BIOBASED BUILDING BLOCKS & PRODUCTS

OPPORTUNITIES IN THE BIOBASED ECONOMY

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15 NOVEMBER 2019

CONTENT

INTRODUCTION

In 2015 the United Nations (UN) General Assembly has adopted the 2030 Agenda for Sustainable Development[i]. As an integral part, 17 Sustainable Development Goals (SDGs, figure 1)) were set to prioritize and integrate a number of pressing issues. They address the global challenges humanity faces, like poverty, inequality, climate, environmental degradation, prosperity, and peace and justice[ii].

Figure 1. Sustainable development Goals as agreed upon by the 193 countries of the United Nation in 2015.

For realizing these ambitious goals the transformation to a biobased economy – an economy based on production, transformation and use of bio-based materials and non-food products – is believed to be essential and is therefore at the Centre of sustainable economic strategies of countries worldwide.

The concept of ‘biobased economy’ revolves around a technology transition, especially technologies, which use bio-resources for non- food applications (figure 2). The biobased economy comprises as such all biomass resources for non- food like wood, grass, algae, sugar beets, corn etc. and biowaste streams such as manure, sludge and vegetable wastes. The ultimate goal is to replace all the fossil based energy and products with a renewable version.

[i] https://www.un.org/sustainabledevelopment/development-agenda/
[ii] https://www.un.org/sustainabledevelopment/sustainable-development-goals/

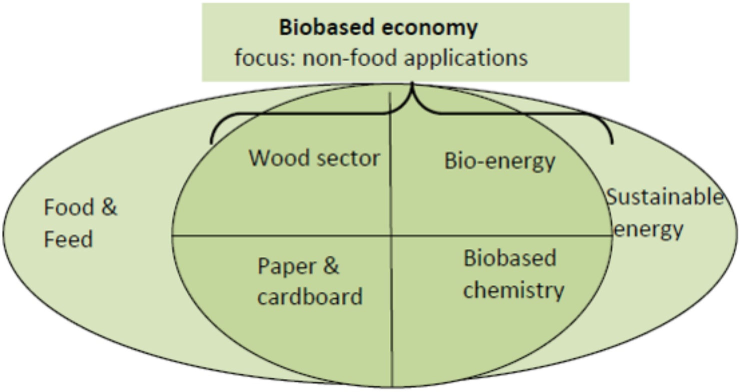

Figure 2. Sectors of the biobased economy[iv]

In the Netherlands the concept of the biobased economy is also seen as an important pillar for green growth and the so called circular economy. The circular economy, where manufacturers design products to be reusable and no waste is produced, is seen as the overall goal to be reached in 2050 in the Netherlands.[iii] The perception is that employment of renewable raw materials leads to new economic opportunities and also a contribution to a sustainable "low carbon economy".[iv]

In order to reach this biobased low (fossil) carbon society three mayor transitions have to be faced today: Energy transition, Protein transition and Material transition. These transitions are all focused on minimize resource depletion and pollution. Solving the global warming problem is regarded as the most important challenge facing humankind in the 21st century. The largest contributor to this effect is CO_2 which is emitted in the air due to massive combustion of fossil fuels for heating purposes, electricity generation and driving cars. The energy transition aims to replace the use of fossil fuels by alternatives like biofuels and use of renewable electricity. The protein transition is focused on changing meat protein consumption by vegetable protein intake. Feeding a prognosed world population of 9 billion people in 2050 with cattle protein is limited by the availability of land for cattle farming and production of the protein the cattle needs. Cattle needs, dependent on the type of animal, 2-5 times more protein intake than itself produces. This also applies to meat replacers made from dairy. For 1 kilo of cheese 7 to 10 liter of cow milk is needed[v].

[iii] https://www.government.nl/topics/circular-economy/from-a-linear-to-a-circular-economy
[iv] Monitoring biobased economy in Nederland 2017, Rijksdienst voor Ondernemend Nederland, www.rvo.nl, 22 februari 2018.
[v] http://www.cheeseboard.co.uk/facts/did_you_know_that-1

Finally for animal welfare, it is also better not to produce and eat meat and dairy, but substitute meat with alternatives like lupin, soy or tofu. Since this transition is strongly dependent on behavioral change of habits this will take generations to be realized.
The material transition is needed because of increasing depletion of resources for materials and pollution due to end-of life problems caused by lack of recycling capabilities. In terms of the material transition 3 groups can be distinguished: metals, mineral material (e.g. glass and concrete) and organic materials like natural fibers (wood, wool, cotton, hemp etc.) and plastics. The first two have challenges especially in energy use during production and in end-of-life applications and/or recycling. The organic material group consists of biobased material direct or indirectly originating from biomass and plastics, almost completely fossil in origin. The plastic materials face the challenge to be transformed into biobased and bio-compatible, i.e. naturally occurring or non-toxic (for example, biodegradable) and better recycling. Success of transformation to a biobased system strongly depends on sustainable use of resources and innovations around bio-based products and processing technologies.[vi] This means that the biobased materials need to have at least the same or even improved qualities in order to replace the existing fossil based materials preferably at lower costs. A challenge not easy to fulfill as we look at for instance to the efforts of Avantium to replace PET for PEF[vii] or the efforts of NPSP to introduce bio composites in the build environment[viii].

To achieve a biobased economy, a transition is needed not only for the production and consumption sector, but also for the government and education. The use of more biomass as a raw material for materials and energy influences the economic system significantly. Due to the lower energy density of renewable sources compared to the fossil resources, especially per surface area, use of renewable sources will lead to a more decentralized economy, leading to potentially significant changes in the regional economy. *The government plays a leading role in this respect: it must encourage innovations and create sufficient scope for incorporating (bio-)circular principles and thus the (re-)use of materials into existing legislation*. The same trend applies to education: new technology and revenue models are entering the sector in the context of the biobased and the circular economy. The new generation must be prepared for this.

