



BRISK

BIOFUELS RESEARCH INFRASTRUCTURE

# Biofuels Summer School 2018

## Fermentation

Francisco Gírio

Head of Bioenergy Unit, LNEG, Portugal

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# Biofuels Summer School 2018 - Agenda

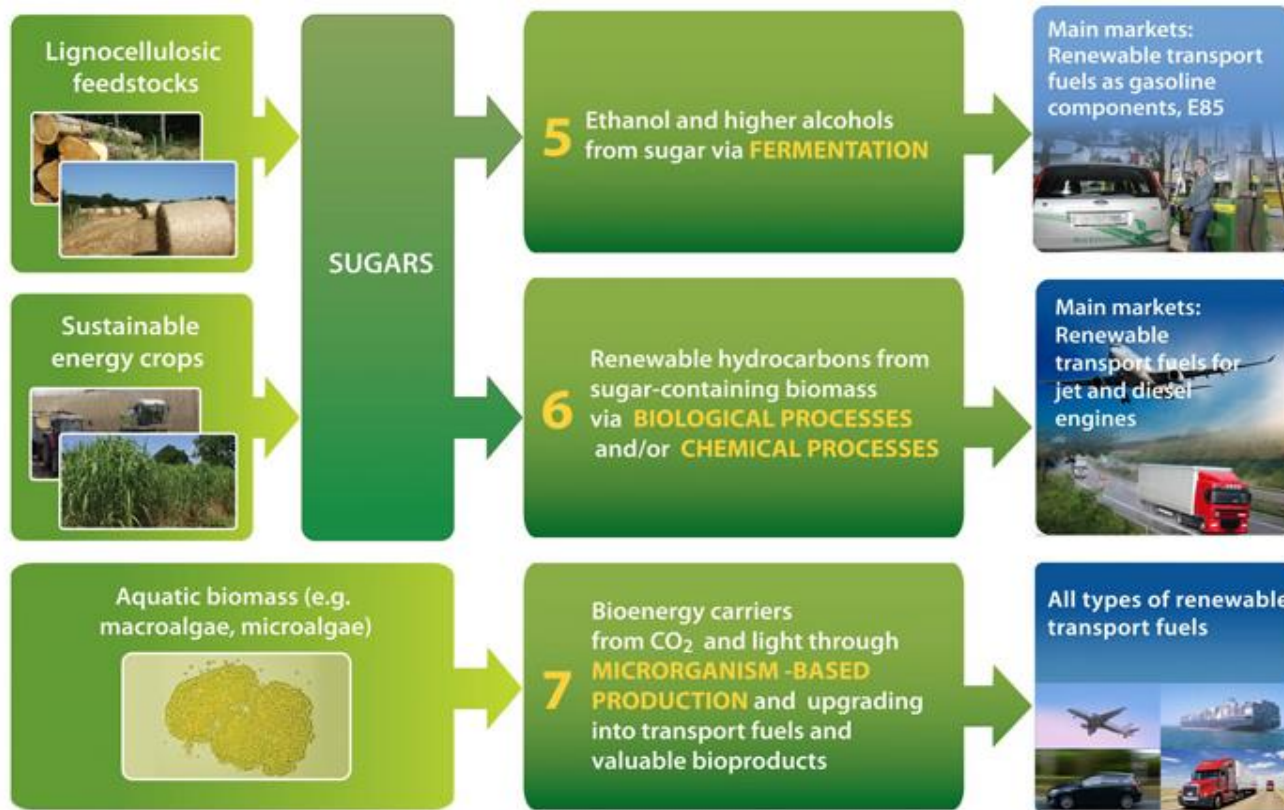
## 1. Fermentation Technology (+/- 60 min):

- Bioprocesses
- Biofuels & bioproducts
- Biocatalysts
- Engineered Microorganisms

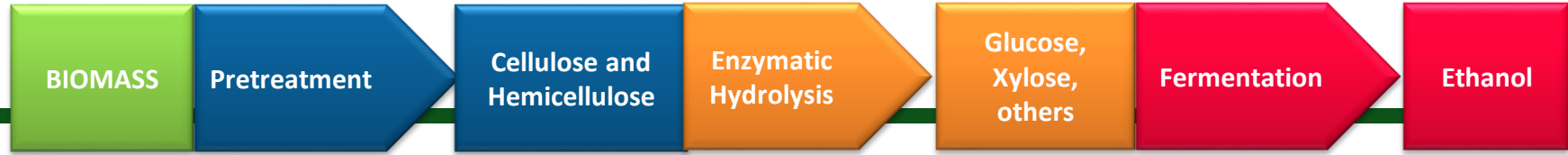
## 2. Case Study & Discussion (+/- 30 min):

- Biofuels vs. E-mobility

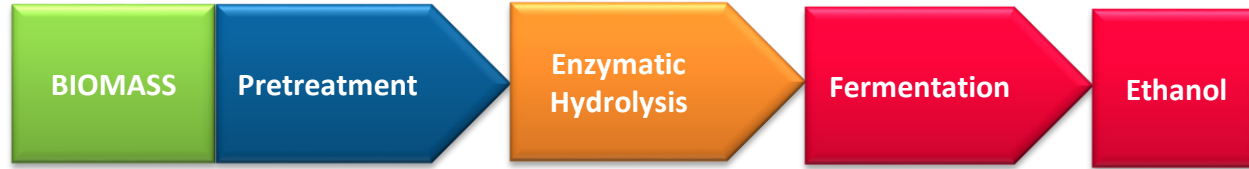
# Biochemical Conversion Value Chains for Biomass



## Lignocellulosic ethanol



## Lignocellulosic higher alcohols and novel biofuel molecules



## Hydrocarbons from sugars (biochemical)



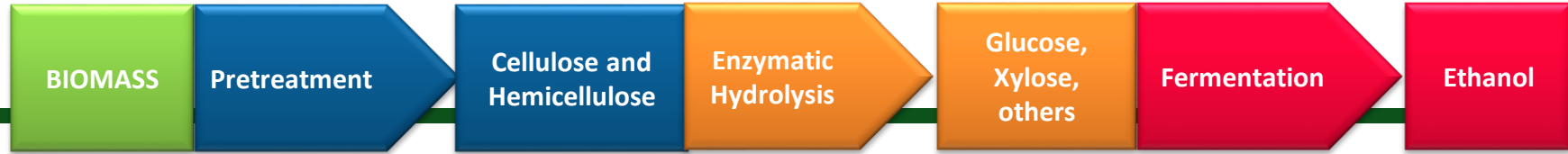
## Hydrocarbons from sugars (chemical)



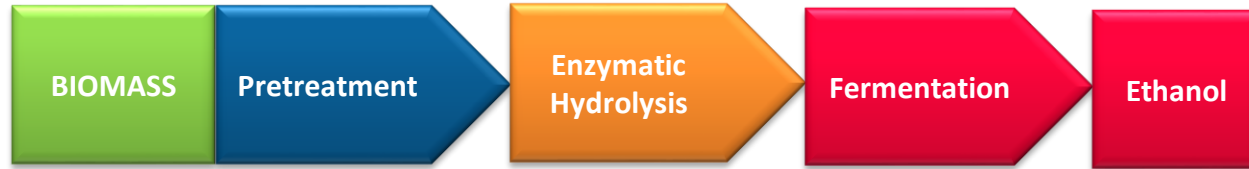
# Sugars (and syngas) to higher alcohols

Company	Site	Products	Year	Cap. ML/yr	Type	Status
Amyris	2*NZ KO, AU	Various non-fuels		50 70	Comm. Comm.	Plan Plan.
DSM (ex-Amyris)	BR	Farnesene	2012	40	1 <sup>st</sup> ind.	Op.
BUTAMAX	UK USA	Isobutanol	2012	0.2	Demo 1 <sup>st</sup> ind.	Com. Plan.
GEVO	USA	Isobutanol	2014	6	1 <sup>st</sup> ind.	Com.
Global Bioenergies	FR	Iso-butene	2017	100 tpa	Demo	Op.
REGI (LS9)	USA	Fatty alcohols	2012	0.13	Demo	Op.
VIRENT	USA	Various fuel/ non-fuel	2009 2013	~ 0.04 ~ 0.02	Demo Demo	Op. Op.
<b>Syngas (CO+H2) to alcohol</b>						
Lanzatech	USA	Ethanol	2018	60	Demo	2018?

## Lignocellulosic ethanol



## Lignocellulosic higher alcohols and novel biofuel molecules



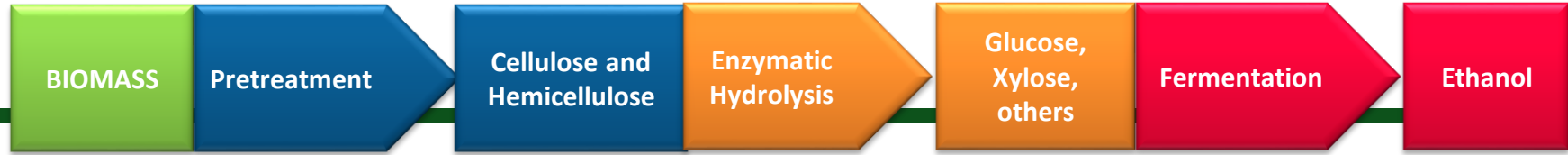
## Hydrocarbons from sugars (biochemical)



## Hydrocarbons from sugars (chemical)



## Lignocellulosic ethanol



## Lignocellulosic higher alcohols and novel biofuel molecules



## Hydrocarbons from sugars (biochemical)









## Hydrocarbons from sugars (chemical)



# Alcohols to hydrocarbons

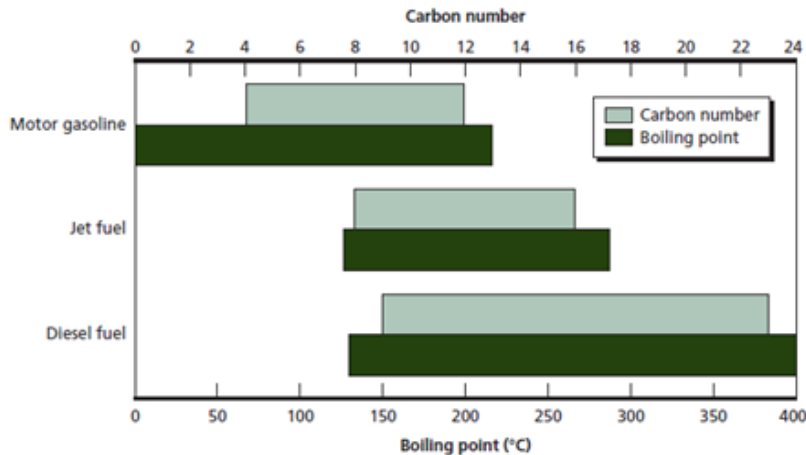
Company	Site	Feed	Year	Cap. ML/yr	Type	Status
<b>Main product= diesel and jet substitutes</b>						
Gevo	USA	Isobutanol	2011	0.5	Demo	Op.
Byogy	USA	Ethanol	2017		Demo	Op.
Sw. Biofuels	SE	Alcohols	2012	0.01	Pilot	Op.
Lanzatech	NZ(USA)	Ethanol	2015		Pilot	Op.
<b>Main product= gasoline substitutes</b>						
Enerkem	CA	Methanol	2018		Pilot	Op.
KIT	DE	Methanol	2014	0.7	Pilot	Op.
Lurgi MTS	DE	Methanol	2008		Pilot	2011
Topsöe TIGAS	DK	Methanol	2014	90	Com.	2018

# Alternative Fuels for Transport

	<i>Road</i>						<i>Air</i>	<i>Rail</i>	<i>Water</i>		
											
<b>Range</b>	<i>Urban</i>	<i>Medium</i>	<i>Long</i>	<i>Short</i>	<i>Medium</i>	<i>Long</i>			<i>Inland</i>	<i>Short sea</i>	<i>Maritime</i>
<b>Natural gas</b>					LNG	LNG	✗		LNG	LNG	LNG
<b>Electricity</b>		✗	✗		✗	✗	✗			✗	
<b>Biofuels</b>											
<b>Hydrogen</b>						✗	✗				✗

Liquid biofuels and methane are the most versatile alternatives!

# Aviation Fuels: Specifications



## Enough energy:

Specific energy:  $> 42.3 \text{ MJ/Kg}$

## Liquid fuel at high altitudes:

Freezing point:  $< -40^\circ \text{C}$

## Safety:

Flash point:  $> 40^\circ \text{C}$

## Engine Specifications:

Density:  $0.775 - 0.845 \text{ Kg/l}$

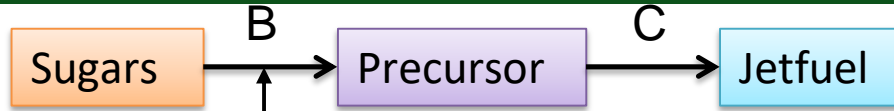
Viscosity:  $< 8 \text{ mm}^2/\text{s}$  ( $-20^\circ \text{C}$ )

Boiling point:  $200-300^\circ \text{C}$

## Kerosene

- 10-15% of a crude barrel
- **Chain length: C8-C16**
- **70-85% made of linear, iso- and cyclo-alkanes**
- some naphthalene and alkenes
- 8-22% is made of aromatics
- Sulfur  $< 300 \text{ ppm}$

# Amyris - Sugarcane to jet and diesel precursors



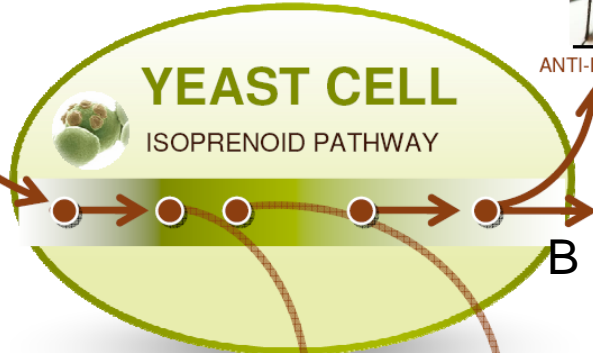
FERMENTATION  
(yeast)



ANTI-MALARIAL DRUG



SUGAR SOURCE



FARNESENE



FARNESANE

*(Certified by ASTM  
for 10% addition to jet-fuel)*

## B - Synthetic biology:

- *S. cerevisiae*
- Isoprenoid pathway

## C - Hydrogenation reaction



ISOPRENE



PINENE  
(JET FUEL)



# Energy (pathways) efficiencies for novel biofuels

Theoretical yields on glucose for selected microbial fuels derived from different metabolic pathways<sup>a</sup>

Product	Pathway	Density <sup>b</sup> (g/mL)	Metabolic mass yield	Gal product/ ton glucose	Enthalpy of combustion (MJ/kg) <sup>b</sup>	Enthalpy of combustion yield
<b>Gasoline replacements</b>						
Ethanol	Fermentative	0.79	51%	155	-29.7	97%
Butanol	Fermentative	0.81	41%	121	-36.1	95%
Isobutanol	Nonfermentative	0.81	41%	122	-35.9	94%
3-Methyl-1-butanol	Nonfermentative	0.81	33%	98	-37.7	80%
<b>Diesel replacements</b>						
Farnesene	Mevalonate	0.84	25%	71	-47.0 <sup>c</sup>	75%
Farnesene	Deoxyxylulose	0.84	29%	83	-47.0 <sup>c</sup>	87%
Ethyl hexadecanoate	Fatty acid	0.86	35%	98	-39.4 <sup>d</sup>	88%
Pentadecane	Fatty acid	0.77	29%	90	-47.0 <sup>c</sup>	87%
<b>Biocrudes</b>						
Squalene	Mevalonate	0.86	25%	70	-47.0 <sup>c</sup>	75%
Squalene	Deoxyxyulose	0.86	29%	81	-47.0 <sup>c</sup>	87%
Hentriacontene	Fatty acid	0.78 <sup>e</sup>	30%	92	-47.0 <sup>c</sup>	90%

<sup>a</sup> Theoretical mass yields and enthalpy of combustion conversion yields were calculated using metabolic flux analysis methods (see supplementary materials for details).

