FERMENTATION CHEMICALS

The next green chemistry disruptor

PRESCOUTER

Fermentation chemicals will be the next disruptor in the green chemical revolution.

While plant-based solutions are generally regarded as more sustainable options compared to fossil-based synthetics, there are uncertainties regarding their carbon neutrality. Fermentation processes, however, present easily implementable methods and offer distinctive opportunities:

Can achieve negative carbon emissions by utilizing biowaste, CO_2 or methane as feedstock.

Processes can be **tightly controlled and optimized**.

High potential for **customization** of the product and process.

Can be **enantiospecific** and **tailored** for various applications.

Not limited by seasons, **no competition with food supply**, **not constrained by raw material availability and lower impact on land and water resources depending on the feedstock used***.

WHAT ARE FERMENTATION CHEMICALS?

Fermentation chemicals are chemicals produced via a fermentation process of biomass utilizing microorganisms (bacteria, yeasts, filamentous fungi and microalgae). They can be considered as a **subsection of biobased chemicals**.

This report highlights

9 commercial fermentation chemicals

that are key in the polymers, personal care, food and cleaning industries.

**applicable to CO_2, methane and waste materials.*

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2 Common chemicals that can be produced from fermentation and their applications

3 The projected market potential of fermentation chemicals

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Understanding the different fermentation processes

BACTERIA

Ancient bioconverters for every transformation

PRODUCTION OF ANTIBIOTICS

“We have learned from bacteria the molecules and now we are making it synthetically.”

BACTERIA ARE A SOURCE OF ENZYMES FOR AGRICULTURE

“Cellulases from bacteria can break down plant material into more simple sugars that can be further fermented.”

PRODUCTION OF BIOPLASTICS

“Secondary metabolism of bacteria produce polymers that can then be converted into biodegradable plastics.”

Figure. Three highlighted areas for bacterial fermentation mentioned by the Subject Matter Expert.

“There's a vast amount of potential. You have 3.5 billion years of evolution. And from my point of view, if it's organic chemistry, there are bacteria that will do the chemical transformation that you want. E. coli, for instance, has been completely re-engineered to produce whatever we want in fed-batch cultures.

Andrew Macrae, PhD

Professor Microbial Biotechnology at Universidade Federal do Rio de Janeiro

YEASTS

Making much more than bread

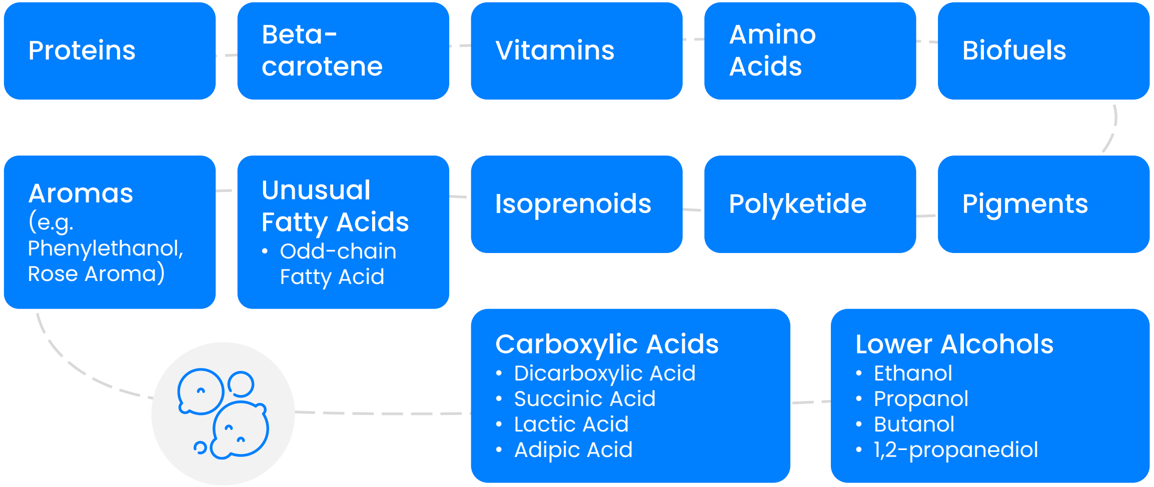


Figure. Variety of chemicals that can be produced via yeast / fungi fermentation.

> "Among the diversity of compounds that can be produced via yeast fermentation, unusual fatty acids are quite interesting because, in this case, the products are less available in nature, not growing in plants. Odd-chain fatty acids have some special properties as lubricant or for energy conservation.

Jean-Marc Nicaud, PhD
Research Director at INRA French National Institute for Agricultural Research.

