FOOD WASTE VALORISATION FOR CHEMICALS, MATERIALS & FUELS

COST
EUROPEAN COOPERATION
IN SCIENCE & TECHNOLOGY

Funded by the Horizon 2020 Framework Programme of the European Union.

COST (European Cooperation in Science and Technology) is a funding agency for research and innovation networks. COST Actions help connect research initiatives across Europe and enable scientists to grow their ideas by sharing them with their peers. This boosts their research, career and innovation.

cost.eu

worldfoodwaste.org/our-work

COST Action EUBIS facilitated training, education and networking of international researchers working on Food Supply Chain Waste.

EXECUTIVE SUMMARY

This COST Action brought together hundreds of researchers from across Europe and the world, almost half of which were Early Stage Researchers (ESR).

Europe generates hundreds of millions of tonnes of Food Supply Chain Waste (FSCW) annually. To tackle a problem of this scale, we split into four working groups who would work towards using this waste as resource to feed the ever growing demand for carbon-based products. To facilitate this work the Action allowed for training, conferences and Short-Term Scientific Missions—where ESR travelled to other institutions to do research. This research included over 20 different FSCW types and many different extraction and processing methods to produce a range of chemicals, materials and fuels.

The success of the Action and its associated network of researchers is demonstrated by a commitment towards multiple future collaborations along with the maintenance and expansion of the network of researchers.

JAMES CLARK

ACTION CHAIR

BACKGROUND

Food supply chain waste (FSCW) in the European Union is estimated to be in excess of 350 million tonnes per year. It is economically and environmentally expensive to dispose of and at the same time society is facing a potential shortage of resources.

REPLACE THE TERM WASTE WITH RESOURCE

CHRISTINE PARRY, AB AGRI, UK

The solution is to begin thinking of waste as a resource that can be exploited, reducing our dependence on crude oil. The impacts of this strategy are manifold. Not only does it reduce the amount of landfill and incineration but the products are created using less energy intensive processes than their oil-based counterparts and use fewer chemicals with a known detrimental impact on the environment.

To facilitate a Europe-wide approach to this, a European Cooperation in Science and Technology (COST) Action was funded for four years (2012—2016). This network, European Union Bio-waste Industrial

EU FSCW is 3.5Mt per year. We also face a resource crisis. Replacing the term waste with resource opens up new avenues for the bio-economy.

Symbiosis (EUBIS), aimed to provide an alternative renewable source of carbon for the production of industrially relevant bio-derived chemicals, fuels and materials via the exploration of novel and advanced routes for food supply chain waste valorisation.

The plan was to achieve this through: developing sustainable valorisation chains for food waste; encouraging the formation of a multidisciplinary scientific community—scientific exchange and expertise transfer; strengthening links between academia and industry; mapping FSCW sources; scoping technologies for selective extraction and processing of FSCW; and providing information in an easy to understand format that is easy for end users to engage with including the general public.

Together, a critical mass of over 300 interdisciplinary researchers from academia and industry would work to bridge barriers in technology and academic disciplines to go beyond first generation recycling, while supporting the learning and development of Early Stage Researchers.

WORKING GROUPS

To meet the aims of the Action four multinational interdisciplinary Working Groups (WG) were devised to facilitate the exchange of information and work together on experimentation. They also prepared materials for the dissemination of the Action's aims and work.

The four WG are:

1. Pre-treatment and extraction: 115 participants, whose objectives included identifying, extracting and scaling up products from FSCW.

2. Bio-processing: 119 participants, aimed to scope new and existing methodologies on the application of white biotechnology to FCSW.

3. Chemical processing: 83 participants, worked to chemically process FSCW with a focus on fruit and vegetable waste.

4. Technical and sustainability assessment/policy analysis: 66 participants, decided upon metrics for evaluating FSCW valorisation processes, including their sustainability, and defining a sound theoretical framework for promoting legislation.

costeubis.org

worldfoodwaste.org/working-groups

Four working groups were created to structure the Action. These groups were pre-treatment, bio-processing, chemical processing and analysis.

