General information	
PPP-number	**AF-15233**
Title	**PEFPACK – Duurzame verpakkigsmaterialen op basis van agrozijstromen** *(Sustainable packaging materials based on agricultural side streams)*
Theme	**Circular**
Implementing institute	**Wageningen Food & Biobased Research**
Project leader research (name + e-mail address)	**Maarten van der Zee (maarten.vanderzee@wur.nl)**
Coordinator (on behalf of private partners)	**Stephan Roest (stephan.roest@corbion.com)**
Project-website address	www.wur.nl/en/Research-Results/kennisonline/PEFPACK
Start date	**01-04-2016**
Final date	**30-05-2019**

Approval by the coordinator of the consortium The final report must be discussed with the coordinator of the consortium. The "TKI's" appreciate additional comments concerning the final report.	
Assessment of the report by the coordinator on behalf of the consortium:	☐ Approved (Rapportage nog niet goedgekeurd) ☐ Not approved
Additional comments concerning the final report:	

Consortium	
Mention any changes in the composition of the project partners:	The project initially started with Corbion and Wageningen Food and Biobased Research (WFBR) as research partners with the intention to include an industrial users group. In the course of the project, two additional industrial partners joined the consortium; juices and beverages producer Refresco in January 2017 and plastic bottle producer Plastipak in October 2017. This completed the consortium with renown parties across the value chain, from feedstock production, to packaging manufacturing, to application of beverage bottles.

Summary of the project	
Problem definition	In the PEFPACK project, Corbion, Plastipak, Refresco and WFBR joined efforts in developing new and sustainable food and beverage packaging based on the biobased plastic PEF and PEF co-polymers. Traditionally, the use of plastics is organised in a linear way. The ambition for the new plastic economy, as for example advocated by the Ellen MacArthur Foundation, is a transition from a linear to a circular economy, for which the EMF identified 3 focus point: 1) create an effective after use economy, 2) avoid leakage into the environment, and 3) decouple plastics from fossil feedstocks. PEFPACK addressed in particular the decoupling of plastics production from fossil feedstocks without forgetting about the other focus points.
Project goals	In the PEFPACK project, Corbion, Refresco, Plastipak and WFBR worked together across the packaging value chain in the research and

	development of PEF, a polymer based on furan dicarboxylic acid (FDCA) obtained by fermentation technology from biomass. Key elements of the project were the production routes of FDCA-based polymers (Corbion and WFBR), and its subsequent conversion in to packaging films (WFBR) and bottles (WFBR and Plastipak) and assessment of these bottles for use for juice and other beverages (Refresco). Unique aspects of the project include the investigation of the effect of co-monomers on improving the properties of PEF (WFBR), as well as exploring the recyclability of the material (Plastipak).

Results	
Planned results in the original project plan	• Production of biobased FDCA on kg-scale • Production of FDCA-based polymers on kg-scale • Insight in mechanical, thermal and barrier properties of developed FDCA-based materials • Insight in the relation between FDCA-based polymer chemistry and their processability into (packaging) products • Demonstration products (injection stretch blow moulded bottles and biaxially stretched films) from FDCA-based materials • Insight in recyclability of FDCA-based polymers • Patent applications when applicable • Dissemination of project results in peer-reviewed journals
Achieved results	• Approx. 50 kg of purified, polymer grade FDCA was produced through microbial oxidation of HMF. This FDCA was used to produce various R&D-, reactor-, and Solid-State Post Condensation (SSPC)grades of PEF. It was characterized with regard to important properties, such as molar mass, intrinsic viscosity, DEG contents, thermal properties, rheological properties, crystallisation behaviour, etc. • A series of PEF polymerization trials was performed to modify the FDCA based polymer (comonomer type and levels) on 30 gram-scale. These were characterized with regard to incorporation ratio, molar mass, DEG content and thermal properties. • A series of reactive extrusion trials was performed to modify the FDCA based polymer. Initially on a 20 gram lab-scale. The most promising compounds were subsequently produced on kilogram-scale, sufficient amounts for sheet extrusion • Sheet-extrusion trials performed with SSPC grade PEF, including optimization of processing procedures, resulting in PEF film samples for 2D biaxial stretching trials to modify/vary the mechanical and barrier properties of the material. • 2D stretching trials were performed on PEF film samples, providing essential information on stretching behaviour, such as the natural stretch ratio (NSR) in relation to various process and material parameters, required for optimization processing conditions for packaging film and bottle production. • A method was developed for analysing stretching behaviour on gram-scale, based on the EVF module in an Ares Rheometer. These results were validated and translated to Biaxial stretching trials, and used to evaluate stretching behaviour of systematically synthesised small scale samples. • ISBM (Injection Stretch Blow Moulding) trials were performed on newly developed materials to produce 1 liter test bottles. There were two successful trials at ~10 kg scale. The test bottles performed well with regard to mechanical properties, and in maintaining the quality of fruit juices (reduction of browning and vitamin C losses).

