Project: Guidance development and case study documentation of green chemistry and technologies

MICROORGANISMS IN GREEN CHEMISTRY

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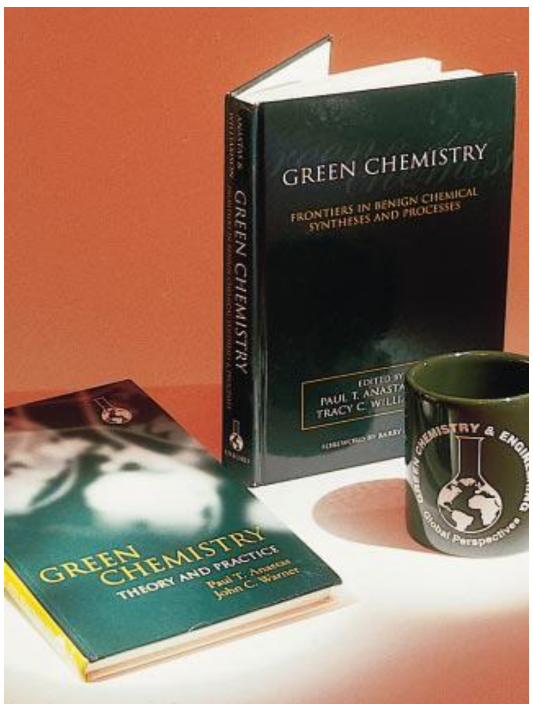
University of Belgrade – Faculty of Chemistry, 30.11.2018
https://greenchemistryserb.wixsite.com/green-serbia

WHAT IS GREEN CHEMISTRY?

"Green chemistry is the design of new products and processes that reduce or eliminate the use and generation of hazardous substances"

Paul Anastas
1997



EPA United States Environmental Protection Agency

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Related Topics: Green Chemistry

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Presidential Green Chemistry Challenge Winners

On this page:

Award winners by year with links to technology summaries and podcasts (for some).

On other pages:

- Summaries of all winning technologies in PDF format: 1996-2016 PGCC Award Recipients Booklet
- Winning technologies indexed by technology
- Winning technologies indexed by industry sector

Disclaimer: Mention of trade names, products, or services does not convey official EPA approval, endorsement, or recommendation.

https://www.epa.gov/greenchemistry/presidential-green-chemistry-challenge-winners

RECALL WHAT IS THE BIOTECHNOLOGY!

»Biotechnology is the integration of natural sciences and engineering sciences in order to achieve the application of organisms, cells, parts thereof and molecular analogues for products and services»
(General Assembly of the European Federation of Biotechnology, 1989)

»Biotechnology is the application of science and technology to living organisms as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services»
(OECD, 2002)

Color Type	Area of Biotech Activities
Red	Health, Medical, Diagnostics
Yellow	Food Biotechnology, Nutrition Science
Blue	Aquaculture, Coastal and Marine Biotech
Green	Agricultural, Environmental Biotechnology – Biofuels, Biofertilizers, Bioremediation, Geomicrobiology
Brown	Arid Zone and Desert Biotechnology
Dark	Bioterrorism, Biowarfare, Biocrimes, Anticrop warfare
Purple	Patents, Publications, Inventions, IPRs
White	Gene-based Bioindustries
Gold	Bioinformatics, Nanobiotechnology
Grey	Classical Fermentation and Bioprocess Technology

http://www.ejbiotechnology.info/index.php/ejbiotechnology/article/view/1114/1496

Biotechnology meets some of the principles of green chemistry and environmental protection:

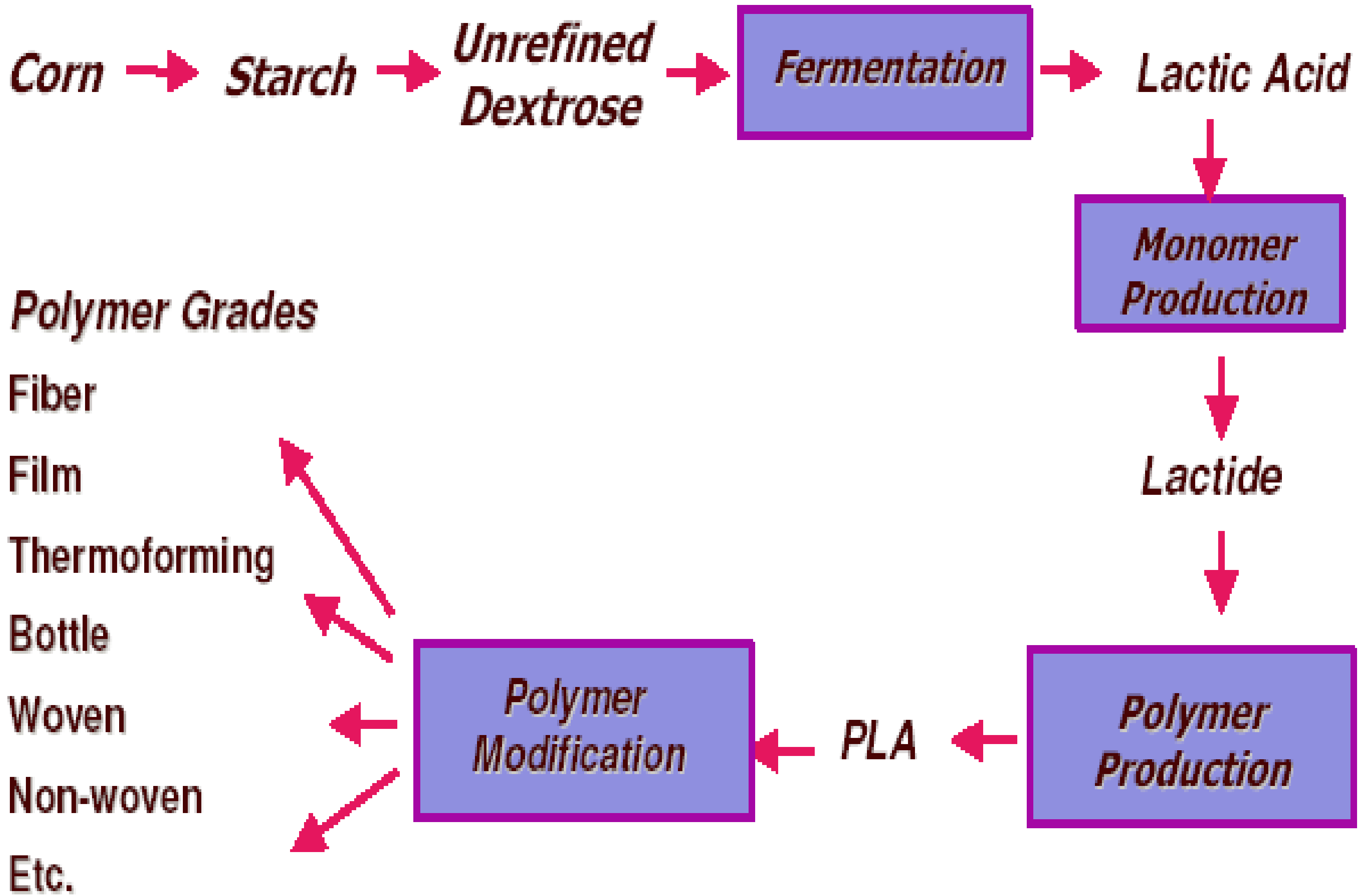
- mild reaction conditions (physiological pH and temperature)
- use of enzymes, microorganisms and plant tissues;
- environmentally compatible catalysts and solvents (often water) in combination with high activity and selectivity in multifunctional molecules;
- sustainable approaches for the production of fine chemicals (aromas, polymers, pharmaceuticals and enzymes);
- use of renewable sources or agroindustrial residues;
- recycling of biocatalysts;
- finally minimizing of waste.

