Presidencia de la Nación

Ministerio de Ciencia, Tecnología e Innovación Productiva

BIOECONOMÍA ARGENTINA 2015
EL POTENCIAL DE LAS REGIONES

Production of biodegradable plastics from bacterial cells

Profª. Drª. Luiziana Ferreira da Silva
Laboratory of Bioproducts
Laboratório de Bioprodutos ICB - USP
Institute of Biomedical Sciences
University of São Paulo
Brazil
University of São Paulo

Overview
Laboratory of Bioproducts

Laboratório de Bioprodutos ICB - USP

Impact of different metabolic networks

Carbon Sources → **Bacterial factories** → **Biobased Products**

Sucrose
Glucose
Xylose
Glycerol
Fatty acids
Plant oils
Soybean molasses
Agro industrial residues
Others...

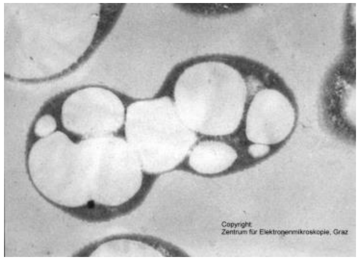
Pseudomonas sp.
B. sacchari
E. coli
Platforms for...

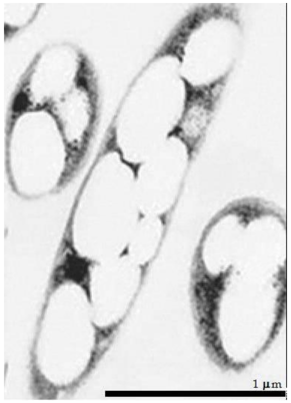
PHA – Biodegradable plastics
Rhamonolipids
1,3-Propanediol
Others…

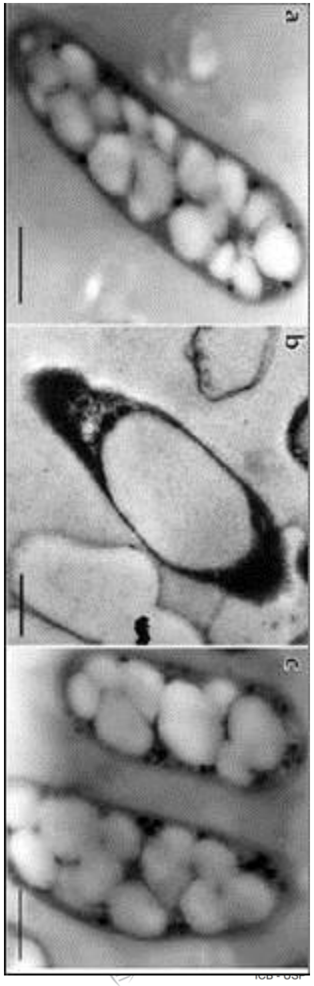
University of São Paulo

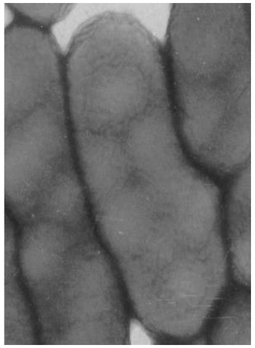
ICB USP 45 anos

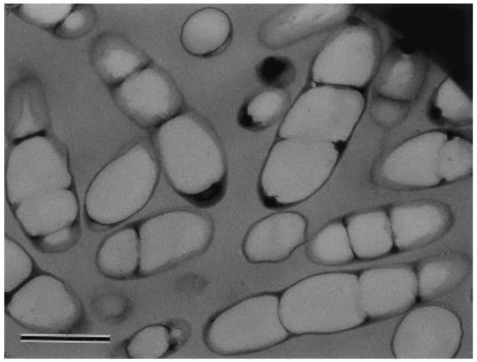
Polyhydroxyalkanoate (PHA) biodegradable & biocompatible polymers accumulated by bacteria