Explanation of changes relative to the project plan	• Patent applications were explored but deemed not feasible or strategically interesting from a business point of view. • Scientific publication is in preparation, but was not yet published at the end of the project.

What was the added value created by the project for:	
Participating "Knowledge Institutes" (scientific, new technologies, collaboration)	• Increased insight in the relation between FDCA purity, FDCA-based polymer chemistry and their processability into (packaging) products • Increased insight in mechanical, thermal and barrier properties of developed FDCA-based materials • Increased experience with condensation polymerisation of polyesters on kg-scale and corresponding SSPC-processes • Increased insight in recyclability of FDCA-based polymers • Collaborations with leading industrial parties across the value chain, from feedstock production, to packaging manufacturing, to application of beverage bottles. • Additional access to external facilities such as biaxial stretching (Uni Lille, FR)
Participating private partners (practical application of the results, within which period of time?)	Corbion: Increased knowledge of Corbion's propriety route to biobased FDCA and FDCA-based polymers, their properties and processability into packaging products. Plastipak: Increased knowledge on ISBM of FDCA-based polymers into bottles, and the properties of the bottles obtained. Increased knowledge on the recyclability of FDCA-based polymers. Practical application in the next year Refresco: Increased knowledge on the possibilities regarding FDCA-based bottles and their properties in relation to their application in Refresco's product portfolio such as influence on shelf life.
Society (social, environment, economy)	PEF is a bio-based alternative polymer to PET which is commonly used in packaging applications. PEF can be made from the bi-products of agricultural streams and therefore contributes to the efficient use of renewable resources. As it is a bio-based material, PEF leads to a reduction in CO2 emissions when replacing PET (which is based on fossil-based TPA (terephthalic acid). Additionally, PEF shows to have properties that will lead to better packaging functionality in terms of both manufacture and performance. Benefits include lower energy consumption in production, improved barrier properties for increased shelf-life of packaged food, as well as lighter-weight packaging needed to deliver equivalent performance. As a direct replacement for PET, there would be no impact on conversion and logistical chains.
Possibly other stakeholders (spin-offs)	The PEFPACK project shows that biobased plastics can be made and processed into end products that even outperform the currently used products on not only environmental impact but also technical properties. This know-how can be used by other parties interested in alternatives for fossil based plastics.

Follow-up	
Did the PPP result in one or more patents (first filings)?	Up to this moment of time it was decided not to file any patents.
Are there any follow-up projects planned? If yes, explain. (Contract research resulting from this project, additional funding, or new PPP projects)	Momentarily not in the same consortium composition. Corbion and Plastipak are pursuing their activities regarding development of FDCA-based polymers and bottles.

Deliverables/products during the entire course of the PPP (provide the titles and/or a brief description of the products/deliverables or a link to a website.

Scientific articles:

- Manuscript in preparation on the effect of polymer chemistry and morphology of FDCA-based polymers on their stretching behaviour in relation to polymer processing into biaxially oriented (packaging) products.

External reports:

- N/A

Articles in professional journals/magazines:

- Suikers en hout, het nieuwe zwarte goud. Article in Chemie Magazine, Jul/Aug 2017, 18-21
- Building a better plastic bottle. Article in Chemical and Engineering News, 95(43), 2017, 17-19

(Poster) presentations at workshops, seminars or symposia.

- Stephan Roest (2017). Corbion's proprietary route to FDCA from renewable resources. Presentation at the 12th European Bioplastics Conference, Berlin, 30 November 2017.
- Maarten van der Zee (2019). Presentation at the TKI Agri&Food mirror group meeting of Theme Circular on November 7, 2019.

TV/ radio / social media / newspaper:

- Opschaling van bioplastics: essentiële stap richting de circulaire economie. Article in Duurzaambedrijfsleven.nl 15-04-2019

Remaining deliverables (techniques, devices, methods, etc.):

- Development of in house technique for analysing stretching behaviour polymers on gram-scale, based on the EVF module in an Ares Rheometer.