European Commission

EU Biorefinery Outlook to 2030

Studies to support R&I policy in the area of bio-based products and services

FINAL PRESENTATION AND MEETING

Research and Innovation

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Contents

Introduction

Structure and objectives of the study

This project is part of three studies for The Directorate-General for Research and Innovation (DG RTD)

The overall objective is to provide a range of new information and analysis that will help identify **future policy directions, emerging technologies, societal demands, challenges and opportunities** in the fields of the Bioeconomy related to bio-based products and the bio-based innovation.

Hence, DG RTD has commissioned three studies on support to R&I policy in the area of bio-based products and services:

LOT 1 – Carbon economy

LOT 2 – Life and biological sciences and technologies as engines for bio-based innovation

LOT 3 – Biorefinery pathways and outlook for deployment (lot 3) “EU Biorefinery Outlook to 2030”

The study can be used to help make decisions & take actions to accelerate biorefinery deployment to 2030

AIM: To provide an **outlook for chemical and material driven biorefineries** enabling **stakeholders** such as the scientific community, industry (primary producers and manufacturers), investors, policymakers, and NGOs to take the present-day **decisions** necessary **to shape the future** sustainable bioeconomy

The study’s seven WPs meet the objectives of the EU Biorefinery Outlook to 2030 study…

✔ **Describe, categorise** and **develop** a robust **classification system** for different types of biorefineries and the products they could produce considering the needs of a range of stakeholders, including policy and decision makers in the EU and regional level	*WP1*
✔ **Report** on the **status of biorefinery development** and the **markets** for related bio-based chemicals and materials	*WP 4 & 5*
✔ **Determine** the **attractiveness of different bio-based products** and their **market potential** (demand) based on **drivers** and benefits of **chemical and material driven biorefineries**, bio-based products and the applications and markets they could access	*WP 2 & 5*
✔ **Identify** the technical and market **barriers** that need to be overcome to commercialise biorefineries	*WP 2 & 3*
✔ Identify the **R&D&I needs** of biorefinery pathways and future **policy actions** that could incentivise their uptake	*WP 3 & 6*

...and result in a roadmap and outlook for deployment to 2030

- Develop **scenarios** for the **potential ramp up of biorefinery deployment** in Europe **to 2030** taking into consideration technology, market and resource considerations as well as considering the **policy lines** of the European Green Deal
- Develop a **roadmap for biorefinery deployment in the EU to 2030** segmented by biorefinery **pathways**, including the number of biorefineries, installed **capacity** by volume and **capital investment** in new biorefinery construction, **type of actions** required by different actors, and impact in terms of **sustainability** (GHG savings potential) and **societal benefit** (local jobs)
- Engage relevant **stakeholders** in activities aimed at meeting above objective and develop **communication materials** to effectively communicate the outputs of the study

WP5

WP6 with inputs from WP 1-5

Stakeholder Engagement & WP7

The study will be disseminated through partners websites, stakeholders, social media, and conferences

- The "**EU Biorefinery Outlook to 2030**" report will be made available for download from the dedicated webpage https://www.e4tech.com/biorefinery-outlook.php together with a link to the project **video**
- The study results will be disseminated by consortium partners through the **partners organizations' social media and websites**. Sister projects will be approached by ICONS
- The **database** will be published by the **JRC and BTG via a dashboard** and short technical **report**
- All the **participants in the workshops and SAG meetings** will be informed
- As of February 2021, participation to the following events is planned:
  - **Moving Towards a Competitive European Bioeconomy: Emerging Biorefinery Technologies & Pathways to Deployment** (virtual conference) – 17/02/2021;
  - **EUBCE 2021** (WP4 database presentation led by JRC and BTG - virtual conference) – 26-29/04/2021
  - **Renewable Materials Conference 2021** (TBC - abstract submitted) – 18-20/05/2021.
- Shared to online **external news multipliers** with distribution agreement with ICONS.

EU Biorefinery Outlook to 2030 video

A consortium of 5 partners has developed the study over 14 months with 8 stakeholder events...

WP1 — WAGENINGEN UNIVERSITY & RESEARCH
Biorefinery classification
Classification system for chemical and material driven biorefineries

WP4 — btg
EU and global biorefinery deployment
Database of key companies and their associated plants, existing and planned

WP2 — btg
Drivers and barriers for biorefineries
General and specific drivers and barriers for chemical and material focused biorefineries

WP3 — WAGENINGEN UNIVERSITY & RESEARCH
Available and emerging biorefinery technologies and R&I needs
Analysis of different biorefinery pathways and R&D&I needs to overcome the barriers

WP5 — FNR, E4tech
Market prospects for biorefineries and scenarios to 2030
Demand outlook for biochemicals and biomaterials and supply ramp up for biorefineries

WP6 — E4tech
EU biorefinery outlook and roadmap for deployment
A roadmap with the actions needed to achieve the biorefinery outlook for deployment

WP7 — ICONS
Information and communication strategy
Communication of the project's results and key actions for stakeholders to drive the deployment of biorefineries

Stakeholder engagement meetings and workshops (green)

Meetings with the EC (orange)

January 2020 · March 2020 · May 2020 · July 2020 · September 2020 · November 2021 · February 2021

..incorporating input from over 100 stakeholders through meetings, workshops and interviews

Format of contribution:

- Recommendation and reference to important reports, pilot plants, frameworks and laws
- Introduction of expert contacts
- Validation of the project findings (i.e. classification, pathways, barriers & drivers, roadmap)

→Ensure that final roadmap is taken up, disseminated and implemented

The main comments and support were given by the SAG members whereby some comments aligned with those made by the EC.

Engagement Formats

Stakeholder Advisory Group meetings

Stakeholder Workshops

Semi-Structured Expert Interviews

EU policy context

Policy frameworks and strategies impacting the tender study

A circular biobased economy is important to help build a sustainable future and meet the EU Green Deal's targets

EU Bioeconomy Strategy 2018

- The study supports the **action** to **facilitate** the **development and deployment of new sustainable biorefineries**.
- **Biorefineries** have the potential to play an **important role** for the development of a **carbon-neutral economy**.
- Biorefineries **can increase EU security** of **raw materials** and improve business opportunities by creating local jobs.

Biodiversity Strategy

Farm-to-Fork Strategy

EU GHG reduction by min. 55% by 2030 compared to 1990 levels

Circular Economy Action Plan

- This study can help **inform policy** and biorefinery deployment can help achieve **objectives** at EU level

This study focuses on biorefineries producing high value biobased chemicals and materials

Biorefineries producing non-traditional bio-based chemicals and materials complement existing alternatives to support the development of a climate neutral economy.

Fuels and energy focused biorefineries	*Out of scope*
Bio-based chemicals and materials driven biorefineries	*In scope*
Traditional biomass processing facilities (e.g. pulp & paper)	*Out of scope*
Recycled carbon and CO_2-based chemicals and materials	*Out of scope*
Co-processing of chemicals and materials in existing facilities	*Covered at high level*

The BIO-TIC roadmap published in 2015 projects the development of 300 new biorefineries by 2030

- The European Commission's Bioeconomy Strategy supports the deployment of biorefineries in the EU
- The definition of biobased chemicals and materials driven biorefineries is important when comparing different studies

Biorefinery Outlook ***overall new 42 biorefineries 2020-2030***		BIO-TIC Roadmap ***overall new 300 biorefineries 2008-2030***
• Focus on biorefineries producing **bio-based chemicals and materials** • Analysis of period from 2020 -2030 • Estimate of new biorefineries which can **realistically be deployed** by 2030	**VS**	• **Wider scope** of types of biorefineries considered • Analysis of period from 2008 -2030 • Estimate of **new biorefineries needed** to meet the estimated **demand**

Biorefinery classification and definition of pathways

For this study, the IEA's classification system was modified and extended to a classification system applicable for chemical and material driven biorefineries

FEEDSTOCK	CONVERSION PROCESS	PLATFORM	PRODUCT
Primary biomass • Aquatic biomass • Lignocellulosic from croplands and grasslands • Lignocellulosic wood/forestry • Oil crops • Starch crops • Sugar crops • *Other **Secondary biomass** • Microbial biomass • Residues from agriculture • Residues from aquatic biomass • Residues from forestry • Residues from nature and landscape management • Residues from recycled bio-based products • *Other	**Biochemical** • Aerobic conversion • Anaerobic digestion • Enzymatic process • Fermentation • Insect-based bioconversion • *Other **Chemical** • Catalytic • Esterification • Hydrogenation • Hydrolysis • Methanation • Chemical Pulping • Steam reforming • Water electrolysis • Water gas shift • *Other **Mechanical and thermomechanical** • Blending • Extraction • Mechanical & thermomechanical disruption & fractionation • Mechanical pulping • Separation processes • *Other **Thermochemical** • Combustion • Gasification • Hydrothermal liquefaction • Pyrolysis • Supercritical conversion • Torrefaction & Carbonization • *Other	• Biochar • Bio-coal • Bio-crude • Biogas • Bio-oils • Bio-hydrogen • Bio-naphtha • C5/C6 sugars • Carbon dioxide • Lignin • Oils • Organic fibers • Organic juice • Protein • Pyrolytic liquid • Starch • Syngas • *Other	**Chemicals** • Additives • Agrochemicals • Building blocks • Catalysts & Enzymes • Colorants • Cosmeceuticals • Flavours & Fragrances • Lubricants • Nutraceuticals • Paints & Coatings • Pharmaceuticals • Solvents • Surfactants • *Other **Materials** • Composites • **Fibers • Organic Fertilizers • Polymers • Resins • *Other **Food** **Animal Feed** **Energy** • Cooling agents • Fuels • Heat • Power • *Other

* 'Other' is included to enable new concepts, technologies or product categories to be included.
** 'Fibres' group can be extended to subgroups e.g. textile fibres, paper and board fibres, carbon/specialty fibres and other fibres.

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11 Biorefinery Pathways have been distinguished based on different platforms used; 4 mature (A-D) and 7 still under development (E-K)

