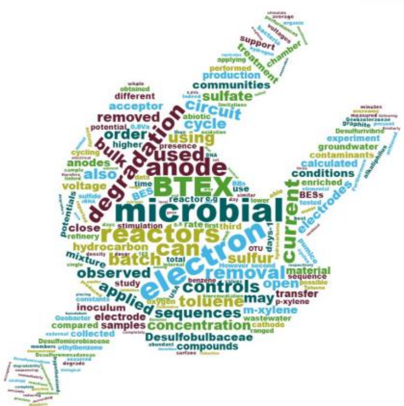
MICROBIAL FUEL CELLS

Aprovechamiento del potencial energético de sedimentos contaminados con hidrocarburos

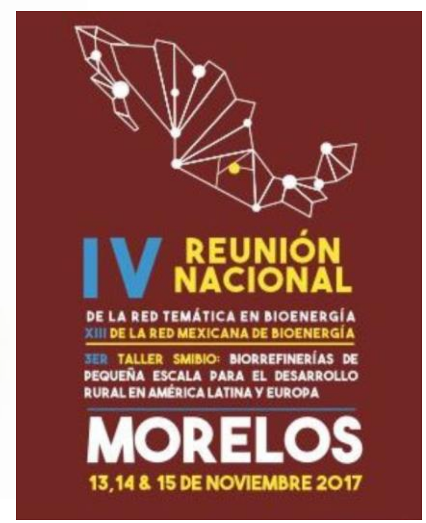
Using anode-respiring bacteria to generate direct electrical current from hydrocarbon sediments



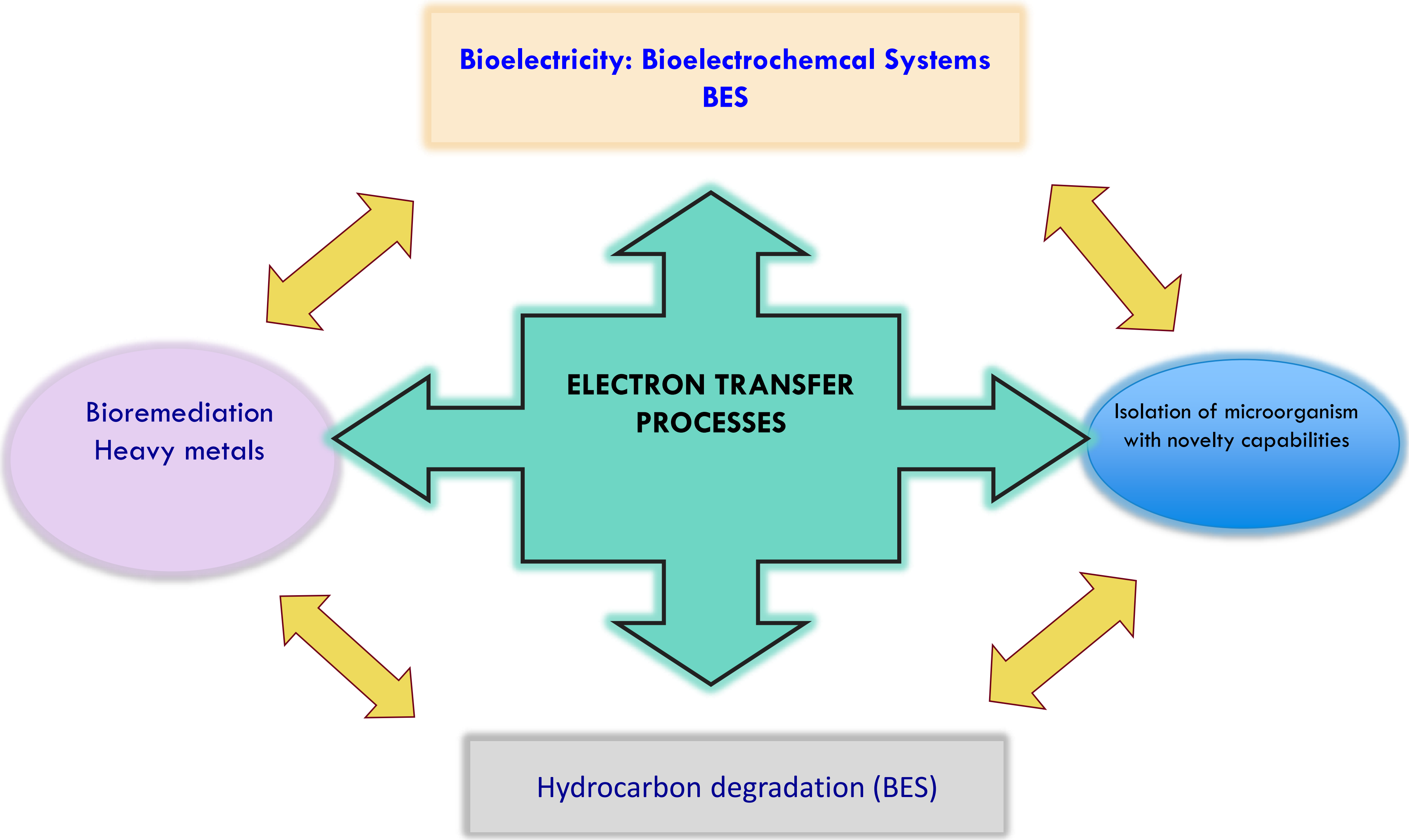
Dra Katy Juárez López

partamento de Ingeniería Celular y Biocatálisis.

Instituto de Biotecnología, UNAM.

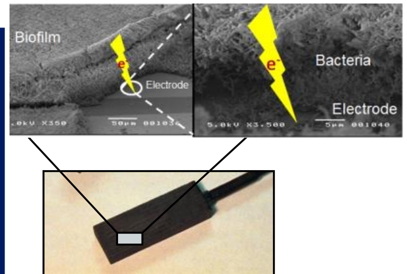


BIOENERGY AND ENVIRONMENT



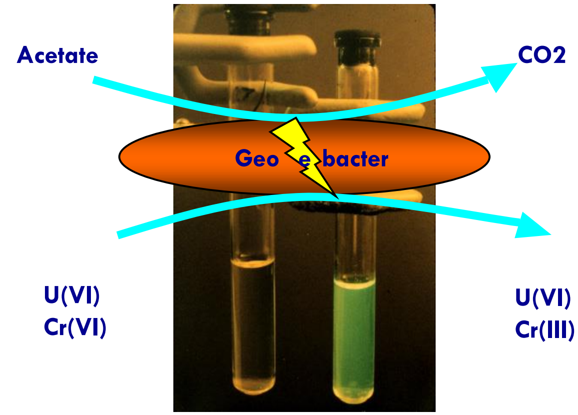
Geobacter sulfurreducens: model bacteria for extracellular electron transfer

bioelectricity



Microbial Fuel Cell (MFC)

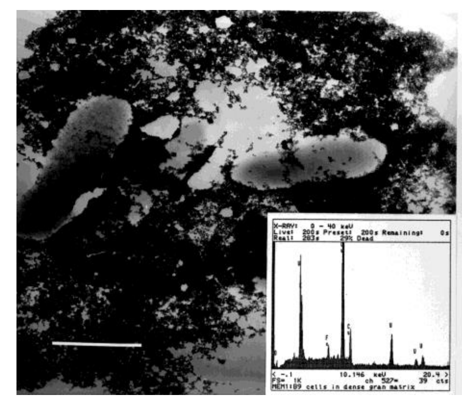
Bioremediation



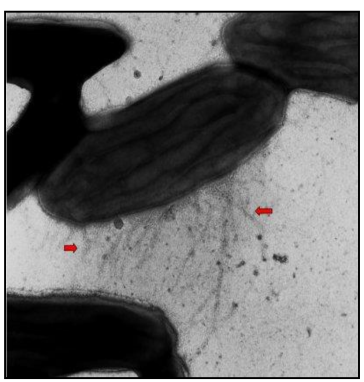
- Subsurface bacteria, anaerobic

- Biogeochemical cycles Fe and Mn.
- Electron transfer to extracellular insoluble acceptors.
- More than 100 cyt

Hydrocarbon degradation



Geopili “nanocables”



Microbial Fuel Cell

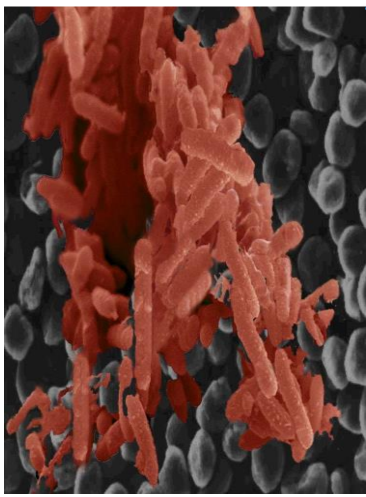
Reaction e⁻ donor : $CH_3COO^- + 3\ H_2O \rightarrow CO_2 + HCO_3^- + 8H^+ + 8e^-$ 0.29 V

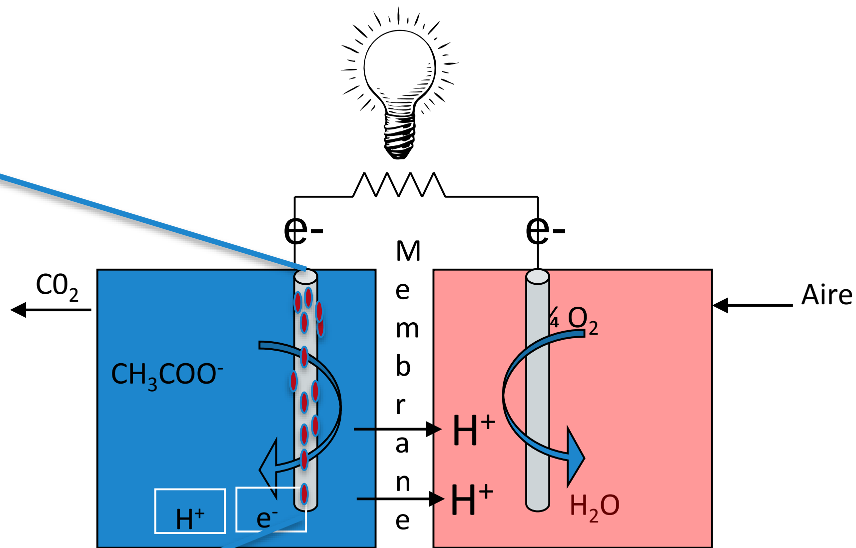
Reaction e⁻ acceptor : $2\ O_2 + 8H^+ + 8e^- \rightarrow 4\ H_2O$ 0.81 V