<sup>b</sup> Values were taken from the 'Handbook of Chemistry and Physics' [67].

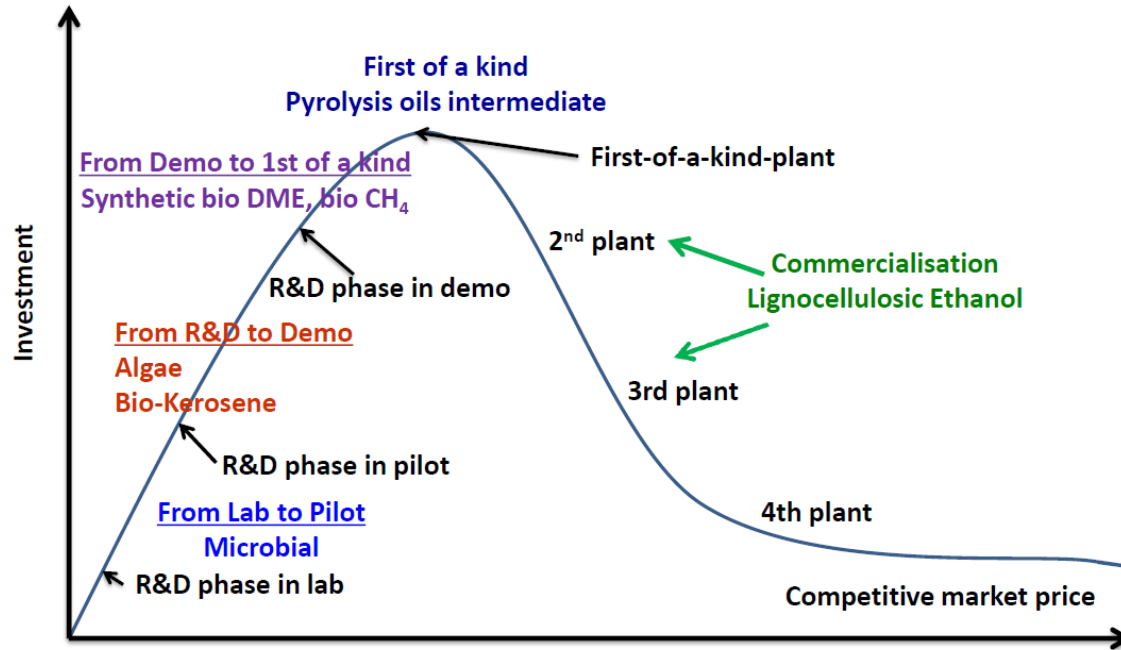
<sup>c</sup> Enthalpy of combustion data is not available for all the hydrocarbons in this table, therefore 47 MJ/kg was used which represents an approximate value for long-chain hydrocarbons.

<sup>d</sup> Value was taken from Ref. [63\*].

<sup>e</sup> Density value for hentriacontane was used instead of hentriacontene.

# Status of Fermentation Technologies for Advanced Biofuels

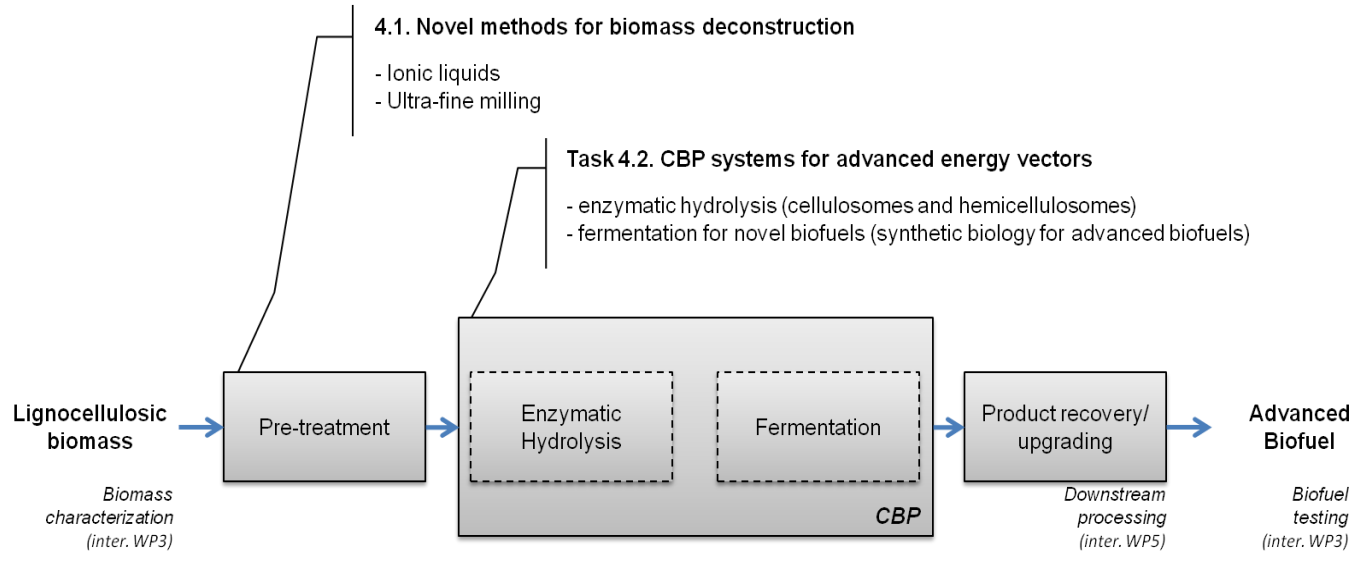
Technology Valley of death: Positioning of FP7 supported technologies



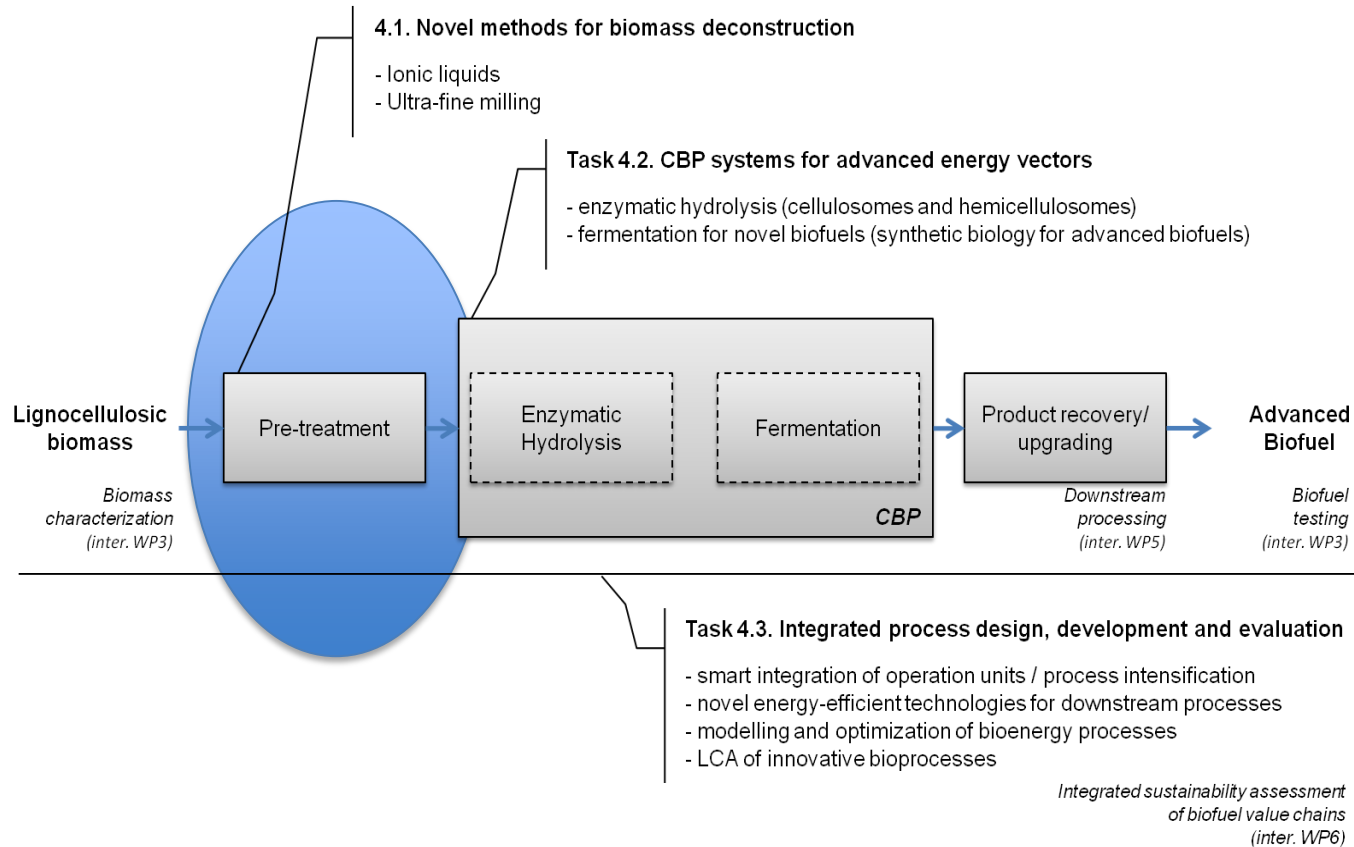
# Processing Operations for Advanced Bioethanol



# Biochemistry Conversion Processes to Advanced Biofuels – Key Challenges

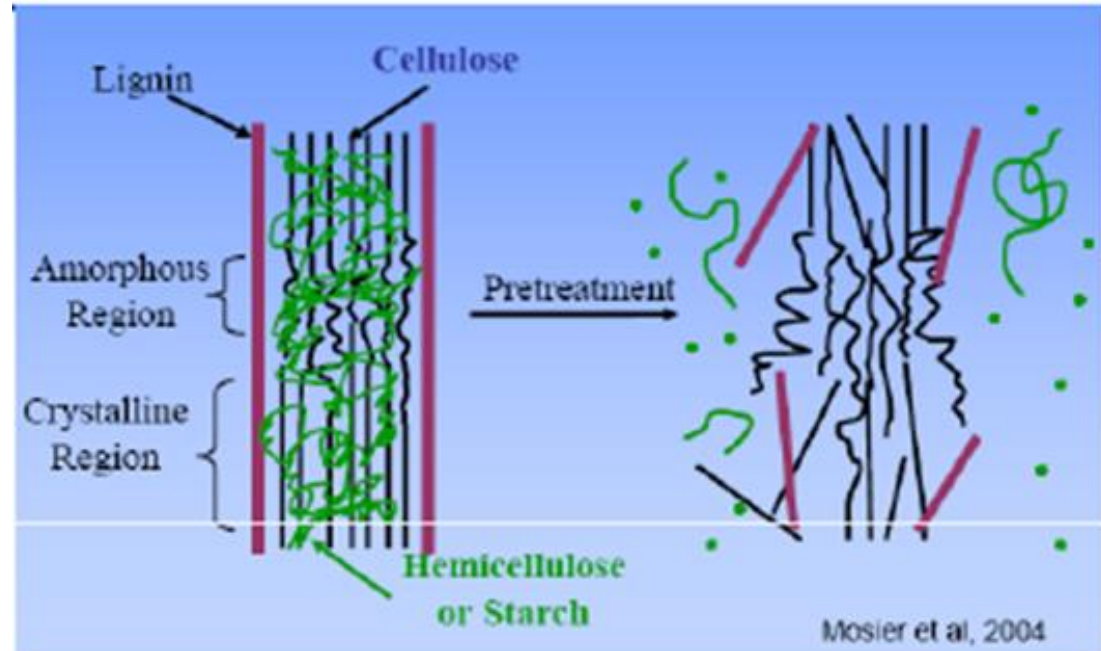


# Biochemistry Conversion Processes to Advanced Biofuels – Key Challenge I



## Feedstock Challenge:

Lignocellulose biomass recalcitrance and heterogeneity is an issue!



Mosier N, Wyman C, Dale B, Elander R, Lee YY, Holtzapfle M, Ladisch MR, 2004.

