RoadToBio – Roadmap for the chemical industry towards a bioeconomy

Webinar

7 February 2018

Today‘s agenda

- Introduction: The best of two worlds – making chemicals more biobased
  - *Kathrin Rübberdt, DECHEMA e.V.*

- Bio-based drop-in, smart drop-in and dedicated chemicals
  - *Lara Dammer, nova-Institut GmbH*

- Bio-based opportunities for the chemical industry -“Where bio-based chemicals meet existing value chains in Europe”
  - *Tijs Lammens, BTG Biomass Technology Group B.V*

DECHEMA

The best of two worlds – making chemicals more biobased

Dr. Kathrin Rübberdt, 07 February 2018

Why do we want to become more bio-based??

Changed framework/ conditions

2005

- Oil and gas resources are limited
- High prices
- Biotechnology
- Substitution of raw materials

Comprehensive substitution!

2017

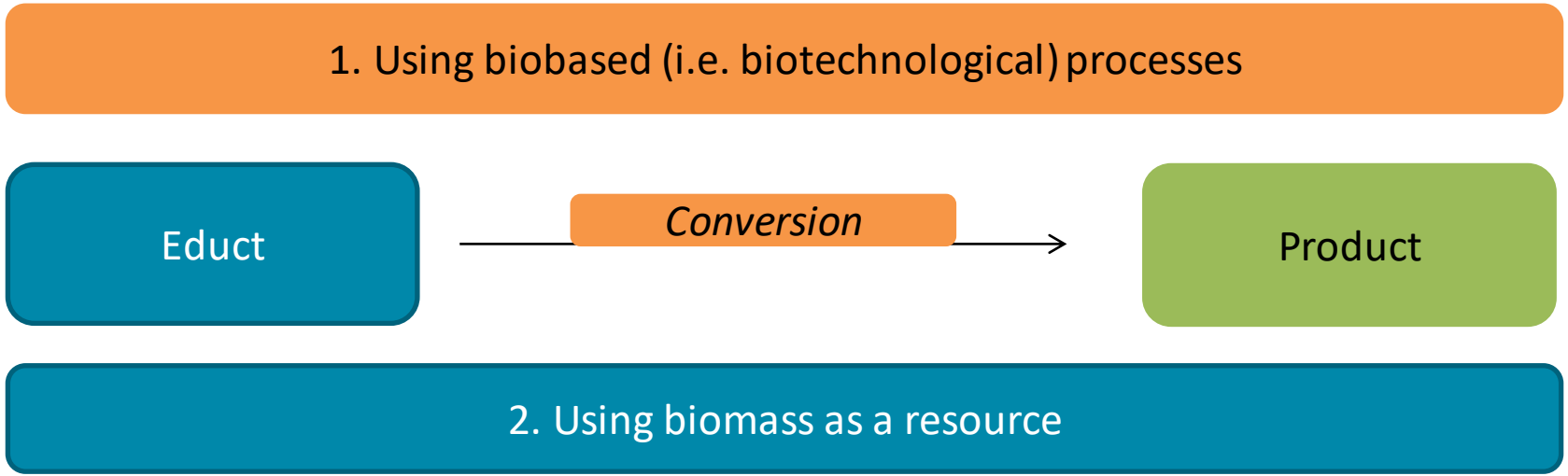
- Long-term availability of oil and gas
- Low, volatile prices
- Converging technologies
- Decarbonisation
- Lower dependency on fossil resources

Innovation for sustainability!

Source: German Bioeconomy Council, European Commission

The latest catchword in this context is „biologisation“

What does it mean with regard to the chemical industry?



Horizon 2020
European Union Funding
for Research & Innovation

BIO-BASED INDUSTRIES
Public-Private Partnership

Bio-based Industries
Consortium

Using biomass and biotechnology can go hand in hand, but they don‘t have to

Chemical conversion of biomass

Bionaphtha —*conventional chemical conversion*→

Biomass → Syngas → MeOH

Biotechnological conversion of fossil resources

CH_4 —*methanotrophic mikcoorganisms*→ Bulk chemicals

Currently not (yet) relevant for production, but conceivable e.g. in the context of the recycling of plastics

The chemical industry is already using „the best of both worlds“

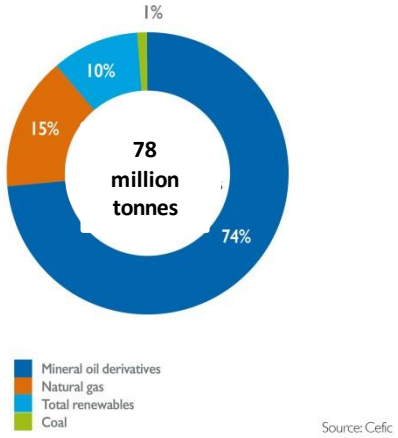
- Data on value creation is hard to obtain because
  biotechnology ≠ „Life-Science-SME“
- Many biotechnological processes are already part of the chemical or pharmaceutical industry
- More than 150 industrial biotransformations and more than 500 industrial products from enzymatic conversion already in 2006

Chemical processes	Biotechnological processes
• Well established, highly efficient • „Verbundproduktion“ – integrated production • High yields both over space and time • High product concentraion • Existing infrastructure and point sources • Organic solvents -> easy to remove, but may be dangerous to health and the environment	• Highly selective • Ususally under mild conditions, lower energy demand • Lower product concentration – high effort in downstream processing • Aquaeous solutions – isolation requires a lot of energy

Road To Bio: focus on renewable resources

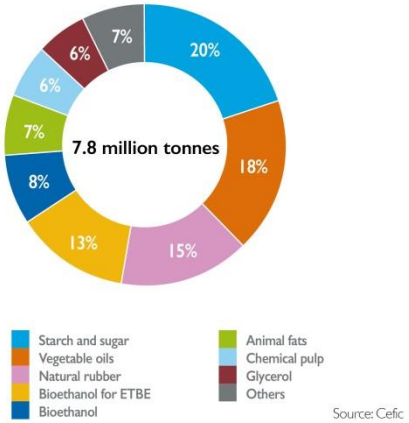
Organic raw material use

Share in total raw materials – material (feedstock) use only
EU chemical industry 2015



Renewables share

Renewables share in total renewables
EU chemical industry 2015



Typical approaches

- Use the existing synthetic potential of nature
- Break the complex natural structures down to smaller building blocks (extreme case: syngas) that then undergo chemical and/or biotechnological conversion routes
- fermentation (mostly) based on sugar

- Goal of the EU: Increase to 25 % (originally 30 %)

The potential is enormous

Analysis

Initial Results

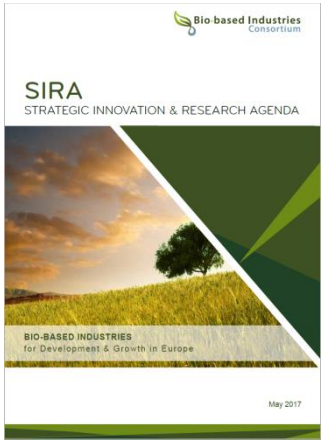
Opportunities for bio-base products

- Lubricants
- Paints Dyes
- Plastics
- Cosmetics
- Agro chemicals
- Adhesives
- Solvents
- Surfact-ants
- Man-made fibres

Project RoadToBio

- Duration: 24 Months
  May 2017 – April 2019
- Budget: 996.000€
- Consortium:

DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e.V.
btg biomass technology group
E4tech Strategy | Energy | Sustainability
nova Institute for Ecology and Innovation



Main goal:

To develop a roadmap for the chemical industry that shows the path towards an overall 30 % share of bio products in the organic chemical industry that meet societal needs in 2030.

Bio-based drop-in, smart drop-in and dedicated chemicals

7 February 2018

RoadToBio webinar

Lara Dammer, nova-Institut GmbH

Why the attempt of a classification?

- Different terms are frequently used in the industry – attempt for clarification
- Different chemicals need different market strategies – attempt for structure
  - NOT a finite exact definition in the scientific sense

- Publication by Carus, Dammer, Puente, Raschka & Arendt (nova-Institute) in late 2017

  https://www.roadtobio.eu/uploads/publications/articles/17-12-18-RoadToBio-Drop-in-paper.pdf