Mehrdad Arshadi, SE

WG1 Leader

Marija Bodroza Solarov, RS

WG1 Deputy

Apostolis Koutinas, GR

WG2 Leader

Katerina Stamatelatou, GR

WG2 Deputy

Nicholas Gathergood, EE

WG3 Leader

Ana Rosa Silva, PT

WG3 Deputy

Piergiuseppe Morone, IT

WG4 Leader

Franka Papendiek, DE

WG4 Deputy

Leaders and Deputies of the Action's Four Working Groups

296 ACTION MEMBERS

48% FEMALE

52% MALE

47% EARLY STAGE RESEARCHERS

31 COST COUNTRIES

Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Lithuania, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom.

4 OTHER COUNTRIES

Albania, Argentina, Brazil, Hong Kong SAR

costeubis.org/members

worldfoodwaste.org/members-area

Of the 296 Action members from 31 countries, 48% were female, 47% were early career researchers.

Location of COST Member's Institutions

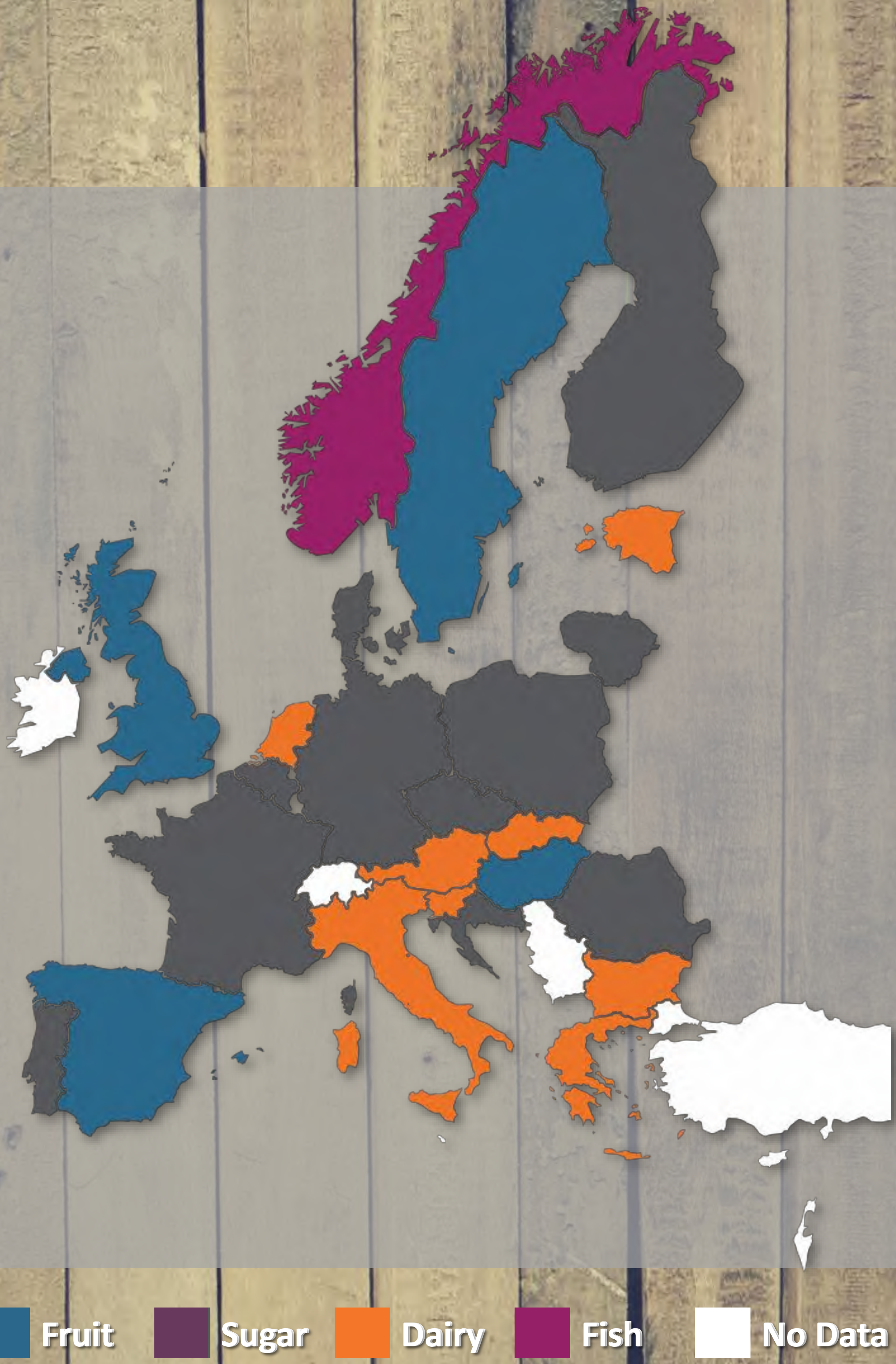
MAPPING FSCW

Countries in Proportion to their Estimated FSCW Tonnage

costeubis.org/news/29

worldfoodwaste.org/waste-mapping

Sugar production derived wastes are estimated to account for 40% of all EU FSCW. Fruit accounts for 19%, Dairy 14% and Meat 7%.



Predominant Food Supply Chain Waste (Estimated)

PROCESSING METHODS

A team of 27 researchers, supported by the Action, compiled and published the most comprehensive review to date of extraction and processing techniques for FSCW. Waste associated with food has features that are different to other biowastes and, therefore, has its own set of processing methods, some of which are highlighted below.

Pre-treatment

Physical

In order to ensure the longevity, transportability and the density of the product they are typically broken into smaller pieces, dried and packed in pellets, bails or briquettes.

Extraction

Water

Subcritical water (100—240°C water) can be used for effective extraction. At these temperatures the water becomes more solvent and is more likely to be in a dissociated state allowing it to be a key part of acid and base reactions.

