URD ABI : combiner chimie verte, biotechnologies et génie des procédés pour valoriser la biomasse

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51110 Pomacle, France

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Les mardis de la Chimie Durable (SCF)

Mardi 9 mars 2021

At the heart of Bazancourt-Pomacle biorefinery

Agro Biotechnologies Industrielles

ARD Private research center
Wheatoleo Biobased surfactants

Global Bioenergies
Start-up

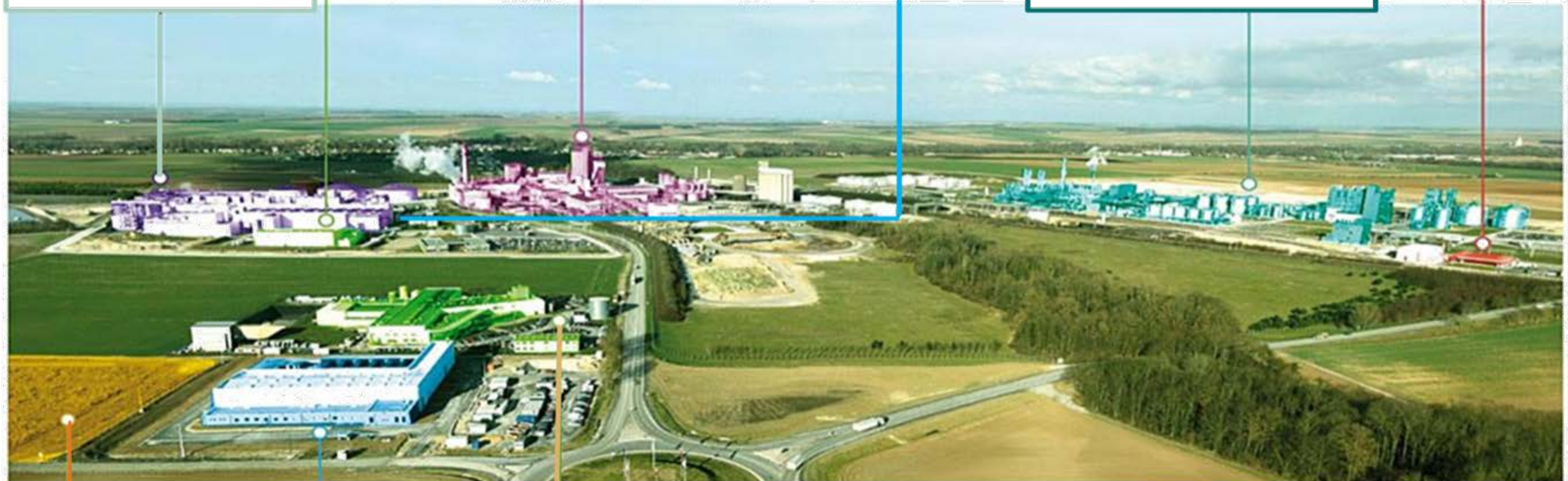
Vivescia
Cooperatives

ADM
Glucosery
Starch

Cristal Union
Sugar refinery

Cristanol
1st generation distillery

Air Liquide



Procethol 2G – Futurol
2nd generation biofuels

Givaudan Active Beauty
Biobased cosmetics

CEBB
Public research center

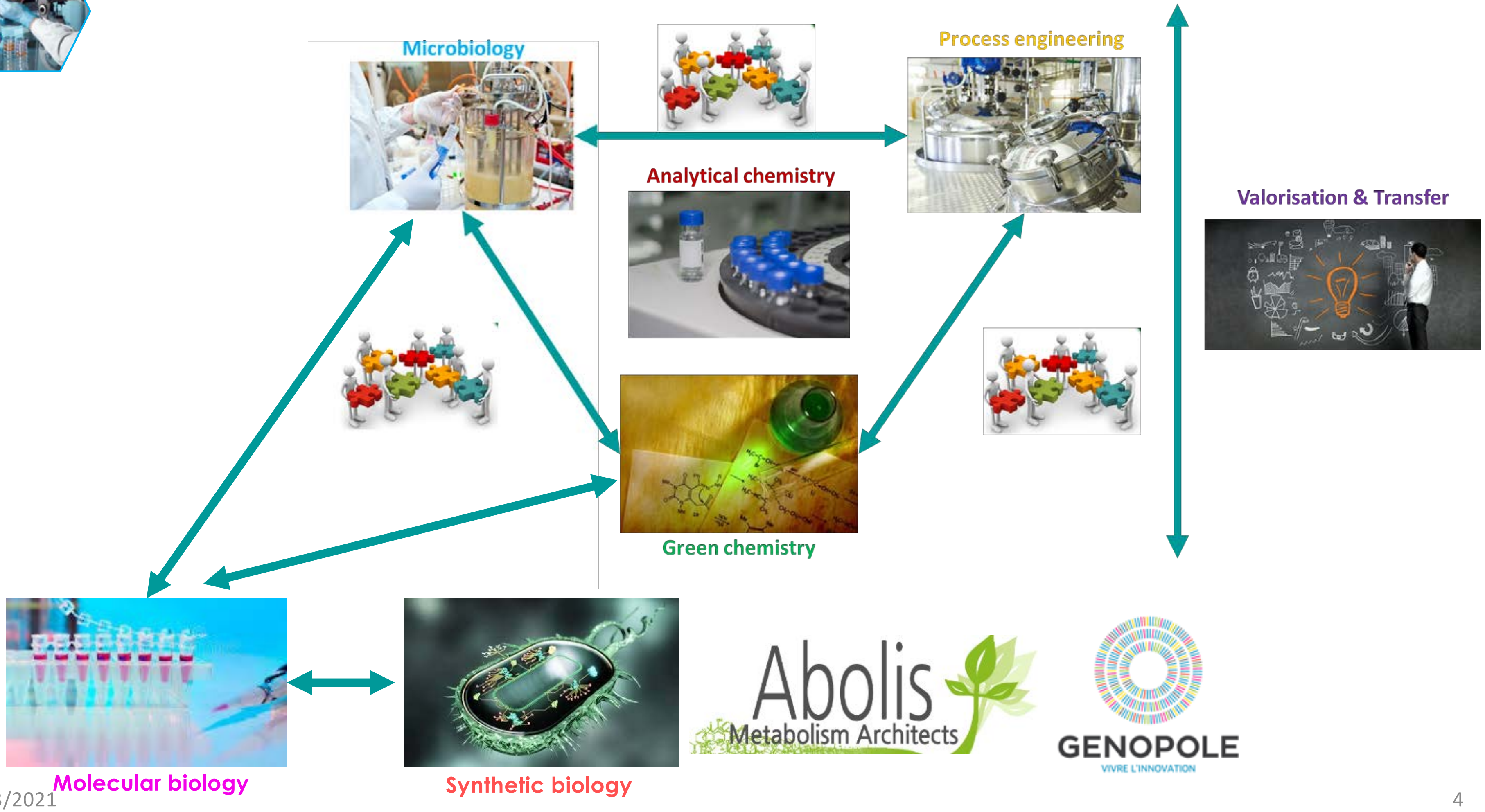
The European Center of Biotechnology & Bioeconomy (CEBB)

Laboratories and offices: 2200 m^2 Technological hall: 400 m^2 Chemistry scale-up zone: 100 m^2