Pathways to different kinds of bio-based chemicals

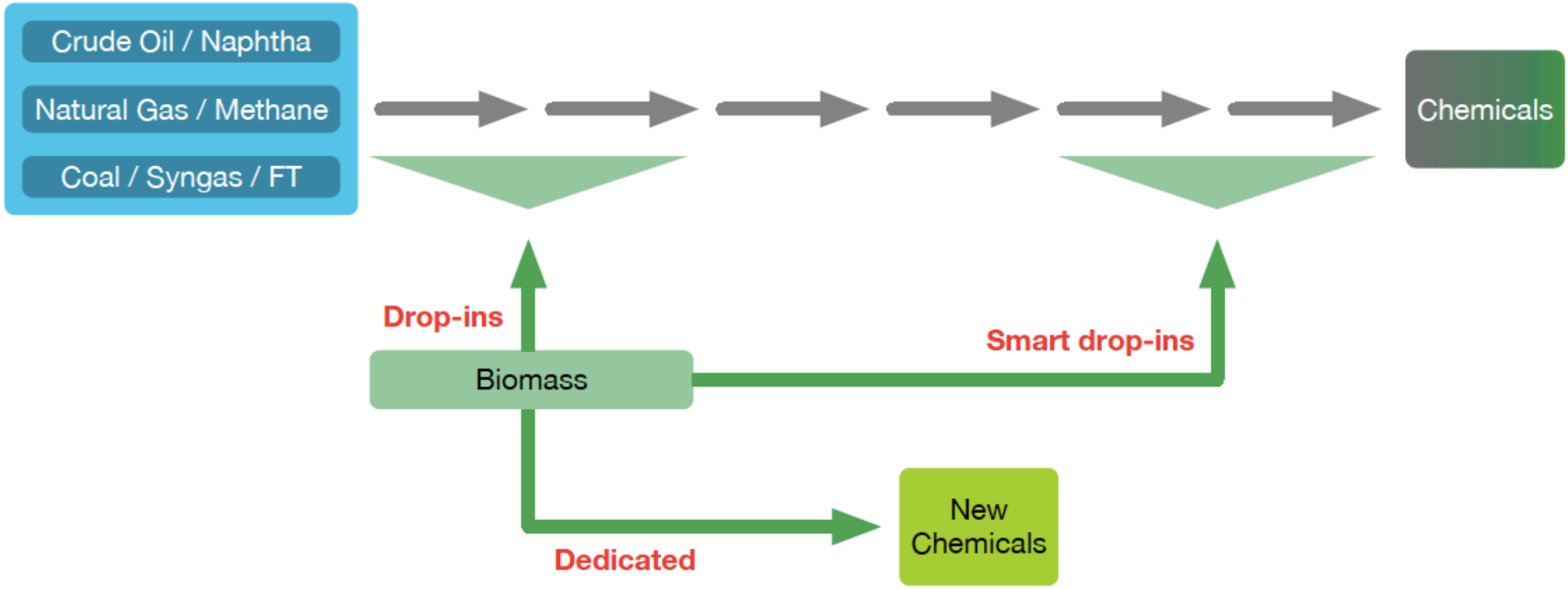


Figure 1: Schematic differentiation of pathways of drop-in, smart drop-in and dedicated bio-based chemicals

Bio-based drop-in chemicals

- Definition: Bio-based drop-in chemicals are bio-based versions of existing petrochemicals which have established markets. They are chemically identical to existing fossil-based chemicals.
- Explanation:
  - normally used in relation to commodity chemicals
  - usually differ from petrochemical counterparts in price and in environmental footprint
  - easy to implement technically due to existing infrastructure
- Examples: Bio-based methane, ethylene/PE/PET, propylene/PET and bio-naphtha

Bio-based smart drop-in chemicals

- Definition: Smart drop-in chemicals are a special sub-group of drop-in chemicals. They are also chemically identical to existing chemicals based on fossil hydrocarbons, but their pathways provide advantages compared to the conventional pathways. We consider drop-in chemicals to be ‘smart drop-ins’ if at least two of the following criteria apply:
  - Higher Biomass Utilization Efficiency (BUE, see Iffland et al. 2015)
  - Less energy consumption for production
  - Shorter time-to-product and less complex production pathways
  - Less toxic or harsh chemicals are used or occur as by-products

Bio-based smart drop-in chemicals

- Explanation:
  - pathways are advantageous combinations of novel/dedicated and conventional chemical pathways
  - e.g. biomass is processed in a new way up to a certain status, and then is fed into the conventional process at a later stage
  - also possible for smaller volumes
- Examples: epichlorohydrin, acetic acid, acrylic acid, adipic acid, aniline, butadiene, 1,4-butanediol, isoprene, PA (6,6), polybutylene succinate, 1,3-propanediol, succinic acid

Example of a smart drop-in chemical

(±)-Epichlorohydrin, a highly reactive building block used in the manufacture of plastics and epoxy resins, is industrially produced from propylene in a three-step process. An alternative two-step process starts from glycerol, a readily available chemical from biodiesel production, which is produced through saponification of triglycerides from plants and animal sources. Glycerol is converted to dichloropropanol with hydrochloric acid in the presence of an acidic catalyst. This smart route avoids the chlorination of propylene using toxic chlorine at 500 °C and yielding many other chlorinated by-products (Hirth et al. 2015).

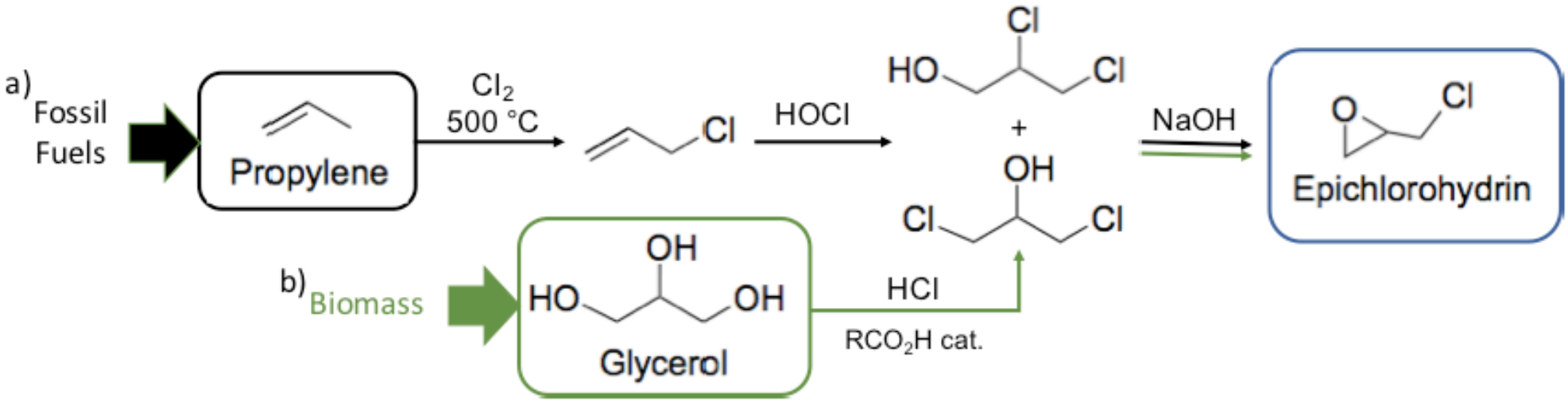


Figure 2: Synthesis of epichlorohydrin following a petrochemical a) or a bio-based b) pathway

Dedicated bio-based chemicals

- Definition: Dedicated bio-based chemicals are chemicals which are produced via a dedicated pathway and do not have an identical fossil-based counterpart. As such, they “can be used to produce products that cannot be obtained through traditional chemical reactions and products that may offer unique and superior properties that are unattainable with fossil-based alternatives” (BIO-TIC 2014)

Dedicated bio-based chemicals

- Explanation:
  - compared to drop-in commodity chemicals, bio-based dedicated pathways are more efficient, utilising not only the carbon in the biomass, but the whole biomass – carbon, oxygen, hydrogen and nitrogen
  - they can take advantage of utilising higher levels of structure (functionalised building blocks) already provided by nature instead of breaking down (defunctionalising) into simple molecules
  - sometimes called “novel”, but many of these have been around for quite some time, at least in scientific literature
  - biotechnology and other novel processing technologies are becoming more and more important

Dedicated bio-based chemicals

- Examples:
  - Glycerol and derivatives, 3-hydroxypropionic acid and 3-hydroxypropanal, itaconic acid, farnesene, furans (HMF, furfural, FDCA), lactic acid, levulinic acid, methylenesuccinic acid, sorbitol, xylitol
  - PEF, PHA, PLA, A (10,10; 10,12 and 12,12)
  - Bio-based lubricants and surfactants, e.g. sophoro- and rhamnolipids, alkylpolyglycosides
  - Cellulose fibres, nano- and microcellulose

Example of a dedicated chemical

Dihydrolevoglucosenone (Cyrene™), a dipolar aprotic solvent, is an example of a dedicated bio-based chemical. It can be directly derived from waste cellulose in two simple steps, having therefore a high stoichiometric Biomass Utilization Efficiency (BUEs) of 79%. Cyrene™ has demonstrated a similar solvent performance as toxic petrochemically derived solvents such as *N*-2-methyl pyrrolidone (NMP), whose industrial synthesis involves multiple reaction steps starting from acetylene and acetaldehyde (Figure 3) (Clark et al. 2014).

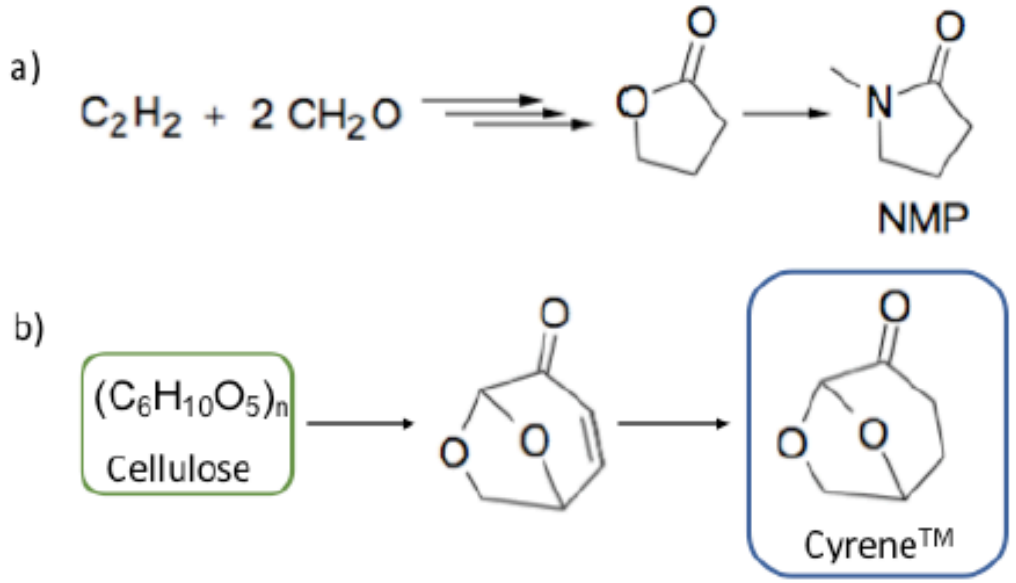


Figure 3: Scheme of the production of a) *N*-2-methyl pyrrolidone (NMP) and b) dihydrolevogluocosenone (Cyrene™)

References

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BIO-TIC (2014): Overcoming hurdles for innovation in industrial biotechnology in Europe, Biobased Chemical Building Blocks, Summary; http://mig.www.industrialbiotech-europe.eu/new/wp-content/uploads/2014/08/Summary-of-the-findings-related-to-chemical-building-blocks.pdf

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Contact: lea.koenig@dechema.de

Next workshop:

19.06.18 in Brussels

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Bio-based opportunities for the chemical industry

"Where bio-based chemicals meet existing value chains in Europe"

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3) *E4tech, United Kingdom*

This project has received funding from the Bio-Based Industries Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No. 745623.