Fermentation beyond CO_2 abatement

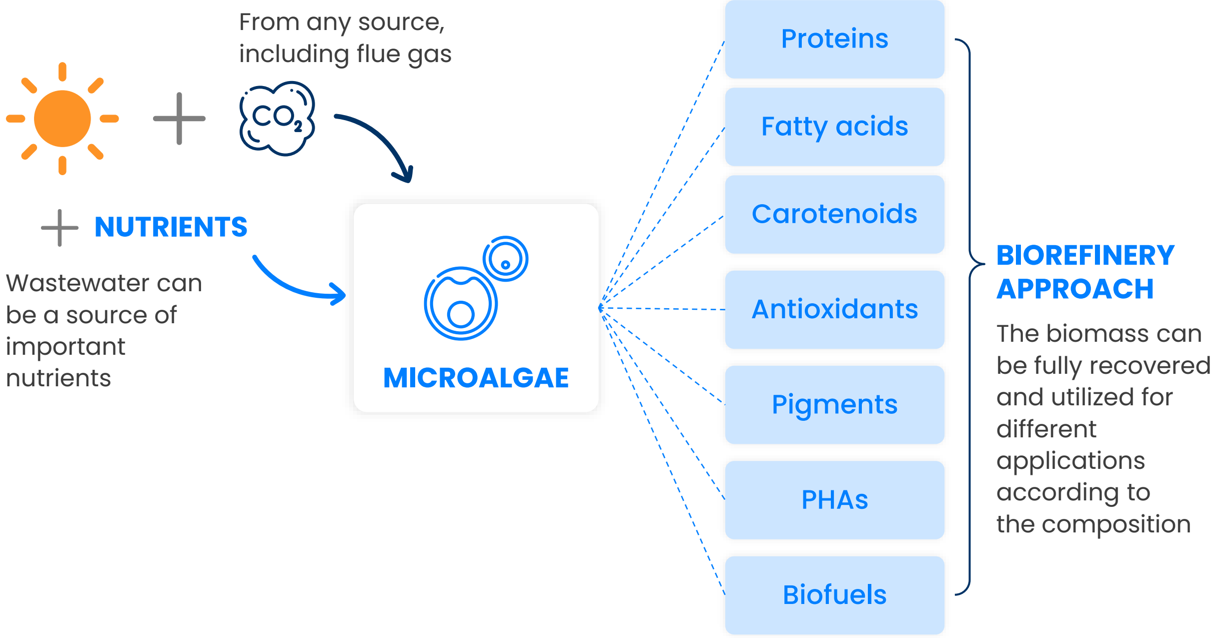


Figure. Potential products that result from microalgae fermentation.

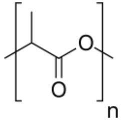
> With climate change happening right now, being able to grow microalgae at industrial scale as one the solutions for CO_2 abatement and, at the same time, producing products that we need in our daily lives, is of highest relevance.

Priscila Costa Carvalho, PhD
Project Architect, PreScouter

Common chemicals that can be produced from fermentation and their applications

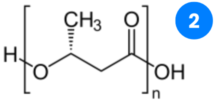
Common chemicals that can be produced via fermentation processes:

Alternatives to fossil-based plastics



1

Polylactic acid (PLA)



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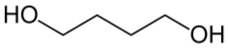
Polyhydroxyalkanoates (PHA)

Alternatives to oil-based diols



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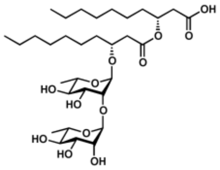
Bio-1,4-Butanediol (Bio-BDO)

Alternatives to fossil-based surfactants



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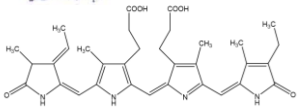
Rhamnolipids

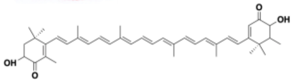
Alternatives to synthetic dyes / colorants

5



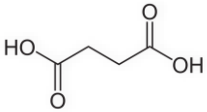
Phycocyanin

6



Natural Astaxanthin

Alternatives to synthetic organic acids from fossil-based sources



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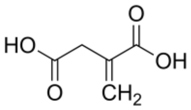
Bio-Succinic acid



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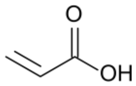
Bio-Itaconic acid