Some of the interesting examples of biotechnology - green chemistry are fermentation processes that produce:

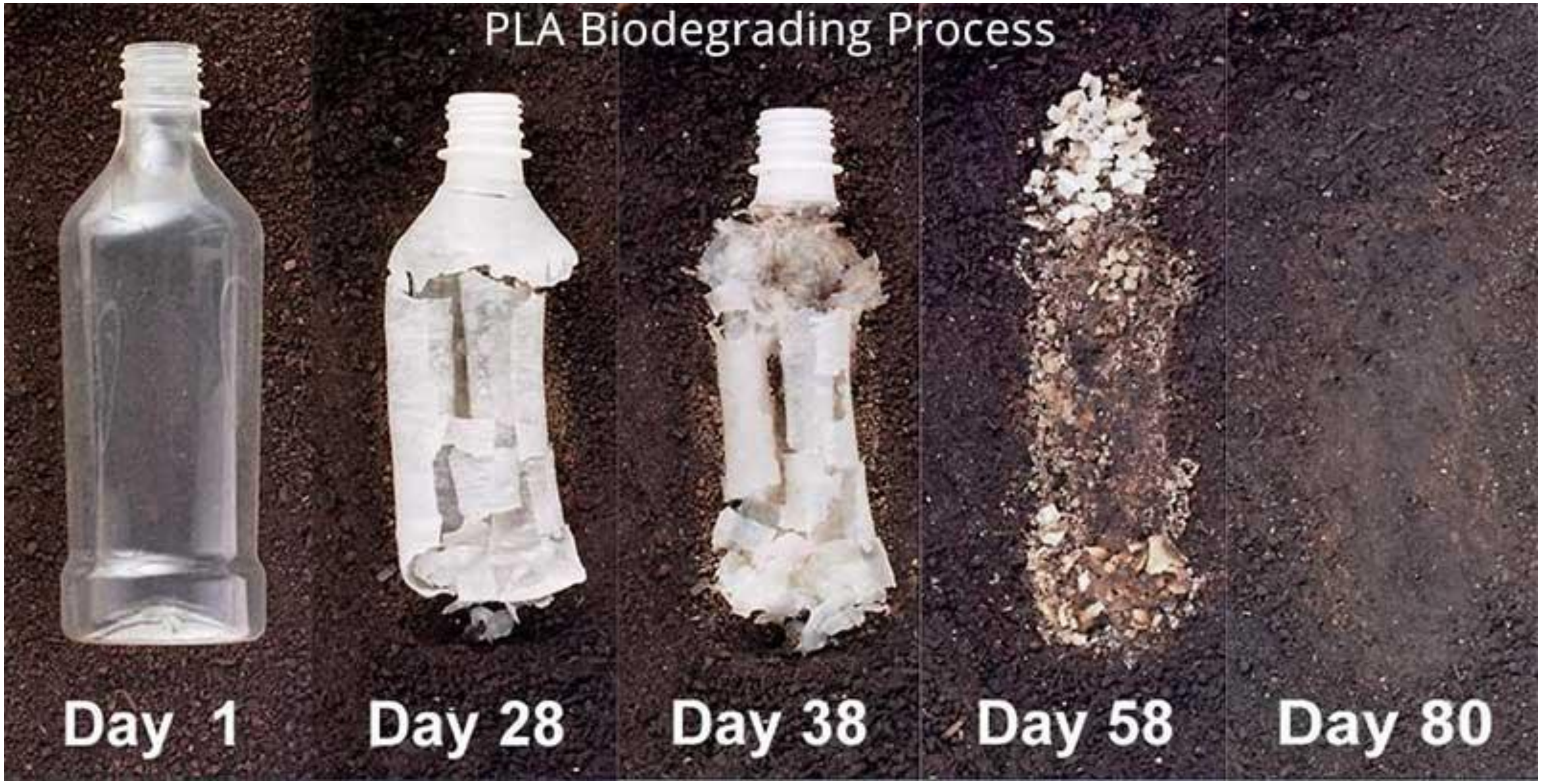
- biodegradable polyhydroxyalkanoate and polylactate - "natural plastic" from renewable sources
- rhamnolipids, biosurfactants that can replace synthetic surfactants and apply in the petroleum industry, agriculture, personal care products ...;
- enzymes for improving recycled paper processing;
- plastics based on greenhouse gases, such as methane;
- simvastatin, the medicine for the treatment of high cholesterol (*Aspergillus terreus*);
- ...

Biopolymers

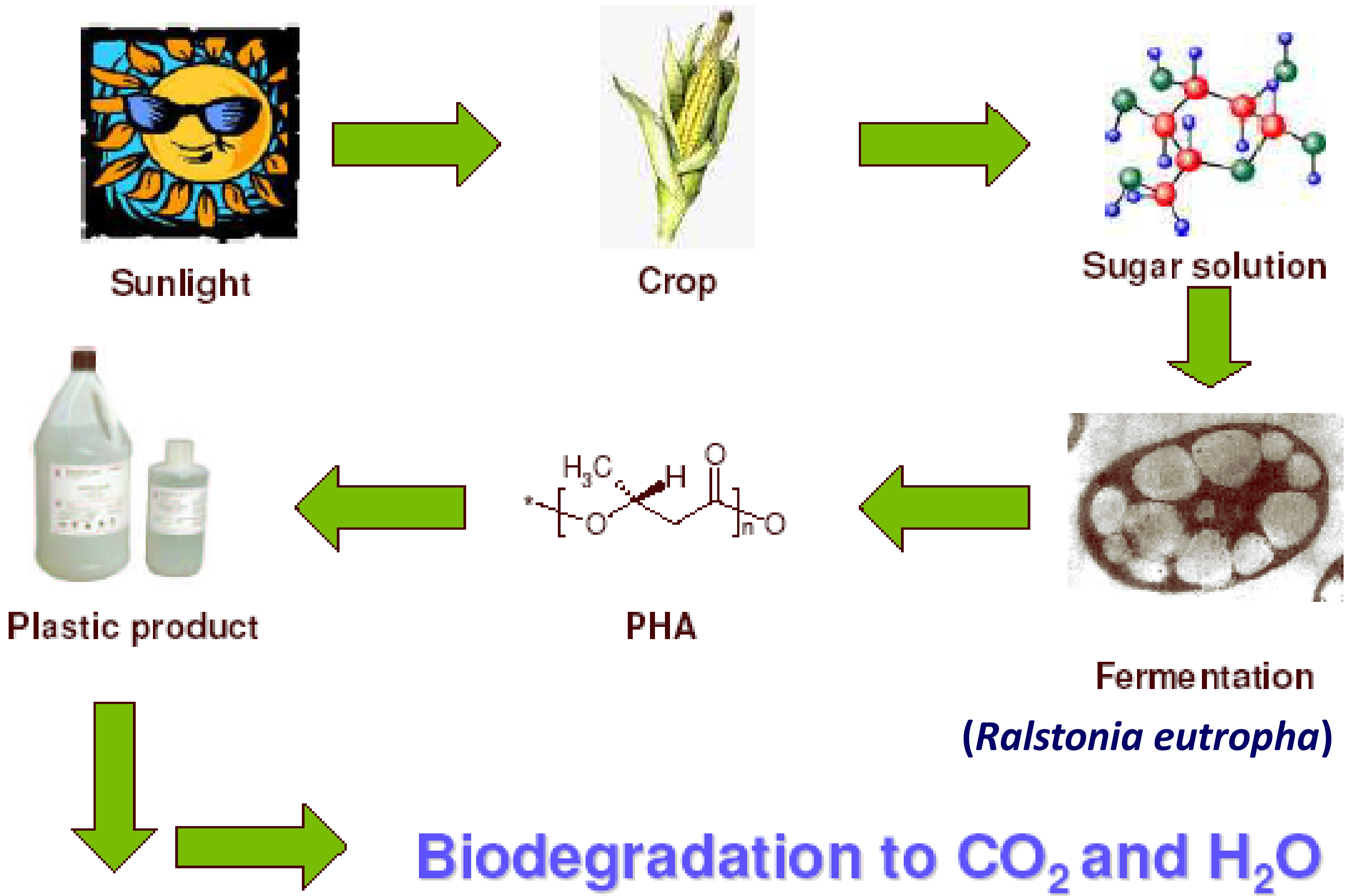
Bioplastics - Polylactic acid - PLA for production of plastics