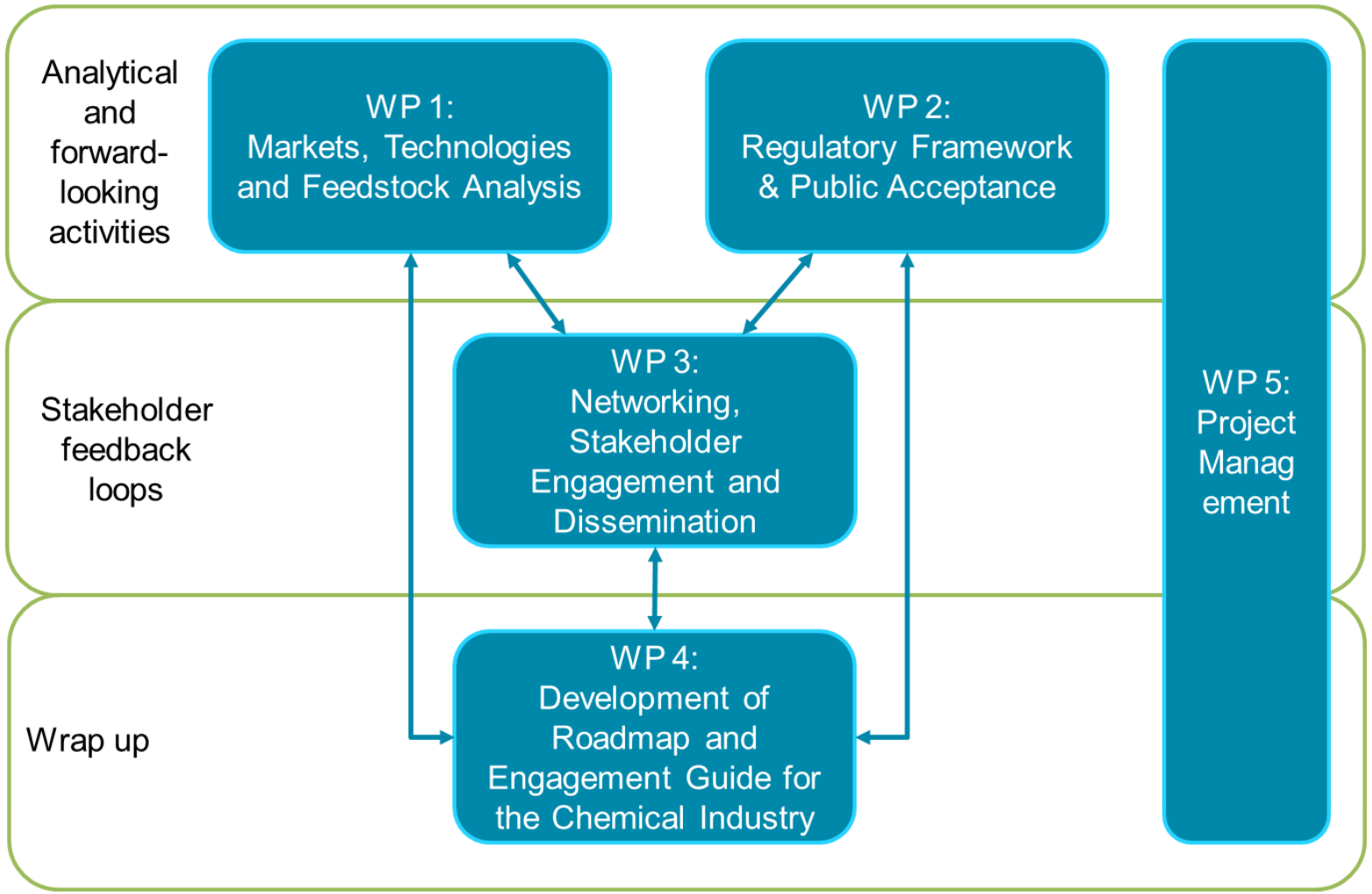
RoadToBio Deliverable 1.1, October 2017

Formal title: 'Report with opportunities for bio-based chemical feedstocks and intermediates in the chemical industry'

Contents

1. **Goal and scope of this report**
   - Role of the first work package in the project
   - Role of this study within the work package
2. **Methodology**
3. **Results:**
   1. Long list of bio-based chemicals
   2. Maps of the value chains in the existing petrochemical industry
   3. The interface between bio-based products and existing value chains
4. **Synthesis of the results**
5. **Discussion and Conclusions**
6. **Outlook and further work**

Introduction of the first work package



Main project goal:

To develop a roadmap for the chemical industry that shows the path towards an overall 30% share of bio-based products in the organic chemical industry in 2030.

Introduction of the first work package

- **Technology, Markets & Feedstocks analysis**
- **Goal: creation of a sound fact-base for the preparation of the roadmap:**
  - Current status of bio-based technology platforms
  - Scout possibilities for bio-based products in the chemical industry
  - Priorities of the chemical industry when developing new products or markets
  - Long-list of opportunities for the chemical industry, including ranking
  - Business case studies for 9 sweet spots for bio-based products

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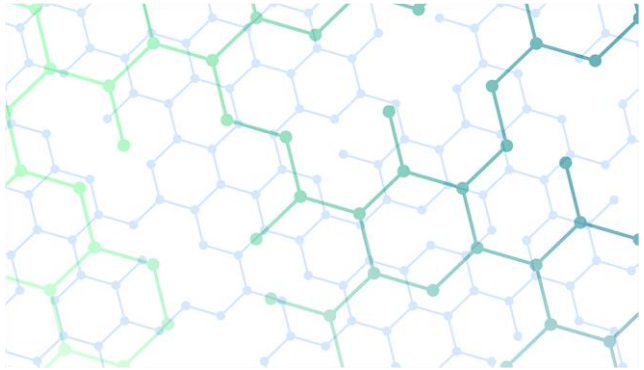
  - ➢ Long-list of opportunities for the chemical industry, including ranking
  - ➢ Business case studies for 9 sweet spots for bio-based products
- **This study:**
  - ➢ Provide overview of bio-based chemicals at demo & (semi-)commercial scale
  - ➢ Map the markets of petrochemical products
  - ➢ Analyze the interface of bio-based chemicals and petrochemical markets

Methodology

Part 1: Bio-based 'possibilities'



Part 2: Petrochemical value chains

Part 3: identifying overlap

Methodology

Part 1: Bio-based 'possibilities'

Identify bio-based chemicals in literature

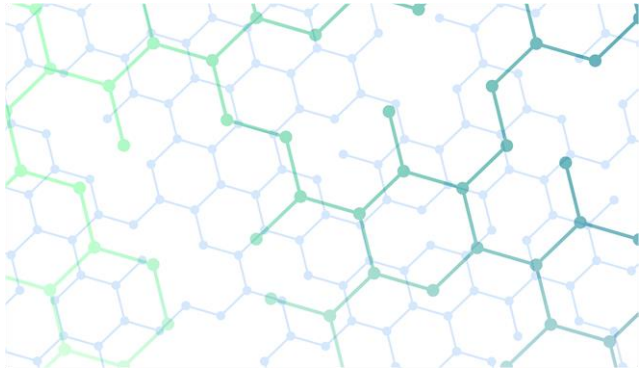
- Assess their TRL
- Assign Prodcom codes
- Classify (drop-in, etc.)
- Feedstock options

Database of ~ 400 bio-based chemicals

- Prodcom market data
- TRL ≥ 6?

