PBS, PCL

- Conventional oil-based plastics
  - PE, PP, PS, PVC, PET ecc.

The European Strategy for Plastics asks for decreasing dependency on oil-based plastics, increasing recycle.

- Bioplastic market is still very less than oil-based plastics, but much faster growth is expected.
Why focusing on PHA?

**Product related Pro’s**
Family of copolymers with tunable composition
PHA can be the main constituent of several bioplastics, with a wide portfolio of applications.

**RES URBIS portfolio**
- Biodegradable commodity film
- Packaging interlayer film
- Specialty durables (such as electronics)
- Slow C-release system for groundwater remediation

**Production process Pro’s**
- A novel open microbial cultures process (not pure strains), to better cope with large heterogeneity of the waste feedstock;
- PHA production process is mostly biological, under mild conditions and reliable.
- Easier integration with existing biological plants for waste and wastewater treatment.

**Appealing**
- Produced from renewable feedstock (no food)
- Produced in biological process (no OGM)
- Biodegradable: not recycled but virgin material

**Applications and economics**
High market potential
As higher as more PHA cost decreases; but still higher value than biogas and compost

Under investigation at TRL 6
High Technology Readyness Level (TRL 5-6): pilot scale investigation is a key-feature of RES URBIS approach

- Working with real and representative feedstock
- Two multi-step pilot plants for production of PHA
- **Treviso (TV) WWTP ATS S.r.l.**
  (Alto Trevigiano Servizi)

<table>
<thead>
<tr>
<th>Biowaste-Sludge Anaerobic Codigestion</th>
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<tbody>
<tr>
<td><strong>Feed characteristics</strong></td>
</tr>
<tr>
<td>Flow, m³/d</td>
</tr>
<tr>
<td>TVS, %TS</td>
</tr>
<tr>
<td><strong>Operational parameters</strong></td>
</tr>
<tr>
<td>OLR, kgVS/m³d</td>
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<tr>
<td>HRT, d</td>
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<tr>
<td>Temperature, °C</td>
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<tr>
<td><strong>Yields</strong></td>
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<tr>
<td>Biogas, Nm³/d</td>
</tr>
<tr>
<td>Methane, %</td>
</tr>
<tr>
<td>SGP, Nm³/kg VS (% biowaste)</td>
</tr>
<tr>
<td>TS removal, %</td>
</tr>
<tr>
<td>VS removal, %</td>
</tr>
</tbody>
</table>
Flow-sheet of biopolymer production from urban biowaste (pilot scale plant in Treviso, Italy)

**Feedstock** (from industrial scale plants, on site)
- Urban wastewater
- OFMSW
- Sludge
- Slurry
- Acidogenic fermentation (anaerobic)

**Process** (on site)
- Biomass production (aerobic SBR)
- Polymer production (aerobic batch)
- Solid/liquid separation
- Quenching
- VFA
- Energy

**Upstream** (on site)
- Anaerobic digestion
- Solid phase to energy recovery

**Downstream** (off-site)
- Extraction/purification/formulation
- Bioplastics

**Solid phase to composting**
- Energy recovery
- Sludge
- Slurry
Progress of waste transformation

OFMSW  Sludge (WAS)  Cake to anaerobic digestion  Filtrate to PHA production  Aerobic biomass slurry  Cake to PHA extraction

Feedstock  Effluent from acidogenic fermentation  Biomass after PHA accumulation
Linking the urban organic waste biorefinery with existing waste/wastewater treatment facilities and plastic industry.
The RES URBIS box-model

Box C Cluster-specific assessment
- Trento Province Italy
- Metropolitan Barcelona Spain
- Metropolitan Lisbon Portugal
- South Wales
- Metropolitan Copenhagen Denmark

Box B Site- and size-specific solutions
- Integration in existing WW plant
- Integration in existing AD plant
- Ex novo designed biorefinery
- Medium or large size

Box A The integrated biorefinery

Box D Portfolio of market applications
- Biodegradable commodity film
- Packaging interlayer film
- Durable specialty
- Controlled C-release
- Fiber biocomposite

Box E Regulation
- LCA
- Exploitation
- Dissemination

Urban organic waste
- OFMSW
- WW sludge
- Garden/parks waste
- Food-processing waste

Urban biorefinery
- PHA
- Biodegradable commodity film
- Biocomposite
- Urban biorefinery

P H A
- Bio-solvents
- Fibers

South Wales
- Ex novo designed biorefinery

Metropolitan Copenaghen Denmark
- Medium or large size

Integration in existing AD plant
- Integration in existing WW plant
RES URBIS consortium