# Pre-treatments Range for 2G EtOH

Inbicon version 2 – C6+C5 mixed fermentation – proven in demo scale

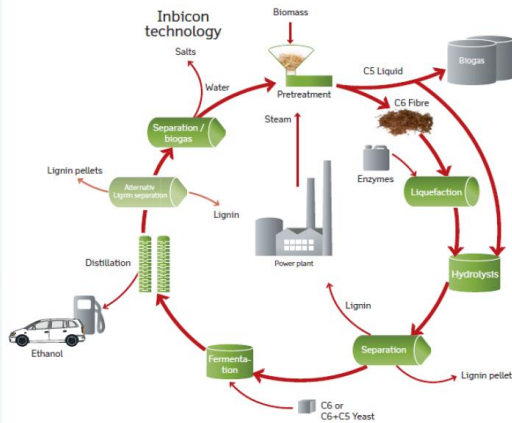
## Inbicon Concepts

- Biomass
- Water
- Enzymes
- Advanced yeast (GMO)

- Bioethanol
- Solid Biofuel
- Vinasses

• Improving ethanol yield with 40% in comparison to Inbicon version 1

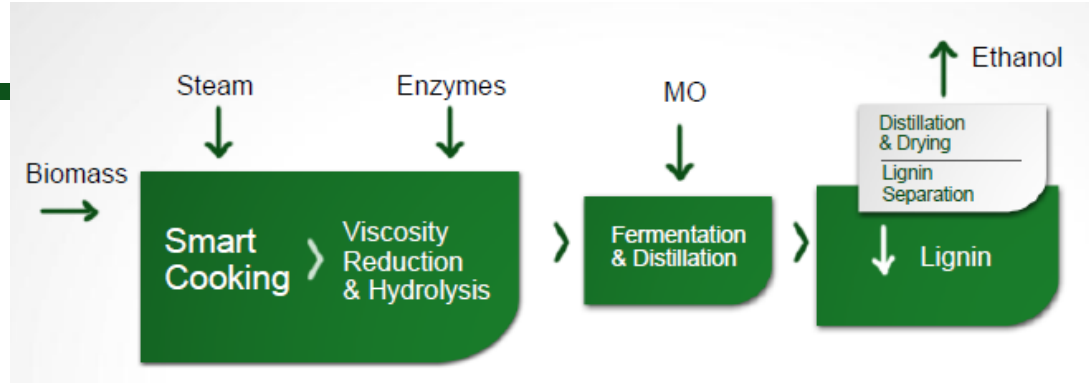
• Typical yield of 280-300 l etoh per ton of biomass dry matter



Inbi  
con

DONG  
energy

6



FEEDSTOCK

PRE-TREATMENT

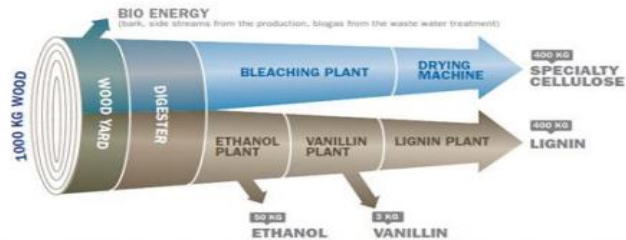
HYDROLYSIS

FERMENTATION

CELLULOSIC ETHANOL



INTEGRATED ENZYME  
PRODUCTION



Cellulose	Lignin	Vanillin	Ethanol
Construction materials	Concrete additives	Food	Car care
Cosmetics	Animal feed	Perfumes	Paint/ varnish
Food	Dyestuff	Pharmaceuticals	Pharmaceutical industry
Tablets	Batteries		Bio Fuel
Textiles	Briquetting		
Filters	Mining		
Paint/ varnish			

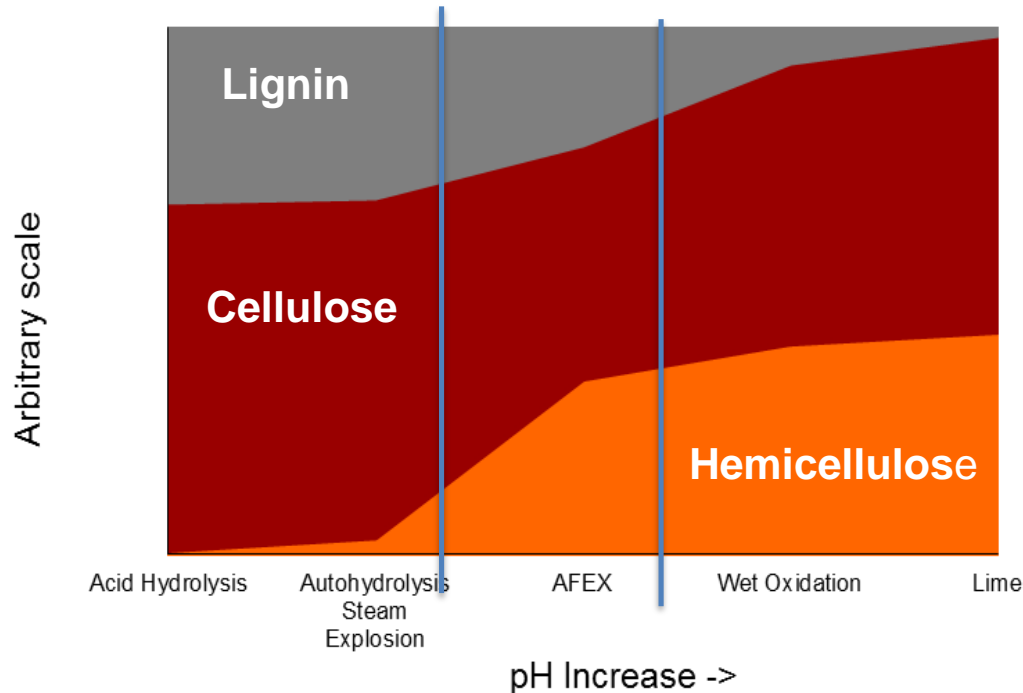
**BALI™ technology**

## Key features and advantages

- Integrated enzyme production
- Fermentation of C6 and C5 sugars into ethanol
- Feedstock and process specific enzymes
- Energy saving ethanol separation technology

# Current Flagships Pre-treatment Technologies

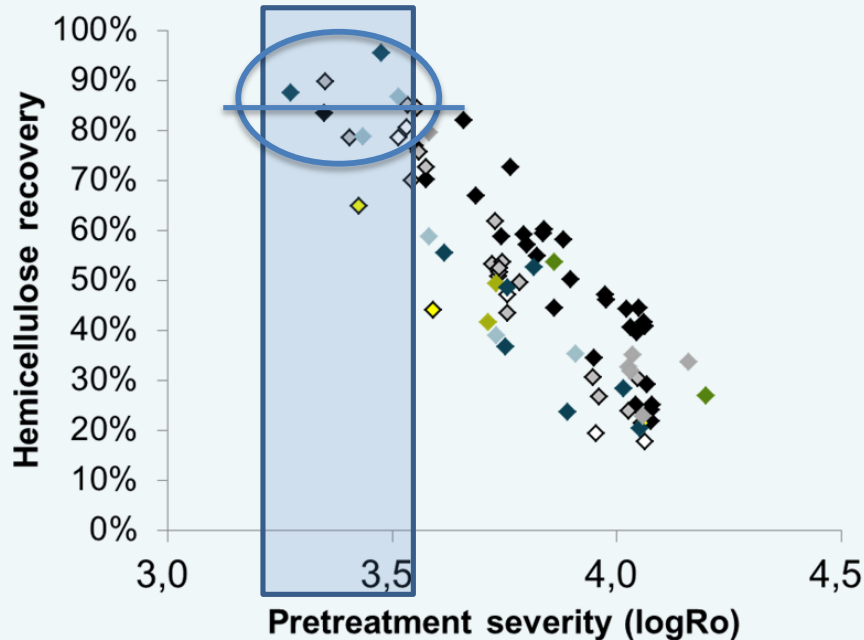
No standard technology available for any type of biomass



In: Carvalho, F., Duarte, L.C.,  
Gírio, F. M. (2008). *J. Scientific  
& Ind. Res.*, 67, 849-864

# Pretreatment | Flexible feedstock is importante!

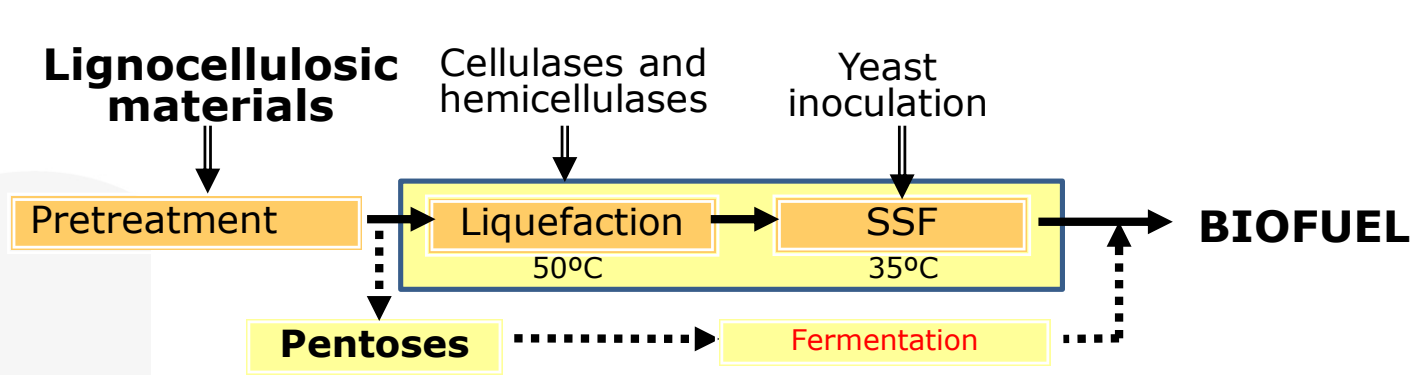
## Inbicon: Development of mixed sugar process (V2) - Process optimisation



- ◆ Wheat straw A
- ◆ Wheat straw B
- ◆ Wheat straw C
- ◇ Wheat straw D
- ◆ Barley straw
- ◆ Rape straw
- ◆ Corn stover
- ◆ Empty fruit bunches (EFB)
- ◆ Sugarcane bagasse

$$\log(R_0) = \log\left(t \cdot \exp\left(\frac{T - T_{ref}}{14,75}\right)\right)$$

# Process Intensification: High-solids SSF ( $\geq 25\%$ DM)



Laboratório Nacional de Energia e Geologia, I. P.

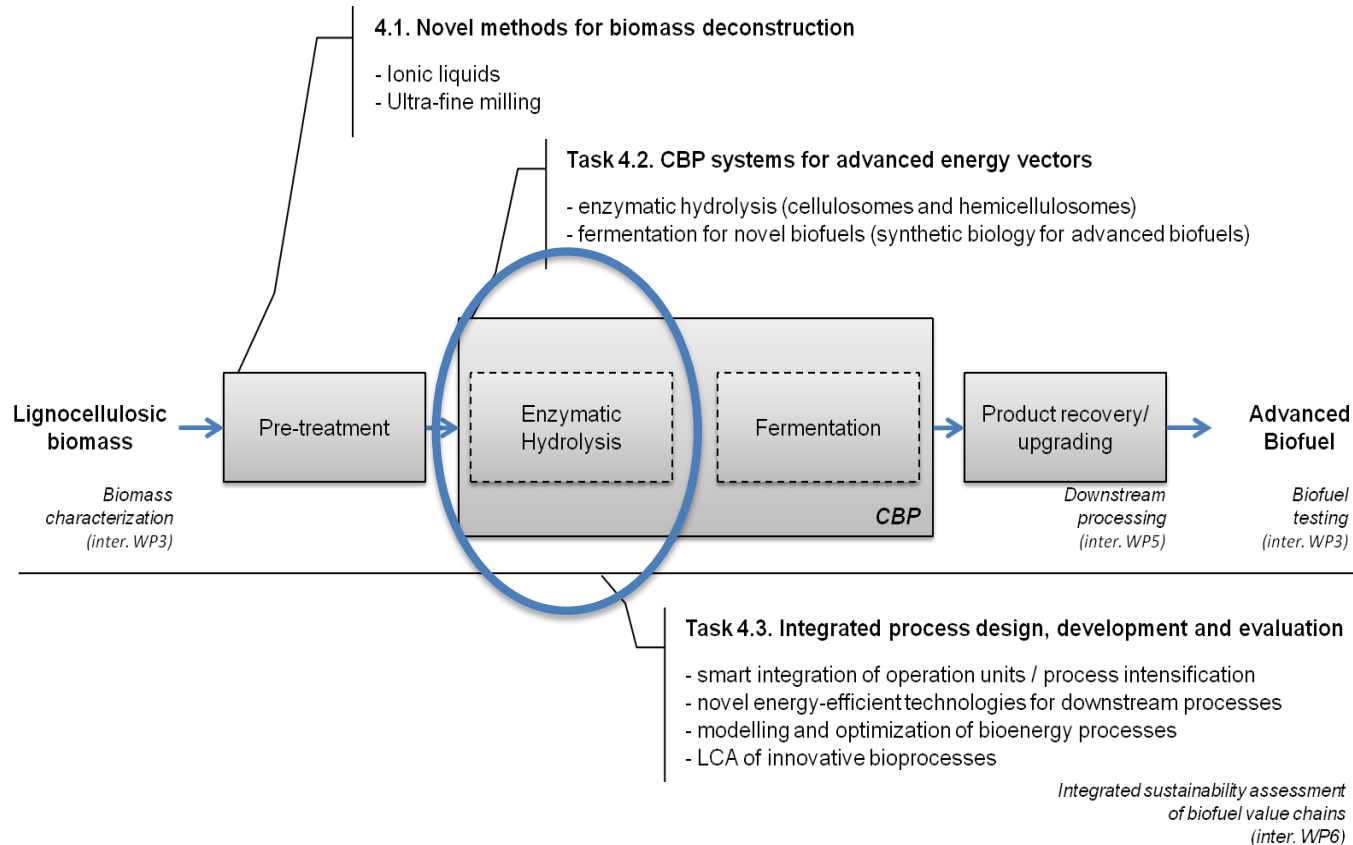


## Sugarcane bagasse

Enzyme load (FPU/ g glucan)	% solid content (w/w)					
	25			30		
	Glucose at 24h	Ethanol (g/l)	LSSF yield (%)	Glucose at 24h	Ethanol (g/l)	LSSF yield (%)
10	92	57	52	116	76	53
20	108	72	61	142	87	59
30	127	80	67	157	92	61



