EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Brussels, 4 June 2019

COST 037/19

**DECISION**

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Subject: **Memorandum of Understanding for the implementation of the COST Action "European network of FURan based chemicals and materials FOR a Sustainable development" (FUR4Sustain) CA18220**

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The COST Member Countries and/or the COST Cooperating State will find attached the Memorandum of Understanding for the COST Action European network of FURan based chemicals and materials FOR a Sustainable development approved by the Committee of Senior Officials through written procedure on 4 June 2019.

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of the European Union

**MEMORANDUM OF UNDERSTANDING**

For the implementation of a COST Action designated as

**COST Action CA18220**
**EUROPEAN NETWORK OF FURAN BASED CHEMICALS AND MATERIALS FOR A SUSTAINABLE DEVELOPMENT (FUR4Sustain)**

The COST Member Countries and/or the COST Cooperating State, accepting the present Memorandum of Understanding (MoU) wish to undertake joint activities of mutual interest and declare their common intention to participate in the COST Action (the Action), referred to above and described in the Technical Annex of this MoU.

The Action will be carried out in accordance with the set of COST Implementation Rules approved by the Committee of Senior Officials (CSO), or any new document amending or replacing them:

a. “Rules for Participation in and Implementation of COST Activities” (COST 132/14 REV2);
b. “COST Action Proposal Submission, Evaluation, Selection and Approval” (COST 133/14 REV);
c. “COST Action Management, Monitoring and Final Assessment” (COST 134/14 REV2);
d. “COST International Cooperation and Specific Organisations Participation” (COST 135/14 REV).

The main aim and objective of the Action is to catalyse a synergistic approach for the whole value-chain of 2,5-furandicarboxylic acid and derivatives, aiming to boost innovation in the research and development status quo and to overcome the scientific, technological and industrial limitations that hinder the wide deployment of FDCA products in market applications. This will be achieved through the specific objectives detailed in the Technical Annex.

The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 84 million in 2018.

The MoU will enter into force once at least seven (7) COST Member Countries and/or COST Cooperating State have accepted it, and the corresponding Management Committee Members have been appointed, as described in the CSO Decision COST 134/14 REV2.

The COST Action will start from the date of the first Management Committee meeting and shall be implemented for a period of four (4) years, unless an extension is approved by the CSO following the procedure described in the CSO Decision COST 134/14 REV2.

**TECHNICAL ANNEX**

## OVERVIEW

### Summary

Modern society relies on a huge quantity of polymeric materials. However, today, these materials are still almost exclusively based on fossil-resources and evolution to a more sustainable model of development is required.

In this perspective, biomass and, in particular carbohydrates from, for example, low value biomass wastes, are outstanding starting feedstocks for the production of added-value chemicals and products. One of such is 2,5-furandicarboxylic acid (FDCA). Nevertheless, efforts on FDCA-based products development have been scattered in individual scientific activities, and moreover joint efforts between Academy and Industry have also been rare, hampering their successful industrialisation and market introduction.

Precisely, this Action will master the scattered pan-European individual efforts to design innovative routes to FDCA-based chemicals and polymeric materials towards lab-to-industry-to-market, by gathering, for the first time, a real critical mass along the complete value-chain, including several experts in FDCA synthesis, polymer science and general materials developing and chemical-physics; together with producer, manufacture and recycling industrial stakeholders; LCA and techno-economic viability experts.

The Action will accomplish these targets by pursuing two-parallel strategies. Firstly, supporting an 'holistic vision' in which FDCA synthetic routes, polymers & polymeric materials development, characterisation, as well as key technical, economic, environmental and social factors are considered together, aiming at supporting and identifying solutions to successful market introduction. Secondly, using intersectorial knowledge, supported by dissemination and networking tools to provide an open platform for collaboration and a common vision addressing research, human resources qualification and industrial implementation.

| Areas of Expertise Relevant for the Action | Keywords |
|---|---|
| ● Chemical sciences: Green chemistry research<br>● Chemical engineering: Chemical engineering: processes and products (others)<br>● Materials engineering: Structural properties of materials<br>● Agriculture, Forestry, and Fisheries: Biomass production from forestry | ● 2,5-furandicarboxylic acid whole-value chain<br>● chemicals, polymers and materials<br>● lab-to-industry-to-market<br>● Network on furans<br>● Sustainable development |

### Specific Objectives

To achieve the main objective described in this MoU, the following specific objectives shall be accomplished:

Research Coordination

● To organise and master the European activity in the area of FDCA-based chemicals, products and materials to target scientific, technical and industrial solutions towards sustainable furan-products market introduction and improving simultaneously human capital qualification.

● To promote an 'holistic vision' in which FDCA synthetic routes, polymers and polymeric materials development, characterisation, as well as key technical, economic, environmental and social factors are considered together aiming at supporting and identifying solutions to successful market introduction.

● To promote cross-sectoral cooperation of polymer scientists and general materials developers with industrial stakeholders to develop products with an applied vision.

● To develop novel technologies for the synthesis of FDCA and related monomers, starting from widely occurring non-edible alternative sources of starting sugars, mainly agro-forest byproducts, such as those rich in cellulose fibres, which are a non-exhaustive source of D-glucose; or pectin rich sources from agroforest byproducts.

● To synthesise novel furan-based polycondensates using FDCA or derivatives and other renewable-based monomers.
● To identify the main economic obstacles, market demands, supply chain challenges, environmental hotspots and also the legislative restrictions that need to be considered so as to ensure a successful introduction of FDCA and its materials in real applications.
● To identify the most promising application fields for newly synthesised FDCA chemicals and materials based on achieved and required product properties; on technological requisites to scale-up processes and manufacture; as well as their environmental, health and safety issues from a life cycle perspective.
● To promote the joint participation in new research and development programmes, that will enable the substantial growth of all activities, fostering the growth of joint scientific and technological development and human resources qualification.

Capacity Building
● To gather a transdisciplinary community with many of the key actors in biomass transformation, polymer and composite materials design and characterisation, LCA and techno-economic assessments, along with key industrial stockholders for the FDCA-based chemicals and materials deployment, and within a synergetic approach.
● To foster the participation of both industrial stockholders and researchers in the seminars, workshops, training schools and all FUR4Sustain activities organised for networking, good practices, knowledge and technology transfer.
● To strengthen and expand the cooperation between Academy and Industry for efficiently connect innovative basic research and products uses, technologic requirements and market demands, by jointly defining appropriate research and development routes and support product development towards successful sustainable market introduction for both furan chemicals and materials.
● To structure and develop a consortia able to develop innovative furan chemicals and materials via joint public-private partnerships.
● To further attract researchers and industrial partners from the manufacture sector among the Action members collaborators/established partnerships of industrial producers.
● To stimulate systematic performance and development of human resources with key competences in the furan domain, addressing Senior and Early Career Investigators (ECI); as well as, researchers from Inclusiveness Target Countries (ITCs) and International Partners and increase the integration of women in science through gender balance and scientific excellence
● To promote a social awareness of the need to move to a more sustainable society also involving policy-makers in this collective consciousness.

# TECHNICAL ANNEX

# 1 S&T EXCELLENCE

## 1.1 SOUNDNESS OF THE CHALLENGE

### 1.1.1 DESCRIPTION OF THE STATE-OF-THE-ART

Modern society relies on a huge quantity of polymeric materials, spanning from those used in common products such as textile, packaging, household and automotive components, to those applied to more sophisticated uses in healthcare and electronics. Today, these polymers are still almost exclusively based on fossil resources; nevertheless growing attention is being focused on polymers derived from renewable resources and related monomers building blocks.[1] The transformation towards a sustainable model society is one of the major challenges faced by decision-makers, science, industry and the society itself. The evolution to this new model, requires, in the medium-long term, a dramatic change in paradigm, from an economy based in fossil resources to produce chemicals and materials (along with energy and fuels) to the so-called bio-based economy, where most of those are produced from renewable feedstocks, *i.e.* mainly biomass. This falls under the biorefinery concept, which 'mimics' conventional oil refineries, and within the even broader concept of circular economy. In this perspective carbohydrates from biomass, such as agricultural wastes and forestry residues, are excellent starting feedstocks for the production of added-value chemicals and products. One of such added value chemicals, coming out of biorefineries, and holding great promise as a key building block, especially due to its resemblance to the petrochemical terephthalic acid (TPA), is 2,5-furandicarboxylic acid (FDCA). In fact, in 2004, FDCA has been identified as a key chemical for the future development of the bio-based economy in a key study conducted by the US National Renewable Energy Laboratory.