Moving: April 2016

Towards increased transdisciplinarity

Agro Biotechnologies Industrielles



Agro Biotechnologies Industrielles

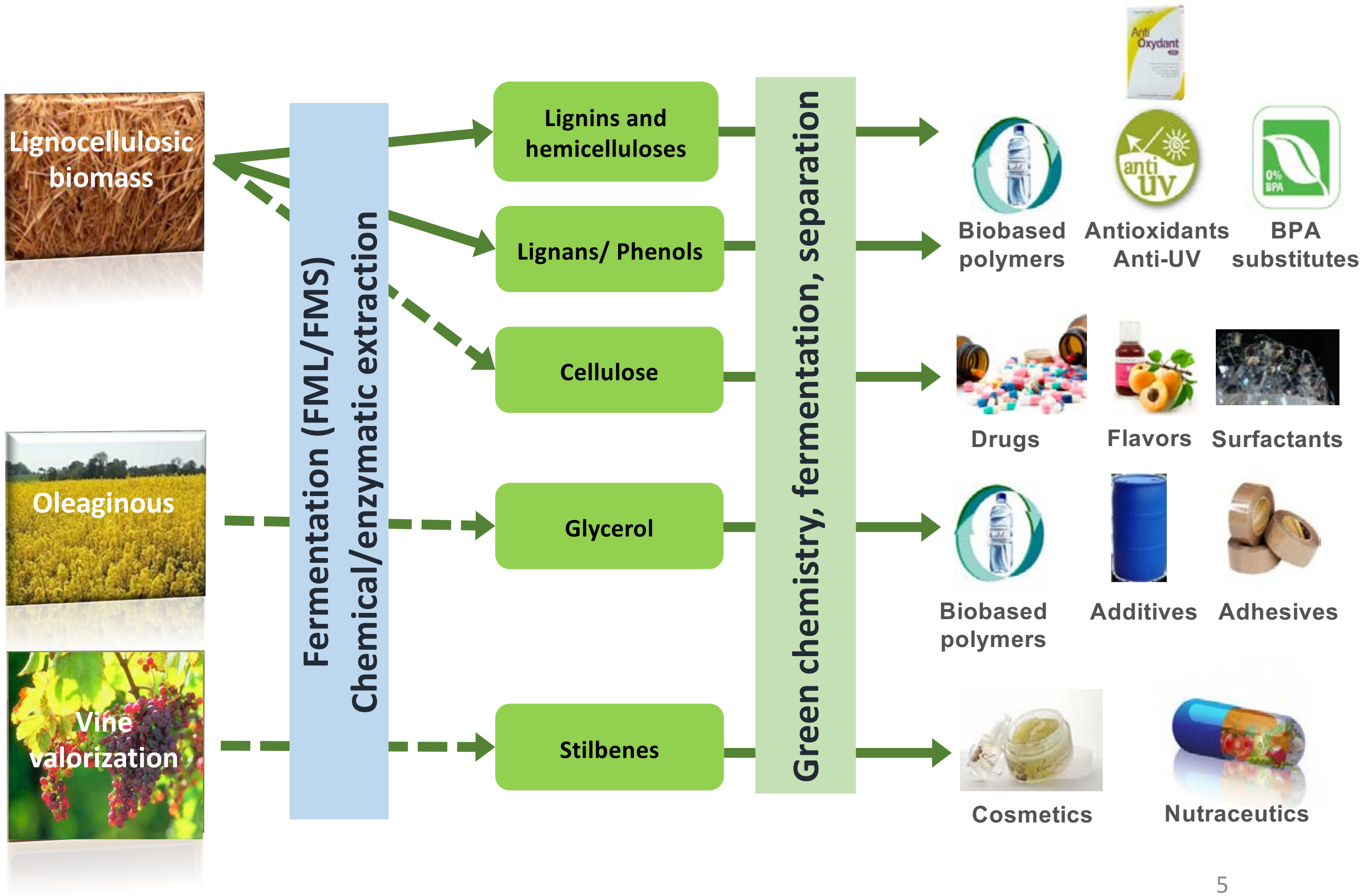
From biomass to biobased products

Key dates

- **June 2011 :** agreement signed
- **October 2012** : Recruitment of Director
- **February 2013 :** Activities start at Collège de Trois Fontaines (Reims)
- **April 2016 :** Moving in the CEBB

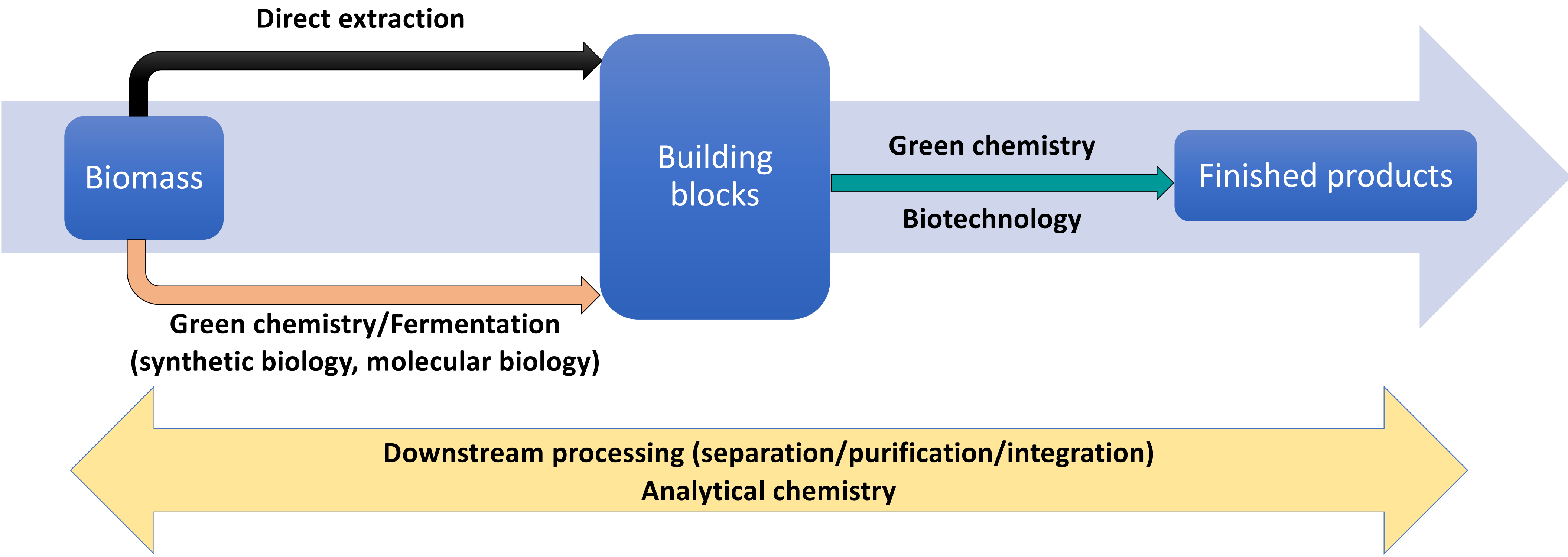
Missions

- Identify and **valorize** agro-resources
- **Combine** fundamental and applied research
- Foster **innovation** for local economy development
- **Teach** in our fields of expertise



Coverage and integration of the entire value chain

Agro Biotechnologies Industrielles



URD Agro Biotechnologies Industrielles by AgroParisTech

AgroParisTech
INSTITUT DES SCIENCES ET INDUSTRIES DU VIVANT ET DE L'ENVIRONNEMENT
PARIS INSTITUTE OF TECHNOLOGY FOR LIFE, FOOD AND ENVIRONMENTAL SCIENCES

CEBB
Centre Européen de Biotechnologie et de Bioéconomie

(Bio)production and valorization of *p*-hydroxycinnamic acids from biomass

16/03/2021

GRAND REIMS COMMUNAUTÉ URBAINE

La Marne LE DÉPARTEMENT

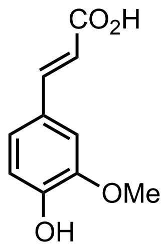
Grand Est ALSACE CHAMPAGNE-ARDENNE LORRAINE

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

Ferulic and sinapic acids extraction from biomass

Enzymatic bio-degradation

Separation & Purification

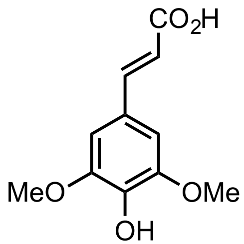


Ferulic acid

© Can Stock Photo

Enzymatic bio-degradation

Separation & Purification



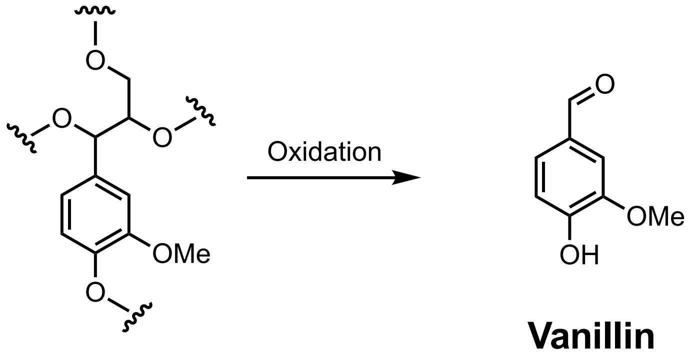
Sinapic acid

S. Dupoiron et al. *Ind. Crops Prod.* **2017**, *105*, 148
S. Dupoiron et al. *Sep. Pur. Technol.* **2018**, *200*, 75
J. Domingos et al. *Sep. Pur. Technol.* **2020**, *242*, 116755