Bioplastics - Polylactic acid - PLA for production of plastics

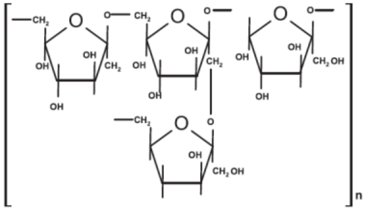


Bioplastics – Polyhydroxyalkanoates PHA's

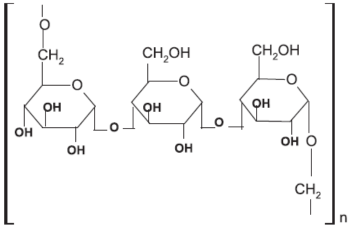


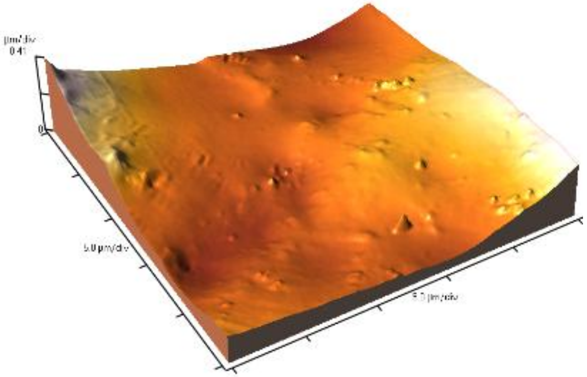
In 2016 260 million tons of plastic were produced worldwide and around 4,2 million tons of bioplastics. Estimations are that 6,1 milion tons will be produced in 2021.

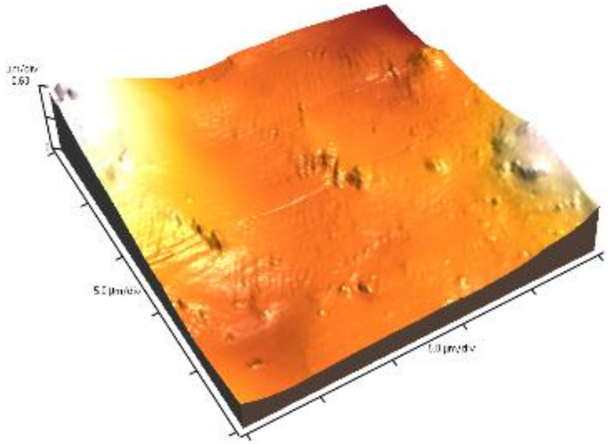
PHA 3-5 EUR/kg
Propilen 1 EUR/kg

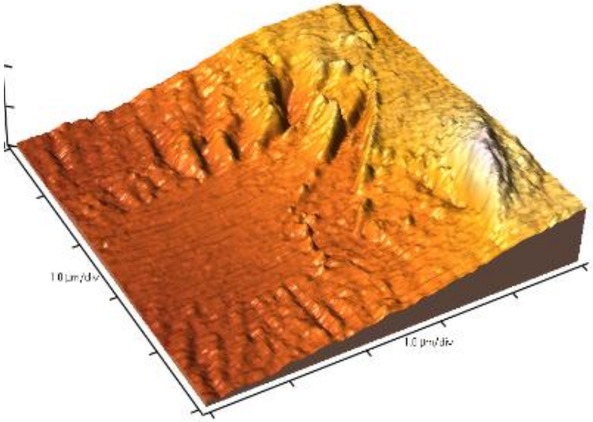


Bioplastics – levan & pullulan










Kurir STOP NASILJU
NASLOVNA
VESTI
STARS
SPORT
HRONIKA
REGION
PLANETA
ZABAVA
EXTRA
STIL
A MASOVNA TUČA! Sevale su pesnice, prštale uvrede, a JEZIVE SCENE su obišle ceo svet (VIDEO)
09:15h
DAČIĆ: Srbiji nisu potrebne verb
NAJNOVIJE VESTI
PENZIONERI, 3.000 DINARA STIŽE VAM U PETAK: Jednokratna pomoć
ŠOK MODA U JUŽNOM DELU MITROVICE: I lutke u butiku obukli u
RAMINA VELIKOALBANSKA PROVOKACIJA: Ovako je s
NJUJORK TAJMS NAHVALIO NIŠKI MEGAPROJEKAT: Umesto kasarne,
Foto: Privatna arhhiva
REGISTRATION DESK
PRVI PUT U SRBIJI EKO-INOVATIVNO RECIKLIRANJE: Bakterije koje jedu plastiku da bi proizvele bioplastiku!
NAJNOVIJE
NAJČITANIJE
REAKCIJE
09:32
SVAKOG JUTRA JELA SAM OVSENU KAŠU SA TOPLOM VODOM: Kada sam videla rezultate 30 dana posle, ŠOKIRALA SAM SE!
09:30
GRUZIJA IZABRALA PRVU ŽENU PREDSEDNIKA: Salome Zurabišvili pobedila u drugom krugu predsedničkih izbora 11
09:29
29. NOVEMBAR: Dan kada je rođena Jugoslavija! 216 383
09:20
TAČI ZA GLAS AMERIKE: Puna mu usta razgraničenja i promene rezolucije 1244, a za takse pravi se lud! Pa još Beogradu postavlja i ovaj uslov?!
09:19
VAJLDER UBO FJURIJA PRSTOM U OKO, A ONDA JE NASTALA MASOVNA TUČA! Sevale su pesnice, prštale uvrede, a JEZIVE SCENE su obišle ceo svet (VIDEO)
adria media group

Biosynthesis and recent advances in the production of bacterial cellulose

Cellulose is the most common natural polymer worldwide and **10^{14} t of cellulose pulp are produced each year**. Due to the presence of components other than cellulose, different **chemical treatments employing** highly polluting chemical products, such as **chlorine gas**, **caustic soda, carbon disulfide**, **carbon monoxide**, and **carbon dioxide**, are often needed prior to use in order to obtain pure cellulose.

Donini et al. compared the productivity of cellulose from plants and microorganisms in order to determine the advantages of producing cellulose from microorganisms. They compared the **production of cellulose** from **1 ha of eucalyptus** with a mean annual increment MAI of 25 t/ha/year. With 7 years from planting to cultivation, yielding about 45 % cellulose contents, this process would yield **about 80 t of cellulose/ha after 7 years of cultivation**.

The same production could be achieved with bacteria to a hypothetical yield of 15 g/L in 50 h of culture (average of 0.3 g/h) in a bioreactor of 500 m^3 in approximately 22 days.

Unlike plant cellulose, BNC is produced in the pure form, devoid of lignin, hemicellulose, pectin, or any other compound present in the plant pulp!!!

Donini I, De Salvi D, Fukumoto F, Lustri W, Barud H, Marchetto R, Messaddeq Y, Ribeiro S (2010) 35:165–178

Bacterial nanocellulose - BNC

BNC can provide improved mechanical qualities to the biomaterial owing to its **biocompatibility**, **biofunctionality**, **lack of toxicity**, and **ease of sterilization**.

BNC is a highly crystalline **linear polymer of glucose** synthesized mainly by the bacterium ***Gluconacetobacter xylinus*** (formerly named *Acetobacter xylinus*). Although BNC production has been studied primarily in *G. xylinus*, other microorganisms also exhibit the ability to synthesize this biopolymer, such as other species of ***Gluconacetobacter***, ***Agrobacterium tumefaciens***, ***Rhizobium* spp**., and Gram positive ***Sarcina ventriculli***.

