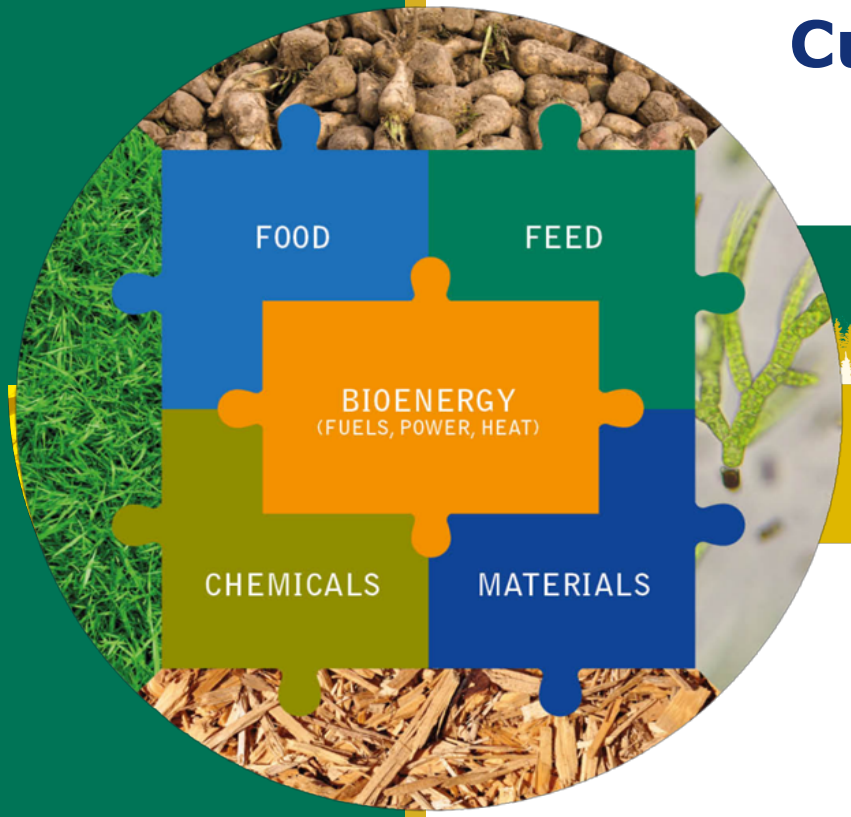
IEA Bioenergy

Task42 – Biorefining in a Future BioEconomy

Biobased Chemicals

-

Current status & Potential



ABLCGlobal

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Ed de Jong

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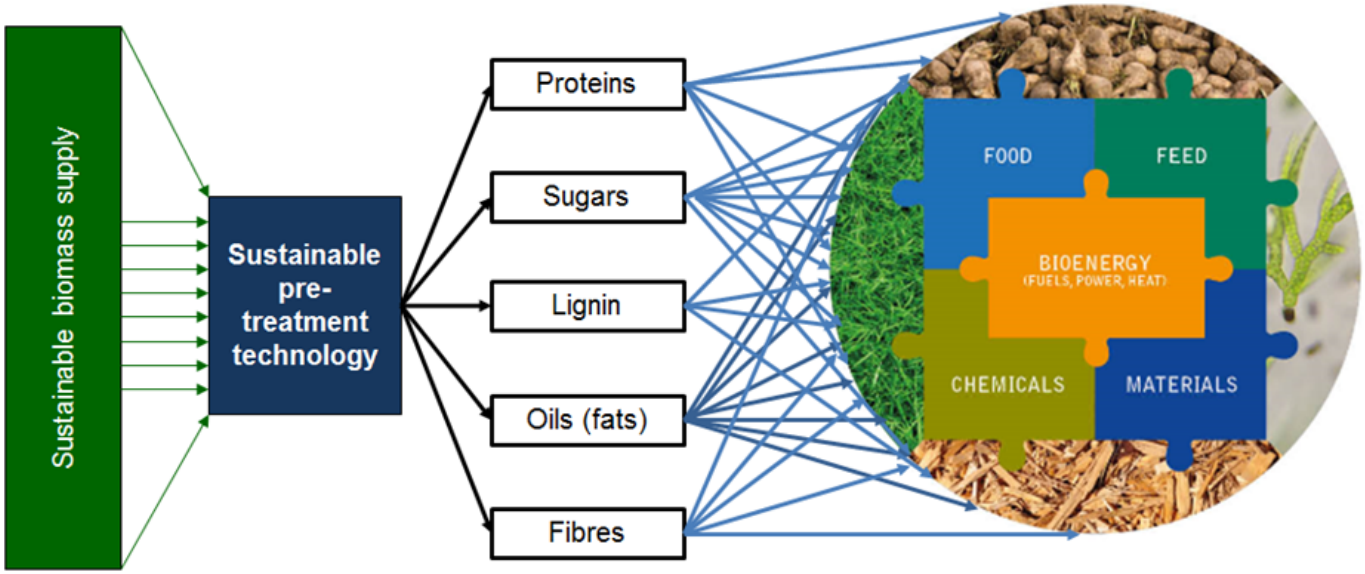
Content

- IEA Bioenergy Task 42 Biorefining
- Introduction on Biobased Chemicals
- Market size and potential GHG savings
- Technology push or market pull?
- List of Bio-based chemicals and producers
- Dilemma: Drop-in versus novel building blocks
- Avantium examples
- Conclusions

