
# The Bio-Based Industries Joint Undertaking as a catalyst for a green transition in Europe under the European Green Deal

Chloe Johnson , Ana Ruiz Sierra , Jan Dettmer , Kleopatra Sidiropoulou , Elina Zicmane , Virginia Puzzolo , Philippe Mengal , Antonella Canalis , Paola Paiano

PII: S2667-0410(21)00014-8
DOI: https://doi.org/10.1016/j.bioeco.2021.100014
Reference: BIOECO 100014

To appear in: *EFB Bioeconomy Journal*

Received date: 15 March 2021
Revised date: 9 June 2021
Accepted date: 10 June 2021

Please cite this article as: Chloe Johnson , Ana Ruiz Sierra , Jan Dettmer , Kleopatra Sidiropoulou , Elina Zicmane , Virginia Puzzolo , Philippe Mengal , Antonella Canalis , Paola Paiano , The Bio-Based Industries Joint Undertaking as a catalyst for a green transition in Europe under the European Green Deal, *EFB Bioeconomy Journal* (2021), doi: https://doi.org/10.1016/j.bioeco.2021.100014

**Highlights:**

- The Bio-Based Industries Joint Undertaking (BBI JU) together with the new Circular Bio-Based Europe partnership will be a key instrument to achieve the objectives of the European Green Deal and to realise a just and green transition
- The BBI JU contributed to key policy areas such as the Bioeconomy Strategy, the Circular Economy Action Plan and the Farm to Fork (F2F) strategy
- The BBI JU funded projects are delivering sustainable, circularly designed bio-based products

# The Bio-Based Industries Joint Undertaking as a catalyst for a green transition in Europe under the European Green Deal

Chloe Johnson[a], Ana Ruiz Sierra[a], Jan Dettmer[a], Kleopatra Sidiropoulou[a], Elina Zicmane[a],Virginia Puzzolo[a], Philippe Mengal,[a] Antonella Canalis,[a] Paola Paiano.[a]

[a] Bio-based Industries Joint Undertaking

**Abstract:** This article describes how the Bio-Based Industries Joint Undertaking (BBI JU) has contributed to address many of the global challenges that are at the core of the new European Green Deal. The BBI JU aims at strengthening and supporting the bio-based industries across Europe by funding research and innovation (R&I) and the establishment of first-of-their-kind biorefineries. Many synergies can be found between the goals of BBI JU and those of the European Green Deal and its relevant policy areas, such as the Circular Economy Action Plan, the Farm to Fork Strategy and the EU Bioeconomy Strategy. This article highlights the main impacts generated by BBI JU funded projects in these policy areas. It presents success stories, in which the projects are delivering sustainable, circular bio-based products as exemples. Finally, the article seeks to analyse how R&I investments by the BBI JU can support the EU in its recovery in a post pandemic era.

**Keywords:** Bio-based industries; European Green Deal; Farm to Fork strategy; Bioeconomy; Sustainable food, Sustainable products

## 1. Introduction

Climate change and environmental degradation are an existential threat to Europe and the world. To overcome these threats, the European Union (EU) has put in place the European Green Deal (EGD), a growth strategy that will transform the EU into a competitive and sustainable economy [1]. The EGD, adopted at the end of 2019, provides the action plan to achieve carbon neutrality, resource efficiency and zero pollution in the EU by 2050. This set of policy initiatives, coupled with the new EU Recovery Plan [2] developed to support the repair of the economic and social damage caused by the COVID-19 pandemic, represents today the most crucial milestones in the green transition towards a more resilient, competitive and environmentally sustainable Europe.

Since its establishment in 2014, the Bio-Based Industries Joint Undertaking (BBI JU) [3] has acted as a key instrument to realise the EU's vision for a sustainable and competitive Europe, leading a transition towards a society which does not depend on depleting fossil-based resources. The €3.7 billion public-private initiative is, in fact, a central part of the implementation of the EU's Bioeconomy Strategy and Action Plan [4], which aims to scale-up and consolidate the bio-based sectors in order to deliver innovative bio-based solutions. The BBI JU programme has already delivered important technological advancements and innovations, by means of the funded projects, which are contributing to the aims of the EGD.

A more detailed description of the initiative's structure, recipe for success and role in developing the bio-based sector has already been discussed in previous publications [5-7]. Therefore, in this article, we seek to highlight how the BBI JU is well aligned with the objectives of the EGD and is partnering with the EU to realise a just and green transition [8]. It also discusses the contribution of BBI JU to the goals of the relevant policy areas, including the Circular Economy Action Plan (CEAP) [9] and the Farm to Fork (F2F) strategy [10] on top of the Bioeconomy Strategy. Finally, building on the achievements of BBI JU, we outline what more can be done through the future partnership for a Circular Bio-based Europe – the successor to BBI JU – under the Horizon Europe programme [11] towards developing sustainable and climate-neutral technologies and supporting the green recovery of Europe in the post COVID-19 pandemic era.

## 2. The BBI JU unlocking the potential of the bio-based industries to drive the green transition to a sustainable European economy

The Strategic Innovation and Research Agenda (SIRA) [12], developed by BIC in consultation with different stakeholders and endorsed by EC, set out the main technological and innovation challenges that the bio-based industry is facing: from the sustainable sourcing of feedstock and the innovation of efficient and economically viable biorefining technologies, up to ensuring public acceptance and market uptake of novel bio-based products and applications. In the frame of this roadmap and after only 7 years of operation, the BBI JU has proven to be an effective instrument to overcome these challenges, and mobilise and consolidate the bio-based industries across Europe [13].

The BBI JU programme implementation, including the level of achievement of the objectives and the expected impacts, is monitored using a set of predefined indicators:

i) specific key performance indicators (KPIs) described in the SIRA to monitor the project outcomes and

ii) expected socio-economic and environmental impacts (job creation, reduction of $CO_2$ emissions, waste reductions, rural development, etc.) generated by the BBI JU projects.

The information presented in this article are based on the data collected from the projects' coordinators via the annual KPI & impact questionnaire. It covers the expected and actual contribution (for ongoing and finalised projects respectively) of the project to the BBI JU KPIs in addition to other socio-economic impacts. The reported percentages are calculated with respect to the number of projects that replied to the survey.