> Select bio-based options

Long list of 120 bio-based chemicals



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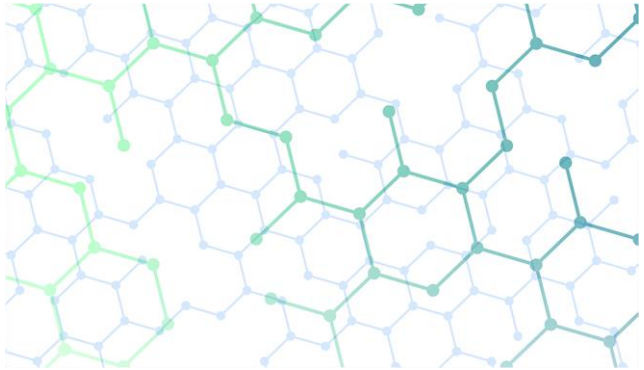

Part 2: Petrochemical value chains

Identify 9 product groups

Per product group:
- Identify petrochemicals
- Describe value chains

Estimate current bio-%

Map of the current petrochemical industry

Assign Prodcom codes to all petrochemical products and intermediates

Part 3: identifying overlap

Methodology

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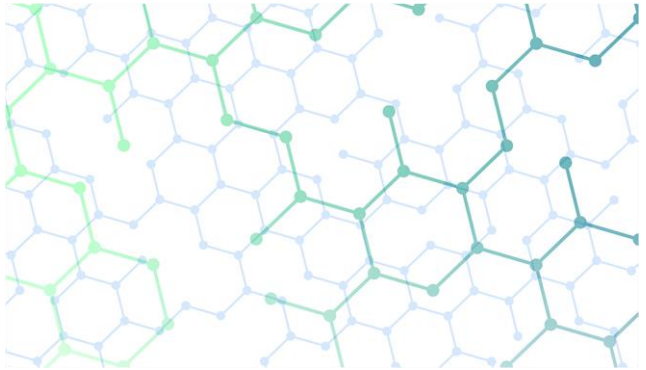

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Part 3: identifying overlap

Identify overlap

Interface bio-based and petrochemicals

Part 1: Database of bio-based chemicals

	A	B	C	D	E	F	G	H	I	J
1	**Platform chemical**	**TRL≥6?**	**Reference**	**Classification**	**Biomass feedstock at highest TRL (≥6)**	**NACE**	**Prodcom**	**Prodcom Volume***	**Prodcom Value***	
2								*kton in 2016*	*Mln Euro in 2016*	
3	Starch	yes	25	dedicated chemical	Starch	Other	10621111	4154	1862	
4	Alkanes (iso-)	yes	5	drop-in commodity	Vegetable oils and fats	20.14	20141120	1056	720	
5	Propane	yes	5	drop-in commodity	Vegetable oils and fats	20.14	20141120	1056	720	
6	Methane	yes	20	drop-in commodity	Biogas	20.14	20141120	1056	720	
7	Ethylene	yes	1	drop-in commodity	Sugar (beet / cane / starch)	20.14	20141130	10360	6908	
8	Propylene	yes	1,36	drop-in commodity	Glycerin	20.14	20141140	9731	4744	
9	Butene (iso-)	yes	1	drop-in commodity	Sugar (beet / cane / starch)	20.14	20141150	1876	1475	
10	Butadiene	yes	1,16	drop-in commodity	Sugar (beet / cane / starch)	20.14	20141160	2412	1131	
11	Isoprene	yes	1	drop-in commodity	Sugar (beet / cane / starch)	20.14	20141160	2412	1131	
12	Farnesene	yes	1,16	dedicated chemical	Sugar (beet / cane / starch)	20.14	20141190	1070	605	
13	Squalene	yes	1	dedicated chemical	Sugar (beet / cane / starch)	20.14	20141190	1070	605	
14	Terpenes	yes	1	dedicated chemical	Sugar (beet / cane / starch)	20.14	20141190	1070	605	
15	Limonene	yes	16	dedicated chemical	Sugar (beet / cane / starch)	20.14	20141215	95	259	
16	Xylene (para-)	no	1,36	drop-in commodity	Sugar (beet / cane / starch)	20.14	20141245	976	536	
17	Ethylene chloride (aka vinyl chloride)	yes	20	drop-in commodity	Sugar (beet / cane / starch)	20.14	20141371	477	204	
18	Fatty alcohols	yes	1,16	dedicated chemical	Vegetable oils and fats	20.14	20142100	419	651	
19	Methanol	yes	5,36	drop-in commodity	Syngas	20.14	20142210	1000	160	
20	Butanol (n-)	yes	1,24	drop-in commodity	Sugar (beet / cane / starch)	20.14	20142230	364	176	
21	Butanol (iso-)	yes	1,24	drop-in commodity	Sugar (beet / cane / starch)	20.14	20142240	85	48	
22	Octanol (2-)	yes	16	dedicated chemical	Vegetable oils and fats	20.14	20142263	688	476	
23	Cetylic alcohol	yes	25	dedicated chemical	Vegetable oils and fats	20.14	20142265	370	588	
24	Heptanol	yes	13	smart drop-in	Vegetable oils and fats	20.14	20142265	370	588	
25	Lauryl alcohol	yes	25	dedicated chemical	Vegetable oils and fats	20.14	20142265	370	588	
26	Ethylene glycol	yes	1,26	drop-in commodity	Sugar (beet / cane / starch)	20.14	20142310	1314	640	
27	Propylene glycol (aka 1,2-propanediol)	yes	1,36	drop-in commodity	Glycerin	20.14	20142320	734	526	
28	Butanediol (1,2-)	yes	1,25	smart drop-in	Sugar (beet / cane / starch)	20.14	20142337	600	1175	
29	Butanediol (2,3-)	yes	1	smart drop-in	Sugar (beet / cane / starch)	20.14	20142337	600	1175	
30	Isosorbide	yes	1,16,26,33	dedicated chemical	Sugar (beet / cane / starch)	20.14	20142337	600	1175	
31	Propanediol (1,3-)	yes	1,26,33,36	smart drop-in	Sugar (beet / cane / starch)	20.14	20142337	600	1175	
32	Butanediol (1,4-)	yes	1,26,33	smart drop-in	Sugar (beet / cane / starch)	20.14	20142337	600	1175	
33	Ethyl acetate	yes	1	drop-in commodity	Sugar (beet / cane / starch)	20.14	20143215	44	40	
34	Butyric acid	yes	1,16	smart drop-in	Sugar (beet / cane / starch)	20.14	20143220	402	456	
35	Palmitic acid (aka hexadecanoic acid)	yes	16	dedicated chemical	Vegetable oils and fats	20.14	20143235	189	280	
36	Stearic acid (aka octadecanoic acid)	yes	16	dedicated chemical	Vegetable oils and fats	20.14	20143235	189	280	
37	Acetic acid	yes	1,16	smart drop-in	Sugar (beet / cane / starch)	20.14	20143271	571	280	
38	Acetic anhydride	yes	25	smart drop-in	Sugar (beet / cane / starch)	20.14	20143277	80	120	
39	Capric acid (aka decanoic acid)	yes	16	dedicated chemical	Vegetable oils and fats	20.14	20143280	320	800	

Note:

Database is available through the report at www.RoadToBio.eu

Part 1: Long-list of bio-based chemicals

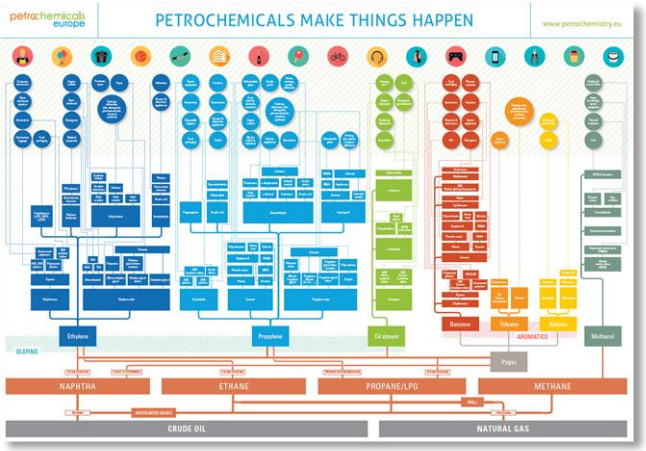
Bio-based chemical	Prodcom code	Bio-based chemical	Prodcom code	Bio-based chemical	Prodcom code
Acetaldehyde	20146113	Ethylene chloride (aka vinyl chloride)	20141371	Phenol formaldehyde resin	20165650
Acetic acid	20143271	Ethylene glycol	20142310	Poly(butylene adipate-co-terephthalate) - PBAT	20164080
Acetic anhydride	20143277	Ethylene oxide	20146373	Poly(butylene succinate) - PBS (aka 'Bionolle')	20164090
Acetone	20146211	Farnesene	20141190	Poly(butylene terephthalate) - PBT	20164080
Acrylic acid	20143310	Fatty alcohols	20142100	Poly(ethylene furanoate) - PEF	20164080
Acrylonitrile[1]	20144350	Fatty amines	20144119	Poly(ethylene glycol) - PEG	20164015
Adipic acid	20143385	Fumaric acid	20143381	Poly(ethylene terephthalate) - PET	20164062
Alkanes (iso-)	20141120	Furan	20145225	Poly(ethylene) - PE	20161035
Alkyl polyglucosides (APG)	20412090	Furandicarboxylic acid (2,5-) (FDCA)	20145225	Poly(hydroxyalkanoate) - PHA	20164090
Alkyl polypentosides (C5-surfactants)	20412090	Furfural	20145215	Poly(hydroxybutyrate) - PHB	20164090
Azelaic acid (aka nonanedioic acid)	20143381	Furfuryl alcohol	20145215	Poly(isosorbide)	20164090
Bio-'Naphtha'	20592000	Glucaric acid / Sodium glucarate	20143381	Poly(lactic acid) - PLA	20164090
Butadiene	20141160	Glycerol	20411000	Poly(methyl methacrylate) - PMMA	20165350
Butanediol (1,2-)	20142337	Glycerol carbonate	20411000	Poly(propiolactone) - PPL	20164090
Butanediol (1,4-)	20142338	Glycolipids	20165960	Poly(propylene) - PP	20165130
Butanediol (2,3-)	20142337	Guayule	20165960	Poly(tetrahydrofuran) - PTHF (aka PTMEG)	20164020
Butanol (iso-)	20142240	Heptanoic acid (aka enanthic acid)	20143280	Poly(trimethylene terephthalate) - PTT	20164080
Butanol (n-)	20142230	Heptanol	20142265	Poly(urethane) - PUR	20165670
Butene (iso-)	20141150	Hyaluronic acid	20165960	Poly(vinyl chloride) - PVC	20163010
Butyric acid	20143220	Hydroxymethylfurfural (5-) (HMF)	20145225	Propane	20141120
Capric acid (aka decanoic acid)	20143280	Hydroxypropionic acid (3-)	20143475	Propanediol (1,3-)	20142337
Caproic acid (aka hexanoic acid)	20143280	Isoprene	20141160	Propylene	20141140
Caprylic acid (aka octanoic acid)	20143280	Isosorbide	20142337	Propylene glycol (aka 1,2-propanediol)	20142320
Carboxymethyl cellulose	20165940	Itaconic acid	20143381	Propylene oxide	20146375
Cellulose	20165940	Lactic acid	20143475	Rayon	20602120
Cetylic alcohol	20142265	Lactide	20143475	Ricinoleic acid (aka 12-Hydroxyoctadec-9-enoic acid)	20143475
Chitin/Chitosan	20165960	Lauric acid (aka dodecanoic acid)	20143280	Sebacic acid (aka decanedioic acid)	20143381
Citric acid	20143473	Lauryl alcohol	20142265	Sophorolipids	20412050
Dimethyl ether (DME)	20146310	Levulinic acid	20143475	Sorbitan	20145225
Dimethyl isosorbide	20145225	Limonene	20141215	Sorbitol	20595770
Docosahexaenoic acid	20143280	Malic acid	20143381	Squalene	20141190
Dodecanedioic acid	20143381	Methane	20141120	Starch	10621111
Epichlorohydrin	20146379	Methanol	20142210	Stearic acid (aka octadecanoic acid)	20143235
Epoxy resins	20164030	Methyl methacrylate (MMA)	20143340	Succinic acid	20143381
Esterquats	20412030	Methyl tert-butyl ether	20146310	Terpenes	20141190
Ethanol	20147400	Octadecanedioic acid (1,18-)	20143381	Tetrahydrofuran (methyl-)	20145225
Ethyl acetate	20143215	Octanol (2-)	20142263	Tetrahydrofuran (THF)	20145215
Ethyl lactate	20143475	Oleic acid	20143350	Turpentine	20147140
Ethyl tert-butyl ether (ETBE)	20146310	Palmitic acid (aka hexadecanoic acid)	20143235	Undecanoic acid (aka undecylic acid)	20143280
Ethylene	20141130	Pelargonic acid (aka nonanoic acid)	20143280	Xylene (para-)	20141245