Copyright: Zentrum für Elektronenmikroskopie, Graz

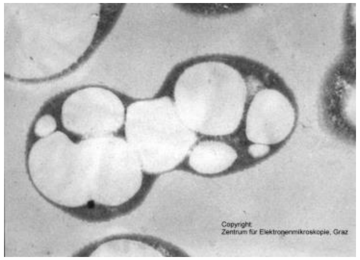


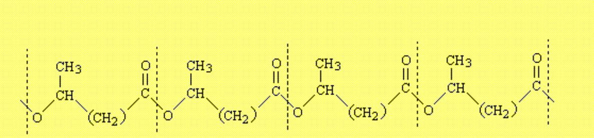




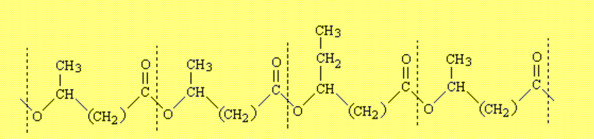


PHA are thermoplastic materials with variable monomer composition



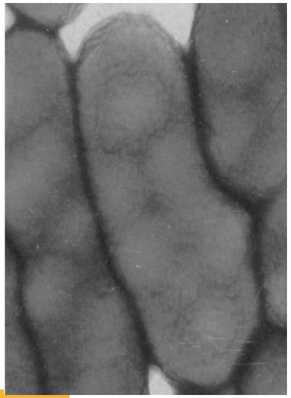


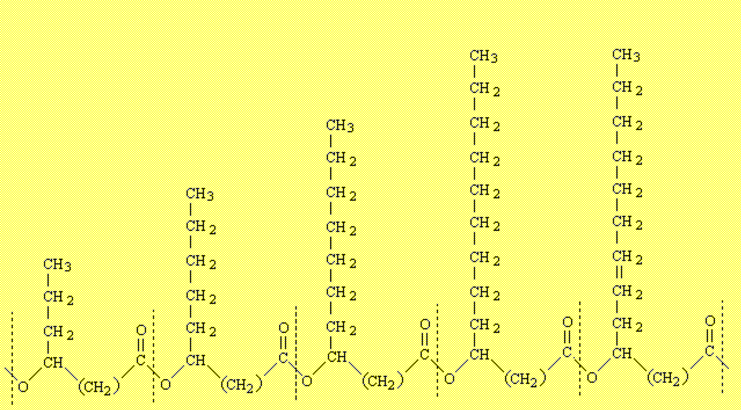
P3HB



P3HB-co-3HV

C4 & C5
Short-chain length monomers
PHA scl

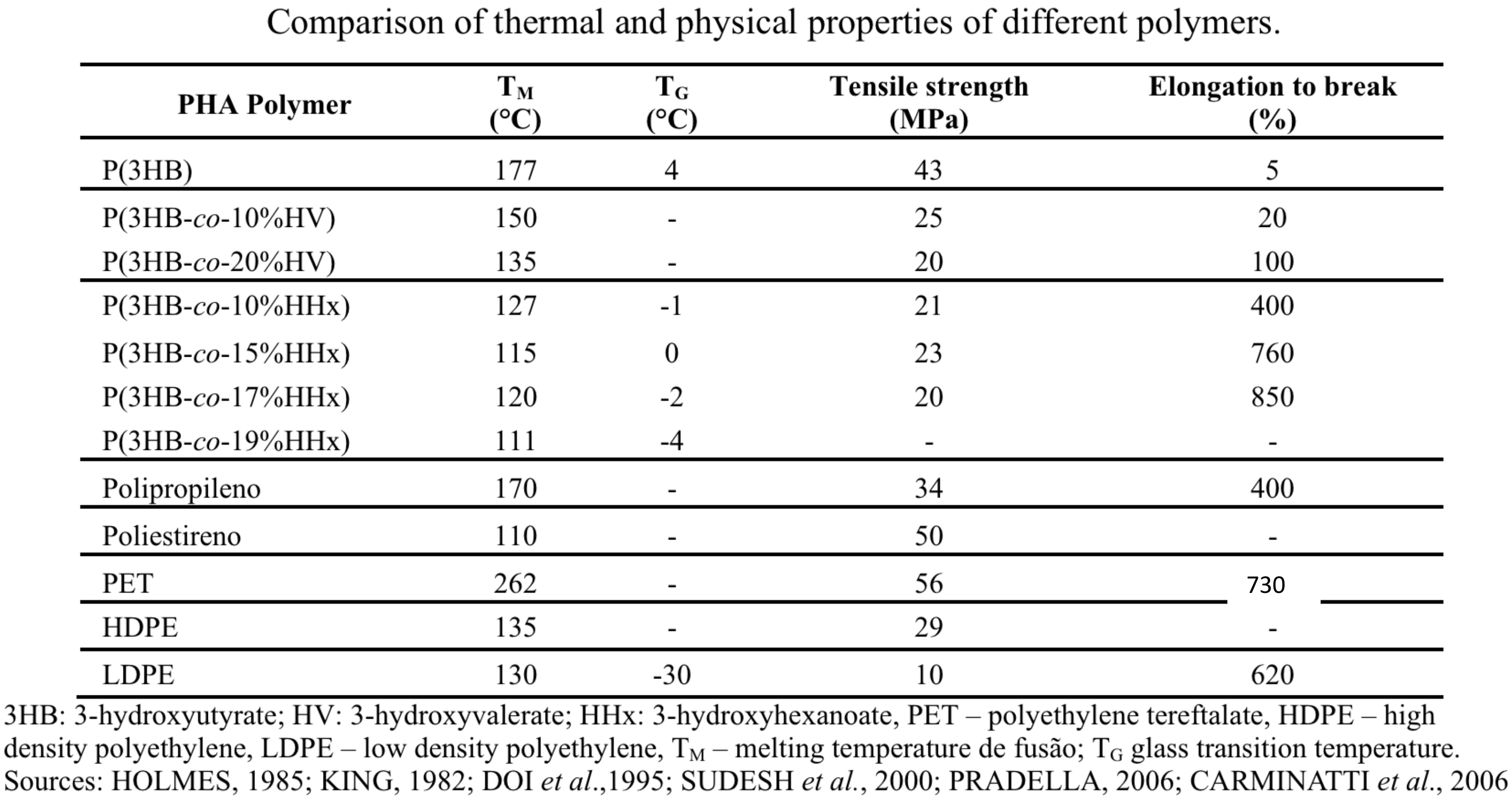




PHAs$_{MCL}$

C6 & C12
Medium-chain length
monomers PHA mcl

Monomer composition is responsible for PHA properties and applications

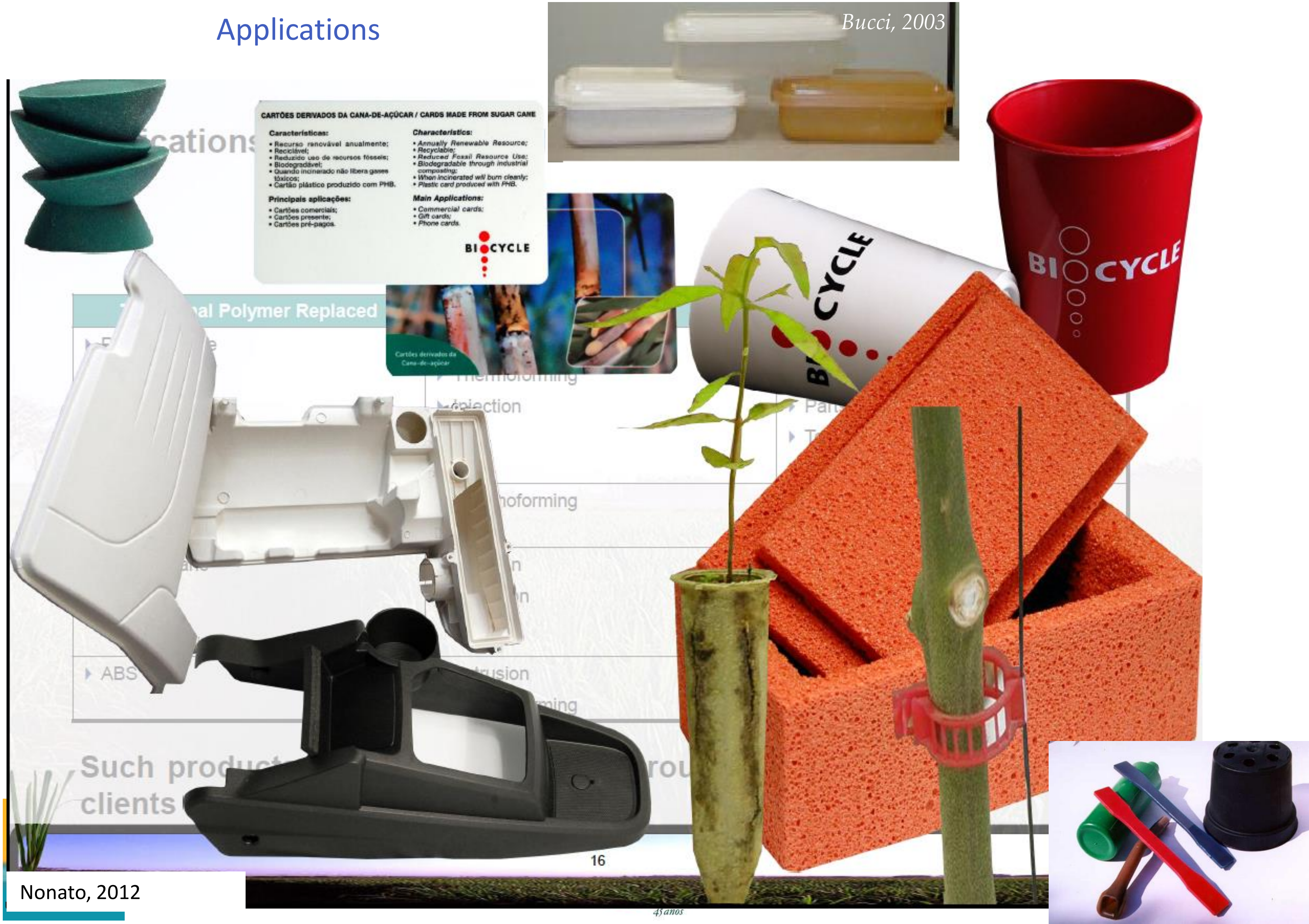


Comparison of thermal and physical properties of different polymers.

PHA Polymer	T_M (°C)	T_G (°C)	Tensile strength (MPa)	Elongation to break (%)
P(3HB)	177	4	43	5
P(3HB-*co*-10%HV)	150	-	25	20
P(3HB-*co*-20%HV)	135	-	20	100
P(3HB-*co*-10%HHx)	127	-1	21	400
P(3HB-*co*-15%HHx)	115	0	23	760
P(3HB-*co*-17%HHx)	120	-2	20	850
P(3HB-*co*-19%HHx)	111	-4	-	-
Polipropileno	170	-	34	400
Poliestireno	110	-	50	-
PET	262	-	56	730
HDPE	135	-	29	-
LDPE	130	-30	10	620

3HB: 3-hydroxyutyrate; HV: 3-hydroxyvalerate; HHx: 3-hydroxyhexanoate, PET – polyethylene tereftalate, HDPE – high density polyethylene, LDPE – low density polyethylene, T_M – melting temperature de fusão; T_G glass transition temperature.
Sources: HOLMES, 1985; KING, 1982; DOI *et al.*,1995; SUDESH *et al.*, 2000; PRADELLA, 2006; CARMINATTI *et al.*, 2006

Applications



Bucci, 2003

CARTÕES DERIVADOS DA CANA-DE-AÇÚCAR / CARDS MADE FROM SUGAR CANE

Características:

- Recurso renovável anualmente;
- Reciclável;
- Reduzido uso de recursos fósseis;
- Biodegradável;
- Quando incinerado não libera gases tóxicos;
- Cartão plástico produzido com PHB.

Principais aplicações:

- Cartões comerciais;
- Cartões presente;
- Cartões pré-pagos.

Characteristics:

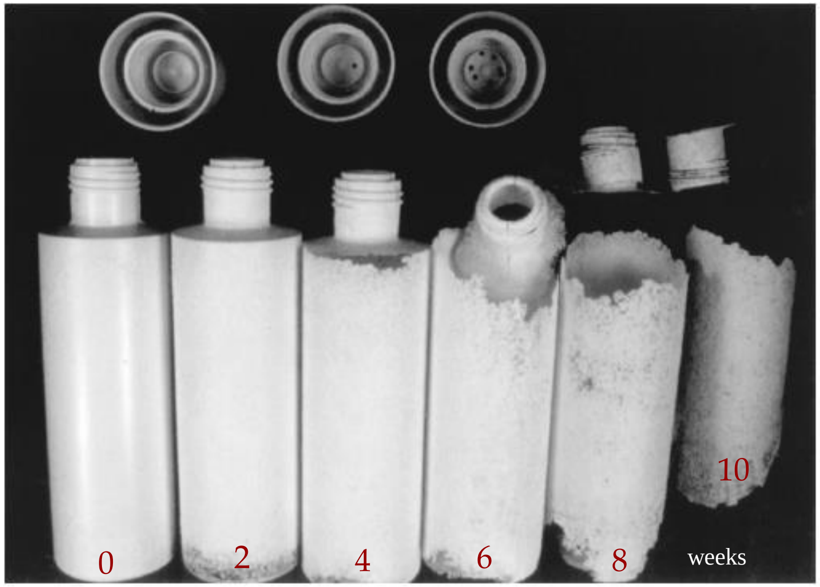
- *Annually Renewable Resource;*
- *Recyclable;*
- *Reduced Fossil Resource Use;*
- *Biodegradable through industrial composting;*
- *When incinerated will burn cleanly;*
- *Plastic card produced with PHB.*

Main Applications:

- *Commercial cards;*
- *Gift cards;*
- *Phone cards.*

Nonato, 2012

PHA are biodegradable materials



Madison & Huisman, 1999

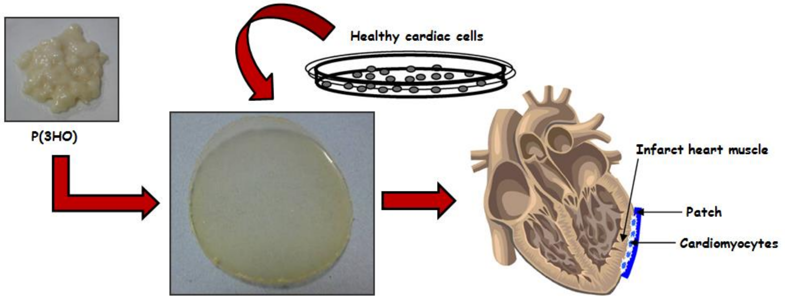
PHA are biocompatible polymers

Applications

Bone tissue engineering
Cartilage Tissue Engineering
Drug delivery
Medical device development:
    Biodegradable drug eluting stents
    Biodegradable nerve conduits

Skin Tissue Engineering/Wound Healing

Cardiac Tissue Engineering



Recently reviewed @

by Dr Ipsita Roy
Imperial College London
Univ. Westminster

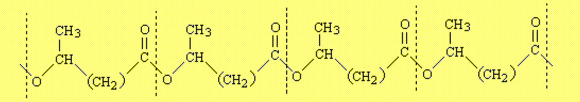
ISBP 2014 Brazil

University of São Paulo

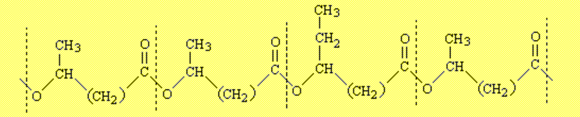
ICB USP 45 anos

Laboratório de Bioprodutos ICB - USP

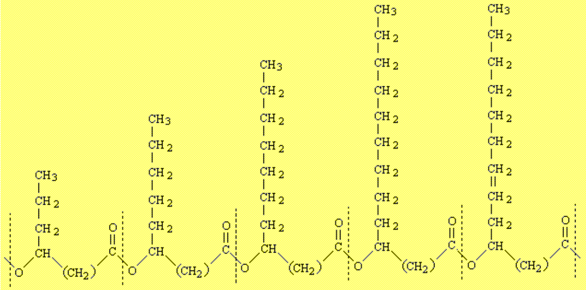
PHA production integrated to a sugar and etanol mill.