The main **synthetic routes to FDCA** involves a two-step approach comprising the synthesis of 5-hydroxymethylfurfural (HMF) by dehydration of hexoses (*i.e.*, D-glucose and D-fructose), followed by its oxidation into FDCA. In what concerns the conversion of HMF into FDCA, it has been addressed in many different ways, and has been the object of intense research for many years, *e.g.* through methodologies based on the use of metal catalysts or even enzymatically catalysed processes. As some of the most studied approaches it should be highlighted here the use of metal catalysts, namely the patented processes from Hoechst (1988),[2] Dupont (2000),[3] and those from ADM (2013)[4] and Avantium (2013).[5] In the former patent,[2] FDCA is obtained from HMF by oxidation in water with oxygen using a Pd/carbon supported catalyst, whereas the latter ones[3–5] are based on air oxidation of specific HMF derivatives, in acetic acid media, using *e.g.* Co/Mn/Br catalysts. Some other interesting studies, comprise the base-free conversion of HMF to FDCA, as in the case of Zhang *et al.*[6] which used a Ru/carbon supported catalyst, circumventing thus any FDCA salt conversion step to obtain FDCA, but still limited by the low yields obtained.

However, despite some recent innovations have been brought to the scientific panorama (as in the latter example),[6] this classical approach based on HMF conversion to FDCA raises two major issues, namely the inherent instability of HMF and the concerns with competition with the food-chains for starting raw materials, since nowadays the main sources of these starting sugars like for example for commercial *D*-fructose resources are high fructose syrups, which are generally produced from starch- containing food crops like corn.[7] These problems have motivated the academic and the industrial communities to address the synthetic routes to FDCA in other perspectives. In relation to the HMF instability issue, for example, from an industrial perspective, Avantium (and now Synvina) produces FDCA from the more stable 5-methoxymethylfurfural (MMF),[5,8] starting from edible fructose syrup. Furthermore, in a recent report by Bitter *et al.*,[9] FDCA esters were prepared starting from uronic acids, *via* ketoaldonic acids, to



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the intermediate formylfuroic acid esters, and subsequently FDCA-esters. Concerning the food competition problems, some studies have focused on the search for alternative and abundant sources of monosaccharides, such as cellulose, coming from non-food feedstocks. Importantly, some other studies focus on the use of abundant agroforest byproducts, like for example, lignocellulosic straws and sugar beet pulp, potato pulp, citrus peels, among other residues.[9,10]

Following the same burgeoning activity trend of the synthetic routes to FDCA (and in that respect also to HMF development) **FDCA-derived polymeric materials** are also generating a growing investment from both academia and industry. Among FDCA-based polymers, polyesters have been definitely spotlighted. The huge number of recent papers and patents about this family of polymers has explored aspects as diverse as polyester synthesis mainly with other renewable-based monomers, leading to the preparation of materials with enhanced thermo-mechanical, recyclability, biodegradability and liquid crystalline properties, among other features.[11–25] Also synthesis innovation, especially using eco-friendly catalysis (*e.g.* enzymes), but also optimum and highly efficient synthetic approaches development have been addressed.[11,26–35] Other aspects studied comprise the detailed and highly-specialised characterisation of polyesters, addressing for example their thermal characterisation using advanced calorimetry techniques.[22,23,30]

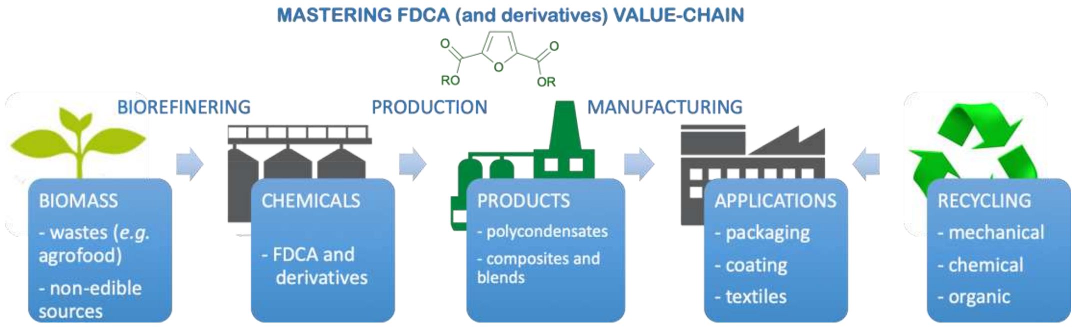
Currently, the most successful example of FDCA-based polyesters is poly(ethylene 2,5-furandicarboxylate) (PEF), the so-called 'furan counterpart of the engineering polyester – poly(ethylene terephthalate)' (PET),[17,36] althought its industrial production and market introduction has many obstacles.[37] Nevertheless, PEF, besides being 100% renewable, has relevant high performance properties (*e.g.* barrier, thermal and mechanical, among others) that expectedly will start by creating market niches and ultimately full market penetration. Techno-economic studies conducted by Eerhart *et al.*[21] have pointed out in this way, and life-cycle analysis (LCA) assessment of PEF against fossil-based PET has shown a potential reduction in greenhouse gas emissions of 45 to 55% (despite new indepth studies are still missing, specially compared with other renewable PET substitutes). First positive step in setting up a PEF recycling stream has also been taken.[38]

Other polyesters mimicking their fossil counterparts, include poly(propylene 2,5-furandicarboxylate) (PPF)[39] and poly(butylene 2,5-furandicarboxylate) (PBF).[18] Also, some authors focus on mimicking the commodity polyethylene (PE), preparing thus, poly(2,5-furandicarboxylate)s incorporating long-chain diols.[12,14] In this vein, Bikiaris *et al.*[12] prepared poly(1,12-dodecylene 2,5-furandicarboxylate), a semicrystalline polyester with a complex melting behaviour, as has been highlighted by more advanced temperature-modulated differential scanning calorimetry (DSC) experiments (observed melting temperature around 111 °C and the equilibrium one, calculated by Hoffman−Weeks extrapolation, at 127 °C).[30] Finally, aiming at preparing (bio)degradable polymers, tailor-made copolyesters have been designed in the last years, incorporating, besides FDCA, glycolic, diglycolic, succinic and/or adipic acids, along with poly(ethylene glycol) or poly(lactic acid) moieties.[11,29,40,41] In general, all these polyesters have been synthesised by conventional bulk polytransesterification approach, although some works follow a different trend. For example, Loos *et al.*[27] has reported the use of biocatalysis in furan chemistry using CALB lipase, achieving, in some cases, relatively high molecular weight polyesters.