According to the most recent data collected in 2020 and reported in Figure 1, the finalised projects alone have already surpassed the targets set for many of the identifies KPIs. For example, 47 new interconnections were established (against a SIRA target of 36), with 225 additional foreseen by 2024 by ongoing projects. Similarly, 33 new value chains have been realised by finalised projects against a target of 10. In this way, the BBI JU has made important progress towards realising its overarching objectives and contributing a green and competitive bioeconomy in Europe.

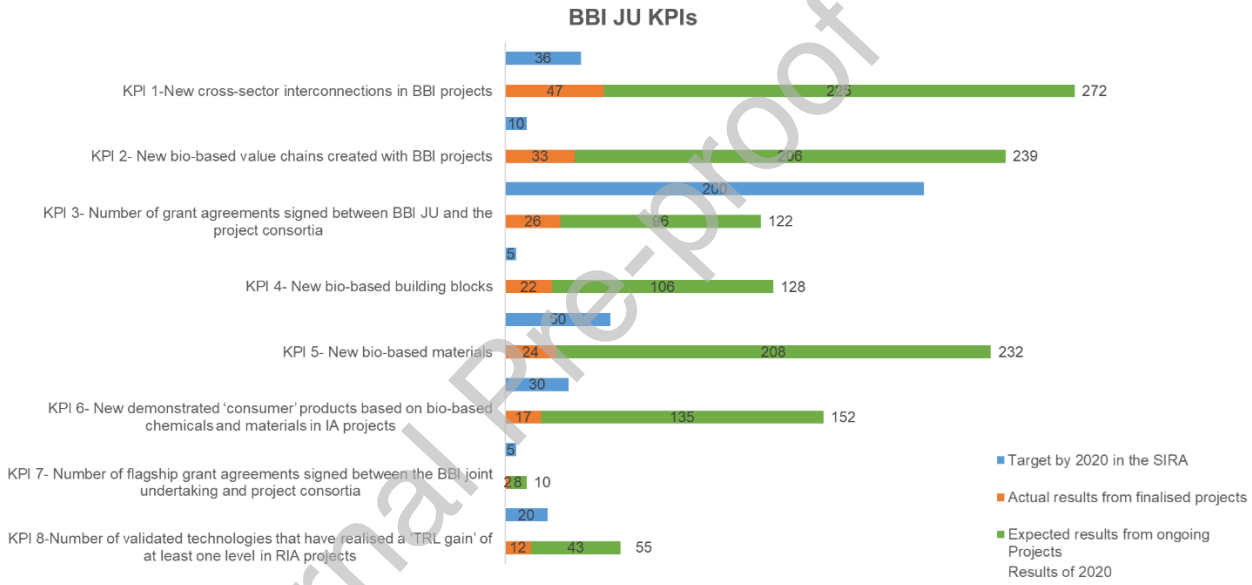



***Figure 1.*** *Expected and actual KPI results versus targets in the SIRA reported in the annual BBI JU KPI & Impact questionnaire survey in 2020.[14]*

In addition, an analysis of the project documentation has been conducted by independent experts to validate the projects' contributions and impacts to the BBI JU programme objectives reported in the KPI & impact questionnaire. In this validation exercise, 50 projects were considered, including the 32 projects finalised by July 2020 and 18 ongoing projects that have undergone at least one project review. The experts analysed each KPI contribution and classified them into 3 validation levels: 1. achievement is empirically documented or tested/demonstrated; 2. achievement is described but without full empirical documentation of all aspects; 3. achievement is not documented. An overview of the analysis for the finalised projects is presented in Figure 2. which shows that the KPIs were described and evidenced, at least moderately, in 89–98% of cases. The new bio-based value chains were particularly well supported, with 86% receiving a validation score of 1.

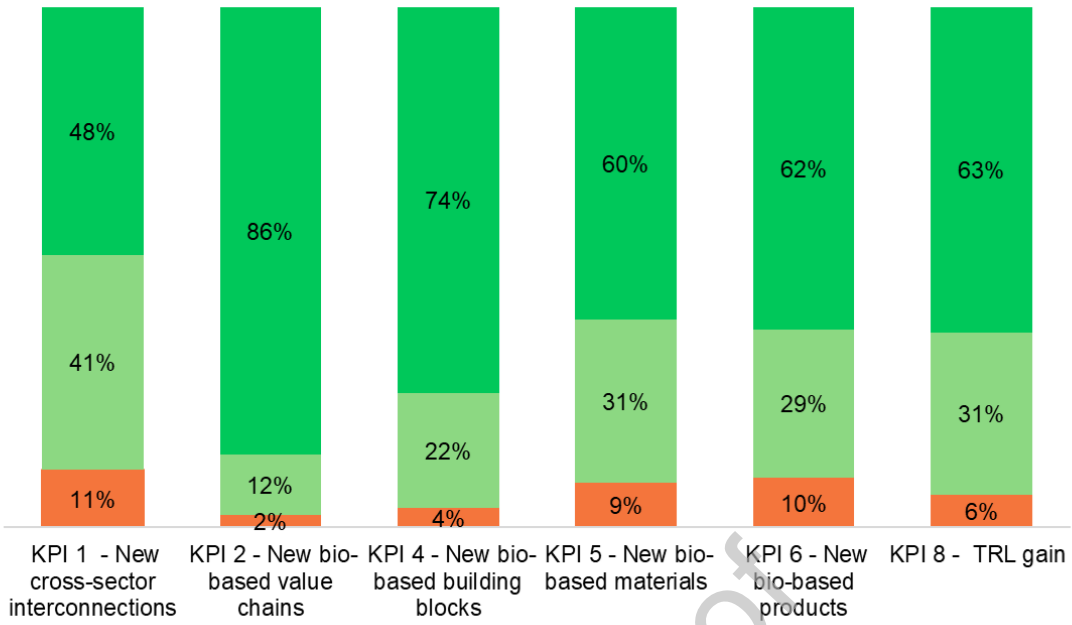



***Figure 2.*** *Validation results of the reported KPIs by BBI finalised projects (KPI 6: only 6 Innovation Actions; all other KPIs: 23 Innovation Actions and Research and Innovation Actions). Dark green: validation score 1; light green: validation score 2; orange: validation score 3.*

Another level of monitoring tracks the leveraging effect of the initiative and has shown that the BBI JU is an effective tool to de-risk private investments. This is well demonstrated by the 11 first-of-its-kind Flagship biorefineries in Europe, which are expected to deliver € 5.7 of private investment for every € 1 spent through BBI JU grants, amounting to a total private investment of € 1.3 billion. In addition, they expect to generate more than 3,500 direct and 10,000 indirect jobs, the majority of which will be in rural areas [13]. Since the Flagship plants have a high potential for replication throughout Europe, the long term positive impacts on investments and jobs in the bio-based economy are anticipated to be very significant.