P3HB



P3HB-co-3HV



PHAs$_{MCL}$

R. V. Nonato · P. E. Mantelatto · C. E. V. Rossell

Integrated production of biodegradable plastic, sugar and ethanol

Appl Microbiol Biotechnol (2001) 57:1–5
DOI 10.1007/s002530100732

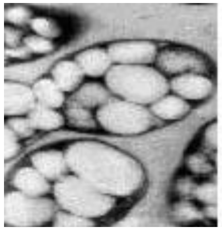
MINI-REVIEW

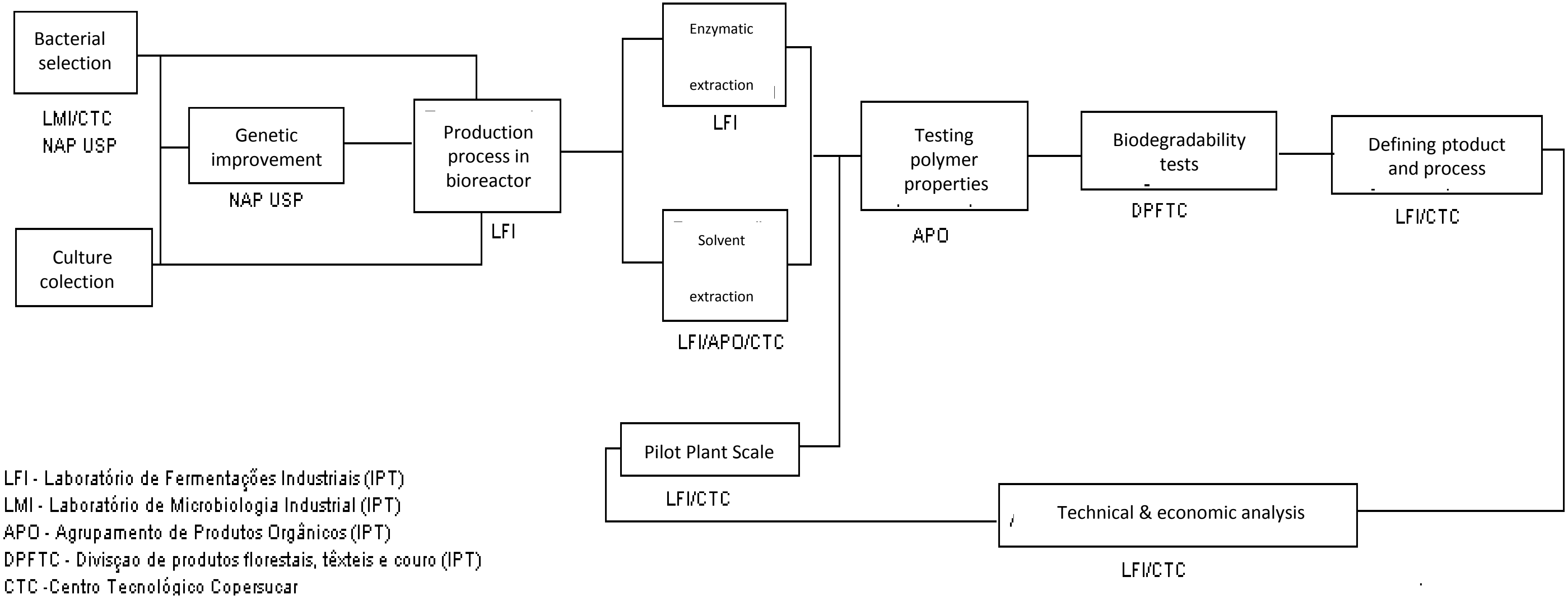
A green cycle for simultaneous poly 3-hydroxybutyric acid, sugar and ethanol production

UNIVERSIDADE DE SÃO PAULO

Instituto de Pesquisas Tecnológicas

COPERSUCAR





Bacterial selection
LMI/CTC
NAP USP

Culture colection

Genetic improvement
NAP USP

Production process in bioreactor
LFI

Enzymatic extraction
LFI

Solvent extraction
LFI/APO/CTC

Testing polymer properties
APO

Biodegradability tests
DPFTC

Defining ptoduct and process
LFI/CTC

Pilot Plant Scale
LFI/CTC

Technical & economic analysis
LFI/CTC

LFI - Laboratório de Fermentações Industriais (IPT)
LMI - Laboratório de Microbiologia Industrial (IPT)
APO - Agrupamento de Produtos Orgânicos (IPT)
DPFTC - Divisçao de produtos florestais, têxteis e couro (IPT)
CTC -Centro Tecnológico Copersucar
NAP - USP Instituto de Ciências Biomédicas (USP) e Universidade Federal da Paraíba

Esquema geral de projeto de pesquisa e desenvolvimento de tecnologia de produção de PHA (Gomez *et al.*, 1993)

Financiamento: PADCT/Finep, CNPq, FAPESP

Process transfer to industry

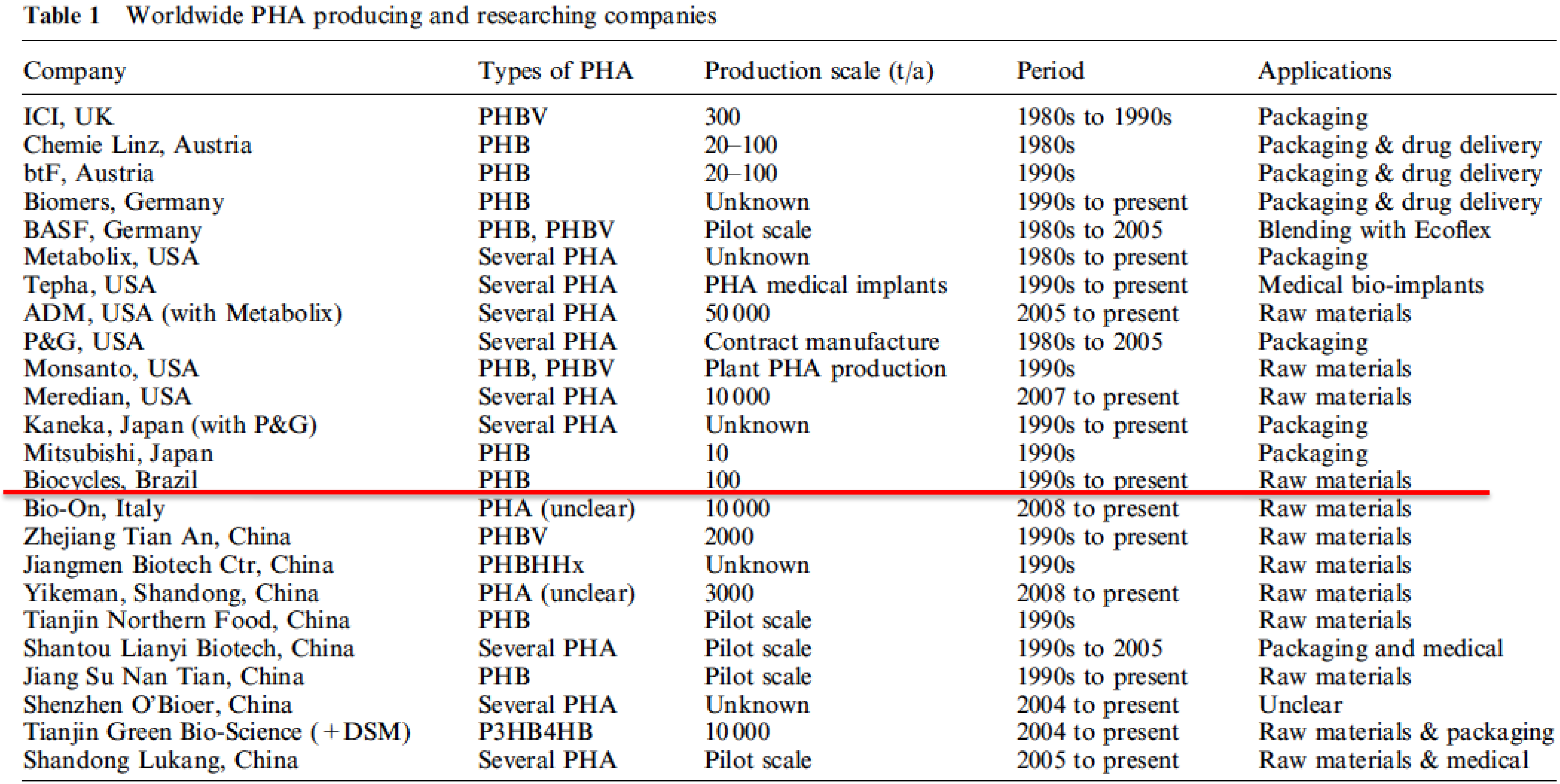
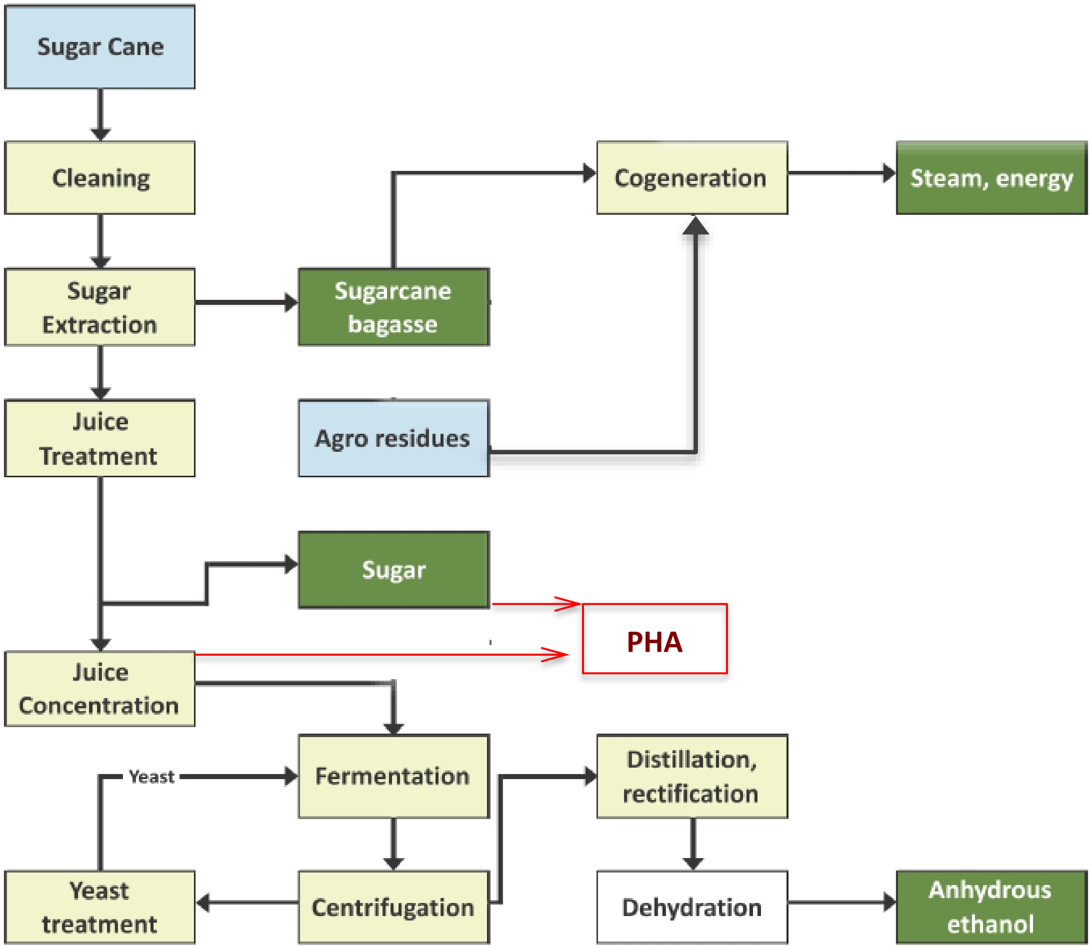