The field of FDCA-derived materials have also expanded to other polycondensates, including polyamides, polyurethanes and epoxy-based resins,[20,32,42–45] yet modestly. For example, in the case of polyamides, progress was most probably hampered by the FDCA decarboxylation problems arising under typical polycondensation conditions.[42,43] Nevertheless, efforts on developing TPA analogues entirely from renewable-based monomers (C4-C12 diamines),[20,32] and using biocatalysis at moderate temperatures have been addressed.[44] In other studies partially renewable copolyamides were developed instead.[42,43] For example, a very interesting and timely work of Jiang and co-workers[42] addresses the synthesis of copolyamides from FDCA, TPA and 1,10-diaminodecane by the typical industrial process (*i.e.* prepolymerisation followed by solid state polymerisation). Results clearly showed the occurrence of a massive FDCA decarboxylation side-reaction, giving rise to low molecular weight polymers, but they still showed high thermal stability (up to 440 °C). In the case of epoxy resins and polyurethanes literature is even more rare, despite their promising properties, such as, for example the FDCA/Eugenol-based epoxy resin which exhibited *e.g.* $T_g$ > 150 °C.[46] In addition, a few studies on polyurethanes prepared from low molecular weight furan polyesters precursors have already shown their potential in the coating field for the replacement of petrochemical homologueous derived from aromatic monomers, such as phthalic anhydride.[45] More recently, blend/composite materials have gained some attention, especially due to the performance improvement they can impart to the ensuing materials, and promising applications among automotive, food packaging, electronic and biomedical fields. In particular, nanocomposite materials, due to the nanoscale of the fillers, are an interesting class of materials that also have started to be investigated. Important novel materials include PEF/nanoclays (montmorillonite and sepiolite),[33,47] PEF/multiwalled carbon nanotubes,[48] having an increased nucleation effect and in some cases also the thermal stability of the composite was increased compared to pristine PEF. However, despite this intense activity, composite materials along with polyamides and other polymeric materials derived from FDCA, as well as low molecular weight FDCA products,[49] still remain a relatively unexplored research field with many challenges ahead.

### 1.1.2 DESCRIPTION OF THE CHALLENGE (MAIN AIM)

The main objective of this COST Action is to catalyse a synergistic approach for the whole value-chain of **2,5-furandicarboxylic acid and derivatives**, aiming concomitantly to boost innovation in the current research & development (R&D) *status quo* and, moreover, to overcome the scientific, technological and the industrial limitations that hinder the wide deployment of new FDCA products developed in actual market applications.




In a global expansion context of polymers production, but in contrast to a more stagnated European panorama, current opportunities come from the so-called 'bioplastic industry'. Additionally, FDCA is considered as a promising platform chemical and key polymer building block from renewable origin, and many efforts on FDCA production and the ensuing polymers synthesis and characterisation have, indeed, shown its huge potential for being the future 'bioplastics'. Hence, exploring the scientific and technical solutions, addressing the opportunities for, and obstacles to market introduction, as well as the environmental issues of the key renewable-based building block FDCA and its polymeric materials production and manufacturing is an opportunity to establish an European leadership, contributing to the reindustrialisation within the UN sustainability goals.[50] A more in-depth analysis of current R&D on FDCA-products clearly shows that efforts are scattered in several individual initiatives and separate from key industrial stakeholders. Hence, a well-organised multidisciplinary network, coordinated through a COST Action is an opportunity to gather for the first time in Europe: FDCA synthesis experts, several polymer scientists and general material developers and chemistry-physics, together with producer and manufacture industrial stakeholders, LCA and techno-economic viability experts, which will identify successful products applications and, in the medium to long term, encourage market introduction within a true sustainable mind-set. Another aspect, of a different nature, regards the present need to a general social awareness about sustainable development to which the wide mass-media divulgation of FUR*4*Sustain achievements and results will definitely contribute.

## 1.2 PROGRESS BEYOND THE STATE-OF-THE-ART

### 1.2.1 APPROACH TO THE CHALLENGE AND PROGRESS BEYOND THE STATE-OF-THE-ART

The current high standards of modern life rely on the consumption/use of a huge quantity of polymeric materials. Just in 2016, approximately, 335 million tons of polymers (representing an effective huge amount compared *e.g.* with metallic/inorganic materials given the intrinsic low density of the former) were produced worldwide, being Asia the largest world producer (50 %), and by very far, Europe (19%) followed.[51] Another fact worth mentioned is that the renewable-based polymer industry is in expansion worldwide. In fact, according to the latest market data compiled by European Bioplastics, the global production capacity of the so-called 'bioplastics' is predicted to grow by 50% in the medium term, from around 4.2 million tons in 2016 to approximately 6.1 million tonnes in 2021. Asia leads the sector with

43 % of the production, followed by European region with only a 27% share.[51] These trends could be tackled and significant progress could be achieved by creating sustainable, innovative and added-value products to high-value markets, transferring knowledge/expertise between different sectors (within the Academy and from the Academy to Industry and *vice versa*) and between European regions, preparing highly qualified human resources and promoting the growth of this key sector, thereby contributing to jobs creation and the reindustrialisation of Europe in a low-carbon economy.[50]

In a more in-detail analysis, it is evident that, despite the enormous ramp-up capacities of the bio-based Industry and the well-defined identification of the most important key-platform chemicals, in which FDCA is clearly positioned, the **synthetic routes to FDCA** (and in that matter also of bio-based Industry, in general) still has many challenges ahead. Regarding the classical two-step approach, one common problem usually associated with FDCA synthesis is related with the catalytic conversion of HMF under basic conditions, resulting in the salt form of FDCA, which cannot be directly used in the polymer industry. Further development could be fostered by the efficient conversion of HMF into FDCA under base-free conditions, which would eliminate the need to convert FDCA salt to FDCA, making the system greener with less waste generation. Another line of investigation, which will foster innovation in the medium to long-term, is focused on circumventing the production of unstable HMF to produce FDCA (or its dimethyl ester). A recently proposed way, still not optimised, starts from abundantly available uronic acids (potentially more than 1.5 Mton per annum from 2nd generation, non-food feedstocks).[9] Finally, regarding the starting biomass feedstocks, today for example starch-containing food crops like corn are some the most important sources of fructose syrups for commercial *D*-fructose sugar, however efforts should definitely turn to alternative and abundant sources of monosaccharides, such as cellulose rich-sources, coming from non-food feedstocks and preferably abundant agro-forest wastes (*e.g.* lignocellulosic byproducts, along with sugar beet pulp, potato pulp, citrus peels, among other residues); furthermore these feedstocks are often rich in hemicelluloses that can be seen as alternative sources or xylose and other pentose sugars (among others), that, can be alternative routes to circumvent the classical HMF-based process.

Research in **FDCA-derived polymer materials** is extremely lively throughout Europe, at both academic and industrial level. However, studies essentially focus on polyesters, and other polycondensates and low molecular weight FDCA-based esters (*e.g.* plasticisers) and composite/blend materials have been scarcely done. Moreover, typically either one of the two following strategies has been adopted: *i) polyester synthesis*; or in a less extent *ii) highly-specialised characterisation* involving essentially thermal studies. More specialised characterisation studies concerning structure-properties relationships provided by in-depth computational studies and or application of advanced studies concerning blowing stretching and strain induced crystallisation, quite relevant to applications have been rarely performed. Finally, there is a clear lack of networking between research groups working in the domain and in particular with Industry. Therefore, significant development would be fostered by tackling these domains of polymeric materials development and characterisation in view of applications, and especially if both are addressed in an integrated transdisciplinary/intersectorial way, strongly supported by an intense and rationally structured networking between experts in specific domain throughout Europe.

Moreover, in general, the furan materials developed so far, except from PEF and another isolated case,[45] were not evaluated in terms of their environmental impact (LCA) and techno-economic viability, along with the assessment of acceptance to merge the newly developed polymers into the existing recycling stream, foreseeable production costs and expected market conditions based on key critical criteria (including users requirements), despite the obvious importance to quantify costs and the impact of sustainable polymers compared with existing petrochemical benchmarks, and moreover the relevant information,[52-53] these analyses would provide to guide the design and development of future materials, again within the scope of a well-structured network of competences. It is evident that there are opportunities in an expanding bioplastic market and research panorama for sustainable furan materials in both high-value areas and in basic applications such as packaging or coating that can be fostered by the network proposed here.

*Summarising*, to joint efforts and multidisciplinary expertise Europe-wide; to develop innovative furan materials with a core of well-characterised properties and with promising indications from techno-viability, LCA studies and users requirements; ultimately, aiming at their application in everyday objects is an overall challenge needed to be addressed, and for which COST is the ideal support scheme. Precisely, this Action will master the scattered pan-European efforts to design novel and innovative routes to FDCA-based chemicals and polymeric materials towards lab-to-market, by gathering, for the first time in Europe, a real critical mass along the whole value-chain, and in all aspects of the biorefinery concept, including FDCA synthesis experts, several polymer scientists and general materials developers and chemistry-physics, together with industrial stakeholders, LCA and techno-economic viability experts, impacting on society in general.