Global reaction: $CH_3COO^- + 2O_2 \rightarrow CO_2 + HCO_3^- + H_2O$ 1.10 V

↓

0.3 - 0.6 V



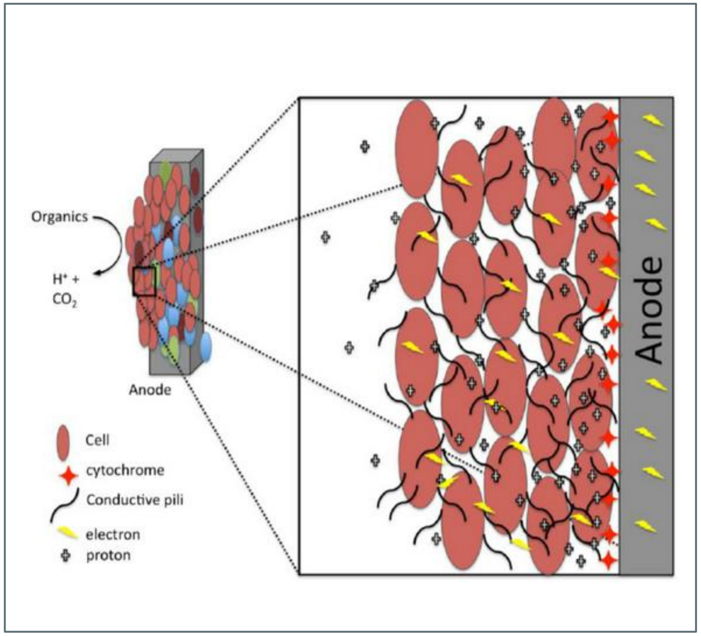


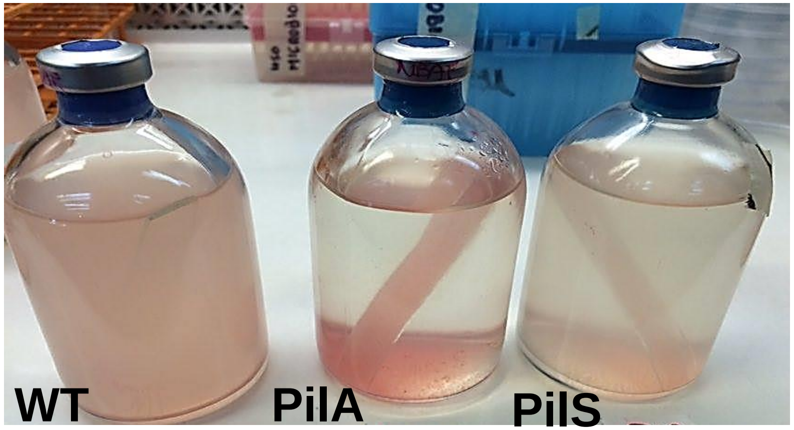
What is the limiting factor ?

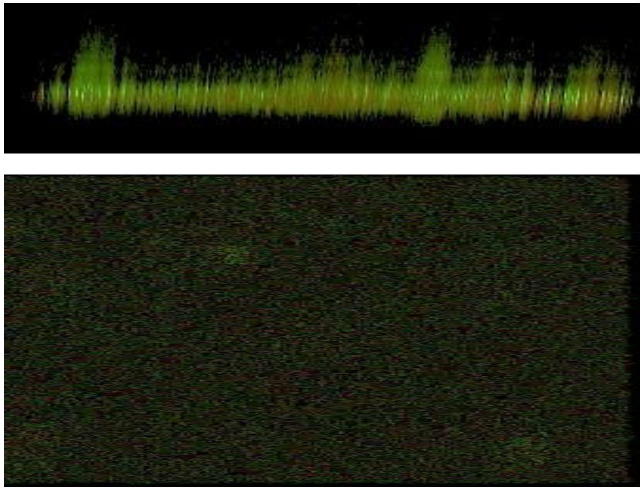
- BIOFILM (electron transfer)

- Anode material and architectute MFC
- Inhibiting metabolites
- Internal resistance

Biofilm characterization in MFC



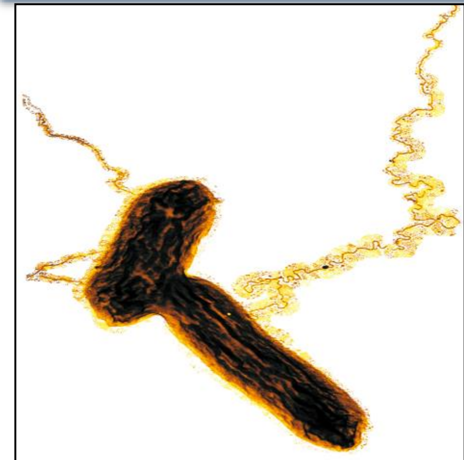


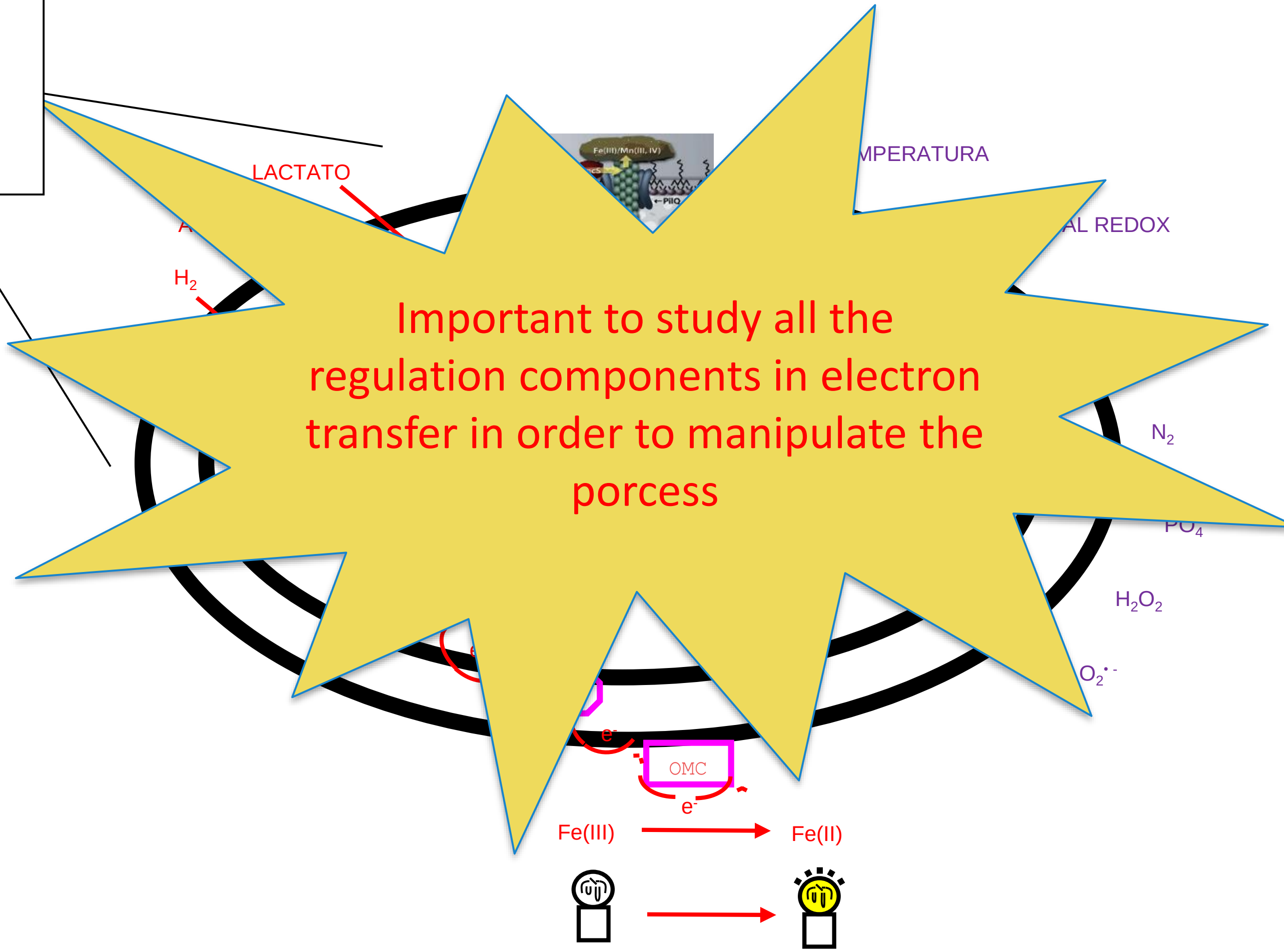


Mutant PilA-
Biofilm non
conductive

Mutante Flp1-

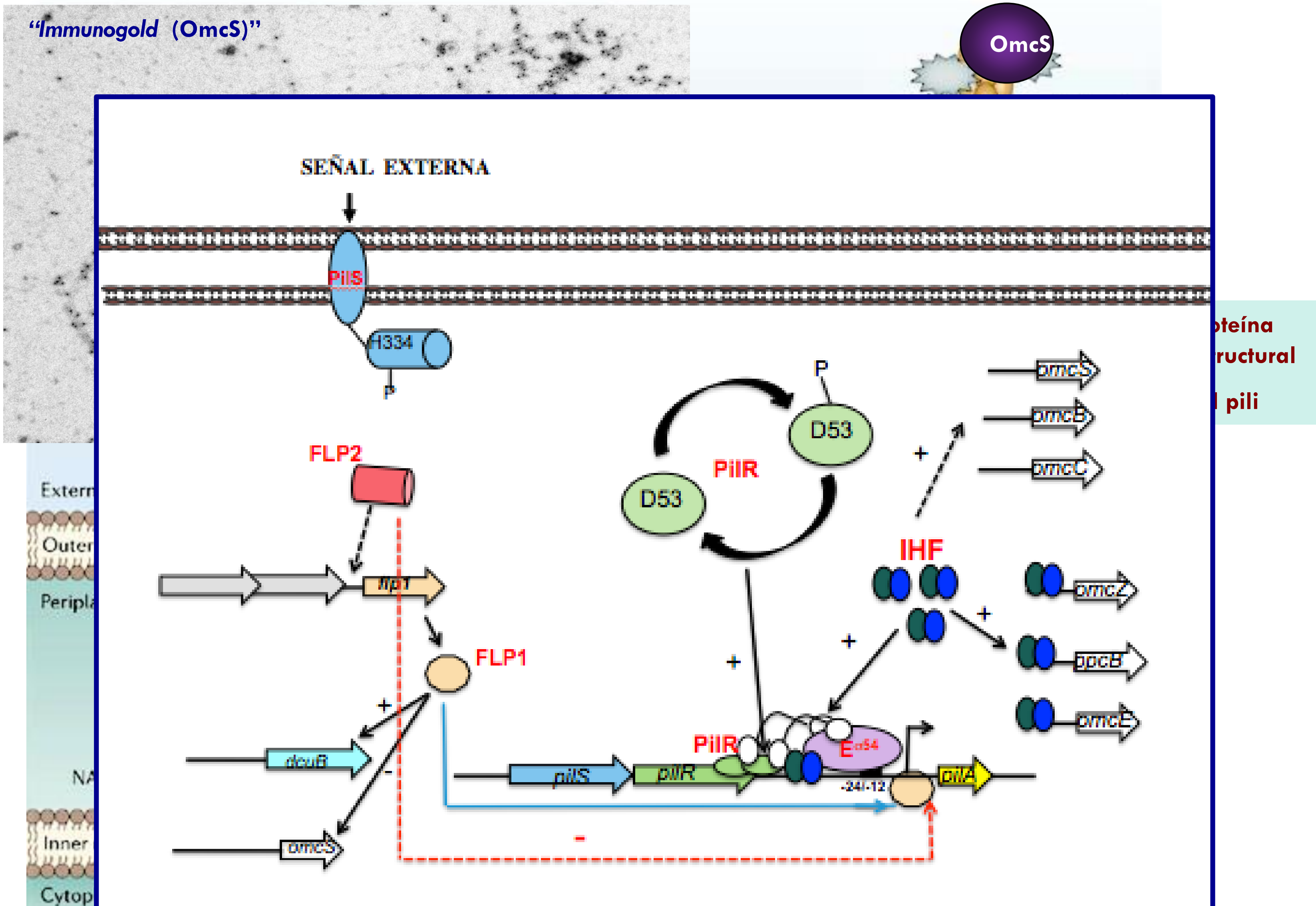
ELECTRON TRANSFER REGULATION Fe(III) other heavy metals and anode in MFC?