Avans Applied University of Applied Sciences stands at the heart of this trend with the Centre of Expertise Biobased Economy (CoEBBE) established in 2013 with the

[vi] https://sustainabledevelopment.un.org/content/documents/982044_Anand_Innovation%20and%20Sustainable%20Development_A%20Bioeconomic%20Perspective.pdf
[vii] https://www.betterworldsolutions.eu/portfolio/avantium-pef-bio-bottle/
[viii] http://www.npsp.nl/textPage4.asp?ID=390

aim of improving and stimulating education and practice-oriented research in this area. In this way, not only the latest existing knowledge is brought into education, but new knowledge is also developed. In the last 10 years the first experiences have been gained with the implementation of biobased knowledge in education and in conducting practice-oriented research. These initial experiences have clearly shown that the transition to a biobased economy is starting to take off, but that it is a road to trial and error:

The shortage of raw materials and the lack of new economic activities requires an economic transition towards a circular economy and a biobased economy. This economy will mainly be based on renewable resources. In the Netherlands there is a lack of innovative entrepreneurship to shape this transition: new forms of entrepreneurship are needed. The gray (chemical) and green (nature and agriculture) sectors are hardly linked: the production of biomass for non-food applications finds insufficient support in society. As a result, opportunities in the field of non-food remain. (KC-Agro, 2015)[ix]

The mission of CoEBBE is to stimulate the transition to a biobased economy via professionalization of education and applied research. It does this mainly via research groups covering the biobased pyramid (figure 3): Biobased Energy (BBE), Biobased Building (BBB), Biobased Marine specialties (BMS) & Biobased Building Blocks & Products (BBB&P).

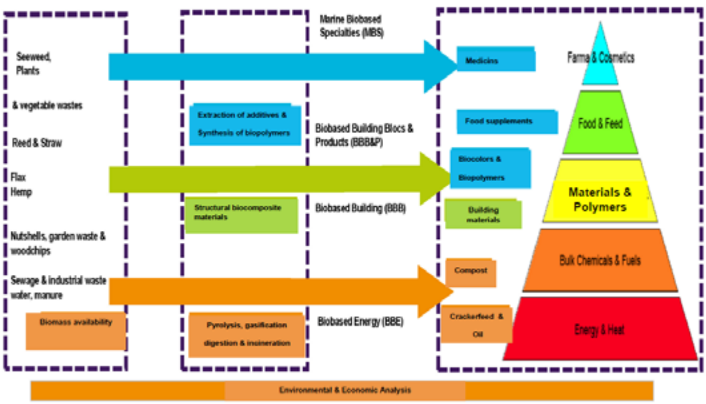

Figure 3. The biobased economy and positioning of research groups CoEBBE

[ix] KC-Agro, 2015. Kennis centrum Agrofood en Ondernemen, CAH Vilentum. http://www.kcagro.nl/Lectoraten/Duurzame-energie-en-groene-grondstoffen.aspx

The latter research group develops knowledge and innovation in the field of green raw materials and makes this knowledge applicable through education.

There is a clear task for the Biobased Building Blocks & Products research group:

- Commitment to expertise, innovation and knowledge transfer about the Biobased Economy;
- Including Biobased Economy knowledge in the Avans training programs. The research group strives, together with those involved, to come up with guidelines and solutions to support the transition to a biobased economy. This is done in two ways:
  - Conduct practical research into and develop knowledge about the biobased economy together with teachers and students;
  - Supporting application centres in the field of biobased building Blocks & Products, by which this knowledge can be transferred to the market.

In line with the intentions from CoEBBE & Avans the research of the BBB&P research group focusses on the following questions:

- How can the use of biobased plastics and biobased additives be encouraged?
- Which innovation practices contribute to the material transition reducing climate change and environmental impact (technology, business cases, pilots)?
- Which innovation practices lead to a more sustainable use of biobased materials (removal of barriers, entrepreneurial risks)?

The knowledge from the research will flow to teachers and students within Avans and beyond through publications, symposia, network meetings, teacher days, lectures and application centres, like the Biopolymer Application Centre (BAC).

1. TRANSITION TOWARDS A BIOBASED ECONOMY

A biobased economy means that in addition to food, biomass is also used to replace fossil carbon-based materials such as plastics, chemicals and fuels. This transition to the massive use of biomass resources questions the amount of available biomass on earth. The question then is how can we achieve this on a sustainable way? Figure 4 shows an overview of the current use of biomass

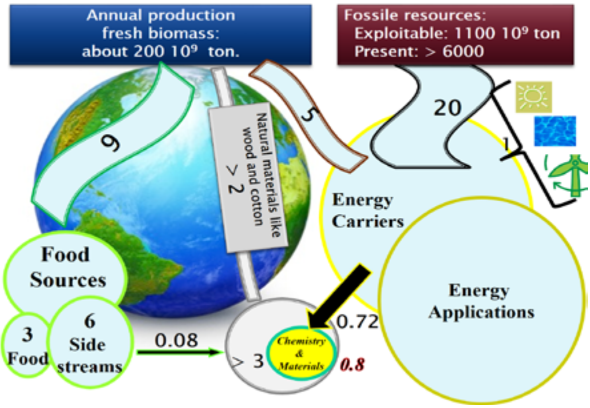

Figure 4. Overview of global biomass production and human use on earth in Gton dry biomass (source: Groene Groei, 2014[3], Houghton_2007[4] and FAOSTAT-Forestry database[x].

It appears that in principle sufficient biomass (around 200 Gton dry matter annually is being produced on land to provide for food (around 9 Gton), energy (25 Gton) and nature even considering a doubling of the world population. The biomass use for supplying all materials and chemicals is relatively low (0.8 Gton) compared to the biomass use for food and energy. In fact, all residual flows from food use (6 Gton) can in principle provide this. It is based on the principle of total crop use via biorefinery principles.