Production of bio-based ferulic/sinapic acids from lignin degradation products

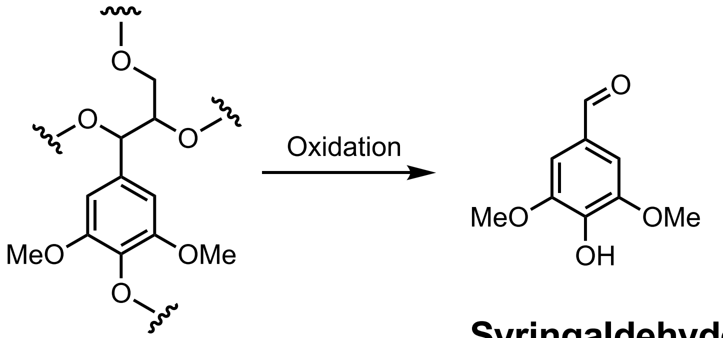
Agro Biotechnologies Industrielles

G-units



Vanillin

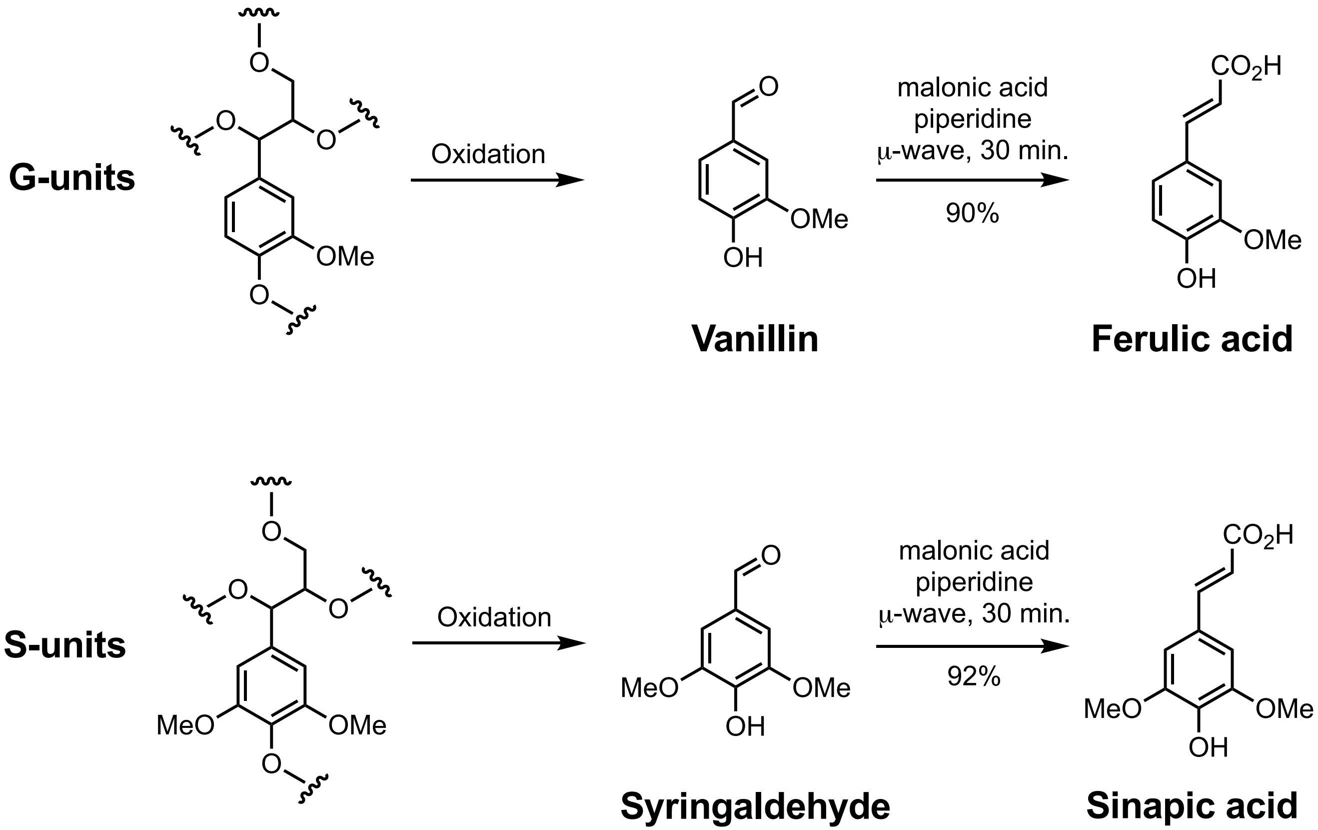
S-units



Syringaldehyde

Production of bio-based ferulic/sinapic acids from lignin degradation products

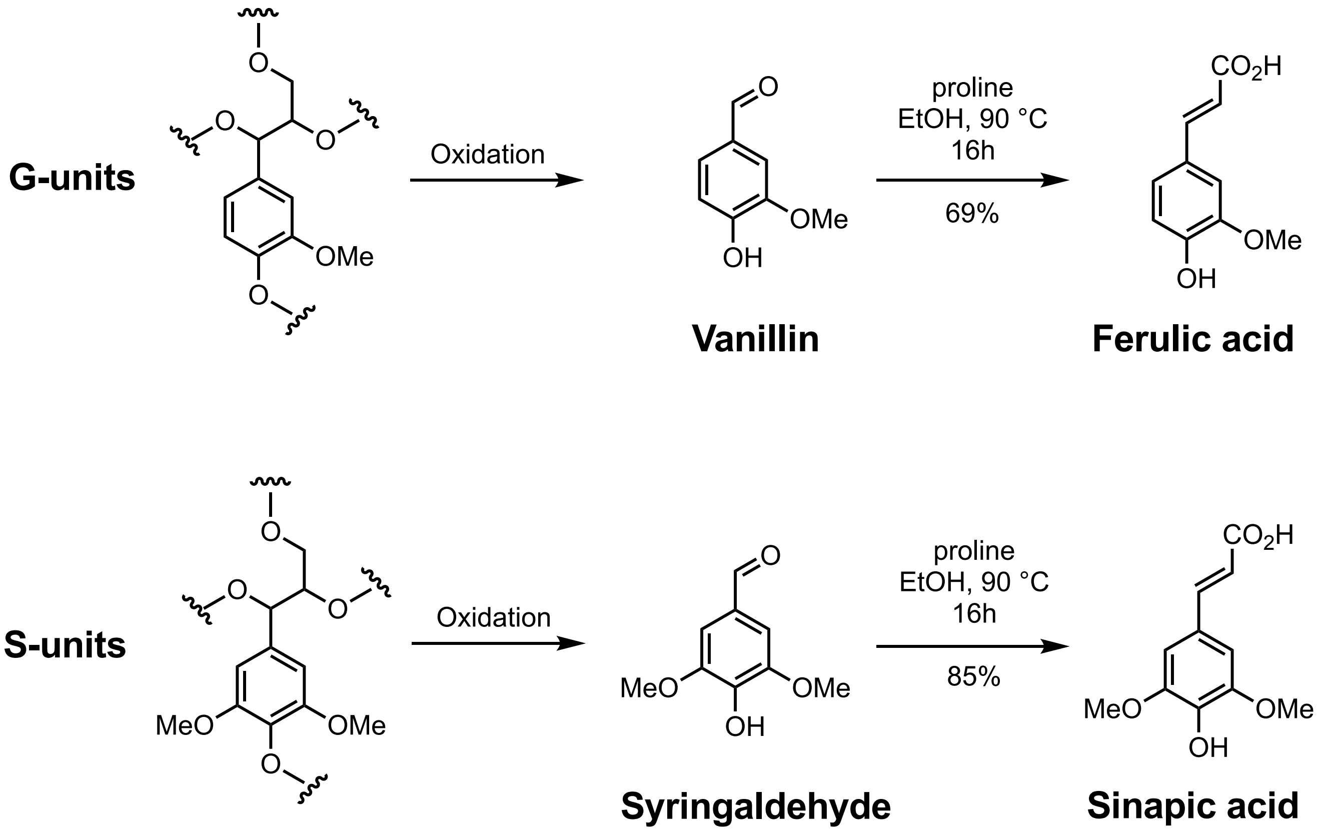
Agro Biotechnologies Industrielles



L. Mouterde, F. Allais *Frontiers Chem.* **2018**, *6*, 426

Production of bio-based ferulic/sinapic acids from lignin degradation products

Agro Biotechnologies Industrielles



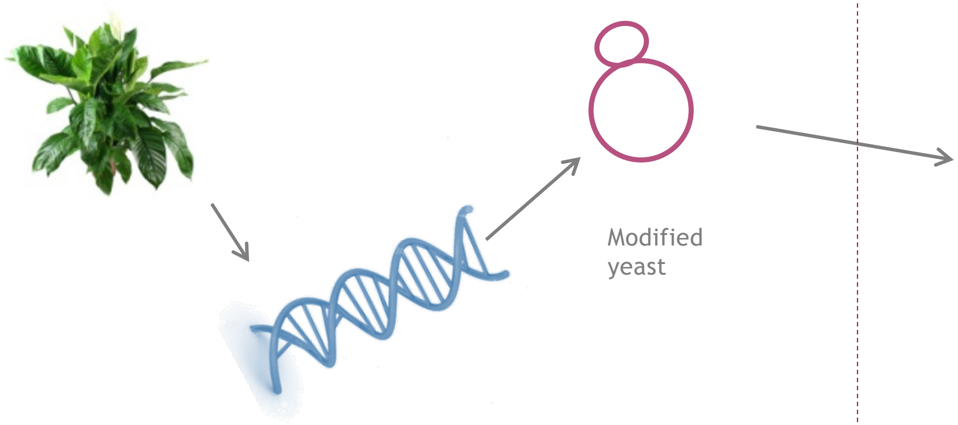
C. Peyrot, A. Peru, L. Mouterde, F. Allais *ACS Sustainable Chem. Eng.* **2019**, *10*, 9422

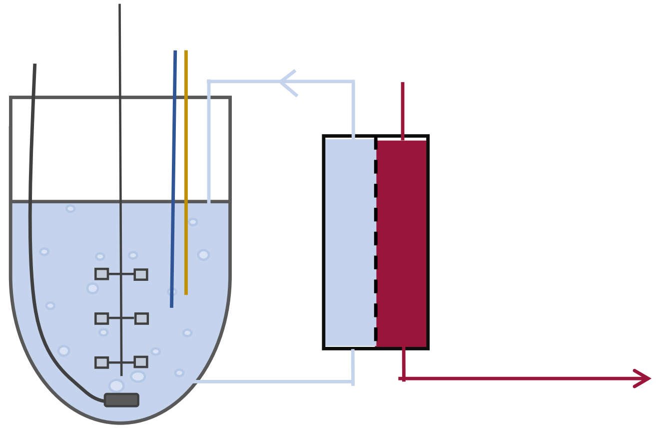
Ferulic and sinapic acids production using synthetic chemistry