# Biochemistry Conversion Processes to Advanced Biofuels – Key Challenge II

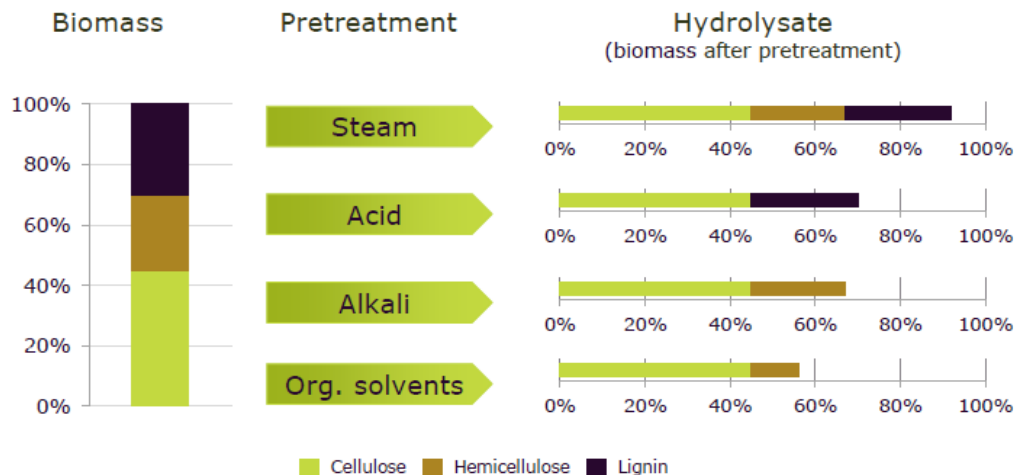


# Enzyme Technology: Moving to tailor-made real cases

AS INDUSTRIALIZED PROCESSES ARE LOCKED INTO PLACE, HIGHLY CUSTOMIZED TECHNOLOGIES ARE NEEDED



- Different pretreatment technologies produce different hydrolysates and inhibitors
- Hemicellulose mix (C5 sugar types) also vary. Enzyme components must be tailored to match



# Maximal Yields

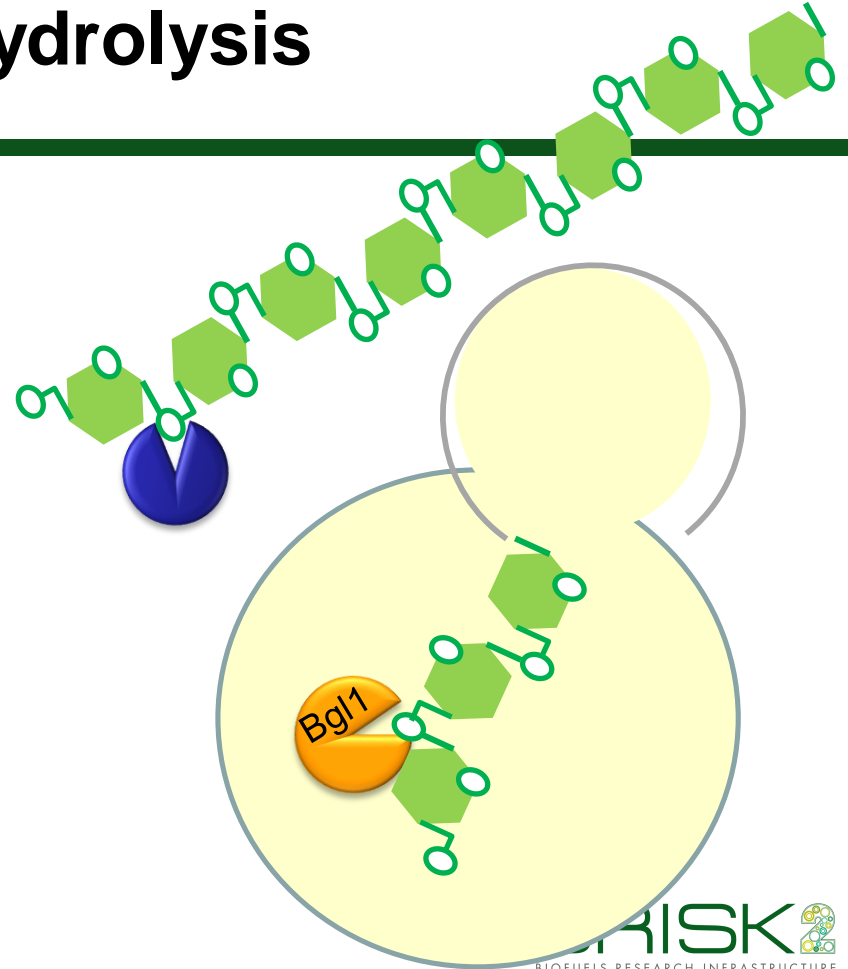
In: Marques, S. et al (2015) EUBCE, Vienna

MATERIAL	Time (h)	[Glc] <sub>max</sub> (g/L)	[Xyl] <sub>max</sub> (g/L)	$\eta_G$ (%)	$\eta_X$ (%)	$\eta_{G+X}$ (%)	
Unbleached pulp	24	83.5 ±1.8	18.0 ±0.5	96.3 ±2.2	72.1 ±2.4	91.2 ±2.2	
Bleached pulp	24	84.4 ±3.5	20.6 ±0.6	94.9 ±4.0	82.6 ±2.7	92.4 ±3.7	
Fines – kraft	24	86.1 ±0.4	19.3 ±0.7	95.8 ±0.4	73.6 ±3.2	91.6 ±0.9	
Branches – kraft	24	76.9 ±0.3	14.0 ±0.6	89.6 ±2.2	63.8 ±2.7	84.8 ±2.3	
Bark – kraft	72	4.3 ±1.4	1.5 ±0.1	3.2 ±1.6	2.7 ±0.7	3.1 ±1.4	
Acacia – kraft	48	75.1 ±0.3	14.5 ±1.0	87.8 ±1.9	62.3 ±5.1	83.2 ±0.7	
Willow – kraft	48	73.0 ±0.5	12.5 ±0.2	77.2 ±1.5	58.3 ±0.9	77.4 ±3.6	
Giant reed – kraft	24	71.8 ±3.1	12.6 ±0.4	86.2 ±3.6	45.4 ±1.7	76.7 ±3.2	
Miscanthus - kraft	48	58.6 ±0.7	15.3 ±0.2	72.2 ±0.9	52.9 ±0.9	69.6 ±0.5	

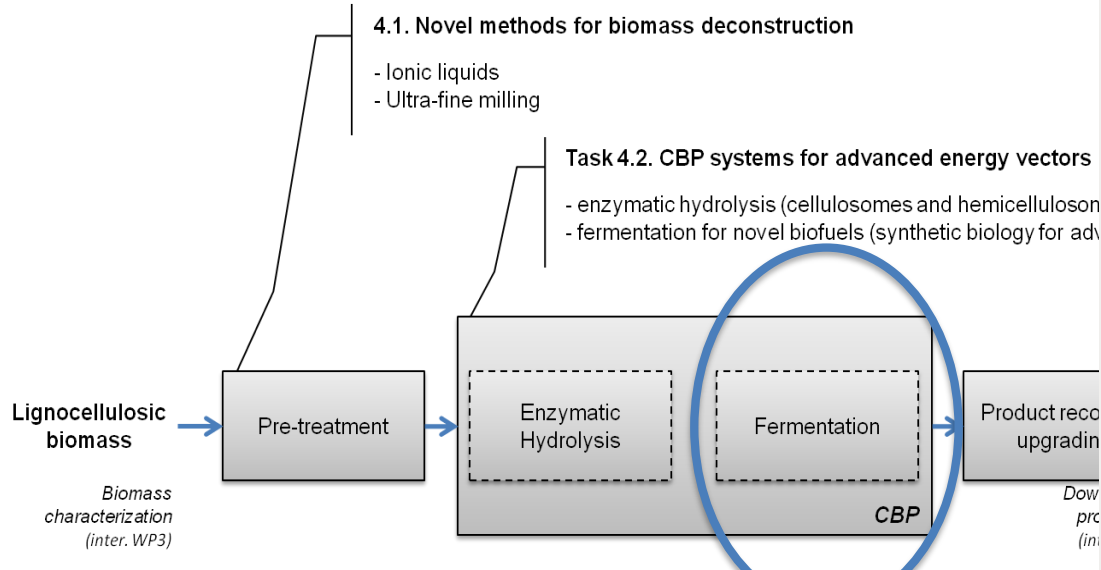
■ Glucose  
■ Xylose

# Enzymatic Hydrolysis

- Cost of unitary enzymes
- Amount of the enzymes needed
- Recyclability?
- Total cost of enzymatic stage



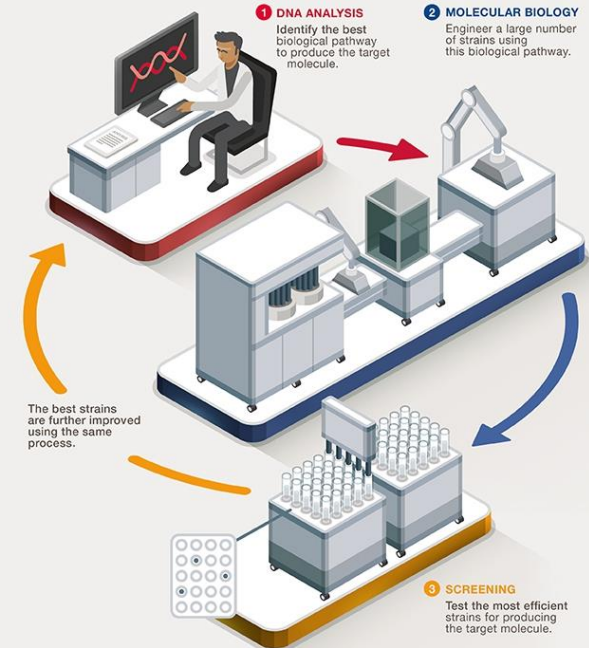
# Biochemistry Conversion Processes to Advanced Biofuels – Key Challenge III



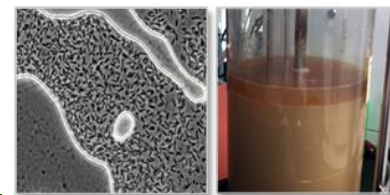
## Task 4.3. Integrated process design, development and optimization

- smart integration of operation units / processes
- novel energy-efficient technologies for downstream processing
- modelling and optimization of bioenergy processes
- LCA of innovative bioprocesses

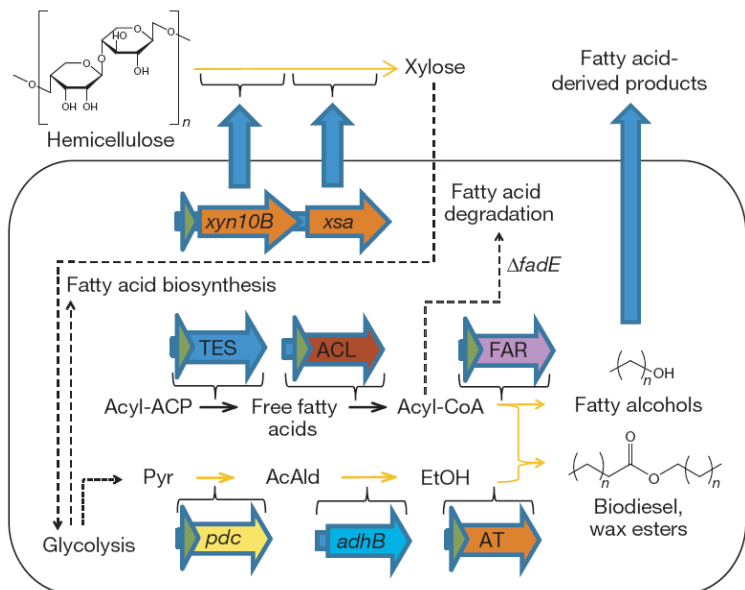
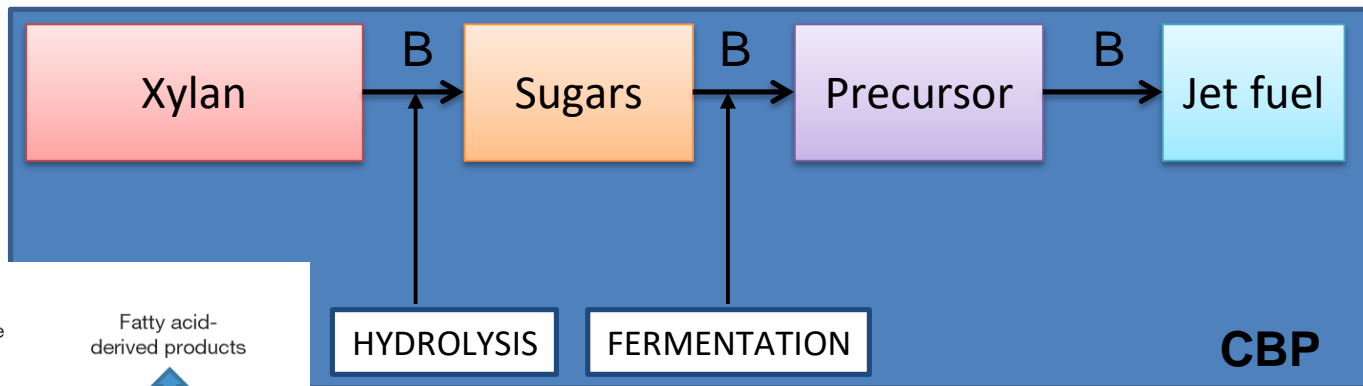
## SCREENING AND ENGINEERING A YEAST STRAIN USING SYNTHETIC BIOLOGY



# Bacterium Engineering for Novel Biofuels



(bought by REGI-  
Renewable Energy Group Inc.)



