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Production of bioplastics as by-products of waste treatment

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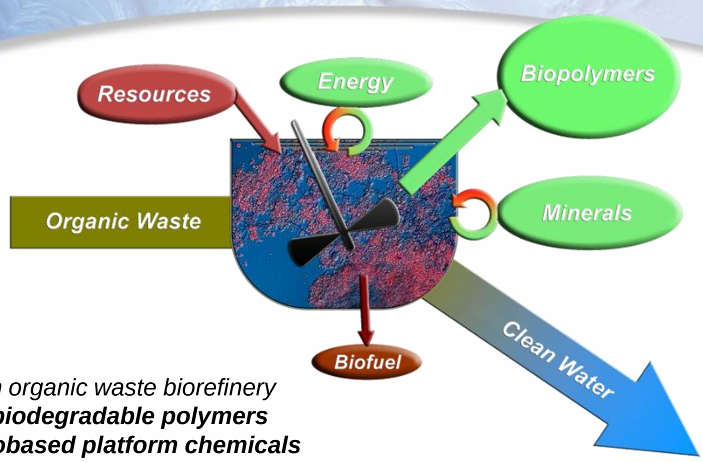
Wastewater treatment - biorefinery for environmental protection



…An organic waste biorefinery
*for **biodegradable polymers***
*and **biobased platform chemicals***
*with **energy** production*
*and **low sludge** production…*

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Content

- Objective
  - To present a promising vision in organic waste cycling
- Linear life of conventional plastics
- Polyhydroxyalkanoate (PHA) bioplastics
- Industrial wastewater treatment plants as biorefineries producing PHAs
- PHAs from wastewater and biosolids

Resarch & Development → Application

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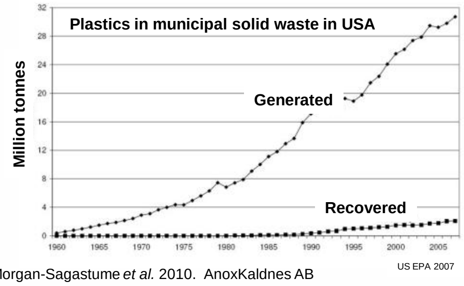
Petroleum-based plastics

- Extensively used, but produced from a non-renewable resource

Municipal solid waste	
Region / Country	**Plastic waste (million tonnes / yr)***
EU 2005	30
USA 2007	31
OECD Countries 2005	70

*OECD Environmental Data 2008; US EPA 2007

Recovery

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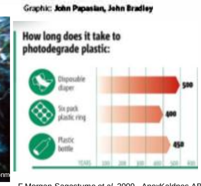
Plastics accumulate and impact ecosystems



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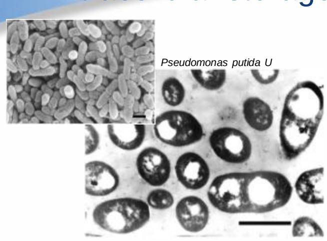
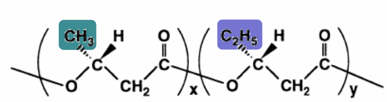
Polyhydroxyalkanoate (PHA) bioplastics

- Microbial short-chain length (scl) polyesters: 3-5 C
- Intracellular storage compounds – energy and C source



- G$^-$ and G$^+$ bacteria: ~75 genera, 300 species
- Pure and mixed cultures under growth-limiting conditions

PHB PHV



(*R*)-3HB (*R*)-3HV

Luengo *et al*. 2003. Current Opinion in Microbiology, 6:251-260

Biologically produced
from renewable resources
Biodegradable
Thermoplastic
Biocompatible

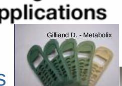
Journal of Chemical Technology and Biotechnology *J Chem Technol Biotechnol* **82**:233–247 (2007)

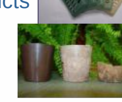
Review

Polyhydroxyalkanoates: biodegradable polymers with a range of applications

S. Philip, T. Keshavarz and I. Roy*
School of Biosciences, University of Westminster, London, UK

- Injection moulded products
- Films and coatings
- Foams
- Biomass products





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Production of commercial PHAs