### 1.2.2 OBJECTIVES

#### 1.2.2.1 Research Coordination Objectives

The main coordination objective of this Action is **to organise and master the European activity in the area of FDCA-based chemicals, products and materials to target scientific, technical and industrial solutions towards sustainable furan-products market introduction** and improving simultaneously human capital qualification. Key components of this main objective, are:

- to promote *an '**holistic vision**' in which FDCA synthetic routes, polymers & polymeric materials development, characterisation, as well as key technical, economic, environmental and social factors are considered together aiming at supporting and identifying solutions to successful market introduction*. FUR*4*Sustain Action promotes this synergetic vision by gathering key experts and stakeholder leaders in each of this fields, that will interact with each other through their participation in common coordination tasks of Management Committee (MC), Core Group and WGs leaders; in face-to-face meetings; and using the appropriate dissemination tools (2.2.2) and specifically supported by the WG4 (3.1.1);
- to promote **cross-sectoral cooperation** of polymer scientists and general materials developers with industrial stakeholders to develop products with an applied vision. This will be achieved through *i*) identification of *unexplored R&D breakthroughs*; *ii)* labelling of *manufacture stakeholders' products needs* and/or key *technical issues;* and *iii)* their interplay by STSMs, meetings (innovation and industry-oriented workshops), among other COST tools (2.2.2 and WG4).

In specific coordination aims:

- to develop novel technologies for the synthesis of FDCA and related monomers, starting from widely occurring non-edible alternative sources of starting sugars, mainly agro-forest byproducts, such as those rich in cellulose fibres, which are a non-exhaustive source of D-glucose; or pectin rich sources from agroforest byproducts;
- to synthesise novel furan-based polycondensates using FDCA or derivatives and other renewable-based monomers;
- to identify the main economic obstacles, market demands, supply chain challenges, environmental hotspots and also the legislative restrictions that need to be considered so as to ensure a successful introduction of FDCA and its materials in real applications;
- to identify the most promising application fields for newly synthesised FDCA chemicals and materials based on achieved and required product properties; on technological requisites to scale-up processes and manufacture; as well as their environmental, health and safety issues from a life cycle perspective.

In the *medium to long term*, taking advantage of the FUR*4*Sustain community, **coordination also aims to promote the joint participation in new R&D programmes**, that will enable the substantial growth of all activities, fostering the growth of joint scientific and technological development and human resources qualification. Furthermore, new projects will inevitably bring together other key international R&D and industrial Bio-based players, which will enable this community to grow and widely implement the major goals of FUR*4*Sustain.

#### 1.2.2.2 Capacity-building Objectives

The core capacity-building objective is to gather a transdisciplinary community with many of the key actors in biomass transformation, polymer and composite materials design and characterisation, LCA and techno-economic assessments, along with key industrial stockholders for the FDCA-based chemicals and materials deployment, and within a synergetic approach. Dissemination actions, such as, STMs and industry-oriented workshops/conferences (2.2.2), will be particularly necessary to fulfil this objective. Specific objectives are:

1. to foster the participation of both industrial stockholders and researchers in the seminars, workshops, training schools and all FUR*4*Sustain activities organised for networking, good practices, knowledge and technology transfer;
2. to strengthen and expand the cooperation between Academy & Industry for efficiently connect innovative basic research & products uses, technologic requirements and market demands, by jointly defining appropriate R&D routes and support product development towards successful sustainable market introduction for both furan chemicals and materials;
3. to structure and develop a consortia able to develop innovative furan chemicals and materials *via* joint public-private partnerships, as well as, by R&D projects (H2020);
4. to further attract researchers and industrial partners from the manufacture sector among the Action members collaborators/established partnerships of industrial producers;
5. to stimulate systematic performance and development of human resources with key competences in the furan domain, addressing Senior and Early Career Investigators (ECI); as well as, researchers from Inclusiveness Target Countries (ITCs) and International Partners and increase the integration of women in science through gender balance and scientific excellence;
   - in particular, to involve young talents and next generation leaders, to train them in the Action knowledge and results, and in science and technology, in general; promoting, thus, high levels of human resources qualification, in a pan-European perspective of the research and labour markets;
6. to promote a social awareness of the need to move to a more sustainable society also involving policy-makers in this collective consciousness.

# 2 NETWORKING EXCELLENCE

## 2.1 ADDED VALUE OF NETWORKING IN S&T EXCELLENCE

### 2.1.1 ADDED VALUE IN RELATION TO EXISTING EFFORTS AT EUROPEAN AND/OR INTERNATIONAL LEVEL

In the past several European R&D programmes addressing FDCA value-chain have been funded, but they were usually wide scope programmes and not strictly focused on furans or FDCA. Other projects addressed FDCA value-chain but only in one of the directions, for example in the physical/chemical fractionation of biomass feedstocks or in polymers' development. Some European R&D projects are: BioSynergy, WaCheUp, AFORE, BioFur, BioConSepT, BIOCLEAN, OXYPOL, among others. At National level, some examples are: 'Polymer go green' (DPI), 'Development of new polyesters derived from 2,5-furandicarboxylic acid' (FCT) or Flippr°. This Action will improve the effectiveness, and the research and technological outputs by: focusing on FDCA and also by linking all fields of FDCA value-chain from lab-to-market to furan materials deployment.

Recently, a network, strictly composed of some industrial-driven participants, have gathered funding through PEFerence project – 'From bio-based feedstocks *via* di-acids to multiple advanced bio-based materials with a preference for polyethylene furanoate'. FUR*4*Sustain Action takes the next step by being an intersectorial platform gathering both academic researchers and several industrial stakeholders working in all aspects of the whole value-chain; besides that, FUR*4*Sustain is interdisciplinary (organic chemistry, polymer and materials development, theoretical chemistry, LCA and techno-economic fields) and will not be restricted to PEF.

This Action will promote the best practices and exchange of knowledge with related running programmes. In practice, this will be achieved by identifying the main related running programmes; and, subsequently making direct invitations to these consortium members to participate in workshops and meetings to foster open knowledge, avoid duplicities and effectively optimise research funding from the different EU and National programmes.

## 2.2 ADDED VALUE OF NETWORKING IN IMPACT

### 2.2.1 SECURING THE CRITICAL MASS AND EXPERTISE

FUR4Sustain Action brings together intersectorial representatives from Academia, research institutes, several large industries, SMEs and governmental organisations. Additionally represented in FUR*4*Sustain Action are the Near Neighbour Country (NNC) University of Sfax/Tunisia and the International Partner Country (IPC) Chinese Academy of Sciences/China.

At the preparation stage, the consortium already gathers, a real interdisciplinary critical mass along the complete value-chain of FDCA: FDCA (and related monomers) synthesis experts, several polymer scientists and general materials developers and chemistry-physics, together with producer and manufacture industrial stakeholders, LCA and techno-economic viability experts. Only with such interdisdiplinary expertise and business oriented cooperative network, supported by COST networking activities, will foster progress in FDCA (and related monomers) value chain towards the sucessuful deployment of innovative products.

Additionally, the pan-European nature of this Action with a wide geographic spread (COST countries, IPCs and NNCs), the excellence of the different Universities and Industries involved, and the wide involvement of Senior and ECI Researchers will stimulate knowledge/expertise transfer between different regions, different entities, different generations and moreover will contribute to long-term collaborations, far beyond the FUR*4*Sustain *terminus*.

### 2.2.2 INVOLVEMENT OF STAKEHOLDERS

The most relevant stakeholders are the **scientific community** for their role in developing new FDCA (and related compounds)-based solutions; and the **industrial parties** for their twofold role of contributing to the development of these innovative products and bringing their practical vision to successful market deployment; as well as other relevant players of the value chain, in upstream (**policy-makers**) and downstream activities (**society**, final end-users).