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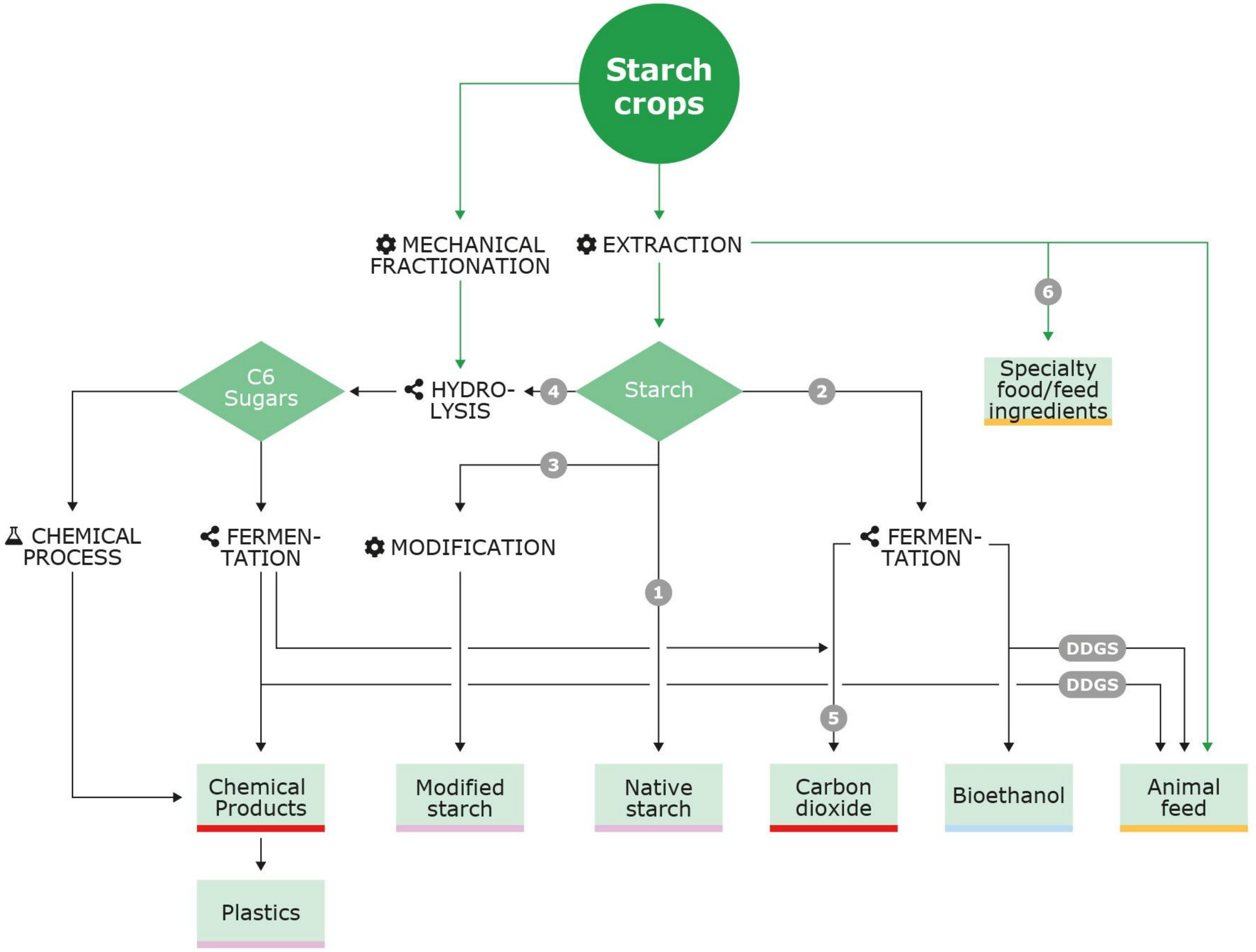
		Name	Feedstocks	Conversion Processes	Platforms	Products
Bottom-up approach	A	One platform (C6 sugars) biorefinery using sugar crops	Sugar crops	Extraction, fermentation, (chemical conversions)	C6 sugars	Chemicals, polymers, food, animal feed, ethanol (building block or fuel), CO_2, power and heat
	B	One platform (starch) biorefinery using starch crops	Starch crops	Extraction, fermentation, (hydrolysis, chemical conversions)	Starch	Chemicals, (modified) starches, polymers, food, animal feed, ethanol (building block or fuel) and CO_2
	C	One platform (oil) biorefinery using oil crops, wastes and residues	Oil crops, waste/residue fats, oil and greases[a]	Pressing, transesterification, (hydrolysis, chemical conversions)	Oil	Chemicals (fatty acids, fatty alcohols, glycerol), food, animal feed, fuels (biodiesel and renewable diesel)
	D	Two-platform (pulp and spent liquor) biorefinery using wood	Lignocellulosic wood/forestry	Mechanical processing, pulping, combustion, (separation, extraction, gasification)	Pulp, spent liquor	Materials (pulp and paper, specialty fibres), chemicals (turpentine, tall oil, acetic acid, furfural, ethanol, methanol, vanillin), lignin, power and heat
Top-down approach	E	Three platform (C5 sugars, C6 sugars and lignin) biorefinery using lignocellulosic biomass	Lignocellulosic crop, wood/forestry, residues from agriculture and forestry	Pre-treatment, hydrolysis, fermentation, combustion, (thermo-/ chemical conversions)	C5 sugars, C6 sugars, lignin	Chemicals, lignin products (materials, aromatics, pyrolytic liquid, syngas), ethanol (building block or fuel), power and heat
	F	Two-platform (organic fibres and organic juice) biorefinery using green biomass	Green biomass[b]	Pressing, fiber separation, anaerobic digestion, combustion, (upgrading, separation)	Organic fibres, organic juice	Materials, chemicals (lactic acid, amino acid), animal feed, organic fertilizer, fuels (biomethane, ethanol), power and heat
	G	Two-platform (oil and biogas) biorefinery using aquatic biomass	Aquatic biomass	Extraction, anaerobic digestion, combustion, esterification, (hydrolysis, chemical conversions)	Oil, biogas	Chemicals (fatty acids, fatty alcohols, glycerol), nutraceuticals, food, organic fertilizer, biodiesel, power and heat
	H	Two-platform (organic fibres and oil) biorefinery using natural fibres	Natural fibres (e.g. hemp, flax)[b]	Fiber separation, extraction, (chemical conversions)	Organic fibres, oil	Materials, chemicals (fatty acids, fatty alcohols, glycerol), nutraceuticals, cannabinoids, food and biodiesel
	I	One platform (syngas) biorefinery using lignocellulosic biomass and municipal solid waste	Lignocellulosic biomass[c], MSW	Pretreatment, gasification, gas conditioning, chemical conversions	Syngas	Chemicals (methanol, hydrogen, olefins), waxes and fuels (F-T biofuels, gasoline, LNG, mixed alcohols)
	J	Two platform (pyrolytic liquid and biochar) biorefinery using lignocellulosic biomass	Lignocellulosic biomass[c]	Pyrolysis, separation, combustion, (gasification, cracking, extraction)	Pyrolytic liquid, biochar	Pyrolysis oil (for materials, chemicals, food flavorings, syngas, biofuels), biochar, power and heat
	K	One platform (bio-crude) biorefinery using lignocellulosic, aquatic biomass, organic residues	Lignocellulosic biomass[c], organic residues, aquatic biomass	Hydrothermal liquefaction, upgrading	Bio-crude	Chemicals and fuels

a Waste/residue fats, oils and greases belong to category "Other organic residues"
b Green biomass and Natural fibres belong to category "Lignocellulosic from croplands and grasslands"
c Lignocellulosic biomass includes Lignocellulosic from croplands, wood/forestry and residues from agriculture and forestry

Example of a Biorefinery Pathway

Biorefinery pathways encompass the different process variants.

The process variants show development of the pathways towards generation of multiple valuable products for multiple markets.



PROCESS VARIANTS

1. Separation of (native) **starch**. Fibres and proteins containing residues attained as by-products are used as **animal feed**. Native starch is used in the food industry or for technical applications.
2. Alternatively, native starch is further processed into **bioethanol** by saccharification and fermentation. Bioethanol fermentation residue DDGS is used as **feed**.
3. Expansion of the product spectrum with **modified starches**. Native **starch** is modified chemically or physically for the production of starch modifications. Starch can also be used in producing biodegradable starch derived thermo-plastics.
4. The hydrolysis of starch yields **C6 sugars**. **C6 sugars** can be used for production of bioethanol or other **chemicals** – such as polyols and for the synthesis of surfactants (so-called alkyl polyglycosides, APG) and other fermentation products. Also use as precursor for bioplastics as described in pathway A.
5. The **carbon dioxide** generated during fermentation process is conditioned and attained as a co-product.
6. Production of specialty **food and animal feed ingredients** from the by-products.

A high-level comparison assessment of the production of 8 case study bio-based products with their fossil alternatives shows both advantages and disadvantages …

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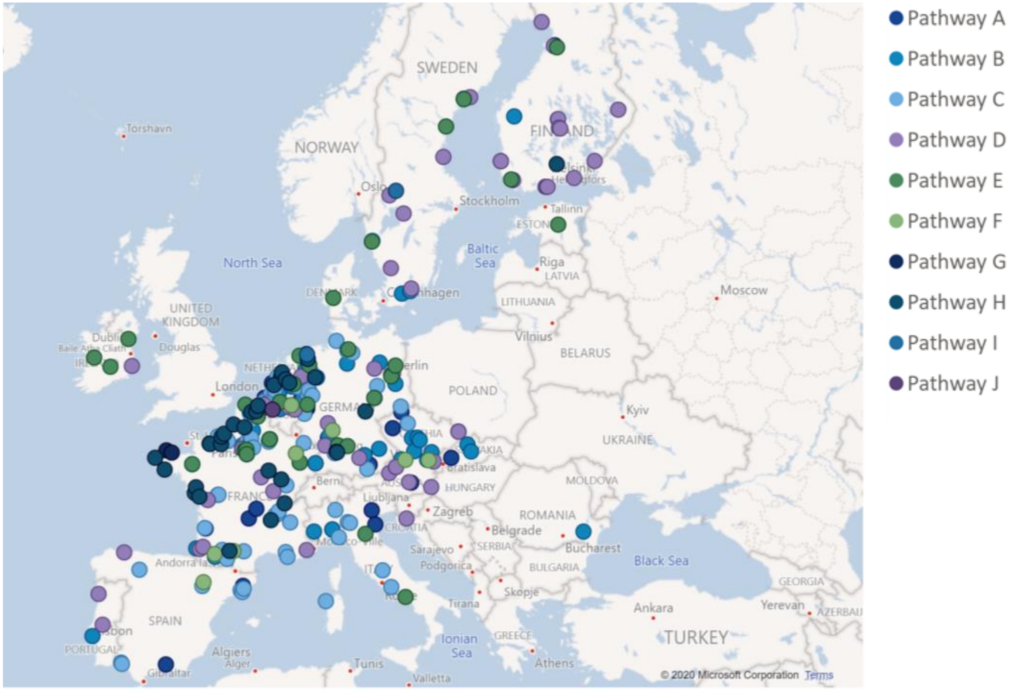
Biobased chemical/material		Drop-in or Dedicated	Biorefinery pathways		Alternative (fossil or CO_2 based) pathways		Advantages/disadvantages to fossil alternatives: Technical performance	Environmental performance	Economic performance	Other considerations
Biobased chemicals										
Additive	Propylene glycol (PG)	Drop-in	C A/B/E	glycerol hydrogenolysis sugar hydrogenolysis	Fossil	hydration of propylene oxide	Identical	about 60% GHG reduction (pathway C); 100% bio-based	Cost competitive (CC)	• Use of oil crops (deforestation), need to switch to waste fats • Competes with the energy use of residue crude glycerol
Building block	1,4 Butanediol (1,4 BDO)	Drop-in	A/B/E	fermentation of sugars	Fossil	via acetylene, butadiene, maleic anhydride and propylene	Identical	about 60% GHG reduction (pathway B); 100% bio-based	Not CC (less than double)	• Use of sugar or starch crops (now), need to switch to lignocellulosic biomass
Building block	Methanol	Drop-in	D I	purification of side-stream gasification, chemical conv.	Fossil CO_2	coal gasification & natural gas + steam reforming reaction with hydrogen from electrolysis	Identical	about 40% GHG reduction compared to NG (pathway I from MSW); 100% bio-based	Cost competitive (CC)	• Allow valorisation of residues and wastes, support waste hierarchy and the circular economy • MSW - use for energy supported, compete with material use
Building block	Lactic acid (LA) + PLA	Dedicated	A/B/E	fermentation of sugars	Fossil	PP/PS/PET, derived from steam cracking of naphtha	Unique, both pos. & neg.	about 70% GHG reduction (pathway A or B); 100% bio-based	Not CC	• Biodegradable & recyclable • High biomass utilization efficiency • Use of sugar or starch crops, need to switch to lignocellulosic
Solvent	Acetic acid	Drop-in	A/B/E D I	fermentation of sugars Extract from spent liquor carbonylation of methanol	Fossil CO_2	via methanol, acetaldehyde and alkane via methanol	Identical	about 85% GHG reduction (pathway D); 100% bio-based	Not CC	• Direct fermentation route will increase efficiency for A/B/E • Pathway D option allows creating value from residual stream • Use of methanol or ethanol for chemical instead of energy use
Surfactant	Fatty alcohol ethoxylate	Drop-in	C + A/B/E	reaction of fatty alcohol from oils + ethylene oxide from sugars	Fossil	fatty alcohol by Oxo or Ziegler process + ethylene oxide derived from steam cracking of naphtha	Identical	lower environmental footprint (pathway A/B+C); 100% bio-based with bio-ethylene oxide use	Not CC	• Biodegradable and low toxicity • Use of oil crops (deforestation), need to switch to waste fats • Use of sugar or starch crops, need to switch to lignocellulosic
Biobased materials										
Fibre	Microfibrillated cellulose (MFC)	Dedicated	D	fibrillation of cellulose	Fossil	plastic films and aluminium foil	Unique, performance enhancer	lower GHG emissions; 100% bio-based	Good prospect	• Provide the same performance using less raw material • Possibility to use agricultural residues beside wood pulp
Resin	Lignin based phenolic resins	Dedicated	D E J	recovery from black liquor pretreatment lignocellulose pyrolysis oil lignin fraction	Fossil	Phenol-based	Unique, same performance	about 45% GHG reduction (pathway D); up to 50% phenol substitution	Cost competitive	• Reduced toxicity of resin • Allow material use of lignin • Possibility to use lignocellulosic residues rather than wood

Current deployment of biorefineries

EU and global biorefinery deployment has been identified and analysed

Objective: To provide an analysis of European (and global) biorefinery construction and planned development based on the biorefinery classification (WP 1), and construct a database in line with the classifications system

Key result: A database was developed containing over 400 chemical and material driven biorefineries at commercial or demonstration scale in the EU and 10 non-EU countries[1]. Approximately 300 of these are in the EU.