Steen et al. (2010) Nature 463:559

## Synthetic Biology:

- *E. coli*
- Xylan breakdown
- C-flow increase through biosynthetic pathway of fatty acids
- Co-expression of ethanol fermentative pathway

# S. cerevisiae Engineering for Pentoses Fermentation

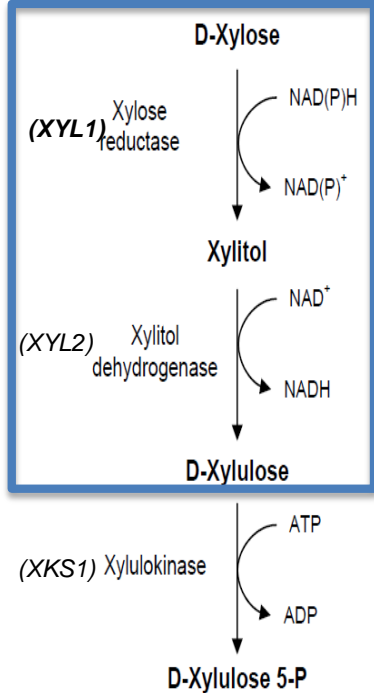
## Background strains

Cassette insertion,  
selection in xylose  
and evolutionary engineering

2nd stage  
Single-mutants

2nd stage  
Double-mutants

2nd stage  
Triple-mutants



Ethanol RED

GXF1/XR/XDH

$\Delta GRE3 \rightarrow \Delta PHO13$

or

PE2

or

$\Delta PHO13$

or

CAT1

XR/XDH

$XKS1 \uparrow$

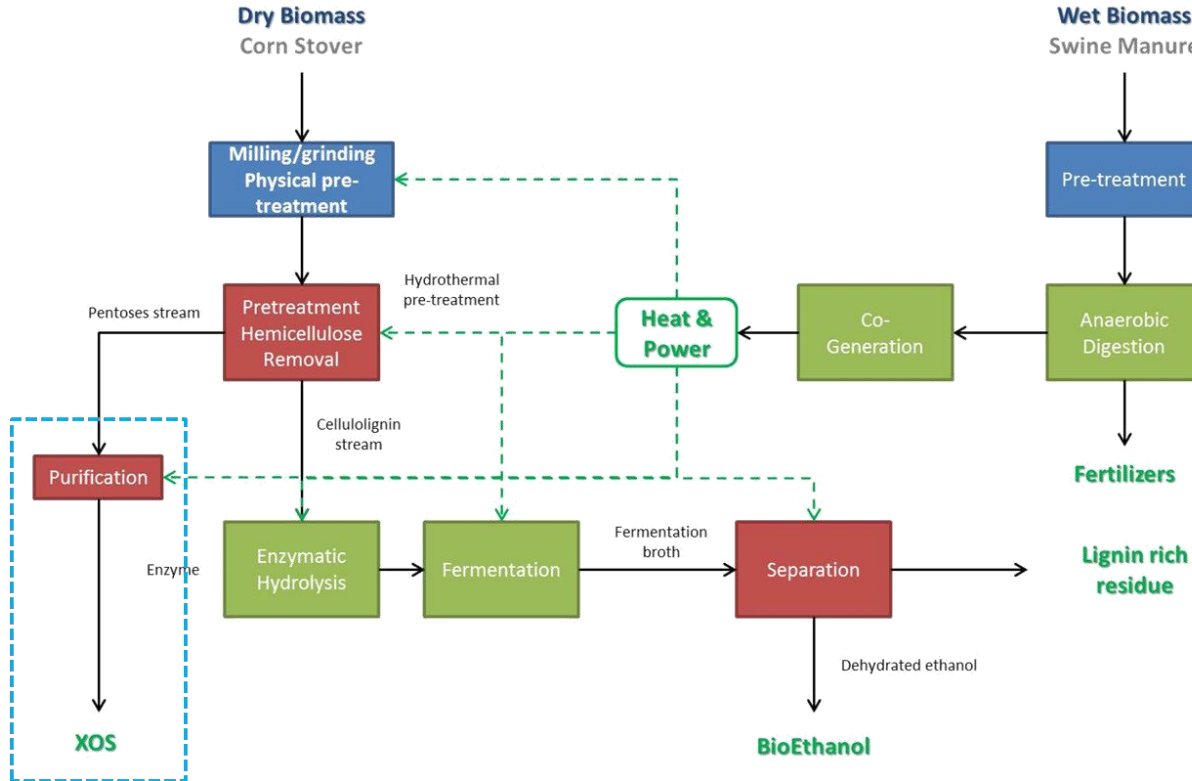
$\Delta GRE3 \rightarrow \Delta PHO13$

or

$\Delta PHO13$

# Engineering Microorganisms vs their influence on Fermentation Technology

## SCENARIO A Ethanol (C6 sugars) + Xylooligosaccharides (XOS) + Lignin (CHP)

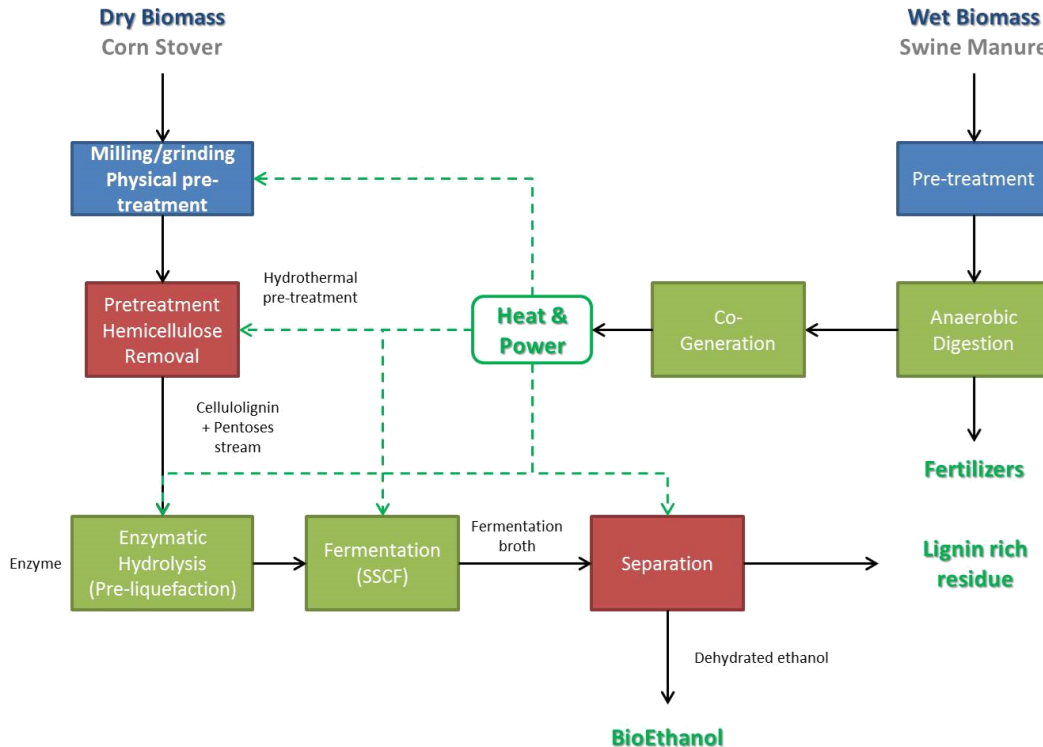


• Fermentation of C6 sugars only (for ethanol)

# Engineering Microorganisms vs their influence on Fermentation Technology

## SCENARIO B

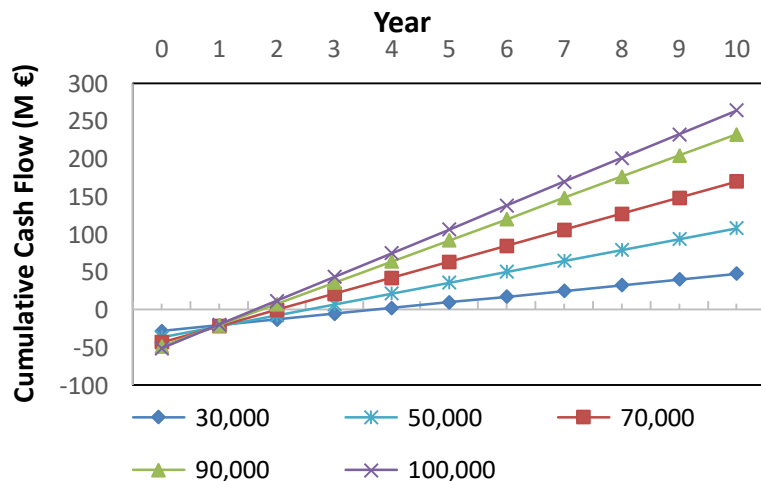
## Ethanol (C5/C6 sugars) + Lignin (CHP)