However, this simplified overall mass balance does not account for the fact that the production of supply is non-evenly spread over the world's surface, that only a small part of the biomass is suitable for human consumption and that locally easily depletion and pollution can occur because of changing weather conditions or high density population. This puts a limitation of the sustainable use of biomass.

[x] FAOSTAT-Forestry database, http://www.fao.org/forestry/statistics/80938/en/

This can be illustrated looking at the transition of our energy supply, which is largely based on fossil sources. As shown in Figure 4, the current energy supply uses more than twice as much carbon as needed for our current food supply. It is therefore to be expected that if we want to replace our fossil energy supply completely with a biomass-based energy supply easily competition can occur between biomass demand for food and energy. The policy to replace gasoline with ethanol and diesel with biodiesel has indeed led to higher food prices in countries such as Mexico (Trouw, 2012)[xi] in the recent past. Also the use of wood for energy applications has raised questions about the sustainability of cutting of forests, despite the claim that the wood comes from sustainable forestry[xii]. These sustainability issues and the questioning of it should be avoided. There is a scenario possible to decrease the amount of biomass for energy use by increasing the amount of other renewable resources like sun, wind and water power (figure 5). Of course also these energy sources have some sustainability issues like social acceptance (not in backyard) and especially strong dependency on local weather conditions. Also the mismatch between supply and demand has to be solved in order to completely substitute the existing fossil based energy systems. In principle however, it is quite possible to cover more than half of the future energy supply by sustainable sources such as sun, wind and water.[5]

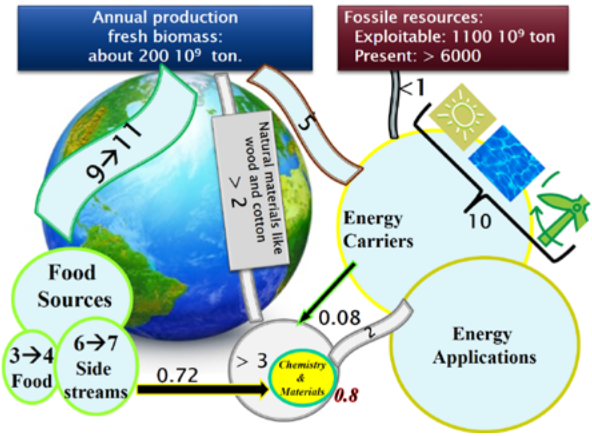

Figure 5. Scenario of a possible future use of global biomass production for a biobased economy. (source: Groene Groei, 2014[3], Houghton_2007[4] and FAOSTAT-Forestry database[x].

[xi] Trouw, 2012. Hoge maisprijs leidt tot honger en instabiliteit http://www.trouw.nl/tr/nl/4332/Groen/article/detail/3330287/2012/10/11/Hoge-maisprijs-leidt-tot-honger-en-instabiliteit.dhtml

[xii] Is wood a green source of energy? Scientists are divided, Warren Cornwall, Jan. 5, 2017 https://www.sciencemag.org/news/2017/01/wood-green-source-energy-scientists-are-divided

This sustainable scenario is possible provided extensive implementation of energy saving measures and alternative energy use e.g. electric driving, heat pumps etc. is carried out. Transition to more sustainable technologies e.g. electric driving, heat pumps, better insulation, circular economy, low temperatures processes, energy neutral greenhouses etc. can lower the present energy consumption with 50% despite growing demand from rising population and development. A respectable part of biomass for energy use remains (5 Gton per year). The challenge is to use this part of the biomass in a sustainable way.

The fact that all organic materials can be provided from agricultural waste streams is reassuring from a resource point of view, but at the same time challenging because some technological barriers have to be taken to achieve this technically and economically. This is the field where the BBB&P research group has its focus: in particular on extracting and converting fresh biomass and biomass residues into chemicals, building blocks for materials and products. This biorefinery concept is defined by the IAE bioenergy as "the sustainable processing of biomass into a spectrum of marketable products and energy". Figure 6 shows the biorefinery concept.

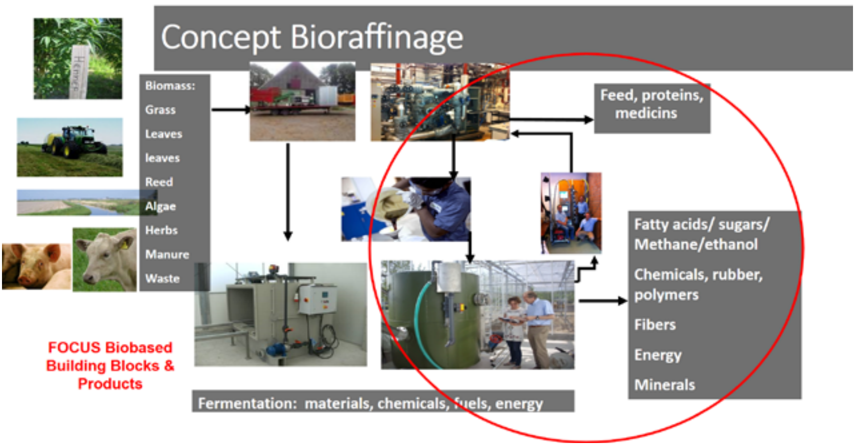

Figure 6. Schematic representation of the concept of biorefining with the focus area of the BBB&P research group.

A Biorefinery involves the disassembly and processing / refining of the compounds / chemicals and minerals present in the biomass into valuable products. This is done in order to achieve maximum value from the available biomass input. Biorefinery focuses on the processing of the biomass molecules via technologies such as separation via extraction and (bio) chemical and thermal treatment. In this way biorefinery contributes to the production of biobased chemicals and materials needed for building up the biobased pyramid. As a result, it builds a bridge between two crucial sectors for the biobased economy: food and non-food.