Task Framework – Biorefining

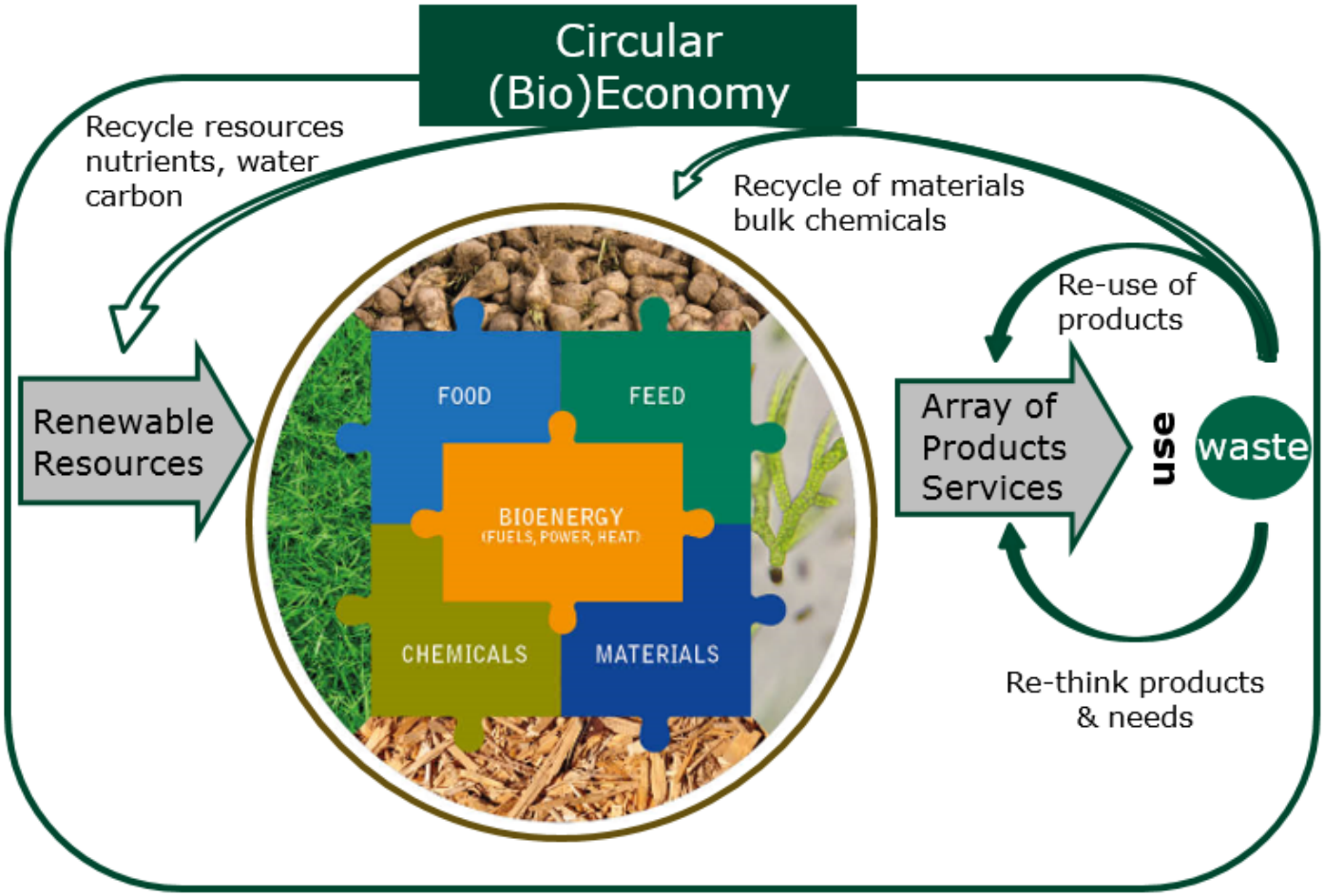
Definition IEA Bioenergy Task42

Sustainable processing of biomass into a portfolio of marketable biobased products (food and feed ingredients, chemicals, materials, fuels, energy, minerals, CO_2) and bioenergy (fuels, power, heat)

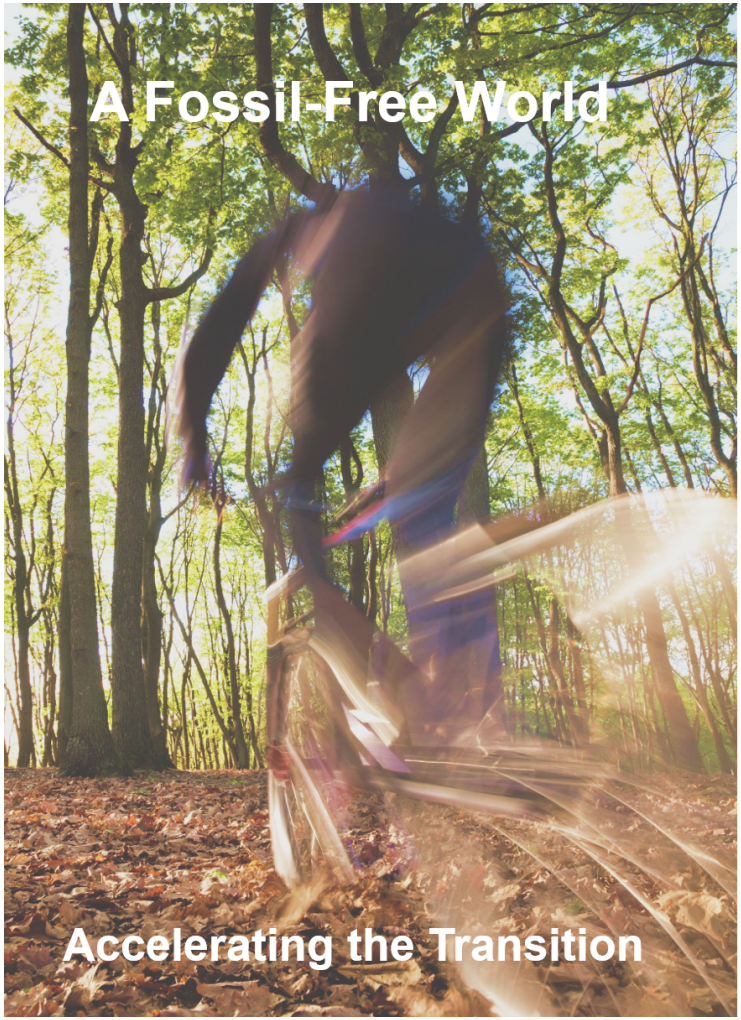


Setting the Scene

Biorefining in a Future Circular (Bio)Economy



Renewable Carbon



There are only three renewable carbon sources available in this world…

Plant-Based	Air-Based	Man-Made
Rediscover	*Reroute*	*Repurpose*
Glucose as Building Block	CO_2 Conversions	Chemical Recycling