tinyurl.com/fscwprocessing

worldfoodwaste.org/processing-methods

FSCW extraction methods adhere to the principles of green chemistry. Being more efficient, using less solvent and using renewable feedstocks.

CO_2

Supercritical CO_2 (>31.1°C, >7.39MPa) is a renewable, non-toxic and easily recyclable super selective solvent. It can be used for the extraction of oils, waxes and other molecules.

MAE

Microwave Assisted Extraction is preferable over traditional heating methods as it has reduced energy and solvent consumption and a reduced extraction time.

Filtration

SMBC

Simulated Moving Bed Chromatography tackles column chromatography inefficiencies by amending the simulated speed, taking the slow moving particles in the direction of the bed and allowing the fast moving a countercurrent flow, facilitating collection from different outlets.

Pre-Consumer

HHSP

High Hydrostatic Pressure is a process in which finished items (already packed) are subjected to pressures in excess of 400MPa, which inactivates bacteria, viruses and moulds.

SHORT TERM SCIENTIFIC MISSIONS

Networking played an essential part in the Action yielding its objectives. One key element of networking was Short-term Scientific Missions (STSM) for Early Stage Researchers (ESR). STSM are commonly supported by COST Actions and frequently yield promising results.

The ESR on STSM worked between collaborating institutions to share knowledge, expertise and facilities to reach a common end goal. A part of this collaboration was ESR travelling, staying and working in a collaborating institution.

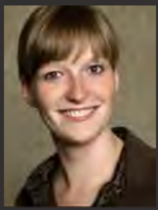
NOW OUR LABS WILL CONTINUE THEIR COLLABORATION

KALLIOPI AVRAMIDOU (STSM FROM GREECE TO ITALY)

Across the four years of the Action 41 STSM were carried out by ESR from 19 different countries working on at least 22 different FSCW types. These collaborations resulted in publications, further collaborations, funding proposals and enhance the camaraderie of EU researchers.

