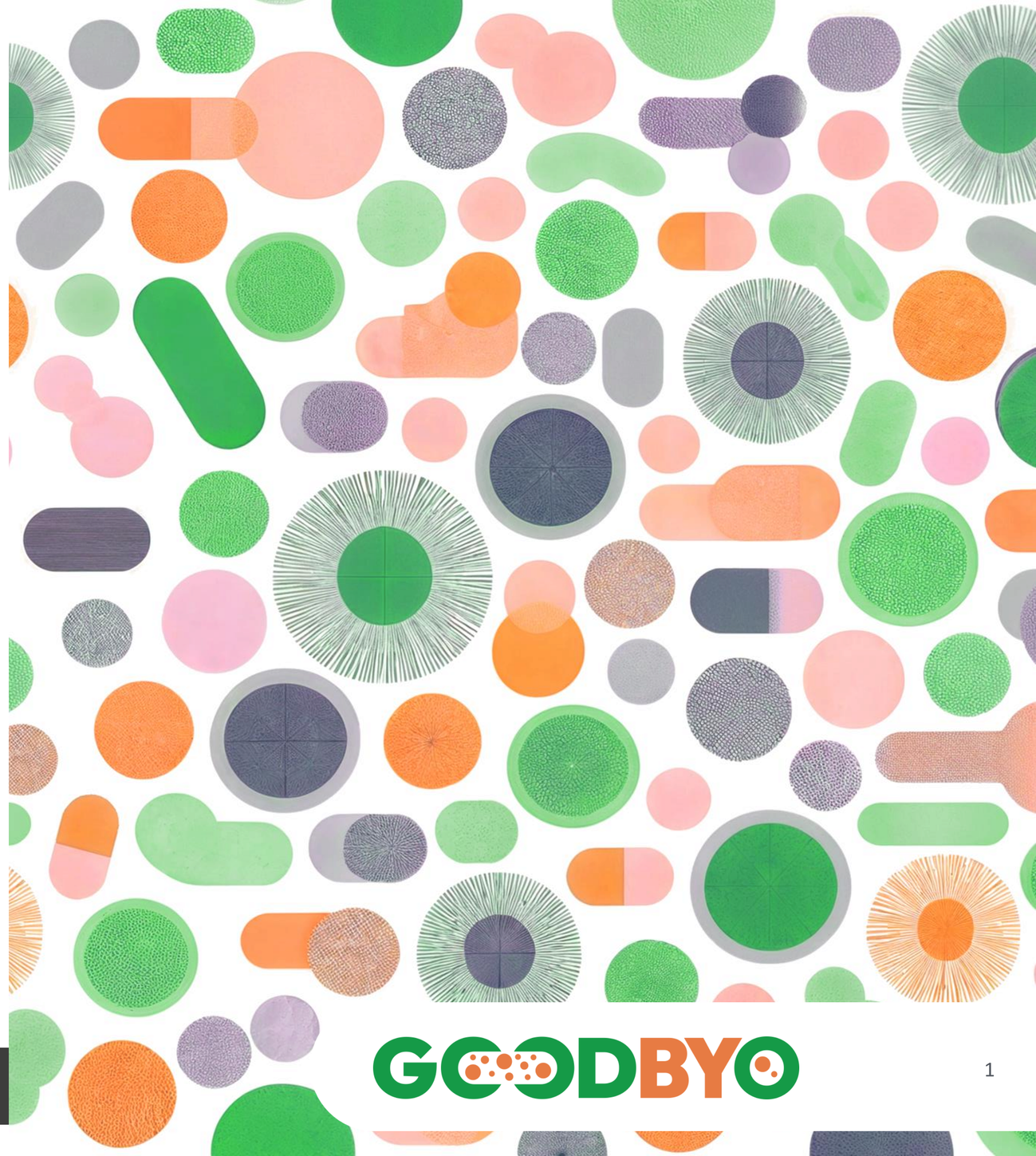
ISTITUTO ITALIANO
DI TECNOLOGIA
CENTER FOR SUSTAINABLE
FUTURE TECHNOLOGIES

IL PROGETTO GOODBYO: LA "GAS FERMENTATION" PER PRODUZIONI A VALORE AGGIUNTO

Dr. Valeria Agostino, Istituto Italiano di Tecnologia

5 Novembre 2025, Area Forum CIB – Pad. D5
Filiere del gas rinnovabile: nuove opportunità, nuove frontiere
A cura di CIB – Consorzio Italiano Biogas



GOODBYO

Circular Bio-based Europe Joint Undertaking
Bio-based Industries Consortium
Co-funded by the European Union
ECOMONDO The green technology expo. NOVEMBER 4 — 7, 2025 RIMINI EXPO CENTRE Italy

ISTITUTO ITALIANO
DI TECNOLOGIA
CENTER FOR SUSTAINABLE
FUTURE TECHNOLOGIES

THE MISSION

Develop innovative and sustainable bioprocesses, materials and technologies for:

- the CO_2 capture and utilization
- the production, storage, and use of green H_2
- the accumulation and management of electrical energy
- the valorization of waste


Carbon dioxide

Hydrogen


Energy


Waste

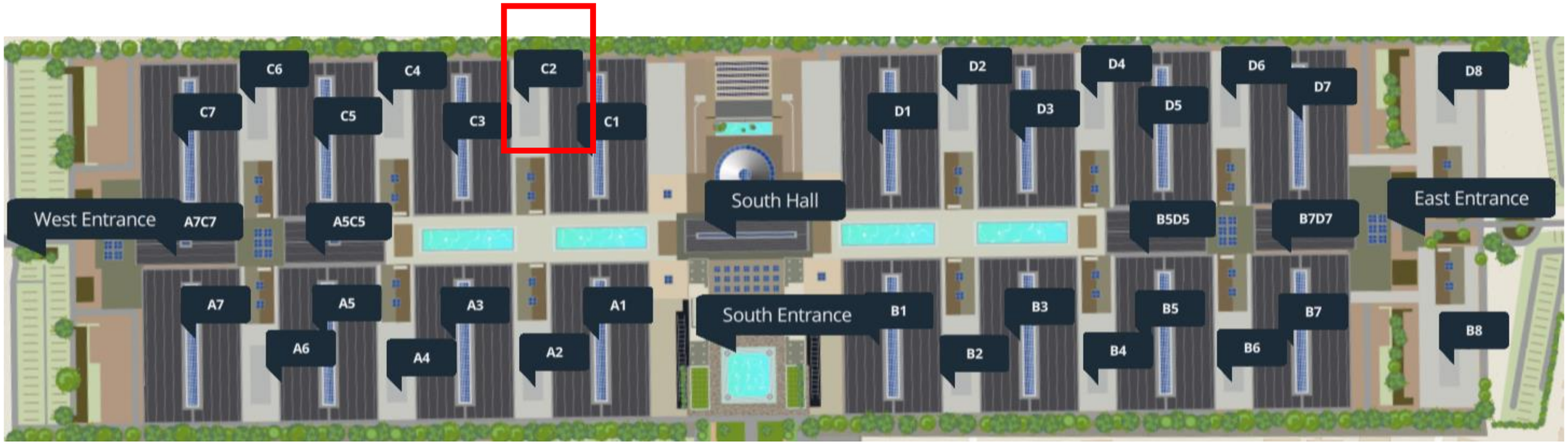
IIT@Torino Center Director: Prof. Fabrizio Pirri

Established in 2018 within the Environment Park in Turin (IT)