Agro Biotechnologies Industrielles

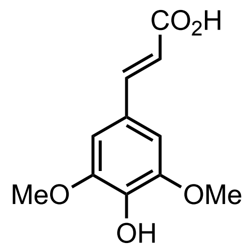
SYNTHETIC BIOLOGY

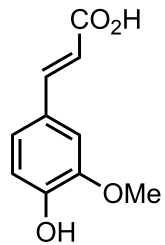
FERMENTATION OPTIMIZATION SEPARATION / PURIFICATION





Bioreactor & membrane contactor





Micalis — Microbiologie de l'Alimentation au service de la Santé

Abolis Metabolism Architects

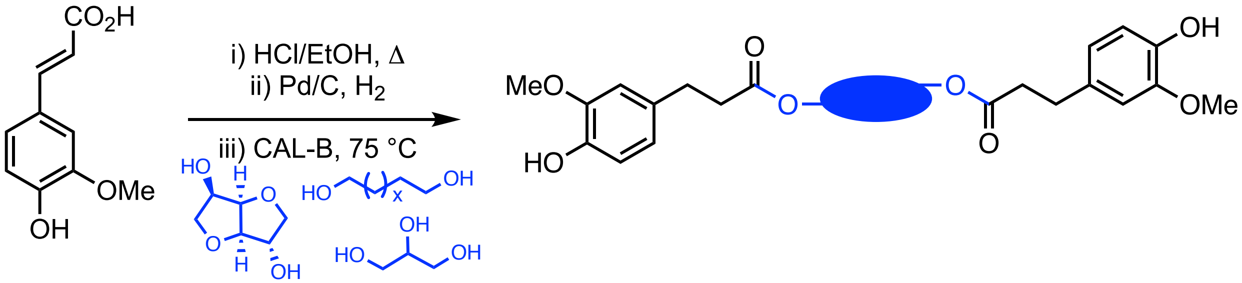
Agro Biotechnologies Industrielles by AgroParisTech

Abolis, Patent pending

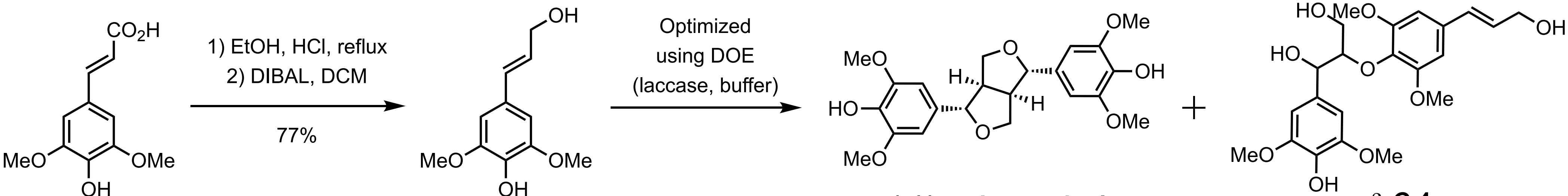
Chemo-enzymatic synthesis of ferulic/sinapic acid-derived based macrobisphenols

Agro Biotechnologies Industrielles

INRAE



<u>Synthesis:</u> Pion, F.; Reano, A.; Ducrot, P.-H. and Allais, F. *RSC Adv.* **2013**, *3*, 8988
<u>Purification – LCA analysis:</u> A. Teixeira et al. *React. Chem. Eng.* **2017**, *2*, 406



(+/-)-syringaresinol
93%

β-***O*-4**
>2%

A. S. Jaufurally, L. Hollande, F. Allais and P. H. Ducrot *ChemistrySelect* **2016**, *1*, 5165

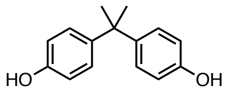
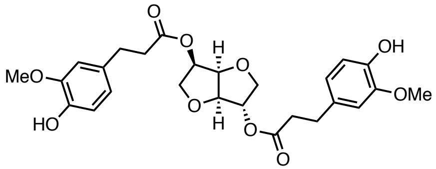
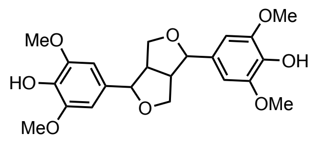
BPA substitutes in epoxy-amine resins

Agro Biotechnologies Industrielles

Rensselaer

INRAE

Inserm Institut national de la santé et de la recherche médicale

		Bisphenol-A (BPA)	**Isosorbide diferulate** (IDF)	**Syringaresinol** (SYR)
				
	Sourcing	☒ Oil	☑ Ferulic acid	☑ Sinapic acid
	Toxicity	☒ Endocrine disruptor	☑ No endocrine activity	☑ No endocrine activity
EPOXY-AMINE RESINS	Mechanical properties	☑ T_g = 150 °C ☑ T_α = 166 °C ☑ T_{deg} = 326 °C	T_g = 85 °C T_α = 99 °C T_{deg} = 295 °C	☑ T_g = 126 °C ☑ T_α = 157 °C ☑ T_{deg} = 298 °C
	Degradation	☑ No degradation (NaOH nor HCl)	☑ Degradable (NaOH and HCl)	☑ No degradation (NaOH nor HCl)

Janvier, M. et al. *ChemSusChem* **2017**, *10*, 738
Maiorana, A. et al. *Green Chem.* **2016**, *18*, 4961-4973

Other applications in polymers/materials

Agro Biotechnologies Industrielles

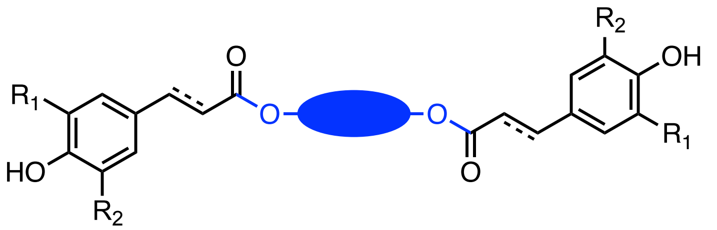
PATENTED

MONASH University

« Additives » for PLA/PHA => shape-memory polymers
Gallos, A. et al. *Biomacromolecules* **2021** *asap*

Université de Reims Champagne-Ardenne

ICMPE Institut de Chimie et des Matériaux Paris-Est



Monomers for polyesters, NIPUs, epoxy-amine resins…
Pion, F. et al. *Macromol. Chem. Phys.* **2014**, *5*, 431
Oulame, Z. et al. *Eur. Polym. J.* **2015**, *63*, 186
Ménard, R. et al. *Ind. Crops Prod.* **2017**, *95*, 83
Ménard, R. et al. *ACS Sustainable Chem. Eng.* **2017**, *2*, 1446
Janvier, M. et al. *ACS Sustainable Chem. Eng.* **2017**, *10*, 8648

INRAE

enscm CHIMIE Montpellier

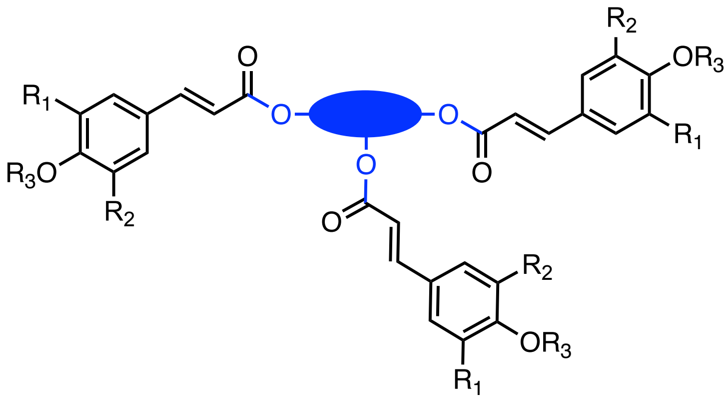


Photo-crosslinkable monomers for self-healing materials
Sinah Roy, P. et al. *submitted*

MONASH University

WARWICK THE UNIVERSITY OF WARWICK

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PARIS INSTITUTE OF TECHNOLOGY FOR LIFE, FOOD AND ENVIRONMENTAL SCIENCES

CEBB
Centre Européen de Biotechnologie et de Bioéconomie

Synthesis of bio-based anti-UV and antioxidant additives

16/03/2021

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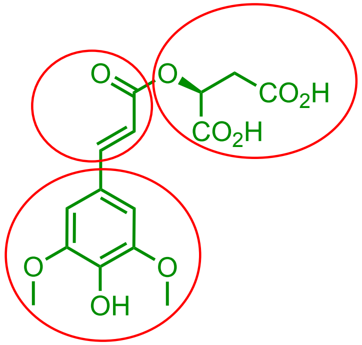
La Marne LE DÉPARTEMENT