Important to study all the regulation components in electron transfer in order to manipulate the porcess

¿Cómo se lleva a cabo la transferencia de electrones?



modificado de Lovley. 2006. *Nat Rev Microbiol* 4, 497

Leang, *et al.* 2010. *Appl Environ Microbiol* 76, 4080

Rollefson, *et al.* 2011. *J. Bacteriol* 193:1023-33

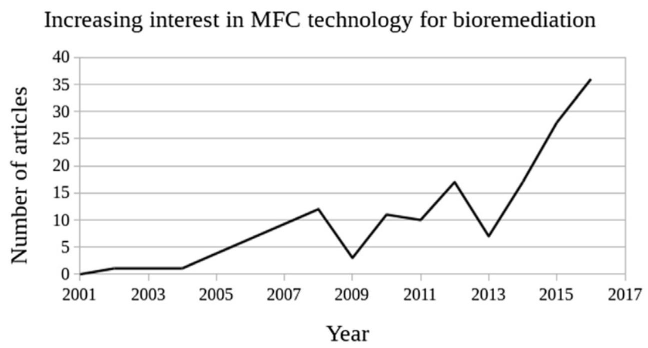


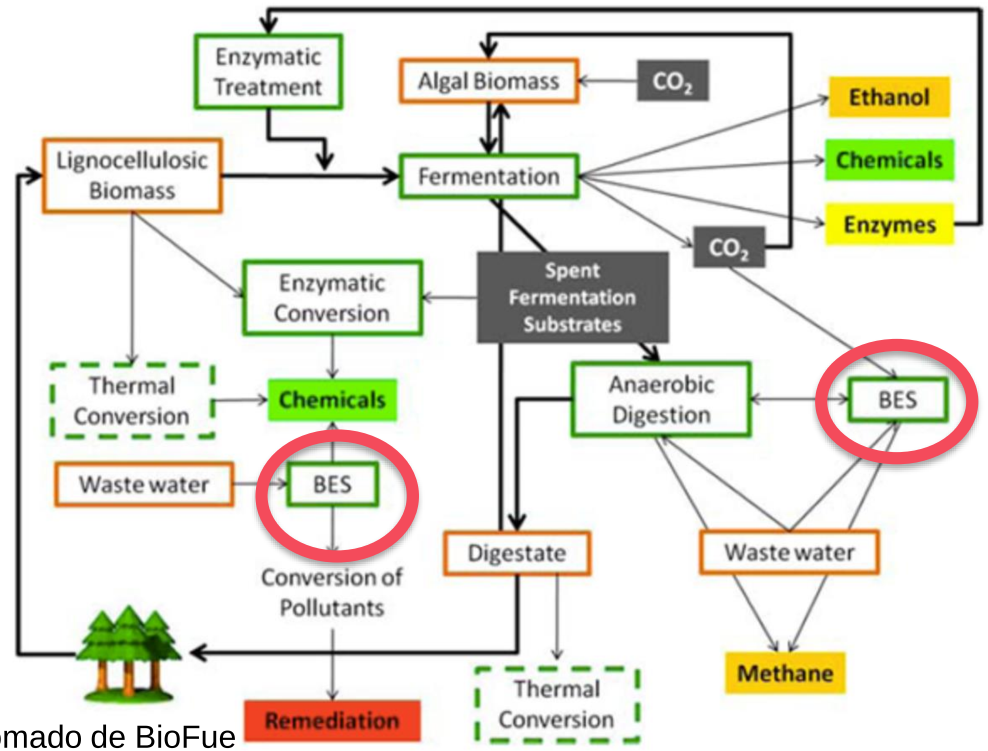
Fig. 1. Number of hits of relevant articles per year (reviews excluded) on "Web of Science" in February 2017 using the key words "bioremediation" and "microbial&fuel&cell".

M. Kronenberg et al. / Environmental Pollution 231 (2017) 509-523

a] Early MFC System Cost in $/m²		b] MFC Cost with New Materials in $/m²	
	Cost		**Cost**
Carbon Cloth	~ $1000	**Anode**	~ $20
Platinum Catalyst	~ $500	**Cathode**	~ $22
Binder	~ $700	**Binder**	~ $1.50
Diffusion Layer	~ $0.30	**Activated Carbon [cathode/catalyst]**	~ $0.40
Separator	~ $1.00	**Diffusion Layer**	~ $0.15
Total	~$2200	**Separator**	~ $1.00
		Total	~ $43

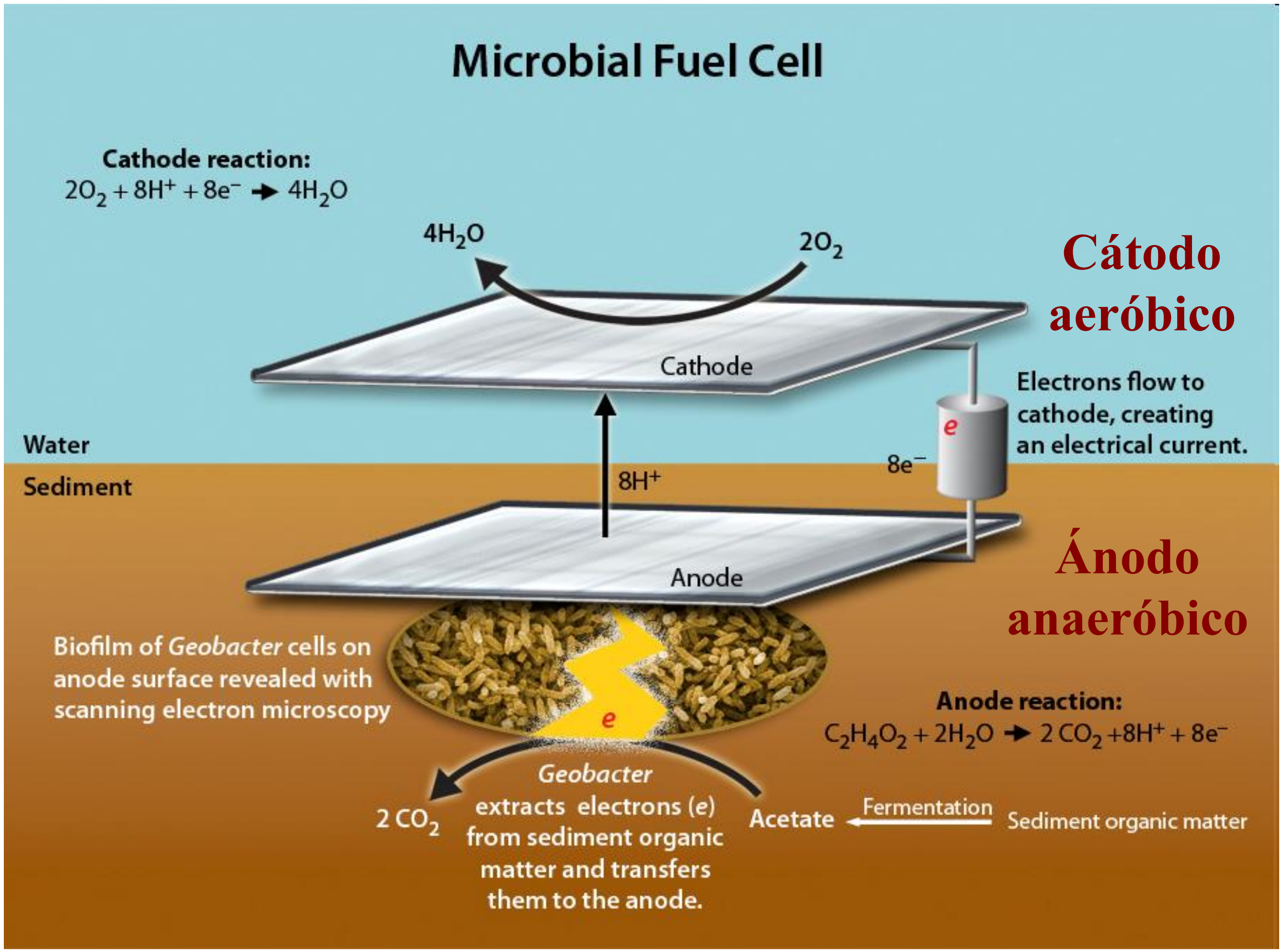
Table 1: a) Breakdown of early MFC costs for materials in $/m² (USD), b) Breakdown of MFC costs using more recent and cost-effective materials. Adapted from [169,170].

Biorefineries



Tomado de BioFue

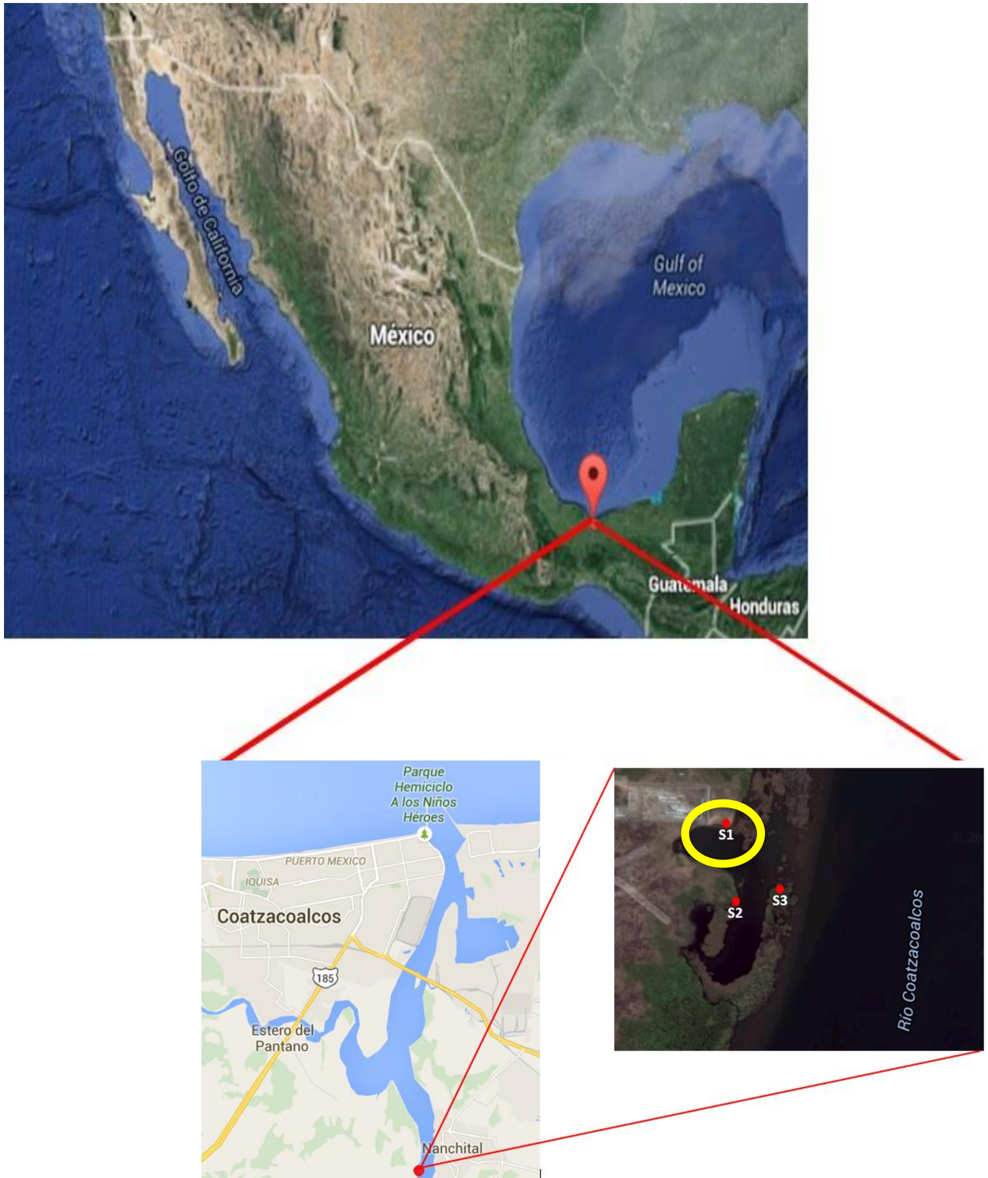
Producción de electricidad de sedimentos acuáticos y desechos orgánicos