A total of 41 Short-term Scientific Missions were carried out by Early Stage Researchers; between them working on over 20 types of FSCW.

Journeys made from Home to Host for STSM



PROFITABILITY OF FODDER LEGUME PRODUCTION

2014 APRIL

by FRANKA PAPANDIEK, ZALF, DE

visiting PIERGIUSEPPE MORONE, UNITELMA-SAPIENZA UNIVERSITY OF ROME, IT

Franka visited Rome to work with and learn from Piergiuseppe, who she met through the Action.

LEARNING ABOUT CBA FROM PIERGIUSEPPE WAS A HUGE ADVANTAGE TO ME AND MY RESEARCH

FRANKA PAPANDIEK, ZALF, DE

They worked on the Cost Benefit Analysis (CBA) of reintroducing fodder legumes into crop cycles. Fodder legumes (FL) use has declined due to cheap imported protein soy to feed cattle and nitrogen fertilisers. However, FL have many advantages:

- providing a sustainable source of nitrogen;
- production is at a relatively consistent cost;
- providing biodiversity—reducing the need for pesticides;
- improving soil structure and composition; and
- producing biomass that can be used in lactic acid production.

tinyurl.com/fodderlegume

worldfoodwaste.org/case-studies

Fodder legumes provide improved profitability, sustainability and environmental impact. However, more research is needed.

To test whether their inclusion in a seven year crop rotation cycle would be advantageous they set up three different scenarios on two different size sites (small and medium) in Northern Germany. The scenarios were as follows:

1. no fodder legume production in rotation—status quo;
2. fodder legume production in rotation; and
3. fodder legume production in rotation with a biorefinery.

WE REALLY SUCCEEDED; GETTING INTERESTING RESULTS IN A SHORT AMOUNT OF TIME

PIERGIUSEPPE MORONE, UNITELMA-SAPIENZA UNIVERSITY OF ROME, IT

The results show that in the first scenario, the internal rate of return (IRR) (i.e. the rate interest would have to be for it to be more profitable to invest the money) was 26% for both farms. This rate increased to 41% for both farms when fodder legume was included into the crop rotation- as outlined in scenario two. This is likely to be linked to the reduced usage of maize silage (replaced by legume silage) and savings associated with barley which grows after the legume—its yield increased by 13% and required no fertiliser. The third scenario, the IRR varies between 15 to 41% for the small farm and 12 to 87% for the medium farm. This is due to variations in the sale price of the fermentation juice. This shows that large benefits can be made but with a large risk.

Going forward, further analysis varying the fermentation media ratios, the locations, crops and the inclusion of environmental impact all require new investigation to support the return of fodder legumes.

MICROWAVE ENABLED SYNTHESIS OF POLYESTERS

2016 APRIL

by ALESSANDRO PELLIS, BOKU, AT

visiting THOMAS FARMER, University of York, UK

Alessandro met Tom at a conference and went to the UK to work with him on enabling the synthesis of polyesters using microwave energy.

TO COMBINE MY BIOCATALYSIS EXPERTISE WITH TOM'S KNOWHOW ON MW-ASSISTED REACTIONS

ALESSANDRO PELLIS, BOKU, AT

The use of microwaves has several advantages over the traditional heating method of using an oil bath. These are:

- avoiding hot spots;
- energy stops and starts immediately;
- energy consumption is low; and
- they have been used successfully with the polymerisation enzyme Candida Antarctica *Lipase B* to produce small esters.

They have also been used in the more green method of solvent-free synthesis of copolymers of polycaprolactone and polystyrene.

tinyurl.com/microwavepolyesters

worldfoodwaste.org/case-studies

Polyester synthesis generally uses hot oil baths. However, microwaves can be used to heat samples—saving time, energy and solvent.

