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יום עיון חדשנות בדלקים והשפעתם על הסביבה, דצמבר-19
לשכת המהנדסים, האדריכלים והאקדמאים במקצועות הטכנולוגיים בישראל

ייצור דלק מימני משפכים ביתיים בעזרת חיידקים

Hydrogen fuel production by microbial devices using wastewater

שמואל רוזנפלד

פרופ' רבקה כהן, המחלקה להנדסה כימית וביוטכנולוגיה
פרופ' אלכס שכטר, המחלקה למדעי הכימיה

Hydrogen as an energy carrier

Hydrogen is the most abundant element in the universe and is principle element in the universe and is the principle element in the solar atmosphere .

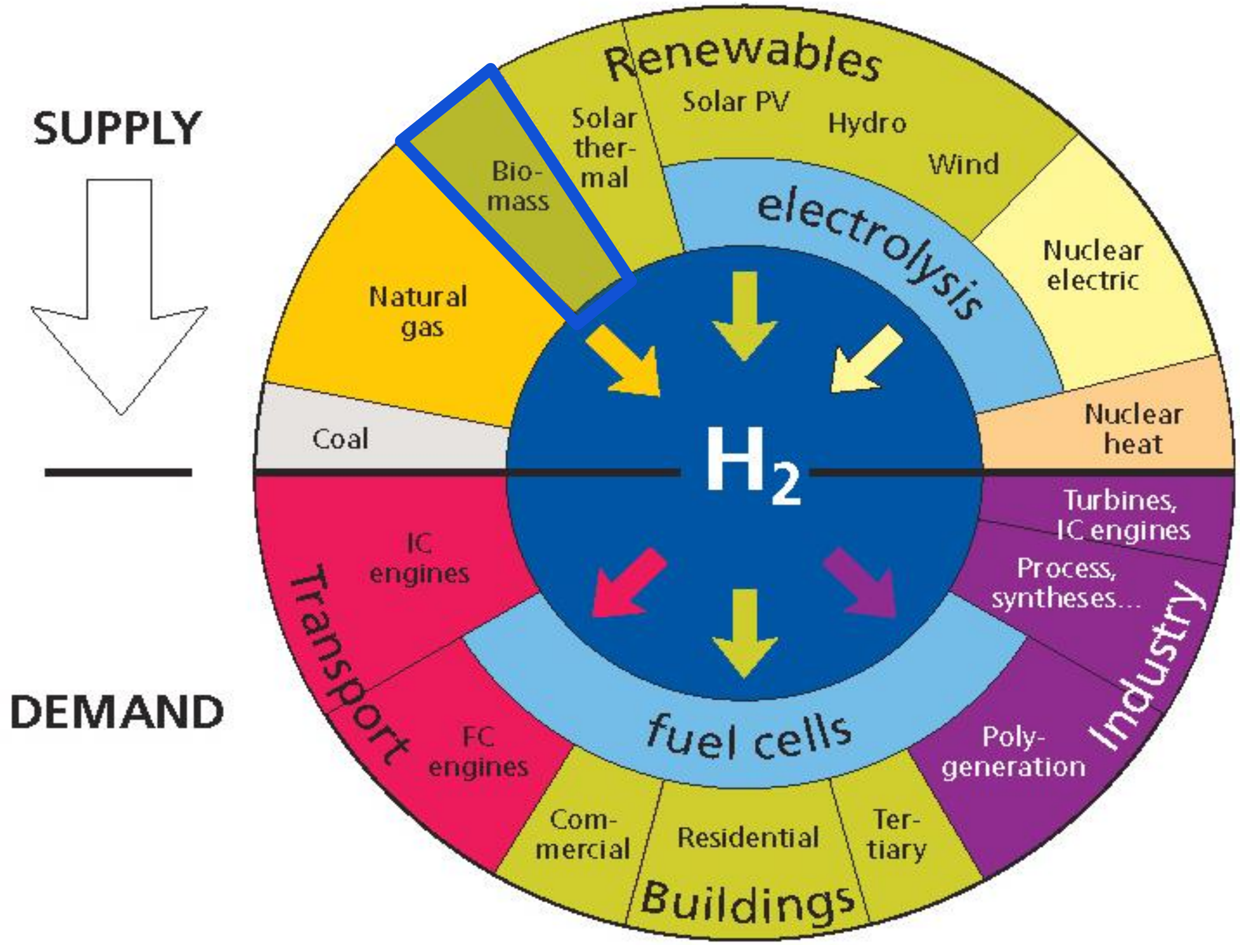
Fuel	Specific Energy kj/g	Density KWH/gal	Chemical Formula	lbs CO2/gal
Propane	50.4	26.8	C3H8	13
Ethanol	29.7	24.7	C2H5OH	13
Gasoline	46.5	36.6	C7H16	20
Diesel	45.8	40.6	C12H26	22
Biodiesel	39.6	35.0	C18H32O2	19
Methane	55.8	27.0	CH4	3
Oil	47.9	40.5	C14H30	20
Wood	14.9	11.3	approx weight	9
Coal	30.2	22.9	approx weight	19
Hydrogen	141.9	10.1	H2	0

Source: DOE, Stanford University, College of the Desert, & Green Econometrics research

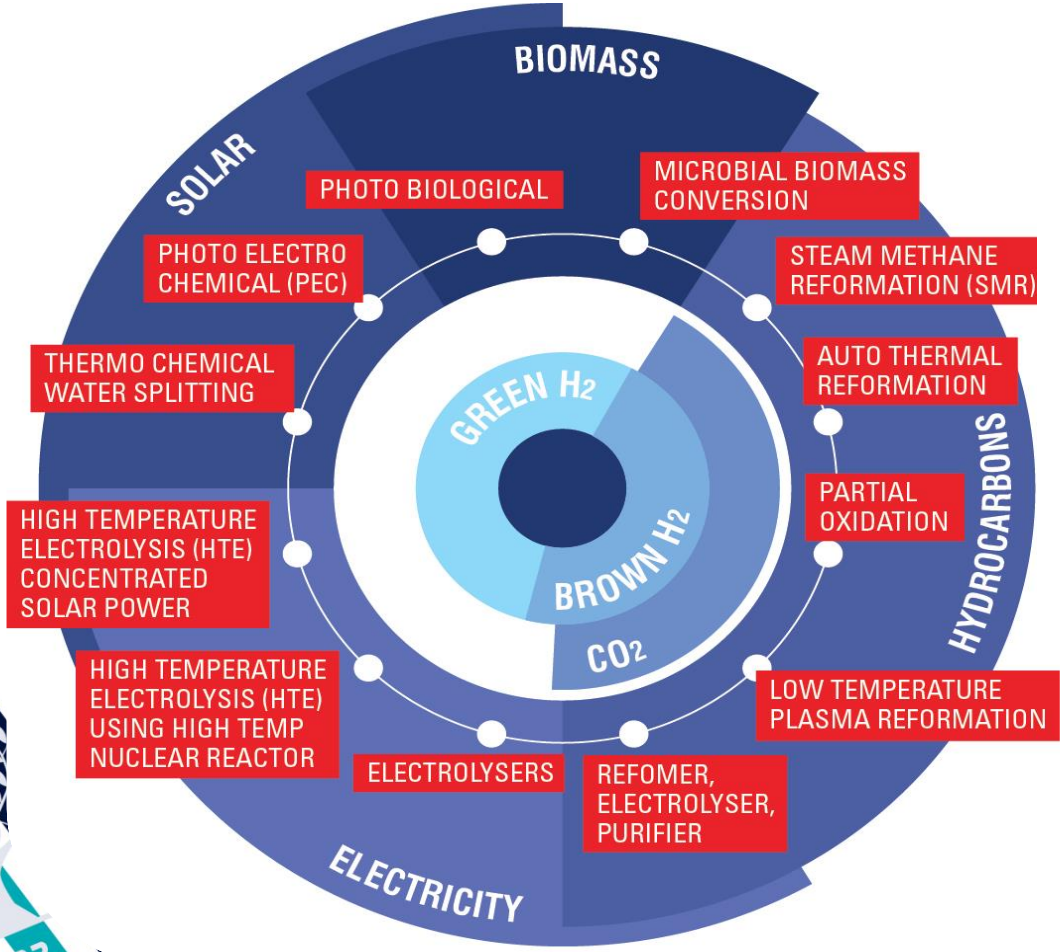
Advantage vs. disadvantage of hydrogen energy