Note

1. Some (drop-in) chemicals did not reach TRL 6 yet but are expected to move quickly to TRL 9 because there is a clear overlap with current petrochemical pathways, e.g. acrylonitrile. These were included in the long list.

Part 2: Mapping the chemical markets

- **The selected product groups:**
  - Adhesives
  - Agrochemicals
  - Cosmetics
  - Lubricants
  - Man-made fibres
  - Paints & Coatings
  - Plastics / Polymers
  - Solvents
  - Surfactants



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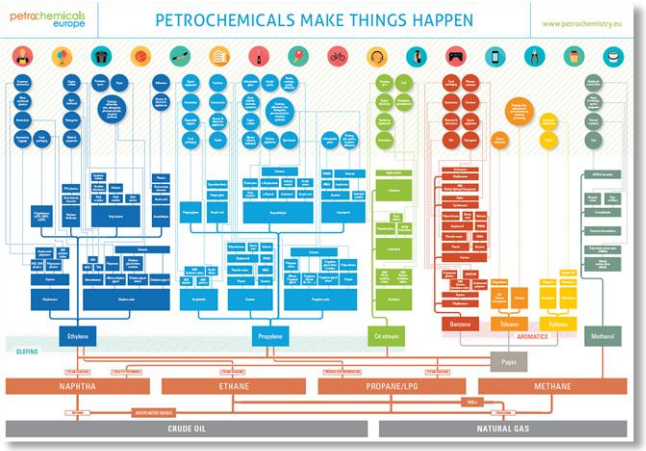

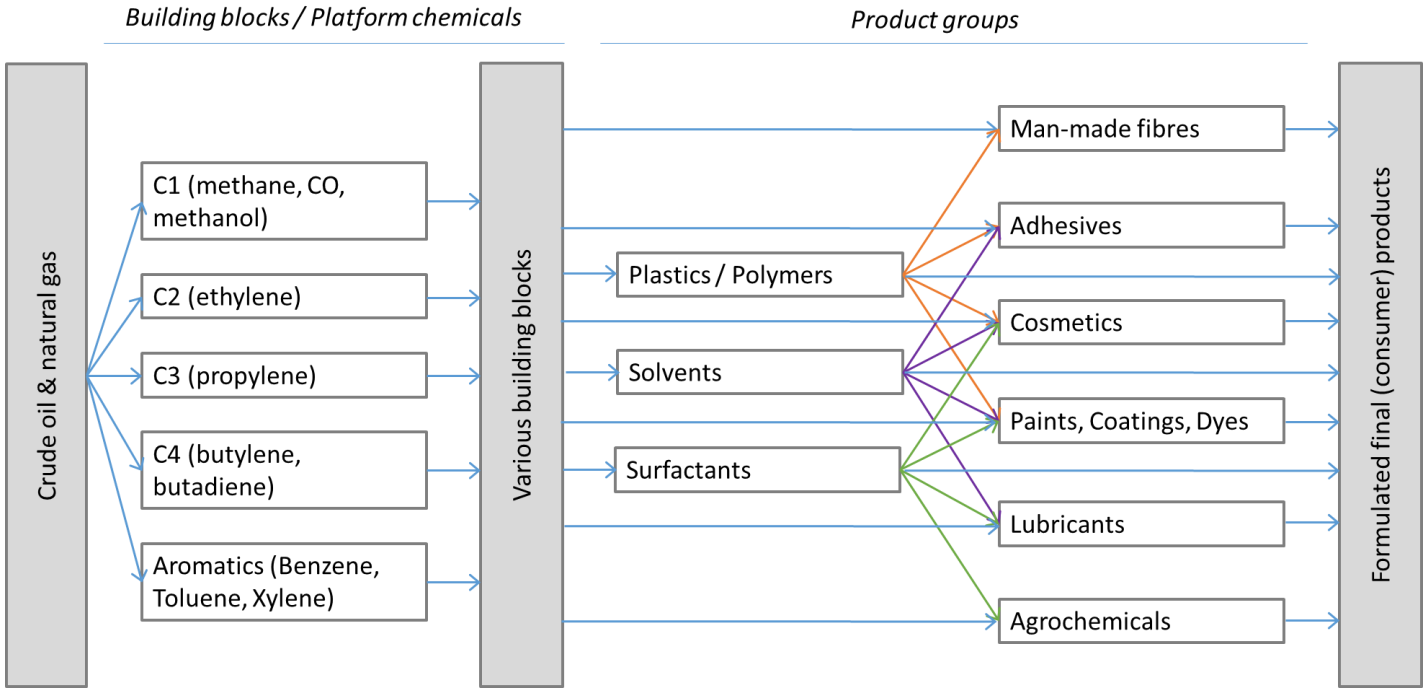

Part 2: Mapping the product groups, 3 examples

- **Plastics**

- **Solvents**

- **Surfactants**

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  Different petrochemical routes for manufacturing the main (co-)polymers were described, including (a.o.):

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  Chlorinated hydrocarbons; alcohols, ketones, esters, ethers; aliphatic solvents, aromatics, white spirits.

- **Surfactants**

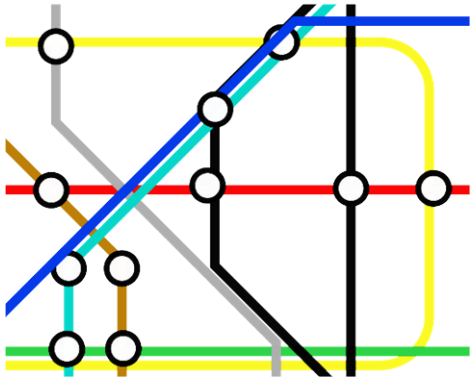
  Four categories were mapped: anionic, cationic, non-ionic and amphoteric surfactants, including (a.o.):

  Salts of alkyl sulfates, sulfated ethoxylated alcohols, alkyl sulphonates, linear alkylbenzene sulphonates; mono alkyl quaternary ammonium salts, esterquats; alkyl amine oxides, polymeric surfactants; ethoxylated aliphatic alcohols, polyethylene glycol esters.