When developing chemistry for future biorefineries, it is important that the methods and techniques used minimize impact on the environment and that the final products are truly green and sustainable. The use of sustainable feedstock is not enough to ensure a prosperous future for later generations; protection of the environment using greener methodologies is also required[7]. The implementation of green chemistry therefore is a must.

In short, it is not only theoretical, but also practically an attractive and feasible target to aim for a biobased economy. In practice this is of course not easy to achieve. A great deal of effort must be focused on removing existing barriers. This requires practice-oriented research and innovations, including innovative business models based on fundamental research. For this practice-oriented research, in which knowledge is delivered relevant to innovations in practice, the universities of Applied Sciences in the Netherlands are ideally suited (Vereniging Hogescholen, 2015)[xiii].

[xiii] Vereniging Hogescholen, 2015. http://www.vereniginghogescholen.nl/themas/praktijk-en-onderzoek/

2. CHALLENGES BIOBASED BUILDING BLOCKS & PRODUCTS

In cooperation with the business community, fellow research institutes and universities the Biobased Building Blocks & Products (BBB&P) research group conducts research to get an answer to practice-driven research questions. The research is carried out by teachers, researchers and students. The results of the research are used by the project partners to foster the biobased business, science and vocational education. In this way the research feeds learning tracks in the field of the biobased economy. Last but not least knowledge is spread throughout the world via publications, symposia, teacher days, network meetings and existing application Centres.

A major technical challenge in the biobased economy is to use the existing chemical and biological systems to make chemicals and materials from waste streams. A lot of research has been undertaken to convert biomass residue streams to chemicals and materials. Lin et al.[8] shows a review of what can be done with food waste streams as raw material for chemicals and building blocks. As shown in figure 7 practically any chemical or building block can be made out of food waste streams: from antioxidants, additives for coatings to chemical building blocks for plastics.

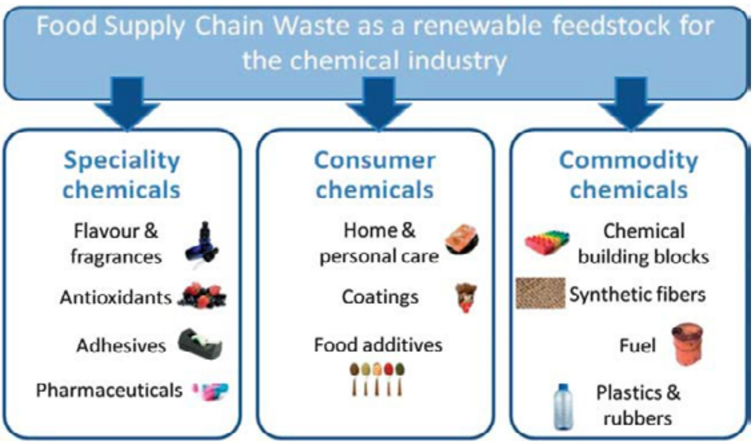

Figure 7. Examples of chemical products made out of food waste streams according to Lin et al.[8]

First of all from the waste streams existing components can be physically or chemically extracted. For instance D-limonene from orange peelings (figure 8)[8] finds use for over 70 years in the manufacture of household and personal cleaning products, partly because of its pleasant aroma. It is also finding uses as an oil-rig cleaning agent, in paints, fragrance additives, cooling fluids, and other specialty products[9].

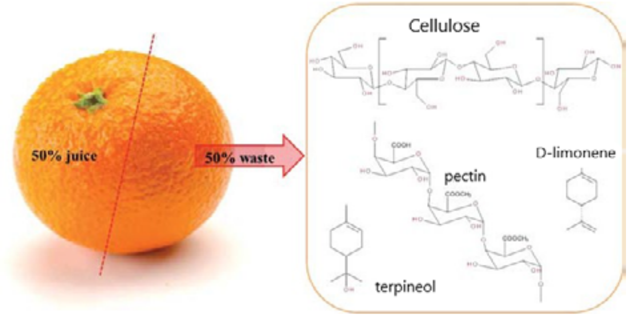

Figure 8. Valorization of orange residues to valuable products[8].

Secondly the building blocks of biomass can be chemically transformed to wanted components. Think of converting cellulose into sugars and sugars into monomers such as lactic acid and polymers such as polylactic acid (PLA) or polyhydroxylalkanoates (PHA). On a lab scale many of these extractions or syntheses have been tried out and investigated showing their technical feasibility. The technical proof of principle is not the bottle neck. The challenge is to scale up these processes and making them economically feasible. For new processes the economic feasibility is especially difficult, because they have to compete with existing processes and mature technology. To overcome this barrier requires a delicate and complicated process of trial and error, timing, marketing, political lobby, adopting rules and regulations, certification and venture capital.

The next paragraphs provide an overview of the challenges in practice-driven research, education and communication that the BBB&P research group focuses on. The research topics can be divided into two main parts:

Biobased Additives and Biobased Polymers

2.1. Biobased additives

This research topic focuses on extracting and using additives for non- food applications arising from the food supply chain waste. 1/3 of all the food in the world is wasted every year[xiv]. This waste could be used as a resource for making chemicals and products. In order to realize that besides technical feasibility especially economic feasibility must be demonstrated. The idea to do that is to induce the necessary market change via aiming at high end markets such as antioxidants for cosmetics and colours, UV stabilizers, plasticizers for material applications.

Examples of biobased additives the research group works on are quercetin from onion peelings, curcumin from curcuma roots, plasticizers from seaweed and bio-carbon from cashewnut shells.

Quercetin

Quercetin is the major flavonoid in our daily diet. It has been the most extensively studied flavonoid that has been shown to exhibit antioxidant, antiviral, antibacterial, anti-inflammatory, and anticarcinogenic properties in lab studies, although there is no evidence that quercetin (via supplements or in food) is useful to treat cancer or any disease[xv]. Since the toxicity of quercetin is low and it exhibits anti-oxidant activity it could be used as an anti-oxidant in skin care products.