Pure cultures and transgenic plants

Product name	PHA type	Company	Price	Production (tonne/yr)
Homopolymers				
Biomer®	P(3HB)	Biotechnology Co., Germany	20€/kg (2003)[a] 3-5€/kg (2010)[a]	50 (2003)[a]
Biocycle	P(3HB)	PHB Industrial S/A, Brazil	-	60
Biogreen®	P(3HB)	Mitsubishi GAS Chemical, Japan	10-12€/kg (2003)[a] 2.5-3€/kg (2010)[a]	1400 (2003), 30-60,000 (2010)[a]
	P(3HB)	Metabolix, USA (BASF, ADM)[b]	ca. 2.2 €/kg (2010)[c]	-
	P(3HB)	Jiangsu Nantian Group, China	-	-
	P(3HO)	Metabolix, USA (BASF, ADM)[b]	ca. 2.2 €/kg (2010)[c]	-
Copolymers				
Biopol®	P(3HB-co-3HV)	Metabolix, USA (BASF, ADM)[b]	10-12€/kg (2003)[a] 3-5€/kg (2010)[a]	1100 (2003)[a]
	P(3HB-co-3HV)	PHB Industrial S/A, Brazil	-	50 (2003)[a], 10,000 (2006)[a]
ENMAT®	P(3HB-co-3HV)	Tianan Biologic Material, China	-	1000
Nodax	P(3HB-co-3HHx)	Procter & Gamble, USA (Kaneka)	2.5 €/kg (2010)[a]	250 (2003)[a], 20-50,000 (2010)[a]
	P(3HB-co-3HHx)	Jiangsu Nantian Group, China	-	-
	P(3HB-co-3HHx)	Lianyi Biotech, China	>5 US$/kg[c]	2000[c]

[a] Techno-economic feasibility of large-scale production of bio-based polymers in Europe, Utrecht University and Fraunhofer Institute for Research (2003) System Innovation Research (2003)
[b] The strategic alliance between ADM and Metabolix will lead to a production of PHAs of 50,000/ tonnes/year in 2008
[c] The fourth Knowledge Millenium Summit on Biotechnology & Nanotechnology, India, O'Bioer Technology Co., Ltd (March 2006)

Jacquel et al. (2008). Isolation and purification of bacterial poly(3-hydroxyalkanoates). Biochemical Engineering Journal 39:15-27.

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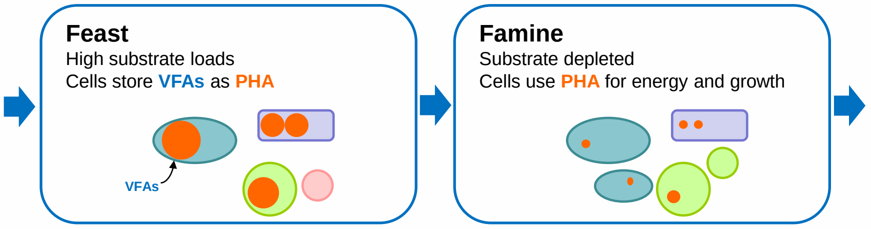
PHA production with open, mixed microbial cultures

- Towards cost effectiveness
  - Recombinant organisms: bacteria, plants, yeasts
  - Other C sources: molasses, sucrose, lactose, glycerol, oils
  - **Open, mixed cultures**: no sterilization and cheaper C sources
    - Harnessing a selective pressure by dynamic conditions
- Substrate dynamics – Aerobic Dynamic Feeding or **Feast-Famine**
  - Volatile fatty acids (VFAs) used for culture enrichment