One important aspect in BNC production is **to identify a low-cost culture medium** that can improve the yield of BNC and be used as an economically viable solution for application in a range of fields.

Bacterial nanocellulose – Carbon source

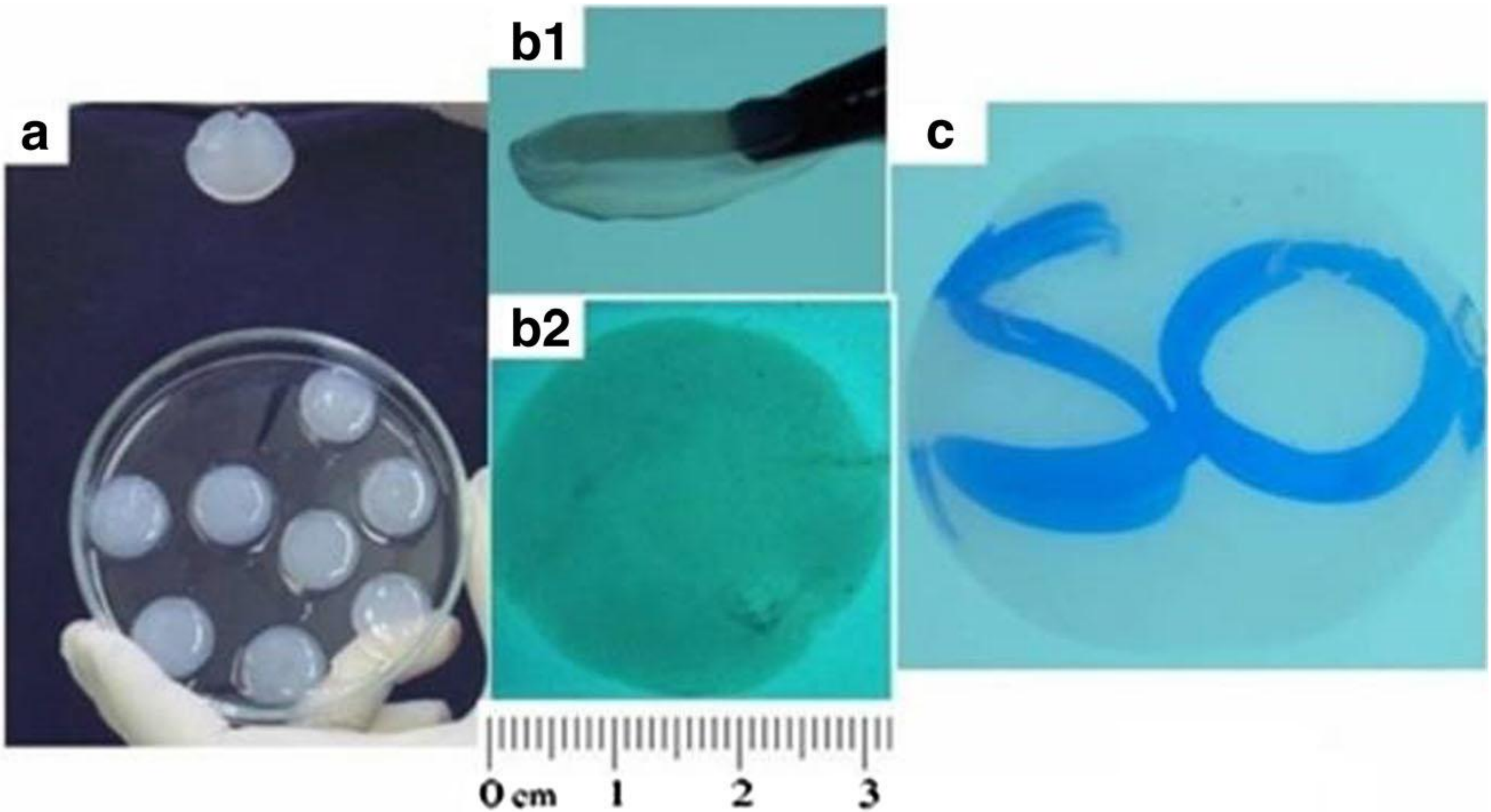
Appl Microbiol Biotechnol

Table 1 Conditions, yields, production methods and microorganisms used to produce bacterial nanocellulose described in the literature starting in 2006

Carbon source	BNC Yield (g/L)	Production method	Microorganism	Reference
HS in the presence of 1 % lignosulfonate	16.32	Static culture at 28 °C for 168 h	*G. xylinus* IFO 13693	(Keshk and Sameshima 2006)
Sucrose	3.83	Static culture at 30 °C for 96 h	*G. xylinus* ATCC 53524	(Mikkelsen et al. 2009)
Orange juice containing nitrogen sources of HS	5.90	Static culture at 30 °C for 96 h	*Acetobacter xylinum NBRC 13693*	(Kurosumi et al. 2009)
Glucose in the presence of MCP-1	1.20	Stirred culture at 30 °C and 125 rpm for 288 h	*Acetobacter xylinum JCM 9730*	(Hu and Catchmark 2010)
Molasses and corn steep liquor in the presence of acetic acid	3.12	Stirred culture at 30 °C and 200 rpm for 168 h	Acetobacter sp. V6	(Jung et al. 2010))
Glucose	2.70	Static culture at 30 °C for 96 h	*G. sacchari*	(Trovatti et al. 2011))
Glucose (HS broth supplemented with n-butanol)	1.33	Static culture at 30 °C for 144 h	*A. xylinum 186*	(Lu et al. 2011)
HS broth supplemented with thin stillage	10.22	Static culture at 30 °C for 168 h	*G. xylinus (BCRC 12334)*	(Wu and Liu 2012)
Industrial residues from olive oil production	1.28	-	*G. sacchari*	Gomes et al. (Gomes et al. 2013)
Molasses	1.64	Static semicontinuous process for 168 h	*G. xylinus (FC01)*	Çakar et al. (Cakar et al. 2014)
Waste beer yeast treated with ultrasonication	7.02	Stirred culture at 30 °C and 150 rpm	*G. hansenii* CGMCC 3917	Lin et al. (Lin et al. 2014)
Rotten fruit culture	60	Static culture at 30 °C and 96 h	*G. xylinus ATCC 53582*	(Jozala et al. 2015))
Wood hot water extract	0.15	Static culture at 28 °C for 672 h	*Acetobacter xylinum 23,769*	(Erbas Kiziltas et al. 2015b)
Waste water of candied jujube hydrolysate	2.25	Static culture at 30 °C for 144 h	*G. xylinus* CGMCC 2955	(Li et al. 2015)
Citrus Juice and sucrose	–	Static culture at 30 °C	*G. sp. gel*_SEA623-2	(Kim et al. 2015)
Lipid fermentation wastewater	0.66	Static culture at 28 °C for 5 days	*G. xylinus* CH001	(Huang et al. 2016)

Jozala et al, Appl Microbiol Biotechnol. 2016, 100(5):2063-72

Bacterial Nanocellulose produced by culture medium composed by rotten fruits: A) After treatment with NaOH; B1, B2 size and thickness, C transparency.



Jozala et al, Appl Microbiol Biotechnol. 2016, 100(5):2063-72

Bacterial nanocellulose applications in different areas

Area	Application
Cosmetics	Stabilizer of emulsions like creams, tonics, conditioners, nail polishes.
Textile industry	Sports clothing, tents and camping equipment
Mining and refinery	Sponges to collect leaking oil, materials for absorbing toxins.
Waste treatment	Recycling of minerals and oils
Sewage purification	Urban sewage purification, ultra filtration water
Communications	Diaphragms for microphones and stereo headphones
Food industry	Edible cellulose (nata de coco)
Paper industry	Artificial replacement of wood, special papers
Medicine/ biomedical	Temporary artificial skin for burns and ulcers, dental implant components; Antimicrobial wound dressing, Nanofilm, Drug Delivery, Drug excipient.
Laboratories	Protein immobilization, chromatographic techniques, tissue culture medium
Electronics	Opto-electronics materials (liquid crystal displays)
Energy	Membrane fuel cell (palladium)

Pesticides

NATURAL PESTICIDES

- Secondary metabolites of microorganisms, plants and insects
- Spinosad insecticide of soil actinomycete (*Saccharopolyspora spinosa)*
- *Bacillus thuringiensis* pesticide
- Insect pheromones...