Alternatives to synthetic superabsorbent polymers



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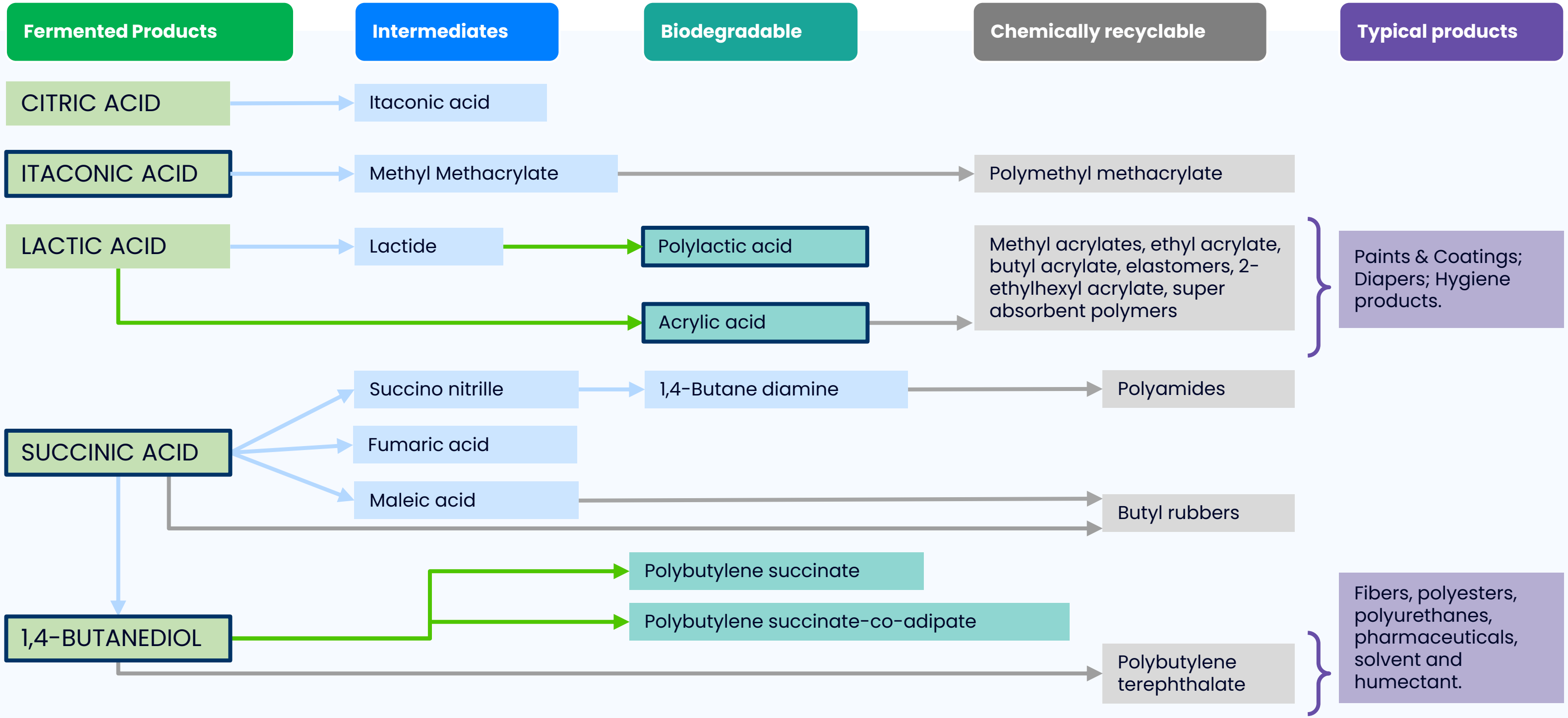
Bio-Acrylic acid

An overview of the conversion routes of fermented products to relevant platform chemicals and materials



Notes:

- Rhamnolipids, phycocyanin, astaxanthin and PHA were not added to the flowchart because they are generally consumed without undergoing further chemical conversions.

☐ Represents the chemicals that are profiled in this report.

- Citric acid is also of interest as a potential bulk chemical as it can be converted chemically to itaconic acid.

Figure. A simplified pathway that illustrates the transformation of fermentation products highlighted in this report. These chemicals undergo conversion using established industrial methods, resulting in products classified as either inherently biodegradable or chemically recyclable. **Source:** Adapted from Royal Society of Chemistry.

Key end-use applications

Packaging
(F&B, food service, consumer goods, medical)

Coatings
(Packaging)

Textile

Sustainable polymers
(PLA and PHA)

Spandex fibers

Paints & Coatings

Solvents

1,4-Butanediol
(intermediate to THF, PBT, polyesters and PU)

Superabsorbent polymers
(diapers, hygiene products, textiles)

Acrylic acid

Note: Tetrahydrofuran (THF); Polybutylene Terephthalate (PBT); Polyurethane (PU)

Personal care, food & cleaning industries

Key end-use applications

- **Nutraceuticals & cosmetics**
- **Food & beverage**
- **Animal feed**

Sustainable pigments
(phycocyanin and astaxanthin)

- **Cleaning products**
  (surfactants, chelating agents)
- **Cosmetics & personal care**

Rhamnolipids & Itaconic acid

The projected market potential of fermentation chemicals

Negative emissions can be obtained using waste as a feedstock for the fermentation process making them an attractive option in achieving net-zero commitments.