ISTITUTO ITALIANO
DI TECNOLOGIA
CENTER FOR SUSTAINABLE
FUTURE TECHNOLOGIES

ECOMONDO
The green technology expo.
NOVEMBER
4 — 7,
2025
RIMINI
EXPO CENTRE
Italy

VISIT US:



PADGLIONE C2, STAND 213

CURRENT FEEDSTOCKS OF THE MANUFACTURING INDUSTRY

ISTITUTO ITALIANO
DI TECNOLOGIA
CENTER FOR SUSTAINABLE
FUTURE TECHNOLOGIES

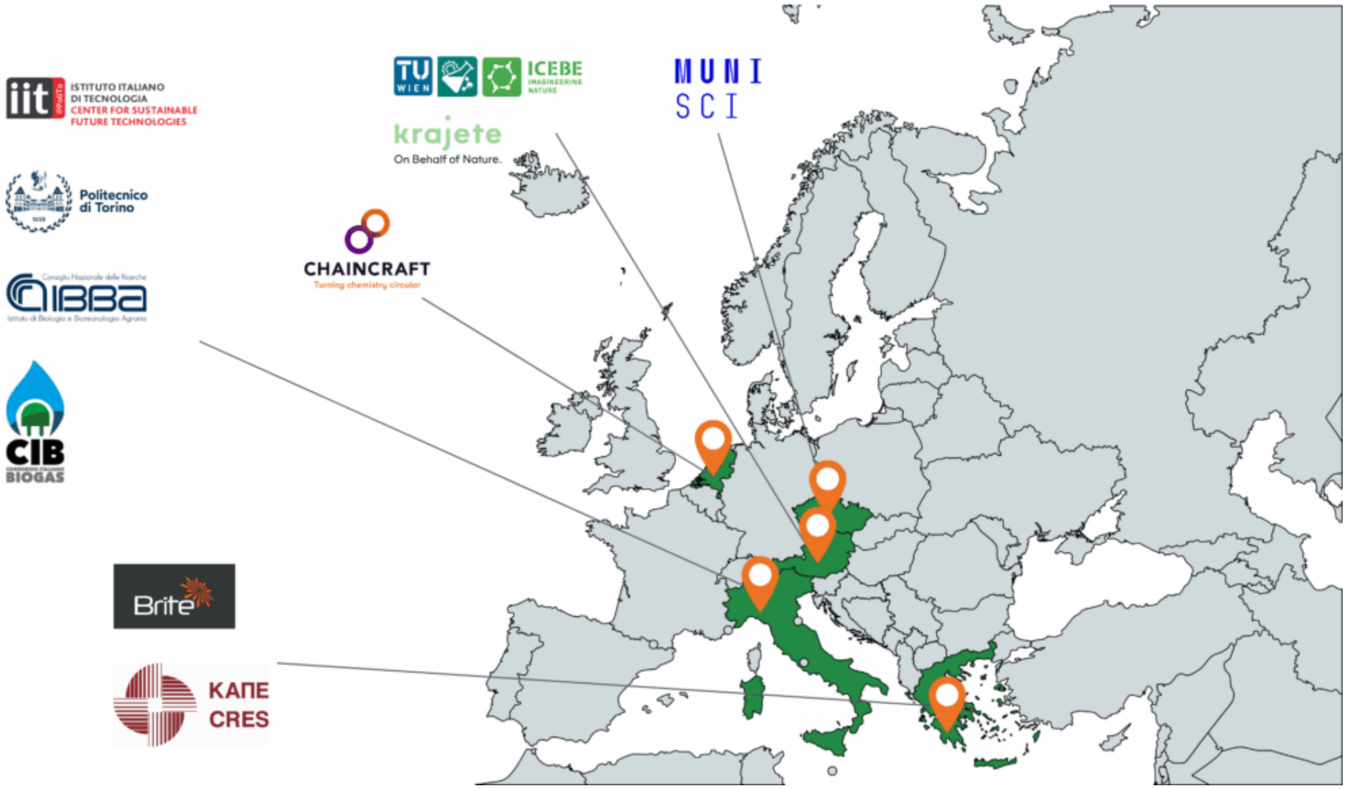
Fossil based energy

Palm-oil based

Crude-oil based

THE GOODBYO PROJECT

Multi-commodities microbial-driven BiOrefinery based on food-processing industry wastes, biogenic CO_2 and bioprocess wastewaters.



3 UNI | 3 RTOs | 3 SMEs | 1 ASSOCIATION

Circular Bio-based Europe Joint Undertaking

Bio-based Industries Consortium

Co-funded by the European Union

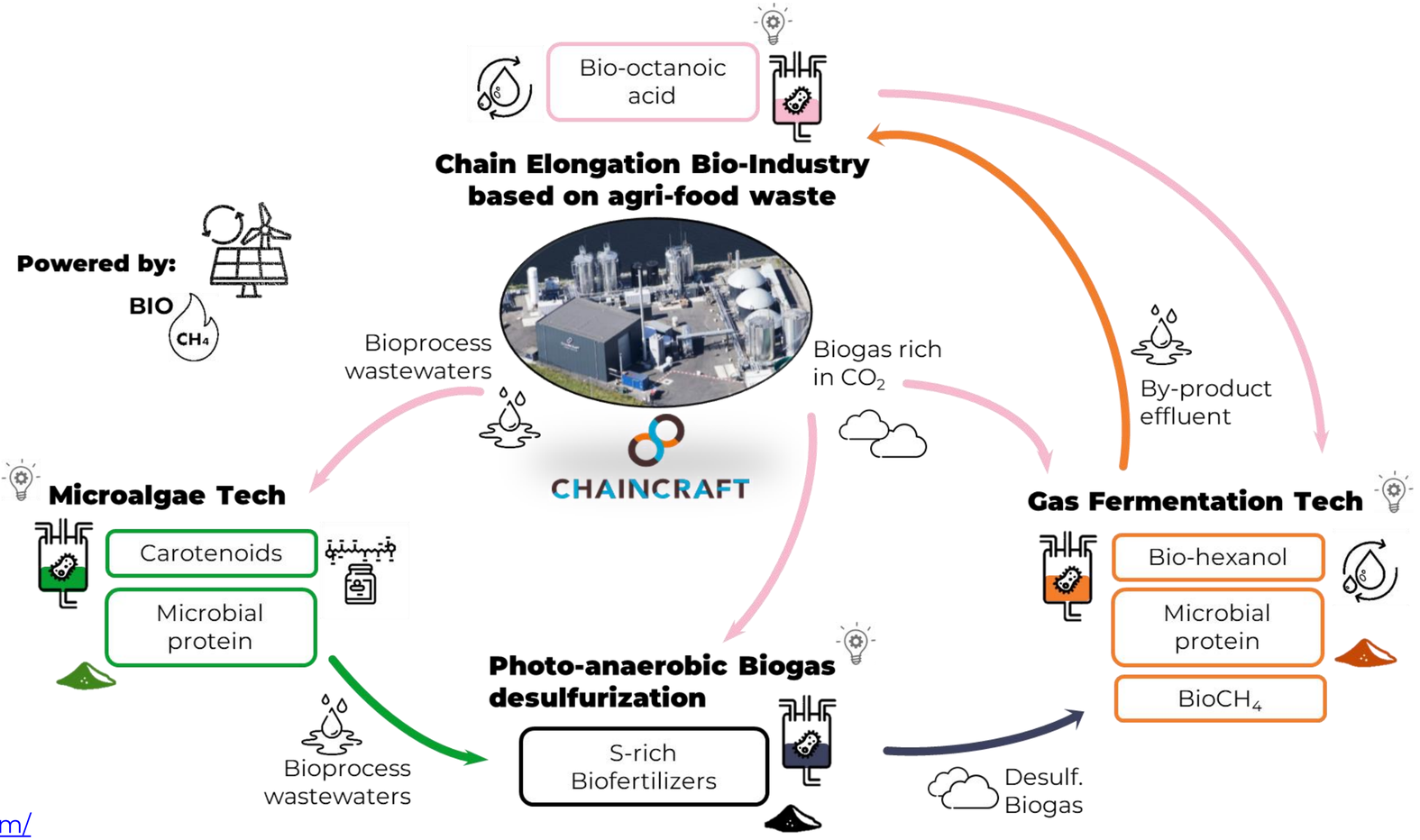
Duration: **42 months** (1/10/2024 –31/3/2028)