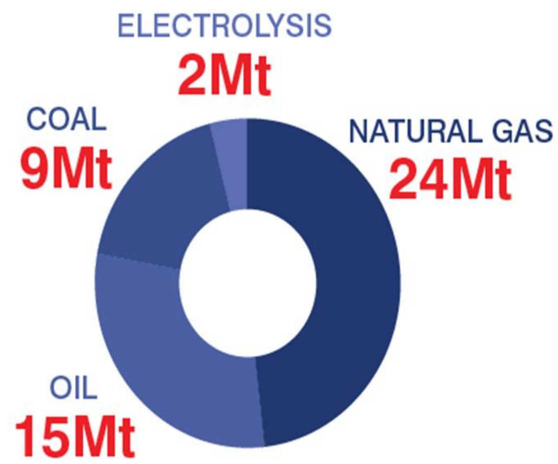
- ✓ Not Explosive In Open Air
- ✓ Not Decomposing
- ✓ Not Oxidizing
- ✓ Not Toxic
- ✓ Not Corrosive
- ✓ Not Cancer Causing
- × Currently more expensive
- × Hydrogen is more difficult to store and distribute.

Hydrogen supply and demand



World hydrogen production





Source: CMB nv, Belgium/ hydroville

Other production methods…

Process	Energy source	Feedstock	Capital cost (M$)	Hydrogen cost [$/kg]	Study year
SMR with CCS	Standard fossil fuels	Natural Gas	226.4	2.27	2005
SMR without CCS	Standard fossil fuels	Natural Gas	180.7	2.08	2005
CG with CCS	Standard fossil fuels	Coal	545.6	1.63	2005
CG without CCS	Standard fossil fuels	Coal	435.9	1.34	2005
ATR of methane with CCS	Standard fossil fuels	Natural Gas	183.8[a]	1.48	2005
Methane Pyrolysis	Internally generated steam	Natural Gas	–	1.59–1.70	1992
Biomass Pyrolysis	Internally generated steam	Woody Biomass	53.4–3.1[b]	1.25–2.20	2004
Biomass Gasification	Internally generated steam	Woody Biomass	149.3–6.4[c]	1.77–2.05	2004
Direct Bio-photolysis	Solar	Water+Algae	50 $/m^2$	2.13	2002
Indirect Bio-photolysis	Solar	Water+Algae	135 $/m^2$	1.42	2002
Dark Fermentation	-	Organic Biomass	–	2.57	2014
Photo-Fermentation	Solar	Organic Biomass	–	2.83	2014
Solar PV Electrolysis	Solar	Water	12–54.5	5.78–23.27	2007
Solar Thermal Electrolysis	Solar	Water	421–22.1[d]	5.10–10.49	2007
Wind Electrolysis	Wind	Water	504.8–499.6[e]	5.89–6.03	2005
Nuclear Electrolysis	Nuclear	Water	–	4.15–7.00	2006
Nuclear Thermolysis	Nuclear	Water	39.6–2107.6[f]	2.17–2.63	2007
Solar Thermolysis	Solar	Water	5.7–16[g]	7.98–8.40	2007
Photo-electrolysis	Solar	Water	–	10.36	2014

Source: P. Nikolaidis, A. Poullikkas / Renewable and Sustainable Energy Reviews 67 (2017) 597–611

Microbial Electrolysis Cells (MEC's)

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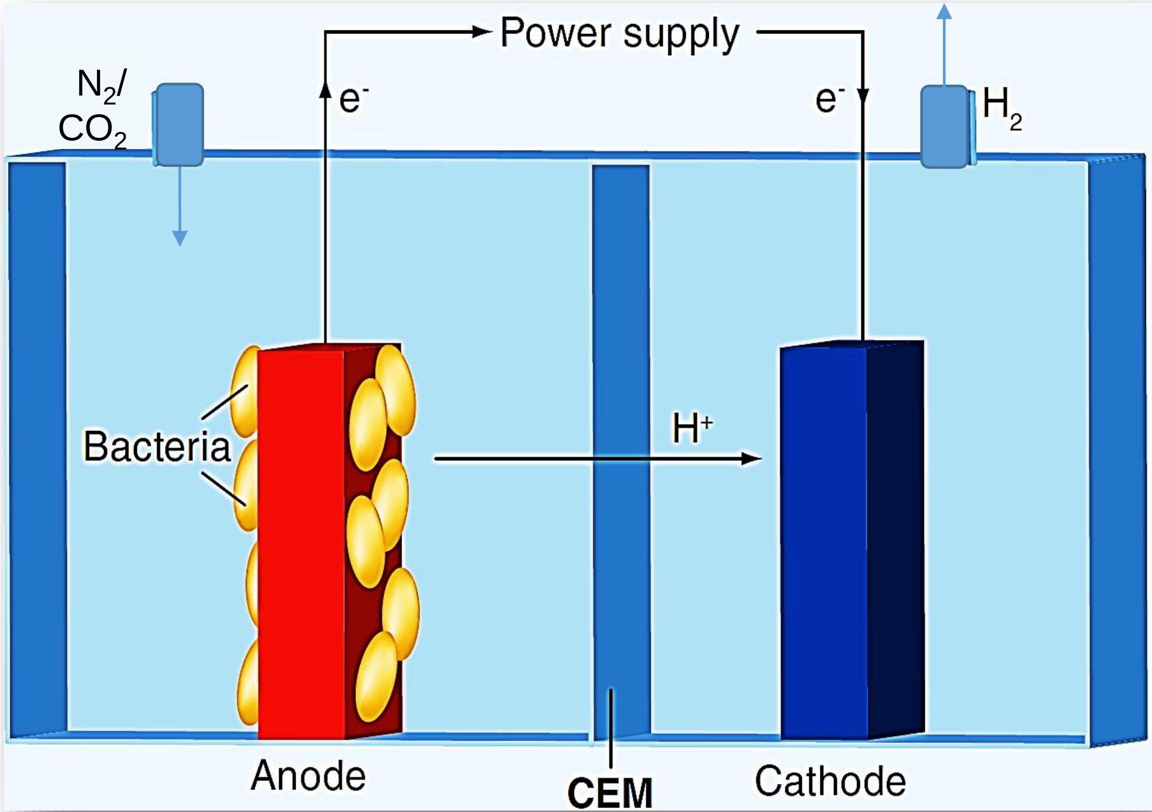
Anode reaction/potential
$CH_3COO^- + 4\,H_2O = 2\,HCO_3^- + 9\,H^+ + 8\,e^-$ (E = -0.279 V)