Grand Est ALSACE CHAMPAGNE-ARDENNE LORRAINE

EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND

Context

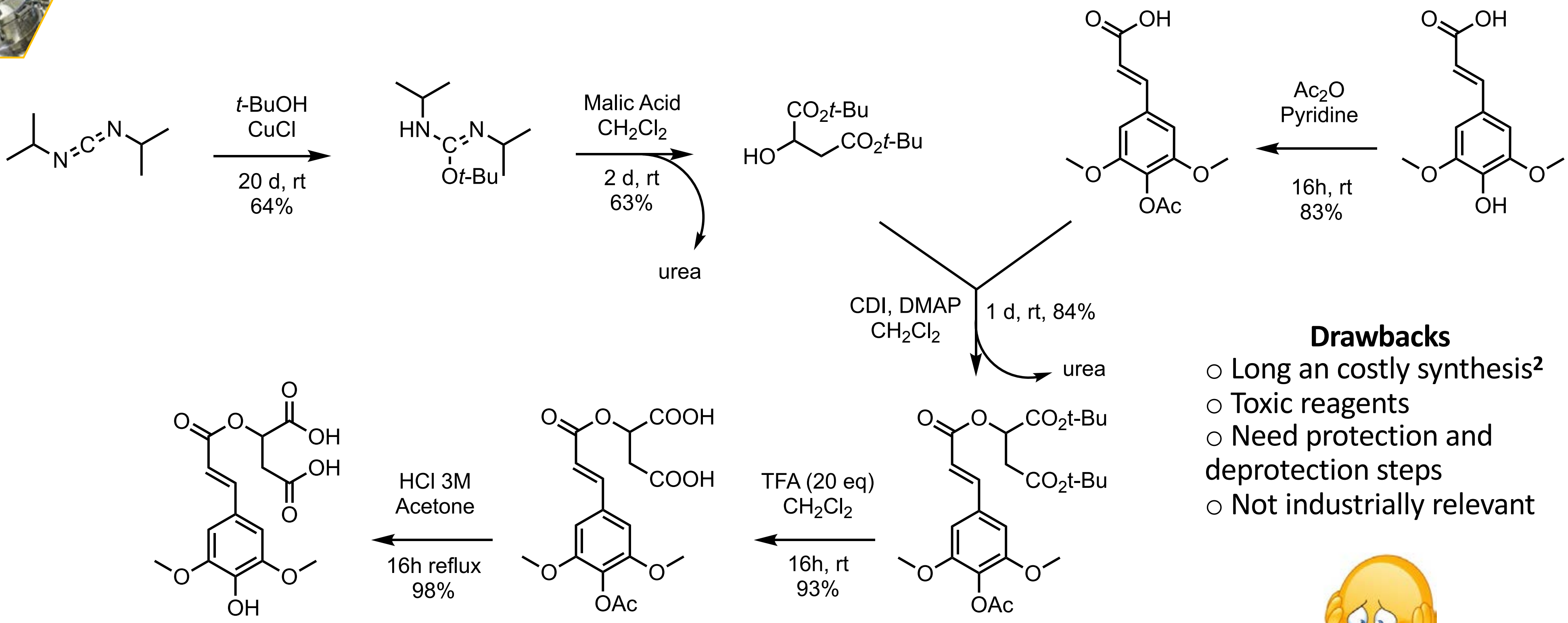
- Sinapoyl malate (SM): plants' natural sunscreen



Disubstituted phenol conjugated with an α,β-unsaturated ester bearing a sterically hindered malic acid

J. C. Dean, R. Kusaka, P. S. Walsh, F. Allais and T. S. Zwier, *J. Am. Chem. Soc.* **2014**, *136*, 14780–14795

A greener and shorter synthesis of sinapoyl malate (1/2)

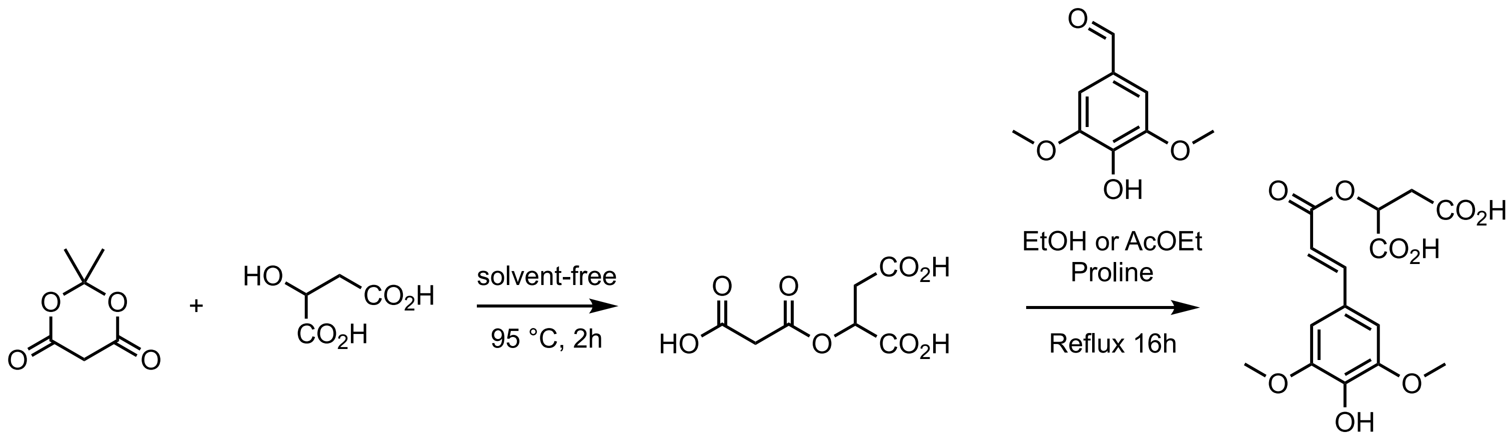


Drawbacks
- ○ Long an costly synthesis[2]
- ○ Toxic reagents
- ○ Need protection and deprotection steps
- ○ Not industrially relevant

Allais et al. *Synthesis* **2009**, *21*, 3571

A greener and shorter synthesis of sinapoyl malate (2/2)

Agro Biotechnologies Industrielles



- 2 steps
- No toxic reagents
- No protection/deprotection steps
- Higher yield
- Industrially relevant

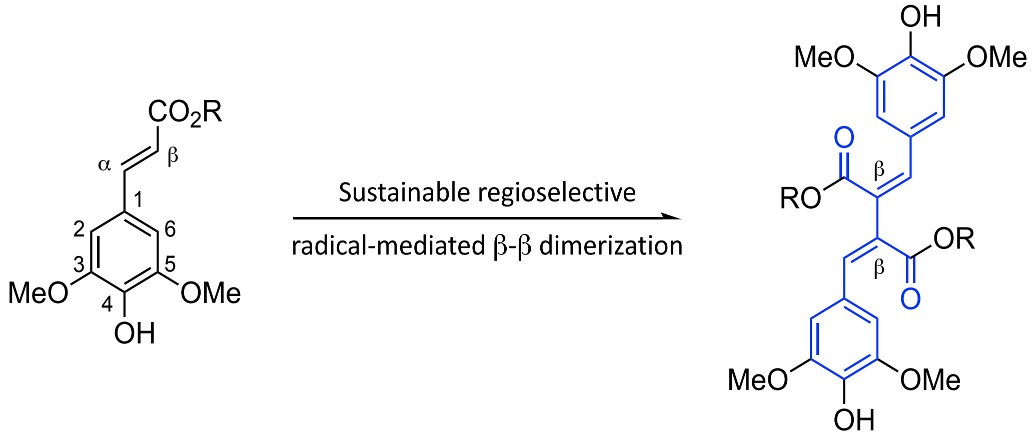
Allais et al. Patent pending

Peyrot et al. *Green Chem.* **2020**, *22*, 6510

Biomimetic dimerization of ethyl sinapate

Agro Biotechnologies Industrielles

- **Objective:** to enhance UV-Visible properties by increasing conjugation *via* **a sustainable and industrially-relevant specific β-β dimerization** of sinapic esters

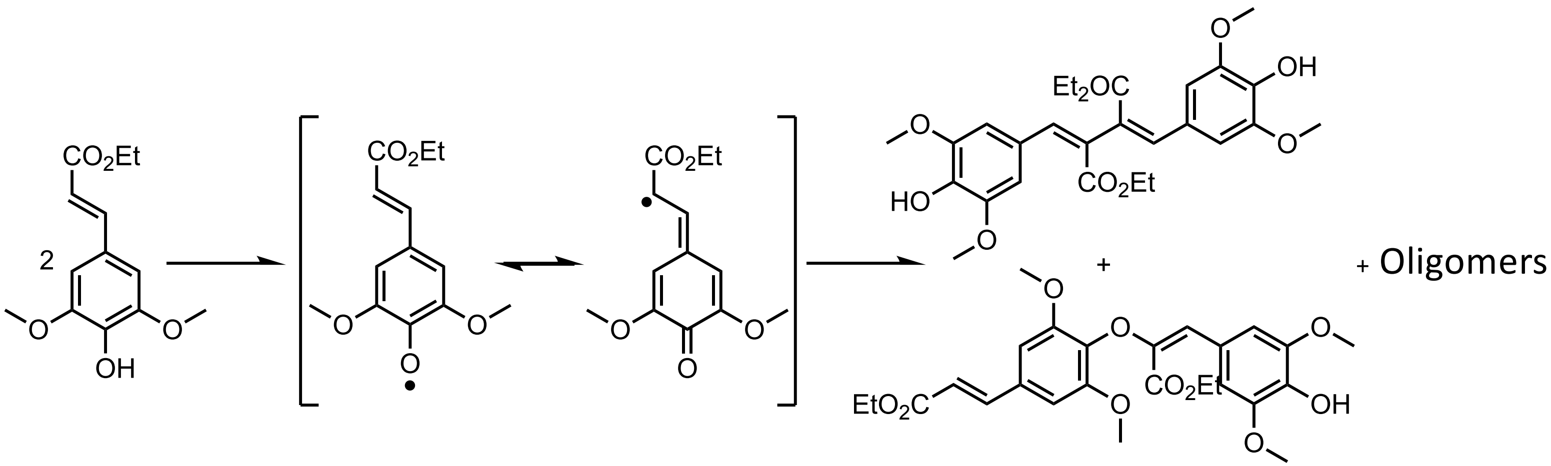


Extended conjugation within the entire molecule (aromatic & olefinic C=C as well as esters C=O):

- enhanced anti-UV activity?
- enhanced antiradical activity?