Note: More information and references can be found in the Supporting Information section.

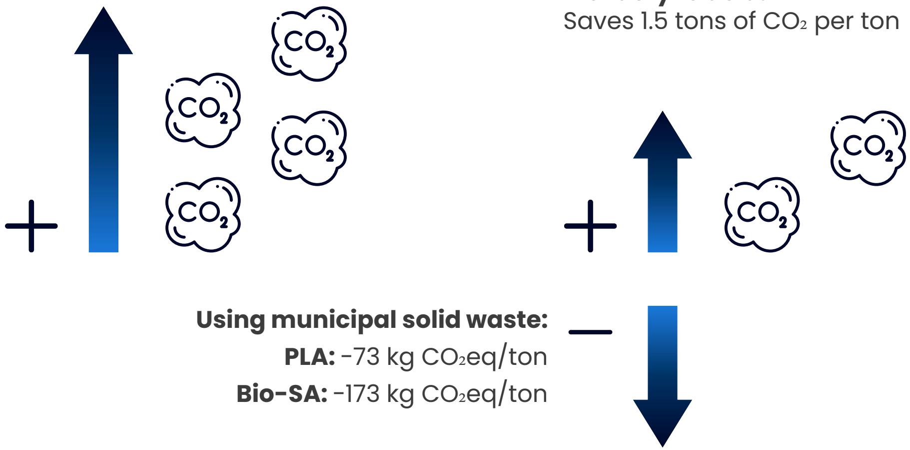
Fossil-based plastics:
1950–3500 kg CO_2eq/ton

PLA (polylactic acid):
500–800 kg CO_2eq/ton (sugarcane)

Bio-BDO:
60% reduction in GHG emissions compared to fossil BDO (cradle to gate)

Bio-Succinic acid (SA):
Saves 4.5 – 5 tons of CO_2 per ton

Bio-acrylic acid:
Saves 1.5 tons of CO_2 per ton



Using municipal solid waste:
PLA: -73 kg CO_2eq/ton
Bio-SA: -173 kg CO_2eq/ton

15 million tons of carbon dioxide can be cut if all BDO manufacturers in the world switch to bio-BDO.

Leading companies are already pioneering this approach.

Licensed **Genomatica**'s BDO technology and announced, in 2023, new agreement with **QIRA** to supply bio-BDO (1,4-Butanediol).

BASF
We create chemistry

Collaboration to produce bio-acrylic acid from **Cargill**'s lactic acid (corn sugar fermentation) as a building block for sustainable superabsorbent polymers or as thickeners for paints & coatings.

P&G

Cited **Evonik** as one of the pillars of Unilever's Clean Future initiative for expertise and supply of rhamnolipids.

Unilever

Ranked 12th in the world's most sustainable companies. **BioProduction** division is a fermentation leader in proteins and downstream purification.

SEKISUI

Novozymes and Chr. Hansen Holding A/S, both leaders in fermentation processes, are amongst the top 10 most sustainable companies. They have recently joined forces and became **Novonesis**.