## 3. The synergies between the objectives of the European Green Deal and the BBI JU programme

The EGD outlines 10 key objectives towards realising a climate neutral, modern and resource-efficient Europe. The long-term objectives of the BBI JU, as established in the SIRA [12], are already well aligned with this ambition. In particular, the targets set by the EGD to decrease greenhouse gas (GHG) emissions by 55% by 2030 and for the EU to reach full carbon neutrality by 2050 are well reflected in the SIRA target to reduce GHG emmissions associated with the production of new bio-based products by at least 50% on average compared to their fossil alternatives by 2030. This, coupled with the targeted replacement of 30% of fossil-based chemicals & materials produced in Europe by bio-based is expected to contribute significantly to the broader EU climate targets.

Furthermore, a bio-based economy and a circular economy go hand-in-hand, as reflected in the SIRA objective of boosting the mobilisation and valorisation of 25% of unused sources (by-products and biowaste) and of pursuing ‘zero-waste’ bio-based operations. In line with the CEAP [9], the bio-based sector is delivering chemicals and materials to resource-intensive sectors, such as plastics, textiles, and construction which are not only derived from traditional waste streams, but are also offering improved end-of-life scenarios.

The BBI JU initiative has many cross-cutting actions with the Farm-To-Fork (F2F) strategy, which aims to ensure stable and fair economic returns for primary producers and healthy, sustainable food for citizens while respecting the boundaries of the environment and reversing biodiversity loss [10]. In particular, the BBI JU is actively contributing to the development of sustainable food systems by targeting the reduction of imported protein to the EU by 50% and phosphorus and potassium by 25%. Moreover, alternative pest control methods and nutrient management strategies developed by BBI JU funded projects can help the EU meet its targets to reduce pesticide and fertiliser use by 50% and 20% respectively by 2030. New innovative solutions will help producers to orientate themselves towards organic farming practices, which not only protects the environment, but also has the potential to increase the livelihoods of farmers as consumer demand for organic produce increases. The EU Bio-based industry aims to create 700,000 jobs by 2030, of which 80% are in rural and currently underdeveloped areas through the development of the bio-based sector. Therefore, to maximise the benefits to primary producers, the BBI JU programme is actively promoting the participation of the primary sector in R&I projects and the creation of new value chains. Since the new bio-based value chains are predominantly valorising agricultural residues and agro-food side streams (vide infra), there is no competition with food production, but rather an opportunity to generate higher incomes across the value chain while also reducing waste.

### 3.1. BBI JU contributions towards sustainable Circular Economy solutions

#### 3.1.1. Sustainable feedstock

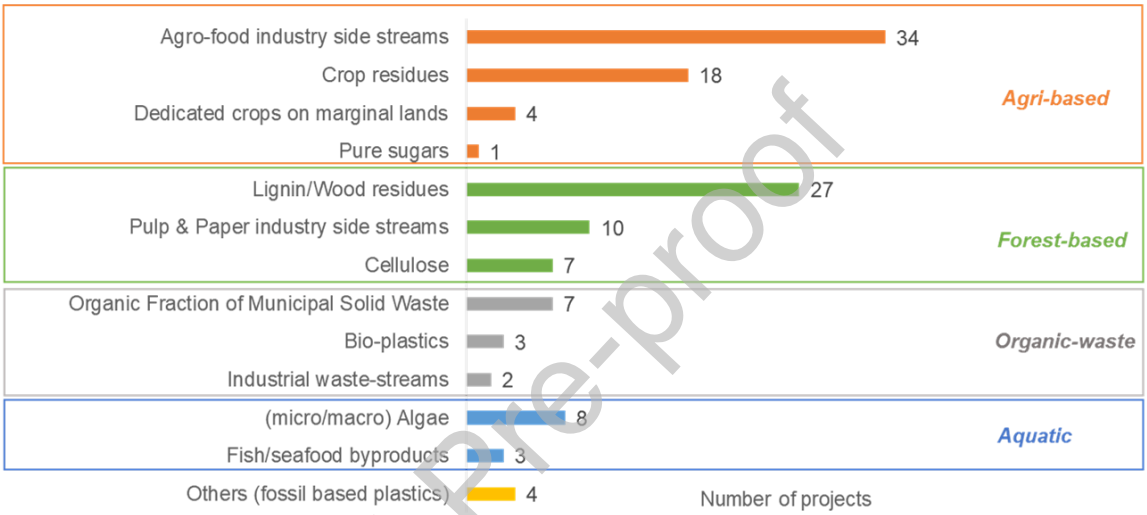
The bio-based industry is driving the transition from a fossil-based economy to a bio-based one which uses sustainably sourced non-food feedstock. This is in line with the Commission's objective of "*decoupling economic growth from resource use*". Likewise, this priority is central to the mission of the BBI JU initiative, exemplified by the fact that of the 128 new building blocks and 232 new materials being developed in BBI JU funded projects, 59% and 40%, respectively, target the complete replacement of fossil-based components by bio-based [14]. Crucially, these bio-based products are produced using sustainable feedstock (see Figure 3a). In fact, 91% of BBI JU projects using feedstock derived from agriculture valorise waste and by-products, with only 7% using dedicated crops grown on marginal lands [8]. In addition, many BBI JU projects utilising agriculture based feedstocks are developing innovations and knowledge to enable sustainable cultivation and exploitation of agricultural biomass. For example, the finalised FIRST2RUN flagship has developed new cardoon hybrids which produce more and higher quality oils, demonstrated new prototypes for harvesting the underexploited cardoons and a low-input protocol for their cultivation, in addition to developing new methods for monitoring field health.