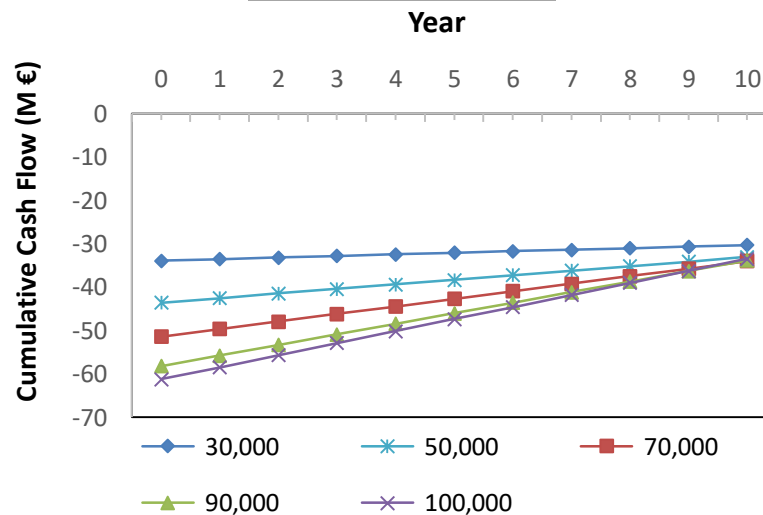
- Fermentation of C5+C6 sugars

# Engineering Microorganisms vs their influence on Fermentation Technology

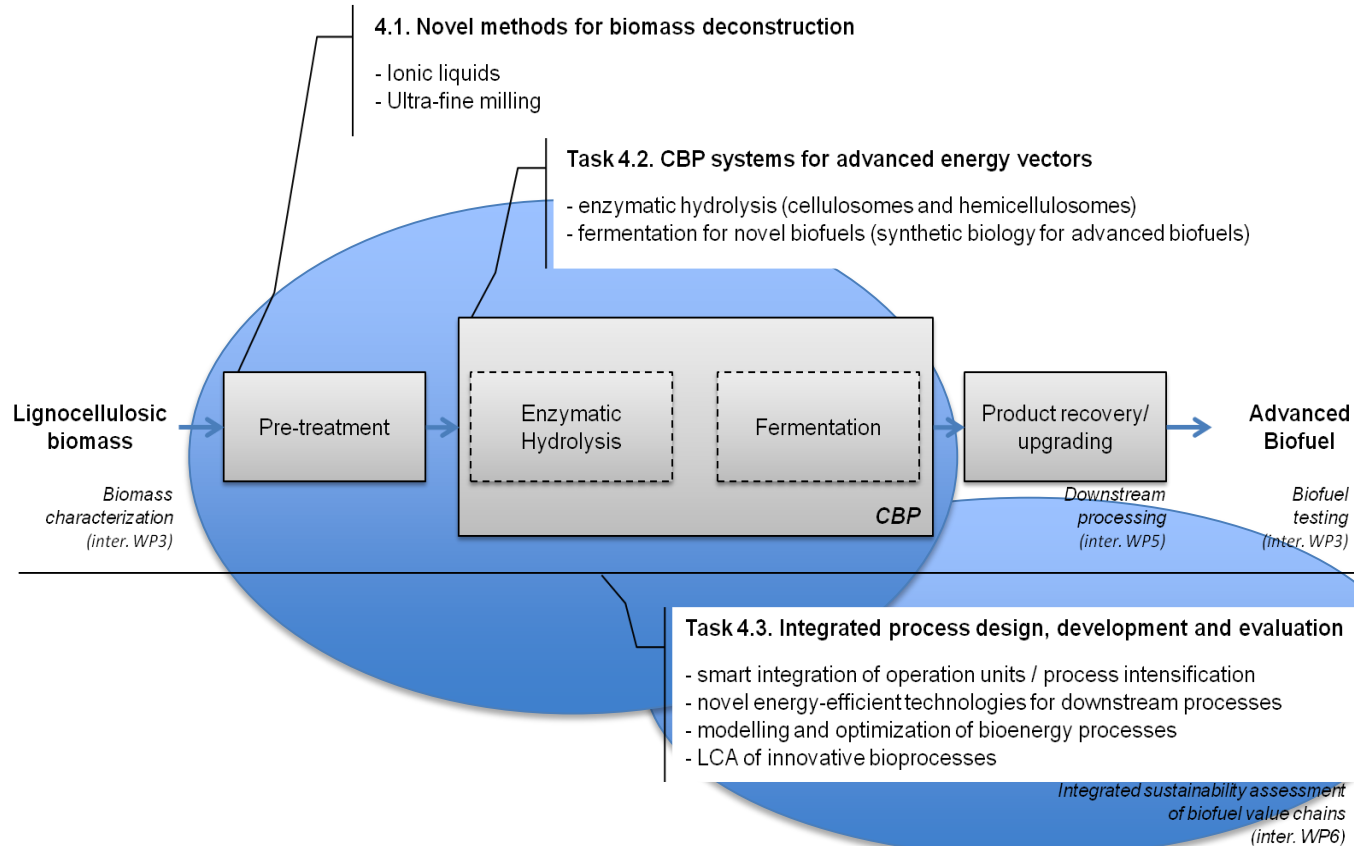
NON-GMO  
SCENARIO A



GMO  
SCENARIO B

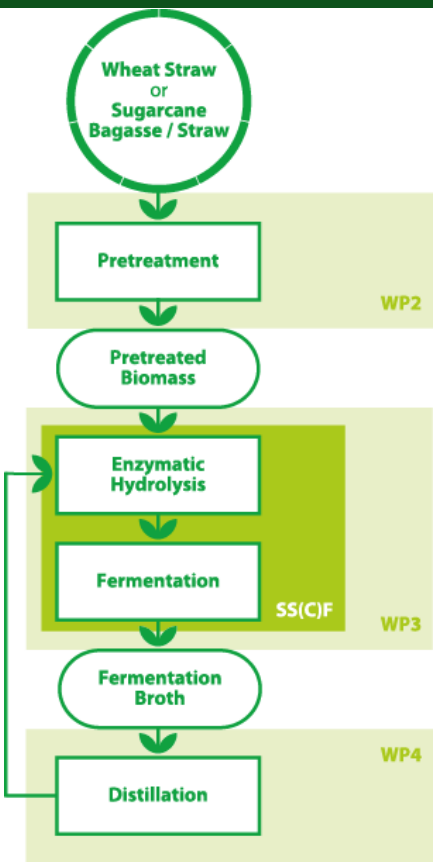


# Biochemistry Conversion Processes to Advanced Biofuels – Key Challenge IV

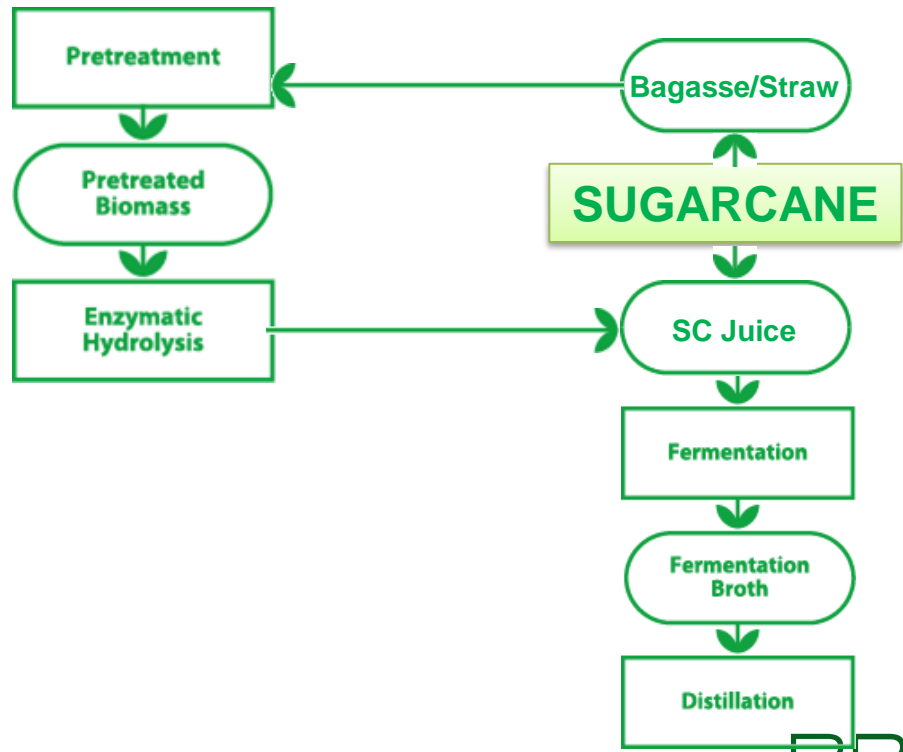


# Example: Process configurations for bioethanol biorefineries in EU & BR

**Stand-alone technology 2G (EU)**

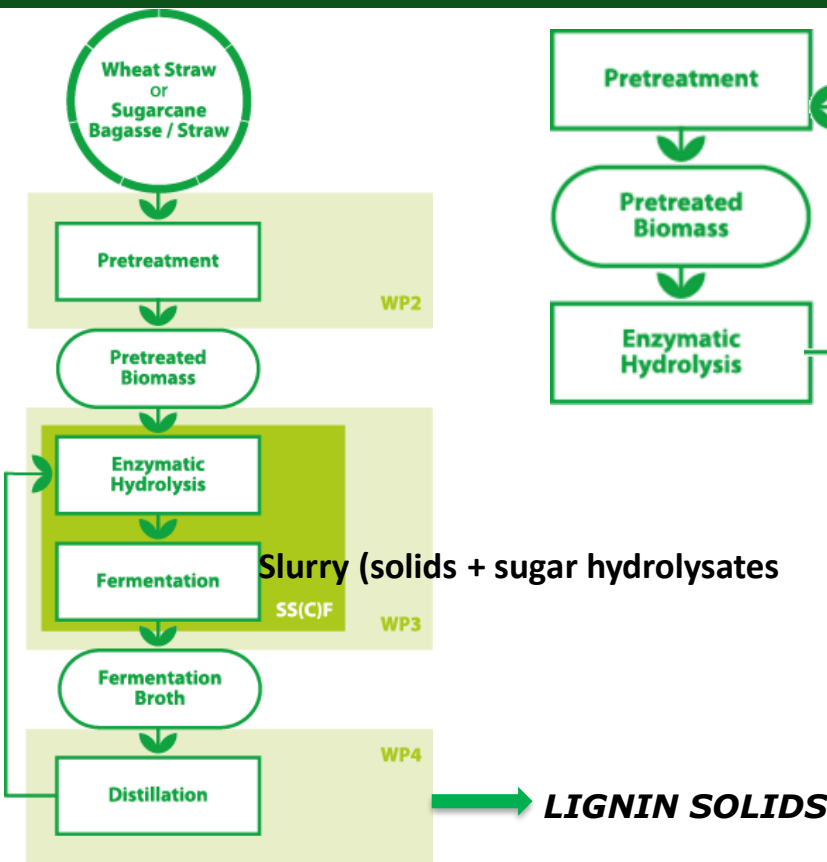


**Clear mash technology 1G2G (BR)**

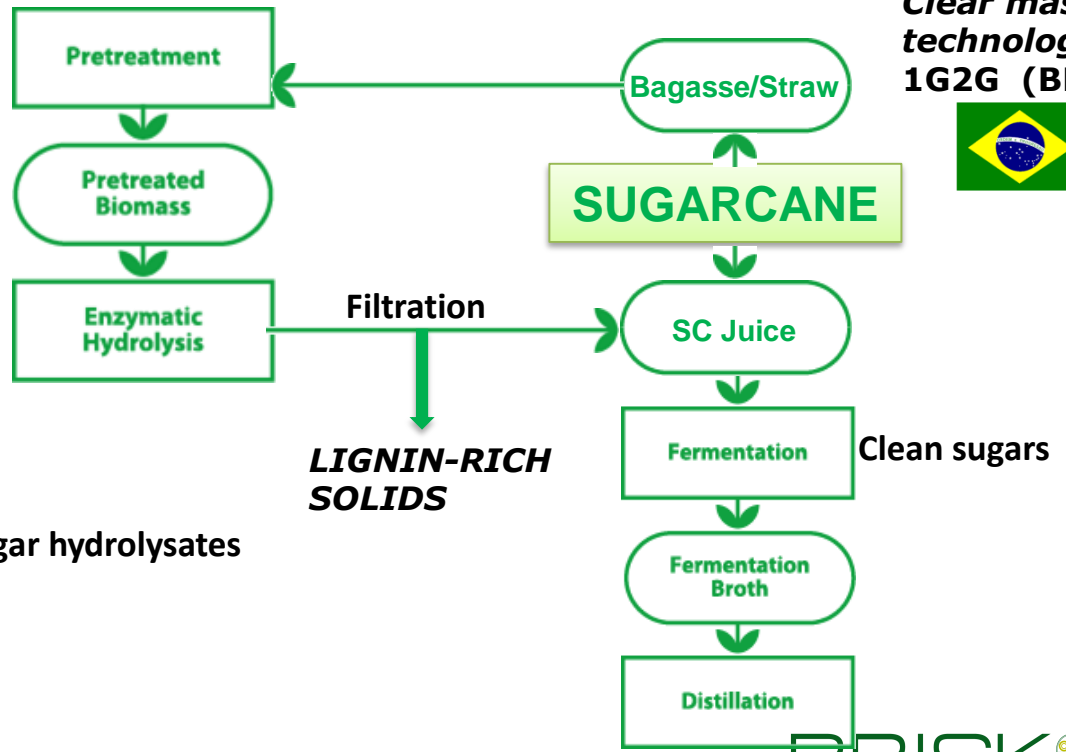


# Example: Process configurations for bioethanol biorefineries in EU & BR

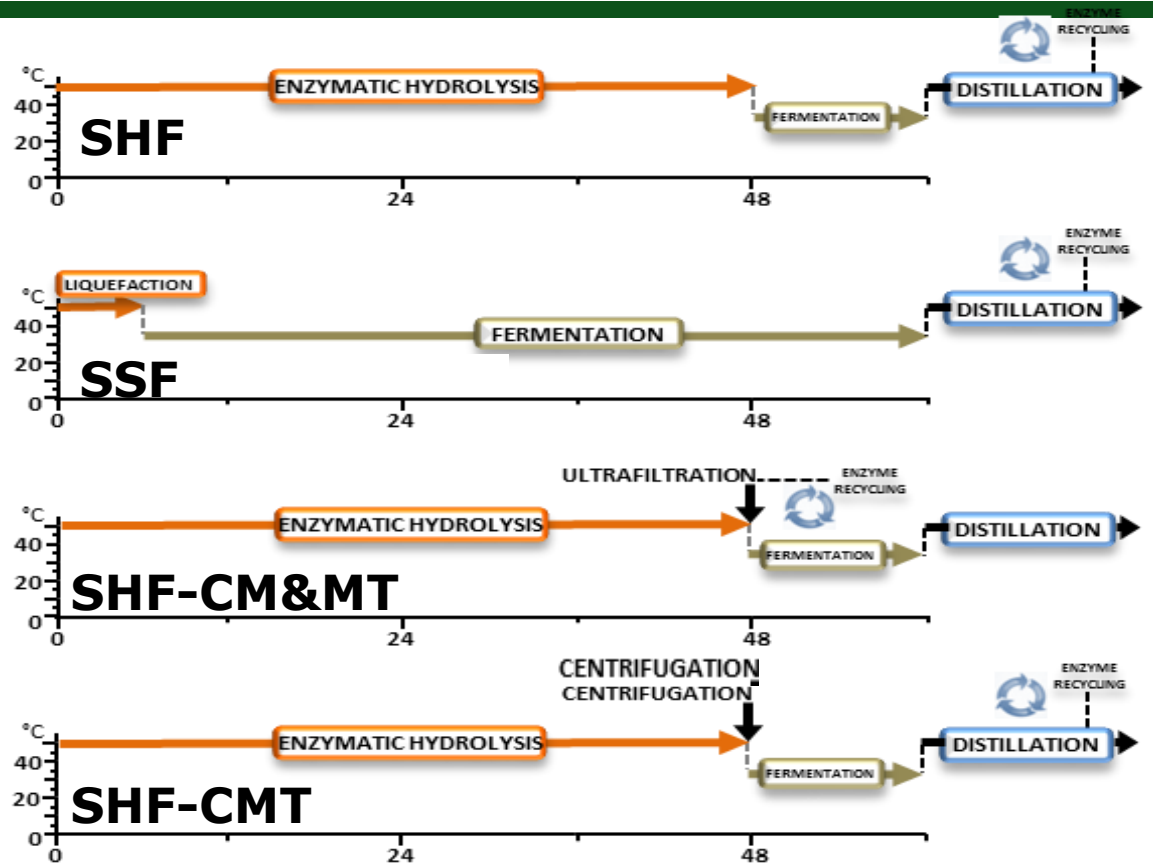
**Stand-alone technology 2G (EU)**



**Clear mash technology 1G2G (BR)**



# Process configurations for bioethanol yield and enzyme recycling

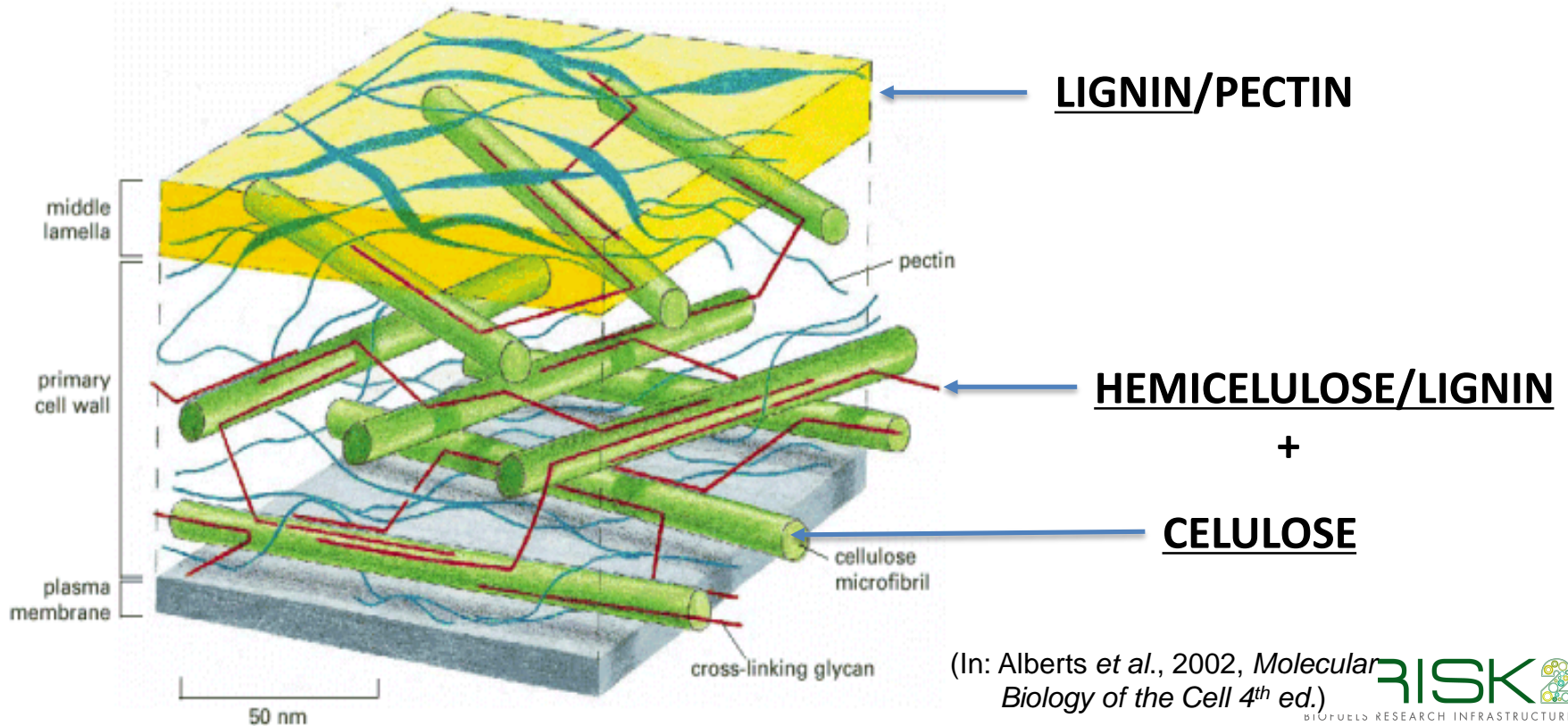


**Stand-alone  
technology – 2G**

**Clear mash  
Technology (w/ or  
w/o Membranes)  
(Brazil) – 1G2G**

# Biomass Feedstock as a whole

- Main Components -



(In: Alberts *et al.*, 2002, *Molecular Biology of the Cell 4<sup>th</sup> ed.*)

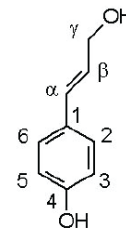
# Lignin Platform



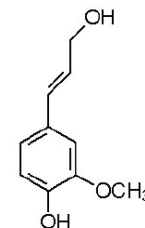
Laboratório Nacional de Energia e Geologia, I. P.