Biofuels

Fuels – Biodiesel and Bioethanol

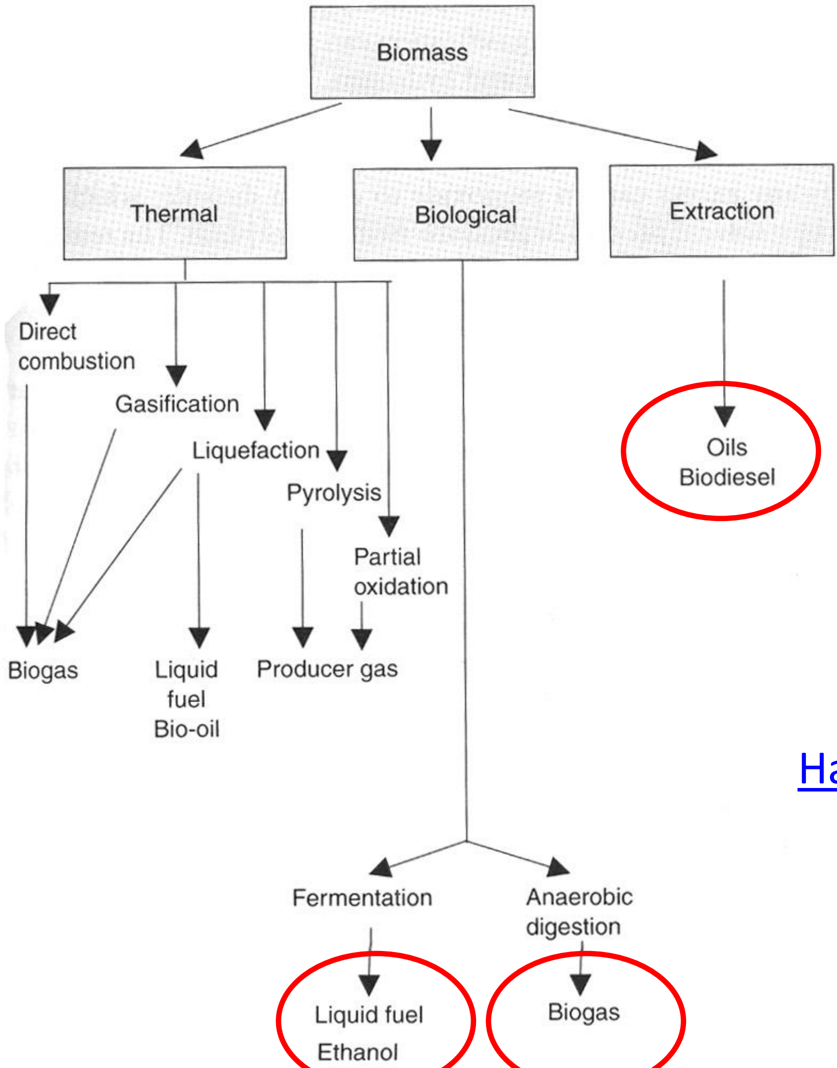
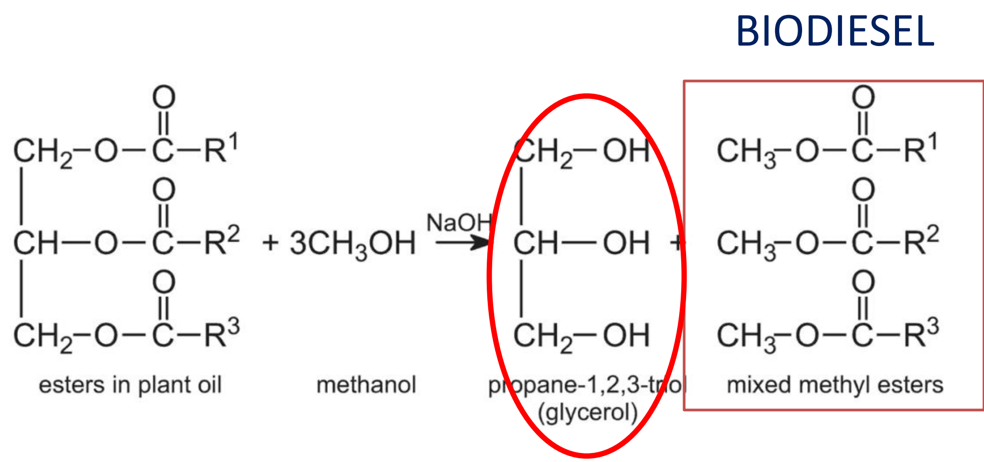


Figure 7.17 The routes for the extraction of energy from biomass using extraction, thermal, and biological methods.



Haider et al., *Nature Chemistry* (2015) 7, 1028–1032

Metal nanoparticles

Recently, synthesizing metal nanoparticles using microorganisms and plants has been extensively studied and has been recognized as a green and efficient way for further exploiting microorganisms as convenient nanofactories!

Applications of metal nanoparticles: electrochemical sensors and biosensors, biomedical, agricultural, environmental, and physiochemical areas.

Gold nanoparticles**:** specific delivery of drugs, for tumor detection, angiogenesis, genetic disease and genetic disorder diagnosis, photoimaging, and photothermal therapy.

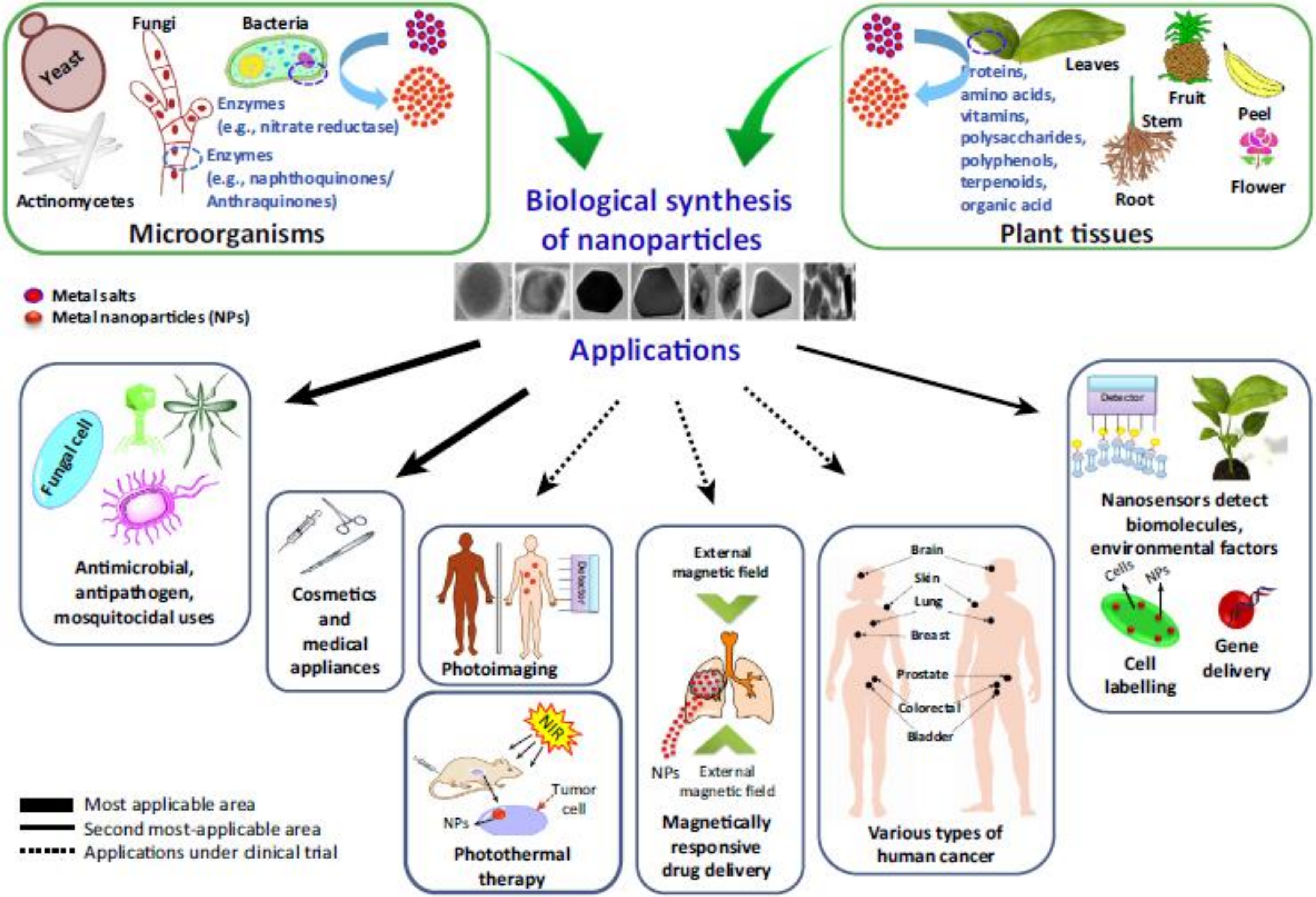
Iron oxide nanoparticles: for cancer therapy, hyperthermia, drug delivery, tissue repair, cell labeling, targeting and immunoassays, detoxification of biological fluids, magnetic resonance imaging, and magnetically responsive drug delivery therapy.