Reserach & Innovation action

Coordinator: ISTITUTO ITALIANO DI TECNOLOGIA CENTER FOR SUSTAINABLE FUTURE TECHNOLOGIES

THE GOODBYO PROJECT

Multi-commodities microbial-driven BiOrefinery based on food-processing industry wastes, biogenic CO_2 and bioprocess wastewaters.



TARGET:

Long-term production stability of GoodByO bioprocesses at **TRL 5**, using **real** gaseous and liquid **feedstocks**

https://chaincraft.com/

https://goodbyo.eu/

THE GOODBYO GAS FERMENTATION PROCESS

ISTITUTO ITALIANO DI TECNOLOGIA
CENTER FOR SUSTAINABLE FUTURE TECHNOLOGIES

CHAINCRAFT
Turning chemistry circular

Biogas rich in CO_2

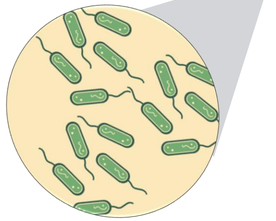
H_2

Gas Fermentation Tech

Bio-hexanol

Microbial protein

$BioCH_4$



Clostridium carboxidivorans_hex21

Simoultaneous **biochemicals production** and **biogas upgrade** into $bioCH_4$

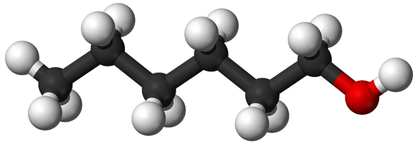
ISTITUTO ITALIANO DI TECNOLOGIA
CENTER FOR SUSTAINABLE FUTURE TECHNOLOGIES

TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

krajete
On Behalf of Nature.

1-HEXANOL MARKET

$C_6H_{13}OH$



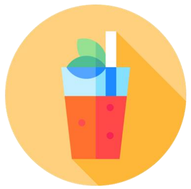
Textile industry

Solvent for pharma industry

Lubricant industry

Plastics manufacturing

Food and beverage



Fragrances & personal care

Actual hexanol production routes:

- Petroleum-based via Ziegler alcohol synthesis and the hydroformylation of 1-pentene followed by hydrogenation

- Palm-oil based via methyl-ester hydrogenation and fatty acid hydrogenation

1-HEXANOL USES IN F&F INDUSTRIES

ISTITUTO ITALIANO DI TECNOLOGIA
CENTER FOR SUSTAINABLE FUTURE TECHNOLOGIES

Flavour

Taste: green, fruity and winey.

It gives a delicate fatty-fruity, woody and fermented profile to fruit, vegetable and alcoholic flavors