…that enable a circular economy

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The Chemical Industry: A Key to Mitigating Climate Change

6 years

until the carbon budget to limit global warming to 1.5 degrees is used
(extrapolating current CO_2 emissions)

90 %

of the chemical products we use are derived from fossil carbon
(this excludes fuels)

this represents 11% of global primary demand for oil and 8% for natural gas

4 X

is the expected growth of the plastic market from 2014-2050

plastics are expected to make up 15% of carbon budget in 2050

1-2% of current plastics are made from renewable feedstock

Source: Carbon Brief 2017, IPCC – Figures correspond to a 50% chance to limit global warming to 1.5 or 2 degrees; IEA, July 2018; Ellen McArthur Foundation '*The new plastics economy*', 2016

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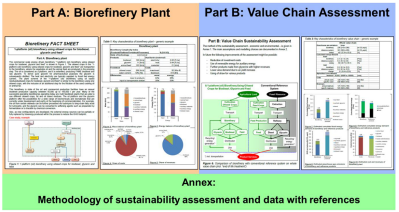
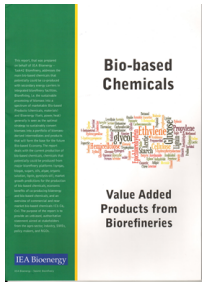
IEA Bioenergy Task42
Deliverables 2016 - 2018

- Biorefinery Factsheets
- Monitoring of international standardisation/ certification activities biomass-use
- Monitoring international BioEconomy developments
- Joint Tasks Projects (bioenergy supply chains)
- Strategic Reports on
  - Proteins for Food and Non-food (2016)
  - Biobased Fibrous Materials
  - **Biobased Chemicals (2018)**
- Updates of National BR Country Reports
- (Thematic) Stakeholder Workshops
- Conference & training contributions
- Biannual newsletters





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Why producing Biobased Chemicals (in conjunction with Bioenergy) in a Biorefinery

- To supply the market with sustainable/renewable chemicals
- To improve the economics of bioenergy production
- To partly make use of existing industrial (energy) infrastructure potentially decreasing initial investments and shorten time-to-market
- To make scaling up easier (makes plant already commercial viable at smaller scales)
- Unique functionality
- Medium term CO_2 storage (depending on chemical)
- Reduction of non renewable energy usage (NREU) usage (both because of renewable product and less fossil fuel used in production

Current Market Size

Fossil based Chemicals:
330 million tonnes

Main molecules:
methanol, ethylene, propylene, butadiene, benzene, toluene and xylene

Biobased Chemicals & Materials:
50 million tonnes

Main molecules:
Non-food starch, cellulose fibres/derivatives, tall oils, fatty acids and fermentation products

Potential for GHG savings

Product	GHG savings ($t\ CO_2$/t of product)	Installed world capacity (million t/year)	Annual GHG savings (million tonne CO_2/ year)[4]
Acetic acid	1.2	8.3	9.6
Acrylic acid	1.5	2.9	4.4
Adipic acid	3.3	2.4	7.9
Butanol	3.9	2.5	9.6
Caprolactam	5.2	3.9	20.0
Ethanol	2.7		7.1
Ethyl lactate	1.9	1.2	2.2
Ethylene	2.5	100.0	246
Lysine	3.6	0.6	2.3
Succinic acid	5.0	1.4	6.8
1,3-propanediol	2.9	-	-
PHA	2.8	57.0	160
PLA	3.3	11.1	36.5

Hermann, B.G., et al. 2007 *Environ. Sci. Technol*. 41, 7915-7921.

Pull or Push ?

- Governmental – Legislative push
  - Sustainability
  - Green House Gas savings /Non Renewable Energy Usage
  - Security of supply
- Technological push
  - Biochemical / Chemical
  - Concepts versus applicability
- Market pull
  - Brand owners
  - Consumers

The Biobased Transition has started, Companies look for Bio-Based Alternatives

	iPhone 7 Environmental Report	"Apple believes that **improving the environmental performance of our business** starts with our products. The careful environmental management of our products includes controlling the types of materials used: **plastics** used in the display frame are made with **28% bio-based content"**
	SUSTAINABILITY REPORT 2016	"the best-known example of how we rethink our packaing is **our breakthrough bio-based, low-carbon, Green Fibre Bottle**. It continues to attract attention and spark discussion"
	 Jørgen Vig Knudstrop CEO	**Lego invests 1 billion DKK** in R&D and implementation of **new, sustainable, raw materials** to manufacture LEGO elements as well as packaging materials; "This is a major step for the LEGO Group on our way towards achieving our 2030 ambition on sustainable materials".
	FY14/15 NIKE, INC. SUSTAINABLE BUSINESS REPORT	"We envision a transition from linear to circular business models and a world that demands closed-loop products…". " We are re-imagining waste streams as value streams…". "…and **encourage broader adoption of renewables** as part of our effort to control absolute emissions"
	L'ORÉAL ANNUAL REPORT 2016	"The new Biolage R.A.W. haircare line was sustainably designed and developed, in response to **consumers' growing expectations** in this area. **Raw materials of natural origin** are preferred, with percentages of natural ingredients between 70% and 100%"
	 Debbie Mielewski Senior Technical Leader	"There are about 400 pounds of plastic on a typical car, our job is to find the right place for **a green composite** to help our impact on the planet"

Also Chemical Companies are increasingly Diversifying into Bio-Based Materials

"I'm very pleased with this joint venture (…) This investment is consistent with our One Total ambition of *expanding in biofuels and bioplastics*, in addition to our more traditional oil- and gas-based products."
Bernard Pinatel, President of Total Refining & Chemicals, on the JV with Corbion to produce bio-PLA