To investigate further Alessandro and Tom set up four scenarios, in which to synthesise polyesters:

1. solvent-free microwave reactions
2. solvent-free oil bath reactions
3. organic media microwave reactions
4. organic media oil bath reactions

The samples from each were then analysed using NMR and chromatography. The results for both the solvent-free and organic media reactions showed that microwave and oil bath heated experiments are comparable in terms of average molecular weight and percentage monomer conversion.

With the exception of maintaining the high temperatures in the microwave, the results of both methods are directly comparable. The higher temperatures in this instance are attributed to denaturing the enzyme.

This study shows that microwaves can be used with enzymes for the polycondensation of polyesters.

WE PRODUCED A PAPER IN A GREAT ENVIRONMENT—I MET LOTS OF NICE PEOPLE...I'M WRITING A PROPOSAL TO MOVE TO THE UK.

ALESSANDRO PELLIS, BOKU, AT

DISSEMINATION OF KNOWLEDGE

One of the desired impacts of the Action was that FSCW valorisation would be of importance to all stakeholders from academia to industry, policy makers and the public. Through numerous forms including a host of publications and events, along with Twitter and a website the Action has facilitated the dissemination of knowledge.

EDUCATION IS KEY TO DEVELOPING THE BIOECONOMY

JAMES CLARK, UNIVERSITY OF YORK, UK

An integral part of this dissemination of knowledge is strengthening the scientific community, not only through interactions but by learning from each other and ensuring the best expertise is passed onto future generations such as the Early Stage Researchers. This was enabled by 41 Short-term Scientific Missions, two training schools and 13 workshops.

These workshops, spanning the entire time of the Action, covering all of Europe allowed for the structured yet informal exchange of ideas between a variety of stakeholders—a sandpit of dynamic intellectuals allowing ideas to thrive.

In addition the Action allowed for the Working Groups to meet to discuss progression, overcome problems, ensure the rapid continuation of work without repetition by colleagues and to plan for future collaborations and avenues of research.

costeubis.org/news

worldfoodwaste.org/publications

@EUBISFoodWaste has been succinctly delivering our research to the world since 2013.

41 STSM

39 PUBLICATIONS

Including editing a Special Section of the Journal of Cleaner Production

13 WORKSHOPS

Turin 2013, Toulouse 2014, Athens 2014, Novi Sad 2014, Mersin 2015, Semmering 2015, York 2015, Milan 2015, Tallinn 2015, Potsdam 2015, EFIB Brussels 2015, Kaunas 2015, Wageningen 2016

8 WORKING GROUP MEETINGS

Rome 2013 (WG4), Athens 2013 (WG2), Stockholm 2013(WG1), Dublin 2013 (WG3), Semmering 2015 (WG1—WG4)

4 FUTURE PROPOSALS

2 TRAINING SCHOOLS

Lisbon 2014, Montreux 2016

1 INTERNATIONAL CONFERENCE

The Future of Food Waste: Challenges and Opportunities for Valorisation in Europe, Wageningen 2016

EVIDENCE FOR UK PARLIAMENT

TRANSNATIONAL COOPERATION

Surveying the members of the network on their research, funding, publications and their connections has allowed for Social Network Analysis to be undertaken. This analysis assessed the evolution and the structure of the network from 2013 to February 2016.

It showed that 84% of members were connected to members at another institution at outset, and this number rose to 100% by the time the survey was taken.

The number of members sharing knowledge rose from 135 to 601—an increase of almost 350%; and the number of members performing joint research increased by 170% from 98 ties to 265 during the Action.

This analysis also showed that Working Group leaders played an essential role in the networks—analyses performed without the WG leaders caused the number of ties for joint research dropping to 156 (a 41% decrease).