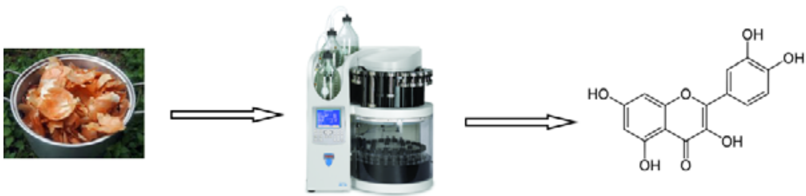

Figure 9. Subcritical water extraction of Quercetin from onion peelings.

[xiv] https://www.wur.nl/en/infographic/Food-waste-towards-half-as-much.htm
[xv] https://lpi.oregonstate.edu/mic/dietary-factors/phytochemicals/flavonoids

Quercetin can be extracted from onion peeling (2-3wt %) via subcritical water and/or supercritical CO_2. Figure 10 shows how the solubility increases as function of the temperature[10].

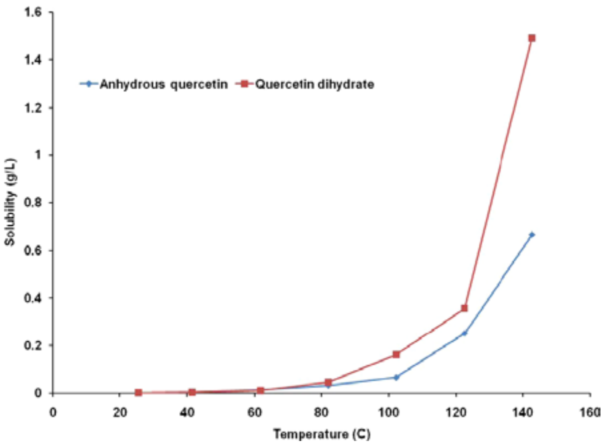

Figure 10. Aqueous solubility of anhydrous quercetin and its dihydrate (g/L) as a function of temperature[10].

Important for the realization of quercetin extraction is the use of the co product, mainly cellulosic fibres. It can be used in paper and cardboard applications, but the amount is too small for this industry to be used. These biomass fibres can be used for other processes such as conversion into sugars or used as a source of nutrients for various agricultures[11]. Dependent on the purity and economy of scale the extraction of quercetin from onion peeling can be made feasible[xvi].

Curcumin

Curcumin is an extract from the curcuma plant and is widely used as anti-oxidant and colouring agent. Less know is that it can be used as UV- stabilizer for clothing as shown by Zhou and Tang[12]. It is possible to modify curcumin in such a way that is can be used as colorant for clothing and at the same time being a UV absorber and highly anti-bacterial, which both are especially interesting for clothing. Our research group is now pursuing the possibility that through chemical modifications of curcumin, a variety of colours with an increased lightfastness can be achieved thus widening its applications.

[xvi] https://issuu.com/avanscoebbe/docs/biobased_update_-_magazine_mei_2018

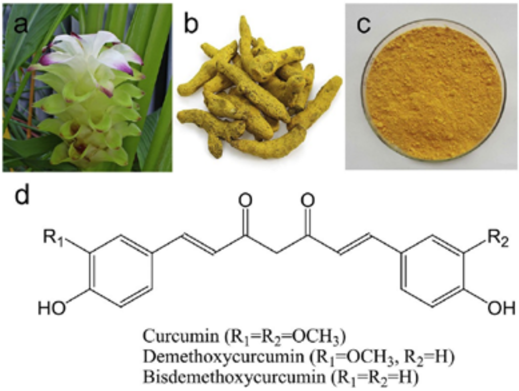

Figure 11. Scheme of Curcuma longa L. (a), the root of Curcuma longa L. (b), curcumin (c), chemical structures of the components present in the root of Curcuma longa L. (d).

Phthalic anhydrides

Modified biobased phthalic anhydrides can be produced via the conversion of sugars from seaweed to furfural and subsequent chemical conversion. Phthalic anhydrides are used as precursor for phthalic esters used as plasticizers in PVC and for the production of polyester and alkyd resins used in paints and lacquers[xvii]. The idea is to modify the phthalic anhydrides to the hexahydro form[xviii], which is expected to give extra improvements for coating applications. Figure 12 shows the value chain for modified phthalic anhydrides.

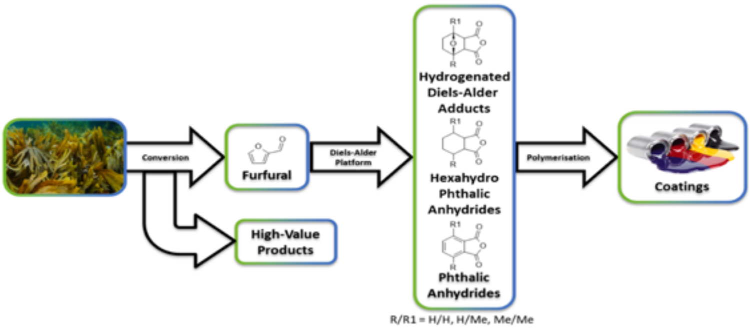

Figure 12. Value chain for seaweed to modified phthalic anhydride for coatings (Biorizon).

[xvii] https://thechemco.com/chemical/phthalic-anhydride/
[xviii] https://pubchem.ncbi.nlm.nih.gov/compound/Hexahydrophthalic-anhydride

Of all chemicals produced by the chemical industry, 40% are aromatic in nature, with a global (annual) size of 122 million tons, corresponding to a value of 115-122 billion euros. The aromatics are used in plastics, paints, additives (e.g. UV stabilizers and pigments), fibres, cosmetics, pharmaceuticals and food ingredients (vitamins, colouring and flavourings), etc. The production of aromatics is currently based on the refining of fossil oil. Finding alternative biobased sources for producing aromatics is becoming interesting, given its present use and size and the growing scarcity of oil.