Part 2: Mapping the product groups, plastics map

Feedstock	Building Block 1		Building Block 2		Building Block 3		Building Block 4		Final Chemical		Application
Crude Oil & Natural gas (1)	Ethylene	20.14.11.30	>>>>>>>>>>>>>>>>>>>>>>>>						Polyethylene LDPE	20.16.10.39	Plastics (3)
									Polyethylene HDPE	20.16.10.50	
									Polyethylene LLDPE	20.16.10.35	
									Other polymers of ethylene (excluding polyet	20.16.10.90	
			Ethylbenzene	20.14.12.60	Styrene	20.14.12.50	>>>>>>>		Acrylonitril-Butadiene-Styrene (ABS) copolymer	20.16.20.70	
									Styrene-acrylonitrile (SAN) copolymers	20.16.20.50	
									Polystyrene, in primary forms	20.16.20.39	
									Expansible polystyrene	20.16.20.35	
									Styrene-butadiene synthetic rubber (SBR) an other p	20.16.20.90	
									Unsaturated polyesters (excluding polyaceta	20.16.40.80	
			Etlylene dichloride	20.14.13.53	Vinyl chloride	20.14.13.53	>>>>>>>		Poly(vinyl chloride) PVC (+▼)	20.16.30.10	
									Non-plasticised polyvinyl chloride mixed with any other subst	20.16.30.23	
									Plasticised polyvinyl chloride mixed with any other substance	20.16.30.23	
									Vinyl chloride-vinyl acetate copolymers and o	20.16.30.40	
			Ethanol	20.14.74.00	Ethyl acrylate	20.14.33.20	>>>>>>>		Synthetic rubbers	20.17.10.90	
			Acetaldehyde	20.14.61.13	Acetic acid	20.14.32.71	Vinyl acetate	20.14.32.19	Ethylene-vinyl acetate copolymers	20.16.10.70	
									Vinyl chloride-vinyl acetate copolymers and o	20.16.30.40	
									Other polymers of vinyl acetate	0.16.52.30 (aque	
			Ethylene oxide	20.14.63.73	(Mono) ethylene glycol	20.14.23.10	>>>>>>>		Poly(etlylene glycol) PEG	20.16.40.15	
									Polyesters (excluding polyacetals, polyethers	20.16.40.90	
	Propylene	20.14.11.40	Acrylonitrile	20.14.43.50	>>>>>>>>>>>>>>>>>>>>>>>>				Acrylonitril-Butadiene-Styrene (ABS) copolymer	20.16.20.70	
									Styrene-acrylonitrile (SAN) copolymers	20.16.20.50	
									NBR Synthetic rubber	20.16.51.50	
			>>>>>>>>>>>>>>>>>>>>>>>>						Polypropylene PP	20.16.51.30	
			Propylene oxide	20.14.63.75	Polyols (Mono) Propylene glycol	20.14.23.37 20.14.23.20	>>>>>>>		Polyurethane PUR Polyester resins	20.16.56.70 20.16.40.90	
			Acrylic acid	20.14.33.10	Acrylic Esters ▼ methyl acrylate ethyl acrylate *n*-butyl acrylate	20.14.33.20	>>>>>>> >>>>>> >>>>>> >>>>>>		Polyacrylates (excluding Polymethyl methacr Polyacrylates (excluding Polymethyl methacr Polyacrylates (excluding Polymethyl methacr Polyacrylates (excluding Polymethyl methacr	20.16.53.90 20.16.53.90 20.16.53.90 20.16.53.90	
			Butyraldehyde	20.14.61.15	Ethyl hexanol	20.14.22.65	>>>>>>>		Plasticizer	20.59.56.40	
			Allyl chloride	20.14.13.79	Epichlorohydrin	20.14.63.79	>>>>>>>		epoxy resins	20.16.40.30	
	Butadiene	20.14.11.60	>>>>>>>>>>>>>>>>>>>>>>>>						Styrene-butadiene synthetic rubber (SBR)	20.16.20.90	
									NBR Nitrite Synthetic rubber	20.16.51.50	
			Chloroprene (2-chlorobuta-1,3-diene)	20.14.19.30	>>>>>>>				Neoprene	20.17.10.90	
									Other Synthetic rubbers	20.17.10.90	
			Adiponitrile	20.14.43.70	Adipic acid	20.14.33.85	>>>>>>>		Nylon 6,6 (Polyamides) (2)	20.16.54.50	
	Benzene		Ethylbenzene	20.14.12.60	Styrene	20.14.12.50	>>>>>>>		Acrylonitril-Butadiene-Styrene (ABS) copolymer	20.16.20.70	
									Styrene-acrylonitrile (SAN) copolymers	20.16.20.50	
									Polystyrene	20.16.20.39	
									Styrene-butadiene synthetic rubber (SBR)	20.16.20.90	
									Unsaturated polyesters (excluding polyaceta	20.16.40.80	
	•Benzene-Toluene-	20.14.12.23							Phenolic resins ▼	20.16.56.50	

DATA | Adhesives map | Agrochemicals map | Cosmetics map | Lubricants map | Man-made fibres map | Paints, coatings, dyes map | **Plastics map** | Solver ...



Note:

All maps are available through the report at www.RoadToBio.eu

Part 3: The interface of bio-based and petrochemical

- **Definition:**

  The ‘interface’ is formed by all the entry points where bio-based products can enter a specific petrochemical value chain.

Feedstock	Building Block 1		Building Block 2		Building Block 3		Building Block 4		Final Chemical		Application
			>>>>>>>>>>>>>>>>>>>>>>>>						Polyethylene LDPE	20.16.10.39	
									Polyethylene HDPE	20.16.10.50	
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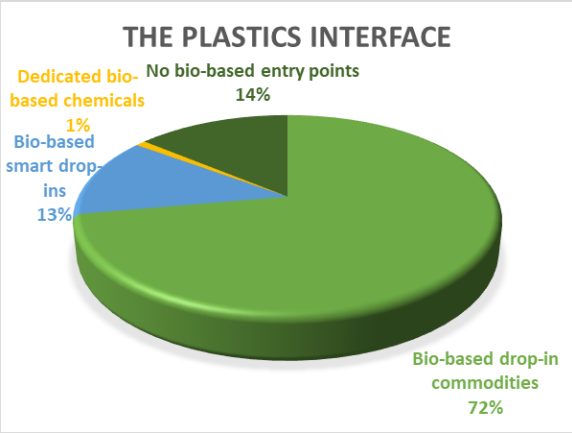
			Ethylene oxide	20.14.63.73	(Mono) ethylene glycol	20.14.23.10	>>>>>>>		Poly(etiylene glycol) PEG	20.16.40.15	
									Polyesters (excluding polyacetals, polyethers	20.16.40.90	

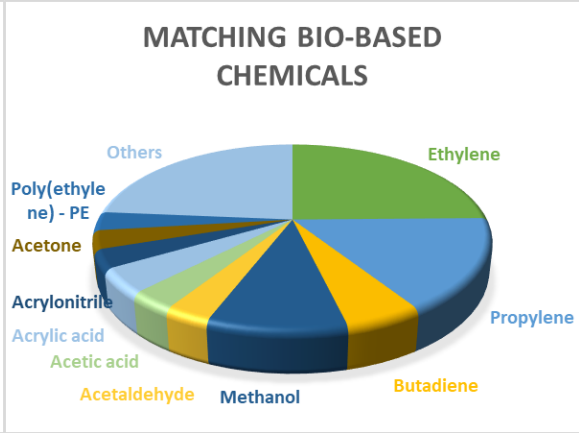
Bio-based chemical	Prodcom code	Bio-based chemical	Prodcom code	Bio-based chemical	Prodcom code
Acetaldehyde	20146113	Ethylene chloride (aka vinyl chloride)	20141371	Phenol formaldehyde resin	20165650
Acetic acid	20143271	Ethylene glycol	20142310	Poly(butylene adipate-co-terephthalate) - PBAT	20164080
Acetic anhydride	20143277	Ethylene oxide	20146373	Poly(butylene succinate) - PBS (aka 'Bionolle')	20164090
Acetone	20146211	Farnesene	20141190	Poly(butylene terephthalate) - PBT	20164080
Acrylic acid	20143310	Fatty alcohols	20142100	Poly(ethylene furanoate) - PEF	20164080
Acrylonitrile[1]	20144350	Fatty amines	20144119	Poly(ethylene glycol) - PEG	20164015
Adipic acid	20143385	Fumaric acid	20143381	Poly(ethylene terephthalate) - PET	20164062
Alkanes (iso-)	20141120	Furan	20145225	Poly(ethylene) - PE	20161035
Alkyl polyglucosides (APG)	20412090	Furandicarboxylic acid (2,5-) (FDCA)	20145225	Poly(hydroxyalkanoate) - PHA	20164090
Alkyl polypentosides (C5-surfactants)	20412090	Furfural	20145215	Poly(hydroxybutyrate) - PHB	20164090
Azelaic acid (aka nonanedioic acid)	20143381	Furfuryl alcohol	20145215	Poly(isosorbide)	20164090
Bio-'Naphtha'	20592000	Glucaric acid / Sodium glucarate	20143381	Poly(lactic acid) - PLA	20164090

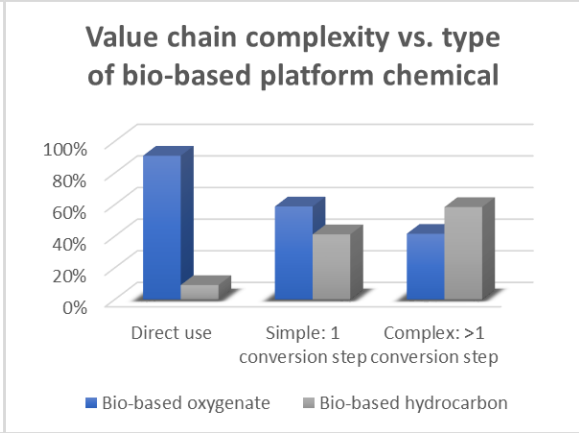
Note

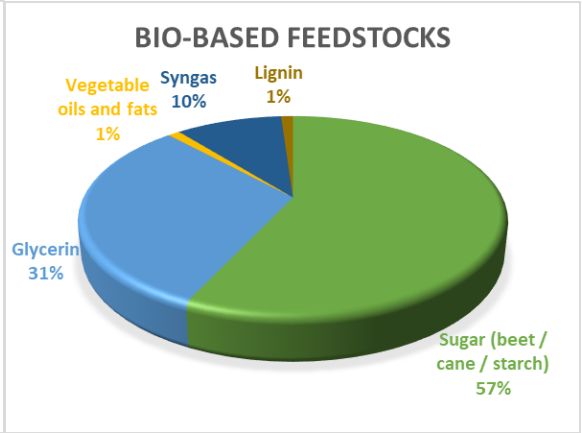
This was done using MS Excel and an in-house created MS Visual Basic programme. The programme matches the bio-based chemicals and petrochemical value chains by Prodcom code and produces a table with the new value chains in which the bio-based chemicals are integrated into the petrochemical value chains. Subsequently a manual check was performed to remove any errors or artefacts.