Cátodo aeróbico

Ánodo anaeróbico

ISOLATION OF MICROBIAL CONSORTIA METAL REDUCERS AND HYDR DEGRADERS



BACTERIAL DIVERSITY 16s DNAr

MICROORAGANISMO	Identidad
Geobacter sp. Strain AK14	96%
Geobacter sp. Strain G02	99%
Geobacter sp. Strain CdA-3	99%
Petrinomonas sp. Strain B50-1	99%
Clostridium sp. Strain AP	99%
Clostridium amygdalinum strain 48AGP6	95%
Porphyromonas sp. HCB-7	95%
Geobacter sp. Strain CdA-3	92%

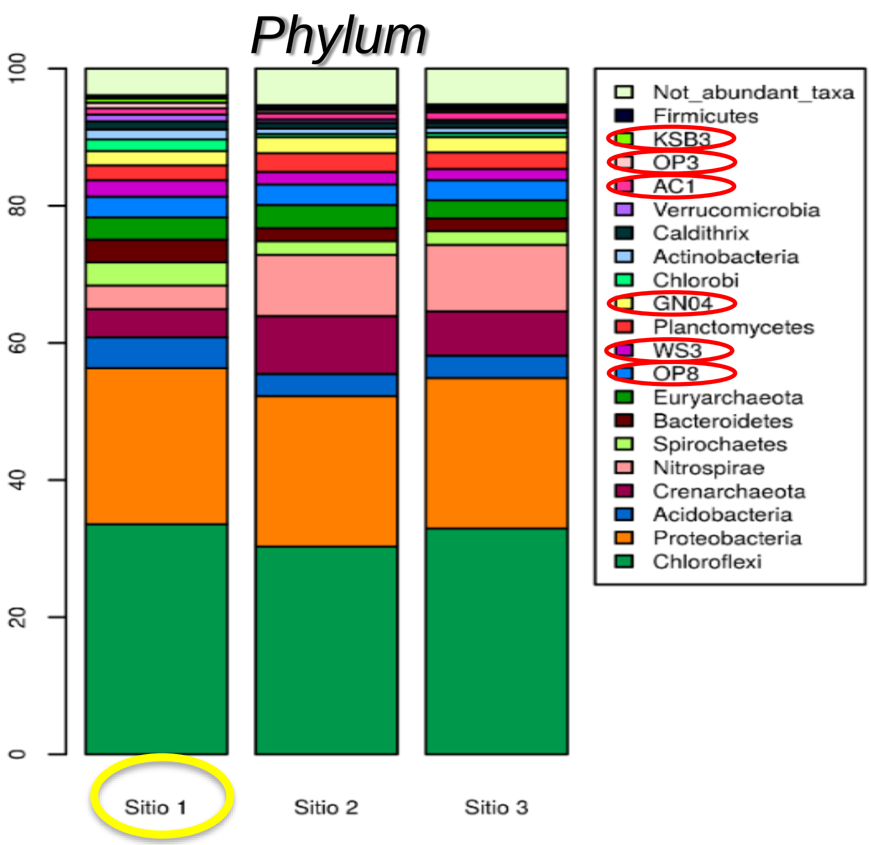
Fe(III) as electron acceptor : acetate and HYD as electron donor.

HEAVY METALS SITE 1

	U (ppm)	Pb (ppm)	Tl (ppm)	Hg (ppm)	Cr (ppm)	Mn (ppm)
SED. SITIO1	0.8	9.3	0.27	120	40.8	300

Limite permisible de Hg en sedimento (OMS) 0.1ppm

MICROBIAL DIVERSITY COATZACOALCOS RIVER



Amplicon 16s rDNA (V3-V4). Taxonomic Assignment Phylum level

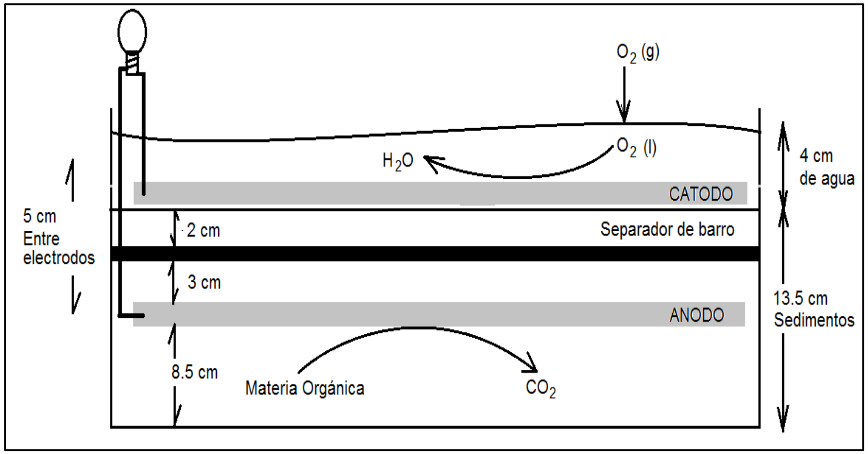
Candidato a Phylum	Procedencia
KSB3 (Tanner *et al., 2000*)	biorreactor anaeróbico de tratamiento de aguas residuales.
OP3 (*Omnitrophica*) (Stevens *et. al* 2008)	Sedimentos marinos con baja concentración de oxígeno.
AC1 (Harris *et al*., 2004)	Sedimento marino, birreactor de desnitrificación
GN04 (Narihiro *et al*.,2015)	Sedimentos marinos, planta tratadora de efluentes industriales
WS3 (Dojka *et al*., 1998)	Acuífero contaminado con hidrocarburo y compuestos clorados
OP8 (*Aminicenantes*) (Farag *et al*., 2014)	Sedimentos acuáticos contaminados con hidrocarburos

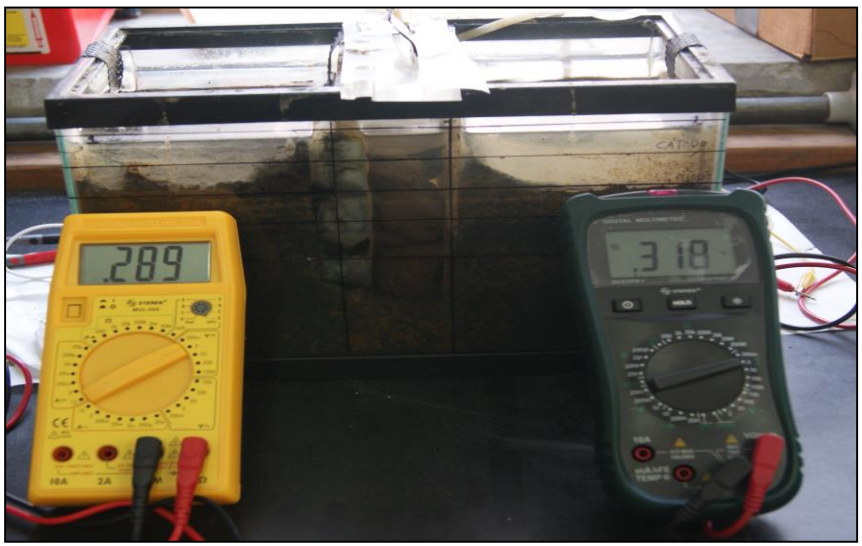
Amplicon 16s rDNA (V3-V4). Taxonomic Assignment Genera level

Clona	Procedencia
GOUTA19 (Alfreider et al., 2002)	Aguas contaminadas con mono-clorobenceno
SJA-88 (Wintzingerode, 1999)	Sedimento en hidrocarburos aromáticos policíclicos
LCP-26 (Kostka *et al*., 2004)	Sedimento marino contaminado mercurio e hidrocarburo
LCP-6 (Kostka *et al*., 2004)	Sedimento marino contaminado mercurio e hidrocarburo