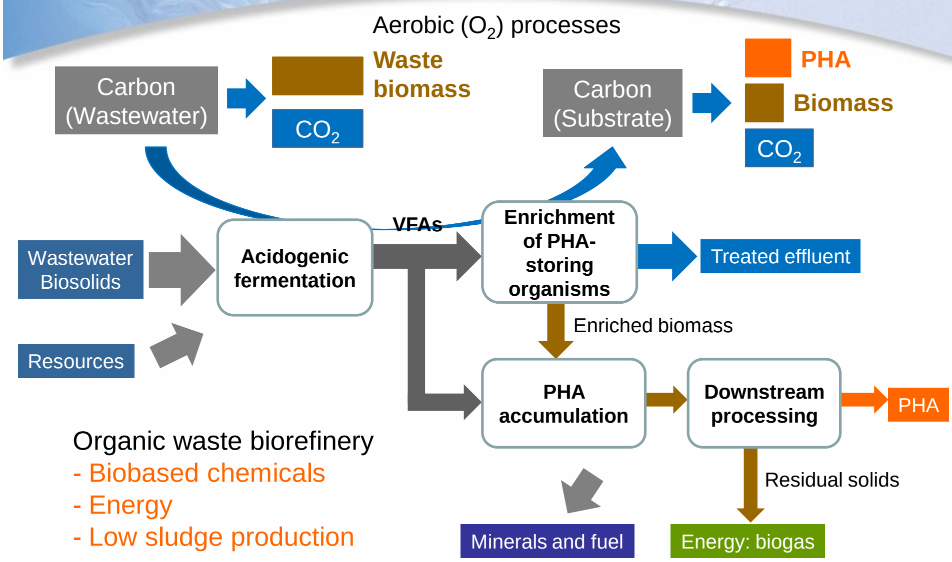
- Electron- acceptor (oxygen) dynamics – anaerobic/aerobic cycling

Bengtsson et al., 2008. Production of polyhydroxyalkanoates by glycogen accumulating organisms treating a paper mill wastewater. Water Sci. Technol. 58 (2): 323-30

F Morgan-Sagastume *et al.* 2010. AnoxKaldnes AB

Mixed culture synergies and opportunities

Wastewater biotreatment ⟷ PHA production



Organic waste biorefinery
- Biobased chemicals
- Energy
- Low sludge production

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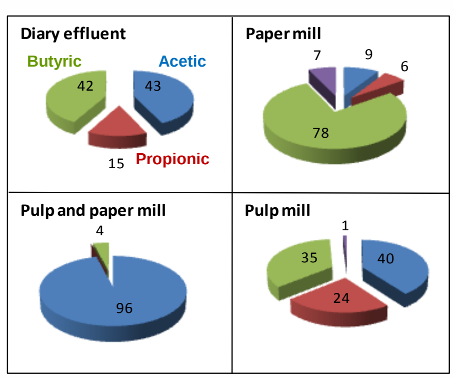
Industrial wastewaters for PHA production

- **VFAs mixtures(acetate, propionate)**
- Food waste
- Olive and palm oil mills effluents
- **Sugar-cane molasses**
- **Diary effluent**
- **Paper mill effluents**
- **Fruit and tomato cannery effluents**
- Brewery effluent
- **Municipal wastewaters**

Acidogenic fermentation
VFA production from
Carbohydrate-rich effluents



Bengtsson, Hallquist, Werker, Welander (2008). Acidogenic fermentation of industrial wastewaters: effects of chemostat retention time and pH on volatile fatty acids production. Biochemical Eng. J. 40: 492-499.

- VFA spectrum depends on wastewater, pH and retention time

- Control of VFA and final PHA monomers in fermenters

- However, full VFA fermentation may not be required with readily degradable carbohydrates (Fruit cannery effluents; Gurieff, 2008)

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PHAs production from wastewater at lab scale

Fermentation → Enrichment → Accumulation → DSP

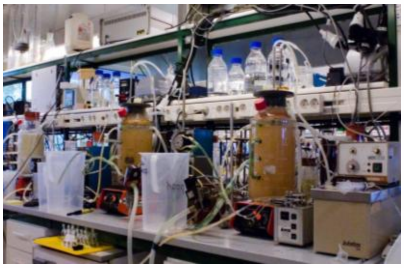
Effluent	Enrichment reactor Feast-Famine	Reference
Sugar cane molasses	SBR	Albuquerque *et al.*, 2007
Paper mill	**Activated sludge**	**Bengtsson *et al.*, 2008**
1° sludge or cannery	SBR	Gurieff, 2008


Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Bioresource Technology 99 (2008) 509–516
BIORESOURCE TECHNOLOGY

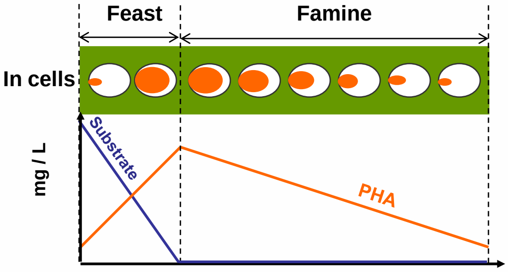
Production of polyhydroxyalkanoates by activated sludge treating a paper mill wastewater