Table 1 Worldwide PHA producing and researching companies

Company	Types of PHA	Production scale (t/a)	Period	Applications
ICI, UK	PHBV	300	1980s to 1990s	Packaging
Chemie Linz, Austria	PHB	20–100	1980s	Packaging & drug delivery
btF, Austria	PHB	20–100	1990s	Packaging & drug delivery
Biomers, Germany	PHB	Unknown	1990s to present	Packaging & drug delivery
BASF, Germany	PHB, PHBV	Pilot scale	1980s to 2005	Blending with Ecoflex
Metabolix, USA	Several PHA	Unknown	1980s to present	Packaging
Tepha, USA	Several PHA	PHA medical implants	1990s to present	Medical bio-implants
ADM, USA (with Metabolix)	Several PHA	50 000	2005 to present	Raw materials
P&G, USA	Several PHA	Contract manufacture	1980s to 2005	Packaging
Monsanto, USA	PHB, PHBV	Plant PHA production	1990s	Raw materials
Meredian, USA	Several PHA	10 000	2007 to present	Raw materials
Kaneka, Japan (with P&G)	Several PHA	Unknown	1990s to present	Packaging
Mitsubishi, Japan	PHB	10	1990s	Packaging
Biocycles, Brazil	PHB	100	1990s to present	Raw materials
Bio-On, Italy	PHA (unclear)	10 000	2008 to present	Raw materials
Zhejiang Tian An, China	PHBV	2000	1990s to present	Raw materials
Jiangmen Biotech Ctr, China	PHBHHx	Unknown	1990s	Raw materials
Yikeman, Shandong, China	PHA (unclear)	3000	2008 to present	Raw materials
Tianjin Northern Food, China	PHB	Pilot scale	1990s	Raw materials
Shantou Lianyi Biotech, China	Several PHA	Pilot scale	1990s to 2005	Packaging and medical
Jiang Su Nan Tian, China	PHB	Pilot scale	1990s to present	Raw materials
Shenzhen O'Bioer, China	Several PHA	Unknown	2004 to present	Unclear
Tianjin Green Bio-Science (+DSM)	P3HB4HB	10 000	2004 to present	Raw materials & packaging
Shandong Lukang, China	Several PHA	Pilot scale	2005 to present	Raw materials & medical

First generation ethanol (1G)
Currently produced from sugar or starch-based raw materials
1st generation PHA



Sugar Cane

Cleaning

Sugar Extraction

Sugarcane bagasse

Cogeneration

Steam, energy

Juice Treatment

Agro residues

Sugar

PHA

Juice Concentration

Yeast

Fermentation

Distillation, rectification

Yeast treatment

Centrifugation

Dehydration

Anhydrous ethanol

Captions

🟩 Products

▨ Raw material

▨ Operations

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Second generation ethanol (2G)

Over 40,000,000 tons bagasse and sugarcane leaves per season
source UNICA

Releasing sugars from bagasse

- Chemical or enzymatic hydrolysis
- Sugar mixtures available for fermentation
  - Glucose,
  - xylose,
  - Arabinose

- Ethanologenic yeasts are unable to ferment xylose efficiently

Scenario in Brazil

Ethanol 2G from ligno & hemicellulose

- Xylose & arabinose available in large amounts
    - Perspective 10^7 ton/year of C5 available*
- Use of xylose to generate ethanol and other products

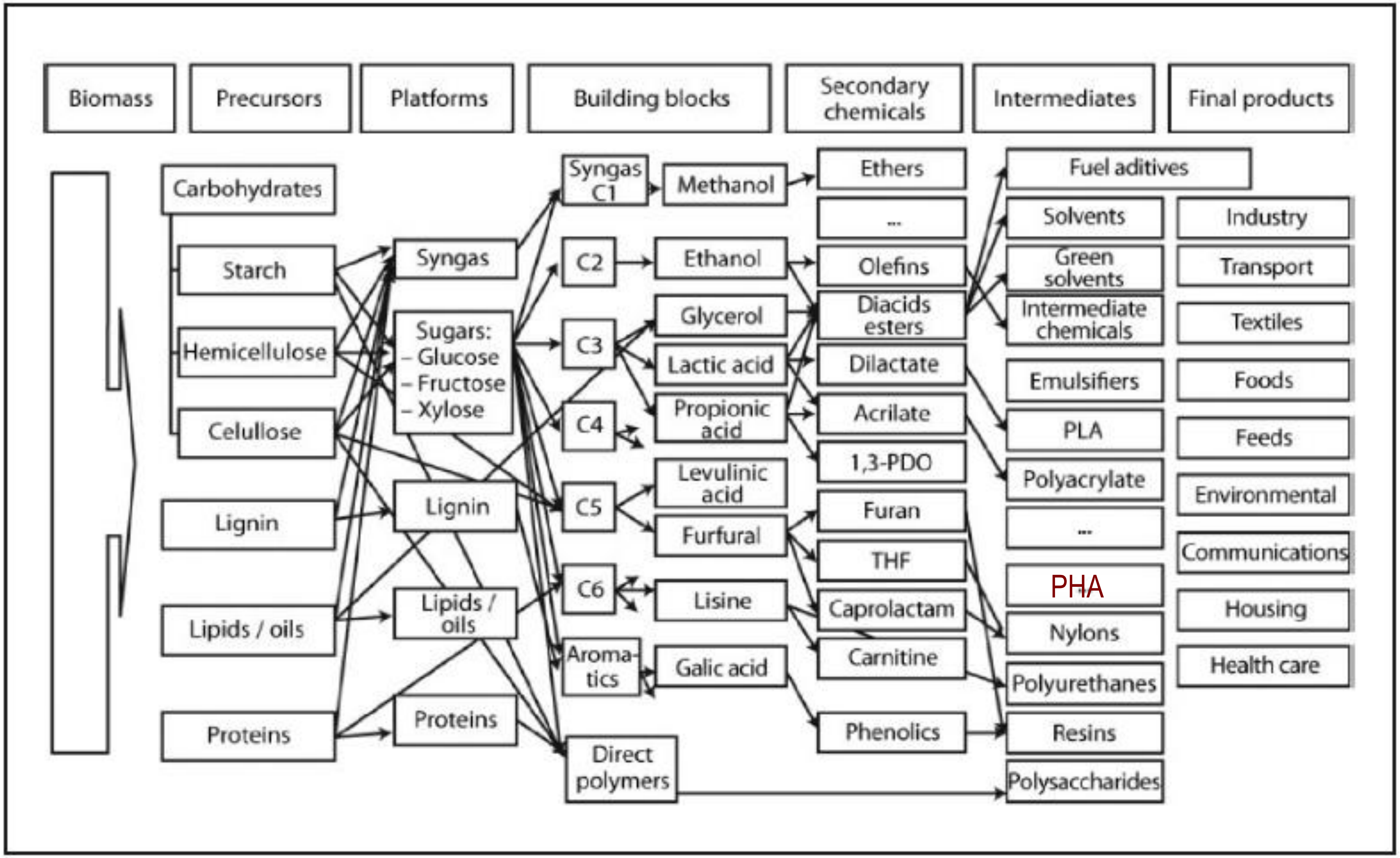
Pradella, 2012, Pereira et al., 2013

Opportunity to expand bioplastics industry

- Sugarcane is an enviromentally sustainable feedstock for bioplastics
- Integration do sugar and ethanol mills

- Green plastics
- PHA
- PLA
- Others

Biorefinery



Biomass

Precursors

Platforms

Building blocks

Secondary chemicals

Intermediates

Final products

Carbohydrates
- Starch
- Hemicellulose
- Celullose

Lignin

Lipids / oils

Proteins

Syngas

Sugars:
- Glucose
- Fructose
- Xylose

Lignin

Lipids / oils

Proteins

Syngas C1

C2

C3

C4

C5

C6

Aromatics

Direct polymers

Methanol

Ethanol

Glycerol

Lactic acid

Propionic acid

Levulinic acid

Furfural

Lisine

Galic acid

Ethers

...

Olefins

Diacids esters

Dilactate

Acrilate

1,3-PDO

Furan

THF

Caprolactam

Carnitine

Phenolics

Fuel aditives

Solvents

Green solvents

Intermediate chemicals

Emulsifiers

PLA

Polyacrylate

...

PHA

Nylons

Polyurethanes

Resins

Polysaccharides

Industry

Transport

Textiles

Foods

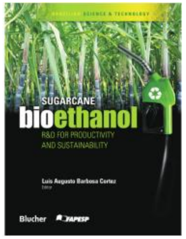
Feeds

Environmental

Communications

Housing

Health care



Kamm et al.., 2006, Franco & Garzón In: Cortez, 2010

Biorefinery
Ethanol and sugar mills

Current

- Include a number of processes already used since 19th century
- Some processes already integrated

Challenges

- Integration of different technologies
  - Metabolic engineering
  - Full knowledge of the raw material (biomass)
  - Addition of new products (intermediates and final)
- Evaluation of social and environmental impacts

sustainability

Bottlenecks/obstacles

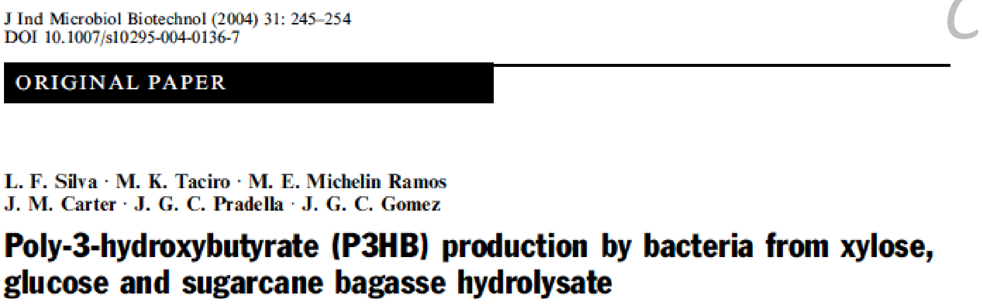
Ethanol 1G

- The potential of ethanol 1G is far from being exhausted
- Productivity gains in the same cultivated area (yield/ha yield/sugarcane ton) – new varieties, GMOs
- Geographical expansion (other areas and other countries)

Ethanol 2G & biorefineries

- Hydrolysis of lignocellulose & hemicellulose to release sugars: toxic compounds are also released
- Development of (micro) organisms and processes to transform sugars into bioproducts