Part 3: Plastics interface



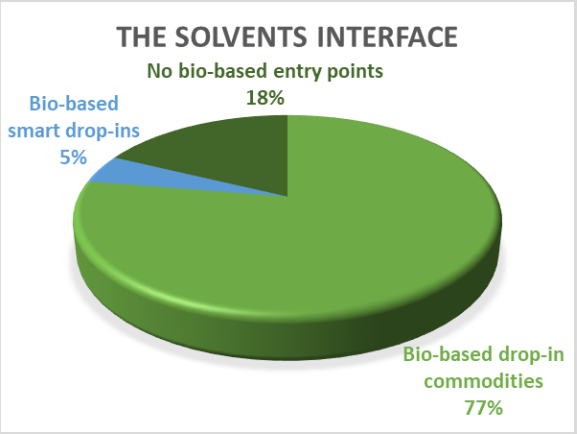


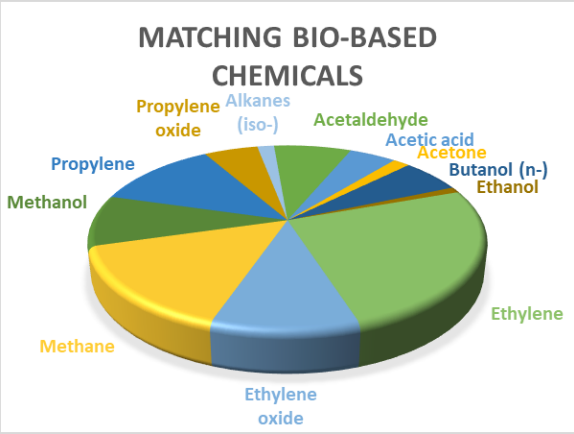


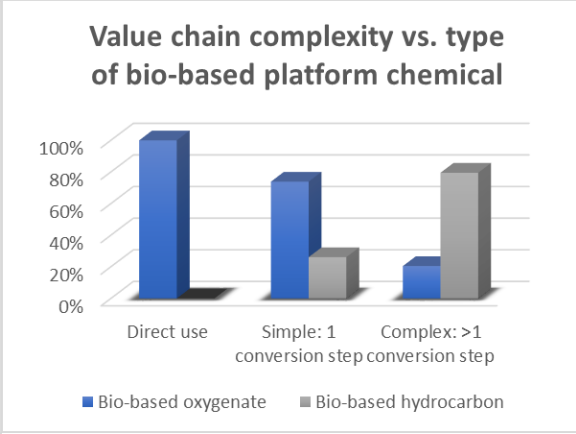


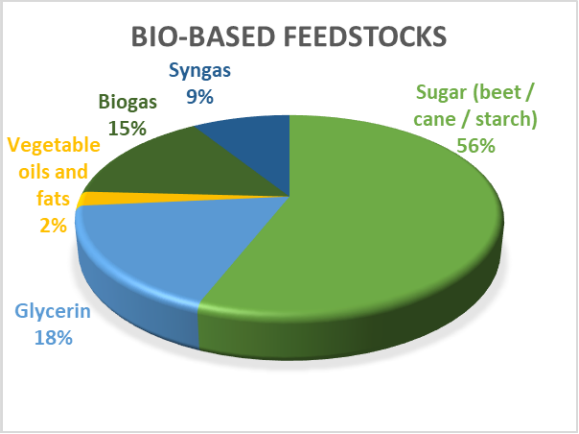
- 43 petrochemical plastics were analysed; at least one entry point for a bio-based chemical was identified for 86% of them, the majority being drop-in commodities, while also quite some smart drop-in options were present.
- 28 bio-based chemicals could enter these value chains at 93 entry points that were found. Ethylene, propylene and methanol made up half of the bio-based entries together.
- The bio-based oxygenates that can be applied directly in this product group are all polymers, of which some bio-based options had a shorter production chain, while for some there is not much difference.
- The main feedstock platforms that can currently provide these fibres are the sugar platform and the glycerine platform.

Part 3: Solvents interface



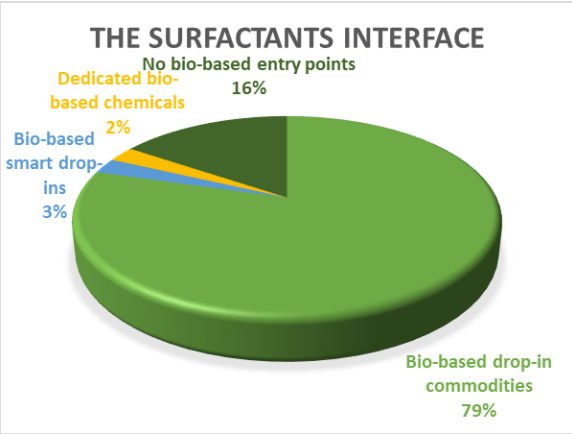


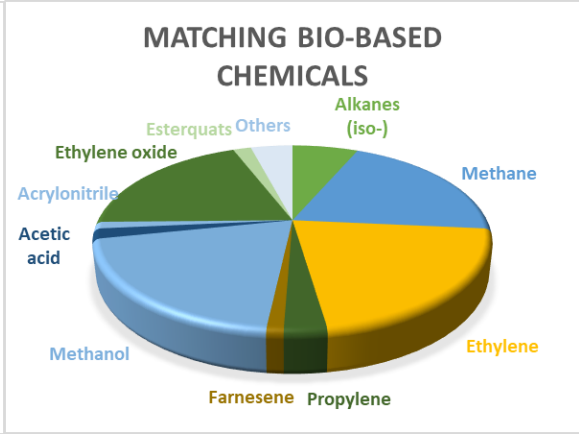


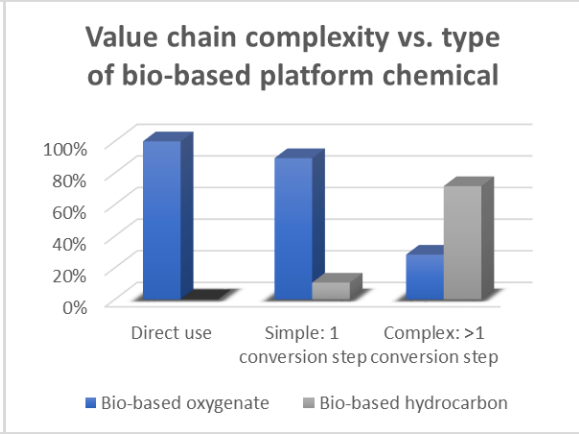


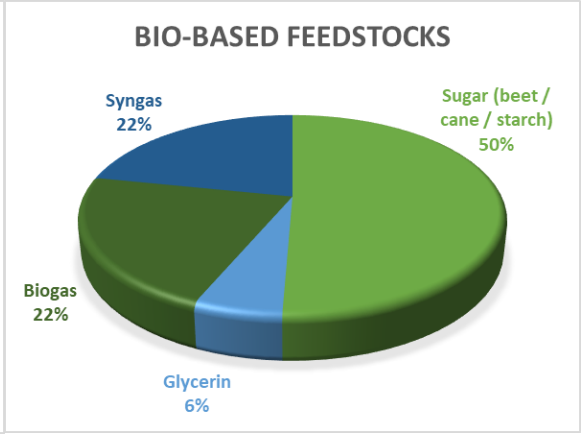
- 135 petrochemical solvents were analysed; at least one entry point for a bio-based chemical in the value chain was identified for 82% of the analysed petrochemical solvents.
- 14 bio-based chemicals from the long-list were responsible for all the entry points in the value chains.
- In general, bio-based oxygenates can enter the solvent value chains further downstream than bio-based hydrocarbons, while two bio-based oxygenates are direct (smart) drop-in replacements for a final product (iso- and n-butanol).
- The main feedstock platforms that can currently provide these bio-based chemicals are the sugar platform, the glycerin platform, and the biogas platform.

Part 3: Surfactants interface









- 90 different surfactants were analysed; at least one entry point for a bio-based chemical in the value chain was identified for 84% of these surfactants.
- 17 bio-based chemicals from the long-list could enter the existing surfactant value chains. Methane, methanol, ethylene and ethylene oxide together are responsible for 80% of these bio-based options.
- The bio-based chemicals from the long-list that could be used directly in this case were esterquats. In general, bio-based oxygenates again result in shorter subsequent value chains.
- The main feedstock platforms that can currently provide these bio-based chemicals are the sugar platform (providing a.o. ethylene and ethylene oxide), the syngas platform (providing methanol), and the biogas platform (providing methane).