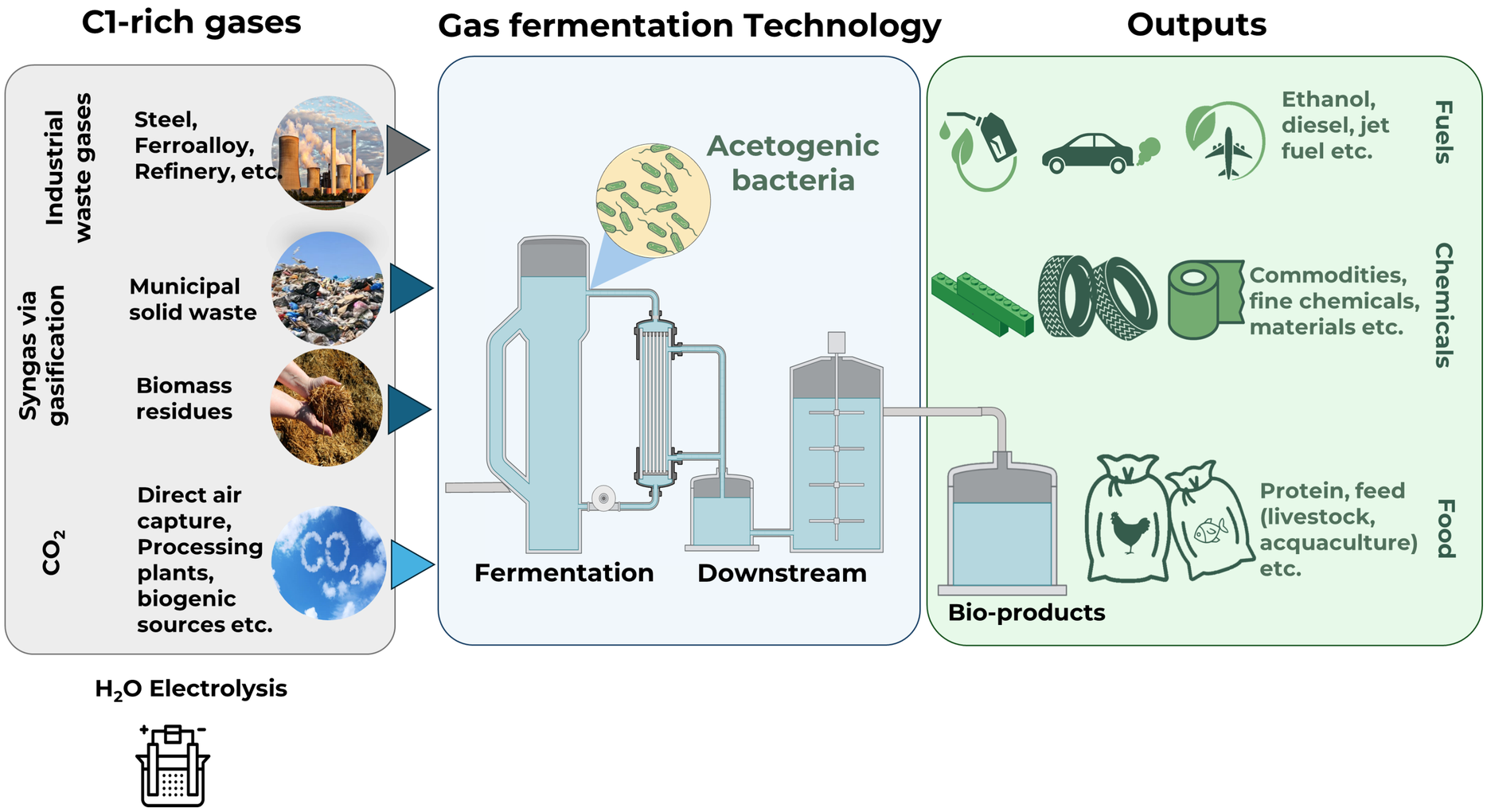
Fragrances

Odor: green; herbaceous; woody; sweet

Floral fragrance family

THE GAS FERMENTATION TECHNOLOGY

ISTITUTO ITALIANO
DI TECNOLOGIA
CENTER FOR SUSTAINABLE
FUTURE TECHNOLOGIES



INDUSTRIAL EXAMPLES OF GAS FERMENTATION

LanzaTech

Ethanol

https://lanzatech.com/

again

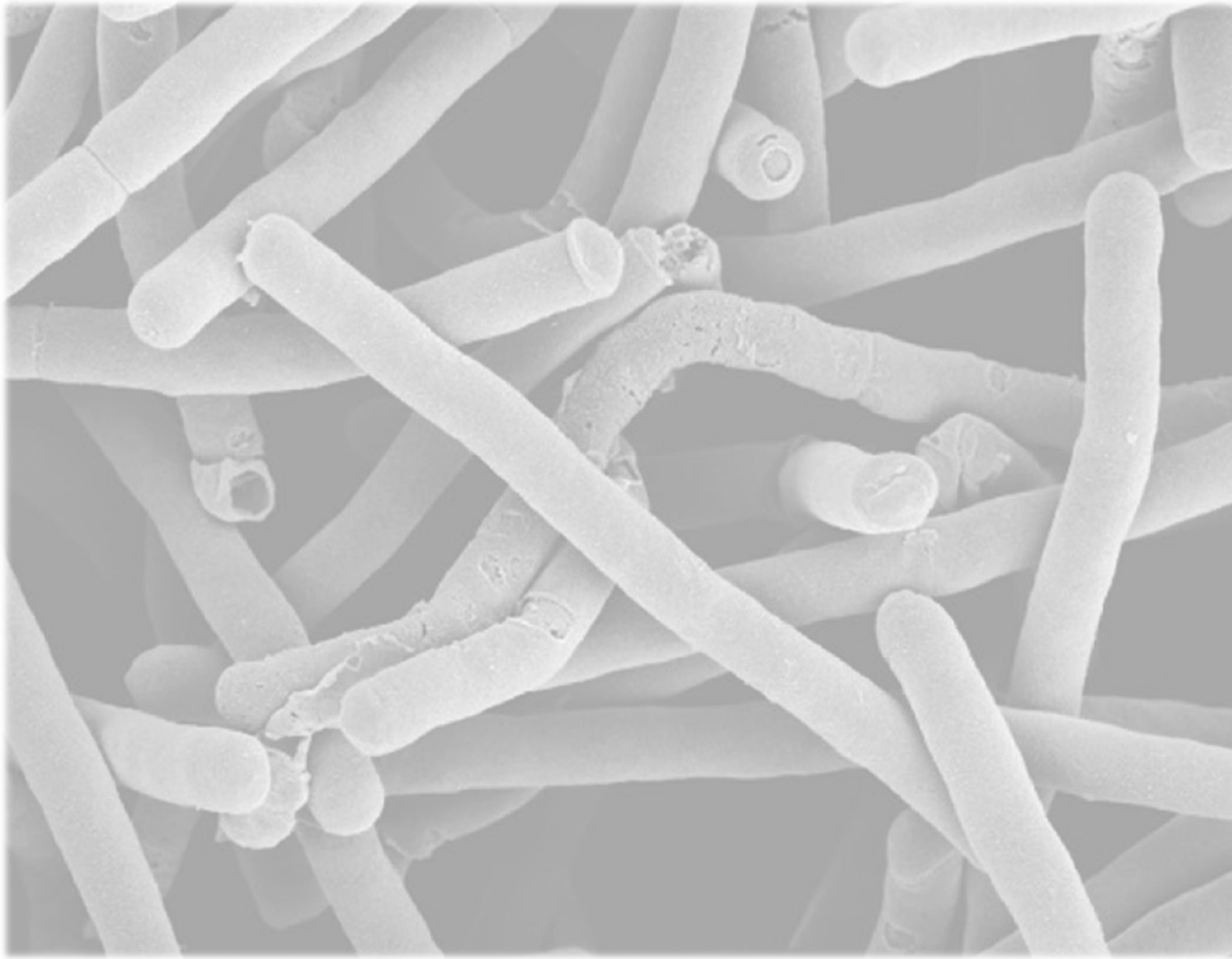
Acetate

https://again.bio/

Producer	Gaseous source	Startup	Capacity per year
Hebei Shoulang New Energy Technology Co., Ltd (China)	Steel-mill	2018	45k tons
Ningxia Shoulang Jiyuan New Energy Technology Co., Ltd (China)	Ferroalloy off-gases	2021	45k tons
Guizhou Jinze New Energy Technology Co., Ltd (China)	Ferroalloy off-gases	2022	60k tons
Ningxia Binze New Energy Technology Co., Ltd (China)	Ferroalloy off-gases	2023	60k tons
IndianOil Corporation (India)	Refinery off-gases	2023	33,5k tons
ArcelorMittal (Belgium)	Steel-mill	2023	64k tons

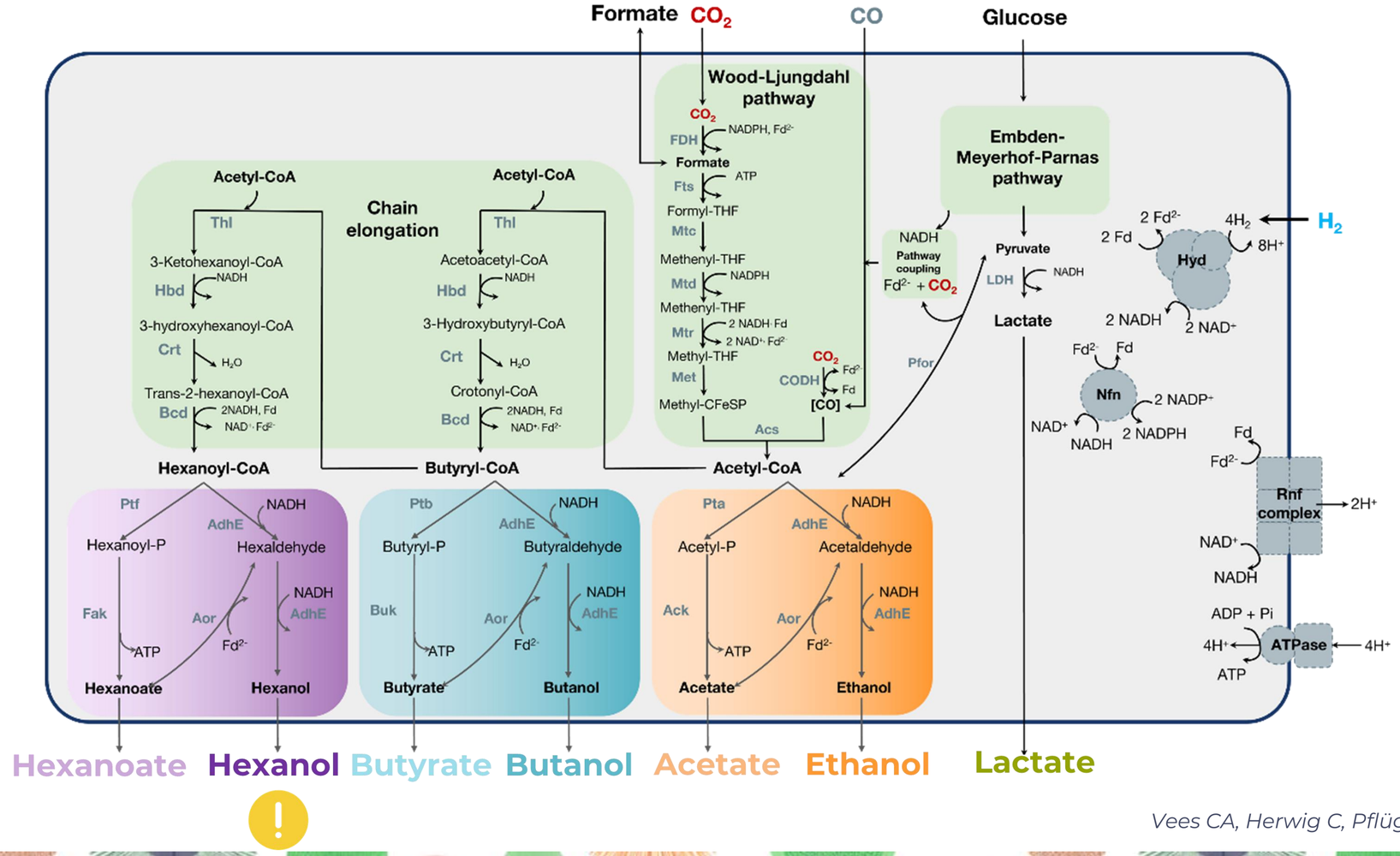
- Danish Start-up, biochemicals production of **from CO_2 and H_2**
- Future production site in Texas using industrial CO_2

