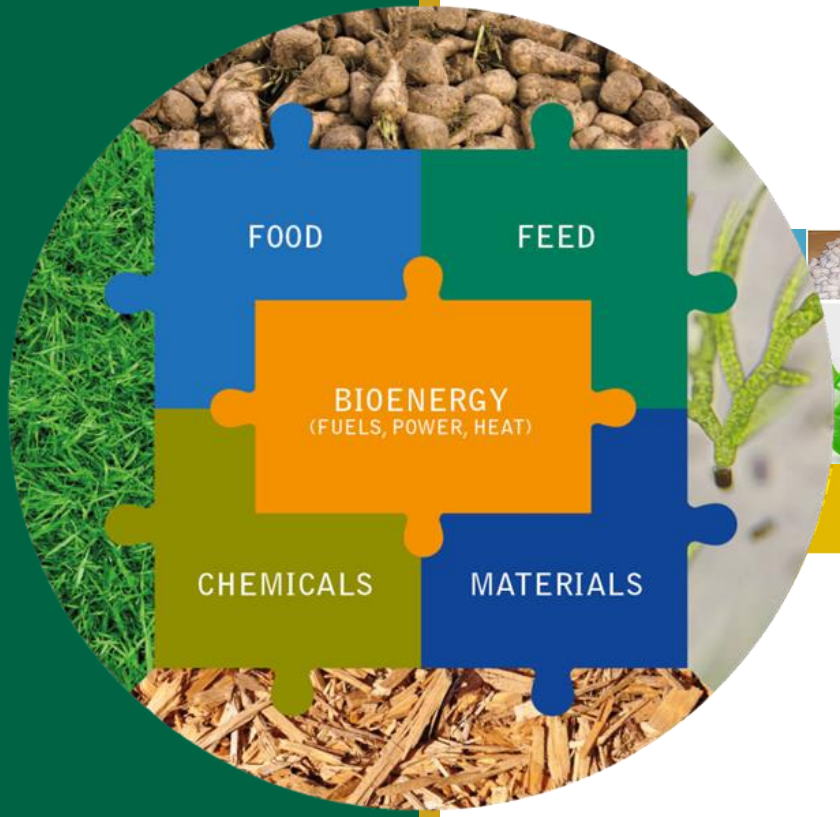
IEA Bioenergy

Task42 – Biorefining in a Future BioEconomy

Biobased Chemicals -

a 2020 status update



IEA Bioenergy Task 42
Webinar
10 March 2020

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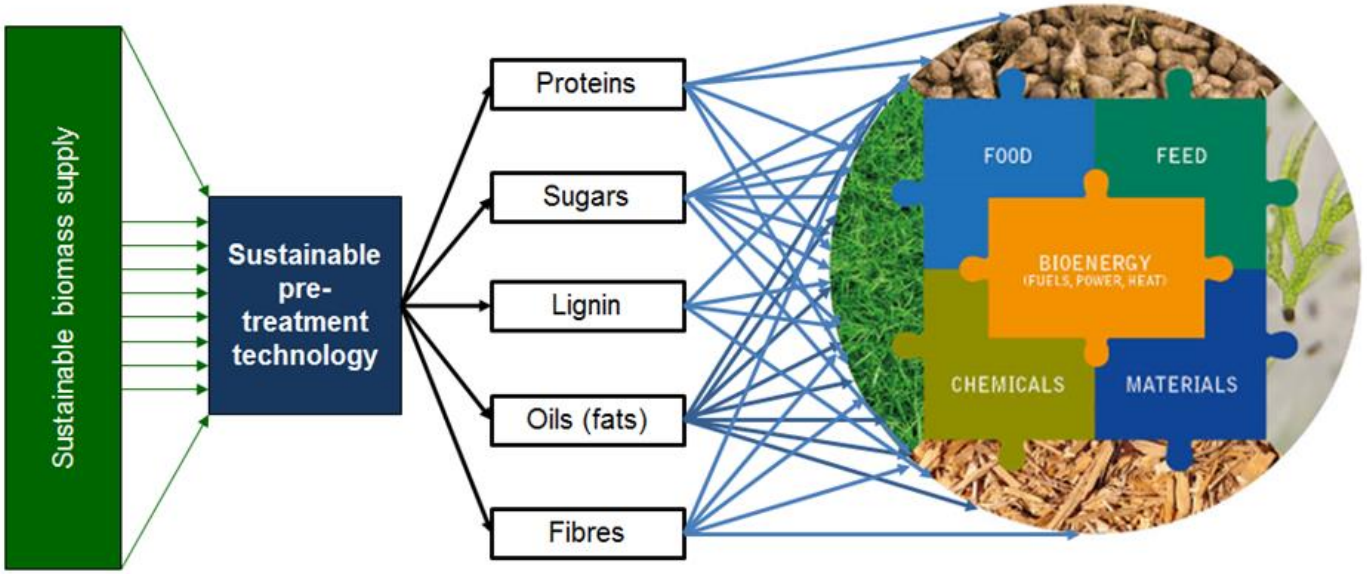
Content