Similarly, all projects valorising forest-based feedstock utilise sustainable feedstock, including wood residues and side-steams from the pulp and paper industry. In addition to this, two BBI JU projects, TECH4EFFECT [15] and EFFORTE [16] dealt specifically with the efficient management of forests to increase the availability of sustainable feedstock. These projects have devised new tools which allow forest managers to minimise the environmental impact – especially the impacts on soil health – while also increasing efficiency.

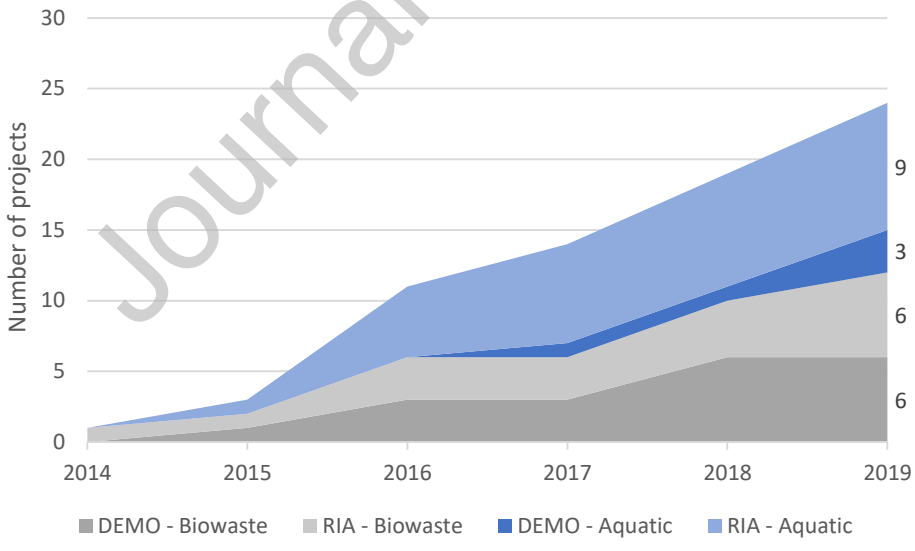
To avoid increased pressure on aquatic resources, the BBI JU is also supporting the development of a circular blue bioeconomy, by exclusively funding projects which utilise (micro)algae or the by-products of the fish and seafood industries. **Figure 3b** shows the steady increase in the number and

TRL of actions valorising aquatic feedstock and the gradual shift towards higher TRL demonstration scale projects achieved so far.

An increasing share of BBI JU projects are valorising bio-waste, such as the organic fraction of municipal solid waste (OFMSW), industrial waste and bio-based materials (bioplastics and biocomposites). Creating new value chains and business models in this arena is a clear answer to the "less waste, more value" priority communicated in the CEAP, which highlights the objective of halving the level of non-recycled municipal waste by 2030. In this context, the EMBRACED [17] project is demonstrating the potential and economic viability of a biorefinery valorising the cellulosic fraction of post-consumer absorbent hygiene product waste to bio-based building blocks, polymers, and fertilisers, diverting 10,000 t/year of waste from landfill and incineration. Further projects are exploring the viability of up-cycling food waste and heterogeneous OFMSW.




**a.**




**b.**

***Figure 3a.*** *Types of feedstock used in BBI JU RIA and IA projects (Call 2014-19). Unit: number of projects; 19 projects valorise mixed feedstock. Source: BBI JU;* ***b.*** *Evolution of the number of BBI JU projects (Call 2014-19; DEMO and RIA) addressing aquatic and biowaste & CO2 feedstock (cumulative data)*

To optimise resource use, the biorefineries operate under cascading and zero waste biorefinery concepts [18]. This means that the biorefineries should maximise the valorisation of feedstock to attain the most value added products by prioritising the production of useful chemicals and materials over the use of biomass for energy. For example, the AFTER-BIOCHEM [19] Flagship aims to utilise the side streams from the sugar industry such as molasses, vinasses and pulp to prepare organic acids and higher value derivatives, with the subsequent by-products being valorised to fertilisers. This is one of many examples of potential industrial symbioses which will help to eliminate waste and to build a circular economy in Europe.

### 3.1.2. Sustainable processes

**GHG emission reduction:** In addition to contributing to the shift to sustainable feedstock, the bio-based industries can contribute to the decarbonisation of the European economy by developing greener processes [20] which is at the core of the European Green Deal objectives. In an annual survey of the ongoing and finalised projects conducted in the second half of 2020, 58% of BBI JU projects reported (expected or actual, depending on the project status) contributions to decreased greenhouse gas (GHG) emissions, while 53% anticipated a reduction in energy consumption [14]. This trend is confirmed by the responses from finalised RIA and IA projects with 56% reporting reduced GHG emissions and 78% reduced energy consumption.

Many of the $CO_2$ savings reported are linked to the utilisation of bio-based feedstock in place of fossil resources, more efficient processes and local sourcing of feedstock. In particular, and due to their scale, the environmental performance of the flagship projects is expected to have a profound effect on $CO_2$ savings. In fact, the first eleven flagship biorefineries alone are expected to save 600 kT of $CO_2$ emissions per year[8].

In order to evaluate the actual environmental performance of the process or product under development, all RIA and IA projects are obliged to conduct a life-cycle assessment (LCA) [21]. An LCA recently published by the AFTER-BIOCHEM project estimates that, due to energy efficiency of their fermentation process, the carbon footprint of their bio-based acids is 81% lower on average compared to their fossil-based equivalents on the market [22]. Similarly, a LCA conducted by the finalised FIRST2RUN flagship estimated 63% and 46% savings in terms of global warming potential (GWP) and non-renewable energy resource consumption (NRER), respectively, through the implementation of their new agro-industrial value chains [23].

**Mild, safe and efficient processes:** BBI JU projects are making significant contributions to the development of biotechnological processes and are demonstrating their application to the production of novel bio-based chemicals and polymers from diverse feedstocks. Processes employing biotechnology are often advantageous from both an economic and environmental perspective, as bioprocessing can in many cases support milder reaction conditions and increased yields and selectivities compared to traditional routes which employ hazardous chemicals [24]. An example are DEEP PURPLE [25] and SMARTBOX [26] projects which are developing technologies in the area of microbial production and enzymatic catalysis.