TOTAL | Corbion

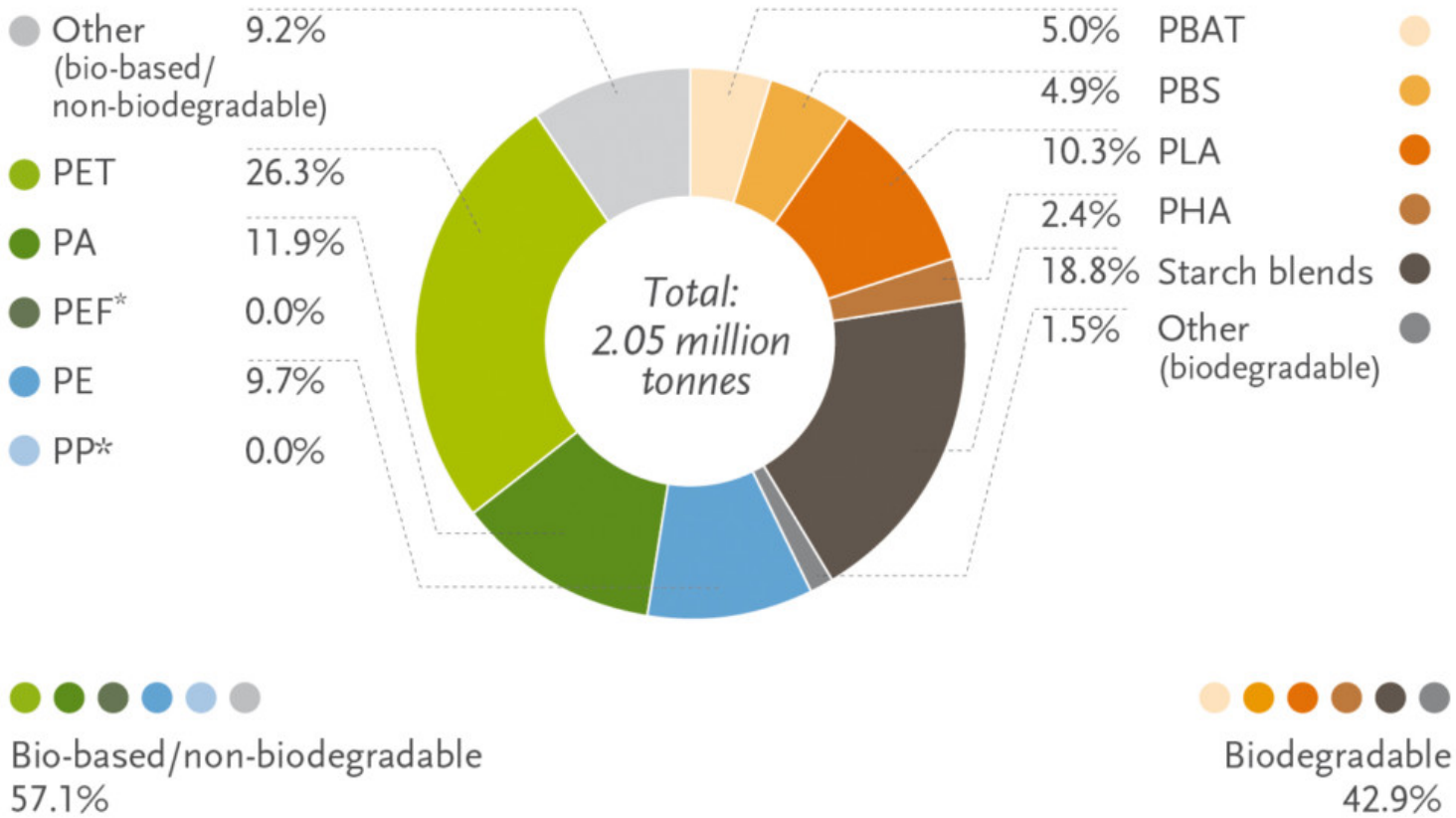
Synvina: BASF and Avantium join forces

BASF | SYNVINA | avantium

"2015-2020: To be recognized as a leader in the production of chemical products and thermoplastic resins from raw renewable materials."
Braskem Sustainable Strategy

Braskem

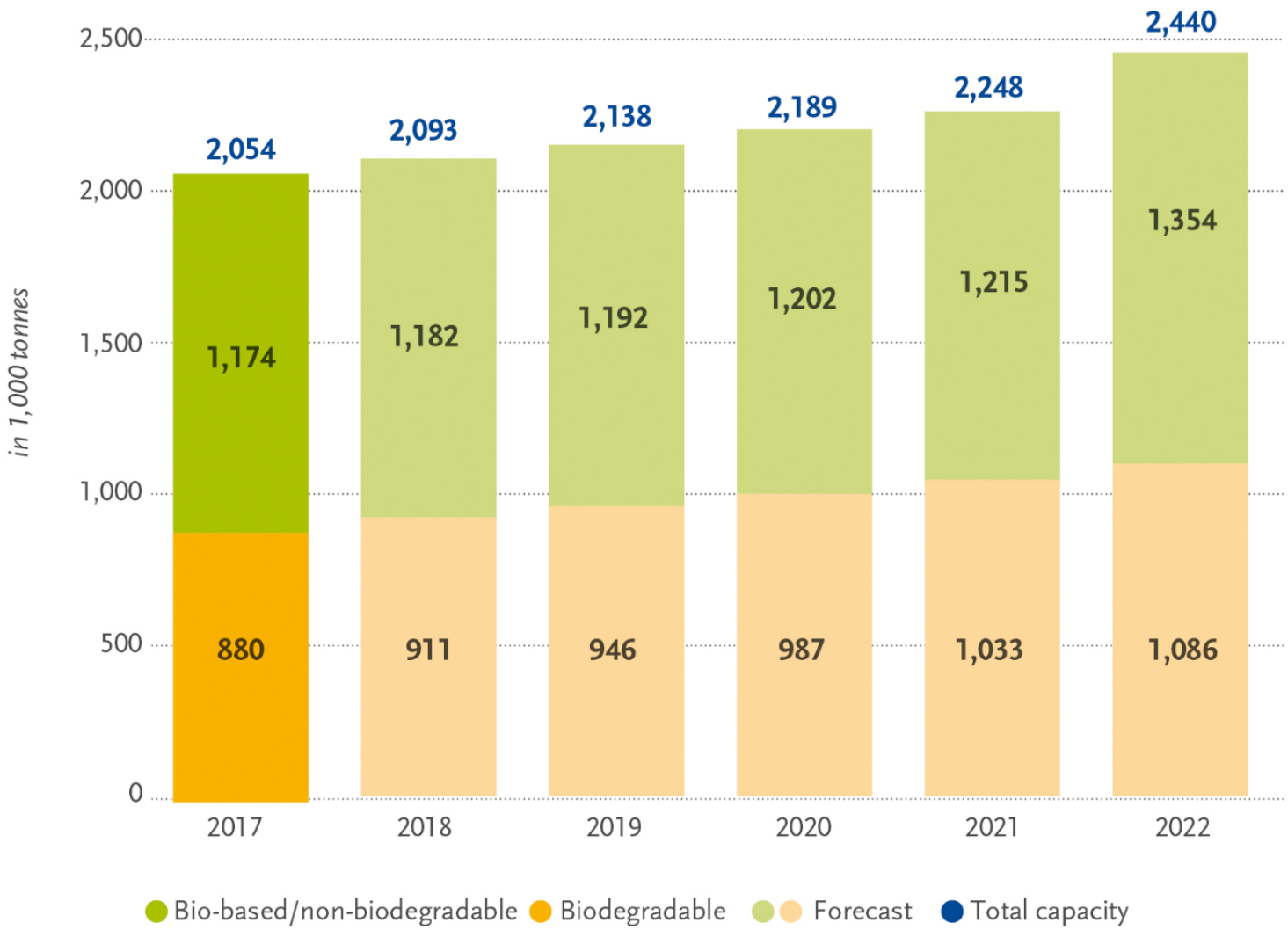
Global production capacities of Bioplastics 2017 (by material type)