- IEA Bioenergy Task 42 Biorefining
- Introduction on Biobased Chemicals
- Sustainable Development Scenario irt Biobased Chemicals
- Technology push or market pull?
- List of Bio-based chemicals and producers
- Dilemma: Drop-in versus novel building blocks
- Biobased Chemicals - SWOT analysis
- Conclusions

Task Framework – Biorefining

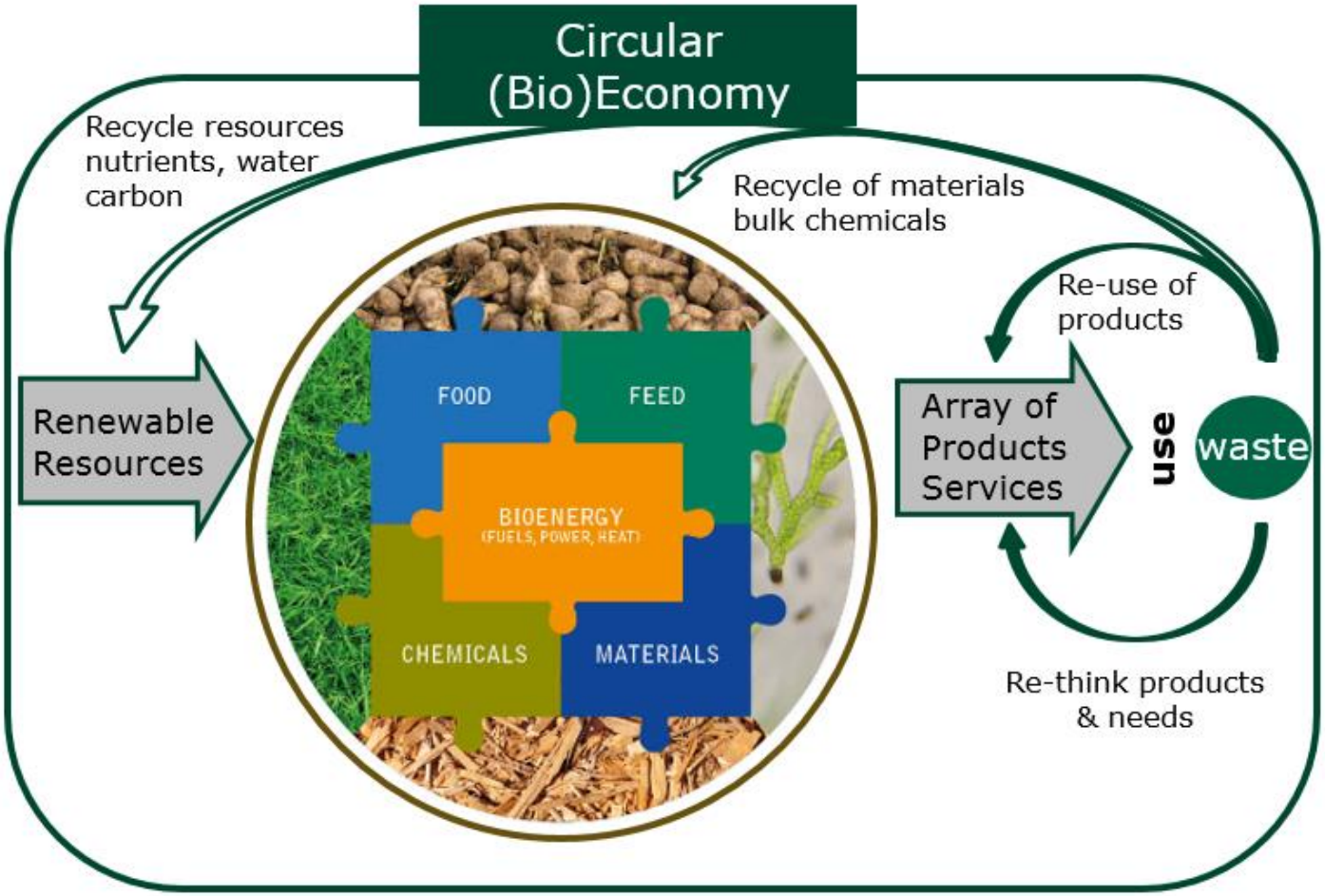
Definition IEA Bioenergy Task42

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)