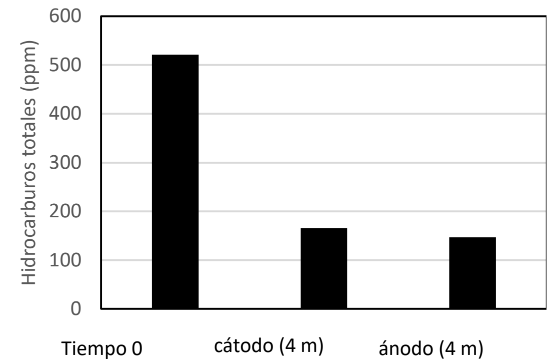
BIOELECTROCHEMICAL SYSTEM: SEDIMENTS SITE 1 COATZACOALCOS

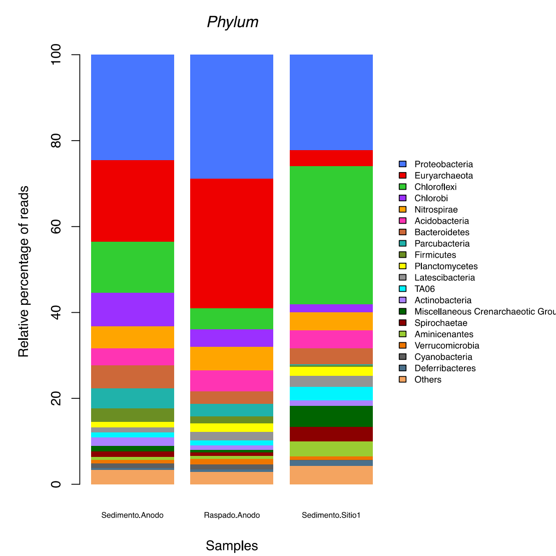
BES : MATERIALS LOW COST





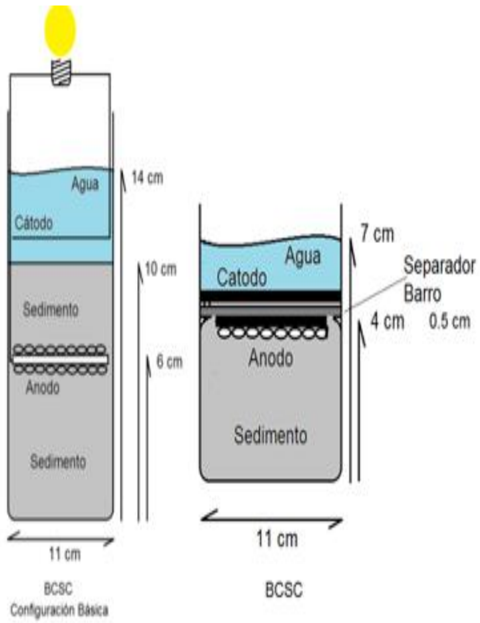
TOTAL HYDROCARBON DEGRADATION

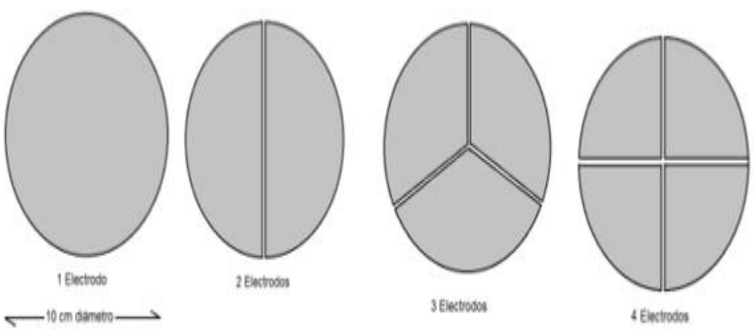




DIFFERENT ARCHITECTURE IN BES AND ANODES

2
a



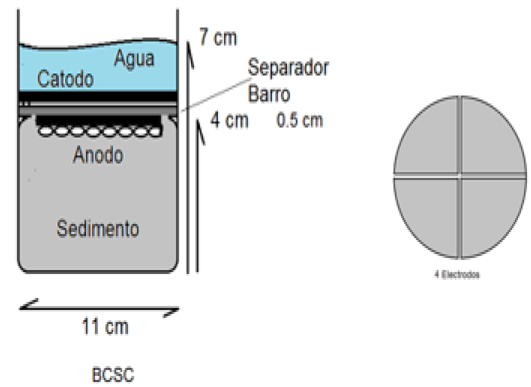


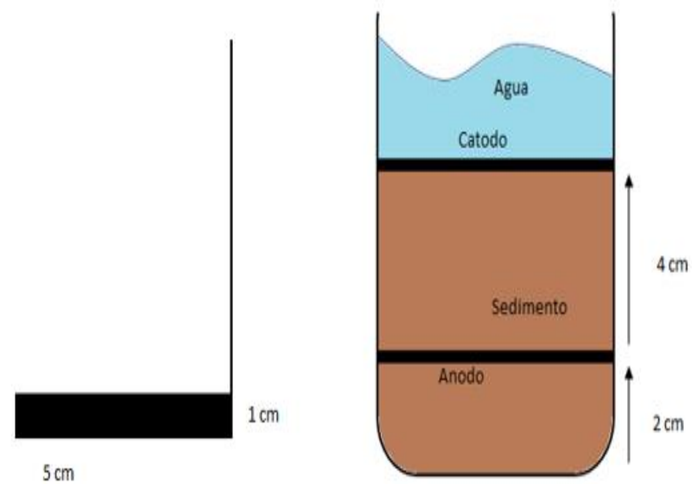
3c1s
3c4s

3c2s

3c3s

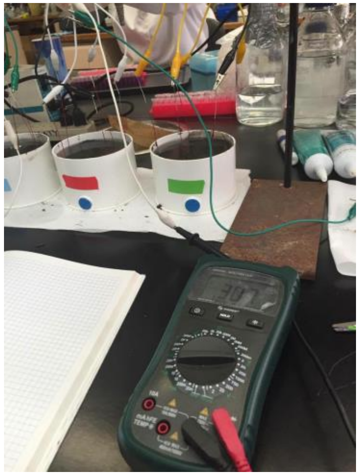
3c4s

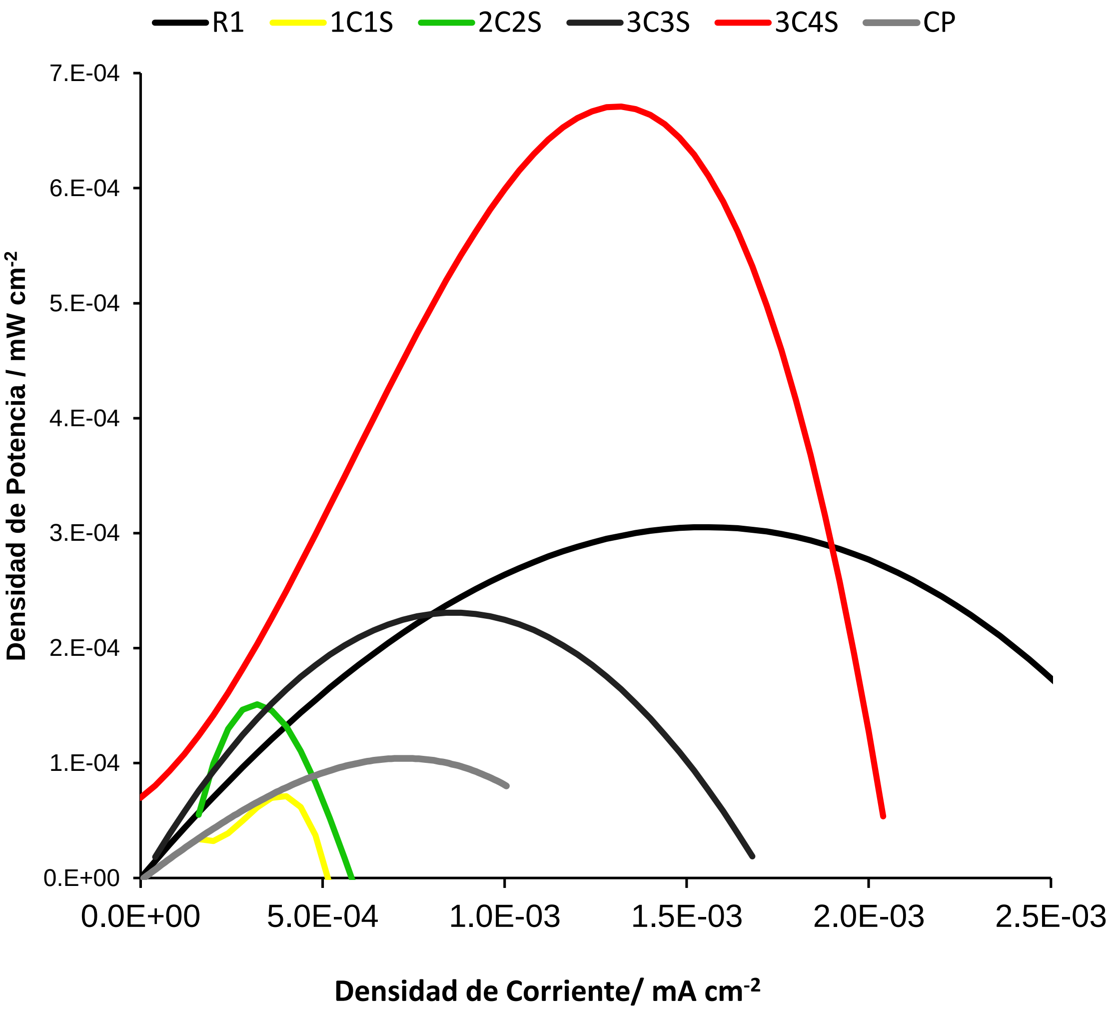




A,B,C Y D

POWER DENSITY OF DIFFERENT CELLS

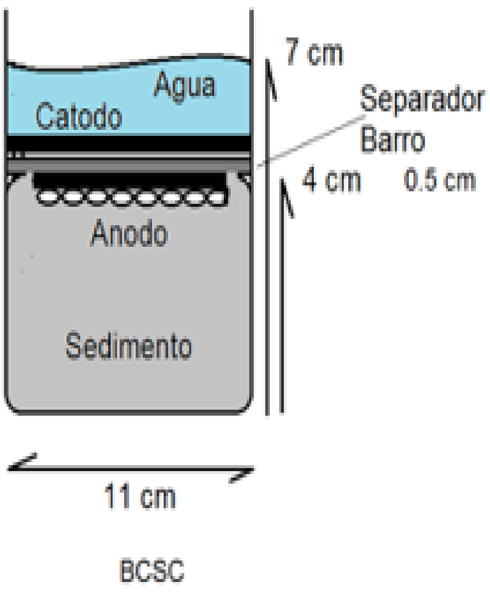


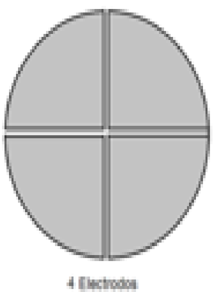


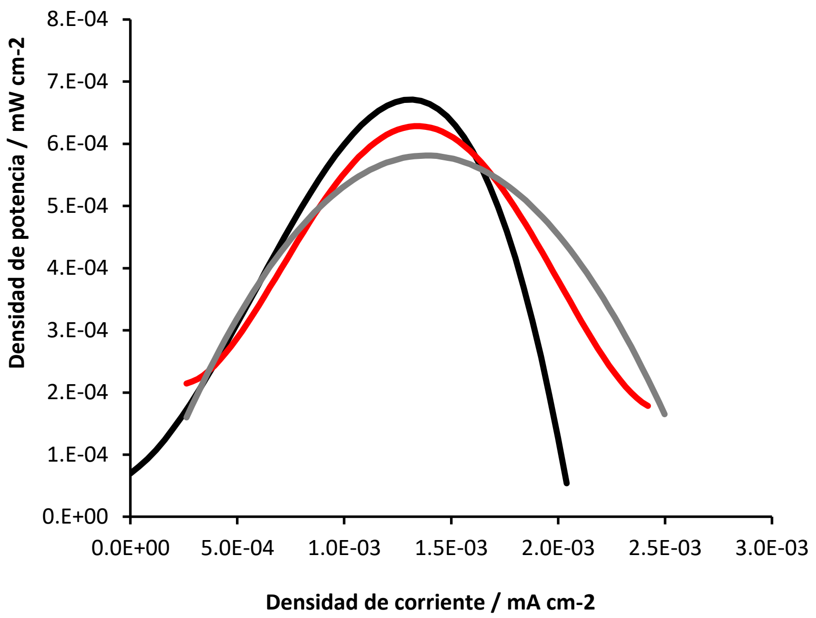
DP

1C1S→7.48*10^{-5}mW/cm^2

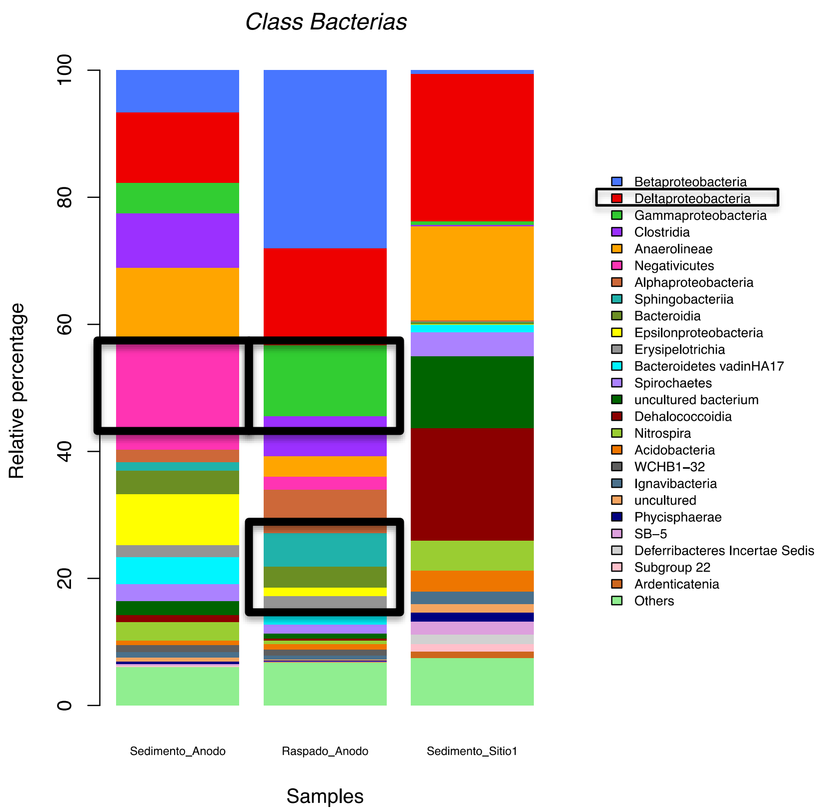
4C4S→6.80*10^{-4}mW/cm^2

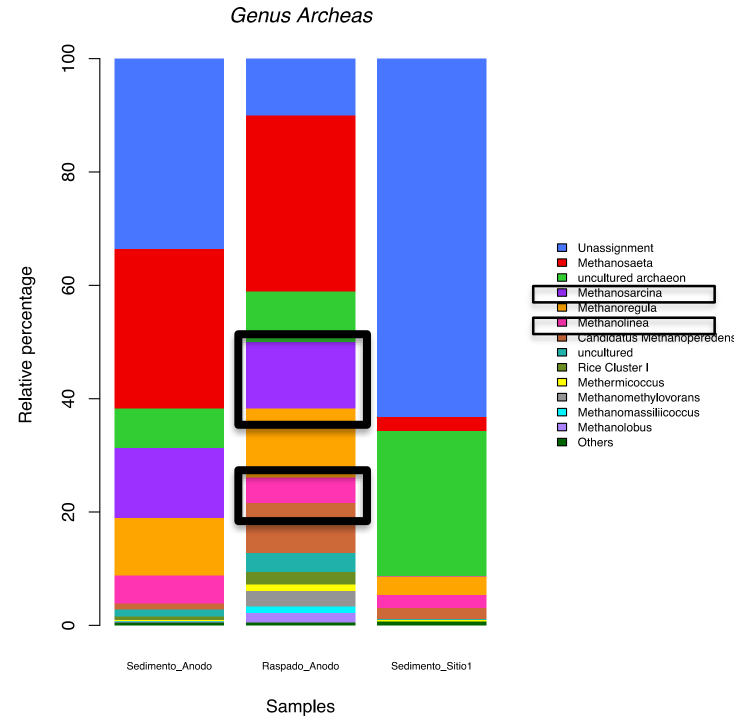


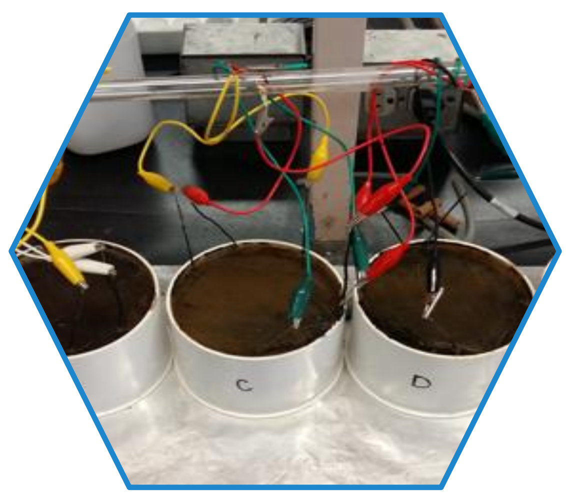


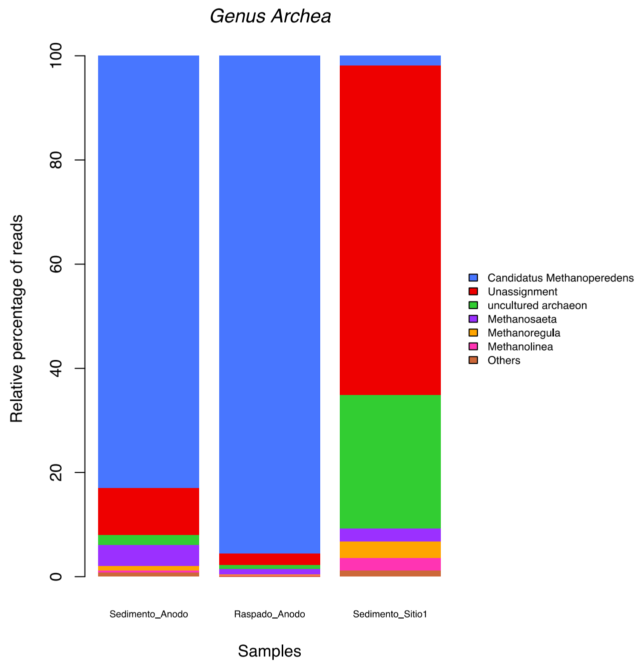


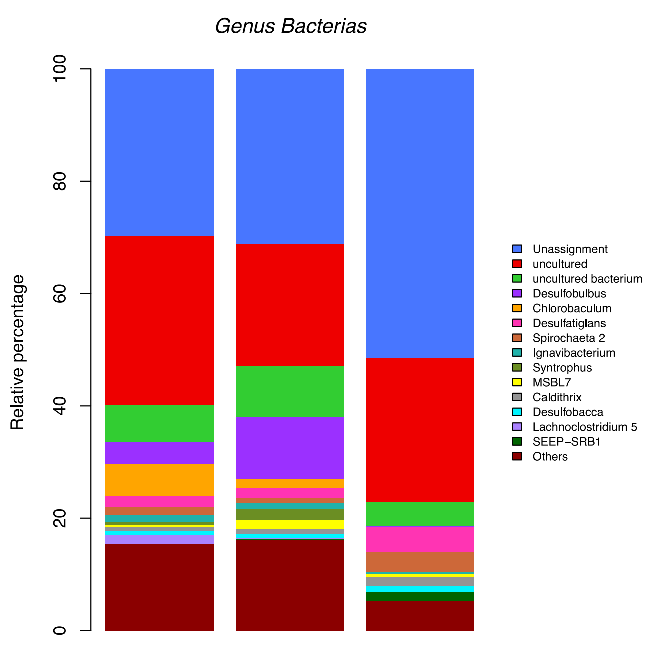
BCM	Sustrato Anolito	Área y Material Ánodo	Área Cátodo CF	Modificación Cátodo	Dist Elect	Separador	PCA V	Resist Interna Ω	DC Max mA cm^{-2}	DP Max mW cm^{-2}