Biomimetic dimerization of ethyl sinapate

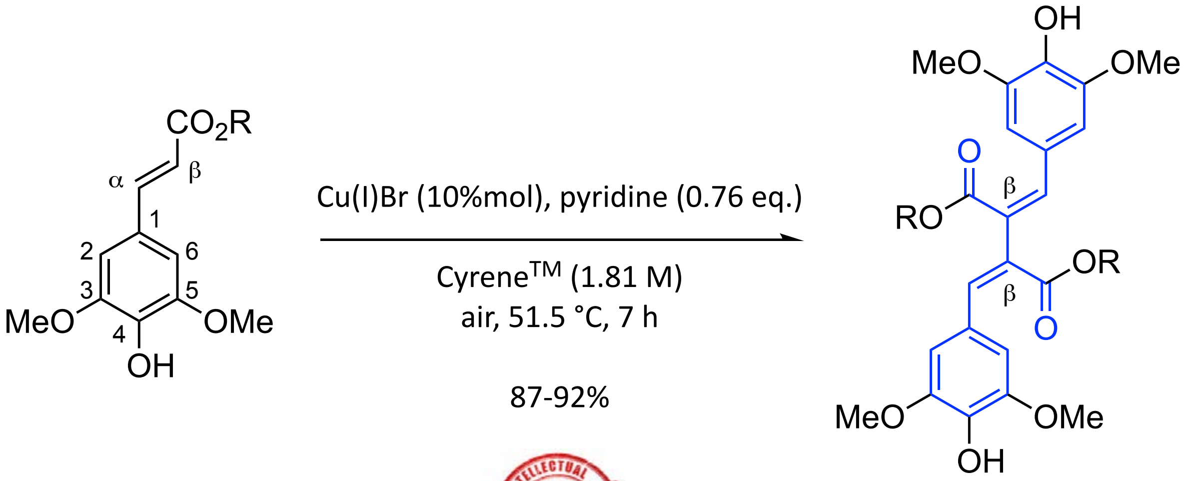
- Laccase-mediated oxidation of ethyl sinapate (radical-radical coupling)



Challenges
- Yield
- Selectivity

F. Allais et al. Patent pending
M. Mention, A. L. Flourat, C. Peyrot, F. Allais *Green Chem.* **2020**, *22,* 2077-2085

Biomimetic dimerization of ethyl sinapate



β-β dimers of ethyl sinapate:

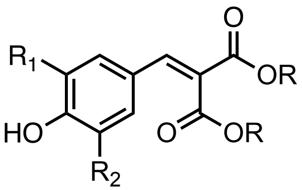
- as good as/better than fossil-based commercial antioxidants
- absorb more UV than sinapoyl malate
- cover both UV-A and UV-B

F. Allais et al. Patent pending

M. Mention, A. L. Flourat, C. Peyrot, F. Allais *Green Chem.* **2020**, *22,* 2077-2085

Other phenolics-based applications

Agro Biotechnologies Industrielles



UV-filters-decorated nanocellulose
Mendoza, D. et al. *ChemSusChem* **2020**, *13*, 6552
Mendoza, D. et al. *ACS Sustainable Chem. Eng.* **2021**, *under review*

Anti-UV ingredients for cosmetic applications
Rioux et al. *Antioxidants* **2020**, *9*, 331
Horbury et al. *Nature Commun.* **2019**, *10*, 4748
Allais et al. Patents Pending

Molecular heaters for crops (BOOSTCROP FET Open H2020)

PATENTED

MONASH University

Agence Nationale de la Recherche ANR

FUNDING OPPORTUNITIES
FUTURE & EMERGING TECHNOLOGIES

WARWICK THE UNIVERSITY OF WARWICK

BfR Bundesinstitut für Risikobewertung

University of BRISTOL

Radboud Universiteit Nijmegen

PLANTRESPONSE STRONGER BY NATURE

Faculté des Sciences Aix*Marseille Université

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PARIS INSTITUTE OF TECHNOLOGY FOR LIFE, FOOD AND ENVIRONMENTAL SCIENCES

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Sawdust Valorization: From Levoglucosenone to High Value Synthons and Green Solvent

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La Marne LE DÉPARTEMENT

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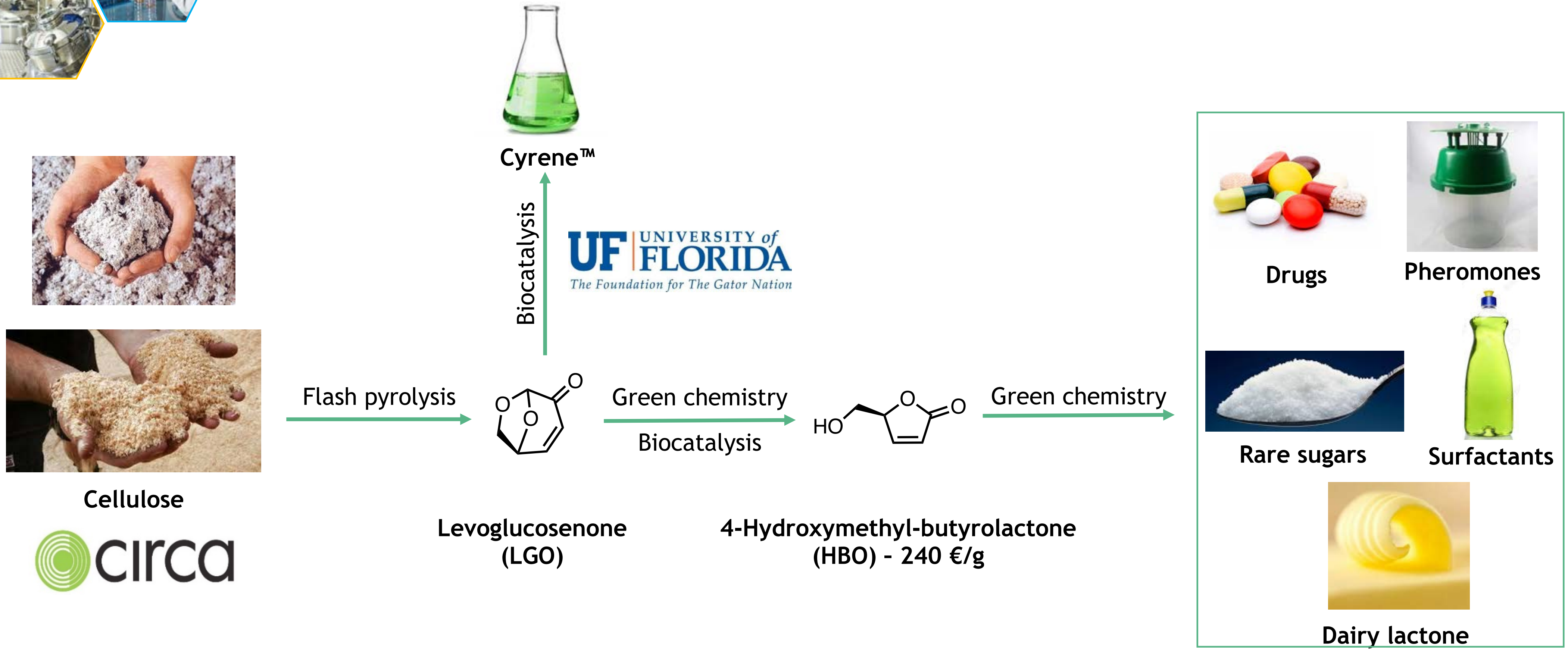
EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND

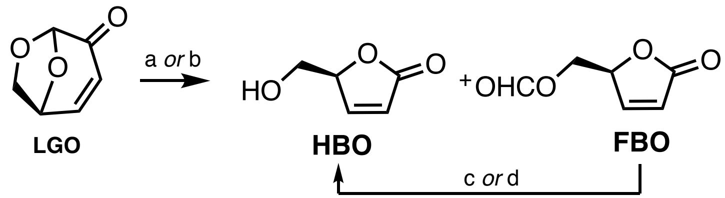
16/03/2021

Building a new sustainable value-chain from celulose-derived Levoglucosenone

Agro Biotechnologies Industrielles



Chemical syntheses of HBO via Baeyer-Villiger oxidation



Koseki's procedure: a) MCPBA or AcOOH, Me_2S, 48 h, rt
c) MeOH, HCl, 45 °C, overnight
Paris' procedure: b) metal-zeolite, 100 °C, 4 to 48 h
d) Amberlyst-15, rt

Yields (**HBO**) = 80-90%

Koseki's procedure drawbacks

Large amount of peracids (explosive)
Dichloromethane as solvent
Long reaction time (48 hours)