Cathode reaction/ potential
$2\,H^+ + 2\,e^- = H_2$ (E = -0.414 V)

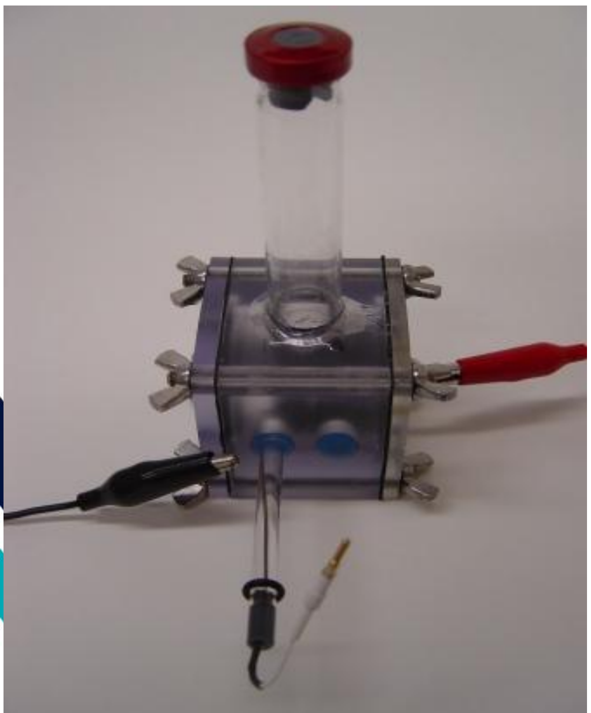
Source: Biofuels (2010)

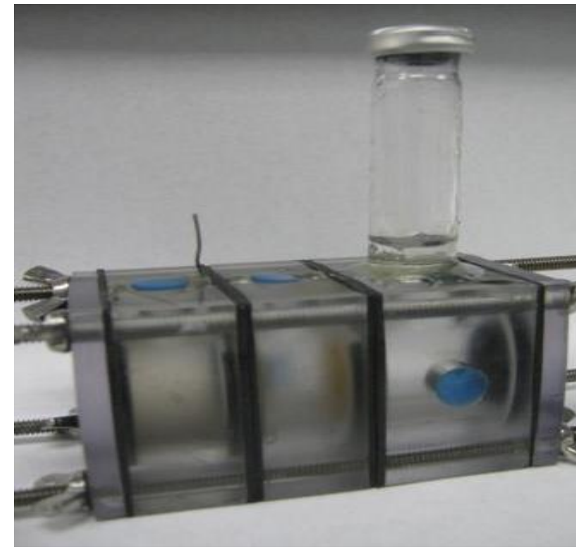
US Department of Energy Fuel Cell Technology Office (FCTO) identified MEC as a key technology to be developed in order to meet the cost goals of \$2-4/gge (gaso- line gallon equivalent) H_2 from renewable biomass (2013) gasoline equivalent (gge) = ~121 MJ = ~115,000 Btu = ~1 kg H2

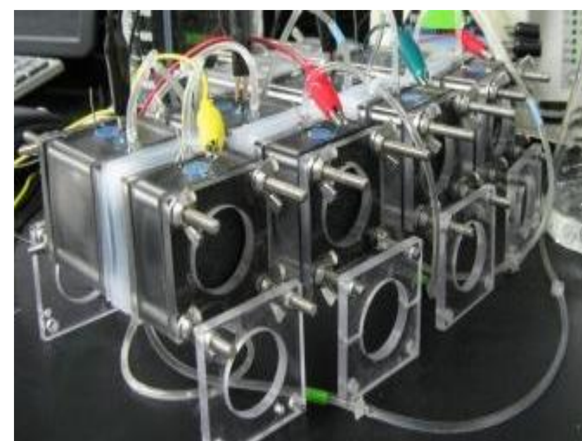
MEC's configuration & design

I. Use of a membrane in **two-chamber** MEC systems can reduce the amount of impurities in the hydrogen gas <u>but</u> increase the internal resistance

II. Removal of the membrane in **single-chamber** MEC simplifies the reactor design and decrease the internal resistance <u>but</u> increases the possibility for hydrogen consumption by methanogenic (CH_4) bacteria

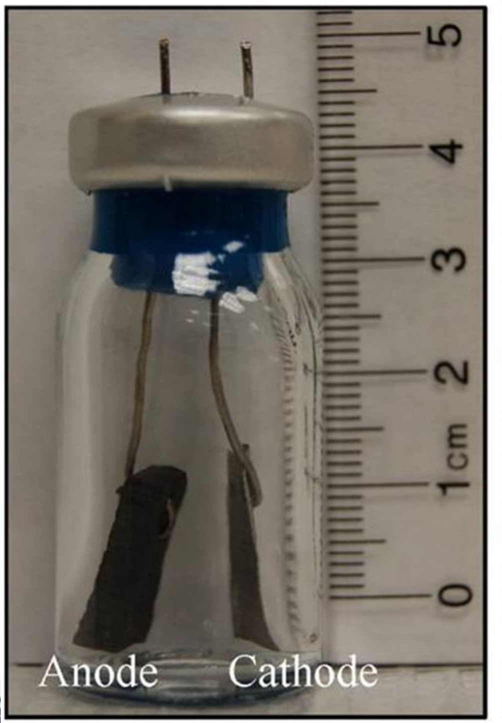






Call & Logan (2008). Mehanna et al. (2011), Kim & Logan (2011).

Small (5mL) vs. large (1000L) scale



Call and Logan (2011b). Cusick et al. (2011).

How bacteria form a biofilm?