The **scientific community** working on different disciplines related with the Action (furan synthetic routes, polymer chemistry, materials developing and chemistry-physics, LCA and techno-economic assessments) have been consulted and directly involved in the preparation of this Action to ensure their participation and facilitate future coordination. The main **industrial stakeholders** are European ‘bioplastic’ and chemicals production industries, along with the chemical/polymers manufacture industries (mainly packaging companies). Several industrial partners from both chemical and polymer materials production fields are already actively involved in the preparation of this Action and join WG3 (4.1.1). The same applies to the manufacture industry (packaging companies and coating industry) and to recycling sector. Furthermore, this Action also previews industry-oriented workshops and conferences (3.2.2), so as to ensure a wider participation of industrial parties in FUR*4*Sustain activity. **Policy-makers** for their responsibility in making policies and legislation at European/national/regional levels that promote and encourage the production and use of renewable products instead of petrochemical ones, especially those that are derived from non-edible biomass and simultaneously are recyclable or biodegradable. Their mobilisation will be guaranteed with direct invitation to participate in conferences/seminars/round tables (3.2.2) and, in a broader spectrum, using general mass-media dissemination tools to alert them to the FUR*4*Sustain values. In this way, also **society** will be alerted to the benefits of a sustainable development using furan materials.

### 2.2.3 MUTUAL BENEFITS OF THE INVOLVEMENT OF SECONDARY PROPOSERS FROM NEAR NEIGHBOUR OR INTERNATIONAL PARTNER COUNTRIES OR INTERNATIONAL ORGANISATIONS

The consortium gathers partners from the University of Sfax/Tunisia (NNC) and from the Chinese Academy of Sciences/China (IPC) due to their specific field of working within furan-based chemicals, polyesters and polyurethanes. Their involvement in the FUR*4*Sustain will have also a positive impact on both the consortium and on them by broadening knowledge and network of contacts.

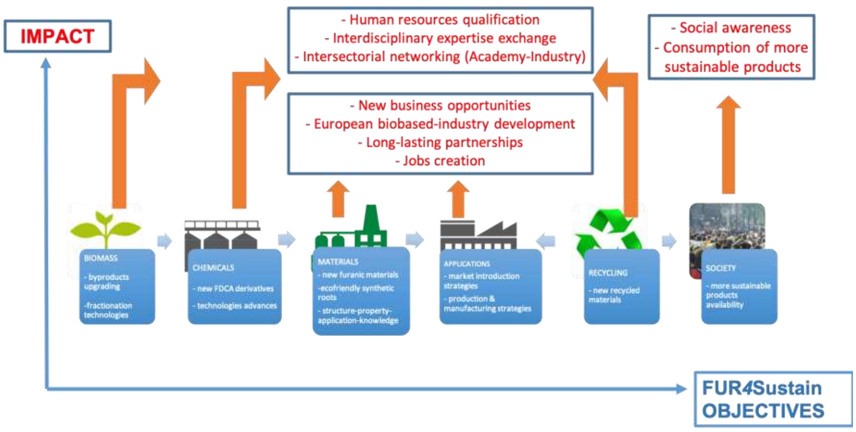
COST
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

# 3 IMPACT

## 3.1 IMPACT TO SCIENCE, SOCIETY AND COMPETITIVENESS, AND POTENTIAL FOR INNOVATION/BREAK-THROUGHS

### 3.1.1 SCIENTIFIC, TECHNOLOGICAL, AND/OR SOCIOECONOMIC IMPACTS (INCLUDING POTENTIAL INNOVATIONS AND/OR BREAKTHROUGHS)

In this Action, **innovation** will be fostered by tackling old problems and novel domains of FDCA products as clearly defined in the strategy of each Working Group (WG) (4.1.1). This innovation will be **built on the ongoing experience and vision of the network, thus, enhancing success and reducing/circumventing problems.** Innovation by:




- **WG1: developing FDCA synthetic routes**

In the *short term*, by mastering development on the synthetic routs to obtain FDCA and related monomers (*e.g.* bifuranic-diols and diacids) that do not rely on edible feedstocks, and/or circumvent common problems of FDCA production are ground breaking scientific and technological innovations. This implies the use of other sources of starting sugars (some very interesting are agroforest byproducts), developing their processing concepts, and esteblishing routes avoiding HMF production or searching for technology advances in base-free conversion of HMF to FDCA, along with the sustainability and efficiency of these technologies.

- **WG2: developing new FDCA-based polycondensates and related properties knowledge**

Furan materials, broad/specialised characterisation and ecofriendly synthesis are ground breaking scientific innovations. However, some of these areas are still unexplored such as polyamides, polyurethanes and blend/composite materials development, as well as other furan products like for example polymer additives (*e.g.* plasticisers). In addition, highly-specialised domains of characterisation (computational chemistry; blowing stretching and strain induced crystallisation and the thermal, mechanical and barrier properties as a function of the processing conditions) could also be extensively explored. More progress in these domains have been hampered by the fact that development of furan materials corresponds largely to scattered individual efforts, carried out at a national level, and without an intersectorial approach (Academy & Industry), however in the *short term*, in FUR*4*Sustain they will benefit from a cooperative, interdisciplinary multinational programme that guarantees scientific and technological progress through cooperation.

- **WG3: fostering ways to the introduction of newly developed FDCA products in the market**

In the *short/medium term*: defining ways to the successful introduction of newly developed FDCA products in the market, as part of the development of a sustainable industry, will bring clear economic benefits, as well as social and sustainable progress. Furthermore, in Europe oppositely to worldwide, the polymeric materials industry is quite stagnated. Still sustainable and innovative products discloser would allow to counteract this trend in the *log term*, promoting the growth in the bio-based industry, contributing, thus, to jobs creation, and the reindustrialisation of Europe in a low-carbon economy. However, almost all studies carried out until now are still limited to lab-, and successful deployment in the market has not occurred. This panorama is mainly due to the fact that this implies the consideration of multiple factors, corresponding to very specialised expertise of different actors, including for example defining the most promising applications of FDCA products and the best technological stretagies to produce and manufacture them; as well as, the economic, environmental, recycling, health and safety demands, as well as the market scenarios. The Action already gathers different actors (organic chemists, materials scientists, techno-viability and LCA experts, industrial partners from both production and manufacture fields and even users) and will provide a strong interaction between them by regular joint activities promoting networking. Additionally, the strong academic-industry foundation of FUR*4*Sustain provides considerable opportunities for innovation, especially at interfaces between production and discovery.

## 3.2 MEASURES TO MAXIMISE IMPACT

### 3.2.1 KNOWLEDGE CREATION, TRANSFER OF KNOWLEDGE AND CAREER DEVELOPMENT

**The impact of this Action will be accomplished by three main levels:**

- **Level 1 – research**
  - ➢ accomplishment of innovative scientific outcomes with an industrial perspective for new FDCA based chemicals and polymeric materials;
  - ➢ creation of a multidisciplinary cluster with key actors in biomass transformation, polymer and composite materials design and characterisation, LCA and techno-economic assessments, along with key stakeholder within production and manufacture industry (otherwise scattered in individual efforts), resulting in the long-term, of successful products applications and within a true bio-based economy mind-set;
- **Level 2 – industry**
  - ➢ further development of the (European) bio-based Industry, *via* exploitation of new technologies and furan chemicals, polymers and polymeric materials research results;
  - ➢ collaboration platform creation to organise networking between the involved research institutes, associations and industry, establishing, thus, a knowledge and communication platform to supply knowledge/technologies to all involved parties, and cooperating far beyond the Action *terminus*;
- **Level 3 – socio-economic**
  - ➢ preparation of highly qualified human resources and promoting the growth of bio-based sector, contributing, thus, *in the long-term* to jobs creation, together with new start-ups and the reindustrialisation of Europe in a CO2 neutral platform;
  - ➢ contribute to sustainable products production (renewable, recyclable and/or biodegradable) for end-users;
  - ➢ contribution to the social awareness for the need of using sustainable materials, and ultimately, influencing global policies and gathering funding.