LOTS OF SMALL ACTORS ARE PRESENT AND WE WANT TO SEE THEM GROW

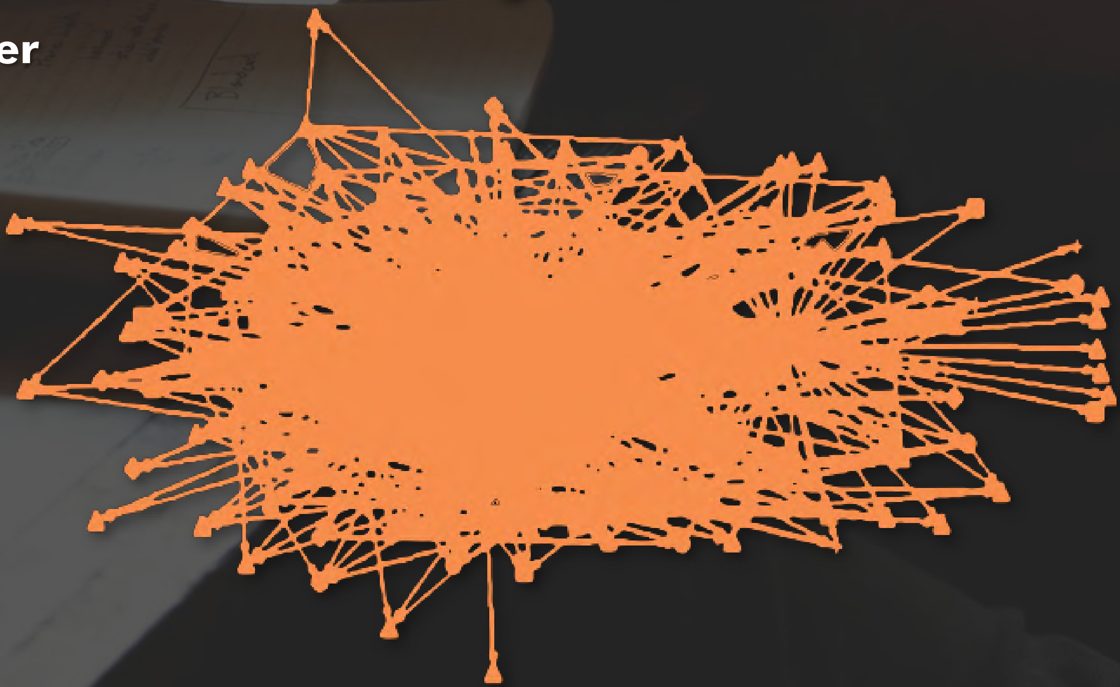
PIERGUISEPPE MORONE, UNITELMA-SAPIENZA UNIVERSITY OF ROME, IT

Promisingly, many members in the centre of the network (the ones with many ties) are Early Stage Researchers, small actors, who are perfectly positioned in terms of who they know. This will allow them to grow, cooperate, exchange knowledge and work together on future projects such as the European H2020 funded project STAR-ProBio.

The network grew to be 100% inclusive. Every member was connected to others. Early Stage Researchers are pivotal to this network.

Before

After



'Who Knows Who' Networks at Different Intervals

POLICY IMPACT ASSESSMENT

Several initiatives and policy instruments are being implemented with the aim of ensuring a better governance of relationships between academia and industry. Among these, COST Actions aim at establishing a bridge between science, policy makers and society on very specific topics, through the establishment of heterogeneous research networks.

This Action, EUBIS, established itself as a very effective collaborative network of researchers at a multidisciplinary interface, aiming to develop the use of food supply chain waste for bioproducts. By making academic research relevant to and accessible by industry and policy makers, EUBIS has increased the effectiveness of research as a source of innovation and societal changes.