Source: Andrew Dopheide, 2011

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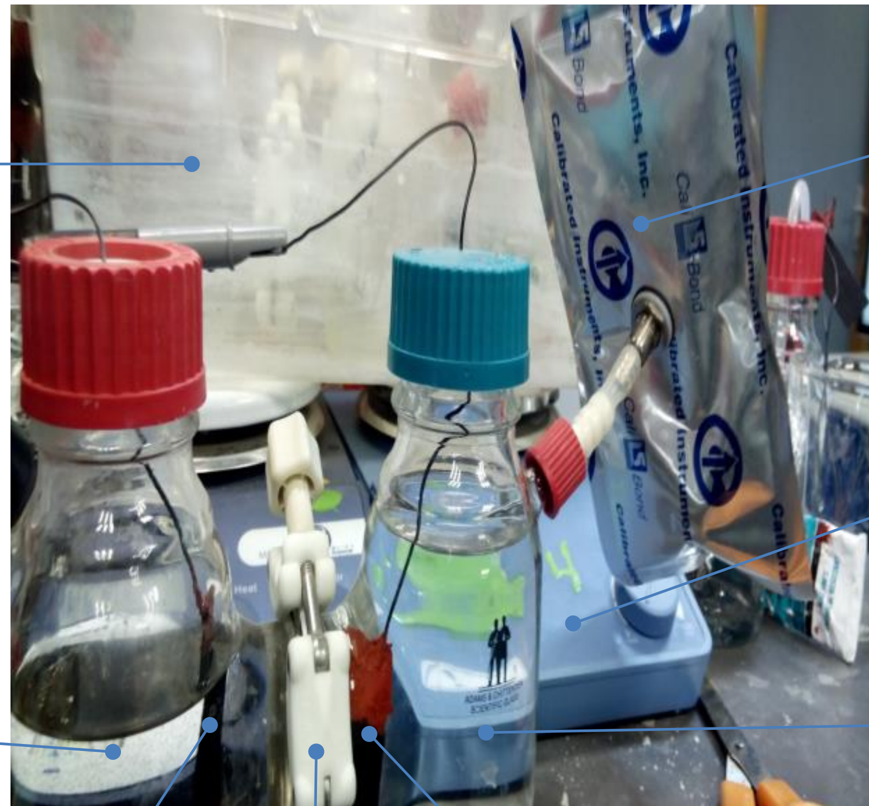
Carbon sources

Substrates Used in MECs

None- fermentable Substrates	Fermentable and Complex Substrates	Wastewater
Acetate	Glucose ($C_6H_{12}O_6$)	Domestic WW
Acetic acid	Cellulose	Livestock (swine farm) WW
Butyric acid	Maltose	Refinery WW
Lactic acid	Saccharose	Food processing & industrial
Propionic acid	Cellobiose	Winery wastewater
Valeric acid	Lignocellulosic biomass	Potato processing WW
Formic acid	Effluent from anaerobic-baffled reactor	Dairy manure WW
Glycerol		Landfill WW
Ethanol		Sewage sludge
Lactate		

Kadier et al. Renewable and Sustainable Energy Reviews, 2016

MEC’s final construction-1



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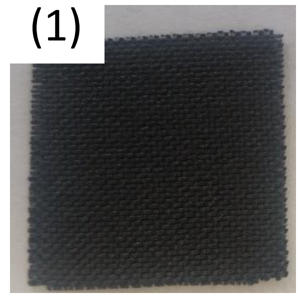
Research Aims

Development of a low cost MEC reactor for high efficiency bio-hydrogen fuel production

- Electrode materials
  - Carbon cloth (1)
  - Stainless steel mesh (2)
  - Comb. Electrodes (3)
- Surface treatments
  - Flame treatment (4)
  - Nitrogen cold plasma treatment (5)
- Catalysts
  - Nano MoS_2 catalyst (6)
  - Oxidative catalysts (for anode)
- Separators
  - Nitrocellulose membrane (7)
  - Polyamide textile (8)
  - Polymeric mesh (9)

(1)


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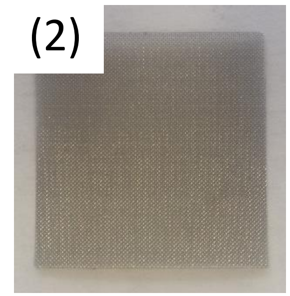

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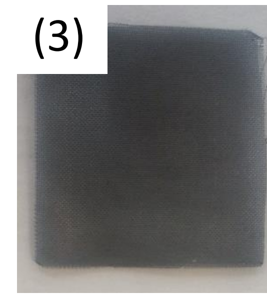

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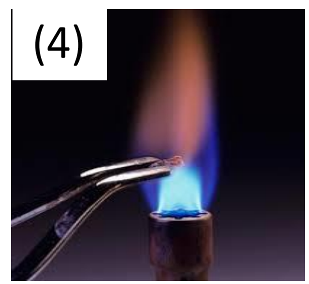

(5)


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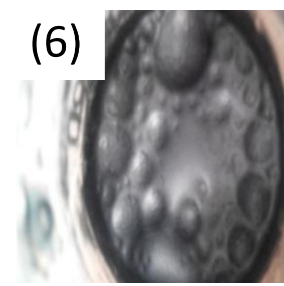

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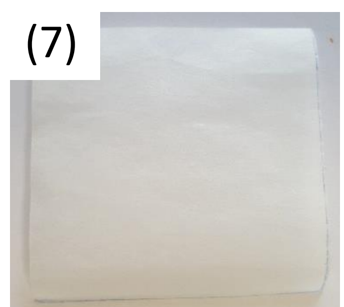

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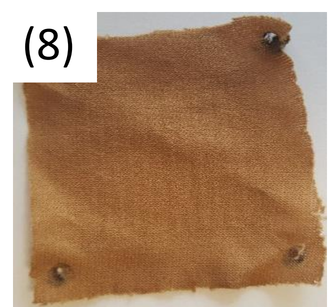