## Lignin Industry Today

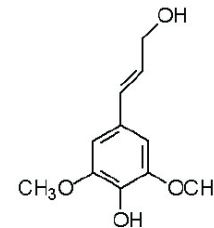
- ❑ Exclusively based on pulp and paper industry
- ❑ By-product from Kraft and Sulphite pulping process
- ❑ Applications limited by inherent characteristics of extracted lignin
- ❑ Current chemical pulping processes (Kraft and Sulphite) leads to: i) chemical adulteration of the extracted lignin (Na, S, Mg, etc), ii) chemical modification (condensation) and iii) require extensive and expensive post-treatment to return to desired properties
- ❑ **Almost 1 Billion € business**



*p*-coumaryl alcohol  
Mol Wt 150



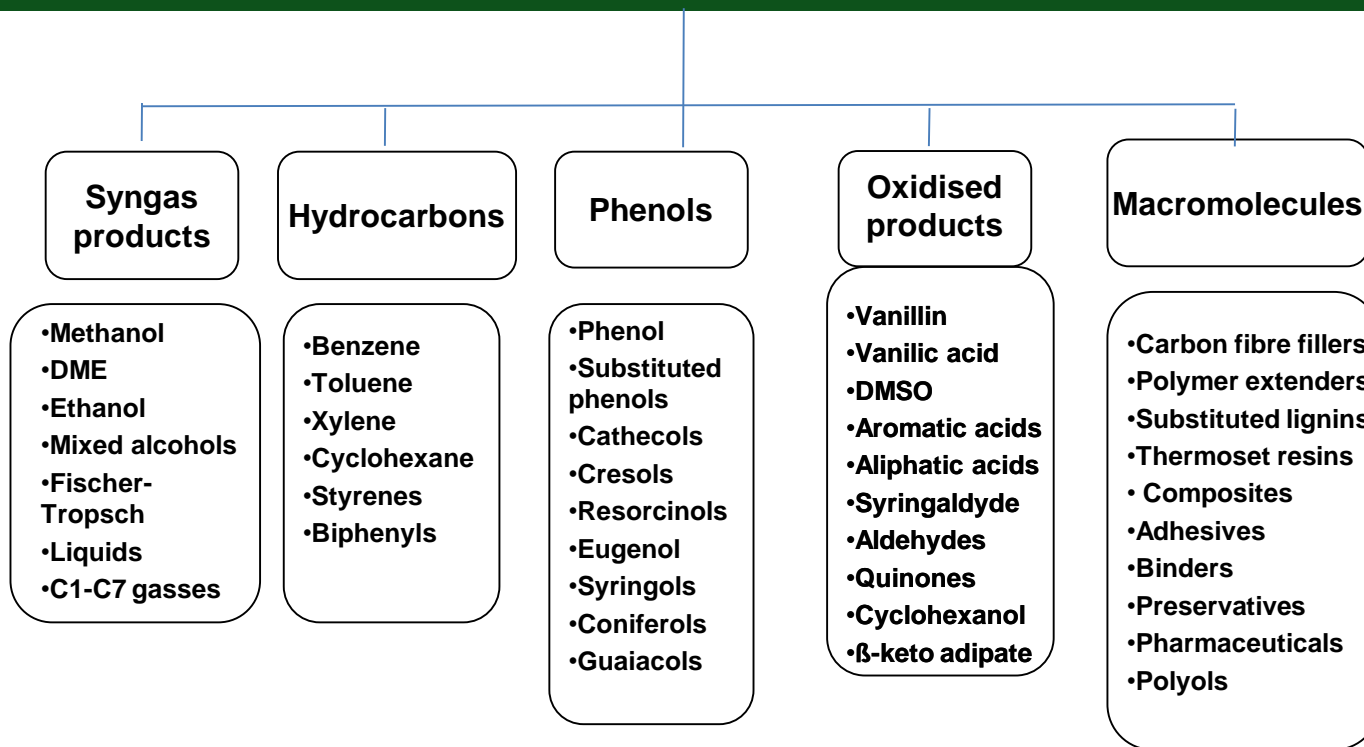
Coniferyl alcohol  
Mol Wt 180



Sinapyl alcohol  
Mol Wt 210

# Lignin Platform

## - Higher-Added Value Products -



IEA Bioenergy- Task 42 Biorefinery (2012), *Bio-based chemicals: value added products from biorefineries.*

# Lignin Extraction & Upgrading

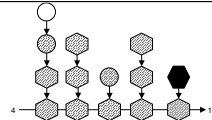
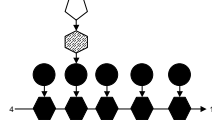
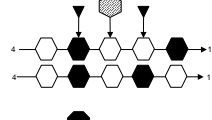
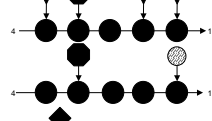
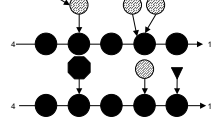
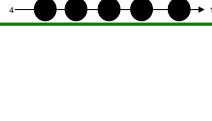
- Industrial Status -

Company		Feed	Process	BL lignin Prod	Status
Valmet	FI	Black liquor	Precipitation	Lignoboost	Industrial
Suncarbon	SE	Black liquor	Membrane filtr.	Lignin concent.	Pilot
Company		Feed	Process	Upgrading	Status
Beta Renew.	IT	Hydrolysis	Hydrogenolysis	Hydrogenation	Pilot
RenFuel,	SE	BL lignin	Thermal	Esterification. Refinery.	Pilot
SCA	SE	Black liquor	n.a.	n.a.	Pilot
Suncarbon	SE	BL lignin	HTL	Refinery	Bench
Licella	AU/CA	Black liquor	HTL	Refinery	Pilot
Lignojet	SE	BL lignin	Hydrogenolysis	Refinery	Bench
Chalmers	SE	Black liquor	Near SC	Refinery	Pilot

**Other entities process lignin for non-fuel purposes (resins, phenols, plastics)**

# Hemicellulose Platform

## - Biomass Chemical Diversity -

Polysaccharide type	Biological origin	Abrev.	Amount <sup>a</sup>	Units			DP	Schematic representation
				Backbone	Side chains	Linkage		
Arabinogalactan	Softwoods	AG	1-3;35*	$\beta$ -D-Galp	$\beta$ -D-Galp $\alpha$ -L-Araf $\beta$ -L-Arap	$\beta$ -(1 $\rightarrow$ 6) $\alpha$ -(1 $\rightarrow$ 3) $\beta$ -(1 $\rightarrow$ 3)	100-600	
Xyloglucan	Hardwoods, grasses	XG	2-25	$\beta$ -D-Glcp $\beta$ -D-Xylp	$\beta$ -D-Xylp $\beta$ -D-Galp $\alpha$ -L-Araf $\alpha$ -L-Fucp Acetyl	$\beta$ -(1 $\rightarrow$ 4) $\alpha$ -(1 $\rightarrow$ 3) $\beta$ -(1 $\rightarrow$ 2) $\alpha$ -(1 $\rightarrow$ 2) $\alpha$ -(1 $\rightarrow$ 2)		
Galactoglucomannan	Softwoods	GGM	10-25	$\beta$ -D-Manp $\beta$ -D-Glcp	$\beta$ -D-Galp Acetyl	$\alpha$ -(1 $\rightarrow$ 6)	40-100	
Glucomannan	Softwoods and Hardwoods	GM	2-5	$\beta$ -D-Manp $\beta$ -D-Glcp			40-70	
Glucuronoxyylan	Hardwoods	GX	15-30	$\beta$ -D-Xylp	4-O-Me- $\alpha$ -D-GlcpA Acetyl	$\alpha$ -(1 $\rightarrow$ 2)	100-200	
Arabinoglucuronoxyylan	Grasses and cereals, softwoods	AGX	5-10	$\beta$ -D-Xylp	4-O-Me- $\alpha$ -D-GlcpA $\beta$ -L-Araf	$\alpha$ -(1 $\rightarrow$ 2) $\alpha$ -(1 $\rightarrow$ 3)	50-185	
Arabinoxylyans	Cereals	AX	0.15-30	$\beta$ -D-Xylp	$\alpha$ -L-Araf  Feruloy	$\alpha$ -(1 $\rightarrow$ 2) $\alpha$ -(1 $\rightarrow$ 3)		
Glucuronoarabinoxylyans	Grasses and cereals	GAX	15-30	$\beta$ -D-Xylp	$\alpha$ -L-Araf 4-O-Me- $\alpha$ -D-GlcpA Acetyl	$\alpha$ -(1 $\rightarrow$ 2) $\alpha$ -(1 $\rightarrow$ 3)		
Homoxylyans	Algae	X		$\beta$ -D-Xylp <sup>b</sup>				

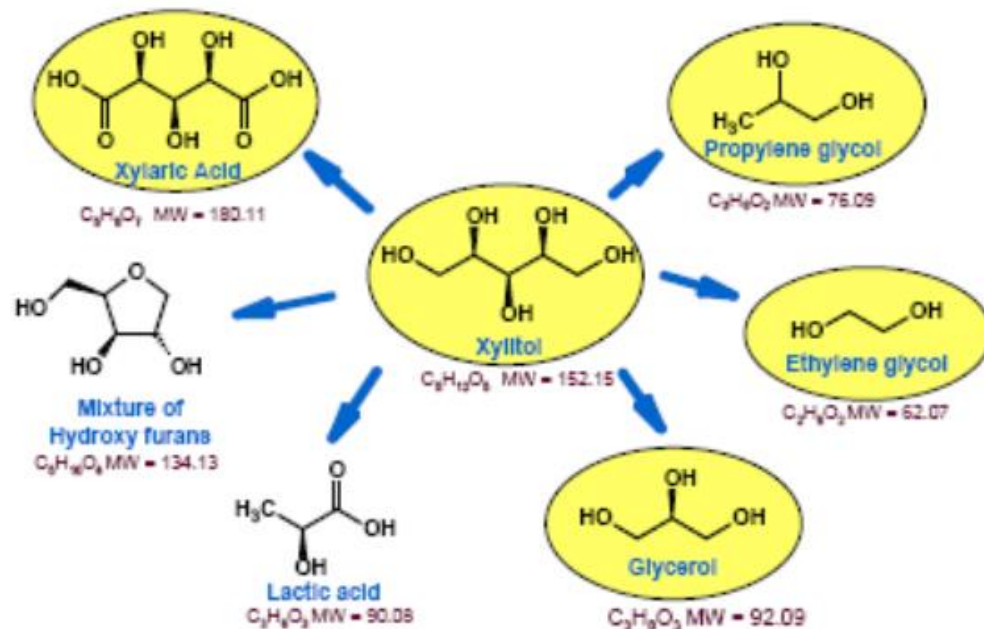
In: Gírio FM, Fonseca C, Carvalho F, Duarte LC, Marques S & Bogel-Lukasik R (2010), "Hemicelluloses for fuel ethanol: a review", *Bioresource Technology* **101:4775-4800**.

<sup>a</sup>% on dry biomass; <sup>b</sup> may also present  $\beta$ -(1 $\rightarrow$ 3) linkages on the backbone; \* (up to) in the heartwood of larches

# Hemicellulose Platform

## - Top 10 Sugar-derived Products as Building Blocks -

- Ethanol
- Furans (**Furfural**, HMF, FDCA)
- Glycerol & derivatives
- Biohydrocarbons (isoprene, other)
- **Lactic acid**
- **Succinic acid**
- 3- hydroxypropionic acid/aldehyde
- Levulinic acid
- Sorbitol
- Xylitol

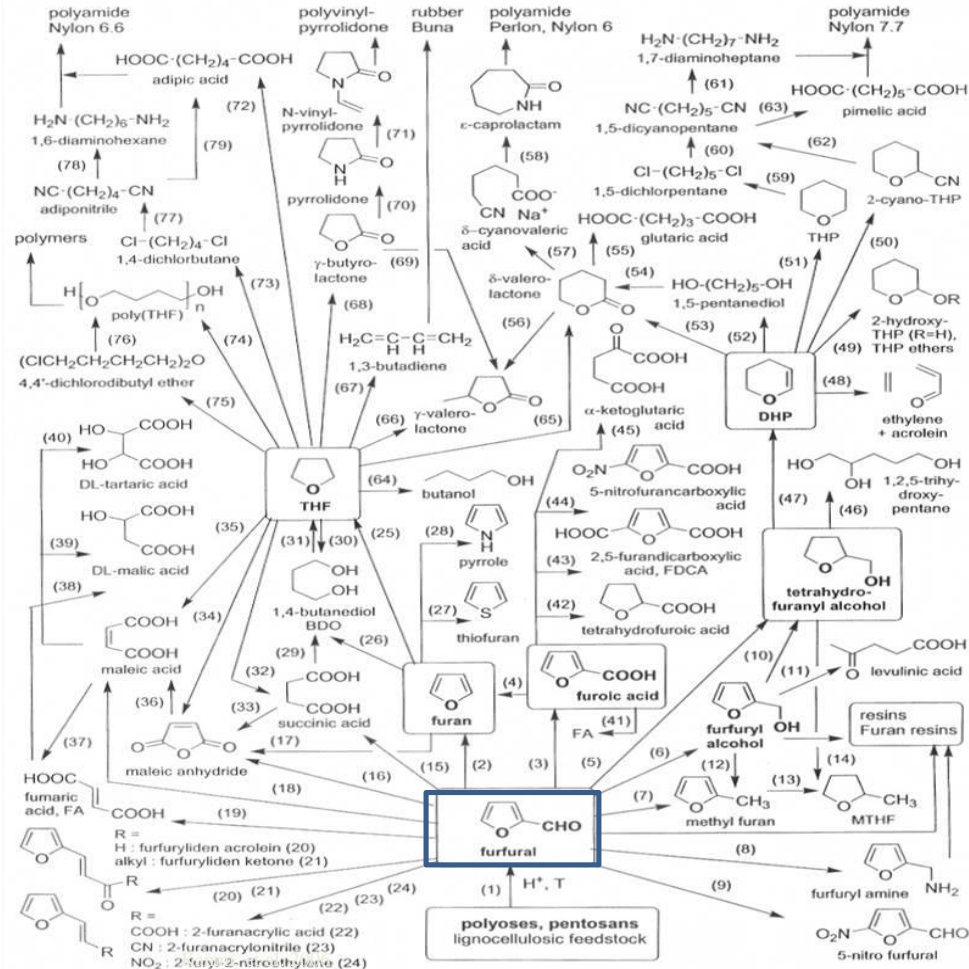


In: Bozell & Petersen (2010) Green Chem, 12: 539-554.