*Bio-based PP and PEF are currently in development and predicted to be available in commercial scale in 2020.

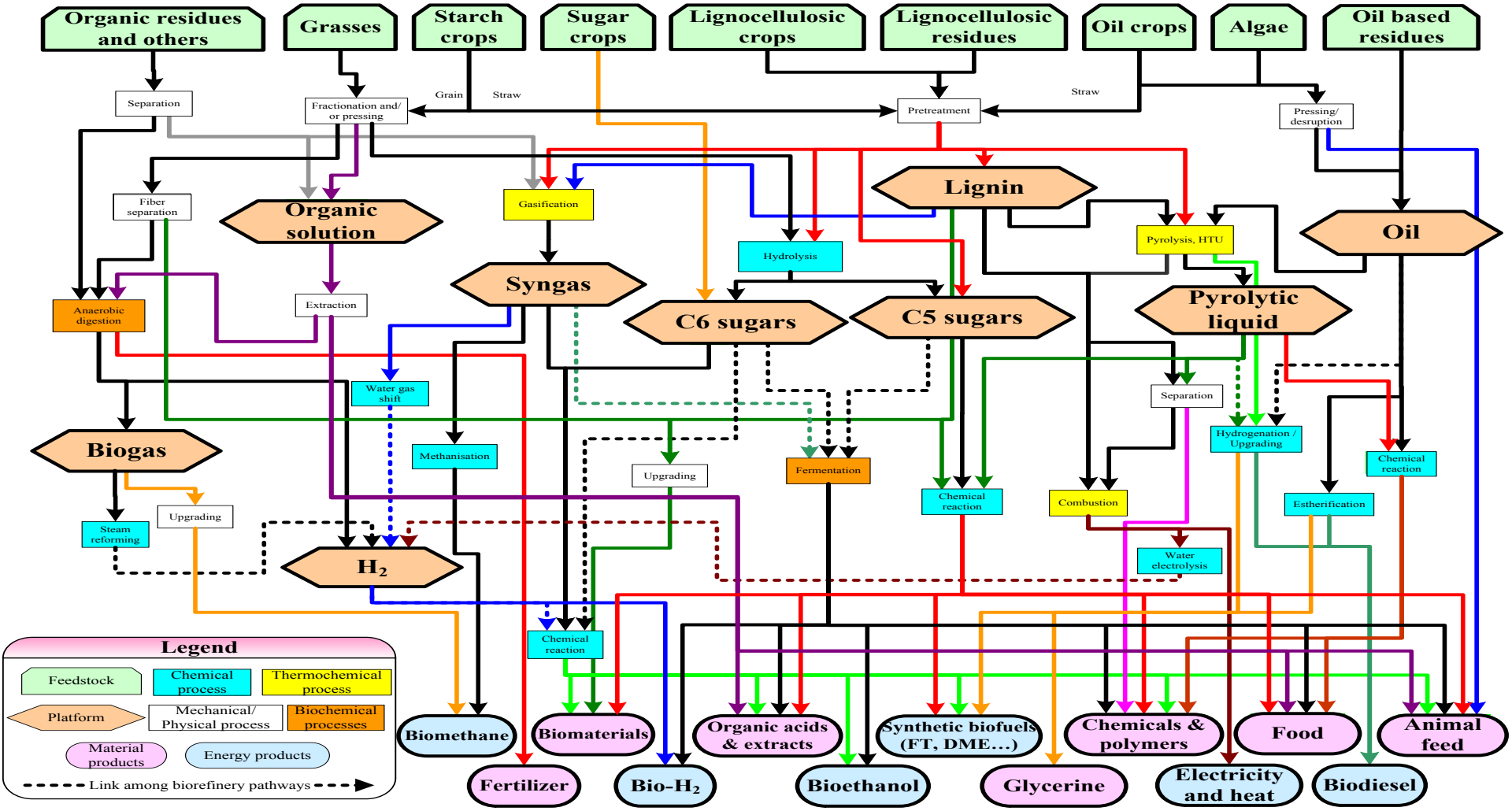
Source: European Bioplastics, nova-Institute (2017).
More information: **www.bio-based.eu/markets** and **www.european-bioplastics.org/market**