WHAT ABOUT GAS FERMENTATION WITH *Clostridium carboxidivorans*?



PRODUCT VERSATILITY OF THE ACETOGEN *Clostridium carboxidivorans*

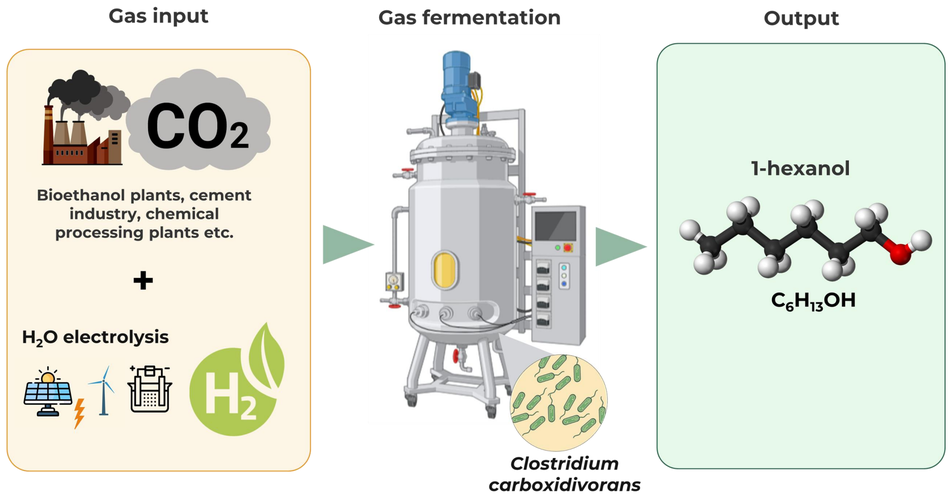
ISTITUTO ITALIANO DI TECNOLOGIA
CENTER FOR SUSTAINABLE FUTURE TECHNOLOGIES



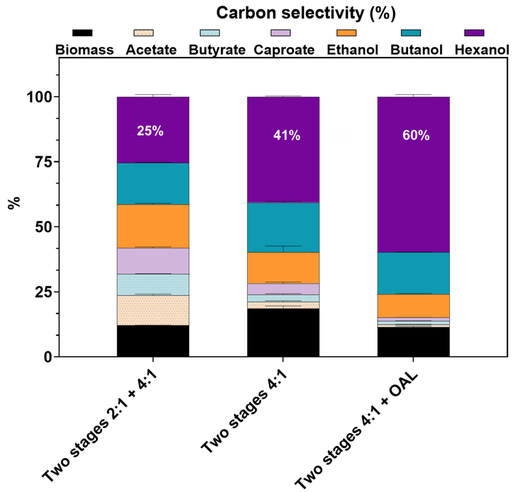
Vees CA, Herwig C, Pflügl S. 2022 Bioresour Technol. 353

TOWARD BIO-HEXANOL PRODUCTION

ISTITUTO ITALIANO
DI TECNOLOGIA
CENTER FOR SUSTAINABLE
FUTURE TECHNOLOGIES



Giacomo Antonicelli
PhD work, IIT



Bioresource Technology 387 (2023) 129689

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Expanding the product portfolio of carbon dioxide and hydrogen-based gas fermentation with an evolved strain of *Clostridium carboxidivorans*

G. Antonicelli [a,b,1], L. Ricci [a], L. Tarraran [a,c], S. Fraterrigo Garofalo [c], A. Re [c], N.S. Vasile [a,b], F. Verga [b], C.F. Pirri [a,c], B. Menin [a,d], V. Agostino [a,1,*]

First time hexanol production from CO_2 and H_2

Bioresource Technology 418 (2025) 131966

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Harnessing an adapted strain of *Clostridium carboxidivorans* to unlock hexanol production from carbon dioxide and hydrogen in elevated-pressure stirred tank reactors

G. Antonicelli [a,b], N. Vasile [a,b], E. Piro [a,e], S. Fraterrigo Garofalo [c], B. Menin [a,d], F. Verga [b], F. Pirri [a,c], V. Agostino [a,*]

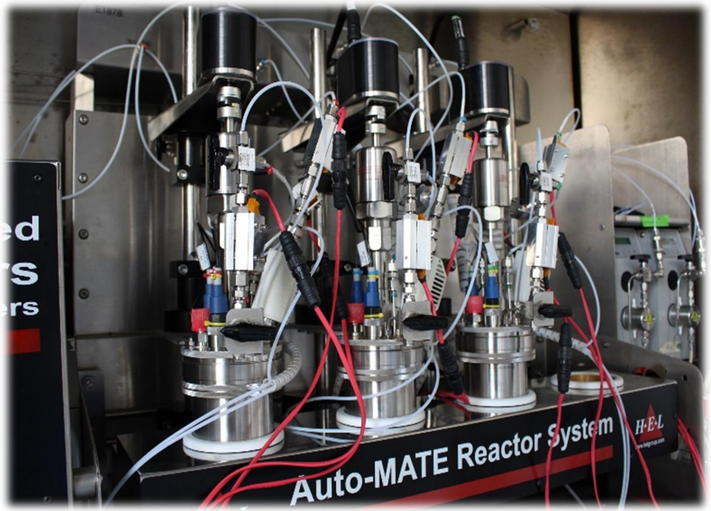
Unprecedented 60% hexanol selectivity

Circular Bio-based Europe Joint Undertaking
Bio-based Industries Consortium
Co-funded by the European Union