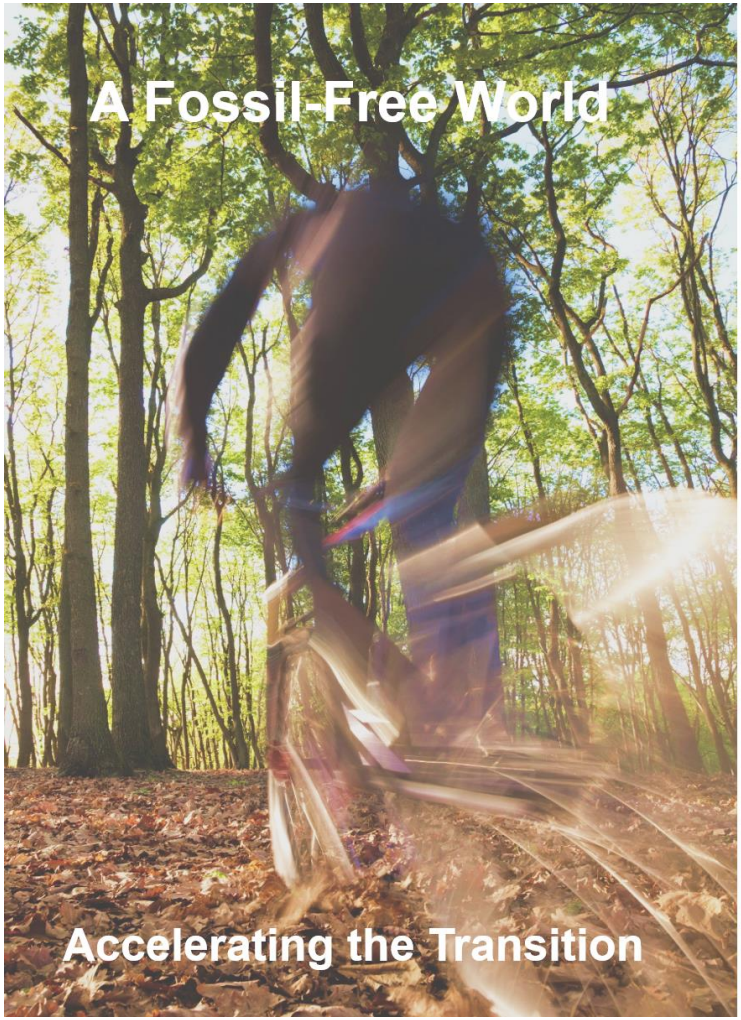


Setting the Scene

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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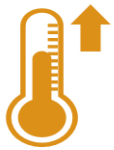
The Chemical Industry: A Key to Mitigating Climate Change



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

ı Brief 2017, IPCC – Figures correspond to a 50% chance to limit global warming to 1.5 or 2 degrees; IEA, July 2018; Ellen McArthur
e new plastics economy', 2016

WTI (West Texas Intermediate) crude oil daily closing prices over the last 10 years

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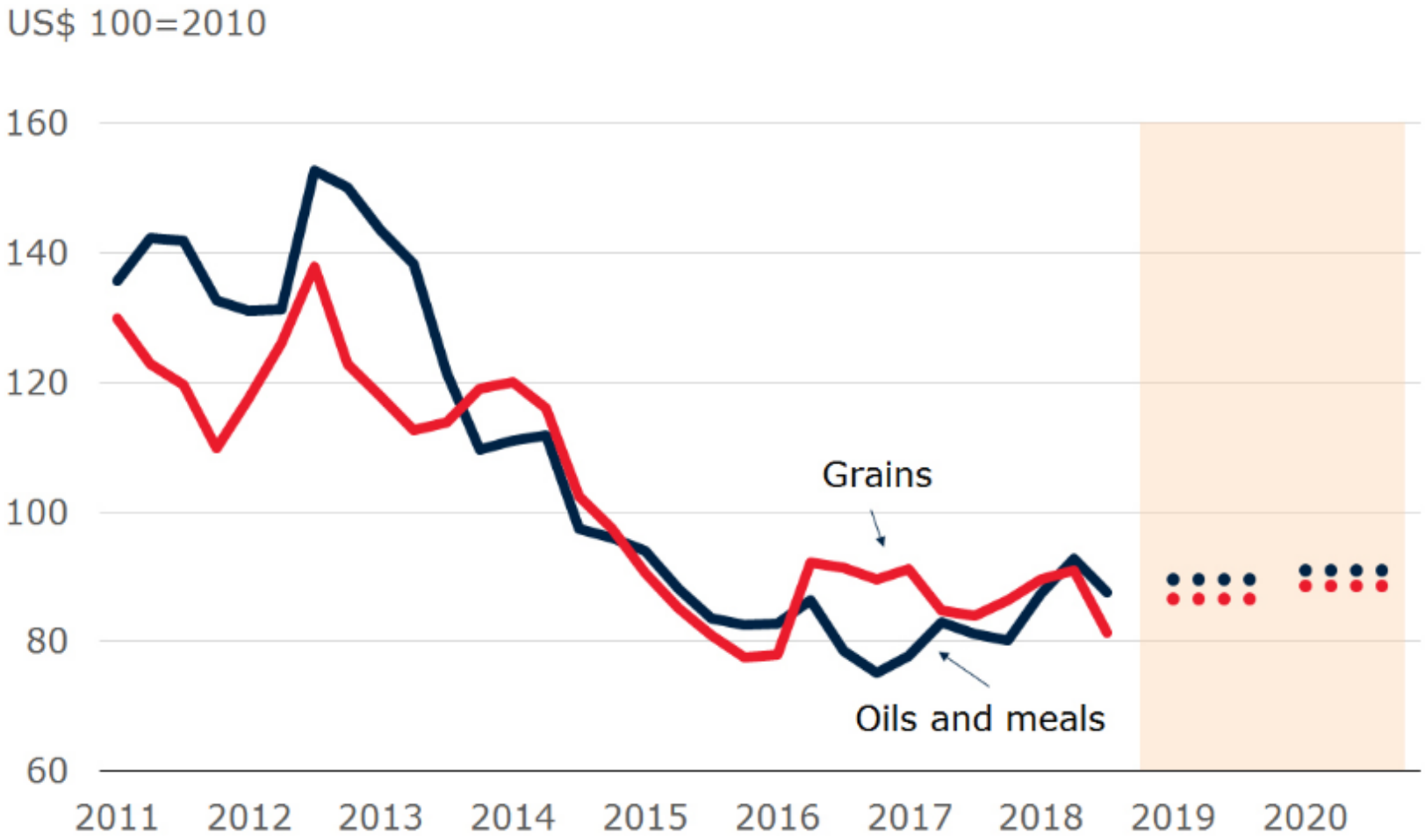
Global Prices of Key Food Commodities (*Source*: World Bank, last observation is 2018Q3. Shaded areas denotes forecasts)