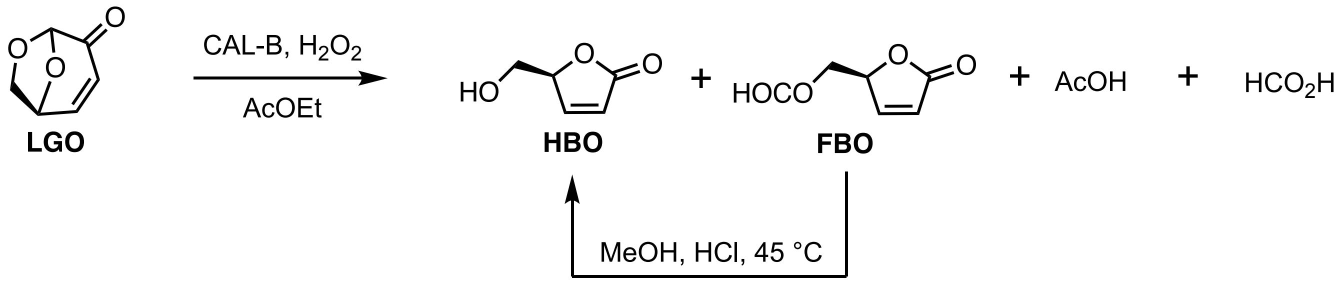
Paris' procedure drawbacks

Tin-based zeolites (toxicity)
« High » temperature
1,4-dioxane as solvent

K. Koseki et al. *US 4,9947,585* Feb. 19th, **1991**
C. Paris, M. Moliner, A. Corma, *Green Chem.* **2013**, *15*, 2101

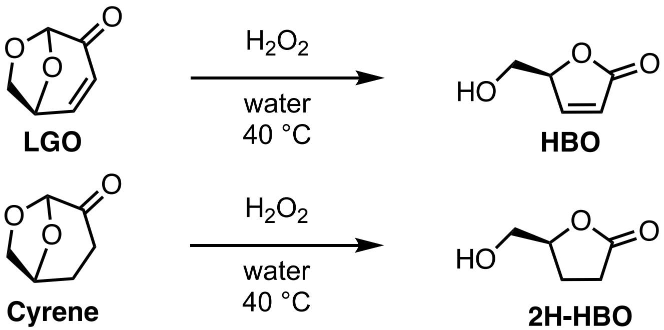
An easier way to produce HBO

Agro Biotechnologies Industrielles



Benefits

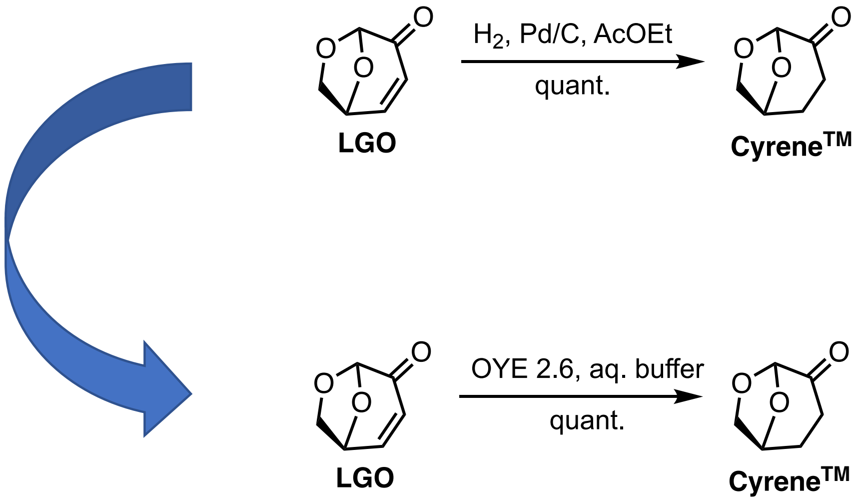
- Reaction time : 8 hours
- Yields ca. 80%
- No enzyme
- No organic solvent
- Purification by distillation



CAL-B route: A. L. Flourat et al. *Green Chem.* **2013**, *89*, 67
A. R. S. Teixeira et al. *Frontiers Chem.* **2016**, *4*, 16
F. Allais et al. US2017152536
H_2O_2-route: Bonneau et al. *Green Chem.* **2018**, *20*, 2455
Allais, F. et al. Patent WO2018007764

Making Cyrene™ using biotechnology

Agro Biotechnologies Industrielles



UF UNIVERSITY of FLORIDA

PATENTED

Disadvantage

- Cost

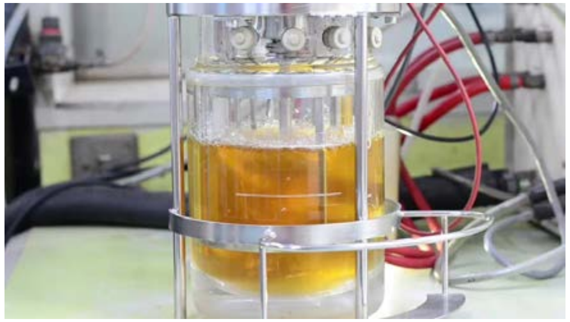
Benefits

- Metal-free process
- Organic solvent-free process
- Purification by distillation
- Suitable for high value added applications: drugs, food, electronics…

Allais, F.; Mouterde, L.M.M; Stewart, J.D. Patent US62/478430
Allais, F.; Mouterde, L.M.M; Stewart, J.D. *Green Chem.* **2018**, *20*, 5528-5532

From the bench to the production plant

Agro Biotechnologies Industrielles



ReSolute
biomasse: moteur de l'économie circulaire

URD Agro Biotechnologies Industrielles by AgroParisTech

UF UNIVERSITY of FLORIDA

BIO-BASED INDUSTRIES Public-Private Partnership

MERCK

circa

https://wholesaleinvestor.com.au/circa-group-has-announced-it-is-leading-the-consortium-for-the-new-eu-project-resolute/

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CEBB Centre Européen de Biotechnologie et de Bioéconomie

Valorization of resveratrol

16/03/2021

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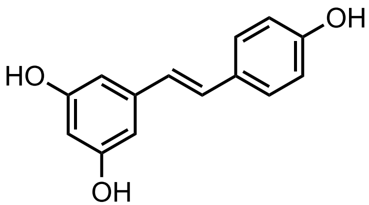
Grand Est ALSACE CHAMPAGNE-ARDENNE LORRAINE

EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND

Production for vine cell culture

Agro
Biotechnologies
Industrielles

Université
de Reims
Champagne-Ardenne



37.6 $g.kg^{-1}$ of cell (fresh biomass)

Vs.

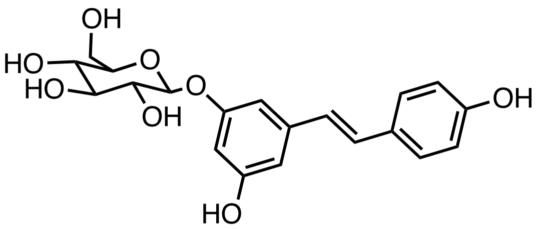
Vine shoots
250 $mg.kg^{-1}$

Productivity x150 !!!!

Extraction

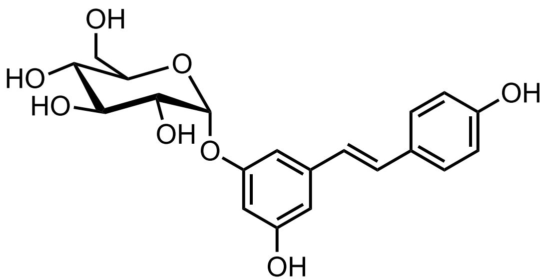
One chemo-enzymatic step: three benefits!

Agro Biotechnologies Industrielles



Piceid (Resveratrol 3-*O*-*β*-D-glucopyranoside)

- ➔ 10 times more soluble than resveratrol (hydrophilic)
- ➔ Stabilization of resveratrol (no oligomerization)

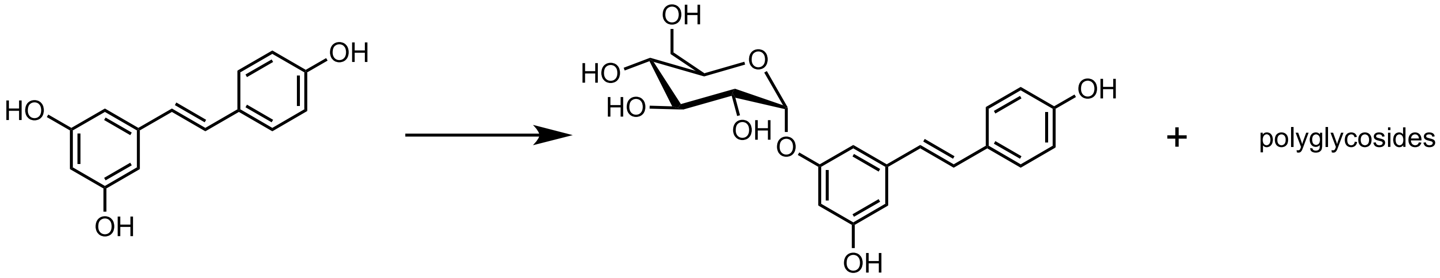


Enzymatic α-glycosylation of resveratrol[1]

- ➔ 60 times more soluble than resveratrol (hydrophilic) = improved bioavailability
- ➔ Stabilization of resveratrol
- ➔ Surfactant properties

[1] P. Torres et al., *Adv. Synth. Catal.* **2011**, *353*,1077

An improved glycosylation procedure



Torres et al.[1]