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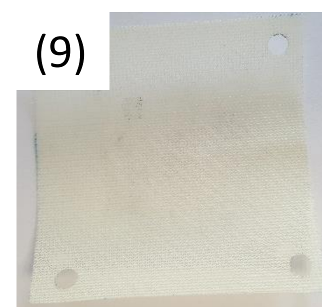
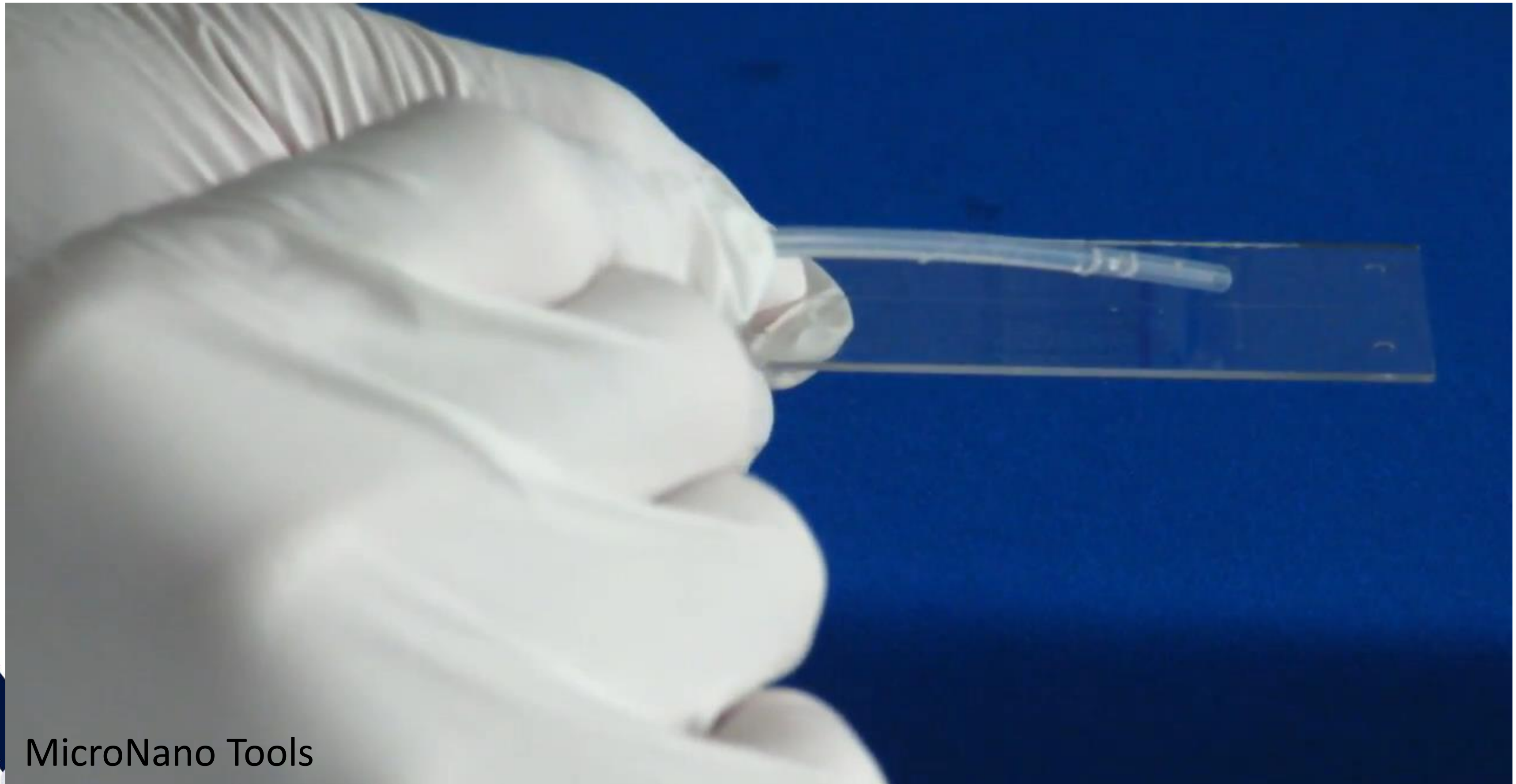
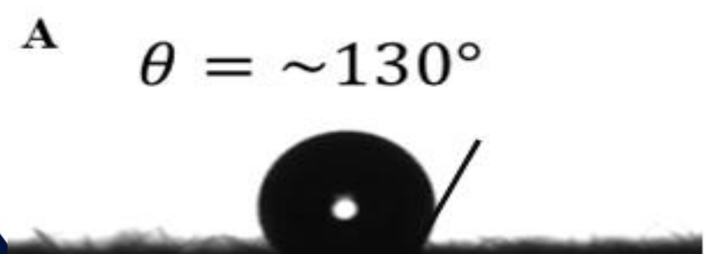


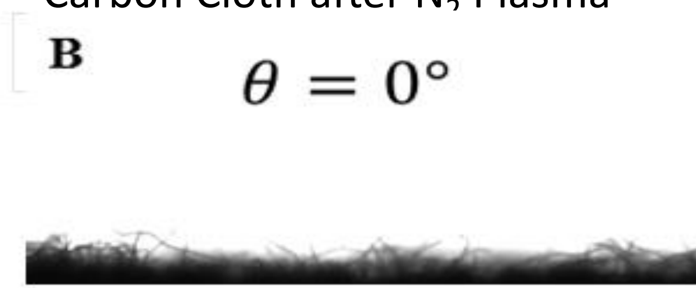
Cold nitrogen plasma treatment



Carbon Cloth pristine



Carbon Cloth after N_2 Plasma



Nano MoS_2 synthesis

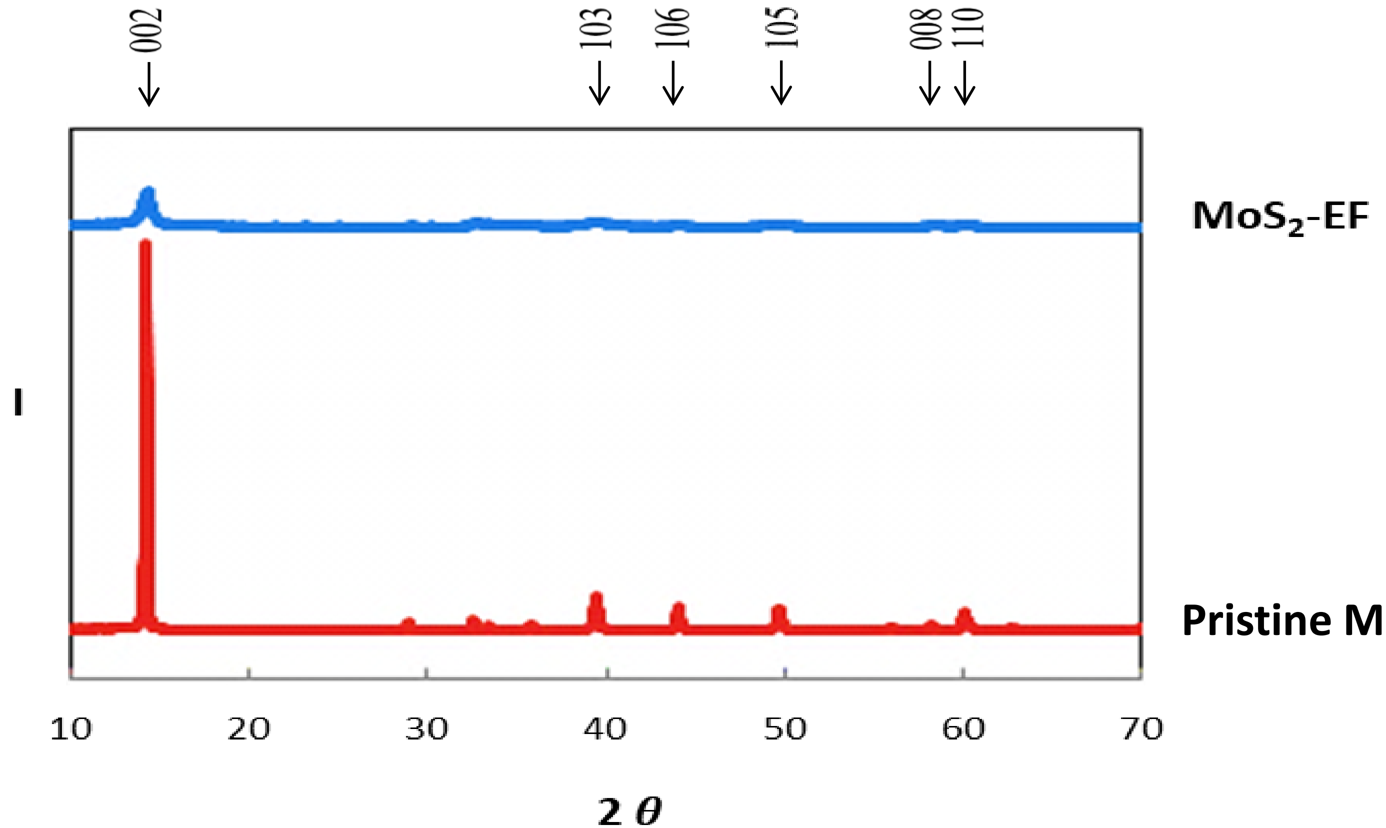
- Reagent 1: MoS_2-P (Sigma Aldrich,~2µm)
- Reagent 2: BuLi, C_4H_9Li (Sigma Aldrich, 1.6M)
- At least 48 h. stir at room temp., under nitrogen atmosphere
- Ultrasonication during 1 h.