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 & derived Materials:

90 million tonnes

Main molecules:

Fermentation products (e.g. ethanol), fatty acids (derivatives)

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"

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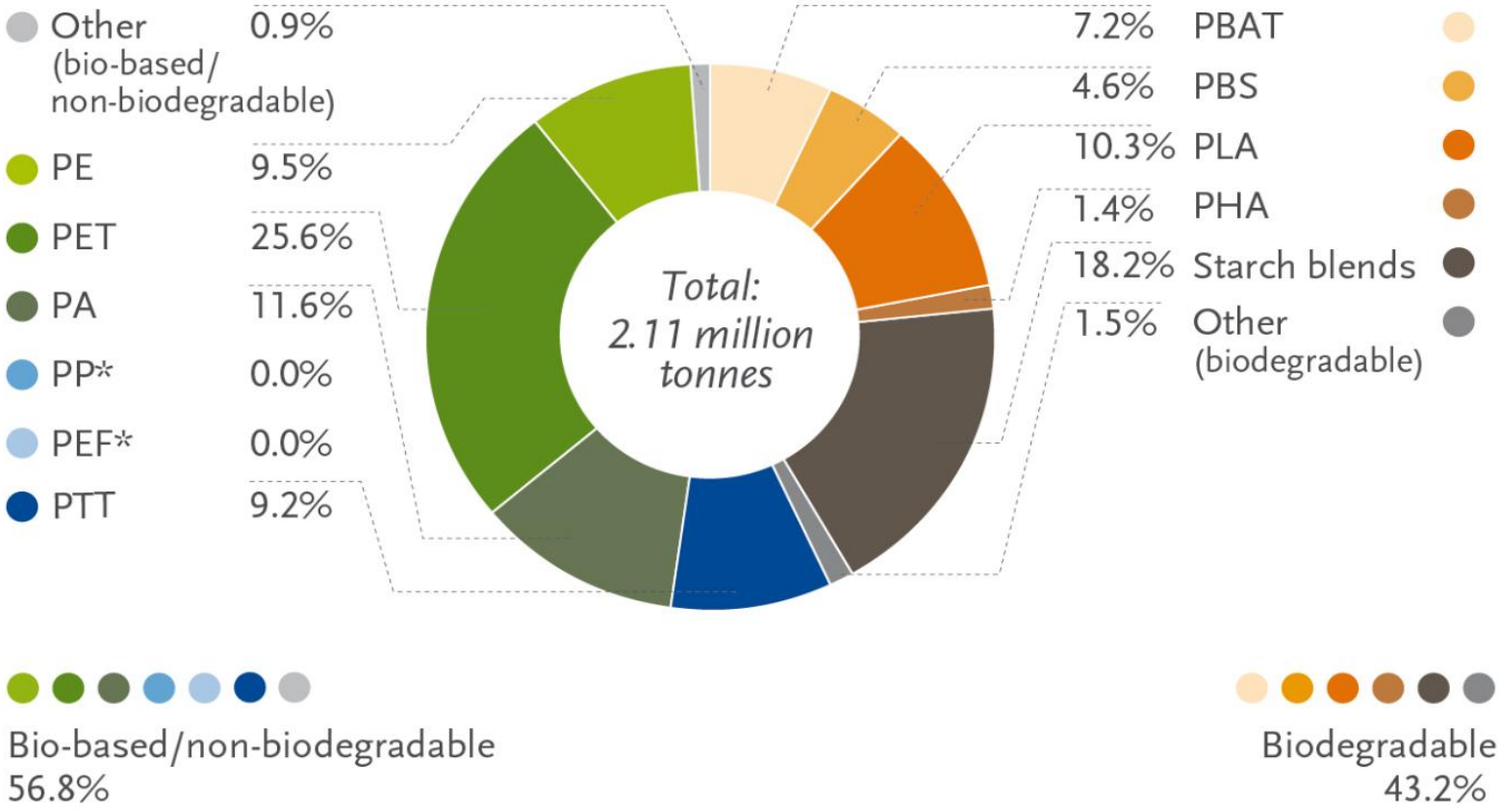
Global production capacities of Bioplastics 2018 (by material type)



*Bio-based PP and PEF are currently in development and predicted to be available at commercial scale in 2023

Source: European Bioplastics, nova-Institute (2018)
More information: **www.european-bioplastics.org/market** and **www.bio-based.eu/markets**