Silver nanoparticles**:** antimicrobial purposes, anticancer, anti-inflammatory, and wound treatment applications.

Zinc and **titanium** nanoparticles**:** biomedicine, cosmetic, ultraviolet (UV)-blocking agents, and various cutting-edge processing applications.

Copper and **palladium** nanoparticles**:** batteries, polymers, plastics plasmonic wave guides, and optical limiting devices, as antimicrobial agents.

Biological Synthesis and Applications of Metal Nanoparticles in Biomedical and Environmental Fields

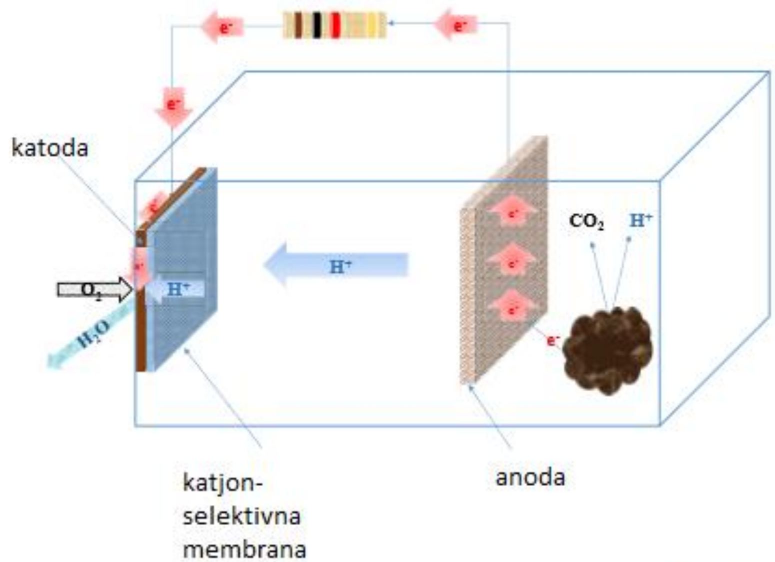


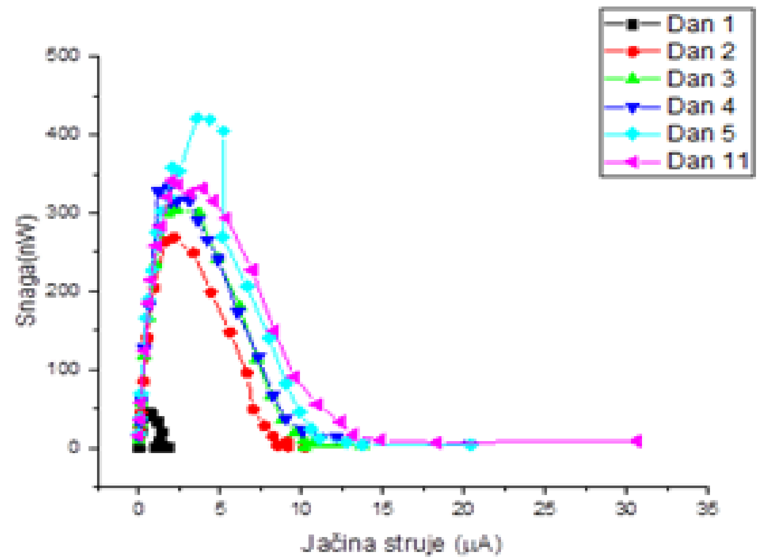
Singh et al., Trends in Biotechnology, July 2016, Vol. 34, No.

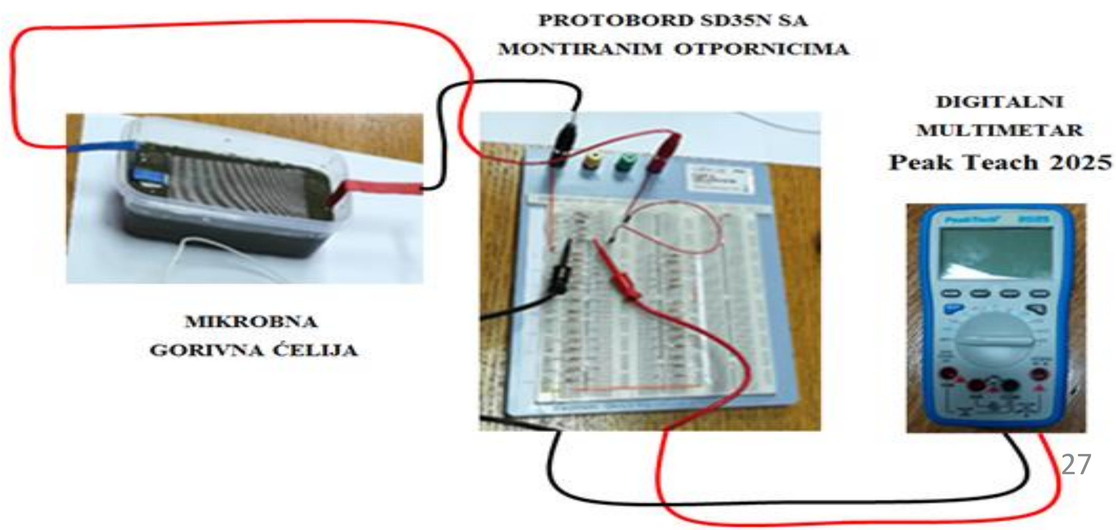
Microbial Fuel Cells

Electricity from Microorganisms

Grafik zavisnosti snage razvijene na nizu otpornika od jačine struje koja protiče kroz otpornike