$$MoS_2 + C_4H_9Li \longrightarrow LiMoS_2 + 1/2C_8H_{18}$$

$$LiMoS_2 + H_2O \longrightarrow (MoS_2)_{\text{single layers}} + LiOH + 1/2H_2$$

Rozenfeld S. et al. Bioelectrochemistry, 2018

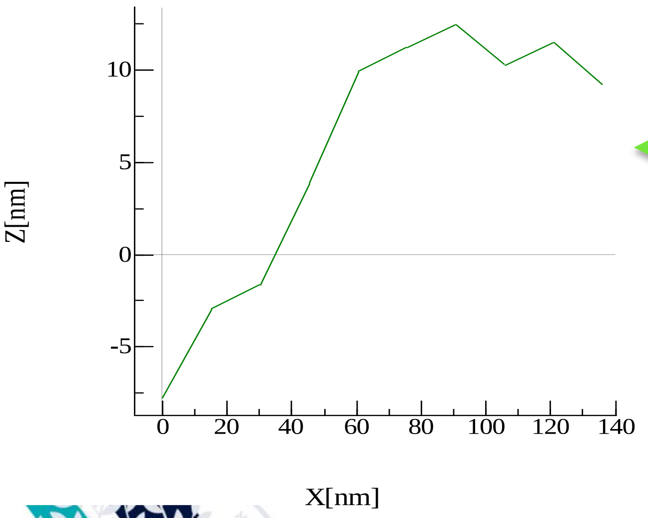
MoS_2 catalyst diffraction by XRD analysis



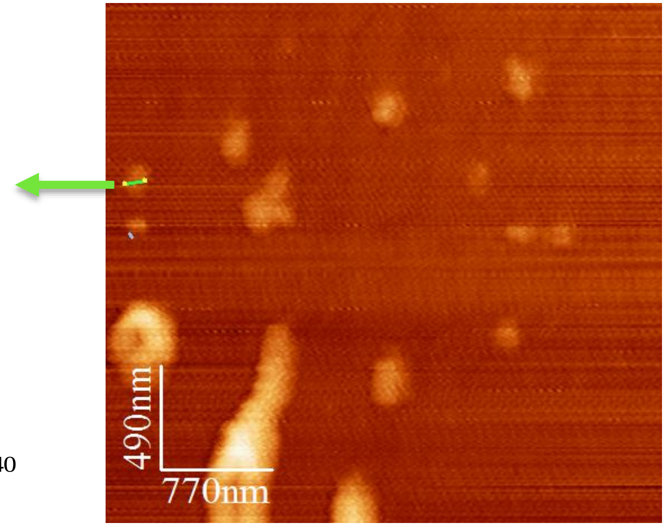
Rozenfeld S. et al. Bioelectrochemistry, 2018

Nano synthesized catalyst at Atomic Force Microscopy (AFM)