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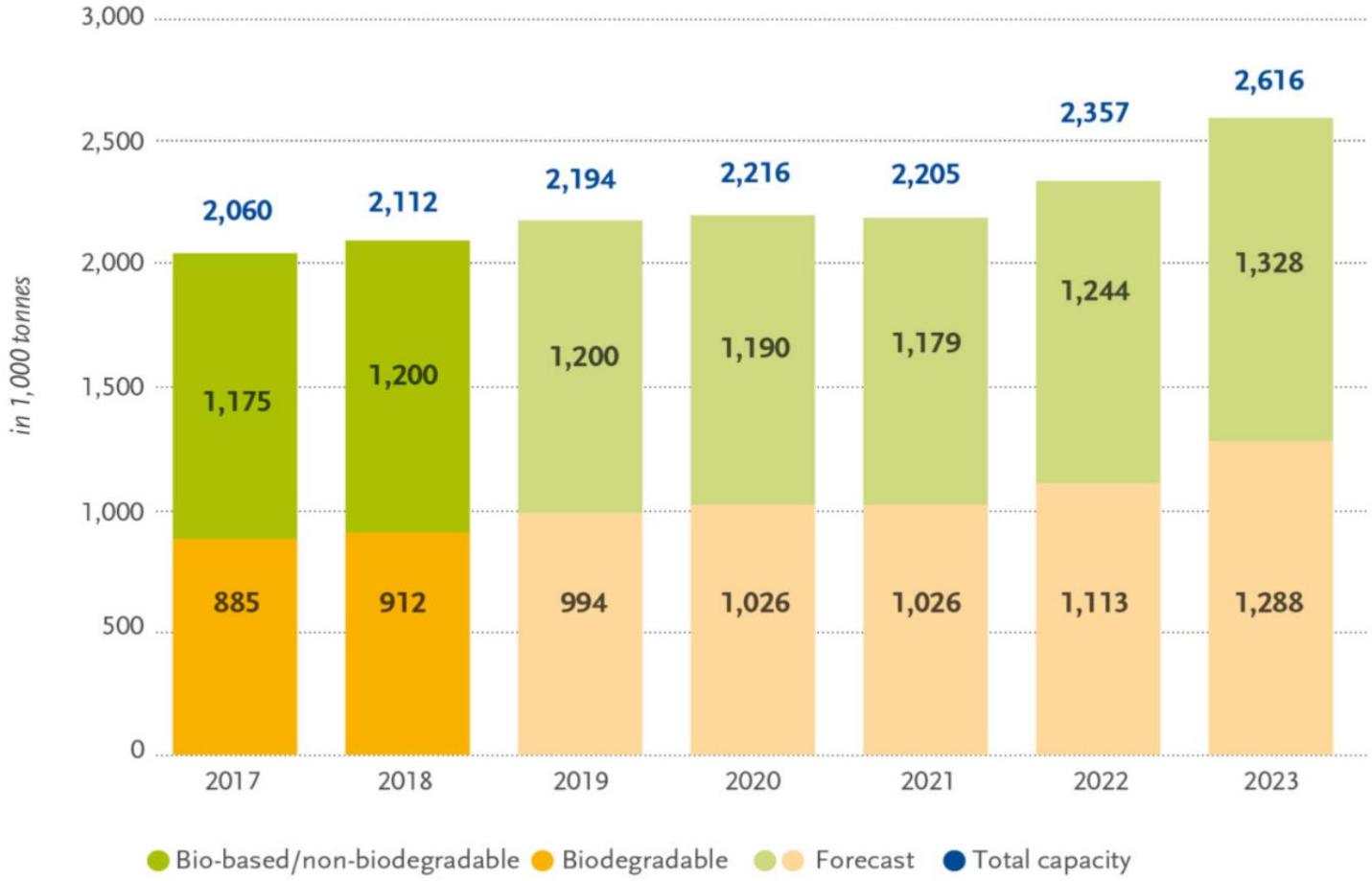
Global Production Capacities of Bioplastics (2017 – 2023)



Source: European Bioplastics, nova-Institute (2018)
More information: ***www.european-bioplastics.org/market*** *and* ***www.bio-based.eu/markets***