Chemical and material driven biorefineries are **widely distributed** across the EU, particularly Western and Central Europe.

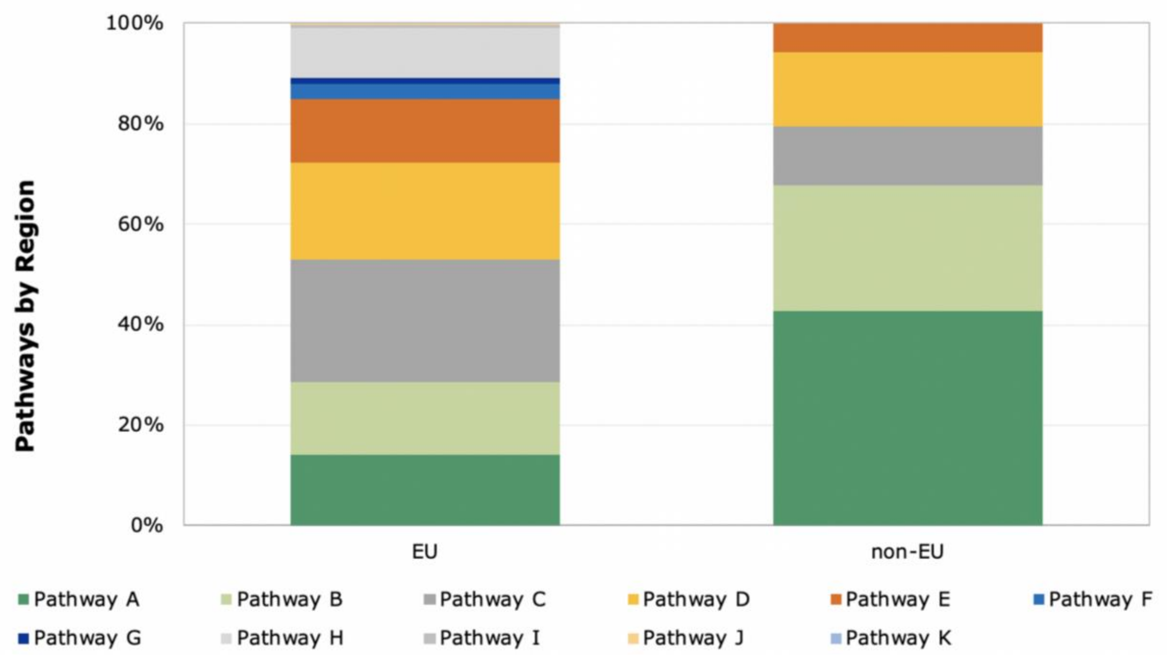
[1]Norway, Switzerland, United Kingdom, USA, Canada, Australia, New Zealand, Japan, Brazil, China, India and Thailand

Pathways using food/feed crops and lignocellulosic wood/ forestry dominate; more so in non-EU biorefineries

Pathways most prominent in the EU are the C6 sugar and starch platform (A and B) and the oil platform (C). These pathways – utilizing food and feed crops - together account for 56% of all biorefineries in the EU.

The pulp and spent liquor pathway (D) makes up nearly 20% of biorefineries in the EU. Most biorefineries in this pathway use secondary feedstocks

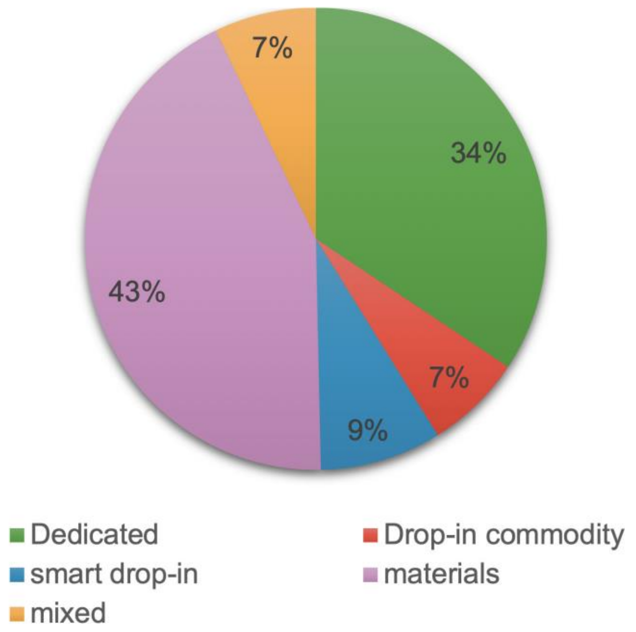
A-D make up over 80% of non-EU biorefineries identified in the database; more so than for the EU biorefineries



Distribution of pathways by region (%), EU vs. Non-EU

Existing biorefineries produce drop-ins, smart drop-ins and dedicated products

Percentage of EU biorefineries producing a certain product



From the biorefineries that produce chemical products, most produce dedicated bio-based chemicals. However, there are also a lot of biorefineries that produce drop-in, smart drop-in or a combination.

All the three bio-based product options (drop-in, smart drop-in and dedicated) **appear to be able to compete in their market segments**

The databased was developed based on the JRC platform. Together with the JRC, it will be made widely available. Information on non-EU biorefineries could be made available through IEA Task 42

Barriers to deployment

Key drivers and barriers for biorefinery deployment were identified and analysed

btg biomass technology group

Objective: to provide a comprehensive and structured analysis of the barriers & drivers that pertain to biorefineries as classified in WP 1.

Key results: A comprehensive and structured overview and analysis of key drivers and barriers was developed, structured around seven relevant categories. General drivers and barriers were elaborated, as well as specific drivers and barriers – focused on 10 product groups. All results were verified in stakeholder meetings and interviews

Relevant categories

1. Business (perspective, models, etc.)
2. Innovation (advancing technology)
3. Economic (growth, jobs, etc.)
4. Access to feedstock (availability, flexibility, etc.)
5. Environmental (CO_2 mitigation, ...)
6. Societal (personal health, ..)
7. Policy and regulation

Product group	Chemical/Material
Additives	1,2-Propylene glycol
lubricants	
Solvents	
Surfactants	
Fibres	Microfibrillated cellulose
Polymers & Plastics	Thermoplastic starch & Lactic Acid
Building blocks	1,4-butanediol
Building blocks	Lactic acid
Building blocks	Methanol
Resins	Lignin based phenolic resins

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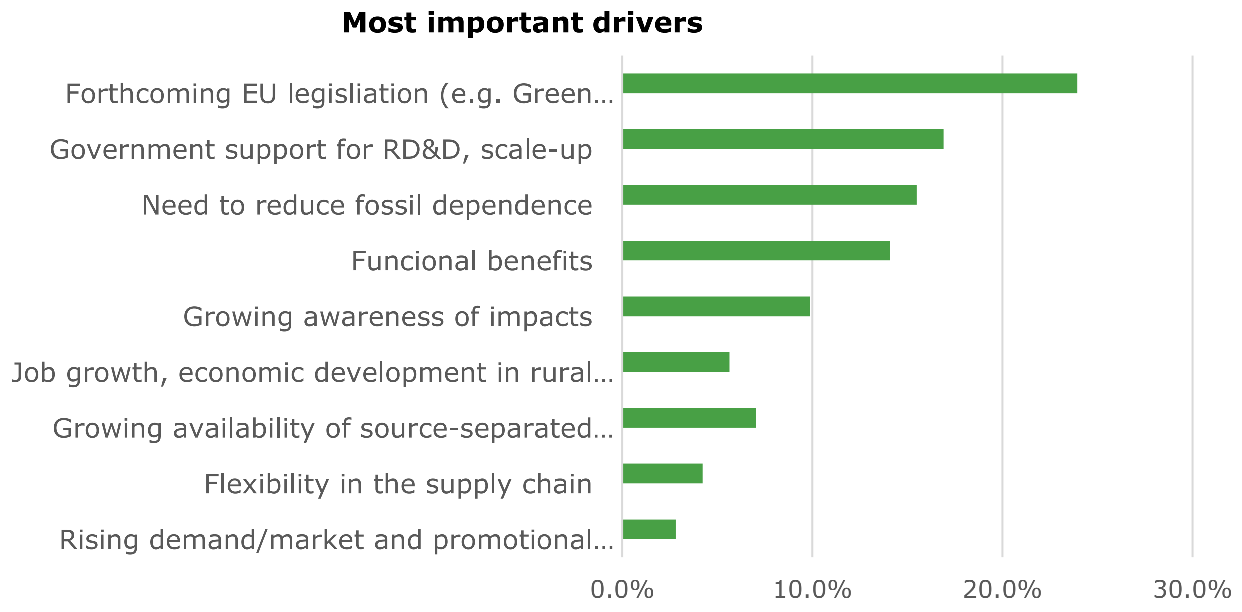
Building blocks	Lactic acid
Building blocks	Methanol
Resins	Lignin based phenolic resins

Stakeholders identified the main drivers as EU legislation and government support…

General **drivers**:

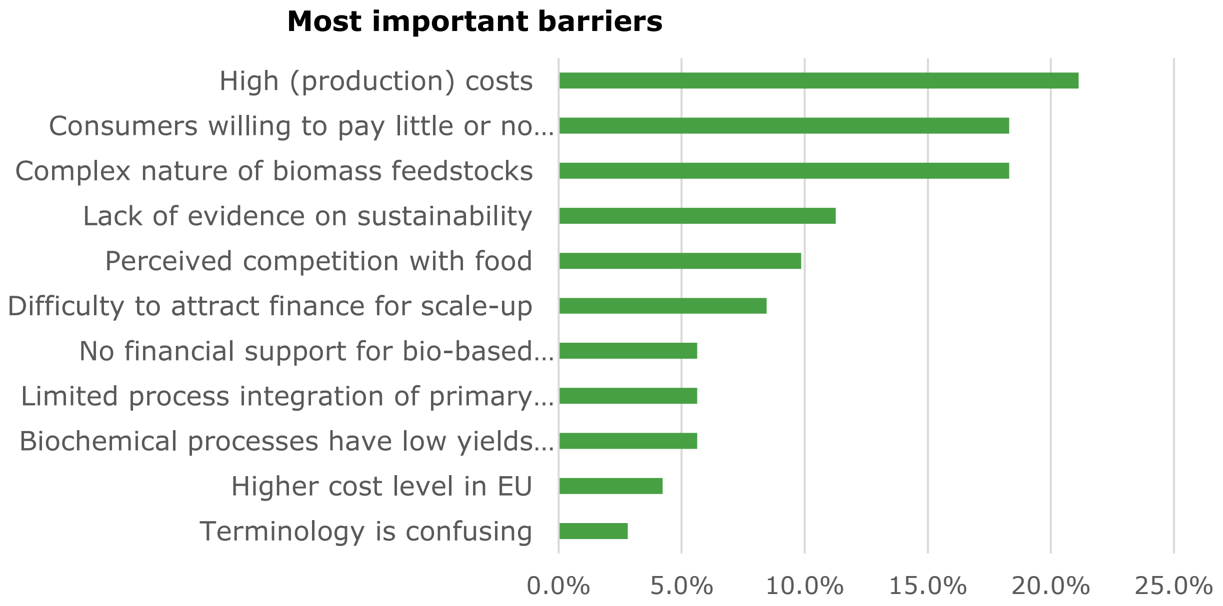
- The ***need to reduce dependency on fossil materials and products and GHG emissions*** Biobased products can have ***functional benefits,*** and/or environmental benefits, like replacing fossil materials, and lower toxicity and/or biodegradability.
- Governmental support such as ***EU Green Deal*** and support for ***RD&D and scale-up***
- There is ***growing awareness of the impacts***, *e.g. on* ***jobs and economic growth****,* thus giving rise to ***rising demand***
- ***Feedstock flexibility*** and a ***growing availability of source-separated waste***