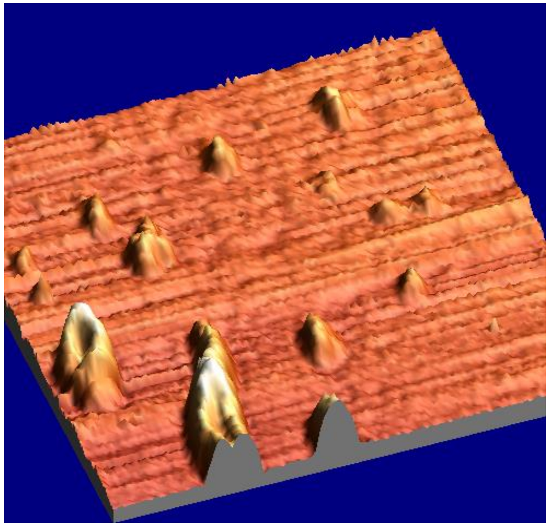
Z-Profile of particle



2D AFM

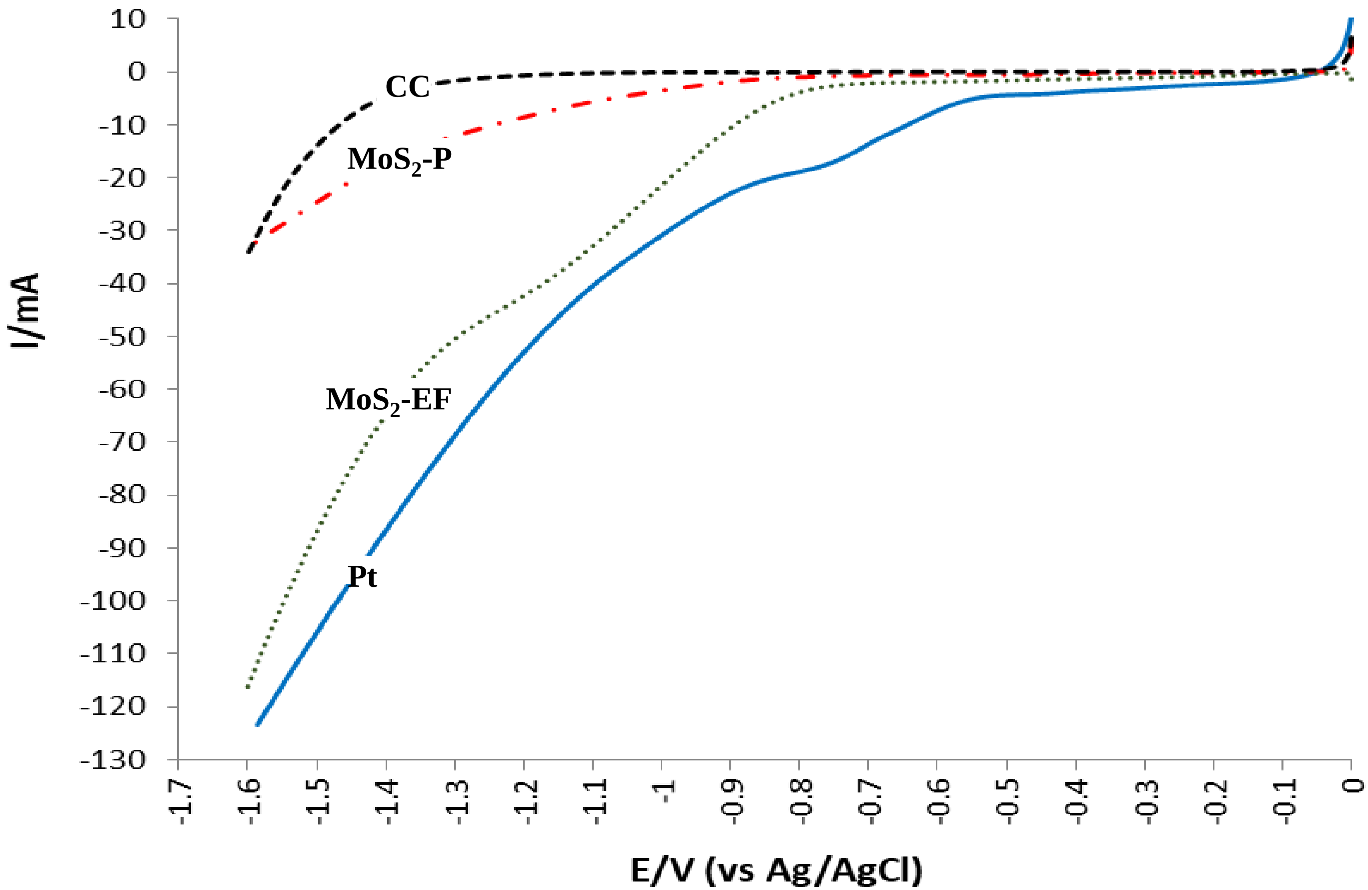


3D AFM



Rozenfeld S. et al. Bioelectrochemistry, 2018

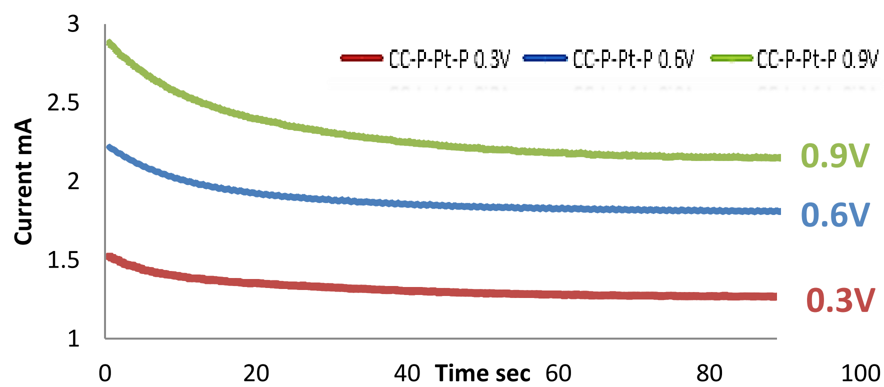
Electrochemical activity of MEC's based on cathodic reduction by LSV polarization technique



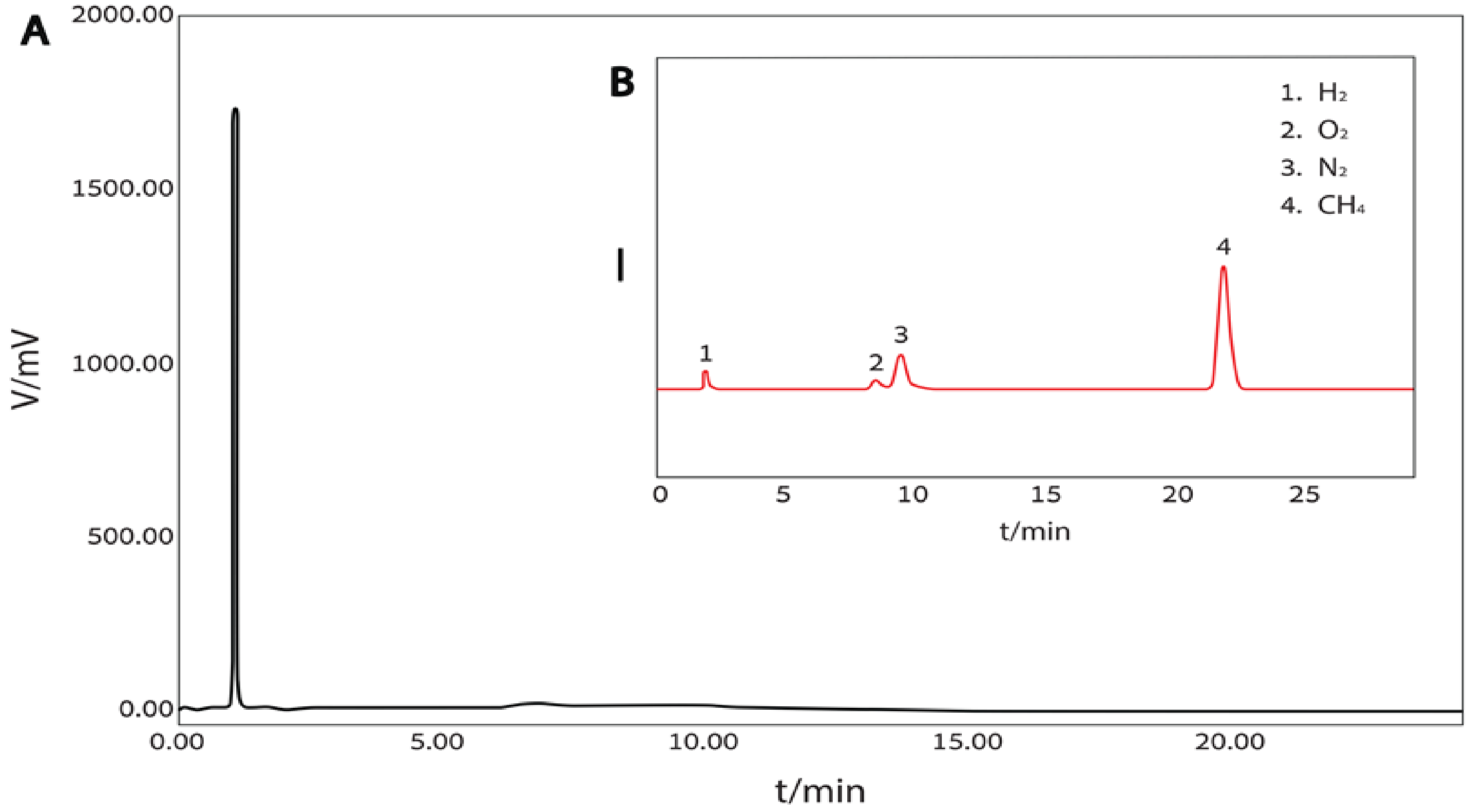
Rozenfeld S. et al. Bioelectrochemistry, 2018