novozymes

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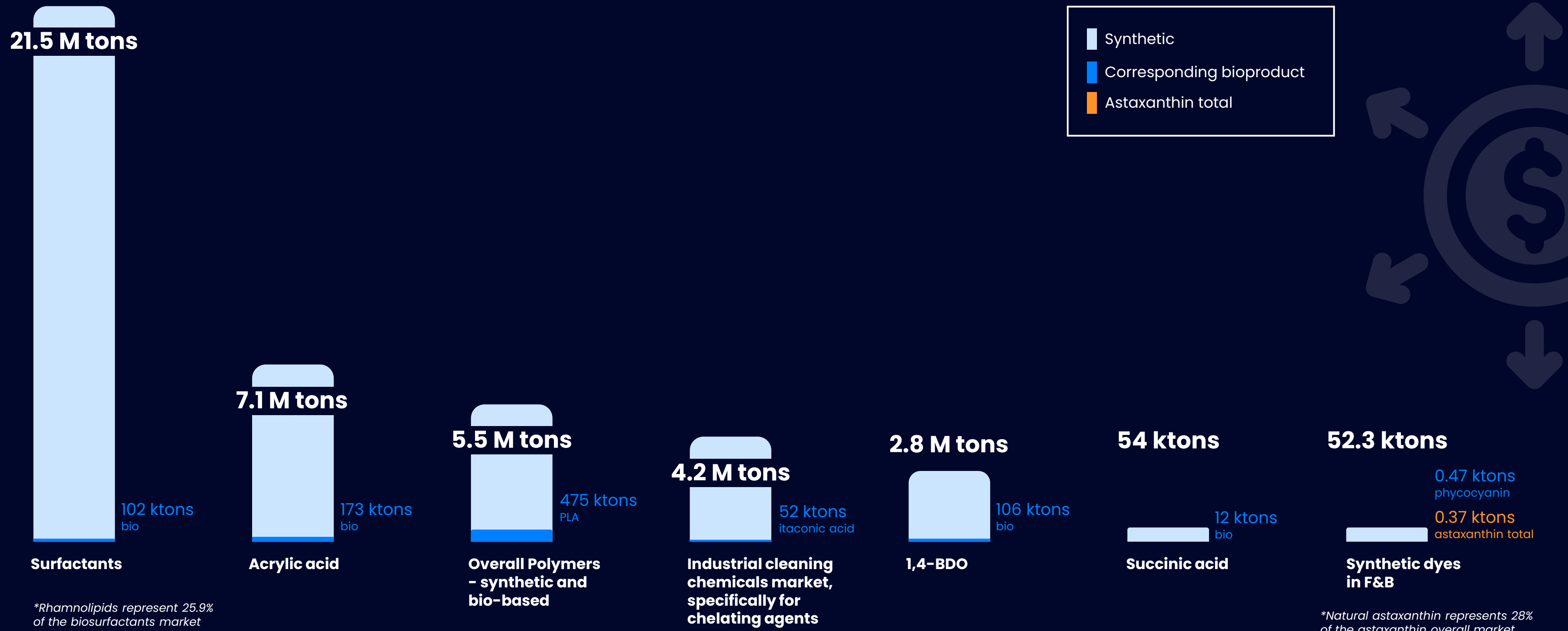
BY VOLUME | Market Size 2023

The market is relatively small, but expanding.



**Rhamnolipids represent 25.9% of the biosurfactants market*

**Natural astaxanthin represents 28% of the astaxanthin overall market*

More than half of the chemicals we profile will have double-digit growth before 2030.

In terms of value, 5 of the 9 chemicals profiled in this report are predicted to grow at a compounded annual growth rate higher than 15%.

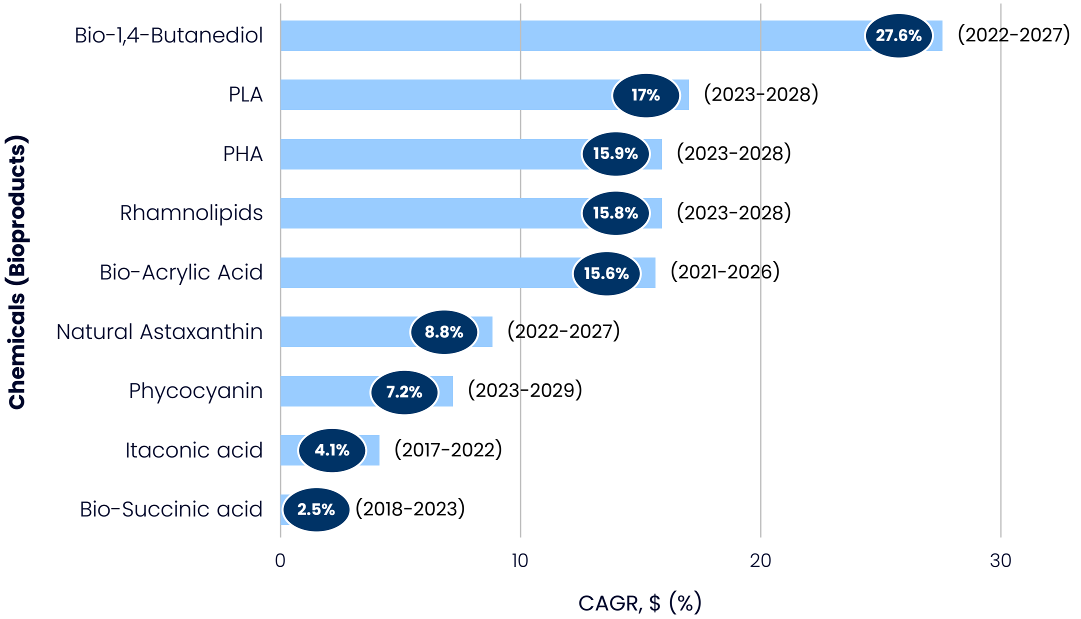


Figure. Compounded annual growth rates of 9 chemicals profiled in this report.