Furthermore, this Action is aligned with key H2020 Societal Challenges, as well as National and regional smart specialisation strategies (RIS3) related with 'bioeconomy' and 'resource efficiency and raw materials' and also of 'Europe in a changing world - inclusive, innovative and reflective societies' which have been elected by their unequivocal potential to contribute to the **scientific**, **industrial** and **social** progress, including human resources qualification.

### 3.2.2 PLAN FOR DISSEMINATION AND/OR EXPLOITATION AND DIALOGUE WITH THE GENERAL PUBLIC OR POLICY

Exploitation of the main scientific and technological achievements of FUR4Sustain Action will be addressed through an intersectorial strategy (involving Academy and Industry) adequately supported by COST dissemination tools and WG3. FUR4Sustain will foster results exploitation, whenever adequate, through intellectual property protection (in compliance with COST rules) and management of intellectual property rights and its commercial value, promotion of entrepreneurship, support for the promotion of business innovation, making the match between the needs of businesses and the skills of researchers. Importantly, the dissemination plan will include a clear roadmap of exploitation of the Action results. **Dissemination actions will be directed towards five different audiences:**

- **Level 1 - within the consortium:** To guarantee clear communication channels within/between WGs or between the AC, the different management bodies, and each COST action member face-to-face meetings will be organised periodically, *viz.*:
  - ➢ intra/inter WGs meetings;

- seminars/workshops/training schools will be also used for specific discussions.

Whenever needed, along with email, the long-distance web video-conference tools (using professional video conference platforms of the institutions or even Skype) will be used for short meetings.

To allow easy and efficient information transfer between members a functional and a secure knowledge management system will be implemented:

- e-learning platforms (*e.g.* Moodle)
- web collaborative tools as *e.g.* Dropbox or OneDrive.

- **Level 2 - towards industry:** Dissemination activities specifically directed towards SMEs and other companies already in the Action and/or cross-borders, along with business associations, aiming at their involvement in FUR*4*Sustain and concomitantely on R&D results exploitation will be:
  - industry-oriented workshops: the main idea is to solve industrial issues. Round table discussions for specific items will enable a more detailed exchange of information;
  - conferences: direct invitation to participate in the conference organised by the Action, where the main results will be presented to them, aiming at the valorisation of the new furan products and processes/technologies on their pilot or industrial machines, in line with one of the main focus of this COST Action. This will be a first step of technological implementation and transfer into mass manufacturing.
- **Level 3 - towards the scientific community:** The members' knowledge, leadership and networking (even across COST Action borders) in the very competitive domain of FUR*4*Sustain will be consolidated in multiple ways:
  - organising expert workshops: gathering scientists from all interested entities and to address specific issues;
  - organising conferences/seminars/workshops: open to the research community in general;
  - to maximise these former meetings impact, broad-dissemination tools of hot-plenaries will be considered (*e.g.* YouTube channel);
  - organising joint publications;
  - promoting the members' participation in suitable scientific meetings to inform the objectives, scope, achievements and progress results of the Action (COST conference grants scheme);
  - in the context of Open Access to Scientific Publications and Research Data of H2020 FUR*4*Sustain will make scientific publications available free of charge, by online access for any user in 'Green' open access (Self-archiving) taking in consideration any 'embargo period' or in 'Gold' open access (open access publishing). Gold open access will be considered for three selected papers per year on average.
- **Level 4 - towards Young Researchers:** Early Career Investigators and in particular young talents and next generation leaders, will be motivated to be involved in FUR*4*Sustain aiming at both action knowledge and results dissemination, and concomitantly training them in science and technology. Hence, several practical actions will be taken to motivate them:
  - they will be given some responsibilities, like, *e.g.* networking disseminations or video pod-cast production;
  - several STSMs will be proposed to them;
  - their presence will be favoured in training schools and workshops;
  - collaborative works including bibliographic surveys, data analysis (experimental data, LCA, simulations, *etc.*) will be proposed for groups of students, belonging to the different Universities involved in the Action, and as part of their MSc/PhD Theses work.
- **Level 5 - towards and with society:** Dissemination to general public of sound results and, more generally, to promote a social awareness of the need to move to a more sustainable society also involving policy-makers, will be target by preparing:
  - website and Facebook pages;
  - LinkedIn and Research gate network pages;
  - newsletter summarising the activity of the Action or instead in a specific hot topic important for the network. This will be accessible on the website so that all COST members can use it in scientific events, thus increasing the visibility of the Action;
  - press-releases, disseminated using the members institutional press offices and science dissemination channels;
  - invite consumers' societies, policy-makers, among others society key players to attend the organised conferences/seminars, enabling open discussion with for example round tables, so that the Action can profit from their contribution and all from the knowledge generated through the Action;
  - participating in several science-related national, as well as, European events. At least once members of each country, will participate in the Europeans Researchers Night. Activities promoted by the project Responsible Research and Innovation will also be considered.

# 4 IMPLEMENTATION

## 4.1 COHERENCE AND EFFECTIVENESS OF THE WORK PLAN

### 4.1.1 DESCRIPTION OF WORKING GROUPS, TASKS AND ACTIVITIES

- **WG1: Synthetic approaches towards FDCA and related monomers**

2,5-Furandicarboxylic acid is one of the most important key bio-based platform chemical coming out from biorefineries. However, its large scale production/exploitation has still many key challenges. Some of the most important are related with the use of edible starting biomass feedstocks (especially corn); others concern the catalytic conversion of HMF under basic conditions, resulting in the FDCA salt form, which cannot be directly used in the polymer industry; or the development of additional furan-routes that circumvent the production of unstable HMF. These important challenges will be addressed in this Action, in fact in WG1 the **quest for innovative routes to obtain FDCA and related monomers such as, for example, bifuranic-diols and diacids (that can be viewed as an expansion of FDCA type monomers), in high purity and yield, with a special emphasis on the use of non-edible renewable feedstocks and on low-value industrial waste residues, along with the sustainability and efficiency of the technologies involved (WG3), will be targeted.**

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| **OBJECTIVES:** WG1 aims to develop novel technologies for the synthesis of FDCA and related monomers, starting from widely occurring non-edible alternative sources of starting sugars, mainly agro-forest byproducts, such as those rich in cellulose fibres, which are a non-exhaustive source of D-glucose. Pectin rich sources from agroforest byproducts are concomitantly considered as source of uronic acids, circumventing, thus, the production of HMF. Particular efforts will be done on the conversion of furfural into FDCA and other related bifuranic-diacids and diols. Complementary efforts are focused on the production of FDCA (among others) directly from HMF, but using new catalysts and techniques like *e.g.* alternative reaction media (ionic liquids, deep eutectic solvents) and microwave-, ultra-sound- or Ohmic-assisted syntheses. Parameters like reaction temperature, time, reaction media, catalysts, catalyst type (homogeneous, heterogeneous, enzymes) will be systematically accessed to derive the optimal parameters for conversion into the intended products both at the lab and pilot scale. Hence, insights from experts in techno-economics and LCA assessments (WG3) about the protocols/processes development, are needed to ensure both viability and sustainability of the processes. Concomitantly, with reassurance of the monomers adequacy to polymer synthesis (*e.g.* purity) (WG2). |
| **TASKS: T1.1** Starting inventory of the current *status-quo* of FDCA-routes (and FDCA-based materials). Information will be collected not only through literature search and patent analysis but also through the organisation of a topic-dedicated seminar and workshop.<br>**T1.2** Mapping/analysis of the information collected in T1.1 and brainstorming event to create the basis for new/most promising roots to follow.<br>**T1.3** On-going grouping and ordering of results of WG1 activities towards FDCA (and related derivatives) to create a new overview to be discussed in multidisciplinary panels, formed by researchers, technologists/industry covering the complete value chain, market and LCA experts. This, on the one hand, to promote synergetic approaches among WGs members; and on the other hand, to define the most promising approaches, especially regarding their practical implementation, for development under WG3, and/or the technological evolution needed for their successful development. |

- **WG2: Materials development, their processing and characterisation, and computational studies**

The rational development of FDCA-based polymeric materials requires the holistic integration of synthesis/design of polyesters (among other polycondensates) and composite materials, their processing and in-depth characterisation; as well as the use of theoretical calculations, to predict and understand structure/properties relationship. This together with the evaluation of performance/viability/sustainability towards market introduction (WG3). Synthesis of polymeric materials and composites preparation are routinely carried out in 'conventional' laboratories by some of the individual participants. In the same way, high-tech characterisation techniques and theoretical calculation studies are often carried out by specialised research groups, by some of the individual participants. Also, in general, all these studies are apart from industry and market demands. Their entanglement would **build the knowledge needed to deeply understand, develop/design and monitor new high-valuable furan materials**.