TOWARD BIO-HEXANOL PRODUCTION
PROCESS FEASIBILITY ANALYSIS

ISTITUTO ITALIANO DI TECNOLOGIA
CENTER FOR SUSTAINABLE FUTURE TECHNOLOGIES

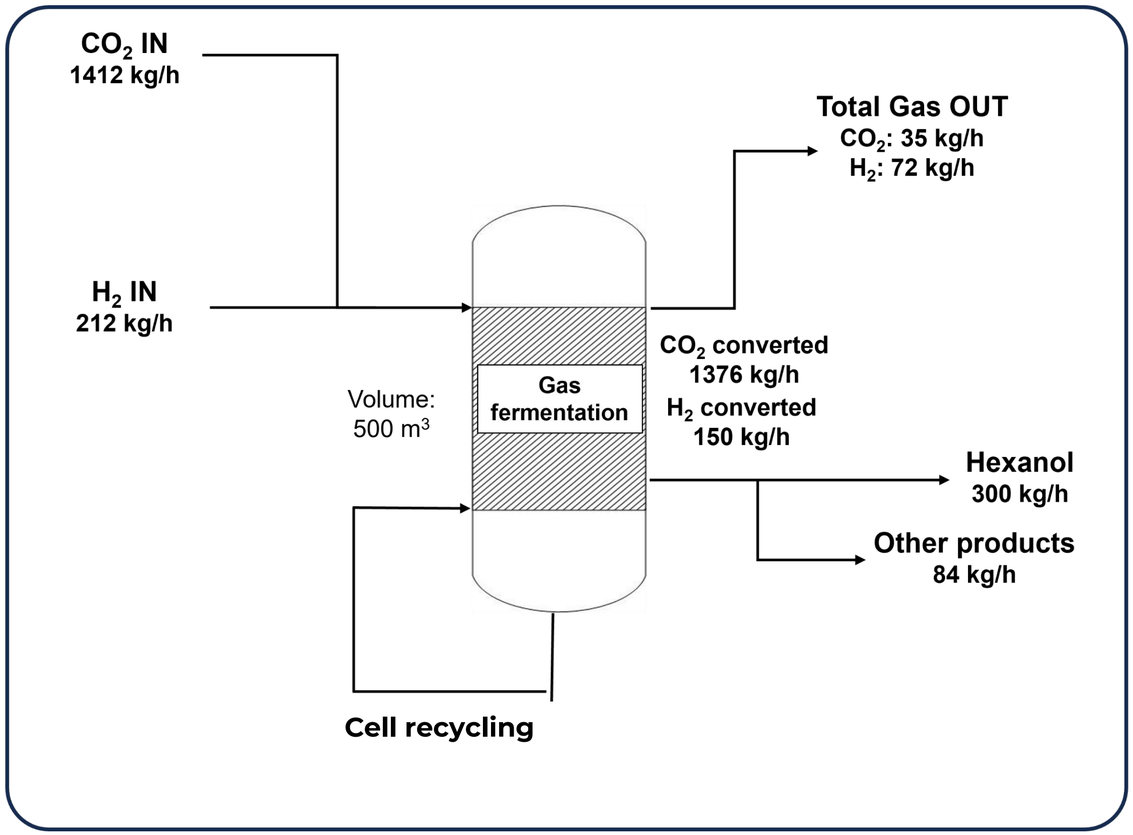
	Biomass	Butyrate	Caproate	Ethanol	Butanol	Hexanol	H_2O
$CO_2 + 2.89\ H_2 \rightarrow$	$0.149\ CH_{1.8}O_{0.5}$	$+ 0.001\ C_4H_8O_2$	$+ 0.001\ C_6H_{12}O_2$	$+ 0.046\ C_2H_6O$	$+ 0.043\ C_4H_{10}O$	$+ 0.096\ C_6H_{14}O$	$+ 1.75\ H_2O$
Carbon selectivity	**0.149**	**0.006**	**0.007**	**0.092**	**0.171**	**0.576**	



Industrial reasonable hexanol volumetric productivity of **15 g/L per day if using cell-retention** to reach a **steady-state biomass of 20 g/L**

Circular Bio-based Europe Joint Undertaking
Bio-based Industries Consortium
Co-funded by the European Union
GOODBYO

TOWARD BIO-HEXANOL PRODUCTION
PROCESS FEASIBILITY ANALYSIS



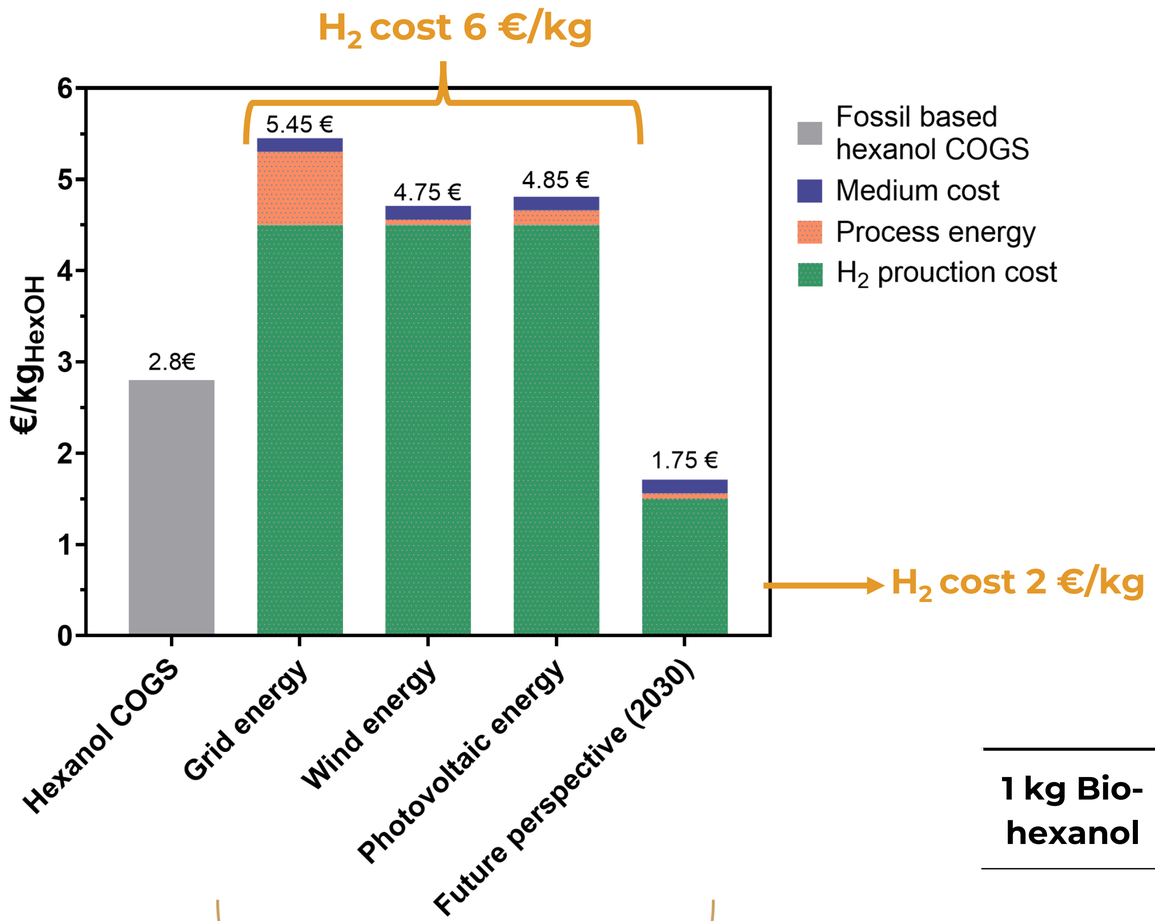
With a bio-hexanol volumetric productivity of 15 g/L per day

Annual production (340 days)	
Hexanol produced (tons)	2500
CO_2 valorized (tons)	11200
H_2 required (tons)	1730

Antonicelli et al., 2025 Bioresource Technology 418

TOWARD BIO-HEXANOL PRODUCTION
PROCESS FEASIBILITY ANALYSIS

Bio-hexanol Cost Of Goods Sold prediction (No CAPEX considered)



Green H_2 is the primary cost driver!