...and the main barriers as economic viability and scale-up related challenges

Non-technical barriers:

- The lack of economic viability, due to the gap between the ***market's willingness to pay little or more*** for bio-based products and their ***high production costs***. Also, there is **lack of financial support for biobased products**, and the ***lower competitiveness of EU biorefineries on the world market***
- Achieving plant scale up is challenging, because of the ***level of investment required,*** coupled with technology, market risk, and fossil competition is hindering financing
- There is in many cases a ***lack of evidence*** on the full life-cycle ***sustainability***
- Concerns regarding certified ***sustainable feedstock supply*** and



Technical barriers were identified: complex feedstock nature, novel conversion processes, improve infrastructure towards product price competitiveness

General technical barriers grouped into:

- **Feedstock related:**
  - Feedstocks are **complex mixture of organic compounds** (inorganics and vast amount of water **require the use of different pre-treatment/valorisation processes**).
  - **Infrastructural barriers** associated with the development of the European agricultural infrastructure (harvesting, collection and storage of the biomass and for residues/wastes management).
- **Conversion process related:**
  - Conversion processes **must overcome significant costs and productivity barriers**. Develop of a new set and combinations of conversion pathways, processes, and design of novel catalytic processes.
- **Platform and product related**
  - Technical developments to improve and **improve product technical performance, price and assurance of real environmental benefits**. Price competitiveness is also expected to improve via economies of scale, when the products are produced at large scale.

RD&I needs identified: more efficient and flexible process in the value chain & enhancement of bio-based products benefits

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RD&I needs to overcome technical and non-technical barriers for 10 products.

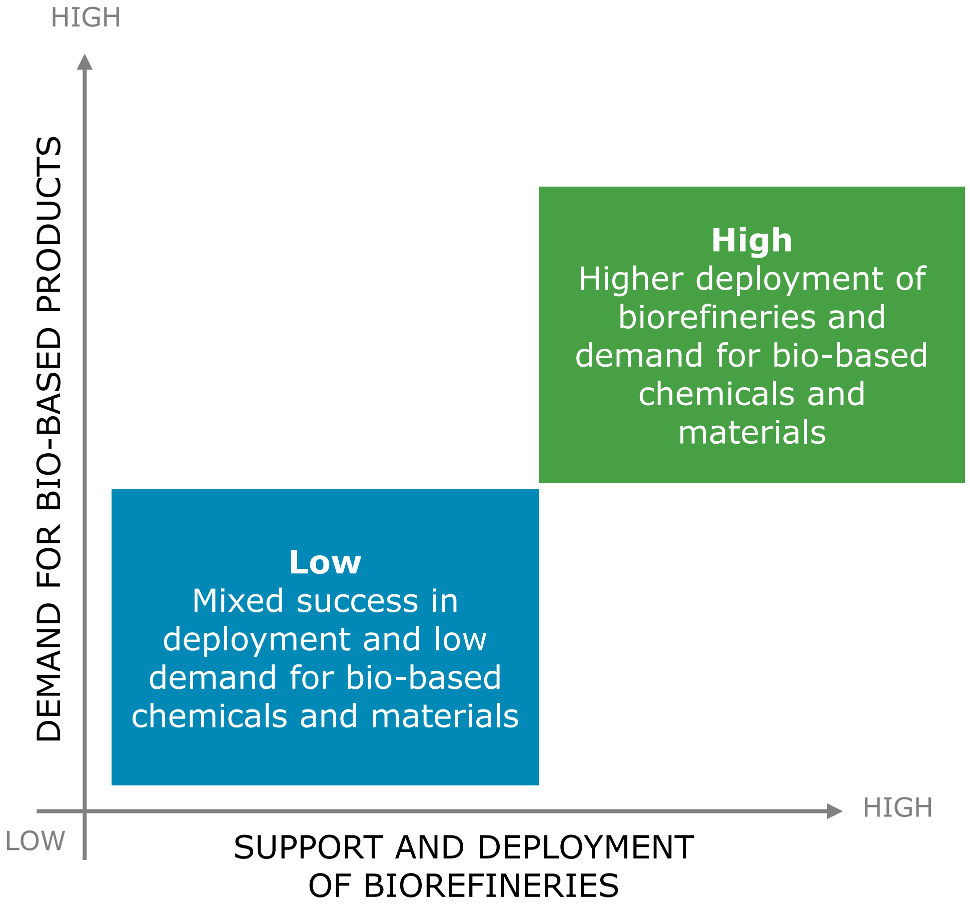
- **Financial support necessary over the full RD&I-trajectory** because of the relatively low TRL (fundamental research, applied research and piloting, demonstration and market support .
- **Develop robust, feedstock flexible, biorefining technologies and logistical systems** (transport, storage) to process the full European available biomass potential, to meet a varying feedstock market demand (volumes over time and place, right quality).
- **Develop primary technologies to convert low-quality biomass feedstocks** in higher quality intermediates that meet the processing requirements of biorefining technologies.
- **Develop more energy efficient and product selective secondary biorefinery processes** (fermentation, gasification, incl. DSP) to increase market competitiveness.
- Development of a clear and understandable **assessment approach**, **efficient communication strategy to enhance market acceptance and consumer awareness.**

Market prospects for biorefineries - demand

We have defined two scenarios to help understand what is possible by 2030

Two scenarios are:

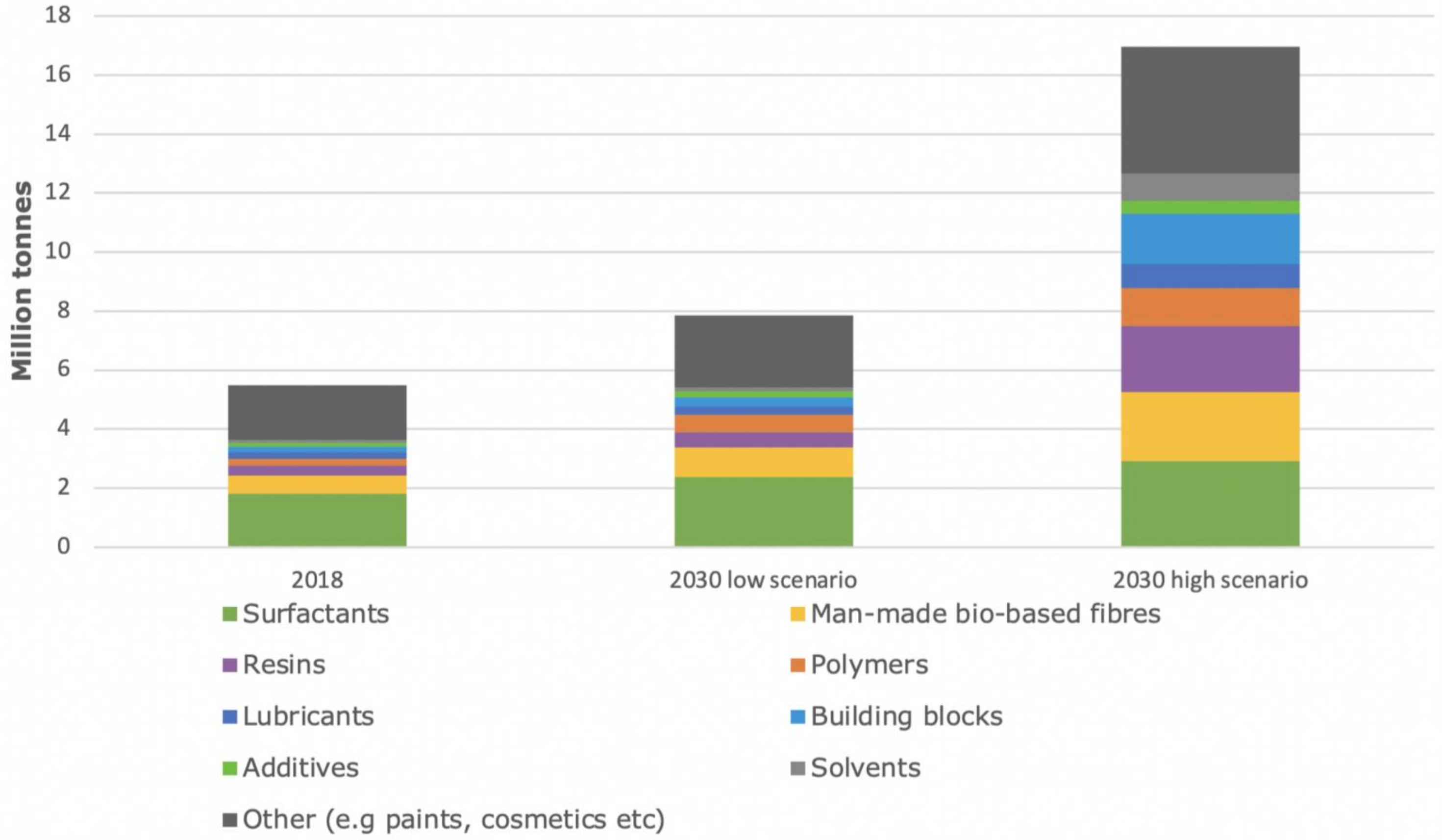
- the **high** case represents higher support and deployment for biorefineries and increased market share as a result of stronger drivers (i.e. significant growth of biochemical and biomaterial demand)
- the **low** scenario represents low increases in demand for bio-based chemicals and materials in the EU and mixed success in future deployment of biorefineries (baseline case - limited additional actions taken by stakeholders)



Demand for bio-based products 2019, and 2030 low- and high scenario: demand could triple by 2030

High growth scenario
- Potential demand can grow at 9.9% in average per year to over **16 Mtpa**
- Positive macroeconomics drive positive developments for all products
- **Policy incentives** will place drop-in and dedicated solutions with identical properties of traditional fossil-based products in a **competitive position**

Low growth scenario
- Low growth scenario could **reach 7.8 Mtpa only**
- **Slow economic growth** and **missing policy incentives** lead to business as usual
- Highest growth expected for **biopolymers** due to **brand driven** developments and **consumer awarenes**s



- Product groups definitions correspond to the JRC study. Not the complete bio-based market is covered.
- Production of paper and board is not included into the product groups.
- Fibres are limited to man-made fibres.

Results from different WPs on the 10 case study products are presented in Case Study formats

BUILDING BLOCK

1,4-Butanediol (BDO)

BDO is a industrial chemical used as solvent and building block to produce plastics, elastic fibres and polyurethanes. BDO is biodegradable and mostly produced through fossil-based pathways. Bio-Based BDO is a drop-in product which could replace fossil BDO since it is chemically identical. It is produced from fermentation of sugars (attained from Pathways A, B or E).

PERFORMANCE

Bio-Based BDO can be produced 100% bio-based. BDO is toxic and BDO derivatives come with health and safety issues. BDO is biodegradable and does not accumulate in nature. Fermentation of bio-based BDO is an energy intensive process. LCA conducted conclude on bio-based BDO that Green House Gas emissions can be reduced by 60% across the life cycle compared with fossil-based BDO. Bio-BDO is identical to fossil-based bio-BDO (i.e. has the same molecular structure). It offers direct drop-in replacement for fossil BDO. It is not currently not cost competitive with fossil-based BDO.

DRIVERS AND BARRIERS

Driver

- Increased use of biodegradable films (e.g. in agriculture)

Barrier

- Regulatory provisions (e.g. EU fertilizer regulation) currently not sufficient
- potential to increased use of BDO in automobile industry not realised due to lack of standardization

ROADMAP ACTIONS

Bio-based 1,4 BDO can be produced by pathways A, B or E. The roadmaps for these pathways include actions for stakeholders to take to scale up these pathways including the production of 1,4 BDO.