**OBJECTIVES:** WG2 is focused on the synthesis of novel furan-based polycondensates (mainly polyesters, but also polyamides, polyurethanes and/or epoxy resins) using FDCA or derivatives (WG1) and other renewable-based monomers. Emphasis on their green synthesis by sustainable technologies and processes (*e.g.* enzymatic-catalysed synthesis), concomitantly with their technical feasibility will be addressed. In particular, WG2 will address the attainment of high-molecular weight polymers, by post-solid state polymerisation of some of the most promising pre-polymers identified in strict interaction between researchers and industry (WG3). Instead, the preparation of moderate molecular weight products *e.g.* polymer additives and curable polymers aiming at applications like coatings, adhesives or inks, will be also pursued in the same Academy-Industry environment (WG3).

A second scientific focus of WG2 is the preparation of still barely explored composites (isotropic or unidirectional) and nanocomposites from selected polymers and bio-based elements such as (nano)cellulose fibres/whiskers, protein fibrils, among others, considering the interactions between the furan matrix and the filler. The preparation of hybrid materials by combination with *e.g.* metal nanoparticles, graphene, carbon nanotubes for high-tech applications will also be considered. Polymer blends are also going to be explored.

A third main focus is the materials processing and detailed characterisation applying both routinely used procedures (mainly structural, thermal and mechanical techniques, but also barrier and biodegradation); as well as, highly specialised ones. A particular important aspect for future applications, but barely/or never reported for FDCA polymers, even for PEF, although extensively studied for TPA-derivatives,[54–56] is the study of the stretch ability to estimate their ability to be used as blown, thermoformed or stretched packaging (WG3). These studies may involve specialised techniques and know-how (*e.g.* specialised protocols including DSC, DMTA and biaxial stretching techniques) only available at a few research centres. Under the auspices of this Action these studies will be supported for the most promising polymers, as identified in strict interaction with WG3. Adding to these characterisation techniques, computational studies constitute an innovation promoted by this Action, in order to deeply interpret experimental results through a basic understanding of structure - property relations of FDCA-polymers. These studies will comprise methods such as, for example, Density Functional Theory (DFT) using recent good quality functionals (M06-2X or double hybrid B2PLYPd3), or more reliable composite *ab initio* based methods (*e.g.* the coupled cluster CCSD(T) based Weizmann theory (W1)) for selected cases. Hence, basic information regarding *e.g.* rotational barriers around polymer backbone linkages, IR or Raman vibrational bands, or NMR chemical shifts will be obtained. Thus, this will imply a strong interaction between WG2 research groups working in different fields (experimental *vs.* computational), besides transversal collaboration with WG3 to bring knowledge in terms of materials applicability, technological demands for scalling-up, sustainability and market prospects. This COST Action will be the ideal strategy to prompt close collaboration.

**TASKS: T2.1** Starting inventory of the current *status-quo* of FDCA-based polymers and materials. Information will be collected through literature search, patent analysis and, topic-dedicated seminar and/or workshop.
**T2.2** Mapping/analysis of the information collected in T2.1 and brainstorming event to create the basis for new/most promissing roots to follow.
**T2.3** On-going inventory of the results of WG2 activities (materials & properties).
**T2.4.** Assessement of the results of WG2 activities (materials & properties, T2.3). Results will be discussed in expert panels to define the most promising polymers and composite materials for further specific characterisation, development under WG3, and/or the technological evolution needed for their successful development.

- **WG3: Applications, routes towards innovation, market diffusion and LCA/sustainability issues**

The **successful introduction of newly developed FDCA-related products** in the market, as part of the development of a sustainable industry, implies the consideration of multiple factors including the most promising applications of FDCA products, the technological, economic, environmental, health and safety demands, as well as the market scenarios. This requires a strong interaction between different actors (organic chemists, materials scientists, techno-viability and LCA experts and industrials-producers, manufactors and recyclers), supported by FUR*4*sustain Action, and which ultimately will provide a platform for long-lasting cooperation, through joint call activities.

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| **OBJECTIVES:** WG3 is focused on identifying the main economic obstacles, market demands, supply chain challenges, environmental hotspots and also the legislative restrictions that need to be considered so as to ensure a successful introduction of FDCA and its materials in real applications. Technological solutions discussed in WG1 and WG2 are here considered from an integrated perspective to study and delineate the relevant strategies and scenarios for their development from lab to market application. Strong interaction with the industry is already considered (by their FUR*4*Sustain membership) in order to understand technological issues for the scaling-up and industrialisation of different processes, and acceptance to merge the newly developed polymers into the existing recycling stream, as well as to identify the non-technological problems that could endanger their market introduction.<br>WG3 also aims to identify the most promising application fields for newly synthesised FDCA chemicals and materials based on achieved and required product properties (WG1, WG2); on technological requisites to scale-up processes and manufacture; as well as their environmental, health and safety issues from a life cycle perspective. This includes identification of the most suitable application field to fully benefit from the material's performance to increase the market potential. Finally, it will be possible to draw conclusions on the market potential and environmental benefits and impacts of FCDA routes and FDCA materials. |
| **TASKS: T3.1** Systematic literature review (meta-study where applicable) on potential applications, economic drivers, barriers and environmental impact and safety issues in case of comparative technologies and products, resulting in a survey/report.<br>**T3.2** Techno-economic and environmental assessment. Scaling up modelling of selected processes (from lab to commercial size); followed by *ex-ante* mass and energy balances as well as emissions will be performed. Additionally, modelling of system scaling up will be done to assess the effects of the introduction of the scaled-up product in the market and environmental impacts.<br>**T3.3** Information collection on marked demands by means of the Kano method and/or an importance-performance assessment according to the structure of the preliminary results. |

- **WG4: Knowledge transfer, dissemination, WGs support and evaluation**

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| **OBJECTIVES:** WG4 aims to facilitate the exchange of information within/from the other WGs to across-borders and application of networking tools.<br>WG4 will have a transversal role, acting: *1) at the consortium level*, by assisting them in organising WGs meetings and in staff mobility (STSMs), as well as, in implementing web collaborative tools to allow large participation, easy and efficient information transfer between members and by boosting joint research activities and publications (fostered by STSMs); *2) towards the scientific community level*, through the creation of professional networks as LinkedIn and ResearchGate and by promoting the participation in suitable congress/seminars/workshops to inform the objectives, scope and results of FUR*4*Sustain Action; and *3) towards and with society level*, through the creation of a web and a Facebook pages, by every 6/12 months writing a press releases, pod-cast videos with grabbing news about FUR*4*Sustain achievements and also calling the attention of local and European policy-makers. *4)* Finally, *at a transversal level*, supporting the organisation of meetings (*e.g.* innovation workshops, industry-oriented workshops and conferences) and training schools (usually designated by summer/winter schools). An Early Career Investigators manager (ECIm) will be nominated to play specific role capturing young researchers and promoting human resources development, while the Industry Committee will have a similar towards industry involvement.<br>WG4 will also have an evaluation and mentoring role, transversal to all WGs, acting at the *1) kick-off* of FUR*4*sustain Action, by coordinating a survey (and report) covering the current *status-quo* of the whole value-chain of FDCA, in order to set the basis for evaluation of the knowledge on FDCA-routes and FDCA-based materials, and thus set the research and innovation ways, but also to disseminate. Information will be collected not only through literature search and patent analysis, but also through the organisation of a seminar/workshop. The same approach will be repeated again at the *2) mid-point* and *3) end* of the Action in order to evaluate (**RE-THINK**) the progress achieved and concomitantly to provide insights into future directions. |