	CO_2 used (kg)	H_2 used (kg)	Energy for H_2 (MJ)	Bio-Process energy (MJ)	Cultivation medium (L)
1 kg Bio-hexanol	4.7	0.75	144	7.2	67

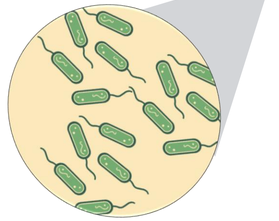
THE GOODBYO GAS FERMENTATION PROCESS

CHAINCRAFT
Turning chemistry circular

Raw Biogas rich in CO_2

H_2

Gas Fermentation Tech



Clostridium carboxidivorans_hex21

- **Bio-hexanol**
- **Microbial protein**
- **BioCH_4**

Let's move toward industrial application:

- Use of raw biogenic CO_2 feedstock
- Validation of a steady-state continuous hexanol production at TRL 5

ISTITUTO ITALIANO DI TECNOLOGIA
CENTER FOR SUSTAINABLE FUTURE TECHNOLOGIES

TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

krajete
On Behalf of Nature.

THE GOODBYO GAS FERMENTATION PROCESS

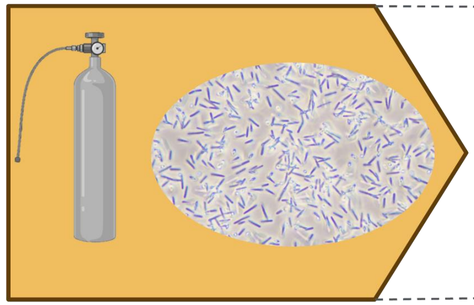
ISTITUTO ITALIANO DI TECNOLOGIA
CENTER FOR SUSTAINABLE FUTURE TECHNOLOGIES

First year of GoodByO

Second year of GoodByO

T 2.1

Biocatalyst optimization and adaptation to real biogas

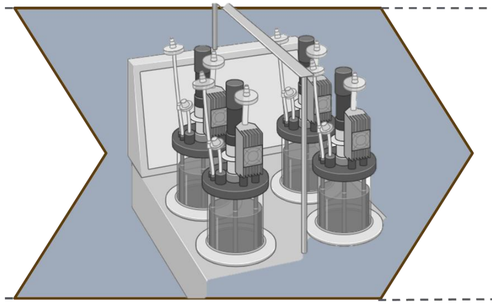


T 2.2

Lowering Cultivation Medium costs

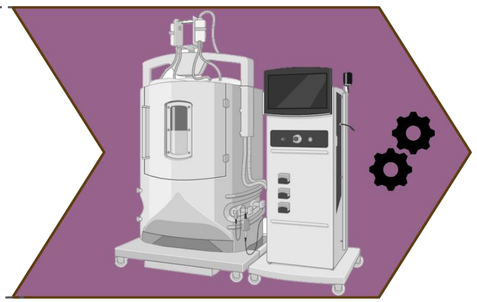
T 2.3

Continuous Gas Fermentation process development



T 2.4

Bioprocess simulation platform



Circular Bio-based Europe Joint Undertaking

Bio-based Industries Consortium

Co-funded by the European Union

GOODBYO

THE GOODBYO GAS FERMENTATION PROCESS

BIOGAS SAMPLING CAMPAIGN

CHAINCRAFT
Turning chemistry circular

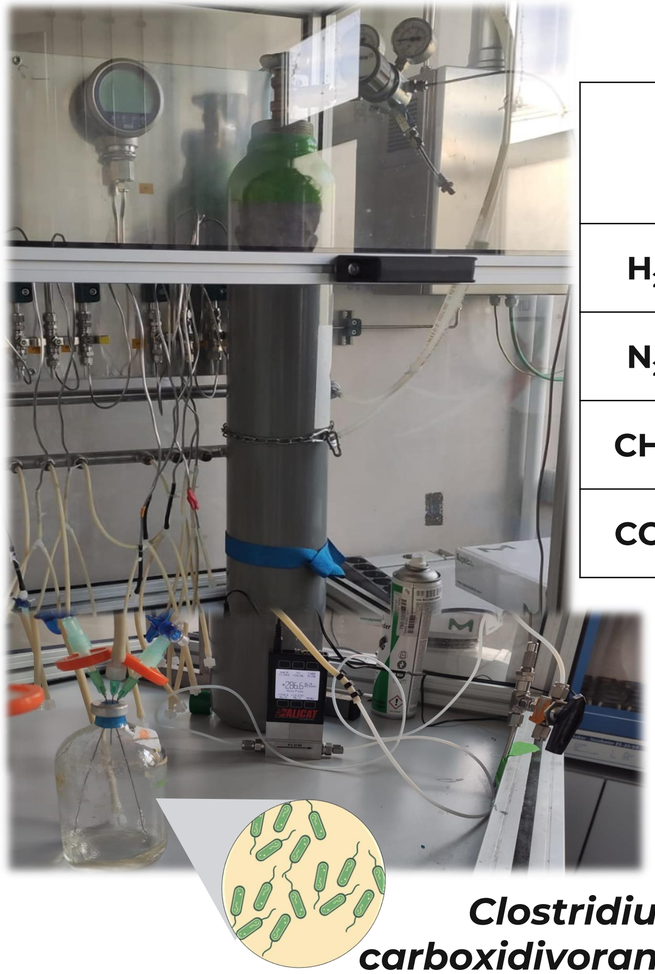
Biogas sampling at ChainCraft plant in Amsterdam by krajete
On Behalf of Nature.

ISTITUTO ITALIANO DI TECNOLOGIA
CENTER FOR SUSTAINABLE FUTURE TECHNOLOGIES

Biogas Delivery in Torino at IIT

THE GOODBYO GAS FERMENTATION PROCESS:
BIOCATALYST GROWTH ON BIOGAS

ISTITUTO ITALIANO DI TECNOLOGIA
@PoliTo
CENTER FOR SUSTAINABLE FUTURE TECHNOLOGIES



Clostridium carboxidivorans_hex21

	CC Biogas	Biogas with H_2	Simulated Biogas with H_2	Control H_2 and CO_2
H_2	0.1%	54%	54%	80%
N_2	36%	16%	32%	/
CH_4	34%	16%	/	/
CO_2	30%	14%	14%	20

	μ (h^{-1})	g_{CDW} / g_{CO2}	g_{CDW} / g_{H2}
Control H_2+CO_2	**0.040** ± 0.001	**0.13** ± 0.00	**1.01** ± 0.03
Real Biogas +H_2	**0.035** ± 0.01	**0.14** ± 0.01	**1.08** ± 0.07
Simulated Biogas +H_2	**0.028** ± 0.01	**0.16** ± 0.02	**1.09** ± 0.02

- Both **real** and **simulated** biogas showed **same growth performance**
- Biomass **growth rate** and **production yield** is the **same** of the **Control** condition