MARKET OUTLOOK

The production of bio-based and biodegradable plastics used e.g. used as agricultural mulch films can be a major driver for BDO, especially if supported by policy and regulation. There is a review of the EU fertilizer directive in 2024, which provides a window of opportunity to add such mulching films to the list of accepted polymers for soil improvement. A recent analysis, which already considered the implications of the COV19 pandemic, estimates the global CAGR for BDO with 6.2% and within Europe forecasts a 4.4% CAGR.

EU BIOREFINERY DEPLOYMENT

The 10 case study products are:

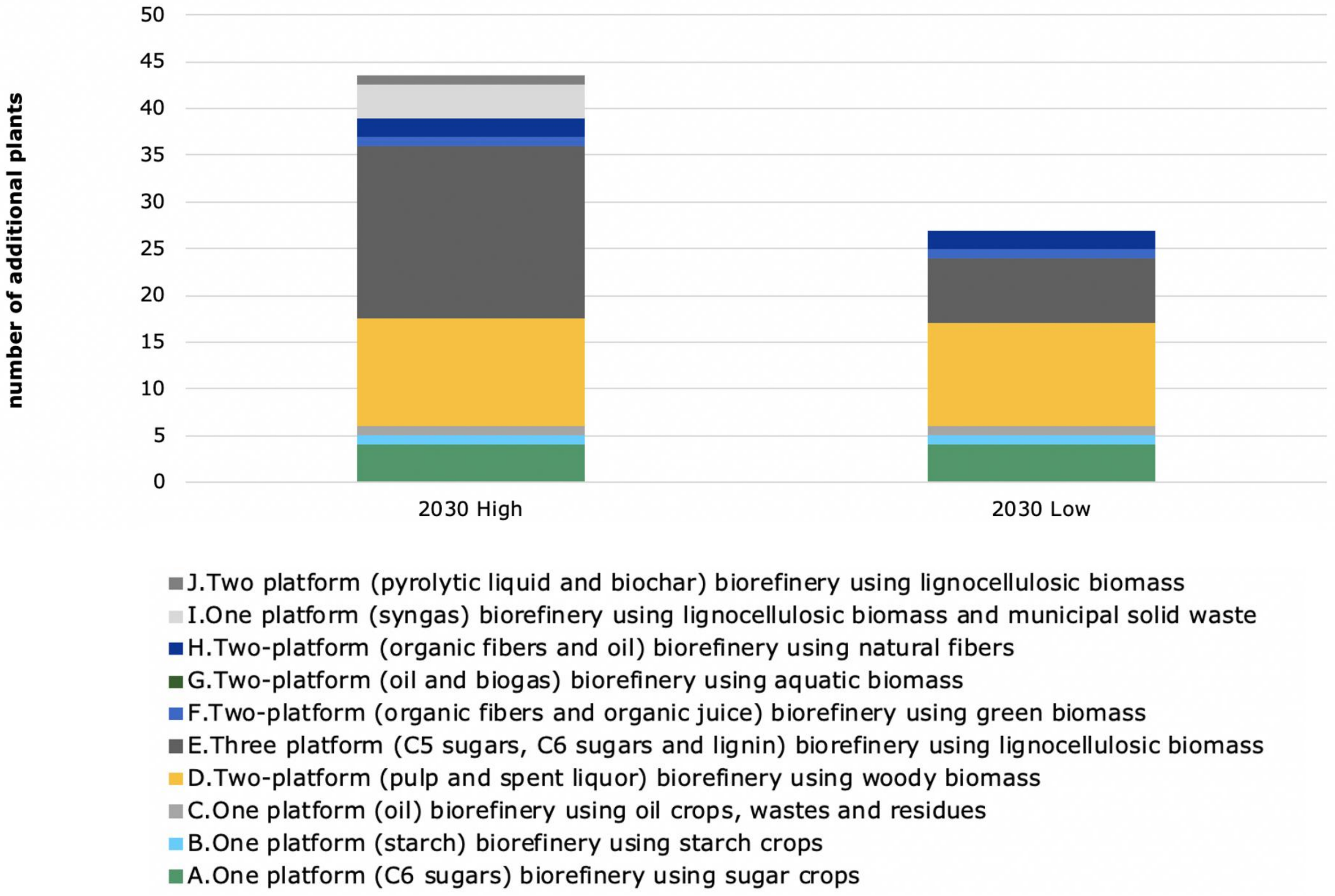
1. 1,4 butanediol
2. Acetic acid
3. Biomethanol
4. Fatty acid PEG esters
5. Fatty alcohol ethoxylate
6. Lactic acid
7. Lignin based phenolic resins
8. Microfibrillated cellulose
9. Thermoplastic starch
10. Propylene glycol

Deployment of EU biorefineries to 2030

Supply ramp up growth scenarios

The ramp up supply model only considers the potential growth rate of biorefineries by 2030

- High growth scenario predicts 44 additional biorefineries by 2030
- Low growth scenario predicts 27 new biorefineries by 2030
- Pathways D and E contribute most new biorefineries in both scenarios
- The ramp up potential of specific pathways depends on ongoing activities and market trends.

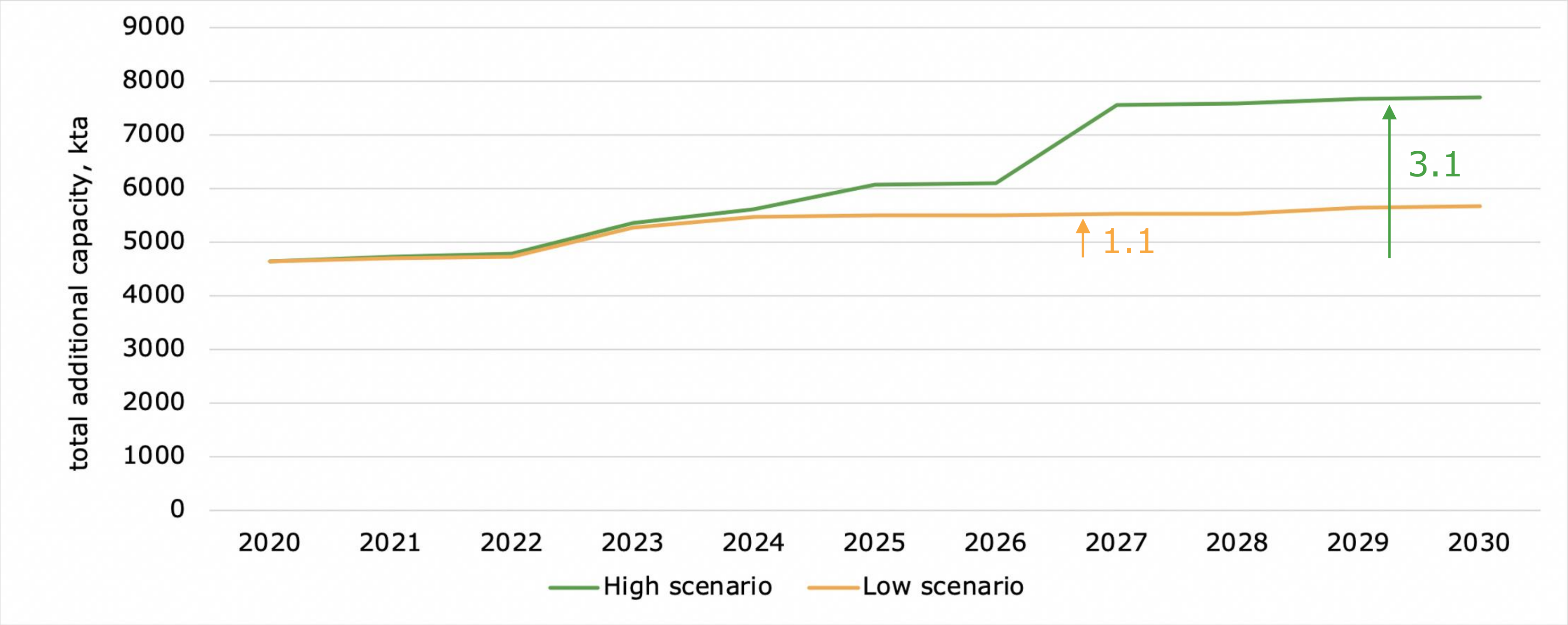


Ramp up of additional plants by 2030 by pathway, high and low growth scenarios

Advanced biofuels could be sold into the chemicals and materials sectors supporting biorefinery deployment

- Some biorefinery pathways share their products with advanced biofuels. Under the **high scenario assumptions,** these are assumed to be built and supply a **proportion to the chemicals sector** as well as the fuels sector.
    - Pathways A, B and E all can produce ethanol
    - Pathway D and I produce biomethanol
    - Pathway J produces pyrolysis oil
- This option is considered in the model since these plants presents several opportunities for increased ramp up of biobased chemicals and materials supply in the EU
    - **Potential large supply of biochemicals**, but currently the willingness to pay does not exist
    - Electrification of road transport suggests a **risk of decreasing market for liquid biofuels,** therefore the potential to partially focus on chemicals and downstream materials.
        - It will also be important to consider in developments to the Renewable Energy Directive (RED II) and the demand for Sustainable Aviation Fuels
    - **Reduced investment risk** since these biorefineries could have two major target markets

In the high scenario, new or expanded biorefineries could add 3.1 million tonnes, and 1.1 million tonnes in the low scenario by 2030

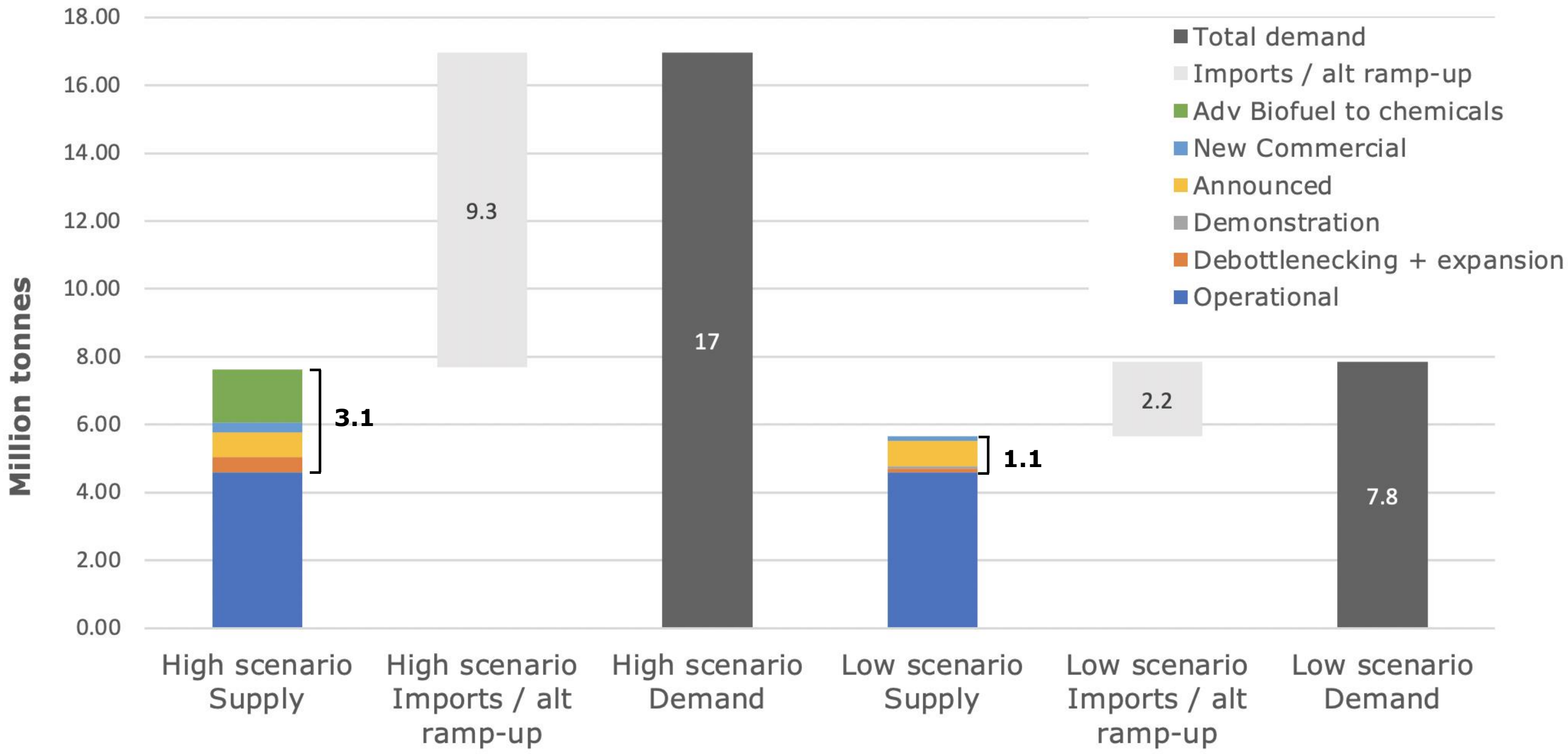


Overall EU biochemicals and biomaterials focused refinery ramp up, high and low scenario.