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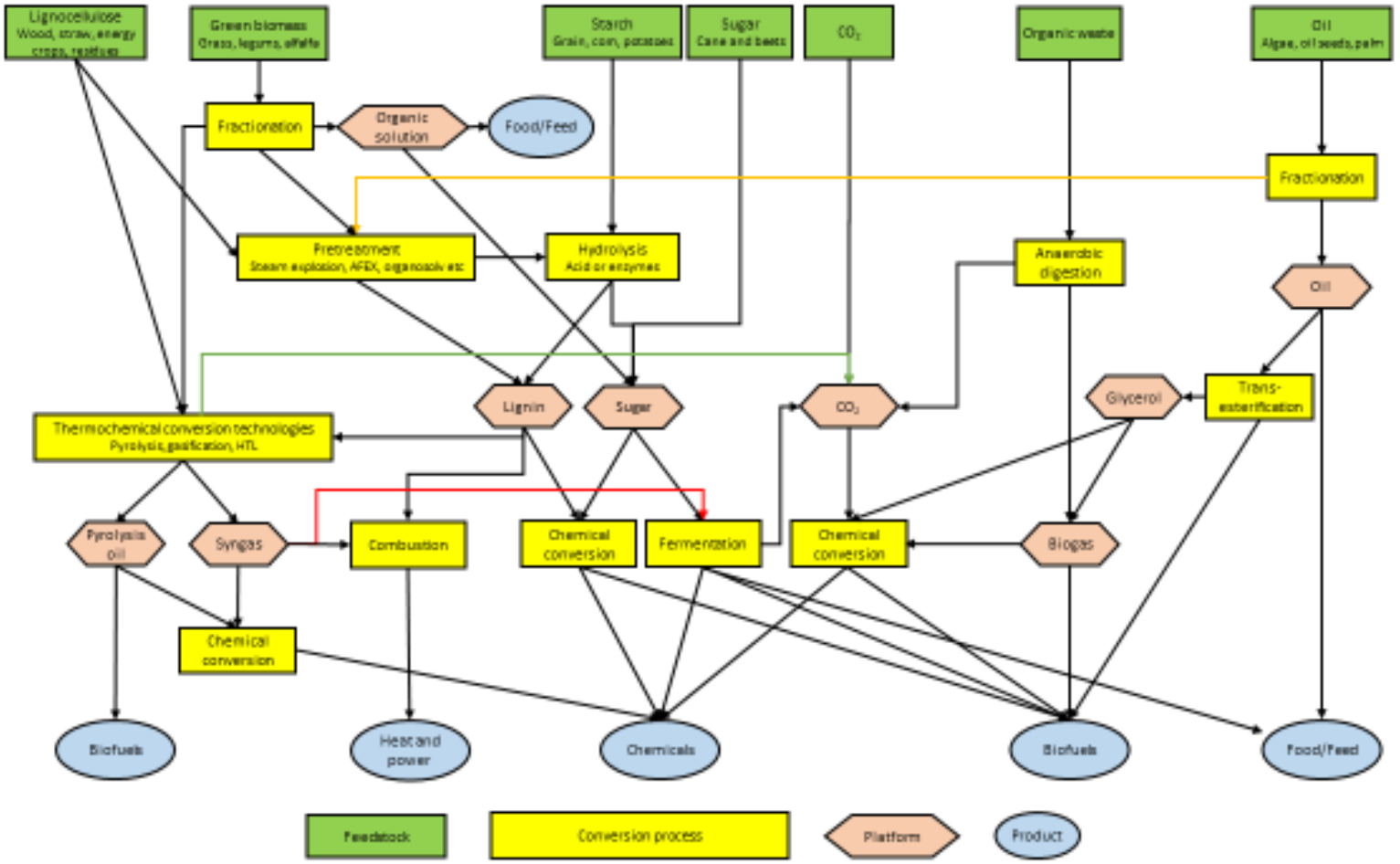
refining in a Future BioEconomy

Conversion technologies for biomass based on IEA Bioenergy Task 42 biorefinery classification system



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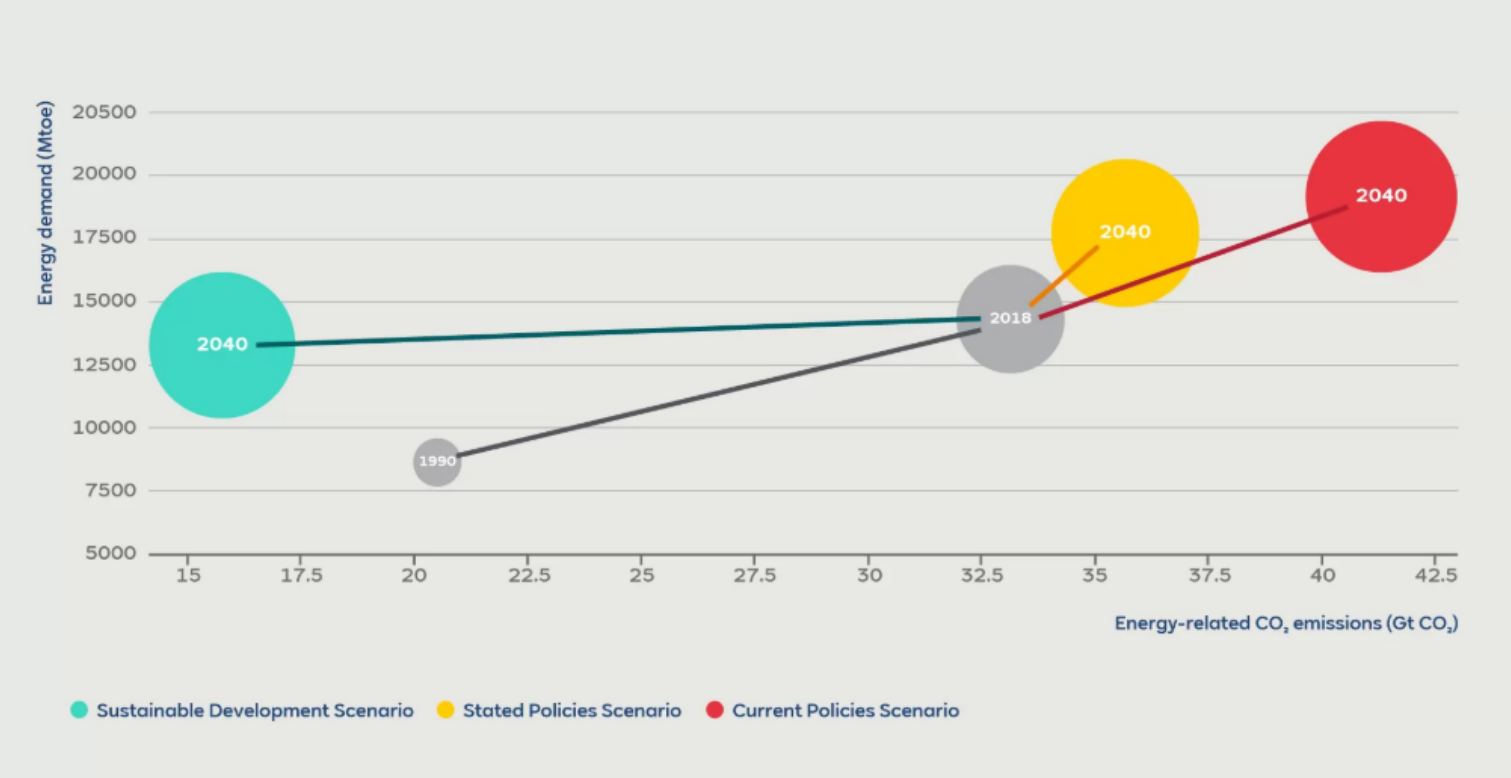
Dominant Platforms