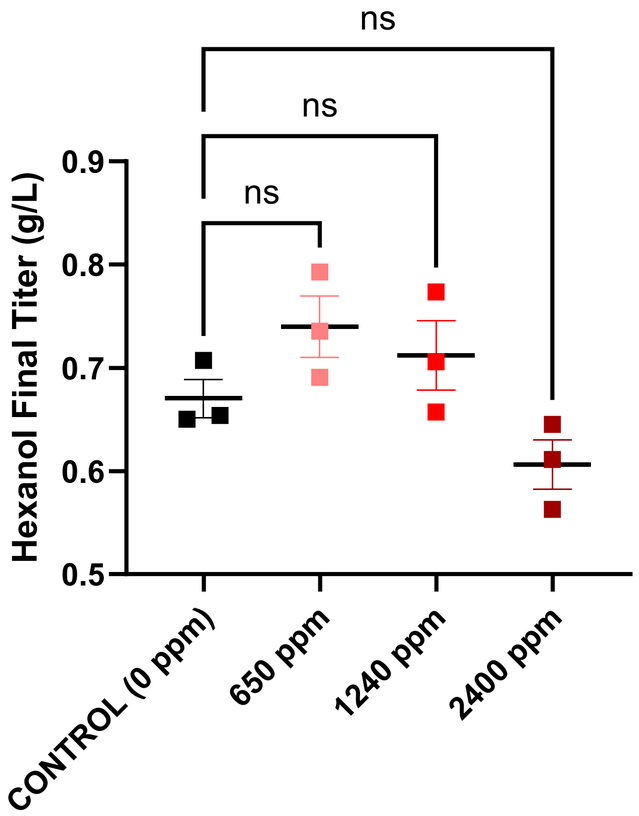
Circular Bio-based Europe Joint Undertaking
Bio-based Industries Consortium
Co-funded by the European Union

GOODBYO

THE GOODBYO GAS FERMENTATION PROCESS:
H_2S TOLERANCE

ISTITUTO ITALIANO DI TECNOLOGIA
CENTER FOR SUSTAINABLE FUTURE TECHNOLOGIES

Bio-hexanol production with the addition of H_2S



	max specific productivity bio-hexanol ($g_{Hexanol}/g_{CDW}h$)	Bio-hexanol Selectivity (%)
650 ppm	0.021 ± 0.002	33.7 ± 0.4
1250 ppm	0.020 ± 0.003	33.0 ± 0.4
2400 ppm	0.019 ± 0.001	28.8 ± 0.8
CTRL (0 ppm)	0.021 ± 0.001	32.3 ± 0.7

The presence of **H_2S DOES NOT affect the hexanol production** performances

THE GOODBYO GAS FERMENTATION PROCESS:
FIRST YEAR ACHIEVEMENTS

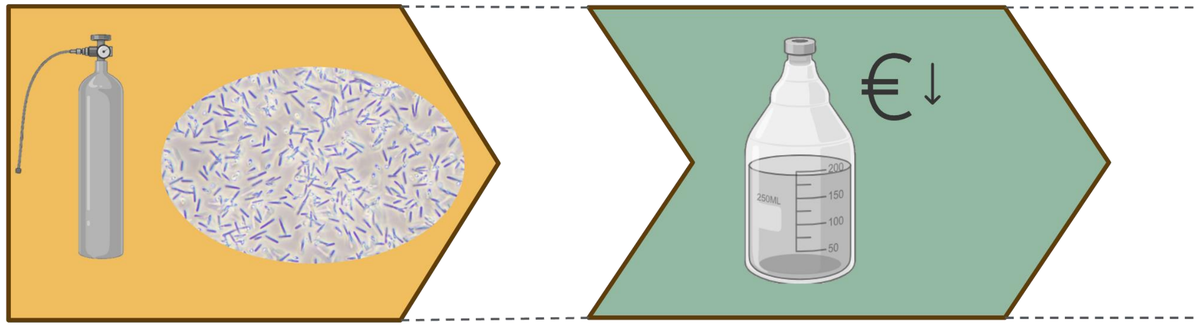
ISTITUTO ITALIANO
DI TECNOLOGIA
CENTER FOR SUSTAINABLE
FUTURE TECHNOLOGIES

T 2.1

Biocatalyst optimization and adaptation to real biogas

T 2.2

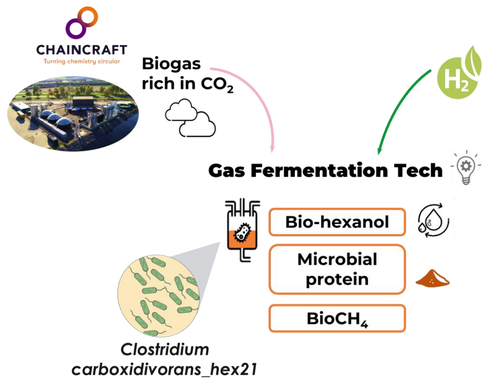
Lowering Cultivation Medium costs



Circular Bio-based Europe Joint Undertaking
Bio-based Industries Consortium
Co-funded by the European Union

THE GOODBYO GAS FERMENTATION PROCESS:
UPCOMING PHASES

ISTITUTO ITALIANO
DI TECNOLOGIA
CENTER FOR SUSTAINABLE
FUTURE TECHNOLOGIES



2

- Cascade continuous process optimization in high pressure lab-scale reactors
- Hexanol purification unit development
- Process modeling

3

- TRL5 Pilot Design
- Process validation in TRL5 Pilot

TARGETS	
Steady-state biomass	>20 g/L
Steady-state bio-hexanol volumetric productivity	>15 g/L day
Bio-hexanol carbon selectivity	>65%
Kg bio-hexanol per kg H_2	>1.5
Bioprocess stability	> 1 month
Purity of hexanol	>97%

Circular Bio-based Europe Joint Undertaking
Bio-based Industries Consortium
Co-funded by the European Union

REPLICABILITY OF THE GOODBYO CONCEPT IN ANAEROBIC DIGESTION PLANTS

ISTITUTO ITALIANO DI TECNOLOGIA
CENTER FOR SUSTAINABLE FUTURE TECHNOLOGIES

- **Bio-CH_4**
- **Chemicals** through Gas Fermentation tech
- **Cosmetics** ingredients through Microalgae tech
- **Microbial proteins**

REPLICABILITY OF THE GOODBYO CONCEPT IN ANAEROBIC DIGESTION PLANTS

ISTITUTO ITALIANO DI TECNOLOGIA
CENTER FOR SUSTAINABLE FUTURE TECHNOLOGIES

Focused project task:

- Evaluate the current regulatory framework and policy analysis of the biogas and biomethane (in the main current EU markets then Germany - France - Italy);

- Understand which limitations are present for the future implementation of **GoodByO** technologies in existing anaerobic digestion plants .

CIB CONSORZIO ITALIANO BIOGAS

ISTITUTO ITALIANO
DI TECNOLOGIA
CENTER FOR SUSTAINABLE
FUTURE TECHNOLOGIES

valeria.agostino@iit.it

GOODBYO

WEBSITE https://goodbyo.eu/

Follow us on LinkedIn

https://www.linkedin.com/company/goodbyo/

COORDINATOR CONTACTS
Center for Sustainable Future Technologies
CSFT@Polito

Dr. Valeria Agostino
valeria.agostino@iit.it

Prof. Fabrizio Pirri
fabrizio.pirri@iit.it

Circular Bio-based Europe Joint Undertaking

Bio-based Industries Consortium

Co-funded by the European Union

The project is supported by the Circular Bio-based Europe Joint Undertaking and its members.
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CBE JU. Neither the European Union nor the CBE JU can be held responsible for them.

GOODBYO