Internationally, it is very much anchored into the Sustainable Food Systems Programme (adopted by the Food and Agriculture Organization and the United Nations), which is a global multi-stakeholder partnership, aiming to promote sustainability along the food value chain. At the EU level, the 2015 Circular Economy Action Plan adopted by the European Commission contains much encouragement for generating value from FSCWs. The Action Plan supports the achievement of the related UN Sustainable Development Goals, designating 'food waste' as a Priority area, where the main target is taking measures to clarify pertinent EU food legislation by facilitating food donation and the use of by-products.

Through intense and long-lasting collaboration activities, many results

ec.europa.eu/programmes/horizon2020

worldfoodwaste.org/policy-impact-assessment

The Action has promoted circular economy concepts, increased public awareness, and stimulated national and European policy discussion.

have been achieved—ranging from enabling knowledge transfer, enhancing innovative capability of partners (building strong relations among academia and industry), and providing valuable networking opportunities for ESR. These have contributed to promote circular economy concepts, increase public awareness, and stimulate national and European policy discussion around FSCW. In this respect, a fundamental legacy of EUBIS is the new H2020 project STAR-ProBio starting in Spring 2017 and dealing specifically with the topic of bio-based products' standards—an area of enquiry which is attracting growing interest from various EC units (e.g. Directorate General for Research & Innovation).

EUBIS has also delivered fundamental results, through its highly transdisciplinary approach, which brings together market development knowhow and research projects at an early stage, encouraging the best prioritisation of resources. This was largely achieved through the constant engagement of the food system stakeholders, as well as the decision to deepen consumer perceptions expertise. Indeed, as it emerged at various stages of the Action, consumers are a vital part of the circular economy. This message was clearly delivered to policy makers, marking another achievement of this Action.

PIERGIUSEPPE MORONE

ACTION VICE-CHAIR

THE FUTURE: STAR-PROBIO

The European Commission's proposal for the advancement of the European economy is smart, sustainable, inclusive growth. Targets include: research and development investment; a reduction in greenhouse gases; and an increase in energy efficiency. Moving towards bio-based products will help achieve these targets.

With the production of oil slowing across the EU and bans on the extraction of fuels from shale in certain countries, the demand is increasing for more sustainable products that can easily replace those traditionally made from fossil fuels.

Sustainability assessment schemes need to be developed in order to ensure consumer and manufacturer confidence in these new bio-based products. These schemes will provide a clear and evidence-based view of the economic, social and environmental impacts of such products promoting market uptake.

A PROJECT OF GREAT RELEVANCE FOR THE BIO-ECONOMY AND ENVIRONMENT

PETER JÜRGEN, REDCERT, DE

In order to achieve this, H2020 funding has been awarded for three years to a collaboration of 15 institutions from 11 countries, including many from across the EUBIS network. The project is led by EUBIS's Vice-Chair Piergiuseppe Morone, who will work on a sustainability scheme blueprint.

star-probio.eu

worldfoodwaste.org/star-probio

STAR-ProBio aims to create a set of standards for bio-based products, which allows consumers to be confident in the product quality.

At present, food from different locations is likely to have different compositions and thus whatever the end product is unlikely to have the same levels of purity. To overcome this the members of the collaboration will develop standards, labels and certifications for bio-based products. These new products will be compared to their oil-based counterparts (used as a benchmark) improving public and industry confidence and increasing their commercial viability.

STANDARDISATION IS LAGGING BEHIND INNOVATION

NICHOLAS GATHERGOOD, TALLINN UNIVERSITY OF TECHNOLOGY, EE

To achieve the aim of the collaboration, the environmental impacts of products, with a focus on the end-of-life and a transition to a circular economy, will be assessed through Life Cycle Analysis, social impact assessment, surveys and field experiments.

Specific case studies will include construction materials, bio-based polymers and fine chemicals ensuring that the research is not too broad and theoretic and allowing for a non-bio benchmark.

Sustainability assessment research will be divided into economic, social and environmental streams, with different research institutions taking a lead on each. These will feed and be fed by the sustainability scheme blueprint, current regulations, knowledge transfer and dissemination.