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

World primary energy demand and energy-related CO_2 emissions by scenario.

Bubble size represents size of global economy



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Required policy actions, consumer behaviour change and technological progress identified by IEA Bioenergy Task 42

Scenario	Sustainable Development Scenario
Policy	• High CO_2 price > 100 $/t • Fossil subsidies are gone • Net CO_2 sequestration incentivised • Circular economy is mandatory • Sustainable forestry and agriculture is mandatory
Technology	High progress: • In up- and downstream processes for bio-based feedstock • Ethanol-to-chemicals • Green H_2- production • Widespread algae/ seaweed utilisation
Social acceptance	High acceptance of climate treat and for climate policy: • Agreement on biomass sustainability and biodiversity • Willingness to change behaviour • Willingness to pay for climate-friendly products • Open attitude to locations of facilities • Less meat demand (resulting in high feedstock availability)

Consequences for the scenarios with respect to more sustainable biobased economy identified by IEA Bioenergy Task 42

Scenario	Sustainable Development Scenario
Prices and renewable energy share	• High prices for GHG-intensive products • Share of electricity from renewable sources 100%, surplus electricity available
Feedstock availability	• No restrictions (1st, 2nd and 3rd generation are available)
Bio-based industries	• Biobased chemicals for all chemical products • Large scale lignocellulosic biomass utilisation • Extensive use of drop-in chemicals from biomass for existing industry • Biogenic CO_2-conversion to chemicals digestion

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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
			CO_2	Climeworks
2	Ethylene	Braskem	Ethyl acetate	Greenyug
	Ethanol	Many	Glycolic acid	Metabolix Explorer
	Ethylene glycol (MEG)	India Glycols Ltd, *HaldorTopsoe, UPM, Avantium*	Acetic acid	Wacker, Godovari Biorefineries Ltd
	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, UPM*	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	Cathay Industrial Bio, Green Biologics, *Celtic Renewables*	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, Fortress	Isoprene/Farnesene	Goodyear/ Genencor, GlycosBio, Amyris
	Glutamic acid	a.o. Global Biotech, Meihua, Fufeng, Juhua	Levulinic acid	GFBiochemicals, Synvina, Bio-on

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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
Competitive nature of market
Need for partnerships
Downstream development opportunities