Contributions to the process



J Ind Microbiol Biotechnol (2004) 31: 245–254
DOI 10.1007/s10295-004-0136-7

ORIGINAL PAPER

L. F. Silva · M. K. Taciro · M. E. Michelin Ramos
J. M. Carter · J. G. C. Pradella · J. G. C. Gomez

Poly-3-hydroxybutyrate (P3HB) production by bacteria from xylose, glucose and sugarcane bagasse hydrolysate

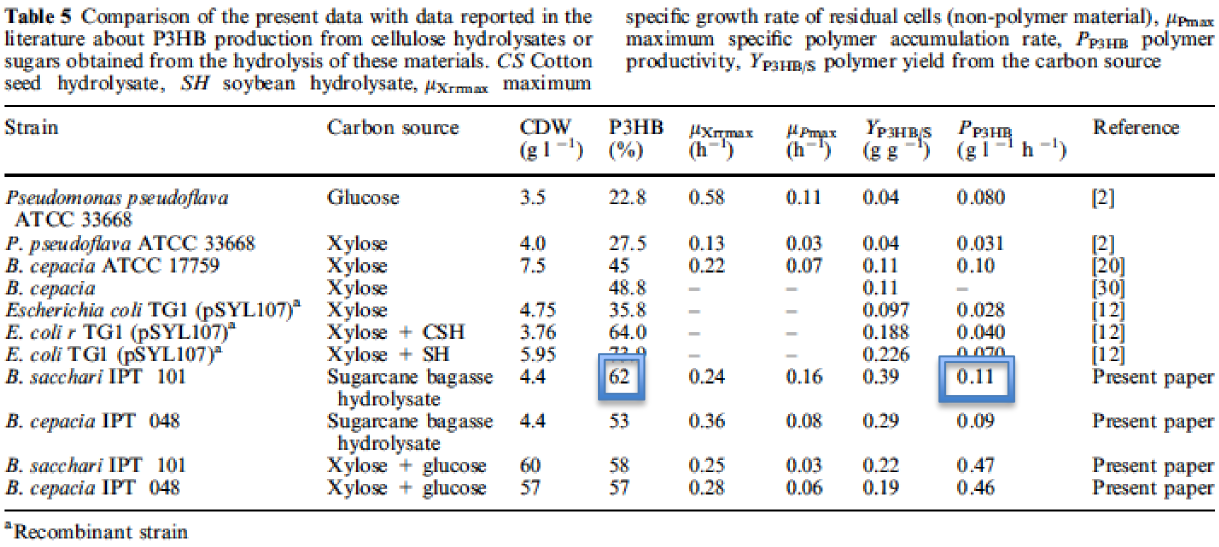


Table 5 Comparison of the present data with data reported in the literature about P3HB production from cellulose hydrolysates or sugars obtained from the hydrolysis of these materials. *CS* Cotton seed hydrolysate, *SH* soybean hydrolysate, μ_{Xrmax} maximum specific growth rate of residual cells (non-polymer material), μ_{Pmax} maximum specific polymer accumulation rate, P_{P3HB} polymer productivity, $Y_{P3HB/S}$ polymer yield from the carbon source

Strain	Carbon source	CDW (g l $^{-1}$)	P3HB (%)	μ_{Xrmax} (h $^{-1}$)	μ_{Pmax} (h $^{-1}$)	$Y_{P3HB/S}$ (g g $^{-1}$)	P_{P3HB} (g l $^{-1}$ h $^{-1}$)	Reference
Pseudomonas pseudoflava ATCC 33668	Glucose	3.5	22.8	0.58	0.11	0.04	0.080	[2]
P. pseudoflava ATCC 33668	Xylose	4.0	27.5	0.13	0.03	0.04	0.031	[2]
B. cepacia ATCC 17759	Xylose	7.5	45	0.22	0.07	0.11	0.10	[20]
B. cepacia	Xylose		48.8	–	–	0.11	–	[30]
Escherichia coli TG1 (pSYL107)[a]	Xylose	4.75	35.8	–	–	0.097	0.028	[12]
E. coli r TG1 (pSYL107)[a]	Xylose + CSH	3.76	64.0	–	–	0.188	0.040	[12]
E. coli TG1 (pSYL107)[a]	Xylose + SH	5.95	73.0	–	–	0.226	0.070	[12]
B. sacchari IPT 101	Sugarcane bagasse hydrolysate	4.4	62	0.24	0.16	0.39	0.11	Present paper
B. cepacia IPT 048	Sugarcane bagasse hydrolysate	4.4	53	0.36	0.08	0.29	0.09	Present paper
B. sacchari IPT 101	Xylose + glucose	60	58	0.25	0.03	0.22	0.47	Present paper
B. cepacia IPT 048	Xylose + glucose	57	57	0.28	0.06	0.19	0.46	Present paper

[a] Recombinant strain

High PHB content

Low productivity

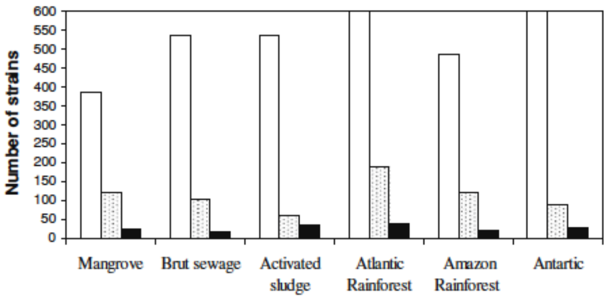
Detoxification of hydrolysate needed

World J Microbiol Biotechnol (2009) 25:1751–1756
DOI 10.1007/s11274-009-0072-9

ORIGINAL PAPER

Screening of bacteria to produce polyhydroxyalkanoates from xylose

Mateus Schreiner Garcez Lopes · Rafael Costa Santos Rocha ·
Sandra Patricia Zanotto · José Gregório Cabrera Gomez ·
Luiziana Ferreira da Silva



Cloning and overexpression of the xylose isomerase gene from *Burkholderia sacchari* and production of polyhydroxybutyrate from xylose

Can. J. Microbiol. 55: 1012–1015 (2009)

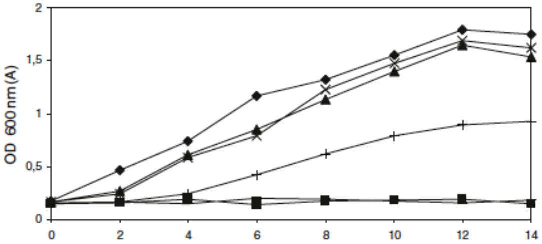
Mateus Schreiner Garcez Lopes, José Gregório Cabrera Gomez, and Luiziana Ferreira Silva

Table 1. Specific xylose isomerase activities (assayed as described in Shamanna and Sanderson (1979)) in wild-type *Burkholderia sacchari* IPT101, *B. sacchari* IPT101 harboring pBBR1MCS-2 used as control, and *B. sacchari* IPT101 harboring pBBR1*xylA* (LFM900).

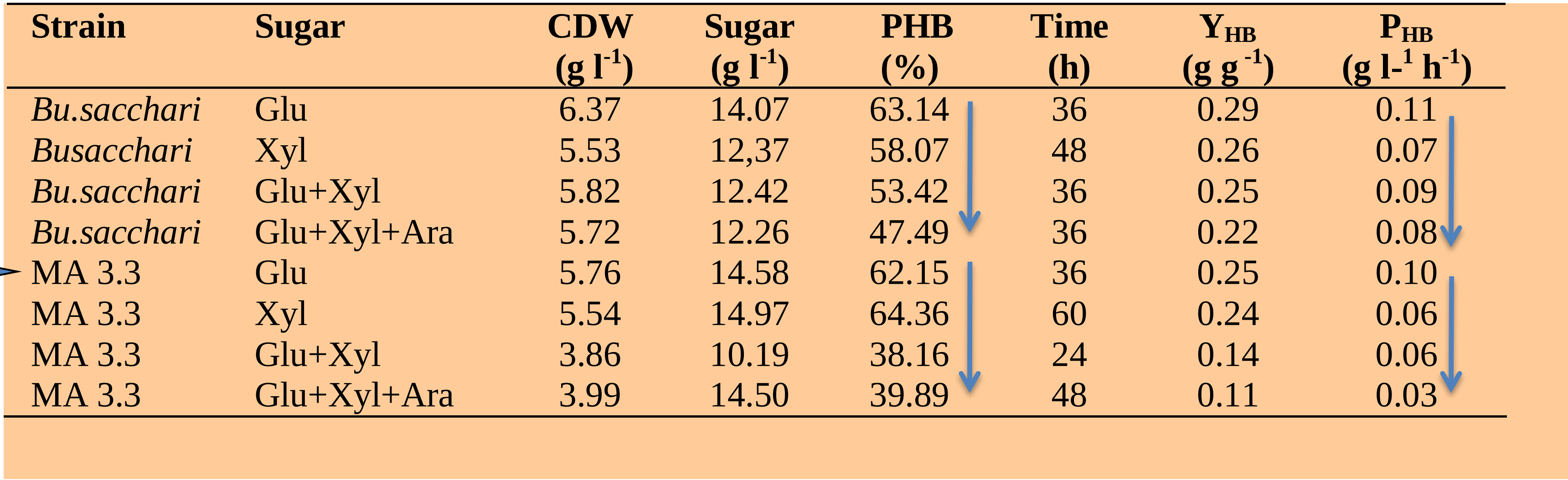
Strain	Activity (U·mg protein^{-1})
B. sacchari IPT101	1.46
B. sacchari:: pBBR1MCS-2	1.32
B. sacchari pBBR1*xylA*	2.44

Note: One unit of isomerase activity is defined as the amount of crude enzyme required to produce 1 µmol product·min^{-1}.

Fig. 2. Growth experiments in mineral media (based on Rocha et al. 2008) with xylose as carbon source (2 g·L^{-1}): ◆, *Burkholderia sacchari* IPT101 wild type; ×, *B. sacchari* harboring pBBR1MCS-2 used as control; ▲, *B. sacchari* LFM900 harboring pBBR1MCS-2 with *xylA* cloned (pBBR1*xylA*); ■, *B. sacchari* xyl$^-$ IPT536, IPT101 mutant unable to grown in xylose; –, *B. sacchari* xyl$^-$ IPT536 harboring pBBR1MCS-2 used as control; +, *B. sacchari* xyl$^-$ IPT536 harboring pBBR1*xylA*.