In addition to increasing efficiency, more than a third of BBI JU projects are developing safer and more environmentally benign processes compared with traditional routes. Many of these improvements are due to the development of innovative biotechnological solutions, the application of green chemistry princliples [27], as well as the optimisation of operational processes. Going one step further, the flagship project ReSolute [28] aims to scale up the production of a bio-based non-

toxic and high-performance solvent, CyreneTM, as an alternative to toxic dipolar solvents currently used in chemical production processes.

**Zero waste:** In line with EU priorities to increase resource efficiency, a common characteristic of BBI JU projects is that the biorefineries operate under cascading and zero waste biorefinery concepts. This means that the biorefineries maximise the valorisation of feedstock to attain the most value added products by prioritising the production of useful chemicals and materials over the use of biomass for energy [18]. Almost 30% of the new bio-based value chains developed in BBI JU IAs are using a cascading approach. The demonstration project Agrimax exemplifies these two features by diverting agricultural and food processing waste from low value applications (e.g. biogas production), to higher applications such as the production of biocompounds for active ingredients, packaging and agricultural materials [29].

### 3.1.3. Environmentaly friendly bio-based products

**Circular design:** The CEAP aims to make sustainable products the new standard [9]. The pressing need to reject linear product life cycle patterns and to drastically reduce our waste output can only be achieved by changing our consumer behaviour and by innovating products with circularity at the heart of their design. Specifically, there is a demand for longer-lasting, recyclable products with increased recycled material content. The European Commission has proposed introducing legislation for extended producer responsibility, which would act as a compelling incentive for the bio-based industries to provide solutions to address all phases of the product life-cycle: from the sustainable sourcing of feedstock and climate-neutral production processes up to tackling product end-of-life issues.

While an essential step towards decreasing our dependence on depleting resources, reducing the percentage of non-renewable components in the final material is not enough. It is estimated that "*80% of products' environmental impacts are determined at the design phase"* [9]. Therefore, in order to truly achieve a green transition in Europe, the eco-design of new materials and products must be prioritised, with circularity encoded in their structure. To answer this, the BBI JU funded projects are offering circular bio-based solutions and are reporting (KPI 5) 232 new bio-based materials by 2024. The finalised projects alone reported the realisation of 24 new materials. Of these new materials, 71% are reported to be biodegradable and 42% recyclable [14]. The same survey confirmed that the SIRA target for new bio-based building blocks (5 new building blocks by 2024) has been substantially exceeded by the finished projects alone, who delivered 22 new building blocks.

What is more, the BBI JU initiative is delivering building blocks and materials that demonstrate comparable or superior performance compared to their fossil-based counterparts. In the spirit of circularity, materials are being targeted to increase the lifetime of the final product. For example, the ECOXY project developed fibre reinforced thermoset composites which are repairable and reshapable in addition to being recyclable (3R) [30]. In the search for durable materials, the BARBARA project developed prototypes for the automotive and construction industries with advanced thermomechanical properties by incorporating extracted biopolymers into bioplastic matrices [31]. Similarly, the SSUCHY project targets lightweight plant fibre composites with improved structural properties for the transportation industry [32-34].

**Bio-based plastics and packaging solutions:** The ever increasing consumption of single-use-plastics is a major global concern. Europe alone generates 25.8 million tonnes of plastic waste every year, a significant portion of which goes to landfill or is incinerated (31% and 39% respectively) [35]. While

reducing the amount of packaging generated in the first place should be prioritised, there is still the need to provide safe food packaging solutions to increase the shelf-life of products, ensuring food safety and preventing food waste.

Packaging constitutes one of the main (most numerous and promising) applications delivered by BBI JU projects with 35 BBI JU projects addressing packaging solutions (Figure 3a), by contributing new bio-based plastics, composites and films, lacquers and coatings, as well as bio-based adhesives to bond materials for multi-layer packaging applications. Many promising 100% bio-based materials, such as recyclable polyhydroxyalkanoates (PHA), polyethylene furanoate (PEF) and polylactic acid (PLA), are being developed from novel feedstock sources such as agri-food industrial side streams in BBI JU projects.

PEF is gaining momentum as a promising alternative to ubiquitous polyethylene terephthalate (PET). In fact, the polymer displays superior gas barrier properties, which would increase food and drink product shelf-life [36]. For example, the PEFerence BBI JU Flagship biorefinery aims to deploy world leading technology in the scale-up of the crucial building block, FDCA (furan dicarboxylic acid), to 5,000 tonnes/year using wheat and corn derived fructose as feedstock [37]. Currently, PEF can be mixed with PET (up to 2% of composition) and mechanically recycled using existing technologies [38]. Other projects, such as BIOBARR [39] and Refucoat [40] are preparing functionalised PHA materials for packaging with antimicrobial and antioxidant activity or improved mechanical and barrier properties. While these materials are promising, they have not yet reached the critical mass necessary to have dedicated recycling facilities. There are still obstacles to overcome to render these alternatives cost competitive and to generate increased market acceptance. Alternatives to plastic packaging are also being investigated in, for example, the Celluwiz project [41], where all-cellulose packaging materials are being developed. An advantage of this solution is that it can be integrated directly into existing waste value chains (recycled along with paper and cardboard waste), therefore decreasing the amount of packaging destined for landfill or incineration.

**Tackling end-of-life of plastic mixtures and composites:** Products containing a mixture of materials, such as composites and plastic mixtures are an even greater challenge to recycle due to their inherent complexity. Composites are ubiquitous in the transport and construction industries. Depending on their intended application, the formulation can vary drastically and the composite may be combined with other materials during manufacturing making it even more difficult to sort the components for recycling [42]. Several BBI JU projects are addressing the end-of-life issues associated with these materials. For example, the BIZENTE [43] and ENZYCLE [44] projects will explore the application of enzymatic degradation technologies to recover useful building blocks from the treatment of thermoset composites and traditionally non-recyclable multi-layered plastics respectively. In comparison with mechanical recycling processes, this technology is still in its infancy [45], but it offers potential to return high quality chemicals from materials that would otherwise go to landfill or incineration due to the absence of current recycling strategies.