Simon Bengtsson [a,b,*], Alan Werker [a], Magnus Christensson [a], Thomas Welander [a]

Sequencing batch reactors (SBRs) enriching for PHA- accumulating organisms



Diary effluent



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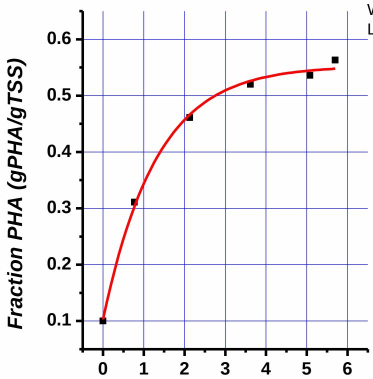
PHA accumulation in fed batch

Effluent	Batch PHA production (g PHA / g dry biomass)	Reference
Sugar cane molasses	0.30	Albuquerque *et al.*, 2007
Paper mill	**0.48**	**Bengtsson *et al.*, 2008**
1° sludge or cannery	0.32-0.39	Gurieff, 2008



Westerberg, Werker, Linden (2008).

- Yields of 50% polymer in biomass accumulation attainable
- Overall yields
  0.10 to 0.20 g PHA/g COD influent

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PHA from biosolids

SIXTH FRAMEWORK PROGRAMME

Neptune FP6 Project

- Biosolids – major operating costs in WWTPs
- Waste activated sludge and 1º solids pretreated with high-pressure thermal hydrolysis (solubilised sludge)

Fermentation into VFAs

- VFA levels = 20 g VFA_{COD}/L
- Yield 50% (g VFA_{COD}/$gCOD_{sol.}$ in)

Semi-continuous fermenters

Enrichment in SBRs

- At high organic loadings 6 g COD/Ld
- High N and P levels
- Non-VFA COD

Two parallel SBRs

Batch PHA accumulation

- 0.25 g PHA/g dry biomass
- 0.33-0.46 PHA Cmol/VFA Cmol
- Under high N and P levels

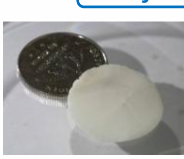
Parallel batch acummulation tests

Downstream processing to final product

- Most costly stage in PHA production and critical
- Optimise for lower PHA content and other matter

Pretreatment → Extraction → Purification

Polymer properties by a suite of techniques



Chlorinated-solvent-free gas chromatographic analysis of biomass containing polyhydroxyalkanoates

Alan Werber, Petter Lind, Simon Bengtsson, Frida Nordström

- Content / composition
  GCMS and FTIR
- Molecular weight
  SEC
- Thermal properties
  DSC
  TGA
- Viscoelasticity
  Melt rheology

Final product

- PHB-PHV with flexible processing potential
- High molecular weights: 500,000 – 1,000,000 g/mol
- High thermal stability

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Pilot testing and PHA production

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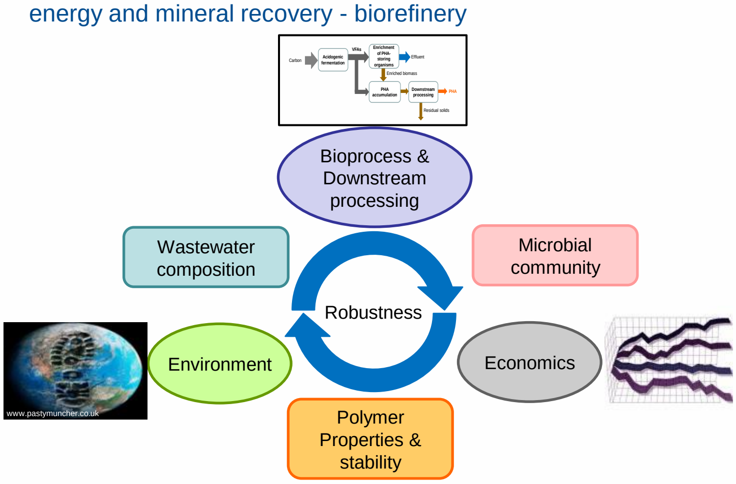
Concluding remarks

- Wastewater treatment can be coupled to the production of PHA bioplastics taking advantage of the existing open, mixed cultures and renewable resources
  - Reduction of waste sludge, aeration and nutrient costs complementing energy and mineral recovery - biorefinery



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