3c 4s	Sedimento sitio 1	4 CF Seg 0.00785 m^2	0.00785 m^2	Sin Modificación	0.005 m	Barro	0.67	1195	$1.5x10^{-3}$	$6.8x10^{-4}$

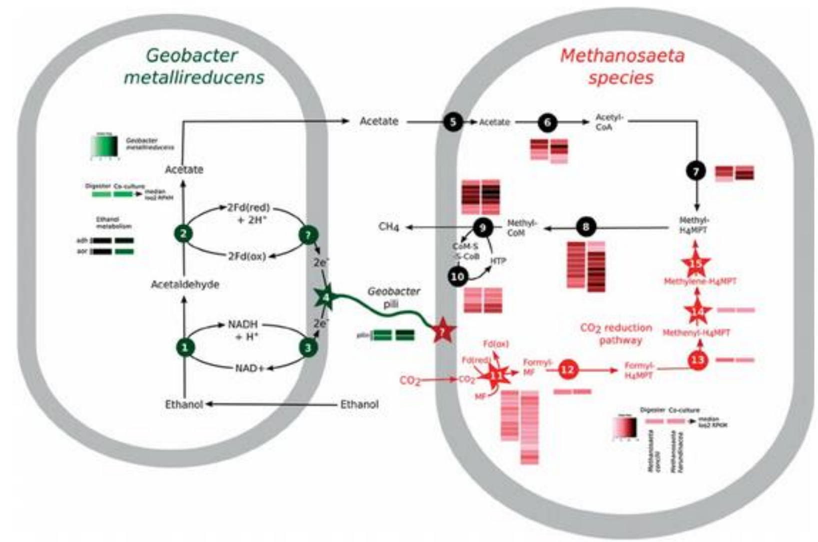

Class Bacterias
Relative percentage
0
20
40
60
80
100
Sedimento_Anodo
Raspado_Anodo
Sedimento_Sitio1
Samples
Betaproteobacteria
Deltaproteobacteria
Gammaproteobacteria
Clostridia
Anaerolineae
Negativicutes
Alphaproteobacteria
Sphingobacteriia
Bacteroidia
Epsilonproteobacteria
Erysipelotrichia
Bacteroidetes vadinHA17
Spirochaetes
uncultured bacterium
Dehalococcoidia
Nitrospira
Acidobacteria
WCHB1−32
Ignavibacteria
uncultured
Phycisphaerae
SB−5
Deferribacteres Incertae Sedis
Subgroup 22
Ardenticatenia
Others


Genus Archeas
Relative percentage
0
20
40
60
80
100
Sedimento_Anodo
Raspado_Anodo
Sedimento_Sitio1
Samples
Unassignment
Methanosaeta
uncultured archaeon
Methanosarcina
Methanoregula
Methanolinea
Candidatus Methanoperedens
uncultured
Rice Cluster I
Methermicoccus
Methanomethylovorans
Methanomassiliicoccus
Methanolobus
Others