Four of the chemicals highlighted could potentially enter billion-dollar markets by 2030.

In terms of value, in 2023, the largest markets according to the sources consulted were PLA, rhamnolipids, and bio-acrylic acid, respectively. For 2030, a slight shift is forecasted, with the largest markets in terms of value being PLA, bio-1,4-butanediol and rhamnolipids, respectively.

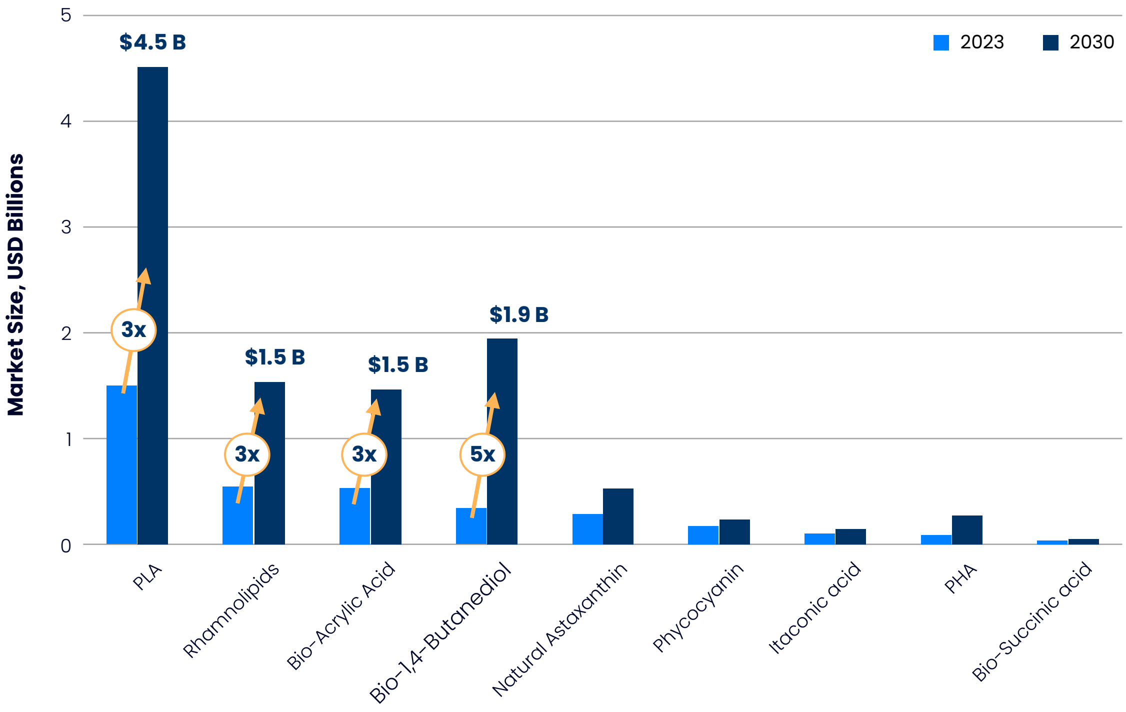


Figure. Global market sizes for 2023 and 2030 (forecast) of 9 chemicals profiled in this report.

Uncovering the biggest current market challenges

Issues with scaling up, the use of genetically modified strains (GMO), registration of the products and high production costs are the main hurdles, according to experts, for fermentation chemicals to be commercially successful.

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PRODUCTIVITY AND COSTS

~80%

of the cost of the process is the carbon source. Strains need to adapt to low price alternative feedstocks.

> 1 g/L.h

of productivity and high final yields will help improve or facilitate the downstream processing of the compounds to be purified.

BIGGEST HURDLES FOR COMMERCIALIZATION

GMO Regulation

This is a quite important factor in yeast fermentation products because it can block a part of the market.

Quality Control

There are always challenges with registering bacteria fermentation products.

High costs

The high production costs of microalgae fermentation products might make other routes more appealing, such as those using yeast or bacteria, as they grow much faster and may require less steps and simpler cultivation processes.

Bacterial fermentation Yeast fermentation Microalgae fermentation

Prices are gradually approaching parity.