Only demonstration scale and larger biorefineries (i.e. TRL 8-9) are expected to have an impact on the biorefinery deployment levels by 2030

- The output presents the production capacity by year to demonstrate the progressive ramp-up EU biorefineries between 2020 and 2030
- The current supply of from EU chemicals and materials based biorefineries is estimated at 4.6 million tonnes.

For both scenarios, the EU demand could be higher than the projected supply in 2030

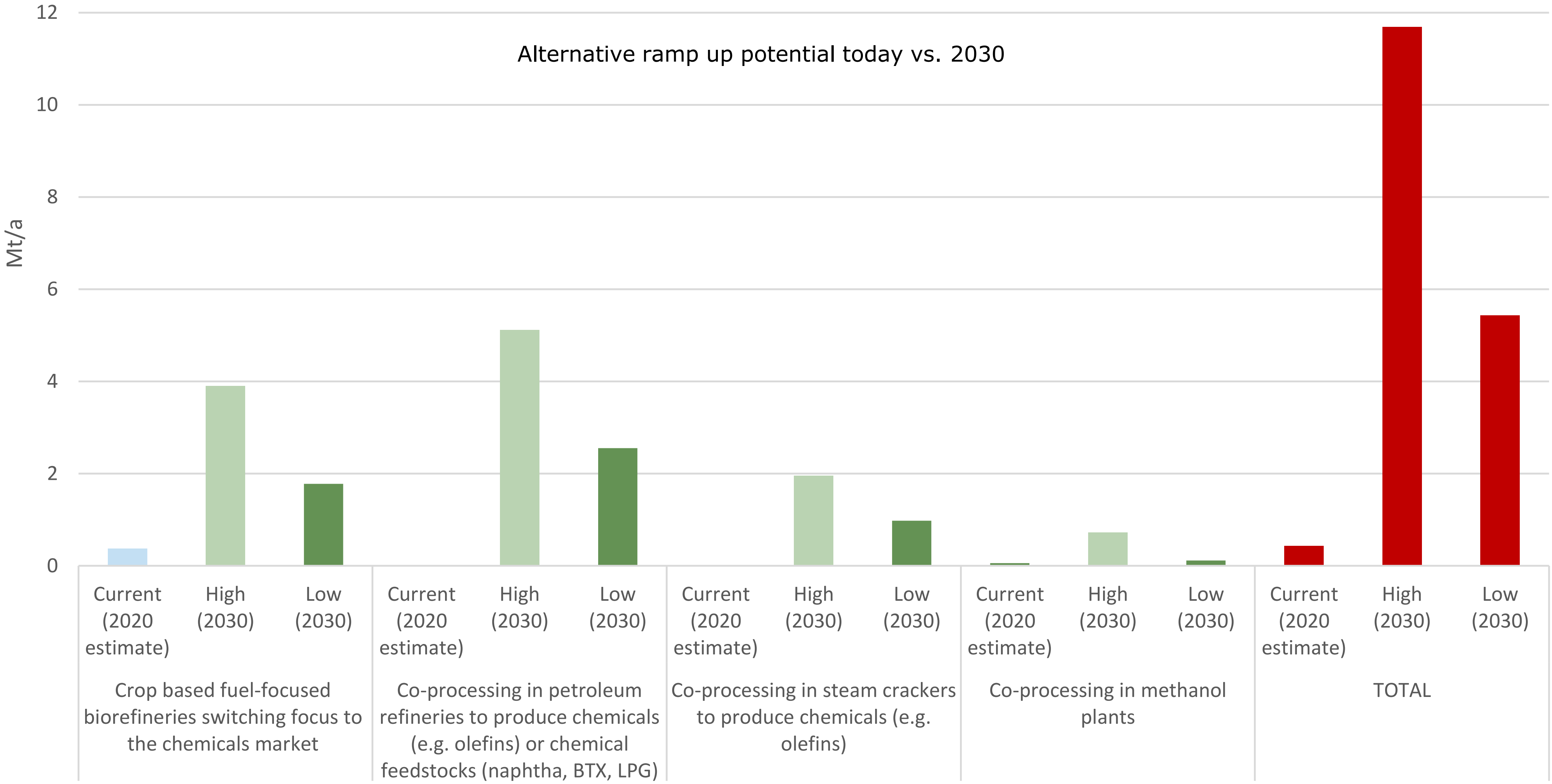


Demand vs. Supply of biochemicals and biomaterials in the EU in 2030.

The shortfall in supply could be met through imports from non-EU countries and/or supply from alternative (alt) ramp-up routes

- **Crop based fuel driven biorefineries** switching focus to the chemicals market
- **Co-processing** in petroleum **refineries** to produce chemicals (e.g. olefins) or chemical feedstocks (naphtha, BTX, LPG)
- **Co-processing** in **steam crackers** to produce chemicals (e.g. olefins)
- **Co-processing** in **methanol** biorefineries

Fuel driven biorefineries and co-processing could be key supply sources of chemical and materials



*Current co-processing of bio-based feedstocks in steam crackers is unknown and not all co-processing in methanol plants has been captured in the 2020 estimate.

Roadmaps

Stakeholders and policy makers need to take action to accelerate towards the high deployment scenario

- The roadmap **actions** aim to **overcome barriers** to increase the likelihood of **reaching** the **outlook for deployment**

Actions are segmented by barrier groups and are listed in order of importance as indicated by stakeholders in WPs 2 and 3

Stakeholder type

- Policy makers
- Bio industry & associations
- Chemical/material industry & Industry associations
- Academia & Research institutions
- NGOs & Civil societies
- Investment community

Action type

- Policy & regulation
- Support for RD&D and scale up
- Information and coordination

Policy M Bio I&A Chem/mats I&A A&R NGOs & CS Invest C

Policy & regulation is essential to close the large gap between the market's willingness to pay and costs

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Policy & regulation is required to achieve this through:

- **Policy** that supports **chemicals and materials** that provide **environmental benefits** (focused on GHG savings): bio-based, recycled, CO_2
  - GHG reduction targets, mandates (e.g. on products sold, in public procurement etc…), bans/reducing targets on use of fossil and non-recycled products, taxes on some fossil products and carbon
- Ensuring that **where production costs are higher** as a result of the above actions, **EU competitiveness is supported** (e.g. through the Carbon Border Adjustment Mechanism)
  - The requirement for this depends on which actions are taken

Policy & regulations need to be developed and implemented in 5 years to have an impact on 2030 deployment

2020 — 2025 — 2030

ECONOMIC

- Set EU sector targets for GHG reduction in EU chemicals and materials production
- Develop EU mandate for GHG reduction in chemicals and materials sold in the EU → Implement increasing EU mandate for GHG reduction in chemicals/materials sold in EU
- Develop EU mandate for bio/low GHG content for hard to recycle products → Implement EU mandate for bio/low GHG content for hard to recycle products
- Ban sale of selected non-recycled fossil-based products and/or set a reducing target for fossil material used
- Chemical producers and users set voluntary GHG reduction commitments
- Develop MS public procurement standards specifying bio, recycled or CO2-based products → Implement MS public procurement standards specifying bio, recycled or CO_2-based products
- Tax fossil input to chemicals and materials industries
- Reform EU ETS to increase CO_2 price
- Develop Carbon Border Adjustment Mechanism → Implement Carbon Border Adjustment Mechanism
- Consider CCU in the EU ETS
- Develop regional bioeconomy strategies

One of these actions is required at least – a GHG reduction mandate is recommended

If mandates on sales are **not** developed, these actions could help support biorefineries and EU competitiveness

Policy M | Bio I&A | Chem/mats I&A | A&R | NGOs & CS | Invest C

To achieve lower environmental impacts, the strategic direction should be focused on selected pathways

STRATEGIC DIRECTION	2020 – 2030
	Consider all biomass and land-using activities when setting strategies for each. For example, on circular economy, bioeconomy and food
	Set strategic objectives for the biorefinery sector overall including acceptable use of land and crops
	Policy design to enable non crop/ low land use impact routes

Policy & regulation **strategic direction** is required to:

- Develop **chemical and materials policies** alongside **other biomass and land uses policy** such as the Common Agricultural Policy (CAP), on biofuels, on the bioeconomy, the circular economy and Farm to Fork strategy, renewable energy, can overlap and conflict.
- **Scale up pathways** with **lower environmental impacts** that are currently more **expensive** and at an **earlier stage** of commercialisation

Policy M | Bio I&A | Chem/mats I&A | A&R | NGOs & CS | Invest C

Supporting Research, Development & Demonstration and feedstock sourcing can help accelerate cost reduction

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2020 2025 2030

ECONOMIC

- Support investigation of optimal use of EU biomass feedstock
- Conduct R&D focusing on cost reduction across all biorefinery pathways through continuing activities such as Horizon Europe, Circular Bio-based Europe and MS support
- Establish partnerships to develop biorefineries on existing industrial sites to reduce costs
- Improve process economics by identifying connections between different pathways and other industries
- Expand biomass/waste feedstock databases to identify low cost resources
- Harmonise bioproducts' sustainability requirements with existing schemes

Support for RD&D and scale up:

- **RD&D** on all pathways to bring **cost savings** (Horizon Europe, Circular Bio-based Europe, MS level support)

Information and coordination:

- **Lower costs** by developing on **existing industrial** sites
- **Connections** between different pathways
- Identification of **low-cost feedstock**

Policy M | Bio I&A | Chem/mats I&A | A&R | NGOs & CS | Invest C

Public finance for RD&D and scale up is crucial to commercialise lower TRL pathways by 2030

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Strategy | Energy | Sustainability

2020 | 2025 | 2030

SCALE UP OF NEW TECHNOLOGIES

- Continue EU public co-financing for pilot/demonstration plants
- Pilot plant data collection to help develop early stage TEAs and modelling
- Reduce scaling up costs by making available/providing support for shared facilities
- Ensure classification of biorefinery projects under the EU's Sustainable Finance Taxonomy
- Increase equity investment in companies
- Implement grant/ loan scheme for feasibility studies
- Additional support for new technologies such as sub-targets or subsidy for limited volumes of products from new pathways
- Invest in enhancing the engineering know-how of academic research teams

- **Sustainable Finance Taxonomy** Draft Act **excludes** the use of **food and feed crops** for bio-based chemicals and plastics
- **Requirements** for financing **need** to be carefully considered to **ensure sustainability** without **unnecessarily restricting biorefinery development**

Support for RD&D and scale up actions focus on **ensuring** the level of **investment required** is provided, by co-financing with public funds via equity in companies and financing projects, as well as reducing costs through supporting shared facilities

Policy M | Bio I&A | Chem/mats I&A | A&R | NGOs & CS | Invest C

Environmental benefits need to be measured and broadly understood by all stakeholders