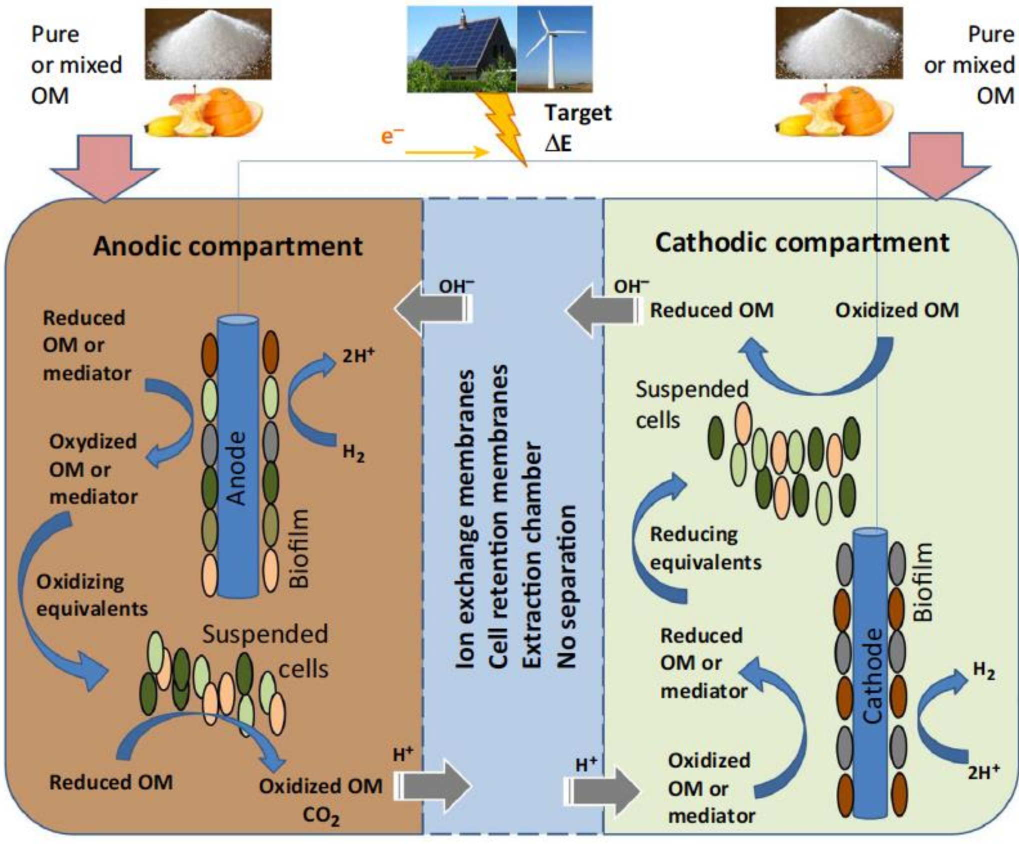

C
D


Genus Archea
Relative percentage of reads
0
20
40
60
80
100
Sedimento_Anodo
Raspado_Anodo
Sedimento_Sitio1
Samples
Candidatus Methanoperedens
Unassignment
uncultured archaeon
Methanosaeta
Methanoregula
Methanolinea
Others


Genus Bacterias
Relative percentage
0
20
40
60
80
100
Sedimento_Anodo
Raspado_Anodo
Sedimento_Sitio1
Unassignment
uncultured
uncultured bacterium
Desulfobulbus
Chlorobaculum
Desulfatiglans
Spirochaeta 2
Ignavibacterium
Syntrophus
MSBL7
Caldithrix
Desulfobacca
Lachnoclostridium 5
SEEP–SRB1
Others

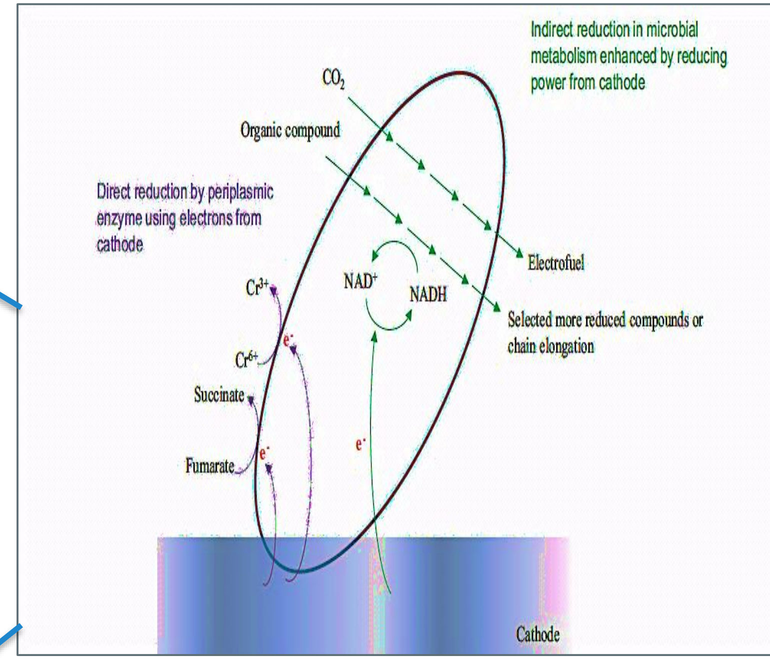

Geobacter metallireducens
Methanosaeta species
Acetate
Acetate
Acetyl-CoA
Acetaldehyde
Ethanol
Ethanol
CH4
Methyl-CoM
Methyl-H4MPT
Geobacter pili
CO2 reduction pathway
CO2
NADH + H+
NAD+
2Fd(red) + 2H+
2Fd(ox)

ANODE AND CATHODE REACTION IN BES



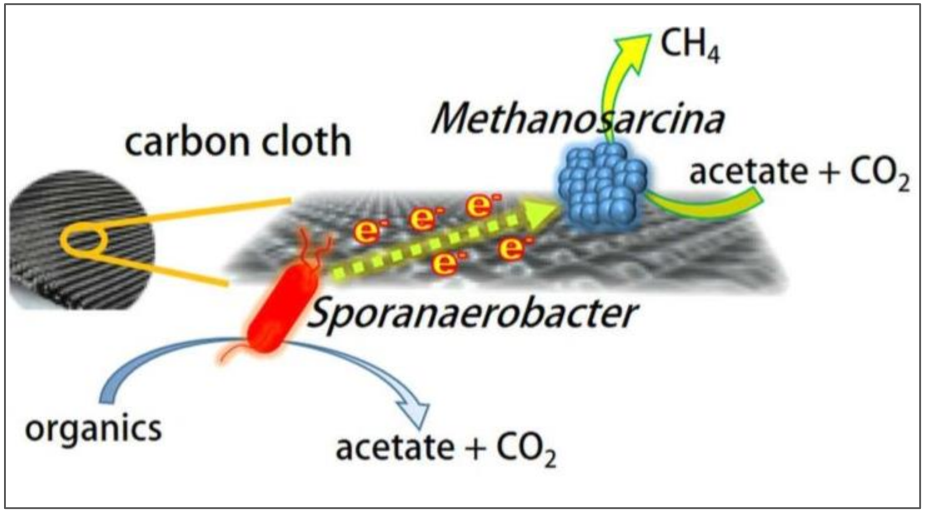
Trends in Biotechnology

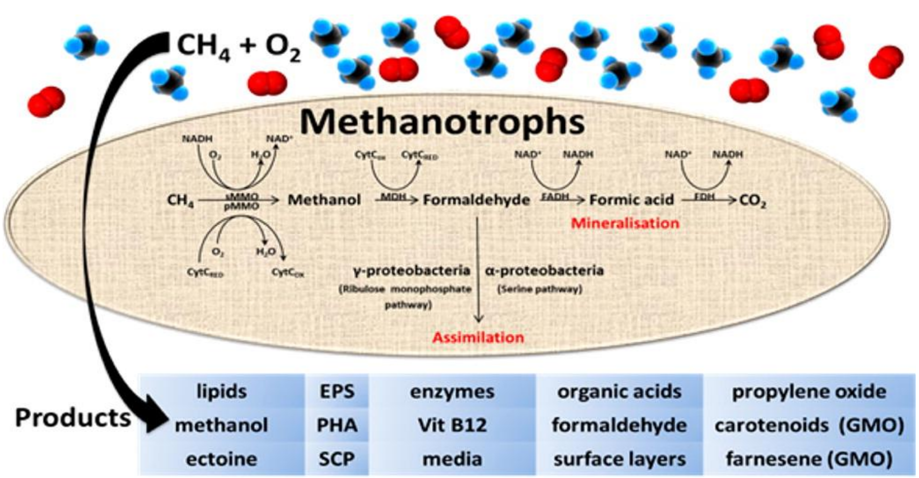
Schievano et al (2016) TIBTEC 1379



Choi &Sang Biotechnol Biofuels (2016) 9:11

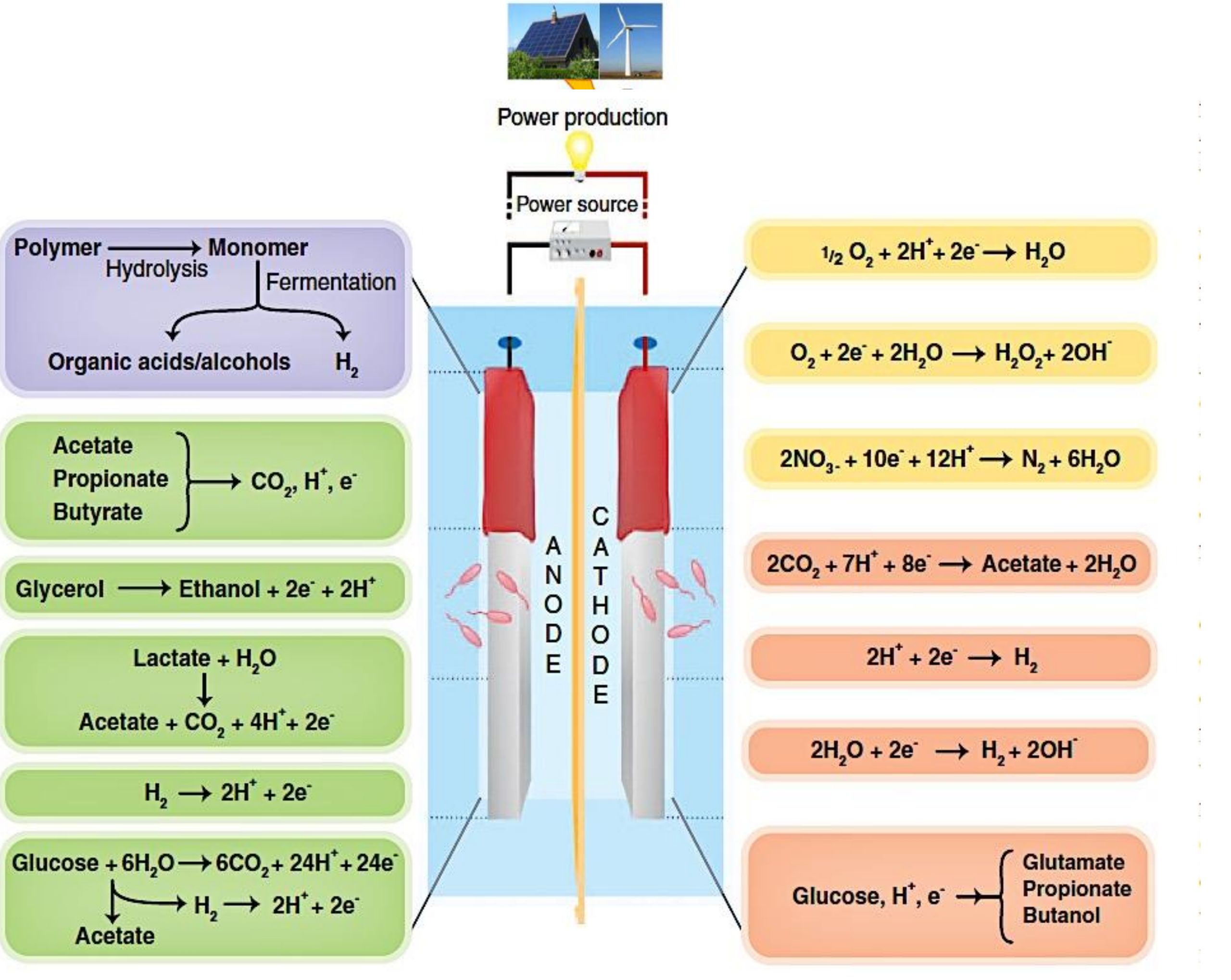
ELECTROACTIVE MICROORGANISMS AND ELECTROTROPHS





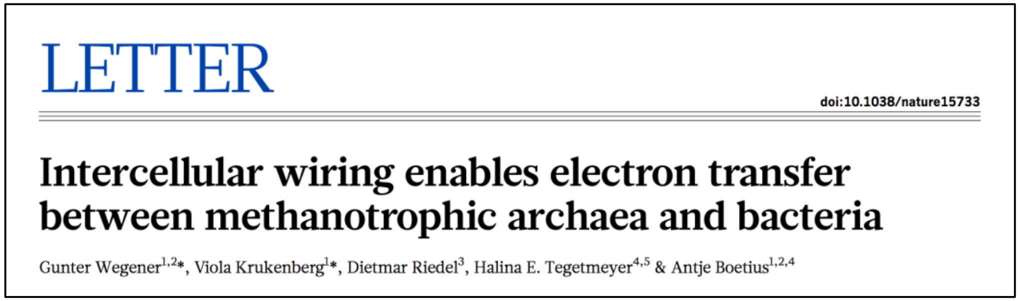
Published in: P. J. Strong; S. Xie; W. P. Clarke; *Environ. Sci. Technol.* **2015,** 49, 4001-4018.