Global Production Capacities of Bioplastics (2017 – 2022)



Source: European Bioplastics, nova-Institute (2017).
More information: ***www.bio-based.eu/markets*** *and* ***www.european-bioplastics.org/market***

Overview of IEA Bioenergy T42 Biorefinery Classification system



Dominant Platforms

Syngas Platform
Biogas Platform
C6 sugar platform*
C6/C5 sugar platform
Plant-based Oil Platform*
Algae Oil Platform
Organic Solutions Platform
Lignin Platform
Pyrolysis Oil Platform

* Currently the dominant platforms for biobased chemicals

Biobased Chemicals Table

- Gives an overview of the biobased chemicals status in two categories
  - High growth potential
  - In the pipeline (demonstration or pilot facility running)
- Organized from C1 (methanol, formic acid etc) to Cn (all molecules with more than 6 C atoms)
- Exhaustive list but certainly not complete
- Biobased Chemicals Field is very dynamic at the moment so probably already some new changes / additions needed

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Biobased Chemicals

Cn	Products with strong growth potential		Bio-Based Chemicals in the pipeline	
	Chemical	Company	Chemical	Company
1	Methanol	BioMCN, Sodra, *AkzoNobel/Enerkem*	Formic acid / formiate	Avantium
	Methane	Many	Formaldehyde	BASF
			Syn gas	BioMCN, Chemrec
			CO_2	Climeworks
2	Ethylene	Braskem	Ethyl acetate	Zeachem, Greenyug
	Ethanol	Many	Glycolic acid	Metabolix Explorer
	Ethyleneglycol (MEG)	India Glycols Ltd, *HaldorTopsoe, UPM, Avantium*	Acetic acid	Wacker, Godovari Biorefineries Ltd, Zeachem
	Ethylene Oxide	Croda, *Biokim*		

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Biobased Chemicals

Cn	Products with strong growth potential		Bio-Based Chemicals in the pipeline	
	Chemical	Company	Chemical	Company
3	Lactic acid (many)	Corbion, NatureWorks, Anhui, Galactic, Henan Jindan,	Acrylic acid	Cargill, Corbion
	Propane	Neste	Isopropanol	Global Bioenergies
	Glycerol	Many	Propylene	Braskem
	Epichlorohydrin (many)	Yihai Kerry Group, Jiangsu Yangnong, Advance Biochemical Thailand	3-Hydroxypropionic acid	Cargill
	1,3-Propanediol	DuPont/Tate&Lyle, *Metabolic Explorer*	n-Propanol	Braskem
	Ethyl lactate	Vertec BioSolvents	Isopropanol	Genomatica
	Propylene Glycol (1,2-Propanediol)	ADM, Oleon, *BASF*	Propylene	Braskem, Dow
	Acetone	Green Biologics	Malonic acid	Sirrus, Lygos

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Biobased Chemicals

Cn	Products with strong growth potential		Bio-Based Chemicals in the pipeline	
	Chemical	Company	Chemical	Company
4	n-Butanol	Green Biologics	2,3-Butanediol	Intrexion
	iso-Butanol	Butamax, Gevo	Methyl methacrylate	Lucite
	Succinic acid	Reverdia, *Myriant,* Succinity	MethylVinyl Glycolate	Haldor Topsoe
	1,4-Butanediol	Genomatica, Novamont, GBL	Butyric acid	Metex, Kemin, Blue Marble Biomaterials
			Iso-butene	Global Bioenergies
5	Furfural	Many	Itaconic acid	a.o. Qingdao Kehai Biochemistry Co
	Xylitol	a.o. Danisco/ Lenzing, S2G Biochem	Isoprene/Farnesene	Goodyear/ Genencor, GlycosBio, Amyris
	Glutamic acid	a.o. Global Biotech, Meihua, Fufeng, Juhua	Levulinic acid	GFBiochemicals, Synvina, Bio-on
			1,5-pentanediamine	CJ Cheiljedang Bio

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Biobased Chemicals

Cn	Products with strong growth potential		Bio-Based Chemicals in the pipeline	
	Chemical	Company	Chemical	Company
6	Sorbitol	a.o. Roquette, ADM	Adipic acid	Genomatica
	Lysine	a.o. Global Biotech, Evonik/RusBiotech, BBCA, Draths, Ajinomoto	FDCA-(esters)	Synvina, Corbion, ADM/DuPont
	Isosorbide	Roquette	1,6-Hexanediol	Rennovia
	Aniline	Covestro	HMF/CMF	Ava Biochem, Mercusius
	Citric acid	a.o. Cargill, DSM, BBCA, Ensign, TTCA, RZBC	Caprolactam	DSM, Genomatica/ Aquafil
			Dehydrolevo-glucosenone	Circa Group
n	PHA	Telles, Meridian plastics	*Para*-Xylene	Bio-BTX, Annellotech, Tesoro (Virent)
	Dicarboxylic acids	Cathay Biotech, Evonik		
	Fatty Acid derivatives	Croda, Elevance		

Product Commercialization Key Criteria

Market assessment

Market fundamentals (local, regional, global)
Feedstock availability & price
Utilities (steam, gas, electricity etc) availability & price
Product profitability
Bankability
Competitive nature of market
Need for partnerships
Downstream development opportunities

Technology assessment

Commercial experience
Necessary capital investment
Process complexity
Access to technology
Environmental considerations

Drop-in versus New Functionality

Bio-based chemical	Reference Petrochemical
Acetic acid	*Acetic acid*
Adipic acid	*Adipic acid*
n-Butanol	*n-Butanol*
Ethylene	*Ethylene*
Bio-MEG	*MEG (mono-Ethyleneglycol)*
Ethyl lactate	Ethyl acetate
FDCA	Terephthalic acid
PHA	HDPE
PLA	PET and PS
Succinic acid	Maleic anhydride