- University
- Research Institute
- Industry
- Public Administration
- Territorial clusters

**Process-related challenges**
- University of Roma "La Sapienza" (Italy)
- New University of Lisbon (Portugal)
- University Ca Foscari of Venice (Italy)
- University of Barcelona (Spain)
- University of South Wales (UK)
- University of Bologna (Italy)
- Biotrend (Portugal)
- CNR – IRSA (Italy)
- Inst. Nat. Recherche Agronomique (France)

**Product-related challenges**
- BioInicia (Spain)
- Mi-Plast (Croatia)
- SABIO (Italy)

**Territorial clustering**
- Aguas do Tejo Atlantico (Portugal)
- Barcelona Metropolitan Area (Spain)
- Province Autonoma di Trento (Italy)
- Rhondda Cynon Taff County Council (UK)*
- City of Copenhagen (Denmark)*

**Economics and exploitation**
- InnoExc (Switzerland)
- Bio-Based and Biodegradable Industries Association (UK)

**Regulation, safety, environmental and social aspects**
- Technical University of Denmark (Denmark)
- National Institute for work safety (Italy)
- University of Verona (Italy)
“End-of-waste” status


1. Member states ensure that waste which has undergone a recycling or other recovery operation is not considered a waste if it complies with:

- the substance is commonly to be used for specific purposes;
- a market or demand exists for such a substance;
- the substance fulfills the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products;
- the use of the substance will not lead to adverse environmental/human health impacts.

*in compliance to ECHA-REACH regulation*

From PCB-PAH-Metals analysis, PHA from organic waste meets all conditions to cease to be a waste

provided that PHA composition is well known and PHA is not dangerous
Polychlorinated Biphenyl Profile in Polyhydroxy-alkanoates Synthesized from Urban Organic Wastes

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3 Chemistry Department, Faculdade de Ciências e Tecnologia-Universidade Nova de Lisboa, 2829-516 Caparica, Portugal; m.matos@campus.ulisboa.pt
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Received: 20 February 2020; Accepted: 12 March 2020; Published: 14 March 2020

Abstract: The microbial synthesis of polyhydroxyalkanoates (PHA) from organic wastes is a valuable process to valorize available renewable resources, such as food wastes and biological sludge. Bioplastics find many applications in various sectors, from medical field to food industry. However, persistent organic pollutants could be transferred from wastes to the final product. The present paper demonstrates that the use of municipal wastes in PHA production is safe for the environment and human health and provides a polychlorinated biphenyl (PCB) profile in both commercial and waste-based PHA samples. PCB analysis in several PHA samples showed very low concentrations of the target analytes. Commercial PHA samples showed a similar PCB level with respect to PHA samples from municipal waste/sludge and higher than PHA samples from fruit waste. For all analyzed PCBs, detected concentrations were consistently lower than the ones reported in regulatory framework or guidelines.

Elemental concentration and migratability in bioplastics derived from organic waste

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HIGHLIGHTS

- Elemental composition of a new PHA derived from organic waste is reported.
- Feedstock type and production process affect the element levels of PHA.
- Migratability is evaluated using different solvents and conditions.
- Migratability increases under simulated acidic conditions and with heating.
- Elemental composition of PHA was evaluated by comparison with regulations and guidelines.

GRAPHICAL ABSTRACT

- Polychlorinated biphenyl profile
- Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs)
- Polycyclic aromatic hydrocarbons (PAHs)
- Polychlorinated naphthalenes (PCNs)
- Elemental composition
- Migratability
RES URBIS value chain innovation

A key question is where RES URBIS value chain is positioned and who are the potential investors interested in its scale up.

RES URBIS technology provides for possible treatment for biowaste, complementary to composting and biogas production. Both vertical integration in Municipal Waste Companies and non-integrated 3rd party service model are possible scenarios.
The products portfolio and perspectives of the market uptake

Application:

- **Interlayer film**, total market value € 2-3 billion (PHA used as pure component through electrospinning).
- **Adjacent adhesive market** (bio substitutes of polyether polyurethanes) market value approximately € 35 billion.
- **Packaging film** up to 25% of PHA content in the formulation; market value € 20 billion.
- **Durables**, e.g. flexible handles, interior furniture: up to 60% in the formulation, total market value € 1-2 billion (flexible handles realized).
- **Environmental remediation** total market value up to € 1 billion. This is a niche application in which PHA has shown good performances.

Overall the size of the accessible market is approximately € **60 billion**, large enough for **RES URBIS** to establish its product lines in the market.