To realize this impact, the research group BBB&P works together with the Biorizon Shared Research Centre[xix], a cross-border open-innovation initiative with the focus on technology development for the production of renewable bulk aromatics and functionalized biobased aromatics for performance materials, chemicals & coatings. Biorizon's mission is to make commercial production of bio-aromatics possible in 2025. The techno-economic feasibility of the developed technological routes to convert biomass into aromatics is therefore a crucial step.

Biocarbon

Biocarbon is defined as a solid (co-) product from thermochemical conversion processes like biomass pyrolysis and gasification. The common biomass input materials for these thermo-chemical processes are wood residues, bamboo, miscanthus, grass and reed and other agricultural residues like walnut and cashewnut shells. This biocarbon is promising since it is expected to replace many applications of fossil carbon black and or other filler materials for plastic materials. In this way biobased plastics can be made fully biobased while enjoying similar properties as the fossil based ones.

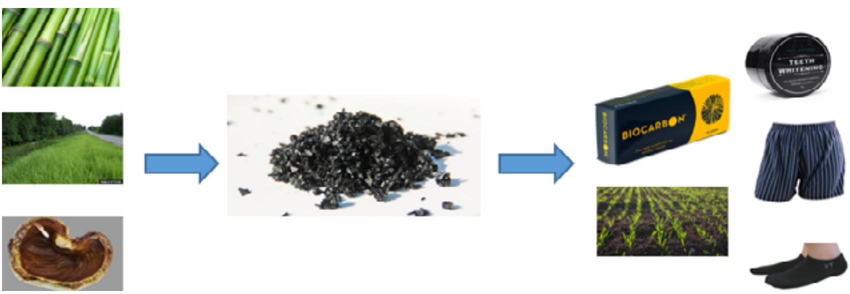

Figure 13. Possible resources and applications of biocarbon.

[xix] https://www.biorizon.eu/

The currently most common biobased polymer is called PLA (poly lactic acid) and this relatively brittle biopolymer is often mixed with additives in order to achieve a similar level of performance when compared to the conventional petroleum-based polymers. Plastics products are made from the polymer mixed with a complex blend of materials known collectively as additives. Commonly used additives are of low-cost mineral origin like talc and $CaCO_3$ which tend to substantially increase the weight of the plastic products. Recent work shows that addition of biocarbon into PLA leads to an enhancement in the rigidity of injection molded samples without compromising the thermal–mechanical properties (figure 14)[13].Ertane et al have reported greater wear resistance for PLA 3D-printed biocomposites containing biocarbon from the stiffness it provides. From these findings, biocarbon addition to biopolymers demonstrates that it can enlarge the applicability of biopolymers like PLA by improving its properties. Additionally, an improved ecological footprint seems to be possible, due biocarbon's low weight and the effect of enhancing the biodegradability.

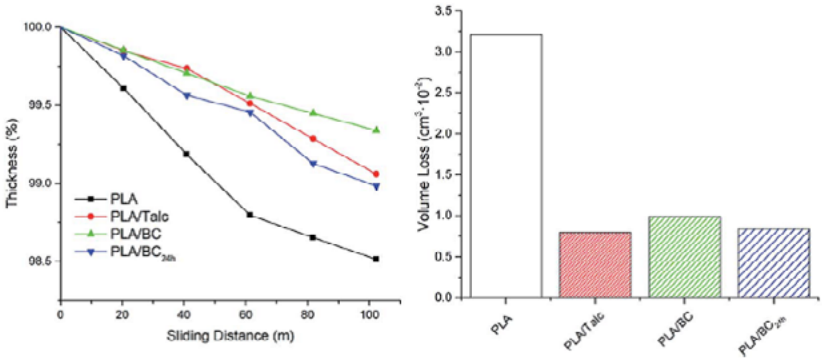

Figure 14. Thickness reduction over sliding distance and total volume loss after abrasive testing of PLA composites[13].

To realize this impact, the research group works together with companies in the knowledge chain and universities to test different product applications like plant pots and mulch films based on PLA and starch.

2.2. Biobased polymers

Most of the present plastic polymeric materials are used in packaging, which has a short lifetime resulting in a high throughput of material in a short time which if not properly dealt with leads to pollution problems (figure 15)[15,xx].

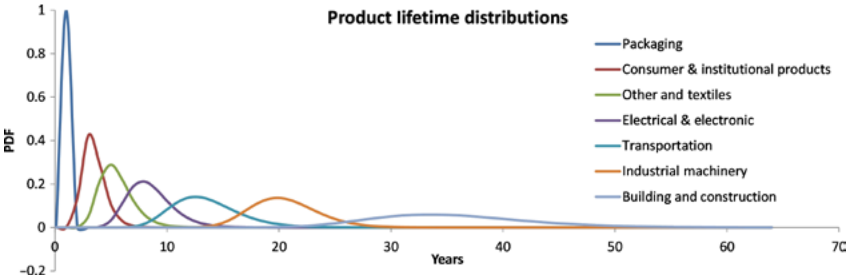

Figure 15 Product life time (PDF) of different polymer applications[15]

The short product lifetime of packaging, typically shorter than 1 year, is causing most of the solid waste issues we are encountering today like the so-called plastic soup in the ocean[xxi]. The products with long lifetimes (> 20 years), mainly durable goods used in building and construction on the contrary diminish pollution by storage of fossil carbon and lower use of resources by recycling after use.