Drop-in versus Unique Functionality

	Drop-in	Unique molecule
Market acceptance	↑ ↑	↓ ↓
Speed of introduction	↑ ↑	↓ ↓
Fit with existing infrastructure	↑ ↑ ↔	↔ ↓
Oil/Feedstock price sensitivity	↑ ↑ ↑ ↑	↑
Sustainability	↑ ↔ ↓	↑ ↑ ↑ ↔
Unique market space	↓ ↓ ↓ ↓	↑ ↑ ↑ ↑
Scalability	↑ ↑ ↑	↑ ↔ ↓
Legislation (e.a. REACH)	↑ ↑ ↑	↑ ↑ ↑ ↓ ↓ ↓

Avantium example: PEF from lignocellulosic feedstocks

Wood Chips

Lignin

Mixed Sugar Syrup

Pure Dextrose Sugar

Bio-MEG

PEF

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Mixture of Novel Functionality & Drop-in

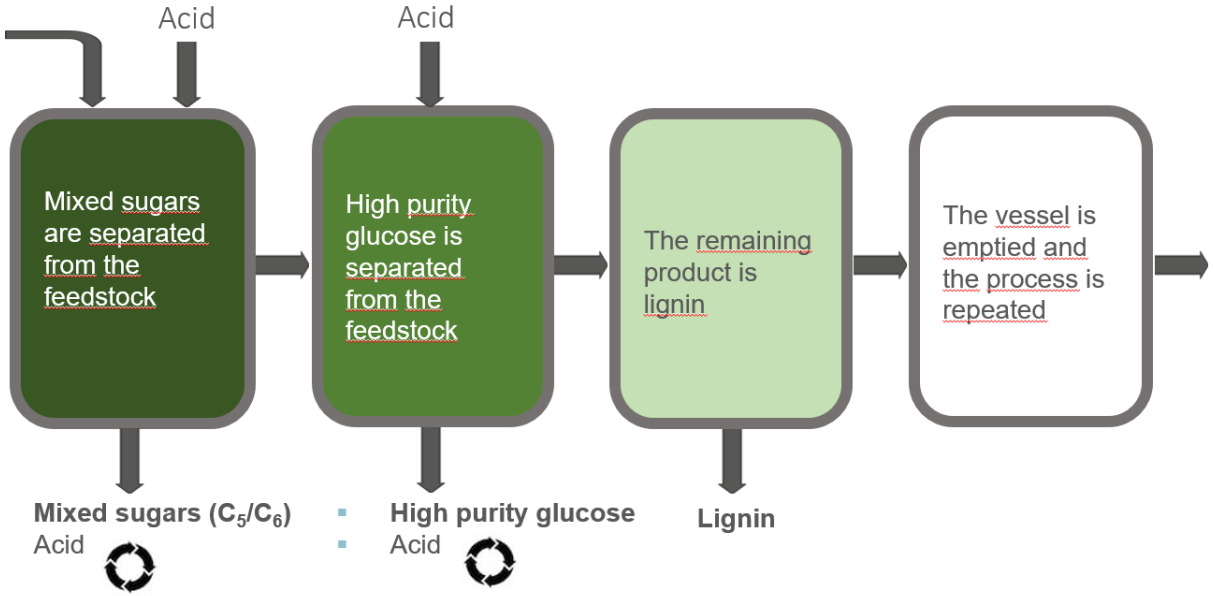
Dawn Technology™

Biorefinery: Woody Biomass To 2G Industrial Sugars and Lignin

About

- A radically improved proven process, through proprietary inventions; reduction of water consumption by 70%
- Unlocks the glucose available in non-food agricultural and forestry residues

Non-food, plant-based feedstock



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Benefits of Drop-ins

Mekong

Industrial Sugars to MEG

About

- Superior carbon efficiency
- Aims to help fulfilling the growing MEG demand (2017-2035 CAGR = 3.5%[A])

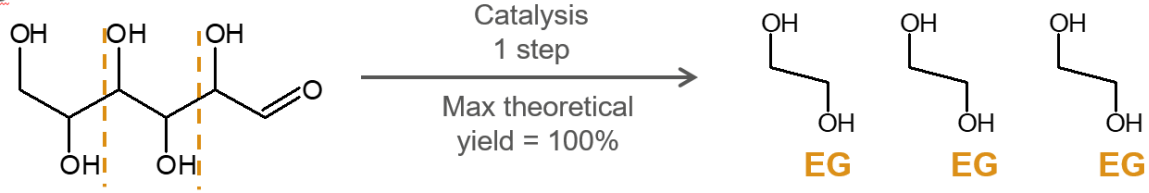
Value proposition

- Drop-in - Same quality as fossil-MEG
- Competitive - Competes with fossil-MEG cost
- Bio-based - Utilize 1G or 2G resources
- Versatile - Worldwide feedstock options
- Scalable - Common unit operations
- Sustainable - Significant CO_2-eq reduction[B]

Mekong Process

Hydrogenolysis

Glucose:



A = CAGR 2017-2025: 3.9% (Nexant Petrochemical Market Dynamics, Polyester & Intermediates, 2017); CAGR 2025-2032: 3.0%
B= Compared to traditional fossil-MEG plant. Data to be verified by third party environmental life-cycle assessment (LCA) based on to be collected demonstration plant data.