Synthesis of the results

Value chains of more than 500 petrochemical final products in total were analysed, across nine different product groups. Key observations:

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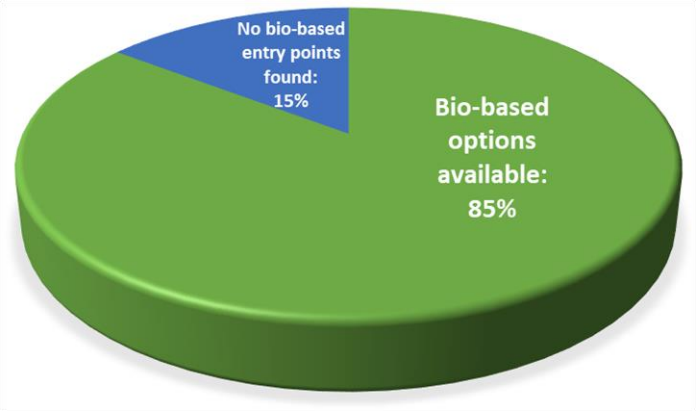

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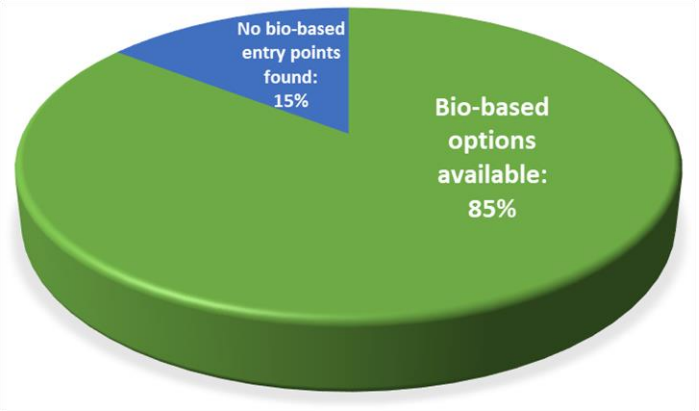

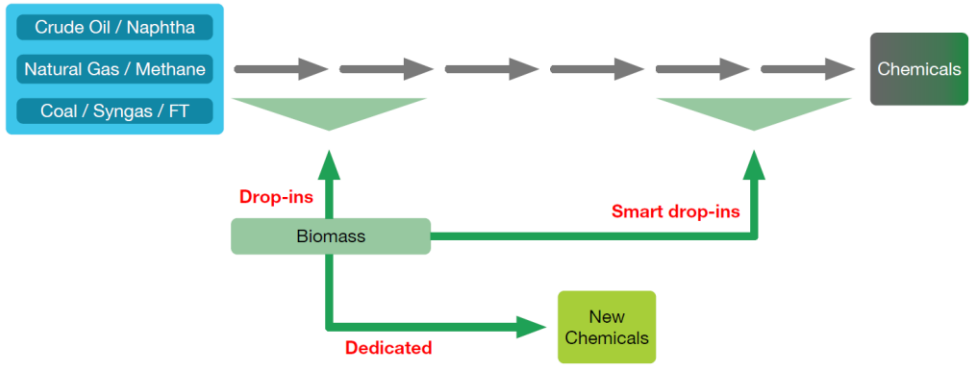

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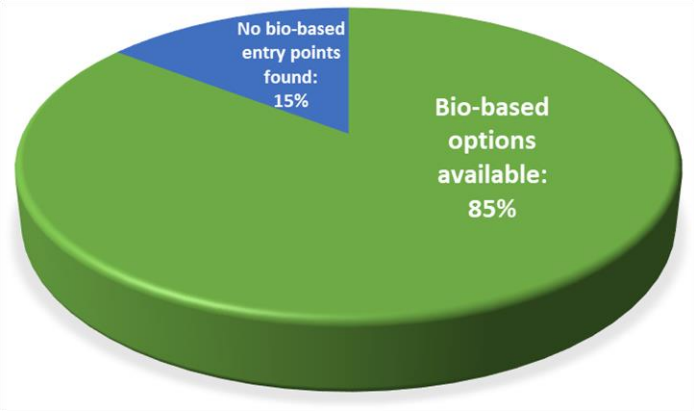
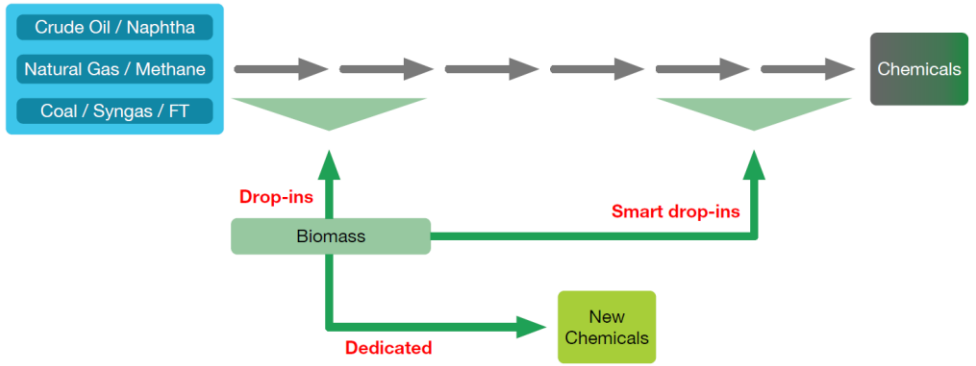
- In total 49 bio-based chemicals showed entry points in these value chains. The others were often 'dedicated chemicals', that have specific (preferential) properties and can replace formulated final products instead of parts of the current value chains.





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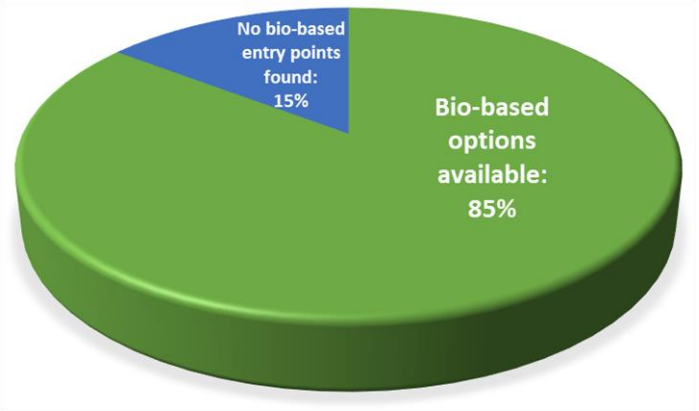
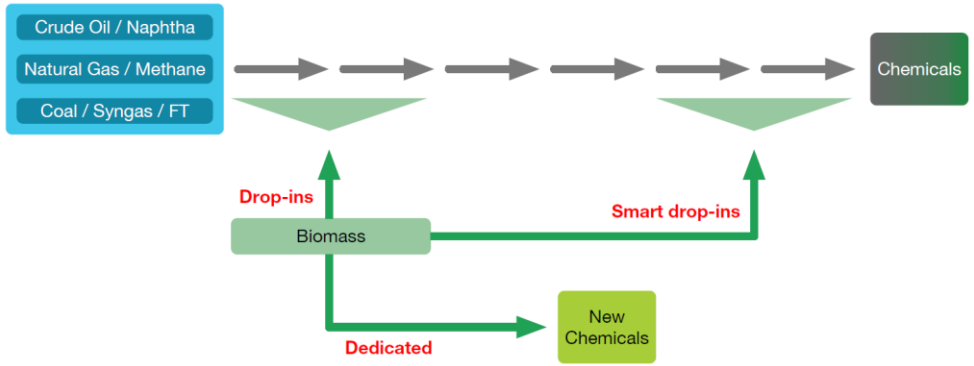
- 85% of the value chains showed at least one entry point for a bio-based chemical, showing a large technical potential for short-term replacement of fossil feedstocks.
- Bio-based oxygenates generally enter petrochemical value chains further downstream, thus the subsequent value chain is shorter. This shows an opportunity for 'smart drop-ins', that make use of oxygen functionalities that are already present in biomass.



- In total 49 bio-based chemicals showed entry points in these value chains. The others were often 'dedicated chemicals', that have specific (preferential) properties and can replace formulated final products instead of parts of the current value chains.
- The feedstock platforms that came out as most important in this analysis are the sugar platform and the glycerine platform, because those platforms are currently responsible for most relevant bio-based chemicals.



Discussion & Conclusions

Important to realise:

- Any analysis has a bias. This Prodcom-based methodology showed a bias for drop-ins. Example: 25% of the entry points was bio-based ethylene.
- An analysis based on functionality of final products instead of chemical intermediates would yield more potential for dedicated bio-based chemicals than this analysis.

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Conclusions

- This study brought together information on many value chains in the chemical industry and where possibilities lie for replacement of large volumes of fossil feedstocks, and showed that there are numerous technical possibilities for using sustainable bio-based feedstocks in the chemical industry.
- This study will serve as part of the knowledge-base for the subsequent activities in the RoadToBio project.

Outlook

Ongoing work

- Long list of 120 bio-based chemicals: estimate market potential (volume, value, growth) and time to market, in order to rank the list.
- Define criteria for selecting 9 business case studies that will provide more detailed insight on specific bio-based chemicals and related value chains.
- Identify barriers in EU legislation and public perception.

Future work

- Until summer: select and execute the case studies.
- June 19: industry workshop to further show and discuss our intermediate results.
- After summer: start compiling a roadmap towards 30% bio-based feedstocks in the chemical industry by 2030.

Thank you! Any questions?

Project Title:	**Roadmap for the Chemical Industry in Europe towards a Bioeconomy**
Acronym:	**RoadToBio**
Grant Agreement No:	**745623**
Start Date:	**01 May 2017**
Duration of the Project:	**24 Months**

www.roadtobio.eu

Deliverable No.	D1.1
Deliverable Title	Report with opportunities for bio-based chemical feedstocks and intermediates in the chemical industry
Date Delivered	31 October 2017
Prepared by (Lead Partner)	BTG Biomass Technology Group B.V. Contact: Lammens@btgworld.com

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