Performance in sugar mixtures (bagasse hydrolysate main sugars)



Strain	Sugar	CDW (g l^{-1})	Sugar (g l^{-1})	PHB (%)	Time (h)	Y_{HB} (g g $^{-1}$)	P_{HB} (g l-^{1} h^{-1})
Bu.sacchari	Glu	6.37	14.07	63.14	36	0.29	0.11
Busacchari	Xyl	5.53	12,37	58.07	48	0.26	0.07
Bu.sacchari	Glu+Xyl	5.82	12.42	53.42	36	0.25	0.09
Bu.sacchari	Glu+Xyl+Ara	5.72	12.26	47.49	36	0.22	0.08
MA 3.3	Glu	5.76	14.58	62.15	36	0.25	0.10
MA 3.3	Xyl	5.54	14.97	64.36	60	0.24	0.06
MA 3.3	Glu+Xyl	3.86	10.19	38.16	24	0.14	0.06
MA 3.3	Glu+Xyl+Ara	3.99	14.50	39.89	48	0.11	0.03

Cell dry weight (CDW), PHB content of the cell dry weight (%PHB) PHB yield from carbon source ($Y_{PHB/C}$), and PHB volumetric productivity (P_{PHB})

Bacillus megaterium

- P_{PHB} is 40% lower in xylose than in glucose

-In sugar mixtures parameters were lower: %PHB, $Y_{PHB/C}$ e P_{PHB}.

J Mol Microbiol Biotechnol 2011;20:63–69
DOI: 10.1159/000324502 Lopes et al.

Curr Microbiol (2011) 63:319–326
DOI 10.1007/s00284-011-9981-6

PHB Biosynthesis in Catabolite Repression Mutant of *Burkholderia sacchari*

**Mateus Schreiner Garcez Lopes · Guillermo Gosset ·
Rafael Costa Santos Rocha · José Gregório Cabrera Gomez ·
Luiziana Ferreira da Silva**

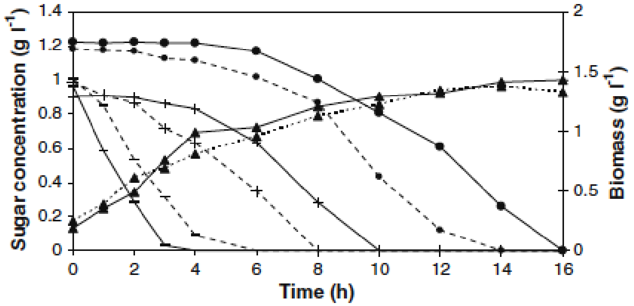
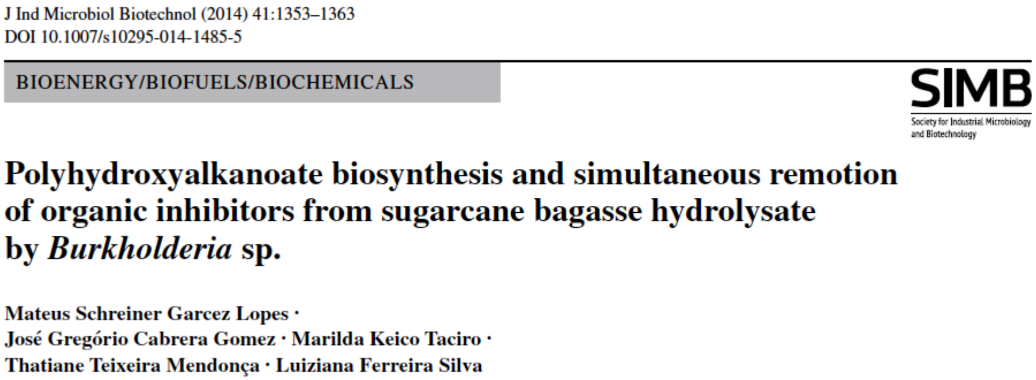


Fig. 3 Growth experiments in triple sugar mixtures with wild type *B. sacchari* IPT101 (*solid line*) and *B. sacchari* LFM828 PTS$^-$ glucose$^+$ (*dotted line*): (*filled triangle*) biomass, (*minus*) glucose, (*plus*) arabinose, and (*filled circle*) xylose

Improving simultaneous consumption of different sugars from bagasse

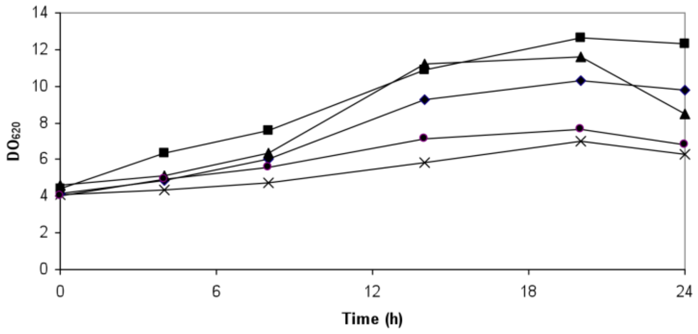


J Ind Microbiol Biotechnol (2014) 41:1353–1363
DOI 10.1007/s10295-014-1485-5

BIOENERGY/BIOFUELS/BIOCHEMICALS

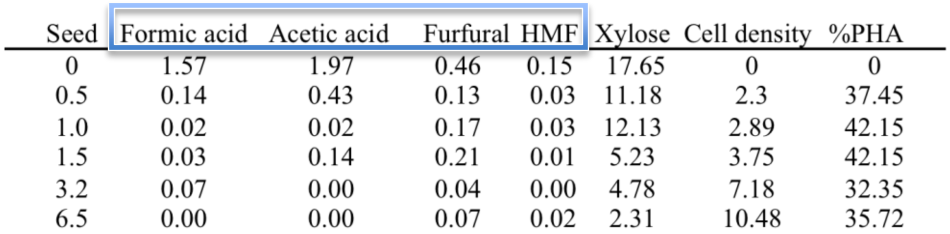
Polyhydroxyalkanoate biosynthesis and simultaneous remotion of organic inhibitors from sugarcane bagasse hydrolysate by *Burkholderia* sp.

Mateus Schreiner Garcez Lopes · José Gregório Cabrera Gomez · Marilda Keico Taciro · Thatiane Teixeira Mendonça · Luiziana Ferreira Silva



Growth experiment with F24 in mineral media with xylose (10 g l^{-1}) and individual compounds: (■) 2.5 g l^{-1} of acetic acid, (▲) 1.25 g l^{-1} of formic acid, (♦) control experiment only with xylose, (●) 0.5 g l^{-1} of HMF, and (x) 0.5 g l^{-1} of furfural.

Isolate F24 (*Burkholderia* sp) can use toxic compounds from sugarcane hydrolysate

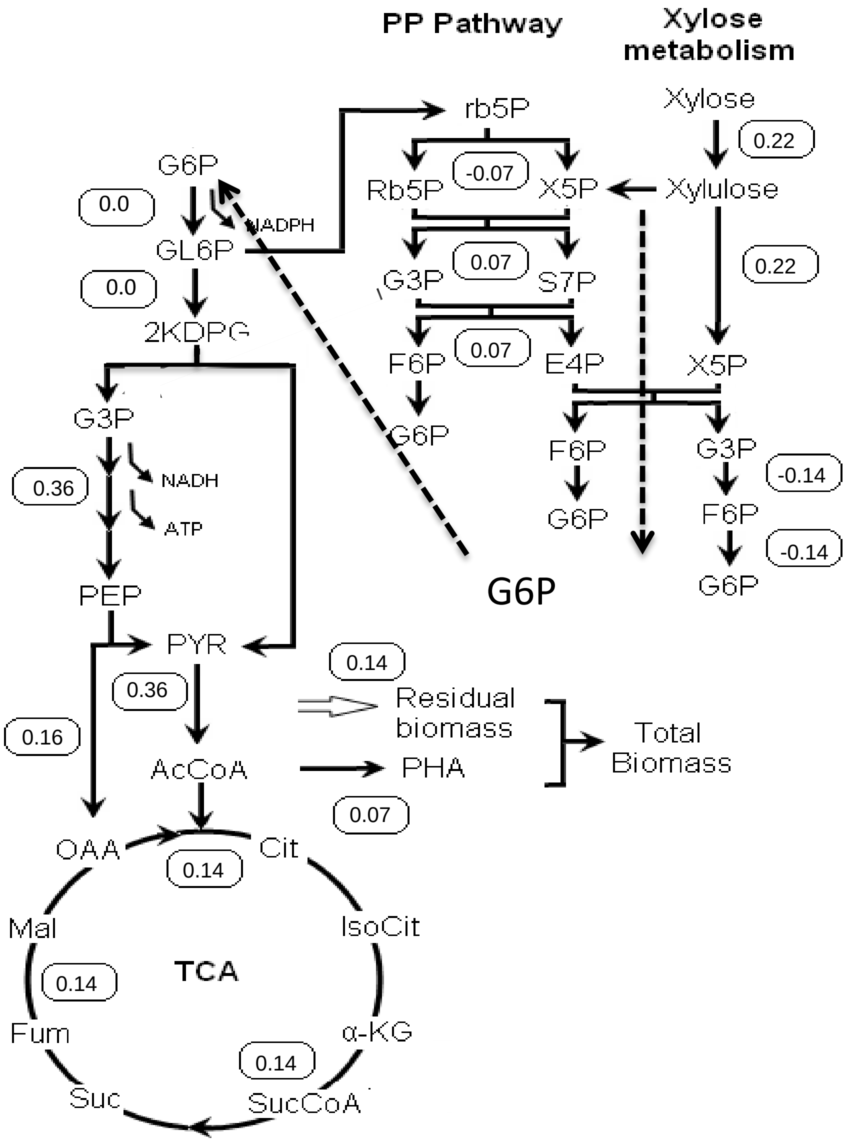


Seed	Formic acid	Acetic acid	Furfural	HMF	Xylose	Cell density	%PHA
0	1.57	1.97	0.46	0.15	17.65	0	0
0.5	0.14	0.43	0.13	0.03	11.18	2.3	37.45
1.0	0.02	0.02	0.17	0.03	12.13	2.89	42.15
1.5	0.03	0.14	0.21	0.01	5.23	3.75	42.15
3.2	0.07	0.00	0.04	0.00	4.78	7.18	32.35
6.5	0.00	0.00	0.07	0.02	2.31	10.48	35.72

Effect of the inoculum size (g l^{-1}) on utilization of hydrolysates (g l^{-1}), cell growth (g l^{-1}) and PHA biosynthesis (% of PHA of the cell dry weight) in hydrolysate medium after 48 hours