ANODE AND CATHODE REACTION IN BES



Logan and Rabaey, 2012 Science

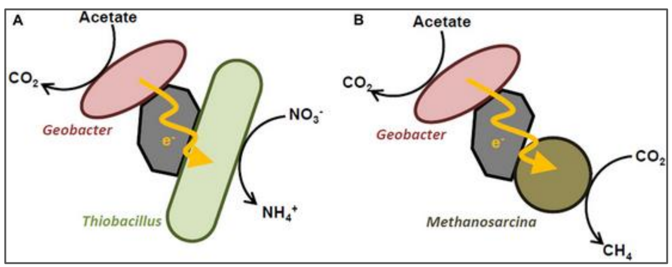
ELECTRON TRANSFER INTER-SPECIES BACTERIA:ARCHAEA

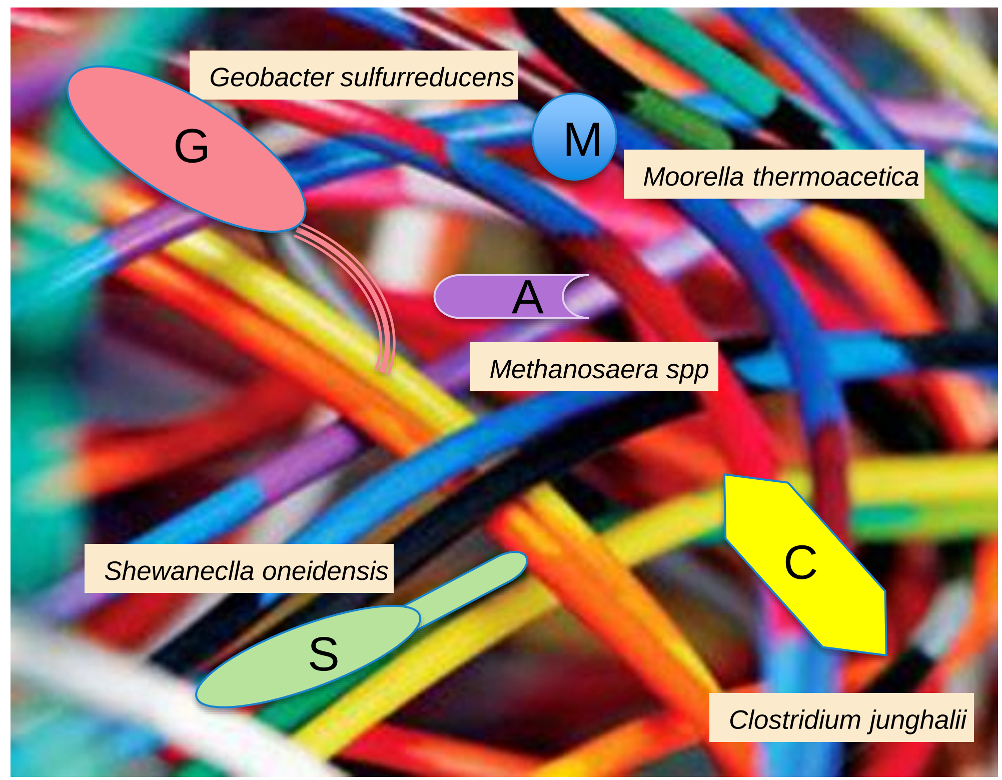

LETTER

doi:10.1038/nature15733

Intercellular wiring enables electron transfer between methanotrophic archaea and bacteria

Gunter Wegener[1,2]*, Viola Krukenberg[1]*, Dietmar Riedel[3], Halina E. Tegetmeyer[4,5] & Antje Boetius[1,2,4]





BCM	Sustrato Anolito	Área y Material Ánodo	Área Cátodo CF	Modificación Cátodo	Dist Elect	Separador	PCA V	Resist Interna Ω	DC Max mA cm^{-2}	DP Max mW cm^{-2}
Pecera 1	Sedimento sitio 1	CF 0.0112 m^2	0.01125 m^2	Sin Modificación	0.05 m	Barro y Sedimento	0.3	2042	$7x10^{-4}$	$1.2x10^{-4}$
Pecera 2	Sedimento sitio 1	CF 0.0112 m^2	0.01125 m^2	Acetato cámara anódica	0.05 m	Barro y Sedimento	0.6	3149	$4.8x10^{-4}$	$7.21x10^{-5}$
2a	Sedimento sitio 1	CF 0.00785 m^2	0.00785 m^2	Sin Modificación	0.04 m	Sedimento	0.3	1013	$1.5x10^{-3}$	$3.1x10^{-4}$
3c 1s	Sedimento sitio 1	1 CF Seg 0.00785 m^2	0.00785 m^2	Sin Modificación	0.005 m	Barro	0.48	4592	$3.74x10^{-4}$	$7.48x10^{-5}$
3c 2s	Sedimento sitio 1	2 CF Seg 0.00785 m^2	0.00785 m^2	Sin Modificación	0.005 m	Barro	0.77	9847	$3.6x10^{-4}$	$1.6x10^{-4}$
3c 3s	Sedimento sitio 1	3 CF Seg 0.00785 m^2	0.00785 m^2	Sin Modificación	0.005 m	Barro	0.58	4613	$8.4x10^{-4}$	$2.52x10^{-4}$
3c 4s	Sedimento sitio 1	4 CF Seg 0.00785 m^2	0.00785 m^2	Sin Modificación	0.005 m	Barro	0.67	1195	$1.5x10^{-3}$	$6.8x10^{-4}$
3c 4s Aire en Catolito	Sedimento sitio 1	4 CF Seg 0.00785 m^2	0.00785 m^2	Sin Modificación	0.005 m	Barro	0.33	1314	$1.8x10^{-3}$	$2.5x10^{-4}$

DATA OF DIFFERENT BES CHARACTERIZED

BCM	Sustrato Anolito	Área y Material Ánodo	Área Cátodo CF	Modificación Cátodo	Dist Elect	Separador	PCA V	Resist Interna Ω	DC Max mA cm^{-2}	DP Max mW cm^{-2}
Celda A	Sedimento sitio 4	5 CP Seg 0.0025 m^2	0.00785 m^2	Sin Modificación	0.04 m	Sedimento	0.69	7856	$2.2x10^{-3}$	$6.5x10^{-4}$
Celda B	Sedimento + 3 g. Diésel	4 CF Seg 0.0025 m^2	0.00785 m^2	Sin Modificación	0.04 m	Sedimento	0.6	9371	$1.3x10^{-3}$	$6x10^{-4}$
Celda C	Sedimento + 9 g. Diésel	4 CF Seg 0.0025 m^2	0.00785 m^2	Sin Modificación	0.04 m	Sedimento	0.64	7927	$2.7x10^{-3}$	$8.7x10^{-4}$
Celda D	Sedimento + 15 g. Diésel	4 CF Seg 0.0025 m^2	0.00785 m^2	Sin Modificación	0.04 m	Sedimento	0.56	7199	$1.4x10^{-3}$	$8.5x10^{-4}$
Celda A	Sedimento sitio 4	5 CP Seg 0.0025 m^2	0.00785 m^2	Catalizado $KMnO_4$	0.04 m	Sedimento	0.71	1654	$4.7x10^{-3}$	$1.8x10^{-3}$
Celda B	Sedimento + 3 g. Diésel	4 CF Seg 0.0025 m^2	0.00785 m^2	Catalizado $KMnO_4$	0.04 m	Sedimento	0.77	1365	$7.2x10^{-3}$	$2.3x10^{-3}$
Celda C	Sedimento + 9 g. Diésel	4 CF Seg 0.0025 m^2	0.00785 m^2	Catalizado $KMnO_4$	0.04 m	Sedimento	0.76	4162	$3.3x10^{-3}$	$1.3x10^{-3}$

REFERENCIA	DP Max
Bioresurce Tecnology (Chandrasekhar et al., 2012)	$4.23x10^{-4}$ mW cm^{-2}. Lodos de refinería.
Chemical Engineering Journal(Morros et al., 2008)	$3.2x10^{-3}$ mW cm^{-2}. Agua subterránea contaminada+diésel. Identificación de bacterias.
Biosensors and Bioelectronics (Li et al., 2016)	$1.73x10^{-3}$ mW cm^{-2}. Suelo contaminado con hidrocarburo.Plataforma petrolera

Agradecimientos

CATEDRA-CONACYT
Dr. J. Alberto Hernández
- Manuel Huerta (L)

ESTUDIANTES
- Lidia Piñones (L)
- Nadia Moreno(L)
- David Papaqui (L)
- Emmanuel Alvizo(M)
- Xadeni Flores(M)
- Berenice Cruz (M)
- Fanny A. Flores(D)
- Getzabeth González (D)
- Paloma Lara (D)

COLABORADORES

- Dr. Alberto Alvarez
CIICAP (UAEM)

- Dra. Margarita Hernández
Instituto de E. Renovables (UNAM)

- Dra. Leticia Vega
CCADET (UNAM)

Dr. Derek Lovley
UMASS

FINANCIAMIENTO

Geobacter Project
www.geobacter.org

CONACYT

U.S. DEPARTMENT OF ENERGY

dgapa
Dirección General de Asuntos del Personal Académico

GRACIAS POR SU ATENCIÓN

CALCULO DE PARÁMETROS ELECTROQUÍMICOS

Tiempo de estabilización

25-33 días

$$i = \frac{V}{R}$$

Donde

i= corriente (A)

V= voltaje (V)

R= resistencia (Ω)

$$DC = \frac{i}{S}$$

Donde

i= corriente (mA)

S= superficie (cm^2)

DC= densidad de corriente (mA/cm^2)

$$DP = \frac{i * V}{S}$$

Donde

i= corriente (mA)

V=voltaje (V)

S= superficie (cm^2)

DP= densidad de potencia (mW/cm^2)