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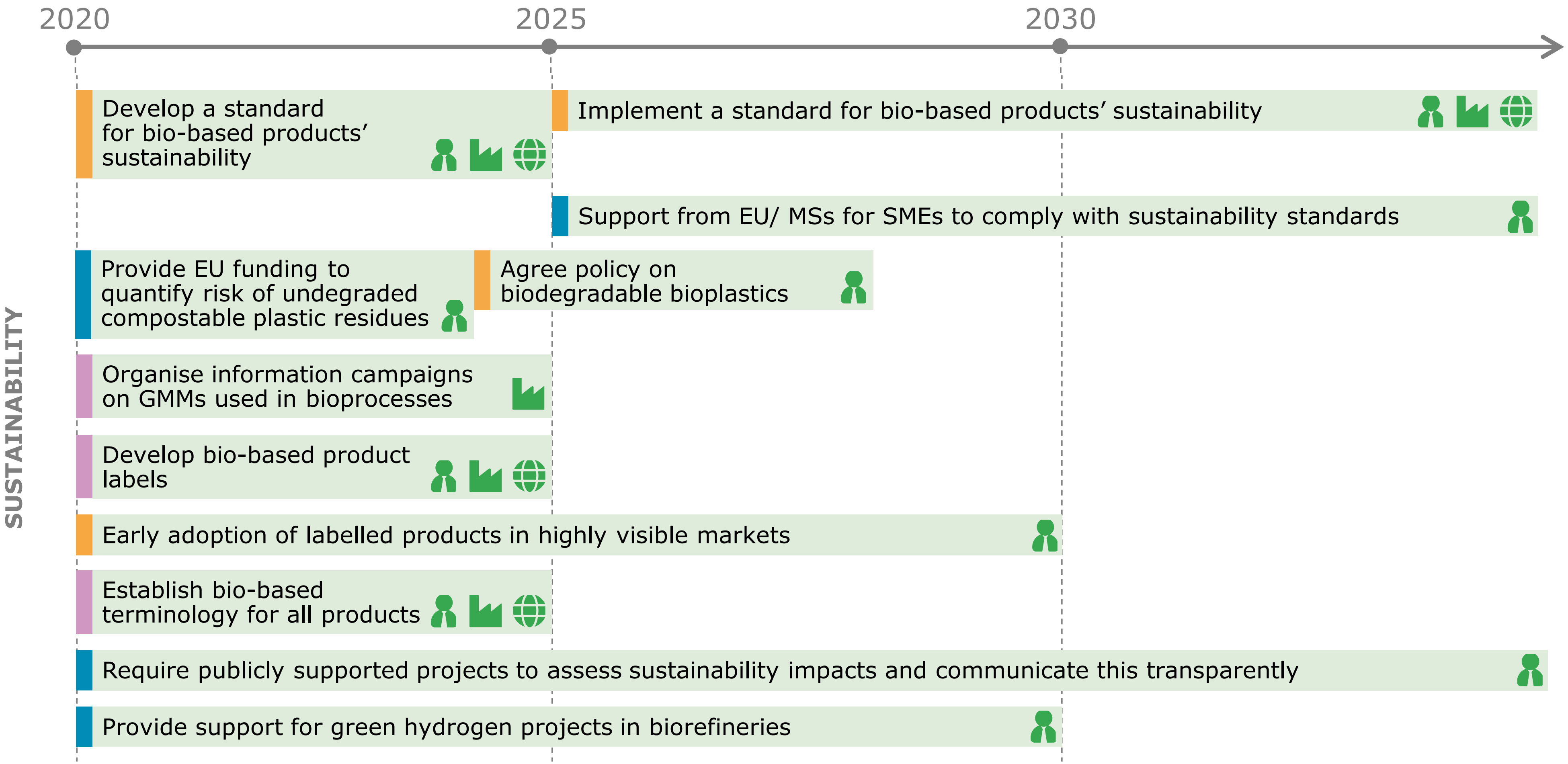
Strategy | Energy | Sustainability



Policy M Bio I&A Chem/mats I&A A&R NGOs & CS Invest C

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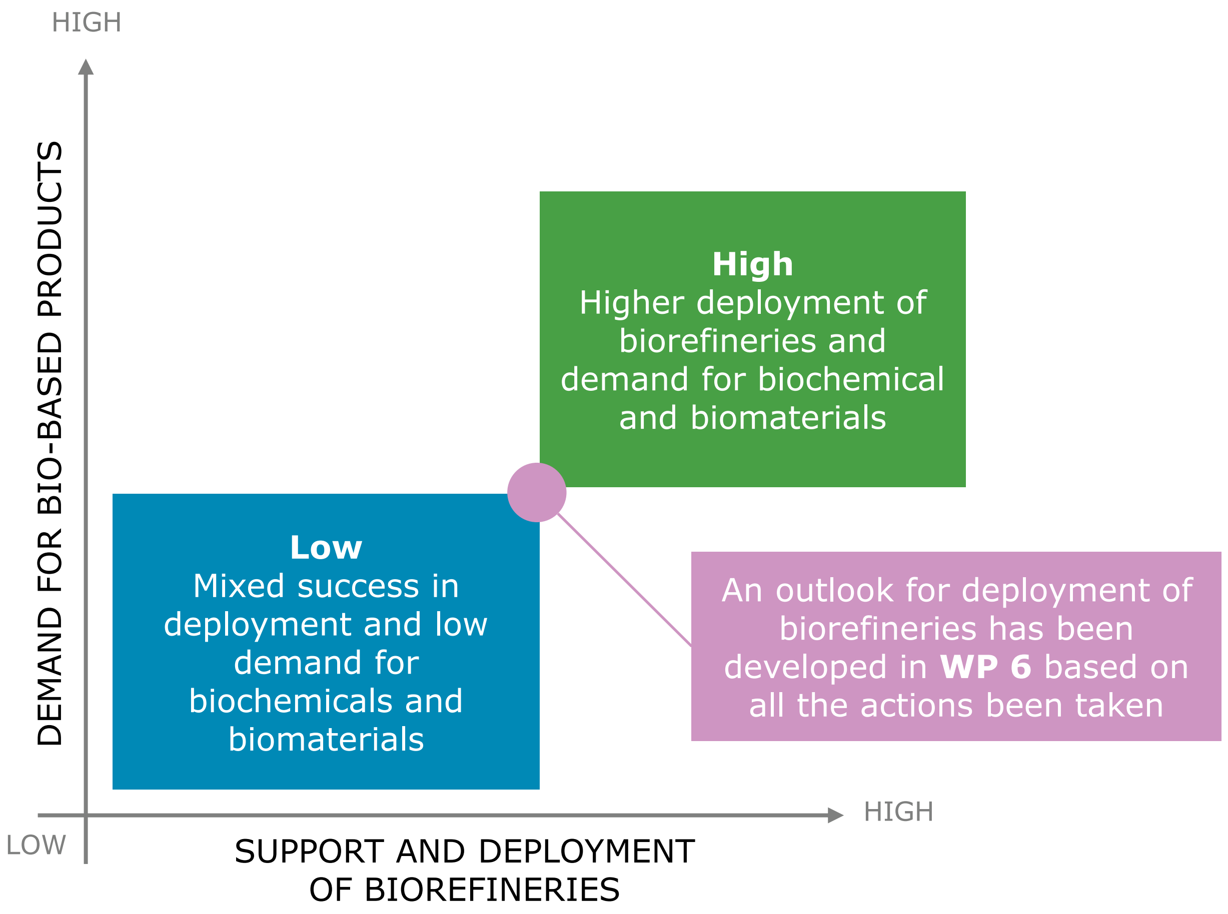
Strategy | Energy | Sustainability

Outlook for deployment

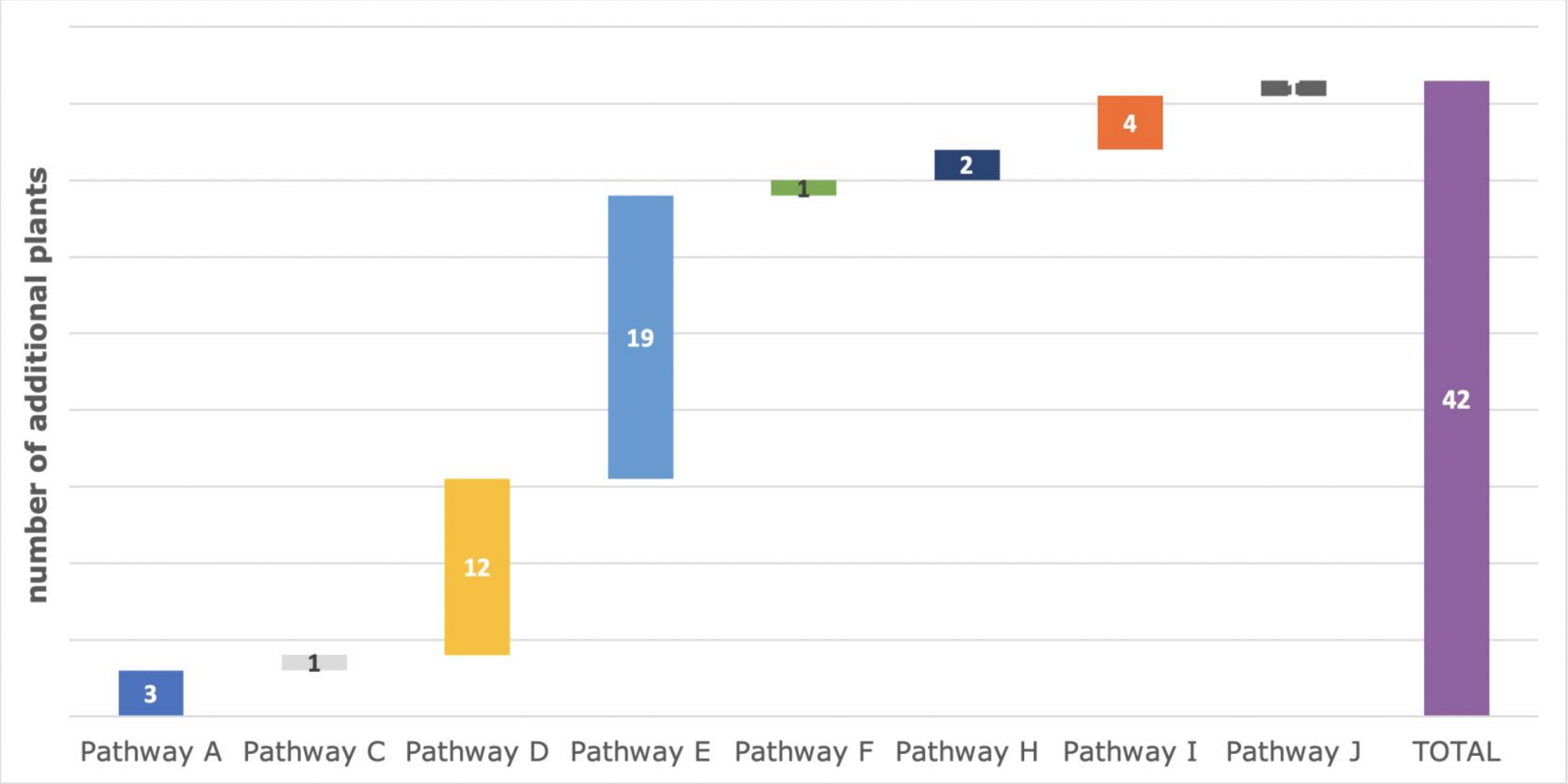
Aligned with the roadmaps and the supply scenarios we developed an outlook for the deployment by 2030



- **Assumptions** aligned with the roadmap **actions** being **completed.**
- **Policy** developments will **help determine** the overall and relative **ramp-up** of these pathways.
- Whilst the **roadmaps suggest areas** of **policy** that should be considered, they do **not** specify **fixed policy actions** including **targets**.
- Favourable policy developments for **secondary feedstocks (non-crop)** to produce chemicals and materials in the EU are **assumed**.

Pathways E, D, I all share products they produce with advanced biofuels and show the strongest supply ramp up potential

- Over 40 new biorefineries could be operational by 2030
- Additional 3.1 million tonnes capacity could be achieved in 2030 with significant volumes from:
  - Debottlenecking/expansion of existing biorefineries (primarily pathways A-E) ~0.5 million
  - New biorefineries ~2.6 million
- The scale of the biorefineries depends on the pathway, feedstock and market activity.