### 3.2. BBI JU contribution towards healthy and sustainable food systems

**Sustainable pest control and nutrient management:** In modern agriculture, the use of pesticides and fertilisers guarantee an increased yield, reliable quality and competitive price, benefiting both farmer and consumer. On the other hand, the improper use of chemical pesticides and fertilisers in agriculture contributes to soil, water and atmospheric pollution as well as to loss of biodiversity [46]. In this context, the BBI JU programme is enabling the innovation and scale-up of bio-based fertilisers

and pesticides with a better environmental profile which will help farmers to transition to sustainable farming practices.

Biopesticides – based on micro-organisms or natural products – are a promising alternative to traditional chemical pesticides as they typically target the pest species with high specificity, rendering them more environmentally benign [47]. Several BBI JU projects are addressing the major obstacles to the wider deployment of biopesticides in agriculture: cost-efficiency and matching the effectiveness of chemical pesticides. For example, pheromones applied as mating disruptors effectively target specific insect species, but presently the cost is prohibitive. The BBI JU funded PHERA [48] project is currently addressing this issue by developing fermentation methods enabling the production of pheromones at an affordable price for the application on large-scale row crops. Similarly, BIOVEXO [49] and BIOBESTicide [50] are developing biopesticides to address the devastating effects of bacterial and fungal pathogens on European olive trees and vineyards, respectively. The latter is developing an oomycete-based biopesticide, the *Pythium oligandrum* strain I-5180, which can colonise vine roots and stimulate the plants natural defences system against Grapevine Trunk Diseases.

Currently, agriculture depends heavily on the use of non-renewable, resource-intense fertilisers to meet the ever rising demand for food and feed. On top of that, the agricultural sector has to deal with a huge loss of nutrients from conventional fertilisers since a major part of the nutrients applied as fertilisers are not available in the right amounts and at the right time to optimise plant growth. As a result, the nutrients get bound in the soil or are leached out into the ground water [51].

One way to improve the sustainability of agricultural management that benefits both nature and the farmers' economy is to develop tailor-made fertilisers based on the reuse of bio-waste. For example, to replace non-renewable, non-domestic and energy intensive raw materials for the production of fertilisers, the B–FERST [52] consortium is aiming to valorise by-product streams from wastewater treatment plants, the agri-food sector and the organic fraction of municipal solid waste (OFMSW). From these by-product streams bio-based solid fertilisers will be developed which include renewable sources of macronutrients (N,P,K) and non-microbial plant biostimulants. Phosphorus, a major fertiliser component is mined and has been identified as a critical resource with 90% being imported into the EU. To replace conventional fertiliser, the SUSFERT [53] project focuses to valorise industrial waste and by-products to sustainable multifunctional bio-based fertilisers to supply phosphorus and iron. The targeted products will allow a controlled release of the nutrients owing to the fertilisers encapsulation in bio-based and biodegradable coatings and increased availability of the nutrients due to the addition of probiotics. In line with the objectives of the F2F and Biodiversity Strategies, these combined effects are expected to contribute to improved nutrient management and decreased soil and water pollution resulting from the overuse of fertilisers.

**Nutrition from waste and sustainable sources:**

The recent EU's demand for plant proteins amounted to about 27 million tonnes of crude protein [54], with 93% by volume consumed by the feed market. To cover protein demand, 17 million tonnes of crude plant protein must be imported (including 13 million tonnes of soya based protein) [55]. Concerns over the economic and environmental consequences of this dependency has prompted the EC to foster the increased supply of EU-grown plant proteins as well as alternative feed materials such as insects, marine feed stocks and by-products from the bio-economy.

BBI JU funded projects are contributing to the above mentioned strategy by using low cost and underexploited biomass that does not compete with traditional food crops for space and resources.

For example, the recently finalised project, GreenProtein [56], demonstrated the extraction of RuBisCo protein, an alternative to egg whites, from sugar beet leaves. A recently published LCA revealed that the extract has a better environmental profile than egg protein concentrate. The project has prompted the innovation of specialised machinery to efficiently collect the leaves, which will facilitate the replication of the business model by other sugar beet producers.

Other examples of innovative sustainable business models with a high potential for replication are the FARMŸNG [57] and ALEHOOP [58] and SYLFEED [59] projects, which exploit insect, microalgal and wood biomass, respectively. The FARMŸNG flagship will demonstrate at industry-scale the efficient conversion of vegetal by-products into mealworm (*Tenebrio molitor*) biomass and the subsequent transformation of those mealworms into sustainable proteins and lipids for fish feed and pet food end markets. The proteins have a better environmental performance compared to animal derived proteins due to the decreased GHG and ammonia emissions and more effient land and water use associated with their production.

## 4. Conclusions

As this article has shown, the BBI JU is accelerating the transition towards a more resililient and sustainable Europe through long term investment into R&I in the bio-based sector. This support has enabled the innovation and scale-up of state-of-the-art technologies which have unlocked the potential of traditionally undervalorised residues and waste streams – from agro-food industry side streams, but also from OFMSW – facilitating the EU transition to a zero waste and circular society. Furthermore, the up-scaled technologies have a lower environmental impact as demonstrated by the $CO_2$ savings of the flagship projects, signalling the potential of the bio-based industries to decarbonise the industrial sector.

The BBI JU has promoted the development and scale up of a new generation of bio-based platform chemicals and materials that are becoming increasingly competitive with fossil-based counterparts in terms of price and performance. The clear added-value of these molecules is their improved environmental profile. The BBI JU projects have delivered significantly more new building blocks (22 realised and a further 106 expected) and materials (24 realised and 208 expected) than anticipated, prompting even more ambitious targets to be set in the future.

A significant portion of the BBI JU portfolio of projects are solving challenges related to the upscaling and performance (technical and environmental) of bio-based plastics and composites for packaging applications. While breakthrough materials such as PEF inherently possess excellent barrier properties, many bio-based polymers need to be complemented with films or coatings. BBI JU projects are developing biodegradable bio-based solutions to address this innovation gap and to enable the replacement of fossil-based packaging by biodegradable and/or recyclable packaging with up to 100% bio-based content. The improved end-of-life performance of these new products is set to enable a truly circular economy.

Another important category of BBI JU projects are those promoting sustainable food systems: bringing alternative proteins derived from novel sources closer to the market and addressing nutrient and pesticide pollution with the innovation of new, tailored bio-based products.