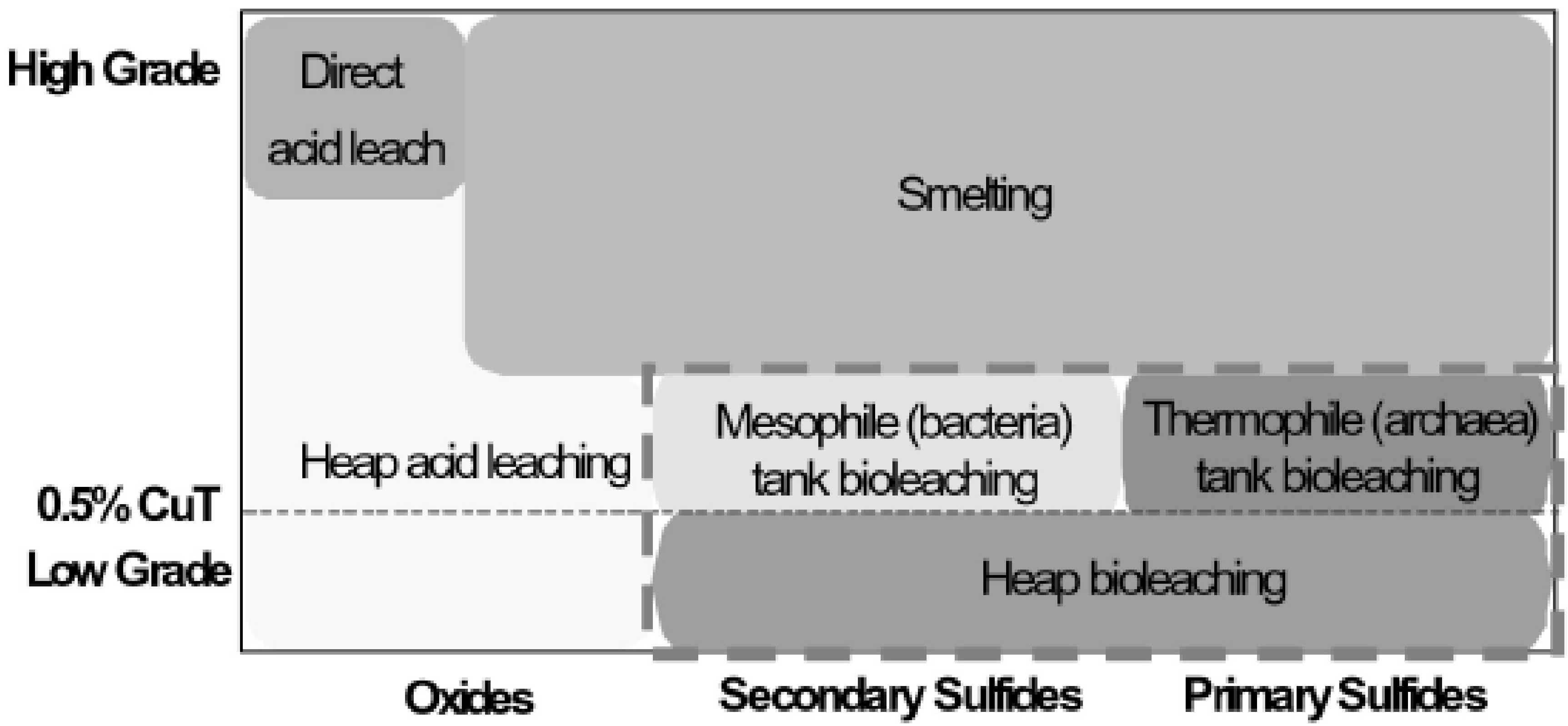






Biohydrometallurgy

Copper Extraction Technologies



Hydrometallurgical:
Mining, crushing, milling, flotation => Copper concentrate => smelter proces => metal

Biohydrometallurgical:
Mining, crushing, milling, => acidic sulfate solution => solvent extraction or electrowinning

BASICS IN BACTERIAL METAL LEACHING IN THE PRESENCE OF PYRITE (FeS_2)

$MS_{(s)} + 2O_2 \rightarrow M^{2+} + SO_4^{2-}$	*At.spp.*	(B)
$FeS_{2(s)} + 3,5O_2 + 0,5H_2O \rightarrow Fe^{3+} + H^+ + 2SO_4^{2-}$	*At.f.*	(B)
$2MS_{2(s)} + 10Fe^{3+} + 4H_2O \rightarrow 2M^{2+} + 10Fe^{2+} + S + 8H^+ + SO_4^{2-}$		(H)
$FeS_{2(s)} + 2Fe^{3+} \rightarrow 3Fe^{2+} + 2S$		(H)
$S + 6Fe^{3+} + 4H_2O \rightarrow 6Fe^{2+} + 8H^+ + SO_4^{2-}$		(H)
$MS_{(s)} \rightarrow M^{2+} + S + 2e^-$		(E)
$0,5O_2 + 2H^+ \rightarrow H_2O - 2e^-$		(E)
$Fe^{2+} + 0,25O_2 + H^+ \rightarrow Fe^{3+} + 0,5H_2O$	*At.f.*	(B)
$S + 1,5O_2 + H_2O \rightarrow 2H^+ + SO_4^{2-}$	*At.th.*	(B)
$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_{3(s)} + 3H^+$		(H)
$M(O, CO_3, SiO_3)_{(s)} + 2H^+ \rightarrow M^{2+} + (CO_2, SiO_2) + H_2O$		(H)

(B)-Biochemical, (H)-Chemical, (E)-Electrochemical

HEAP LEACHING PLANT FOR EXTRACTION OF COPPER FROM OXIDIC ORE IN LOMAS BAYAS, CHILE

Pad-drainage system

Stacker

Irrigated heap drippers

Copper leachate from heap to pond

GEOCOAT® PLANT, EXTRACTION OF GOLD, SOUTH AFRICA

1893-2003

❖**INOCULUM BUILDUP (*Acidithiobacillus ferrooxidans, Acidithiobacillus thiooxidans, Leptospirillum ferrooxidans, thermophilic archaea Sulfolobus and Acidianus*)**

BIOX® plant, extraction of GOLD, South Africa

Mešana populacija: ***Acidithiobacillus ferrooxidans, Acidithiobacillus thiooxidans, Leptospirillum ferrooxidans, Acidithiobacillus caldus, Leptospirillum ferriohilum, Ferroplasma-like archaea***

		Monthly Average					
		May-05	Jun-05	Jul-05	Aug-05	Sep-05	Oct-05
Concentrate treated	tpd	64.1	66.3	69.2	62.2	65.6	69.7
Concentrate gold grade	g/t	103.6	118.0	137.1	91.9	114.0	102.9
Concentrate S^{2-} grade	%	14.3	15.3	14.2	14.2	15.2	14.4
Sulphide oxidation	%	95.9	95.8	95.2	95.3	95.9	96.1
Gold recovery	%	97.5	96.7	96.9	96.8	97.3	97.2
BIOX® availability	%	100.0	99.6	98.8	98.8	97.4	99.4