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| **TASKS: T4.1** Management assistance, by helping the consorptium in the organisation of WGs meetings, staff mobility (STMs), joint research activities, papers, participation in congress/seminars/workshops, among others consortium activities.<br>**T4.2** Implementation of web collaborative/professional platforms: Dropbox, LinkedIn and ResearchGate.<br>**T4.3** Implementation of web and Facebook pages.<br>**T4.4** Dissemination of FUR*4*Sustain main results and achievements: press releases, pod-cast videos, among others.<br>**T4.5** Evaluation and mentoring support. Evolution of the Action progress according to the specific WGs' objectives and support new activities to continuously excellence. Also, reporting of WGs activities. |

### 4.1.2 DESCRIPTION OF DELIVERABLES AND TIMEFRAME

| **delivery number** | **delivery name** | **delivery date** (Month in which the deliverables will be available, starting at month 1) |
|---|---|---|
| **D1-4** | topic-dedicated content book | M1-3; M13-15; M25-27; M37-39 |
| **D5-8** | industry-oriented seminair/workshop abstract book | M4-6; M10-12; M28-30; M34-36 |
| **D9-12** | workshop/seminar abstract book | M16-18; M22-24; M40-42; M46-48 |
| **D13-15** | training schools content book | M16-18; M28-30; M46-48 |
| **D16-D19** | green/golden open access publication | M4-6; M13-15; 25-27; M37-39 |
| **D20** | web collaborative website, FUR4Sustain webpage and LinkedIn and ResearchGate webpages | M1-3 and on regular basis |
| **D21-24** | meetings content book | M7-9; M19-21; M31-33; M43-45 |
| **D25-28** | annual surveys | annualy, starting M4-6 |
| **D29-32** | annual reports | annualy; starting M10-12 |
| **D33** | newsletter, press releases and pod-cast videos | on regular basis |

### 4.1.3 RISK ANALYSIS AND CONTINGENCY PLANS

This Action previews an incisive Contingency plan, based on a continuous evaluation of the Action progress (as previewed in WG4, 4.1.1), **to minimise techno-scientific, management, output and financial risks**. The main risks *vs.* contingency measures are:

**1. Techno-scientific**
Unexpected R&D and technical difficulties (and related delays) can occur during the WG1-3 progress. However, this is intrinsically reduced by the composition of FUR*4*Sustain consortium, thanks to the participation of members with a consolidated experience as leaders in all scientific and technical fields of this Action.

**2. Management**
The **dimension of the COST Action team** can bring management difficulties related with coordination. Nevertheless, this is predictably a low risk difficulty due to the clear coordination structure of Fur*4*Sustain relying on the Action Chair (AC), Action Vice-Chair and WGs leaders. The practical management of daily issues will be carried out by the Core Group. It is also planned to include in the management of Action the role of an Early Career Investigator (ECI) manager and an Industry Committee (IC).

Also, risks related with information collection and coordination could occur. Nevertheless, this Action has been planned to reassure clear communication channels within/between WGs or between the AC, the different management bodies, and each COST Action member using the appropriate dissemination tools (3.2.2) and WG4 (4.1.1) will work specifically on providing the adequate interface between the WGs.

Unpredictable **early COST Action-leaves** by COST members with key roles will be handled by: identifying the personnel with the right competencies to perform the tasks of the project and check their availability (it may occur possible work overload or conflict with already established deadlines of other projects) and election as soon as possible. Possible **delay in producing the deliverables** with respect to the established timeframe of the project is another risk, mitigated by the consortium experience in managing complex European projects (FP7, H2020, COST) and National R&D collaborative projects. Also, delay risks early identification is reassured by the survey (4.1.1) and annual COST reporting, coordination activities (MC/WGs meetings, 4.1.4) and by the continuous evaluation and mentoring role of WG4 (4.1.1), also providing insights into future directions. Difficulties in fostering interest from **industrial stakeholders** may occur. However, this is intrinsically reduced by the composition of FUR*4*Sustain consortium, encompassing several members from industry and by supporting the organisation of industry-oriented workshops/conferences.

**3. Output**

**Quality levels of deliverables** of the project could be low. A first quality check and a first set of measures will be carried out by the corresponding WG leader and supported also by WG4. A second check is previewed by Action MC evaluation and procedures.

**4. Financial**

In case of financial deviations or lack or resources availability, early identification will be reassured by the Grant Holder with the help of the financial management staff of its institution and during the financial reporting elaboration. Corrective measures will be in compliance with COST Vademecum rules and may include redistributing to the remaining partners the activity not fulfilled.

## 4.1.4 GANTT DIAGRAM

| | Year 1 | | | | Year 2 | | | | Year 3 | | | | Year 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **WGs' ACTIVITIES** | | | | | | | | | | | | | | | | |
| **WG1:** Synthetic approaches towards FDCA and related monomers | | | | | | | | | | | | | | | | |
| **T1.1** Starting inventory of the current *status-quo* of FDCA-routes | D1 | | | | | | | | | | | | | | | |
| **T1.2** Mapping/analysis of the information collected in T1.1 and brainstorming | | | | | | | | | | | | | | | | |
| **T1.3** On-going grouping and analysis of results of WG1 activities | | | | | | | | | D3 | | | | | | | |
| **WG2:** Materials development, their processing and characterisation, and computational studies | | | | | | | | | | | | | | | | |
| **T2.1** Starting inventory of the current *status-quo* of FDCA-based polymers and materials | D1 | | | | | | | | | | | | | | | |
| **T2.2** Mapping/analysis of the information collected in T2.1 and brainstorming | | | | | | | | | | | | | | | | |
| **T2.3** On-going inventory of the results of WG2 activities (materials & properties) | | | | | D2 | | | | | | | | | | | |
| **T2.4.** Assessement of the results of WG2 activities (materials & properties) | | | | | | | | | | | | | | | | |
| **WG3:** Applications, routes towards innovation, market diffusion and LCA/sustainability issues | | | | | | | | | | | | | | | | |
| **T3.1** Systematic literature review | D1 | | | | | | | | D3 | | | | D4 | | | |
| **T3.2** Techno-economic and environmental assessment | | | | | | | | | | | | | | | | |
| **T3.3** Information collection on marked demands | | | | | | | | | | | | | D4 | | | |
| **WG4:** Knowledge transfer, dissemination, WGs support and evaluation | | | | | | | | | | | | | | | | |
| **T4.1** Management assistance and reporting | | | | | | | | | | | | | | | | |
| **T4.2** Implementation of web collaborative platforms | D20 | | | | | | | | | | | | | | | |
| **T4.3** Implementation of web, Facebook and professional pages | D20 | | | | | | | | | | | | | | | |
| **T4.4** Dissemination of FUR*4*Sustain main results and achievements | | | | | | | | | | | | | | | | |
| **T4.5** Evaluation and mentoring support | | | | | | | | | | | | | | | | |
| **Action ACTIVITIES** | | | | | | | | | | | | | | | | |
| I COORDINATION activities | | | | | | | | | | | | | | | | |
| ➢ MC/WGs/ECI/IC meetings | | | D21 | D29 | | | D22 | D30 | | | D23 | D31 | | | D24 | D32 |
| II MEETING and TRAINING events | | | | | | | | | | | | | | | | |
| ➢ seminairs/workshops | | D5 | | D6 | | D9 | | D10 | | D7 | | D8 | | D11 | | D12 |
| ➢ training schools | | | | | | D13 | | | | D14 | | | | | | D15 |
| ➢ research exchange/STMs | | | | | | | | | | | | | | | | |
| III SPECIFIC DISSEMINATION activities | | | | | | | | | | | | | | | | |
| ➢ annual survey | | D25 | | | | D26 | | | | D27 | | | | D28 | | |
| ➢ Green/golden open acess publications | | D16 | | | D17 | | | | D18 | | | | D19 | | | |

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