Looking forward, BBI JU and the future partnership Circular Bio-based Europe Joint Undertaking (CBE JU) proposed by EC under Horizon Europe [11] will continue to contribute to achieve the goals of the

EGD and to demonstrate that economic profit and environmental protection can go hand to hand. Sustainability and the enhancement of biodiversity will be central features of the new partnership. CBE JU is also expected to engage further with industry and policy stakeholders to contribute to a more coherent, supportive and stable regulatory framework, to raise awareness about the potential of bio-based industries and facilitate its uptake in Europe. Furthermore, the CBE JU will continue to improve the integration of and benefits to primary producers in new bio-based chains, helping to revive rural, coastal and peripheral regions.

## Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Acknowledgements:**

The authors are grateful for the contributions of colleagues in the BBI JU programme office, to our partners BIC and EC, in particular the Directorate General for Research and Innovation, Internal Market, Industry, Entrepreneurship and SMEs and Agriculture and Rural Development. We are also grateful for the constructive collaboration with BBI JU advisory bodies, the States Representatives Group and the Scientific Committee, as well as for their guidance and support.

**References:**

[1] European Commission, 2019. Communication on the European Green Deal. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588580774040&uri=CELEX%3A52019DC0640 (accessed 3 March 2021)

[2] European Commission, 2020. The EU budget powering the recovery plan for Europe. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2020:442:FIN (accessed 1 March 2021)

[3] Bio-based Industries Joint Undertaking, 2021. https://www.bbi.europa.eu/ (accessed 1 March 2021)

[4] European Commission, 2018. A sustainable bioeconomy for Europe. https://op.europa.eu/en/publication-detail/-/publication/edace3e3-e189-11e8-b690-01aa75ed71a1 (accessed 24 February 2021)

[5] Ruiz Sierra, A., Zika, E., Lange, L., Llorente Ruiz de Azúaa, P., Canalis, A., Mallorquín Estebana, P. Paiano, P., Mengal, P., 2021. The bio-based industries joint undertaking: A high impact initiative that is transforming the bio-based industries in Europe. N. Biotechnol., 60, 105–112. https://doi.org/10.1016/j.nbt.2020.09.003

[6] Mengal, P., Wubbolts, M., Zika, E., Ruiz, A., Brigitta, D., Pieniadz, A., Blacke, S., 2018. Bio-based Industries Joint Undertaking: The catalyst for sustainable bio-based economic growth in Europe. N. Biotechnol., 40, 31–39. https://doi.org/10.1016/j.nbt.2017.06.002.

[7] Lange, L., Connor, K.O., Arason, S., Bundgaard-Jørgensen , U., Canalis, A., Carrez, D., Gallagher, J., Gøtke, N., Huyghe, C., Jarry, B., Llorente, P., Marinova, M., Martins, L.O., Mengal, P., Paiano, P., Panoutsou, C., Rodrigues, L., Stengel, D., van der Meer, Y., Vieira, H., 2021. Developing a Sustainable and Circular Bio-Based Economy in EU: By Partnering Across Sectors, Upscaling and Using New

Knowledge Faster, and For the Benefit of Climate, Environment & Biodiversity, and People & Business. Front. Bioeng. Biotechnol., 8, 1456. https://doi.org/10.3389/fbioe.2020.619066

[8] BBI JU, 2020. A High Impact Initiative for Green Recovery of Europe. https://www.bbi.europa.eu/media/bbi-ju-high-impact-initiative-green-recovery-europe (accessed 24 February 2021)

[9] European Commission, 2020. A new Circular Economy Action Plan for a cleaner and more competitive Europe. 2020. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2020:98:FIN (accessed 24 February 2021)

[10] European Commission, 2020. A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0381 (accessed 25 February 2021)

[11] European Commission, 2021. Proposal for a Council Regulation establishing the Joint Undertakings under Horizon Europe. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:87:FIN (accessed 1 March 2021)

[12] Bio-based Industries Consortium, 2017. SIRA: strategic innovation & research agenda. https://biconsortium.eu/sites/biconsortium.eu/files/downloads/SIRA-2017-Web.pdf (accessed 1 March 2021)

[13] Bio-based Industries Joint Undertaking, 2019. BBI JU 2014-2019: achievements of a high-impact initiative for the bioeconomy in Europe. https://www.bbi-europe.eu/sites/default/files/media/bbi-ju-high-impact-initiative.pdf (accessed 2 March 2021)

[14] BBI JU, 2021. Annual Activity Report 2020. document in preparation.

[15] BBI JU (TECH4EFFECT), 2021. https://www.bbi.europa.eu/projects/tech4effect (accessed 10 March 2021)

[16] BBI JU (EFFORTE), 2021. https://www.bbi.europa.eu/projects/efforte (accessed 10 March 2021)

[17] BBI JU (EMBRACED), 2021. https://www.bbi.europa.eu/projects/embraced (accessed 10 March 2021)

[18] Keegan, D., Kretschmer, B., Elbersen, B., Panoutsou, C., 2013. Cascading use: a systematic approach to biomass beyond the energy sector. Biofuels, Bioprod. Bioref., 7, 193-206. https://doi.org/10.1002/bbb.1351

[19] BBI JU (AFTER-BIOCHEM), 2021. https://www.bbi.europa.eu/projects/afterbiochem (accessed 10 March 2021)

[20] OECD, 2011. Industrial Biotechnology and Climate Change: Opportunities and Challenges. http://www.oecd.org/sti/emerging-tech/reportonindustrialbiotechnologyandclimatechangeopportunitiesandchallenges.htm (accesses 1 March 2021)

[21] BBI JU, 2020. Amended Annual Work Plan & Budget 2020. https://www.bbi.europa.eu/sites/default/files/media/Annex_BBI_GB%20_10_20_second_amended_%20AWP%20and%20budget%202020.pdf (accessed 07 June 2021)

[22] AFTER-BIOCHEM, 2021. https://after-biochem.eu/reduced-carbon-footprint/

[23] CORDIS (EU Publications Office), 2020. Public Summary of LCA analysis. https://cordis.europa.eu/project/id/669029/results

[24] Wenda, S., Illner, S., Mella, A., Kragl, U., 2011. Industrial biotechnology—the future of green chemistry? Green Chem., 13, 3007-3047. https://doi.org/10.1039/C1GC15579B

[25] BBI JU (DEEP PURPLE), 2021. https://www.bbi.europa.eu/projects/deep-purple (accessed 10 March 2021)

[26] BBI JU (SMARTBOX), 2021. https://www.bbi.europa.eu/projects/smartbox (accessed 10 March 2021)

[27] Anastas, P.T., Warner, J.C., 1998. Green Chemistry: Theory and Practice. Oxford University Press, New York, pp.30.