Figure 16 shows the cumulative production of plastic materials since 1950 and its poor waste management. Many attempts have been undertaking to reduce waste and improve the waste management of the plastics. For durable plastic applications this has been implemented, although still improvements are needed. The waste issue focusses on the packaging part and disposables. Already since the early 1990s countries around the world are trying to diminish or phase out the use of plastic bags[xxii]. The EU has recently also started to contribute to diminishing the plastic wastes by setting a ban on disposables[16] in order to reduce the marine plastic litter. Despite the fact that reduction strategies to reduce single-use plastics at source have started more than 20 ago it is still at its infancy given the present (marine) pollution problems[17]. This bad image of plastics however has not prevented the increasing use of plastics making the waste problem more and more urgent.

[xx] https://ourworldindata.org/faq-on-plastics
[xxi] https://www.plasticsoupfoundation.org/en/files/what-is-plastic-soup/
[xxii] https://www.reusethisbag.com/articles/where-are-plastic-bags-banned-around-the-world/

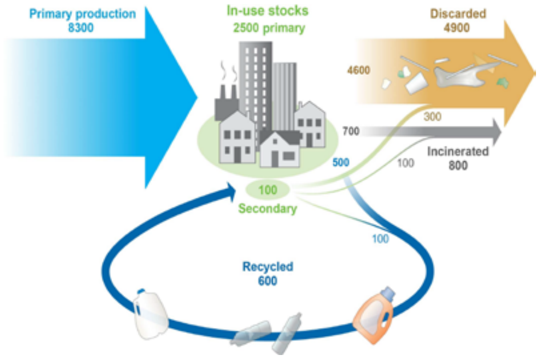

Figure 16. Global production, use, and fate of polymer resins, synthetic fibers, and additives (1950 to 2015; in million metric tons)[15]

One alternative which is coming up is the use of biodegradable plastics, which if discarded will be biological degraded to its building blocks CO_2 and H_2O. These polymers can either be made from fossil oil or from biological sources just as non-degradable polymers also can be made from biological sources. Figure 17 shows an overview of which polymeric material can either be biobased, fossil based and/or biodegradable.

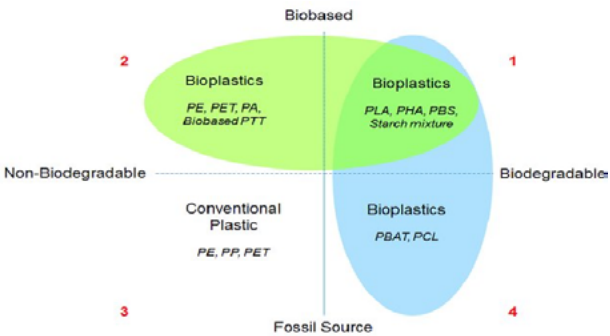

Figure 17. Positioning of (bio)polymeric materials as biobased and/or biodegradable[xxiii].

In principle all plastic materials can be made from biological sources like cellulose, lignin or proteins. One of the main challenges currently facing society is a lack of plastic materials that rapidly and completely decompose under natural environmental conditions, yet retain their properties for a sufficient duration in consumer products[18].

xxiii https://www.european-bioplastics.org/bioplastics/

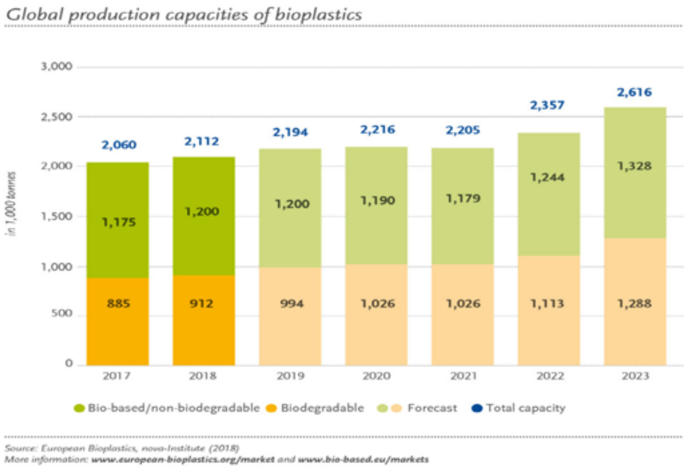

Figure 18. Worldwide Production capacity of Biopolymers[9].

Figure 18 shows the production capacities of the biopolymers worldwide and a forecast for 2023 showing a small but clear increase. PLA (polylactic acid) and PHAs (polyhydroxyalkanoates) are the main drivers for the growth in the field of bio-based, biodegradable plastics. In the field of bio-based, non-biodegradable plastics the drop-in solutions bio-based PE (polyethylene) and bio-based PET (polyethylene terephthalate), as well as bio-based PA (polyamides) are the main drivers. All in all, however, this remains still a (very) small part (1 wt%) of the total plastics produced every year worldwide (335 million tons)[xxiv]. In 2012 this was already recognized and the ambition was formulated for this market share to grow to 5% in 2018. Unfortunately this has been wishful thinking up to now still stressing that the challenge of replacing the fossil based polymers by biobased ones is a difficult path[19].

[xxiv] https://www.european-bioplastics.org/market/

Laminates

A challenge within the plastic recycling and waste management are the multi-layered foils used for food packaging for coffee or crisps. They consists of two or more layers of different type of plastics, which are difficult to separate and therefore difficult to recycle as material. The research group is working on an idea to make the separation of the layers more easy by making one layer dissolvable and recyclable. A biobased polyester layer is produced based on syringaldehyde, which can be recovered from plants like the Syringa vulgaris[xxv] or via oxidation of lignin[20]. Thus syringaldehyde can be converted via the Knoevelnagel reaction to sinapinic acid followed by hydrogenation to dihydrosinapic acid[21].

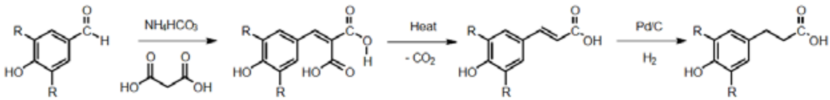

Figure 19. Reaction pathway of dihydrosinapic acid (R=OCH$_3$) from syringaldehyde[21].