This collaboration will make fundamental inroads to making bio-based products in a circular economy a reality.

THE FUTURE: FSCW PRODUCTS

In 2015, 47 delegates from industry, government, research and universities covering 18 countries and 42 institutions discussed the most promising products that could be obtained from FSCW. The top 10 of these are listed below. In addition, all members agreed that for sustainable resources to become routine, a set of standards needs developing and adhering to.

Established Chemicals

Acids — Chiral Carboxylic Acids are group of chemicals already obtained from FSCW. They have a wide range of applications including food, cleaning and pharmaceuticals.

Sugars — Sugars are another established group of chemicals obtained from many sources of FSCW across Europe. They are extensively used in food and drink production.

Terpenes — Used in a wide range of food, cleaning and pharmaceuticals and are obtainable from not only FSCW but from lignocellulosic biomass.

Promising Chemicals

Phenols — Considered to be promising chemicals on the proviso that their extraction is economically viable. Uses include flavours in food, components of drugs and plastic processing.

costeubis.org/news/29

worldfoodwaste.org/fscw-products

Acids, Sugars, Terpenes, Phenols, Furans, PEF, PLA, PHA, Biobutanol and Biodiesel are the ten most promising FSCW derived products.

Furans

Another promising chemical group. Starting with furan, derivatives can be used as speciality solvents or incorporated into various pharmaceuticals.

Materials

PEF

Polyethylene Furanoate, currently made from sugar cane, has the potential to be extracted from bagasse (sugar cane waste). It is an alternative versatile plastic source.

PLA

Poly-lactic acid, derived from bagasse, has extensive uses as a plastic, such as in 3D printers, to make plastic tea bags or hard plastic toys. It is also biodegradable.

PHA

Polyhydroxyalkanoates produced from sugar or lipids can be formed into packing or plastics that biodegrade in cold temperatures, the ocean or *in-vivo*.

Fuels

***Bio* Butanol**

Produced from a variety of feedstocks it has a higher energy density and lower volatility than ethanol, making it safer to use. It can be developed with no impact on food supplies.

***Bio* Diesel**

Derived from waste oils in the food chain it only releases the same amount of carbon the plant absorbed when growing. Standard diesel engines can run on biodiesel.

THE FUTURE: NETWORK

Owing to the fervent success of the network, in February 2017 the EUBIS Management Committee approved the evolution of the network into the World Food Waste Network, which would include, and actively encourage, members from outside of the European Union.

THE SYSTEM NEEDS RESTRUCTURING TO BE REGENERATIVE BY DESIGN

Mats Linder, Ellen MacArthur Foundation, UK

In 2015 the United Nations released 17 Sustainable Development Goals, which include No Poverty, Sustainable Cities and Climate Action. In order to achieve these goals, specific targets were developed that address energy efficiency, protecting heritage and climate change. These targets, others and Goal 12—Responsible Consumption and Production, are the raison d'être of the World Food Waste Network. Researchers, industrialists, policy makers and the public all have an invested interest in working towards a circular economy in which the products we use are sustainable and once we have finished with them they are recyclable (or at worst provide no detrimental impact to the land, sea or air).

The World Food Waste Network (WFWN), allows for Transnational Cooperation for Responsible Production from Food Waste, with a focus on Food Supply Chain Waste such as the chaff and stems from wheat, the bagasse from sugar cane and the pomace from wine or olive production.

World Food Waste Network facilitates the transnational cooperation of knowledge, skills and resources as we work towards circular economy.

WORLD FOODWASTE NETWORK

TRANSNATIONAL COOPERATION FOR RESPONSIBLE PRODUCTION FROM FOOD WASTE

380 MEMBERS

47% FEMALE

53% MALE

37 COUNTRIES

120+ WASTE TYPES

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Publication created by the Department of Chemistry, University of York.