Electrochemical analysis of MEC's based on cathodes

Cathode	Applied voltage (V)	Current (mA)	Current density (mA/cm^2)	HER production rate per cubic meter of the anodic medium ($m^3d^{-1}m^{-3}$)	HER production rate per square meter of electrode ($m^3d^{-1}m^{-2}$)
Pt	0.3	1.4	0.350	0.078	0.039
	0.6	1.9	0.475	0.106	0.053
Pristine MoS_2	0.3	1.2	0.300	0.067	0.033
	0.6	1.5	0.375	0.083	0.042
MoS_2-EF	0.3	1.4	0.350	0.078	0.039
	0.6	2.4	0.600	0.133	0.067

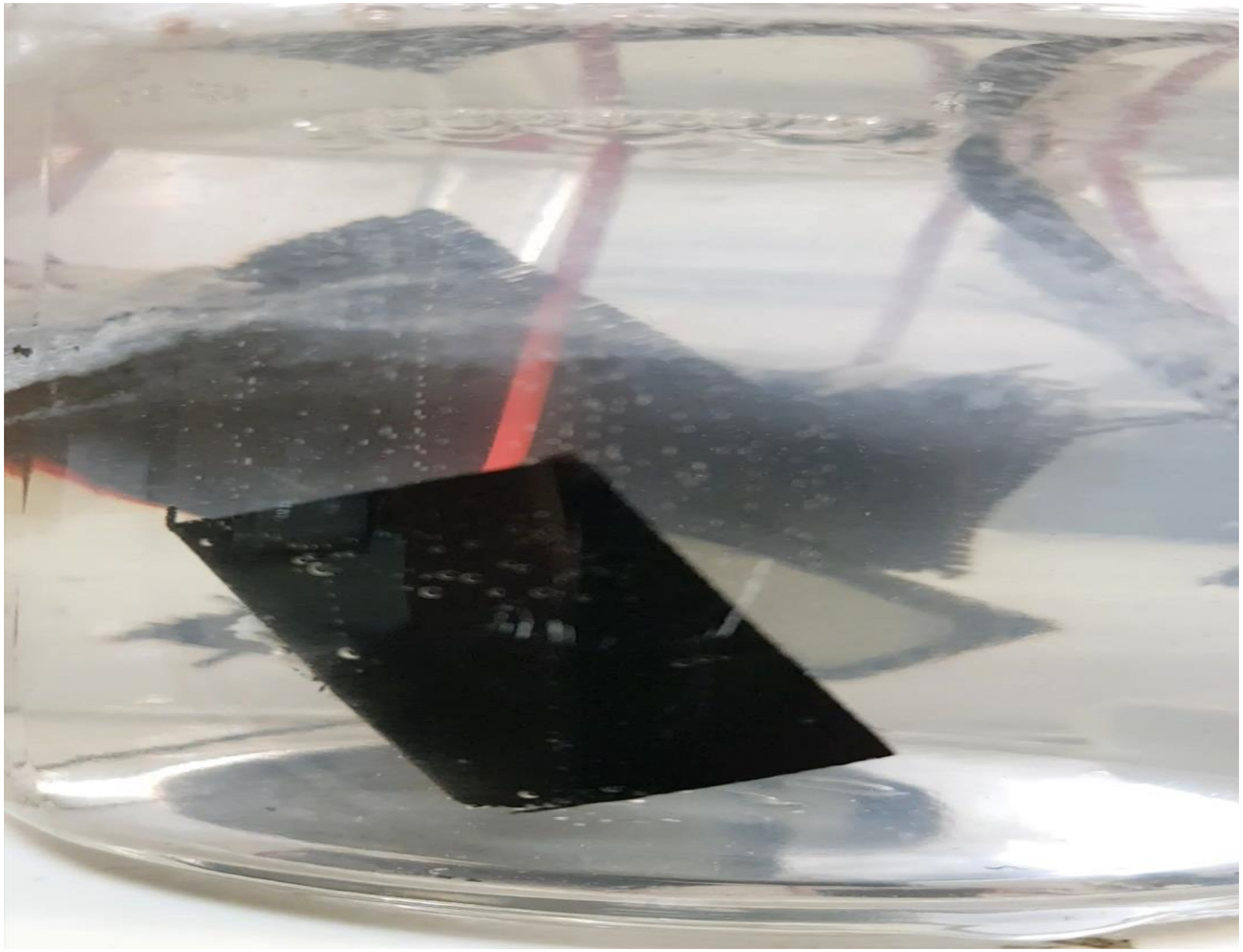


Gas chromatography analysis



Rozenfeld S. et al. Bioelectrochemistry, 2018

Hydrogen fuel production



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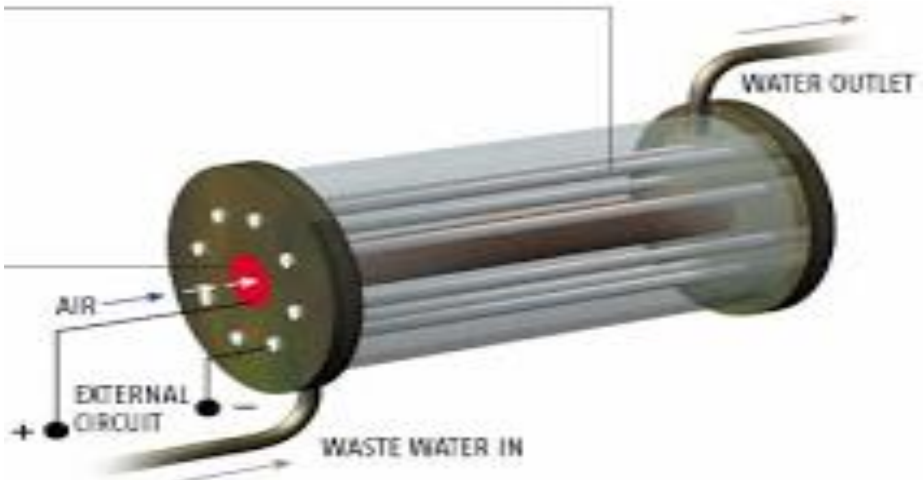
Kayla Matthews, SRE

MudWatt™ Kit



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