Chemical and materials driven biorefinery outlook for deployment – additional biorefineries by 2030

**Pathways B, G and K have been left out as they do not contribute to the overall supply ramp up.*

Biorefinery deployment could result in overall GHG savings and increased raw material security for the EU

- **Saving** of **3.5 million tonnes** of **GHG** emissions
- **Substitution** of **5.6 million tonnes of naphtha** (fraction of crude oil)

Capital investment of **81 to 325 million EUR** required to build the new **demonstration** biorefineries and **~3,300 to >13,335 million EUR** to finance the new **commercial** biorefineries

- Development of biorefineries at existing brownfield site can result in lower the CapEx and OpEx

The type of investment needs to be considered to estimate the capital investment of a biorefinery

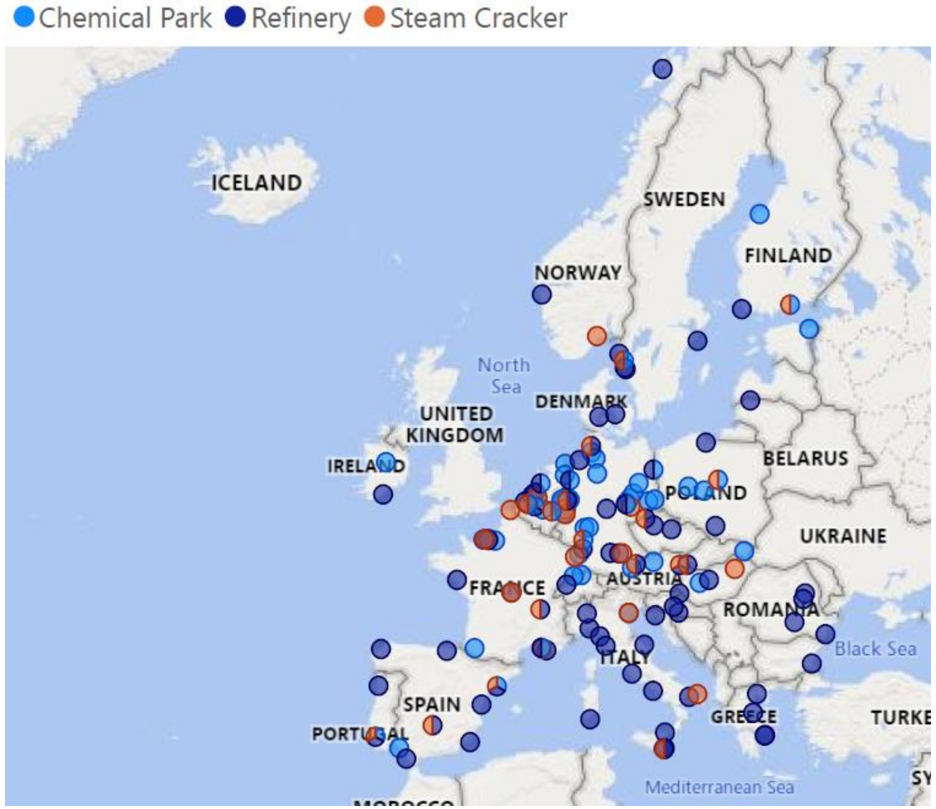
For the same process technology, the CapEx tend to follow this order:

Highest Capex

- **Greenfield biorefinery**
- **New biorefinery** on a **brownfield site** (lower capex from shared services such as steam, water, power, storage, logistics etc…) e.g. UPM Leuna, Germany
- **Re-purposing/conversion** of a plant on existing **brownfield** site (highly project dependent as it only some equipment can be reused) – e.g. Green Biologics to converted a US ethanol plant to n-butanol and acetone facility in 2015 – now closed
- **Expansion** of a biorefinery on a **brownfield site** (e.g. valorizing a side stream) – capacity increase often limited
- **Debottlenecking** (improving processes, revamping or new equipment) to increase the capacity of existing biorefineries - capacity increase is limited however
- **Co-processing / refocus** of existing plants from fuels to chemicals (drop-in such as methanol)

Lowest capex

There are many existing brownfield sites in the EU that could be candidates for biorefinery development



Map of chemical parks, steam crackers and crude refineries in the European Union *(Source: Oil&Gas Journal Database, Enerdata Refinery Database, Petrochemicals Europe, European Chemical Site Promotion Platform)*

Pulp and Paper mills in the European Union *(Source: JRC Bio-based industry visualiser, 2020)*

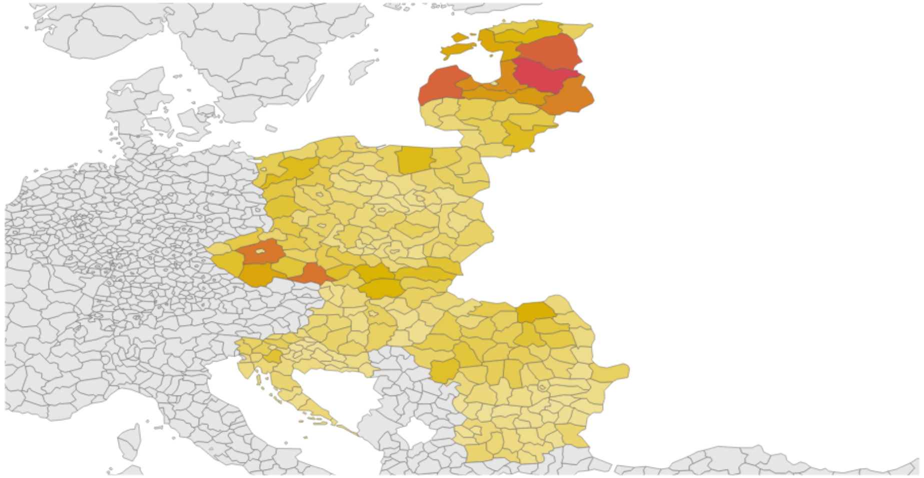
Timber manufacturing in the European Union *(Source: JRC Bio-based industry visualiser, 2020)*

Note: Sugar and starch processing facilities in the European Union also included in the report but not shown here

Despite low historical investment, BIOEAST countries show significant availability of forest and agricultural residues

Figure 2. Map of forest residue potential in BIOEAST initiative countries (kta dry matter)

Forestry Residues (harvesting and process) by NUTS 3 region ktonnes DM /year



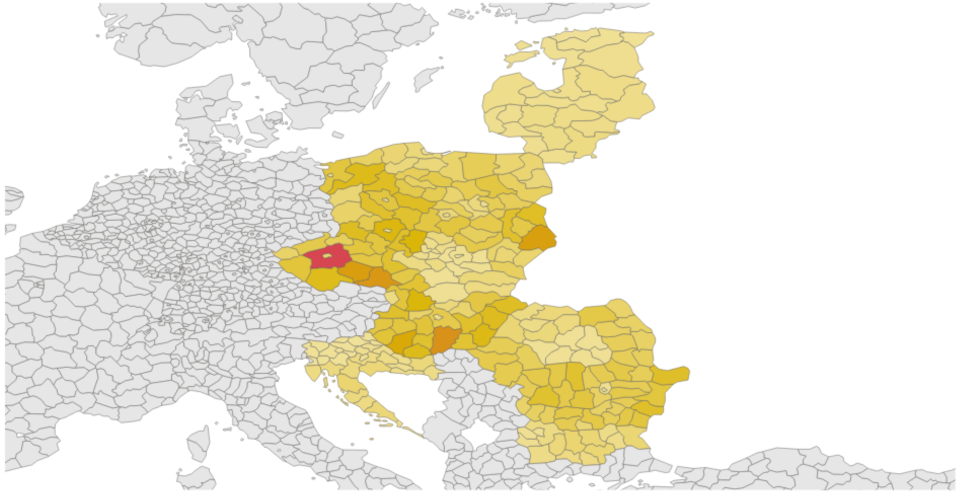
Country	Forestry Residues (harvesting and process)
Poland	28,705.24
Romania	20,663.02
CzechRepublic	13,771.36
Latvia	11,214.70
Estonia	6,694.05
Hungary	6,527.99
Slovakia	5,861.10
Lithuania	5,831.06
Slovenia	5,367.39
Bulgaria	4,533.37
Croatia	3,854.51
Total	**113,023.79**

Classification, Country
- Candidate Country
- EU
- Non-EU
- Potential Candidate

Min of Forestry Residues (harvesting and process)	Max of Forestry Residues (harvesting and process)
40.64	2,836.71

Note: this map shows combined primary and secondary forest residues and product from forest potentials.

Agricultural Residues by NUTS 3 region ktonnes DM /year



Country	Agricultural Residues
Poland	21,509.08
Romania	11,740.90
Hungary	10,186.21
CzechRepublic	7,915.53
Bulgaria	6,701.52
Croatia	2,199.22
Slovakia	2,193.10
Lithuania	732.58
Latvia	396.40
Estonia	130.40
Slovenia	63.40
Total	**63,768.33**

Classification, Cou...
- Candidate Country
- EU
- Non-EU
- Potential Candidate

Min of Agricultural Residues	Max of Agricultural Residues
1.52	1,595.77

Figure 3. Map of agricultural residue potential in BIOEAST initiative countries (kta dry matter)

The study can be used to help make decisions & take actions to accelerate biorefinery deployment to 2030

The study provides:

- Robust **biorefinery classification** system allows standardised categorisation
- Identification of **key drivers and barriers** highlights main areas of progress needed
- Development of **chemical and materials driven biorefinery database**
- Estimation of **demand** and potential **new biorefineries in the EU by 2030** based on ongoing activities
- A **roadmap** with a **set of actions** needed to be taken to accelerate the deployment of biorefineries by 2030

With the right conditions, EU demand / supply of bio-based chemicals and materials could grow significantly by 2030

- **Demand** for bio-based chemicals and materials could **triple by 2030** in in the **high growth scenario**
- In the **high growth deployment scenario**, new or expanded biorefineries could **add 3.1 million tonnes**, and 1.1 million tonnes in the low growth scenario **by 2030**
- For both scenarios, the **EU demand** could be **higher** than the projected **supply** in 2030
  - Existing **fuel driven biorefineries** and **co-processing** could be key **supply sources** of chemical and materials to fill the shortfall, as well as **imports** from non-EU countries
- Stakeholders and policy makers need to take **action** to reach **accelerate towards** the **high growth scenario**

The priority is to put in place policy and regulation that overcomes the economic viability barriers

- Putting **policy and regulation** in place in the **next 5 years** is **essential** to close the large gap between the **market's willingness to pay** and **bio-based chemicals and materials production costs**
  - An EU mandate for GHG reduction in chemicals and materials sold (analogous to RED II) could have the largest impact (bio-based, recycled and CO_2-based)
- To achieve **lower environmental impacts** the strategic **policy & RD&D** direction should be focused on **selected pathways**
- Supporting **RD&D** and **feedstock sourcing** can help accelerate **cost reduction**
- **Public finance** for RD&D and scale up is crucial to **commercialise lower TRL** pathways by 2030
- **Environmental** benefits need to be **measured** and broadly understood by all stakeholders

With action taken and favourable economic conditions the deployment outlook could reach the high scenario

- **Additional 3.1 million tonnes capacity could be achieved in 2030** with significant volumes from:
  - debottlenecking/expansion of existing biorefineries (primarily pathways A-E) ~0.5 million
  - New biorefineries ~2.6 million - over 40 biorefineries could be built

- **Saving** of **3.5 million tonnes** of **GHG** emissions
- **Substitution** of **5.6 million tonnes of naphtha** (fraction of crude oil)

Capital investment of **81 to 325 million EUR** required to build the new **demonstration** biorefineries and **~3,300 to >13,335 million EUR** to finance the new **commercial** biorefineries

Thanks

More information: www.e4tech.com/biorefinery-outlook.php

The information and views set out in this Studies on support to R&I policy in the area of bio-based products and services, Lot 3 Biorefinery pathways and outlook for deployment Service Contract EC DG-RTD no. 2018/RTD/F2/OP/PP-07281/2018/LC-01369322 are those of the author(s) and do not necessarily reflect the official opinion of the Commission. The Commission does not guarantee the accuracy of the data included in this study. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use which may be made of the information contained therein.