Technology assessment

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

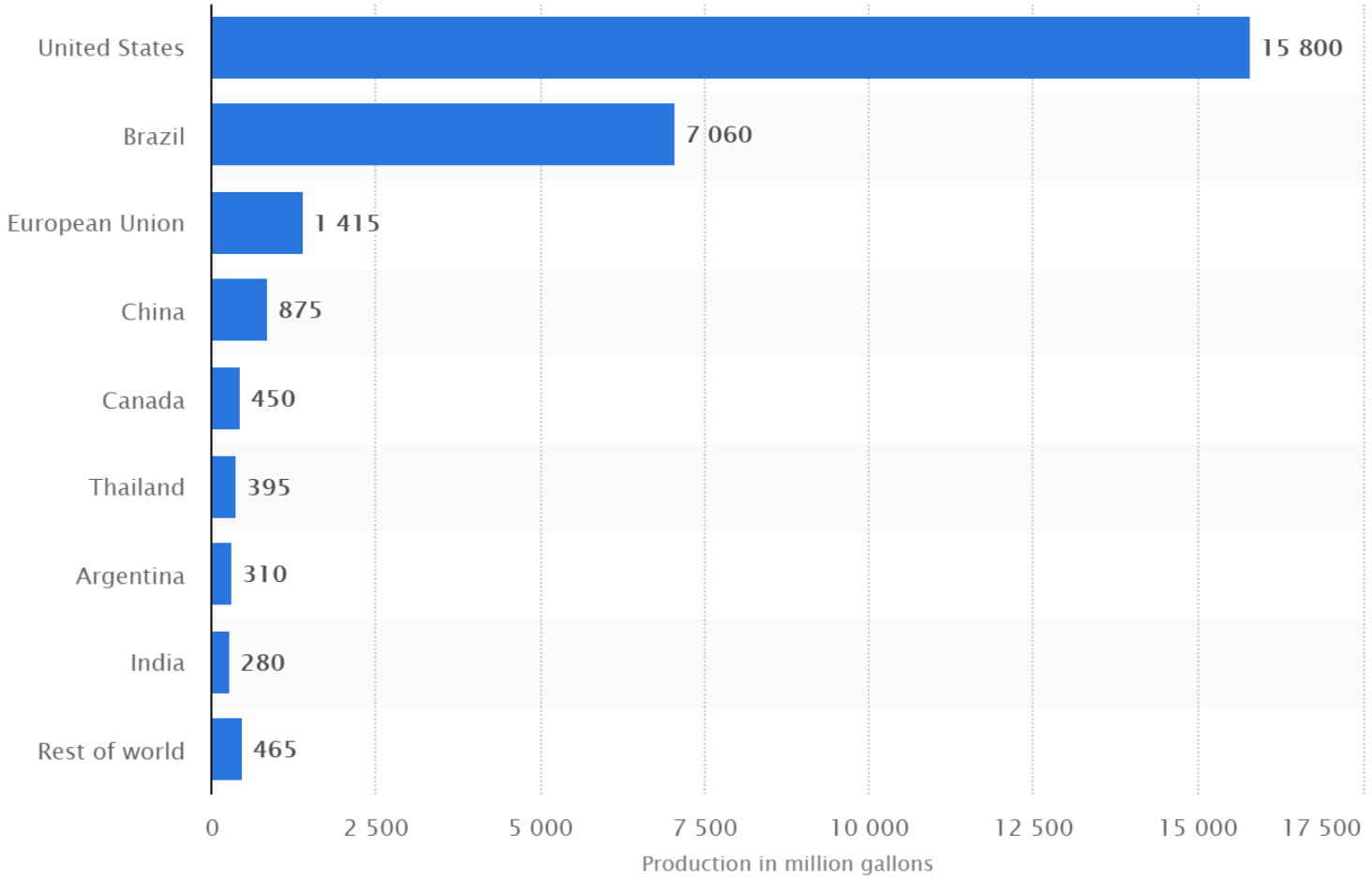
Drop-in versus New Functionality

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)	↑↑↑	↑↑↑↓↓↓

Global ethanol production in million gallons in 2017



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Biobased Chemicals - Strengths (SWOT analysis)

- Adding value to the use of biomass
- Maximising biomass conversion efficiency minimising raw material requirements
- Production of a spectrum of bio-based products (food, feed, materials, chemicals) and bioenergy (fuels, power and/or heat) feeding entire bioeconomy
- Strong knowledge infrastructure available to tackle technical and non-technical issues
- Biorefinery is not new, it builds on agriculture, food and forestry industries

Biobased Chemicals – Weaknesses (SWOT analysis)

- Broad undefined and unclassified area
- Involvement of stakeholders for different market sectors (agriculture, forestry, energy, chemical) over full biomass value chain necessary
- Most promising biorefinery processes / concepts not clear
- Most promising biomass value chains, including current/future market volumes/prices, not clear
- Studying and concept development instead of real market implementation
- Variability of quality and energy density of biomass
- Drop-in chemicals face difficult market penetration due to low oil prices

Biobased Chemicals - Opportunities

- Biorefineries can make a significant contribution to sustainable development
- Challenging national and global policy goals, international focus on sustainable use of biomass for the production of bioenergy
- International consensus on the fact that biomass availability is limited meaning that raw materials should be used as efficiently as possible
- International development of a portfolio of biorefinery concepts, including technical processes
- Strengthening of the economic position of various market sectors (e.g. agriculture, forestry, chemical and energy)
- Strong demand from brand owners for biobased chemicals
- Increased production of plant-based proteins for food and feed

Biobased Chemicals - Threats

- Economic change and volatility in fossil fuel prices
- Fast implementation of other renewable energy technologies feeding the market requests
- Bio-based products and bioenergy are assessed to a higher standard than traditional products (no level playing field)
- Availability and contractibility of raw materials (e.g. climate change, policies, logistics)
- (High) investment capital for pilot and demo initiatives difficult to find, and undepreciated existing industrial infrastructure
- Changing governmental policies
- Questioning of food/feed/fuels (indirect land use competition) and sustainability of biomass production
- Goals of end users often focused on single product

Conclusions

- Biobased Chemicals are essential to come to a circular economy
- Biochemcials production is currently slowly expanding
- Only in a few cases products are market competitive without subsidies at current oil prices
- Currently more traction for new functionality molecules than for drop-in molecules
- Multiple actions in the biobased chemicals space are needed to achieve the Sustainable Development Scenario

Dissemination

- Pdf version available on IEA Bioenergy Task 42 website (http://task42.ieabioenergy.com/publications/bio-based-chemicals-a-2020-update/)
- Feedback: Ed de Jong (ed.dejong@avantium.com)