$1 - 2kg
Fossil-based surfactant

$5 - 7/kg
Synthetic blue dye (indigo)

$1,250/kg
Rhamnolipids

$100 - 600/kg
Phycocyanin

$2.5 - 3/kg
BDO

$2.0 /kg
Succinic acid

$1.5 - 2.0/kg
Itaconic acid

$2.5 - 3/kg
Bio-BDO

$2.3/kg
Bio-Succinic acid

$2 - 2.6/kg
Bio-Itaconic acid

$1.2 /kg
Fossil-based plastic

$1,000 /kg
Synthetic Astaxanthin

$2.4/kg
PLA

$2.4 - 5.5/kg
PHA

$2,000 – $7,000/kg
Natural Astaxanthin

Figure. Prices of fermentation chemicals compared with their synthetic equivalents. The figure illustrates those that are still many times more expensive (left), those that are at least 2x more expensive (center) and those that are close to parity (right).

Expert Insight

Fermentation chemicals cannot compete with synthetic chemical products if the final cost of the product is too low. Because CapEx and OpEx for the fermentation, for most products, are quite high, the product value must be more than €1000 to €2000 per ton.

Jean-Marc Nicaud, PhD
Research Director at *INRA French National Institute for Agricultural Research*

Industry Insight

According to a recent press-release (Jan/24), biomanufacturing firms will likely pursue high-value chemicals with small markets compared to large-volume commodities.

High-capacity fermentation chemicals

9 key players impacting the value chain

9 BIOPRODUCTS

from fermentation as chemical alternatives

NatureWorks

PLA

From corn, cassava, sugar cane, or beets

As an alternative fossil-based plastics

geno

Bio-1,4-butanediol

From plant sugar

As an alternative to oil-based diols

pondtech

Phycocyanin

From algae / microalgae

As an alternative to synthetic dyes

ROQUETTE
Offering the best of nature

Bio-succinic acid

From plant starch

As an alternative to fossil-based organic acids

Cyanotech

Astaxanthin

From microalgae

As an alternative to synthetic dyes

EVONIK
Leading Beyond Chemistry

Rhamnolipids

From corn starch

As an alternative to fossil-based surfactants

danimer scientific
a Biotechnology Company

PHA

From plant seeds like canola and soy

As an alternative to fossil-based plastics

Itaconix

Bio-itaconic acid

From plant sugar

As an alternative to fossil-based organic acids

P&G Cargill

Bio-acrylic acid

From plant sugar

As an alternative to petro-based acrylic acid.

Alternative to **synthetic plastics**

Polylactic acid (PLA) from corn, cassava, sugar cane, or beets (fermentation).

A new facility is under construction which will add 75k metric tons per year in 2024.

Product name: INGEO

HQ: Plymouth, USA

NatureWorks

150 k tons per year

Polyhydroxyalkanoate (PHA) derived from seed oils fermentation.

Product name: Nodax®

HQ: Bainbridge, USA

danimer scientific a Biotechnology Company

10 k tons per year

Alternative to **synthetic organic acids**

Bio-succinic acid from plant starch fermentation.

Product name: Biosuccinium®

HQ: Lestrem, France (plant in Cassano Spinola, Italy).

ROQUETTE Offering the best of nature™

10 k tons per year

SME Insight:

> The succinic acid production is a good example of a high-producing yeast strain.

Jean-Marc Nicaud, PhD
Research Director at INRA

Homopolymer sodium polyitaconate from plant sugars fermentation.

Product name: Itaconix® SF 505

HQ: Stratham, USA

Itaconix

Commercial*

**All information was provided from sources available in the public domain. References can be found in the Supporting Information section. 'Commercial' means that the capacity was not disclosed.*

Bacterial fermentation | Yeast fermentation | Filamentous fungi fermentation

Alternative to **oil-based diols**

Bio-1,4-butanediol from plant sugars fermentation. Combined global production capacity, considering all companies that have license the technology.

Product name: Geno BDO™

HQ: San Diego, USA.

geno.

100 k tons
per year

Rhamnolipids from corn starch fermentation.

Product name:
REWOFERM® RL 100

HQ: Essen, Germany

EVONIK Leading Beyond Chemistry

Commercial*

All information was provided from sources available in the public domain. 'Commercial' means that the capacity was not disclosed.

***Capacity for P&G and Cargill's technology to produce bio-acrylic acid from lactic acid (corn sugar fermentation) was not shown because it is likely at pilot scale, but was commercially proven.*

Alternative to **synthetic dyes**

2 k tons/year of Spirulina algae, which could contain 10% to 20% phycocyanin.

Product name: Phycocyanin

HQ: Markham, Canada

pondtech

2 k tons
per year

70 tons/year of microalgae *H. pluvialis* with 1.5% of astaxanthin.