Figure 20 shows how this dihydrosinapic acid is acetylated into a dicarboxylic acid which can be polymerised into poly dihydrosinapic acid, an aromatic polyester comparable with PET.

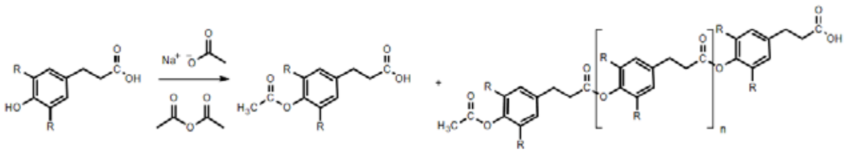

Figure 20. Acetylation and prepolymerisation of dihydrosinapic acid (R=OCH$_3$). N is typically 5.

This prepolymer can be further polymerized into so called poly-H. This poly H has PET like properties and could be used as a substitute. The difference with PET is that poly-H consists of 1 monomer while PET consists of two different monomers (tereftalic acid and mono ethylene glycol). Poly-H can easily be chemically depolymerized into its monomer which can be obtained in a pure form directly suited for repolymerization without costly purifications steps. The chemical breakdown of PET results in a mixture of two monomers which is not directly suited for repolymerisation.

[xxv] https://nl.wikipedia.org/wiki/Syringaldehyde

Biobased themosets

As shown above for biobased thermoplastics also biobased thermosets can be made which are recyclable via chemical recycling methods. Montarnal et al[22] introduced vitrimers: a new polymer type with glassy properties[23]. At low temperature they behave as a thermoset and at high temperature they melt as glass and can be reshaped. Yu et al[24] used this concept to make biobased thermosets which can be chemically recycled. The present epoxybased thermosets cannot be recycled. By using fatty acids as a cross linker for epoxy a reversable linkage is made which can easily decrosslink making the polymer dissovable in monoethylene glycol. The dissolved polymer backbone can be repolymerised by just removing the monoethylene glycol as shown in figure 21. No virgin epoxy is needed for the repolymerisation. Also the mechanical properties remain good after many polymerisation -depolymerisation steps.

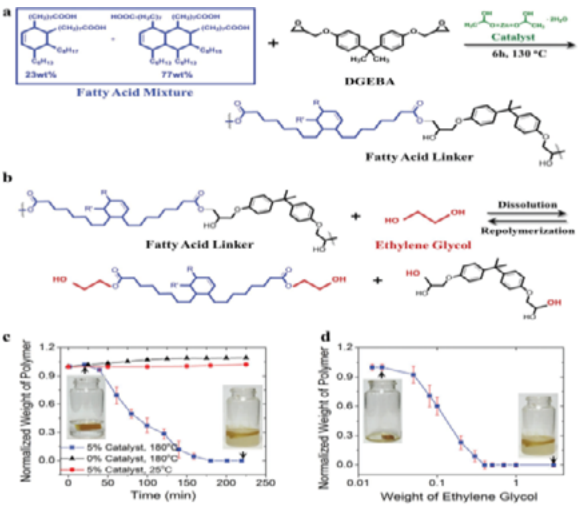

Figure 21. Recyclable epoxies according to Yu et al[24].

Biopolymer Application Centre (BAC)

The Centre for of Expertise Biobased Economy has taken up the challenge for developing more uses and applications of biobased polymers, biodegradable plastics. For this the Biopolymer Application Centre was founded to help existing industry with its conversion from fossil based polymers to biodegradable plastics. Designs can be made of products, produced in small series and tested in the market. Especially the production of examples of products is thought to help the market introduction by showing that biopolymers can be used for products and customers can be convinced of the usability. Also innovations can be promoted by scaling up new developments found in the lab. The plasticizers to be developed as decribed earlier will be tested via this centre in products.

Figure 22. Processing equipment of Biopolymer Application Centre

3. CONCLUSIONS

The transition of a fossil based economy to a biobased economy is based on how to deal with the biogenic resources in an efficient and sustainable way. For all the polymeric materials and chemicals this can be done by producing them from existing waste streams originating from the food supply chain without threatening the future food supply or natural habitats.

The transition to a biobased economy stands at the very beginning. Many innovations must be realized and barriers overcome. This requires not only close cooperation between companies, government and knowledge institutes, but above all awareness, knowledge development and best practices of innovative solutions.

Three questions are leading in this:

- Which innovation practices contribute to the material transition reducing climate change and environmental impact (technology, business cases and pilots)?
- Which innovation practices lead to a more sustainable use of biobased materials (removal of barriers, awareness and entrepreneurial risks)?
- Which innovation practices encourages the use of biobased plastics and biobased additives (technology, new business models and regulations)?

For answers the biobased building blocks & products research group carries out practice-oriented research into the technical, ecological and economic aspects of demand driven innovation practices. Main focus is on how biobased building blocks and chemicals can be obtained, implemented in the processing and manufacturing of end products and how they can be used in a circular way.

In this way the research group plays an important role to the strengthening, the stimulation and the broadening of the view and the possibilities and opportunities of current and future generations, students and entrepreneurs, under the motto: "Opportunities in the biobased economy.

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Han van Kasteren is specialised in the areas of waste technologies, recycling processes for plastic containing waste streams and thermal treatment of (bio) wastes.

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COLOPHON

This is an edition from Avans University of Applied Sciences
Issued at the ocassion of the inauguration of Han van Kasteren.

Coordination
Marketing, Communication and Student Affairs,
Avans University of Applied Sciences

Printing & design
De Studio, powered by Avans & Canon

Acknowledgement
Alwin Hoogendoorn en Ralph Simons

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Centre of Expertise Biobased Economy
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ISBN: 978-90-74611-70-1

AVA190288