Fluxes leading to: $Y_{Xyl/HB} = 0.25\ g\ g^{-1}$

Metabolic flux analysis as a tool for bacterial improvement



NADPH needed for PHA production in *B sacchari*

University of São Paulo

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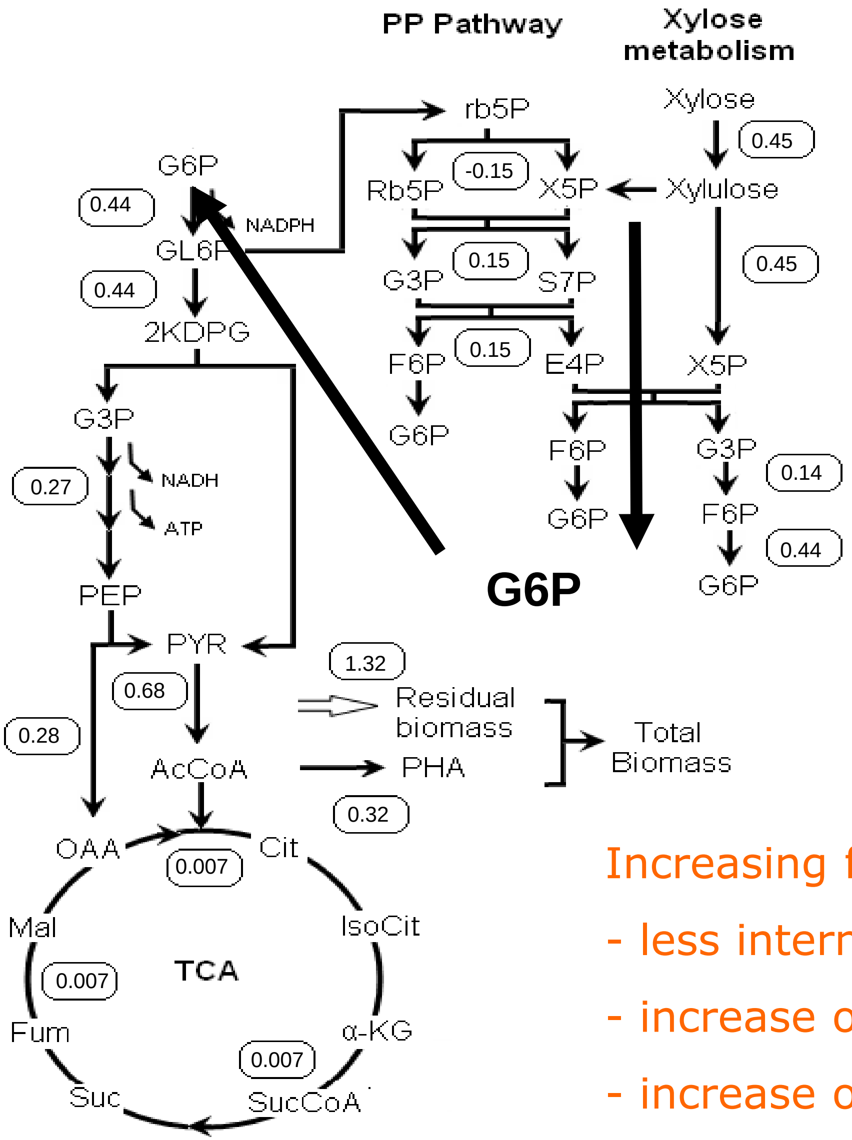
Laboratório de Bioprodutos ICB - USP

Fluxes resulting on: $Y_{Xyl/HB} = 0.41\ g\ g^{-1}$

Metabolic flux analysis as a tool for bacterial improvement



talA

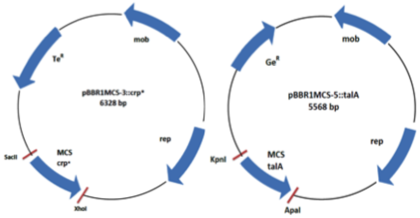
Increasing fluxes on PPP:

- less intermediate accumulation;
- increase on NADPH yield;
- increase on PHB yield;

University of São Paulo

Metabolic engineering of *Burkholderia sacchar*i for improved production of bio-based products from xylose

Linda Guaman, M. Schreiner, J. Cabrera, L.F. da Silva, M. Keico



Plasmid maps of pBBR1MCS-3::crp and pB*
5::talA respectively.

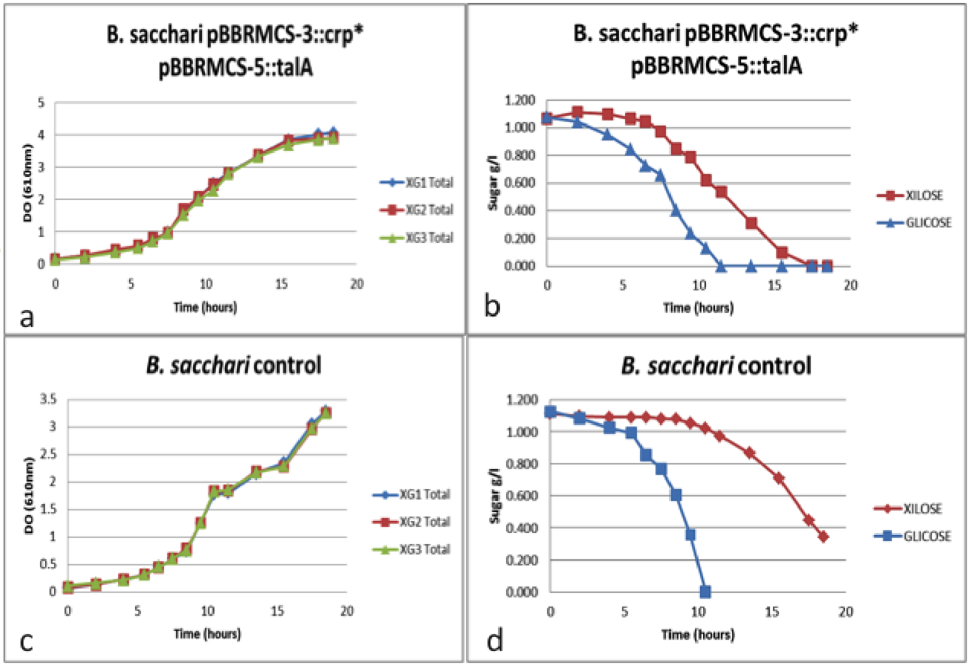


Fig 6. a-c: Bacterial growth curve. b-d: Sugar compsumption

15% increase μ_{max}
35% reduction on lag phase
simultaneous consumption of xylose and glucose
40% productivity CDW.

Metabolic engineering of *Burkholderia sacchar*i for improved production of bio-based products from xylose

Linda Guaman, M. Schreiner, J. Cabrera, L.F. da Silva, M. Keico

Strain	Carbon Source	PHA Composition	CDW (g l^{-1})	%PHB	PHB g/l	Time (h)	Reference
B. sacchari IPT101	Xilose	PHB	4.16	58.07	2.42	48h	Lopes et al., 2009
B. sacchari IPT101	Glicose e xilose	PHB	5.82	53.42	3.11	48h	Lopes et al., 2009
B. sacchari LFM 1103$^{\#}$	Xilose	PHB	7.1	53.71	3.81	48h	This work
B. sacchari LFM 1103$^{\#}$	Glicose e xilose	PHB	7	60.12	4.21	48h	This work
B. sacchari LFM 1105$^{\text{¥}}$	Xilose	PHB	4.12	55.07	2.27	48h	This work
B. sacchari LFM 1105$^{\text{¥}}$	Glicose e xilose	PHB	4.81	52.83	2.54	48h	This work

recombinants harboring *crp** and *talA* increased polymer accumulation

Expanding the spectrum of carbohydrate utilization by *Pseudomonas* sp. LFM046: Xylose utilization

E.R. Oliveira, L.P. Guamán, Luiziana F. Da Silva, J.G. Gomez, M.K. Taciro

Introducing the ability to consume xylose and sugars from biomass to other industrially interesting bacteria

1 2 3

1 2 3

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ORIGINAL ARTICLE

Exploring the potential of *Burkholderia sacchari* to produce polyhydroxyalkanoates

T.T. Mendonça[1], J.G.C. Gomez[1], E. Buffoni[1], R.J. Sánchez Rodriguez[2], J. Schripsema[3], M.S.G. Lopes[1] and L.F. Silva[1]

Modulation of monomer composition of poly(3-hydroxybutyrate-*co*-3-hydroxyhexanoate) P(3HB-*co*-3HHx) produced by *Burkholderia sacchari*

T.T. Mendonça, R. Tavares, J.G.C. Gomez, L.G. Cespedes, M.K. Taciro, Luiziana F. Silva

Figure 3 – Composition of PHA accumulated from glucose (10 g.l^{-1}) and hexanoic acid (0-1.5 g.l^{-1}) by *B. sacchari* wild type (A) and recombinants (B) (*phaPCJ* - left - and *phaCJ* - right)