- ➔ Co-solvant: DMSO, MeOH, AcOEt, Acetone
- ➔ Enzyme: CGTase (Cyclodextrin glucanotransferase)
- ➔ Substrate: starch

Our procedure[2]

- ➔ Co-solvant: none
- ➔ Enzyme: CGTase
- ➔ Substrate: cyclodextrin

Procedure	Yield (%)	Temps (h)
Torres et al.	40	24
Our work	35	2

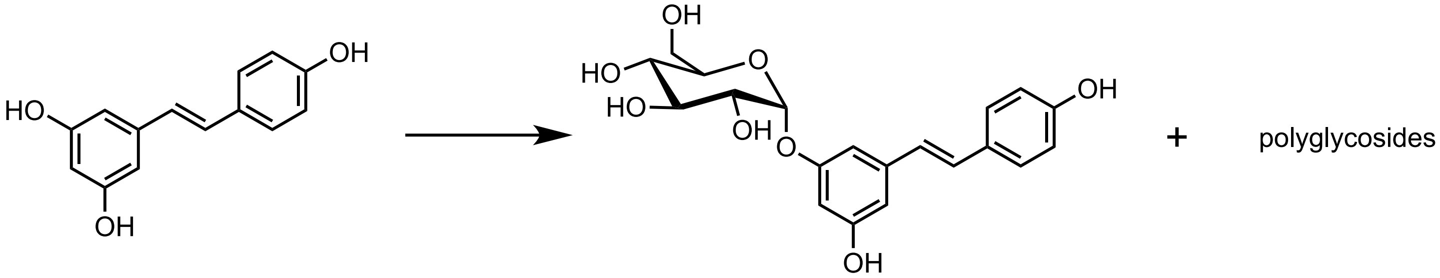
Our procedure is:

As efficient in terms of yield, faster (12-fold), organic solvant-free

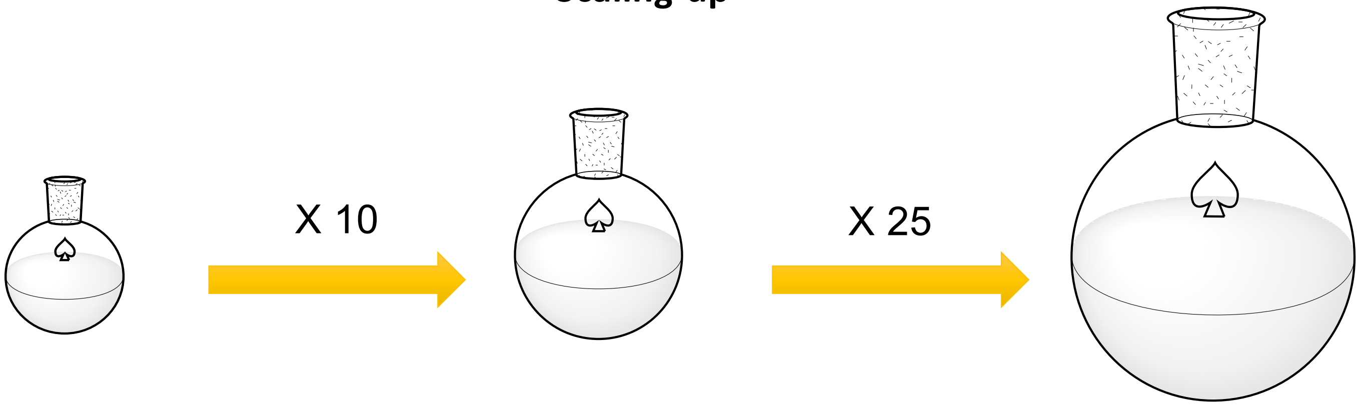
[1] P. Torres et al., *Adv. Synth. Catal.* **2011**, *353*,1077

[2] T. Marié et al. *ACS Sustainable Chem. Eng.* **2018**, *6*, 5370

Scale-up of the glycosylation



Scaling-up



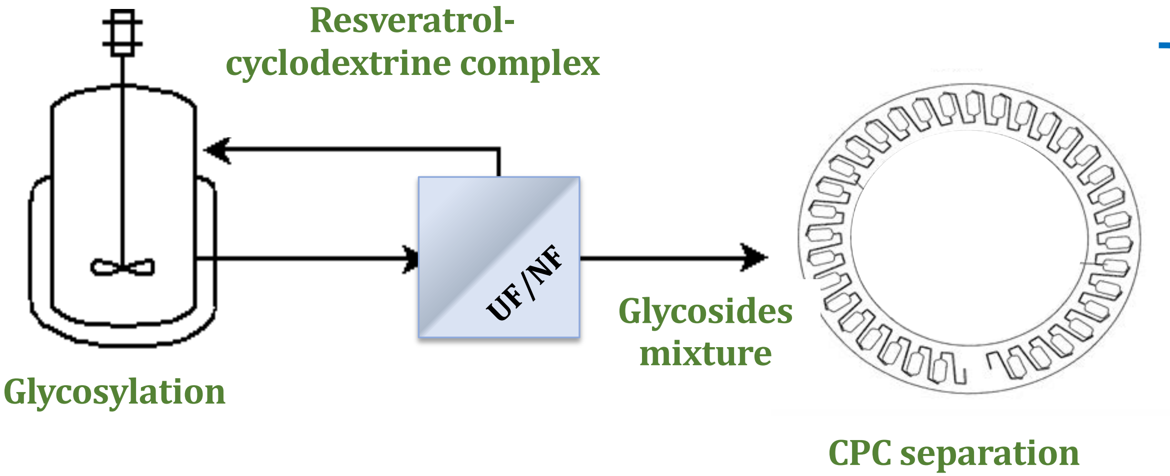
V = 4 mL	V = 40 mL	V = 1 L
[resveratrol] = 1 g/L	[resveratrol] = 1 g/L	[resveratrol] = 1 g/L
Yield = 35%	**Yield = 30 - 36%**	**Yield = 30 - 34%**

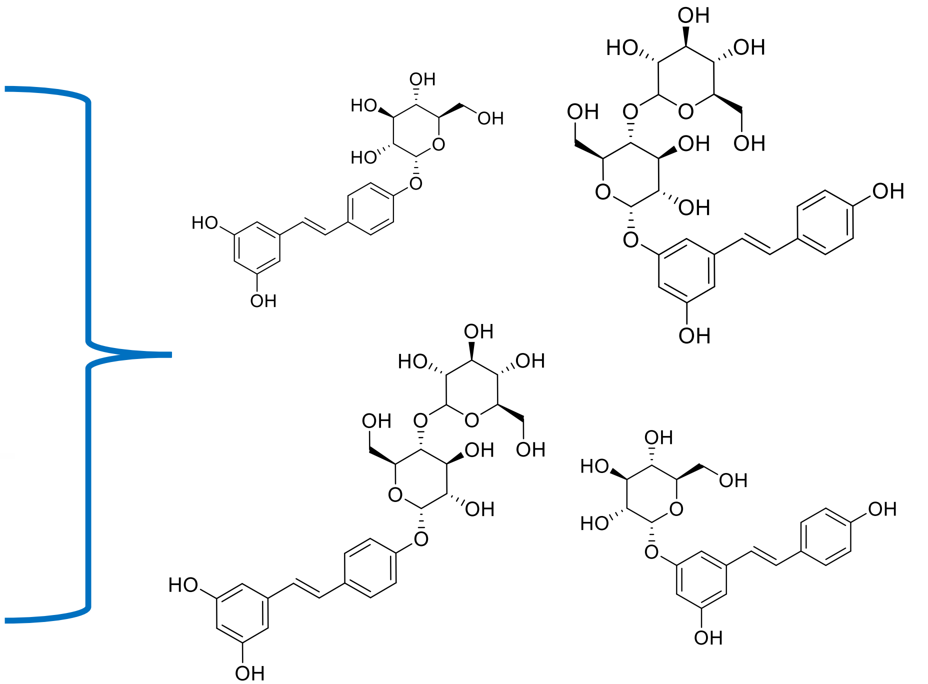
T. Marié et al. *ACS Sustainable Chem. Eng.* **2018**, *6*, 5370

Optimization through the coupling of bioconversion and extraction

Agro Biotechnologies Industrielles

UNIVERSITÉ DE REIMS CHAMPAGNE-ARDENNE





Continuous glycosides extraction using membrane filtration displaces the reaction equilibrium ➔ **increase the reaction yield from 35% to ca. 60%**

I. Ioannou et al. *Pharmaceuticals* **2021**, *under review*

Conclusion

- **Vanillin, syringaldehyde, ferulic and sinapic acids** are valuable biobased building blocks and can be readily derivatized using (bio)catalysis to prepare renewable BPA substitutes, UV-filters, antioxidants, antiradicals, monomers and polymers...

- Cellulose-based **LGO** can be derived into (1) the green solvent **Cyrene™** using OYE 2.6 enzyme, and (2) **HBO**, a valuable chiral chemical platform, *via* lipase- or H_2O_2-mediated Baeyer-Villiger oxidations (BVO), greener and more efficient alternatives to peracid- and zeolite-based BVO.

- The combination of biotechnology and biocatalysis allow the production of **potent glycosides of resveratrol** with enhanced biological properties

- **Combining green chemistry, biotechnology and downstream process is a great asset.**

Acknowledgements

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