ACID MINE DRAINAGE

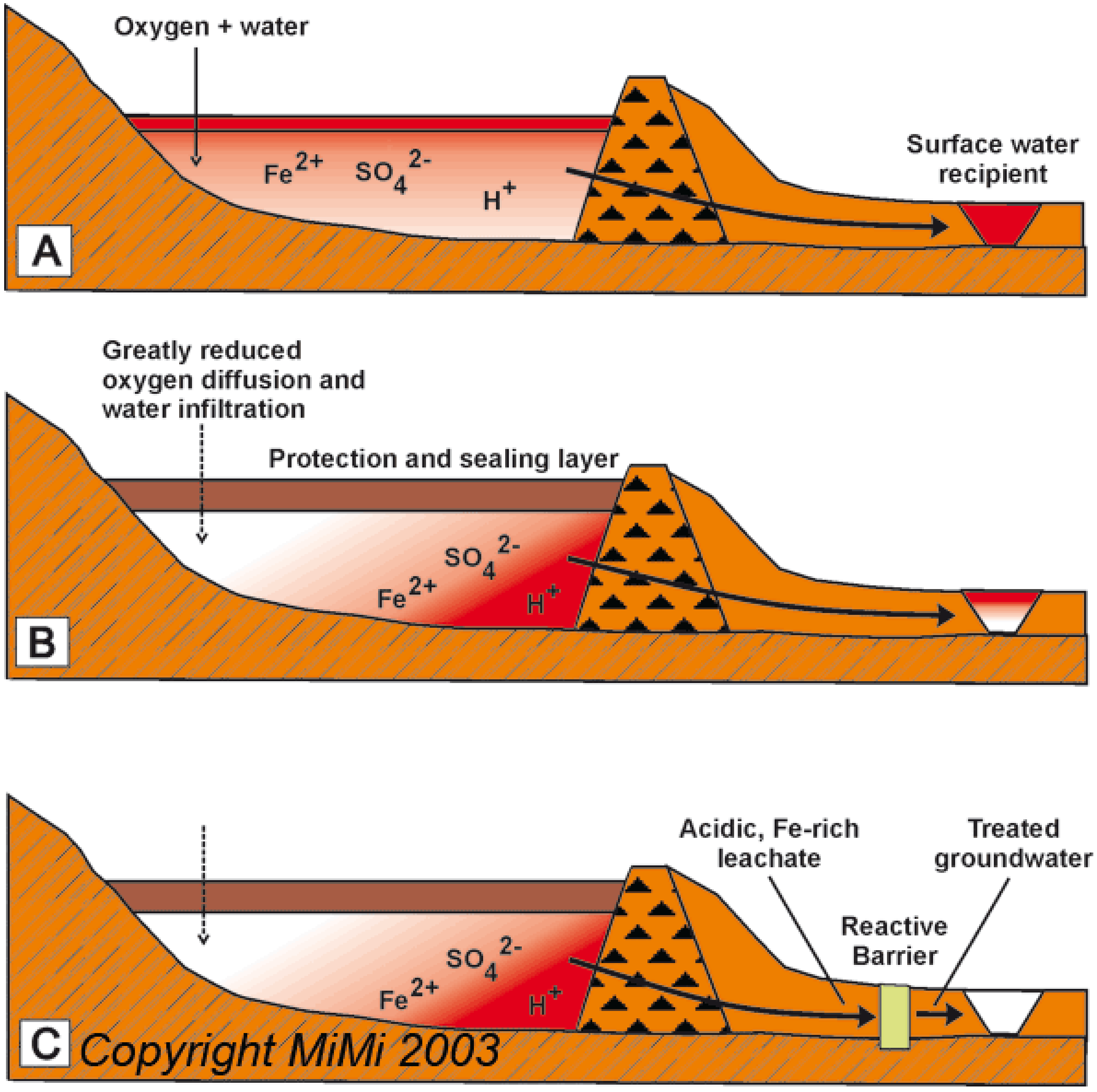
1. Mineral processing and other anthropogenic activities leave by-products exposed to oxygen and moisture in the air. If the by-products are **sulfide minerals** they may start to **bioleach** out of control and cause the environmental problem known as acid mine drainage (AMD). AMD manifests itself as acidified groundwater contaminated by heavy metals.

2. Drainage flowing from or caused by surface mining or coal refuse piles that are typically **highly acidic** with elevated levels of **dissolved metals**.

Acid mine drainage is formed by **uncontrolled bioleaching reactions - **a series of complex geochemical and microbial reactions that occur when **water** and **oxygen** come into **contact** with **pyrite** (iron disulfide minerals) in for example coal, refuse or the overburden of a mine operation.

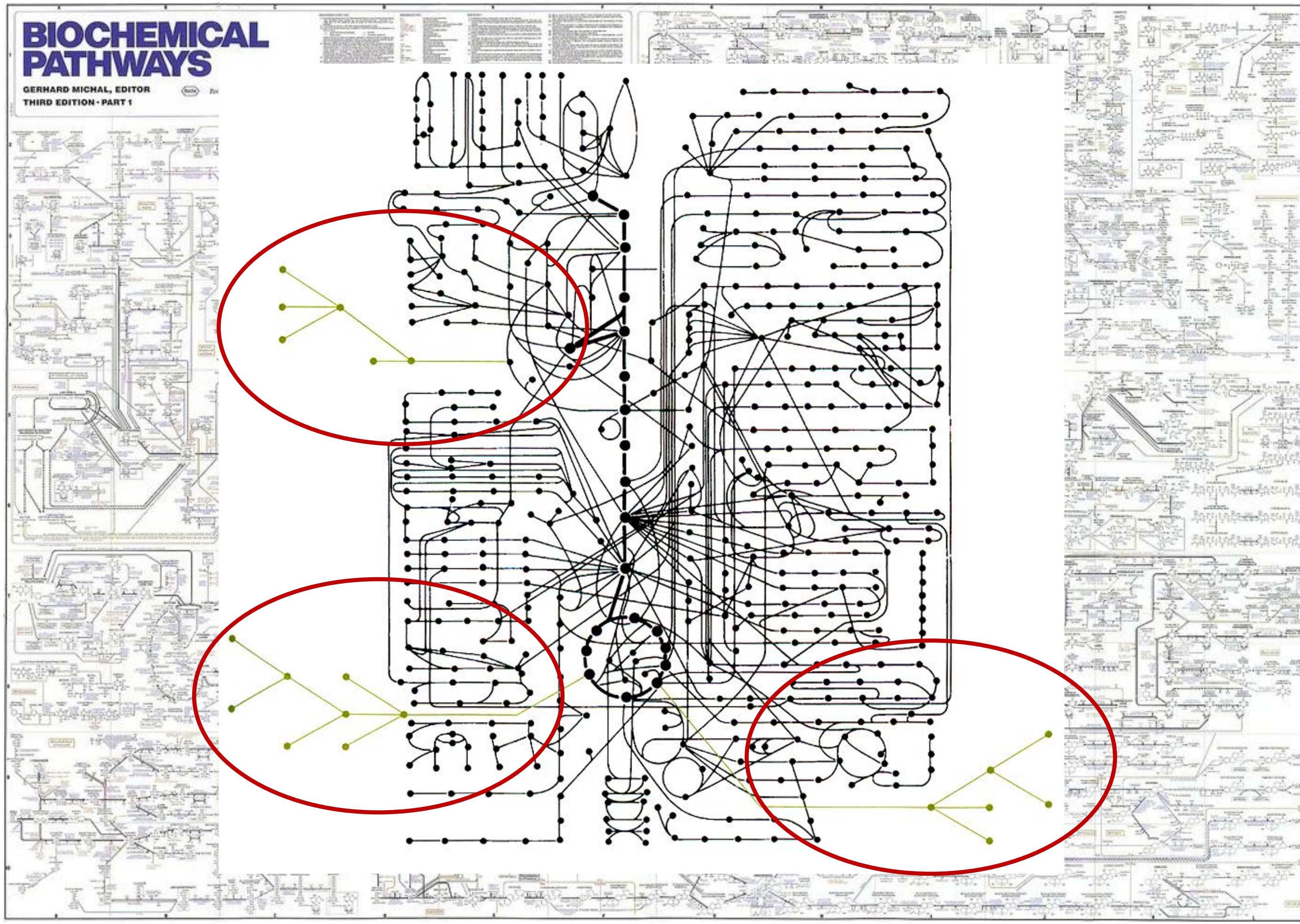
ACID MINE DRAINAGE

[Copper mine Bor]


Oxygen + water
Fe2+ SO4 2- H+
Surface water recipient
A
Greatly reduced oxygen diffusion and water infiltration
Protection and sealing layer
SO4 2- Fe2+ H+
B
Acidic, Fe-rich leachate
Treated groundwater
Reactive Barrier
SO4 2- Fe2+ H+
C
Copyright MiMi 2003

Bioremediation

CHEMICAL AND BIOCHEMICAL ACTIVITY OF MICROORGANISMS



Thank you for your attention