[28] BBI JU (ReSolute), 2021. https://www.bbi.europa.eu/projects/resolute (accessed 07 June 2021)

[29] BBI JU (AgriMax), 2021. https://www.bbi.europa.eu/projects/agrimax (accessed 07 June 2021)

[30] BBI JU (ECOXY), 2021. https://www.bbi.europa.eu/projects/ecoxy (accessed 10 March 2021)

[31] BBI JU (BARBARA), 2021. https://www.bbi.europa.eu/projects/barbara (accessed 10 March 2021)

[32] BBI JU (SSUCHY), 2021. https://www.bbi.europa.eu/projects/ssuchy (accessed 10 March 2021)

[33] Panzera, T.H., Jeannin, T., Gabrion, X., Placet, V., Remillat, C., Farrow, I., Scarpa, F., 2020. Static, fatigue and impact behaviour of an autoclaved flax fibre reinforced composite for aerospace engineering. Compos. B. Eng., 197, 108049. https://doi.org/10.1016/j.compositesb.2020.108049

[34] Grégoire, M., Barthod-Malata, B., Labonne, L., Evon, P., De Luycker, E., Ouagne, P., 2020. Investigation of the potential of hemp fibre straws harvested using a combine machine for the production of technical load-bearing textiles. Ind. Crops Prod., 145, 111988. https://doi.org/10.1016/j.indcrop.2019.111988

[35] European Commission, 2018. A European strategy for plastics in a circular economy. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1516265440535&uri=COM:2018:28:FIN (accessed 2 March 2021)

[36] Rosenboom, J.-G., Hohl, D.K., Fleckenstein, P., Storti, G., Morbidelli, M., 2018. Bottle-grade polyethylene furanoate from ring-opening polymerisation of cyclic oligomers. Nature Communications, 9, 2701.

[37] BBI JU (PEFerence), 2021. https://www.bbi.europa.eu/projects/peference (accessed March 10 2021)

[38] Niaounakis, M., 2019. Recycling of biopolymers – The patent perspective. Eur. Polym. J., 114, 464-475. https://doi.org/10.1016/j.eurpolymj.2019.02.027

[39] BBI JU (BioBarr), 2021. https://www.bbi.europa.eu/projects/biobarr (accessed March 10 2021)

[40] BBI JU (RefuCoat), 2021. https://www.bbi.europa.eu/projects/refucoat (accessed March 10 2021)

[41] BBI JU (CelluWiz), 2021. https://www.bbi.europa.eu/projects/celluwiz (accessed March 10 2021)

[42] Niaounakis, M., 2019. Recycling of biopolymers – The patent perspective. Eur. Polym. J., 114, 464-475. https://doi.org/10.1016/j.eurpolymj.2019.02.027

[43] BBI JU (BIZENTE), 2021. https://www.bbi.europa.eu/projects/bizente (accessed March 10 2021)

[44]BBI JU (ENZYCLE), 2021. https://www.bbi.europa.eu/projects/enzycle (accessed March 10 2021)

[45] Pickering, S.J., 2006. Recycling technologies for thermoset composite materials—current status. Compos. Part A Appl. Sci. Manuf., 37, 1206-1215. https://doi.org/10.1016/j.compositesa.2005.05.030

[46] European Commission, 2020. Combined Evaluation Roadmap/Inception Impact Assessment: Revision of the sustainable use of pesticides Directive. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12413-Sustainable-use-of-pesticides-revision-of-the-EU-rules (accessed 2 March 2021)

[47] EPA, 2016. What are Biopesticides? https://www.epa.gov/ingredients-used-pesticide-products/what-are-biopesticides#classes (accessed 2 March 2021)

[48] BBI JU (PHERA), 2021. https://www.bbi.europa.eu/projects/phera (accessed March 10 2021)

[49] BBI JU (BIOVEXO), 2021. https://www.bbi.europa.eu/projects/biovexo (accessed 07 June 2021)

[50] BBI JU (BIOBESTicide), 2021. https://www.bbi.europa.eu/projects/biobesticide (accessed March 10 2021)

[51] Agostini, F., Tei, F., Silgram, M., Farneselli, M., Benincasa, P., Aller, M.F., 2010. Decreasing Nitrate Leaching in Vegetable Crops with Better N Management. In: Lichtfouse, E. (Ed.), Genetic Engineering, Biofertilisation, Soil Quality and Organic Farming. Sustainable Agriculture Reviews, vol 4., Springer, Dordrecht, pp. 147-200. https://doi.org/10.1007/978-90-481-8741-6_6

[52] BBI JU (B-Ferst), 2021. https://www.bbi.europa.eu/projects/b-ferst (accessed 10 March 2021)

[53] BBI JU (SUSFERT), 2021. https://www.bbi.europa.eu/projects/susfert (accessed 10 March 2021)

[54] European Commission, 2018. Report from the Commission to the Council and the European Parliament on the development of plant proteins in the European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0757 (accessed 11 March 2021)

[55] European External Action Service, 2018. Follow-up to the EU-U.S. Joint Statement of 25 July: Imports of U.S. soybeans increase by over 280%. https://eeas.europa.eu/delegations/united-states-america/49023/follow-eu-us-joint-statement-25-july-imports-us-soybeans-increase-over-280_en (accessed 3 March 2021)

[56] BBI JU (GreenProtein), 2021. https://www.bbi.europa.eu/projects/greenprotein (accessed 07 June 2021)

[57] BBI JU (FARMŸNG), 2021. https://www.bbi.europa.eu/projects/farmyng (accessed 10 March 2021)

[58] BBI JU (ALEHOOP), 2021. https://www.bbi.europa.eu/projects/alehoop (accessed 3 March 2021)

[59] BBI JU (SYLFEED), 2021. https://www.bbi.europa.eu/projects/sylfeed (accessed 11 March 2021)