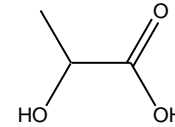
# Furfural

## Great potential:

- Polymers
  - Solvents
  - Additives for fuels (diesel),
  - Composite materials
  - ...
  - “Top value chemical”
- Bozell & Petersen 2010
- Market:  $3 \times 10^{5-13}$  ton/yr



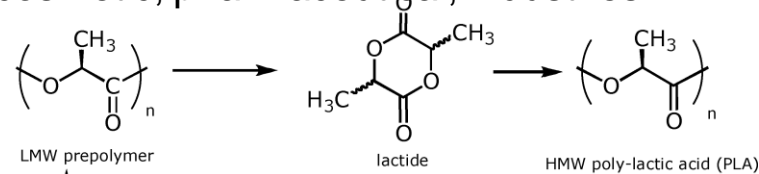
# Lactic acid



## Applications:

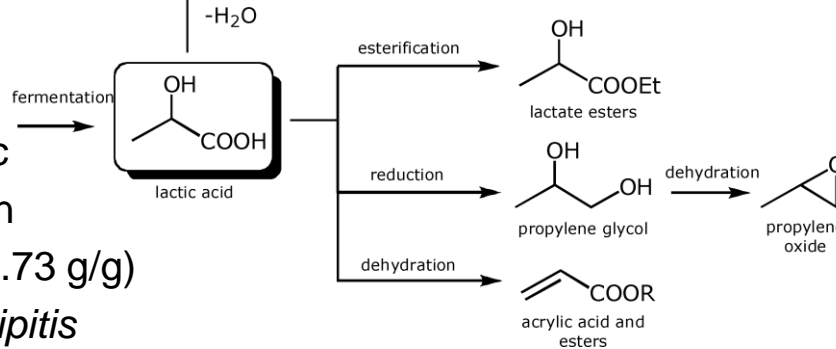
- Food, plastics (polylactates), cosmetic, pharmaceutical, industries
- “Top value chemical”

Bozell & Petersen 2010



## Production:

- Recombinant *E. coli*  
Y = 0.63 g/g xyl. Catabolic  
De-repressed mutants can  
assimilate Xyl +Glc (Y = 0.73 g/g)
- Recombinant *Pichia stipitis*



Higher tolerance to product inhibition

That leads to the use of calcium as neutralizing agent, or the use of membranes (*Simultaneous Fermentation and Separation*)

# Succinic acid

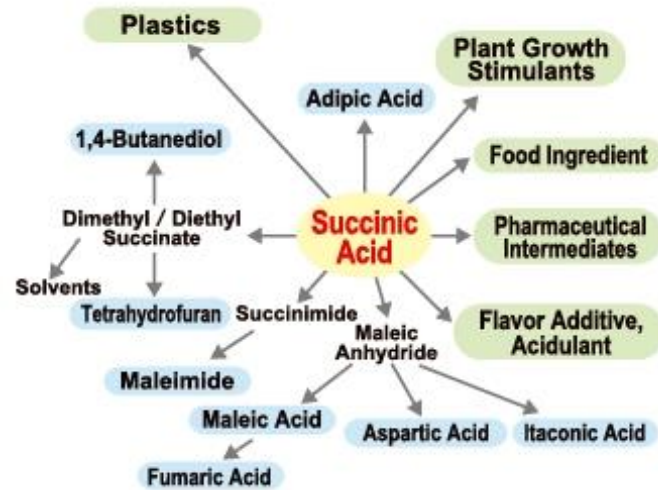
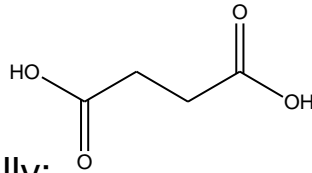
## Applications:

- “Top value chemical”

Werpy & Petersen, 2004, Bozell & Petersen 2010

## Production:

- Microbiologically:
  - *Bacteroides ruminicola*, *B. amylophilus*, *Anaerobiospirillum succiniciproducens*; *Actinobacillus succinogenes*; *Mannheimia succiniciproducens*;
  - Recombinant *E. coli* ( $Y = 0.5$  g/g xyl and  $Y = 0.6$  g/g in the presence of Glc and Xyl); Recombinant *Corynebacterium glutamicum*. Both assimilating glc and xyl without diauxy.
- A competitive process should surpass  $Q > 2.5$  g/Lh, (not yet attained).



# Biochemistry Conversion Processes to Advanced Biofuels – Take-Home Messages

- ❑ Process technologies compatible with utilization of multi-flexible feedstocks
- ❑ Development of flexible (and less energy-intensive) integrated pre-treatment with simultaneous separation of contaminants/inhibitor
- ❑ Reduce fermentation complexity (*one pot vs two pots*) and improve biological performance through maximization of LC sugars utilization
- ❑ Use of synthetic biology for improving novel and robust industrial cell factories platforms
- ❑ Integrate adequately in a “biorefinery context” lignin and side streams
- ❑ Simultaneously, improve the value chain sustainability through cradle-to-gate GHG reductions
- ❑ Full Integration biochemical/chemical technologies

## Acknowledgment:

Some Figures & Tables have been presented before by:

**Lars Waldheim & Francisco Gírio (2018)**

Bioenergy and Biofuels – Conversion technology developments, SPM, ETIP-Bioenergy, Brussels, April 12<sup>th</sup>

Contact: [francisco.girio@Ineg.pt](mailto:francisco.girio@Ineg.pt)

# Biofuels vs. E-mobility

## The case of Lignocellulosic Bioethanol



# E-mobility shall be the clean RE in 2030/2050?

## 1. How important shall be the role of E-mobility in the different transport modes by 2030 and 2050?

- Light road, heavy-duty road, maritime, aviation,...

## 2. Phasing-out of Advanced Biofuels is going to occur? ...What about GHG savings under Paris Agreement?

- Some EU countries announced that only zero emissions vehicles can be sold after 2030

## 3. What will be the role of BIOENERGY in the transportation sector after 2030/2050?

Hip. A – Bioenergy (advanced biofuels) becomes not significant in 2050

Hip. B – Advanced (Bio)Fuels still play the major role in 2050



## 4. Can we forecast that BIOENERGY has only future for Power and H&C?

- Since biomass-fueled power plant is a dispatchable energy can play a significant role in all forms of energy systems (e.g., electrical grids stabilization), and also for e-mobility vehicles.

- e.g. BEV, PHV

# Report Roland Berger (2016) – GHG Removal versus Cost Efficiency

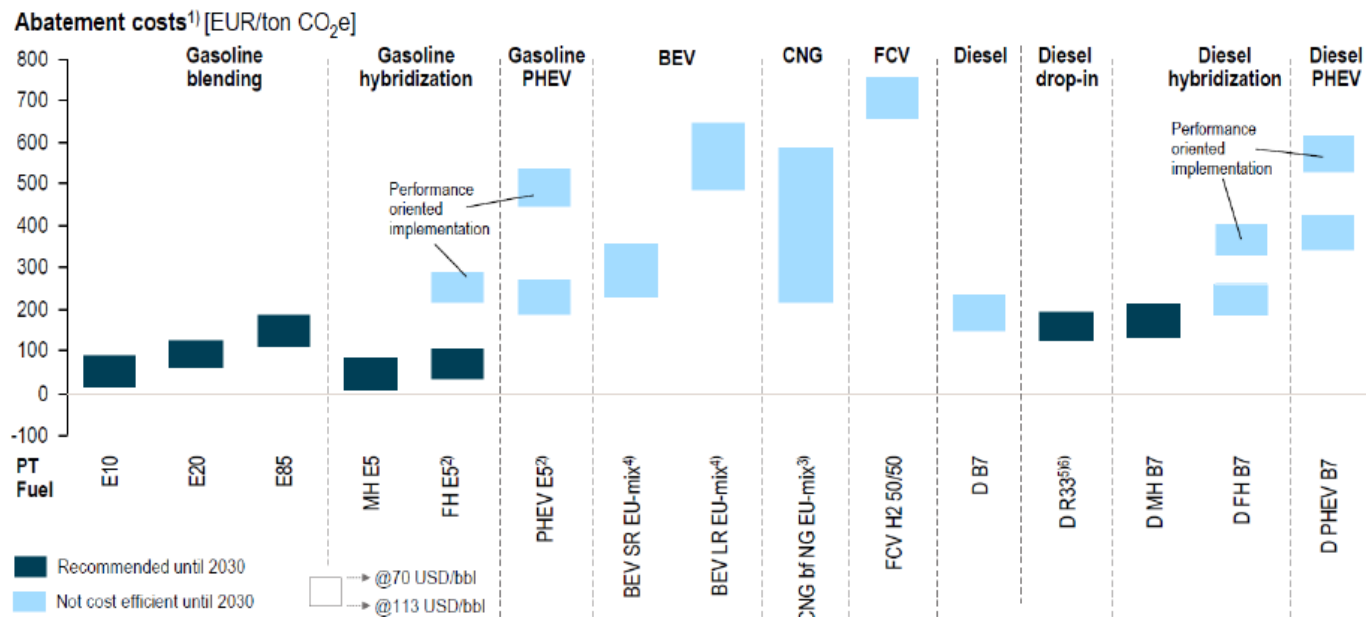
Integrated Fuels  
and Vehicles  
Roadmap to 2030+  
Study results



[http://www.rolandberger.com/media/pdf/Roland\\_Berger\\_Study\\_Integrated\\_Fuels\\_and\\_Vehicles\\_Roadmap\\_to\\_2030\\_v2\\_20160615.pdf](http://www.rolandberger.com/media/pdf/Roland_Berger_Study_Integrated_Fuels_and_Vehicles_Roadmap_to_2030_v2_20160615.pdf)

# Report Roland Berger (2016) – Passengers cars

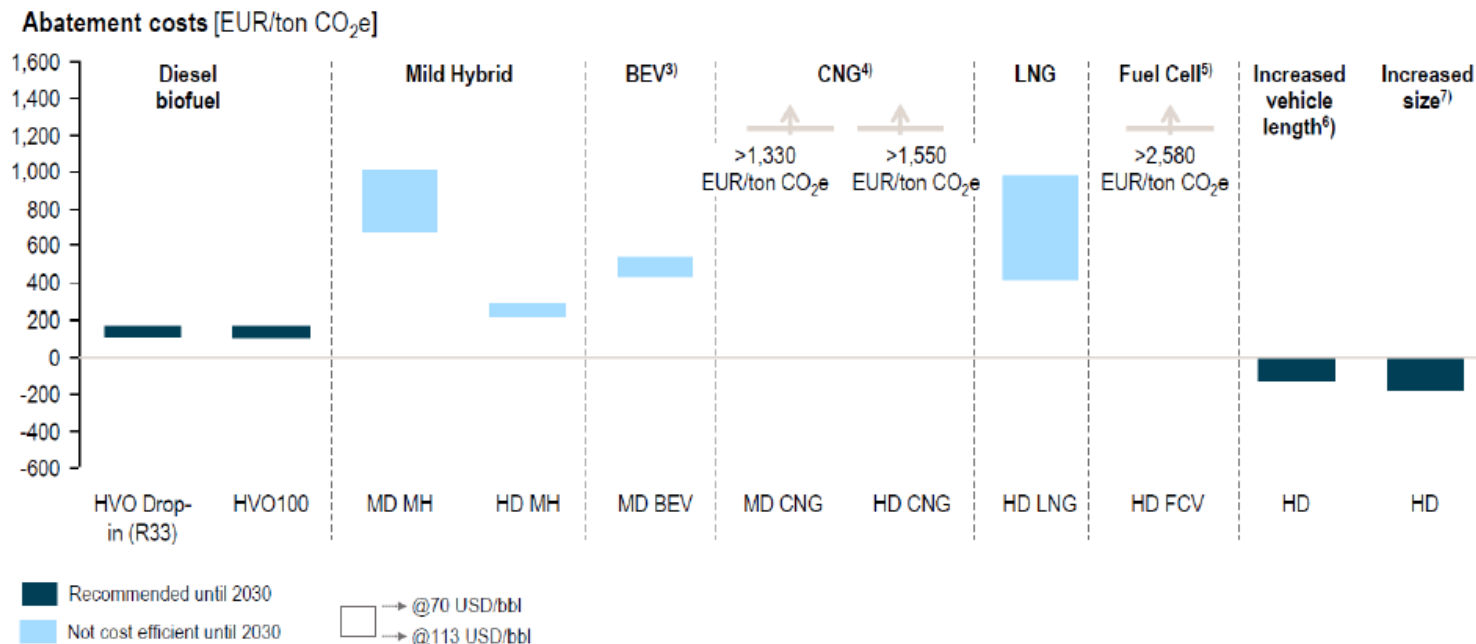
Figure 5: WTW GHG abatement costs pathways, C-segment PCs 2030 [EUR/ton CO<sub>2</sub>e]



1) Compared to optimized Gasoline powertrain 2030 using E5, all technologies with 250,000 km lifetime mileage 2) 30% e-driving, higher e-driving share reduces abatement costs  
 3) Large range between scenarios driven by decoupling effect of natural gas price 4) Risk of higher abatement costs due to need of second battery over lifetime,  
 SR – short range with 35 kWh battery capacity, LR – long range with 65 kWh battery capacity, both using 2030 EU mix electricity, 5) Diesel fuel with 7% FAME and 26% HVO  
 6) Abatement cost in existing vehicle: -87 EUR/ton CO<sub>2</sub> (high oil price), 7 EUR/ton CO<sub>2</sub> (low oil price)

# Report Roland Berger (2016) – Medium & heavy-duty vehicles

Figure 6: WTW GHG abatement costs pathways of medium- and heavy duty vehicle 2030 [EUR/ton CO<sub>2</sub>e]



1) Medium duty 2) Heavy duty 3) Exclusion of HD BEV due to incompatibility of BEV range with long haul requirements 4) High CO<sub>2</sub> abatement costs for CNG and LNG within MD/HD/City Bus result from low quantities of vehicles (missing economies of scale) and CO<sub>2</sub> abatement potential compared to Diesel is small (<5% savings/km) 5) High system cost and low lifetime mileage in medium duty trucks causes very high abatement cost, therefore incompatibility 6) Increased efficiency due to aerodynamic measures to reduce drag 7) Length and gross vehicle weight increase, increased transport efficiency by 10%