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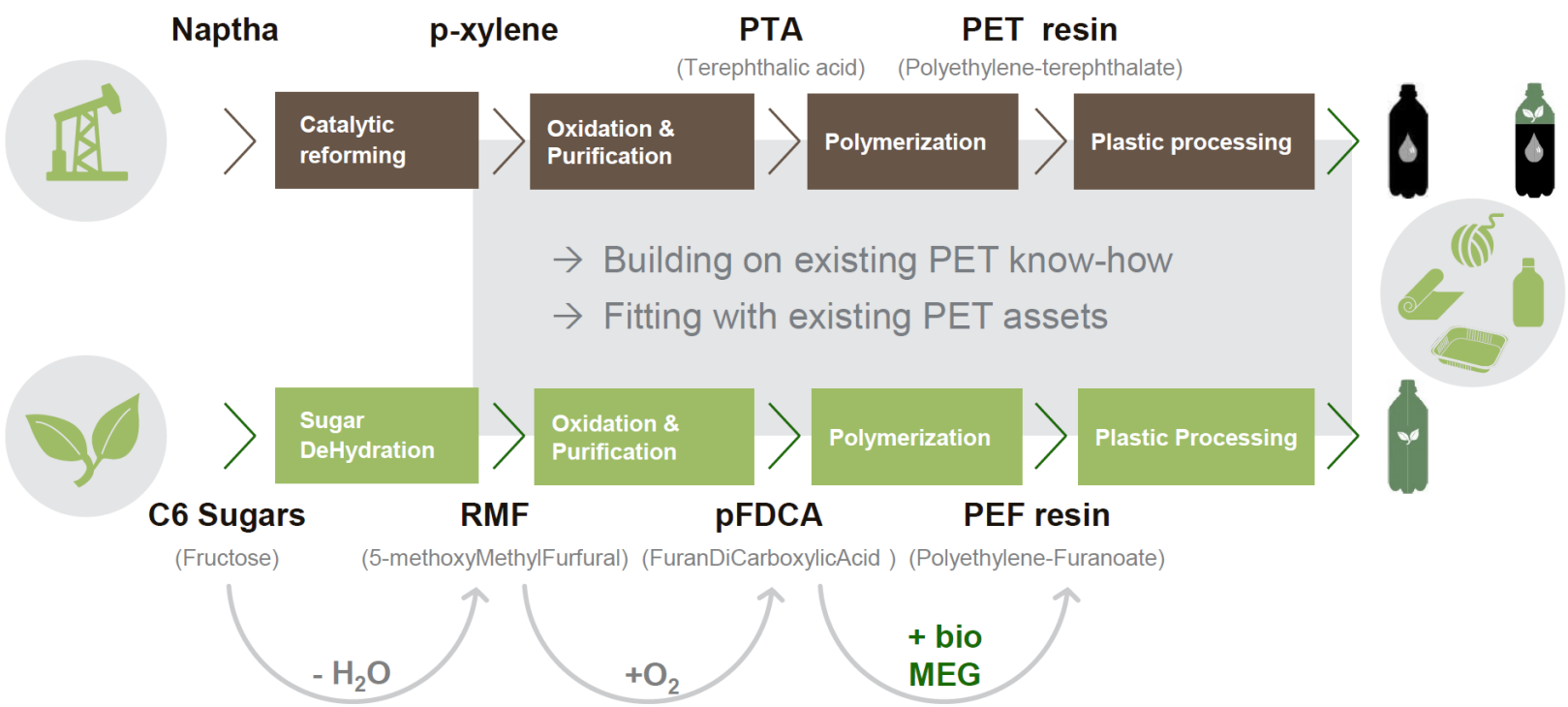
A New Value Chain: From Sugars to PEF

SYNVINA
functional. sustainable. bioplastics.



Catalytic processes, developed with high throughput screening technology

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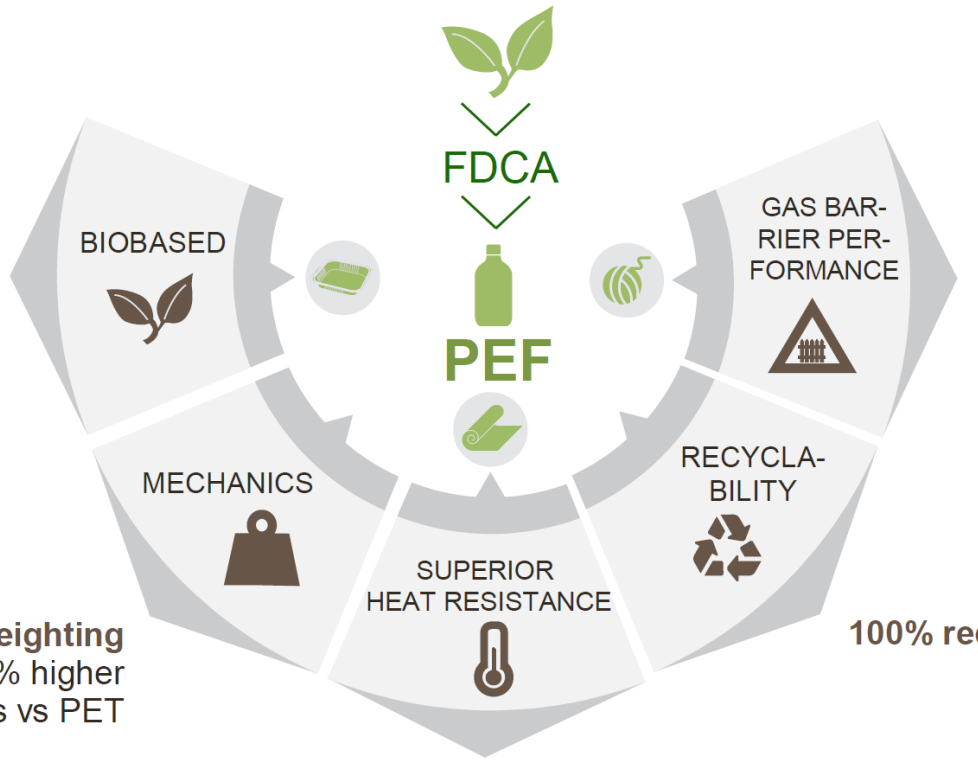
Benefits of Unique Functionality

Synvina: What can PEF do?



Sustainability
100% biobased polymer

Shelf Life
improved transfer rates vs PET:

- O_2 10x
- CO_2 6-10x
- H_2O 3x

Lightweighting
60% higher modulus vs PET

100% recyclable

Hot Filling
12°C higher glass transition vs PET

Conclusions

- Strong Market Pull Biobased Chemicals
- Production is currently expanding at decent pace
- In several cases products are market competitive without subsidies
- No winner between drop-in versus new functionality

Dissemination

- Updated report will be available in 2019
- Pdf version will be available on IEA Bioenergy Task 42 website (http://task42.ieabioenergy.com/)
- Feedback: Ed de Jong (ed.dejong@avantium.com)