Product name: BioAstin®

HQ: Kailua-Kona, Hawaii, USA

Cyanotech

70 tons
per year

Bacterial fermentation   Microalgae fermentation

COMPANIES PROFILED

# of employees	Product name	Composition / Source	Aims to replace / Function	Partnerships	End industry application	Scale of production

For a more in-depth look into the companies profiled, please send your request to Marija Jovic (mjovic@prescouter.com) or Ryan Moran (rmoran@prescouter.com).

COMPANIES PROFILED

Product name	Bioproduct	Carbon source	Microorganism	Fermentation conditions	Environmental Impacts

For a more in-depth look into the companies profiled, please send your request to Marija Jovic (mjovic@prescouter.com) or Ryan Moran (rmoran@prescouter.com).

Bacterial Microalgae Yeast Filamentous fungi

Prepare for the impact in your space:

How can PreScouter help you achieve your goals?

Finding chemicals from alternative feedstocks

We work with your team to identify, profile, analyze and recommend alternative materials that fit your specific needs.

Providing the current state-of-the-art for fermentation technologies

The fermentation space is constantly evolving, and keeping you informed about emerging technologies may give you a significant advantage.

Identifying potential partners or collaborators

We help you understand the market dynamics, including the value chain, key players, and their partnerships. We can conduct anonymous interviews with companies to evaluate their potential as partners, assessing their capabilities and willingness to collaborate.

For detailed information about all the companies profiled in this report, please contact Marija Jovic (mjovic@prescouter.com) or Ryan Moran (rmoran@prescouter.com).

Meet the Experts

Jean-Marc Nicaud, PhD

Research Director at INRA French National Institute for Agricultural Research

Jean-Marc was the responsible for the organization of the first meeting on the yeast Yarrowia lipolytica, in 1995. He has supervised more than 50 members and has been working with Y. lipolytica for over 20 years as a platform for heterologous protein production and lipid metabolism to produce non-usual fatty acids. Jean-Marc has over 200 publications and an h-index of over 60. In addition, he also works as a consultant and is involved and responsible for industrial collaboration, public grant and EEC projects.

Andrew Macrae, PhD

Professor Microbial Biotechnology at Universidade Federal do Rio de Janeiro | Head of Sustainable Biotechnology

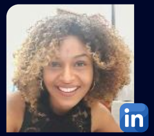
With over 20 years of experience as a Professor Microbial Biotechnology at Universidade Federal do Rio de Janeiro (UFRJ), Andrew leads the Sustainable Biotechnology and Microbial Bioinformatics Laboratory, where he conducts research on identifying microorganisms for agriculture, environmental remediation, bioenergy / carbon cycling and bioprocess optimization.

About the Authors

Priscila Costa Carvalho, PhD

Project Manager

Priscila is one of PreScouter's Project Architects and an expert in microalgal bioprocesses. She has a solid background in Chemistry and Chemical Engineering and holds a Master's degree in Chemistry and a PhD in Chemical Engineering, from the University of São Paulo (Brazil). Her PhD thesis involved the development of processes in photobioreactors for CO_2 bioconversion using high CO_2-tolerant microalgae and production of high value products (lipids and carotenoids). Priscila brings to PreScouter years of experience in the research and development of new materials and bioprocesses, working in multidisciplinary teams and in collaboration with industry.



Laís Pereira Silva, PhD

Senior Analyst

Laís is a Senior Analyst at PreScouter. She has a Ph.D. and a Master's Degree in Analytical Chemistry, from the Federal University of São Carlos (Brazil). Laís has been actively working in the Chemicals, Materials, and Packaging verticals, collaborating with years of experience in materials research and development.

Marija Jović, PhD

Technical Director

Marija is the Technical Director for PreScouter's Chemical, Materials, and Packaging verticals. She has worked across topics such as product and process improvement and development and sustainability throughout the chemicals, materials, and packaging industry. Marija completed her Master's degree in Chemical Engineering from Belgrade University and her PhD in Organometallic Chemistry and Catalysis at the Swiss Federal Institute of Technology (ETH Zurich). Prior to her PhD, Marija worked in the chemical industry on the synthesis of new textile dyes.

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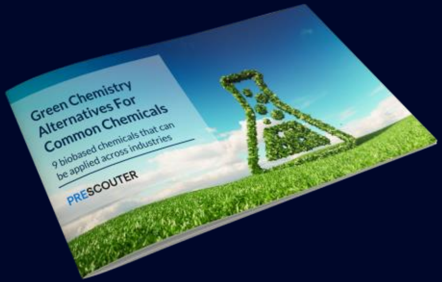

Green Chemistry Alternatives For Common Chemicals

Recycling of Thermoset Materials

PreScouter's insights on the role of alternative feedstocks in decarbonization

Engage our network of experts and researchers on your topic.

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