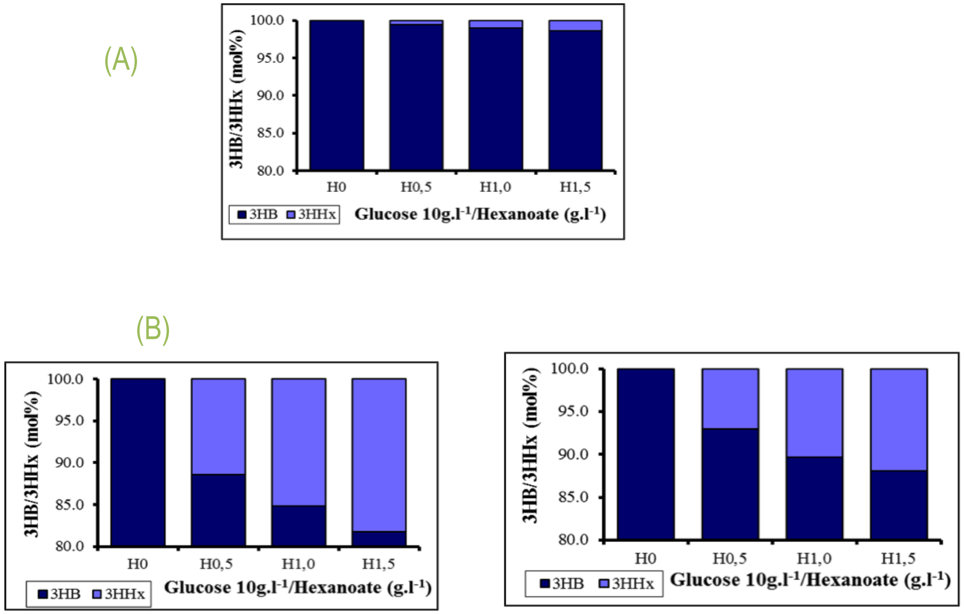
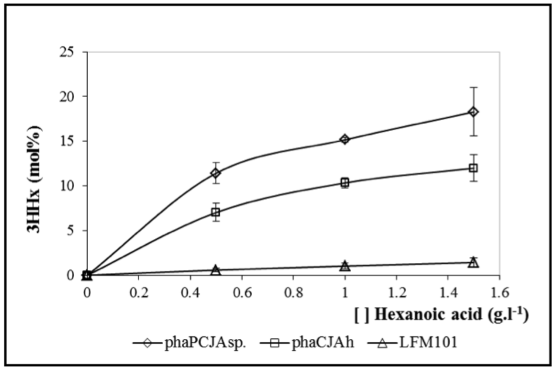
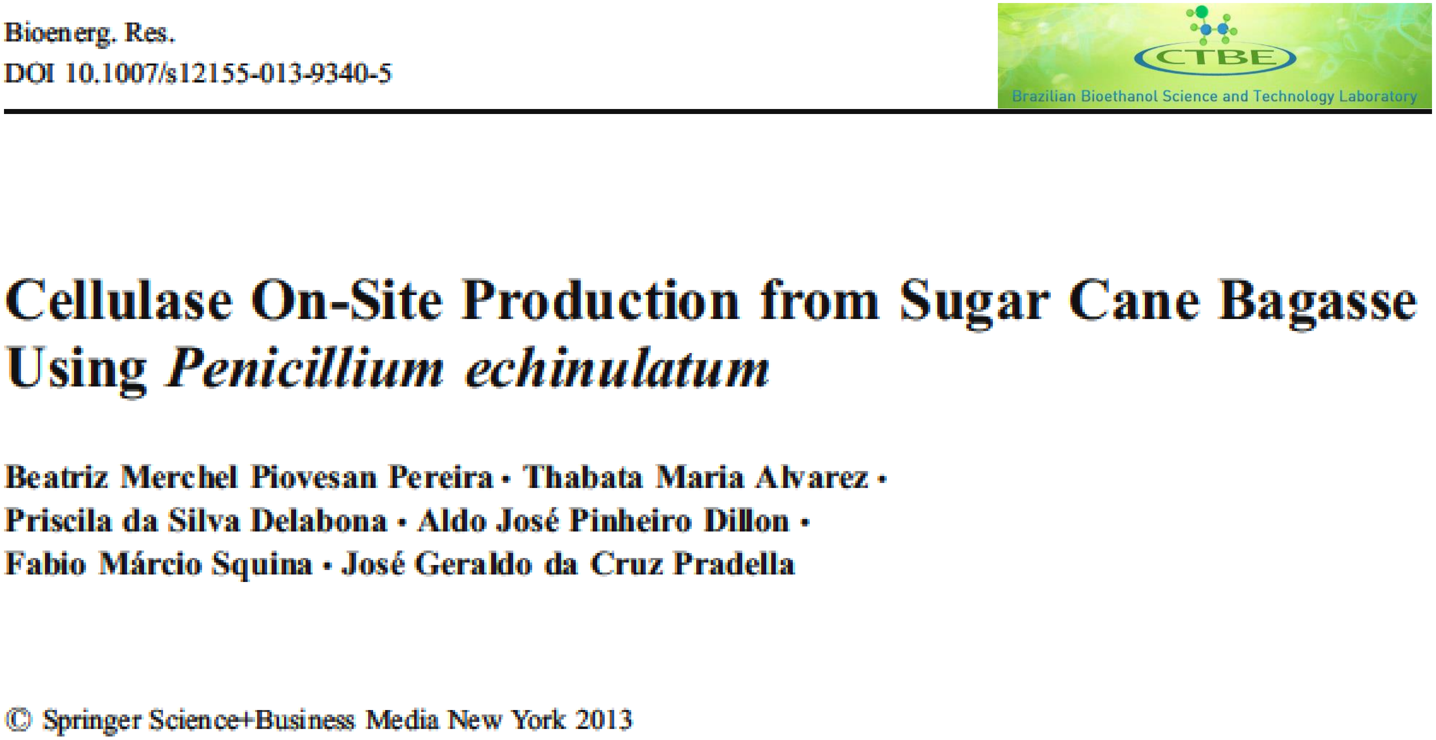


Figure 4 – Correlation of hexanoic acid concentration provided and 3HHx molar fraction obtained in experiments with *B. sacchari* strains (wild type and recombinants)



Other approaches
Integration of bagasse enzymatic hydrolysis to the biorefinery

CTBE
Brazilian Bioethanol Science and Technology Laboratory



Bioenerg. Res.
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Cellulase On-Site Production from Sugar Cane Bagasse Using *Penicillium echinulatum*

Beatriz Merchel Piovesan Pereira · Thabata Maria Alvarez · Priscila da Silva Delabona · Aldo José Pinheiro Dillon · Fabio Márcio Squina · José Geraldo da Cruz Pradella

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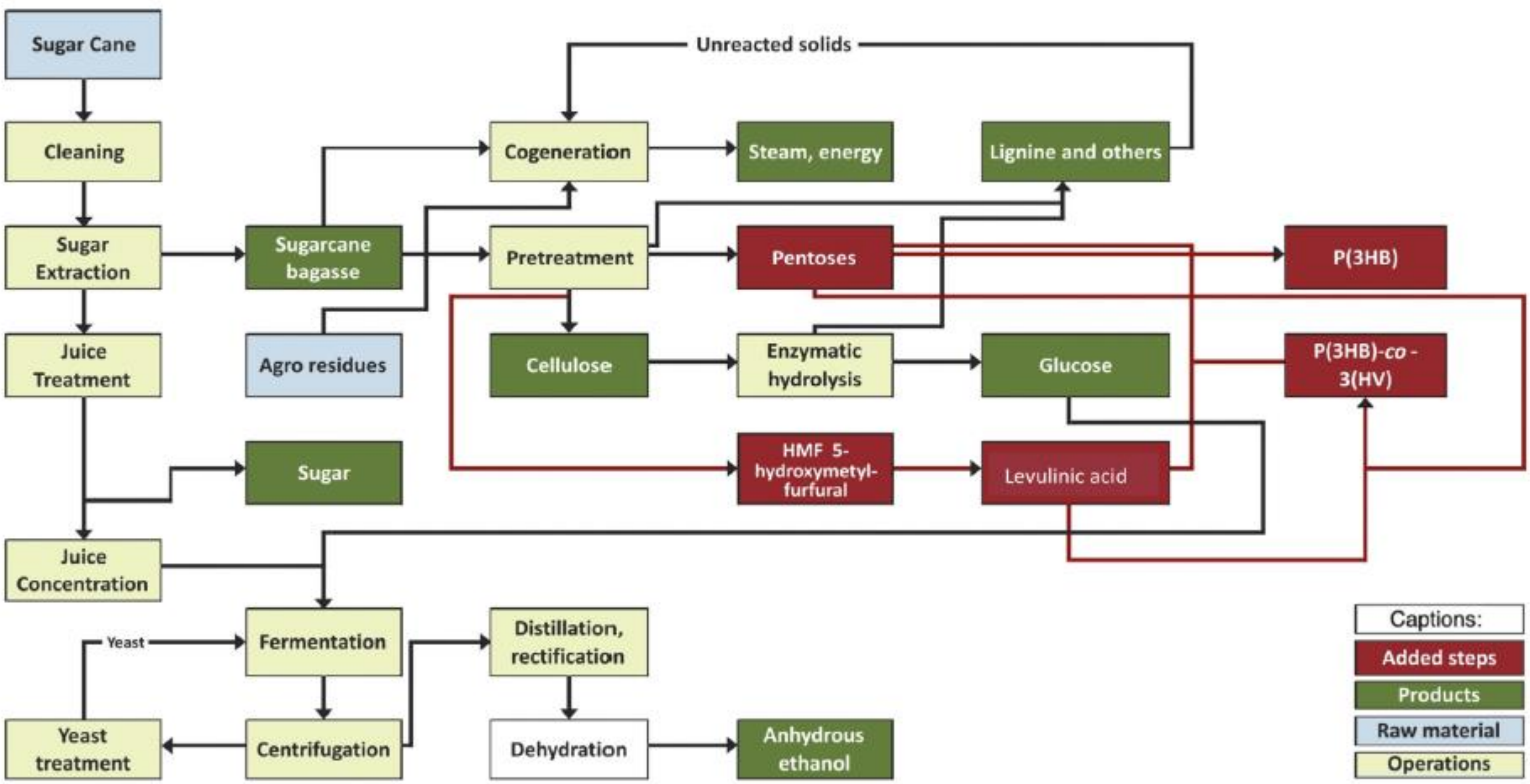
Biopolymer production integrated to a sugar and ethanol mill

L.F. Silva et al. / International Journal of Biological Macromolecules 71 (2014) 2–7



Perspectives and challenges

- *The production of lignocellulosic hydrolysates of sugarcane bagasse, usable by microorganisms, is still a challenge, as well as obtaining ethanologenic yeast or other microorganisms efficient in transforming the resulting hydrolysate in commercially attractive products.*

- Important issues
  - *Use of other residues as raw materials*
  - *Other biorefinery models*
  - *Interdisiplinaty work*
  - *Interaction with industries*
  - *discussion forums involving different areas*
  - *Government policies and support*

ICB USP
45 anos

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Laboratório de Bioprodutos
ICB - USP

Luiziana F. Silva lukneif@usp.br

J.Gregório C. Gomez
Marilda Keico Taciro
Karel Olavarria Gamez
Thatiane T. Mendonça
Gabriela C. Lozano
Linda P. Guaman Bautista
Lucas Garbini Cespedes
Diana Carolina Tusso Pizon
Bernardo Ferreira Camilo
Cesar W. Guzman Moreno
Rafael Nahat
Carlos Farjardo
Thandara Garcia Ravelli
Juliano Cherix
Edmar Ramos de Oliveira Filho
Juan Camilo Roncalo
Aline Carolina C. Lemos
Alexandre A. Alves
Aelson L. Santos

Karen L. Almeida
Odalys Rodriguez Gamez
Arelis Abalos Rodriguez
Jhoanne Hansen
Gisele F. Bueno

Amanda B. Flora

Galo A. C. Le Roux (EP-USP)
Carlos A. M. Riascos (EP-USP)

Paulo Alexandrino (André Fujita)
Juliana Cardinali Rezende

Ruben Sanchez (UENF)
Niels van Stralen (W2C)

Andreas K. Gombert (UNICAMP)
Walter M. van Gulik (TU Delft)
Aljoscha Wahl (TU Delft)
Reza Maleki Seifar (TU Delft)
J. J. (Sef) Heijnen (TU Delft)

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