Photosynthetic bio electrochemical systems (photosynthetic-BES)

Possible areas of application

September 2018

Paolo pb346@cam.ac.uk

@ Department of Biochemistry (University of Cambridge, UK)

Photosynthetic organisms

(few example)

Photosynthetic organisms

(few example)

Products

Fibers/biomass

Fuel(s)

Food(s)

Photosynthetic organisms

(few example)

Products

Fibers/biomass

Fuel(s)

Food(s)

Electricity

Photosynthetic organisms

(few example)

Products

Fibers/biomass

Fuel(s)

Food(s)

Electricity

How does it work?

Photosynthetic organisms generate electricity: how does it work?

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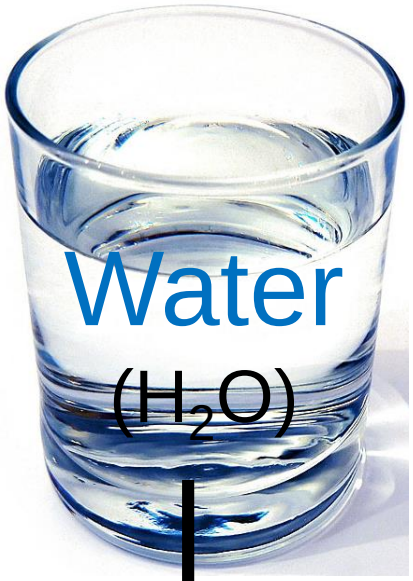
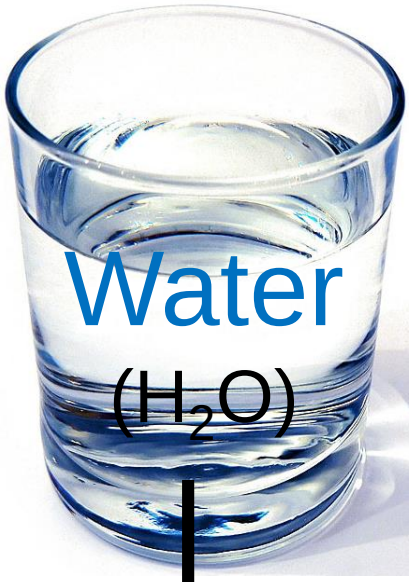


$2H^+$ **(2 protons)**

+ ½ O_2 (½ molecular oxygen)

Photosynthetic organisms generate electricity: how does it work?



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How many **electrons** <u>could</u> be generated from a glass of water (ca. 180mL)

2200 mAh = 7920 C

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2200 mAh = 7920 C

Glass of water = 180 mL

Water molecular weight: 18 mol/g

Water density ~ 1 g/mL

Glass of water= (180 / 18) = 10 mol of H_2O

10 mol of H_2O = 20 mol of elsctron$^-$

Faraday(F) ~ 96500 Coulomb

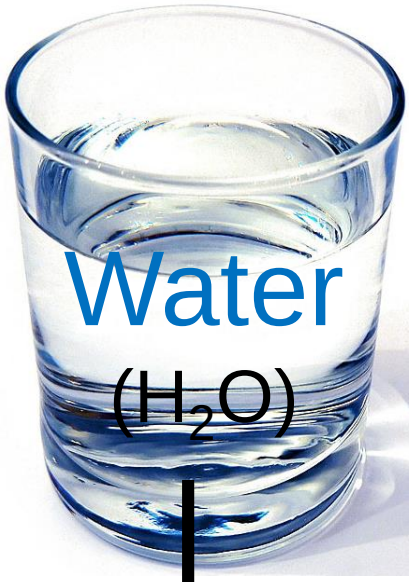
Glass of water = 20 mol x F = 1.93 x 10^6 C

= 1.93 x 10^6 C / 7920 C = 243.7

~244

Glass of water =

Photosynthetic organisms generate electricity: how does it work?



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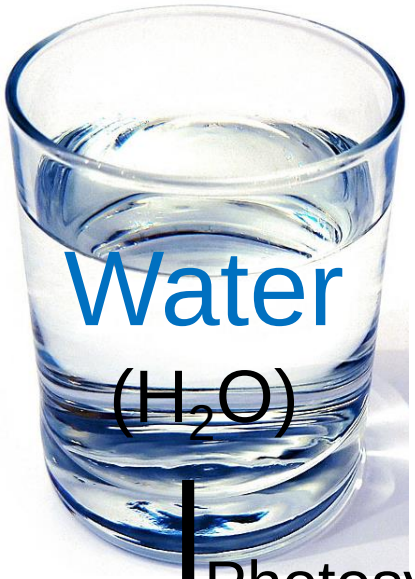

+ **Light**

Photosynthetic (oxygenic) organisms

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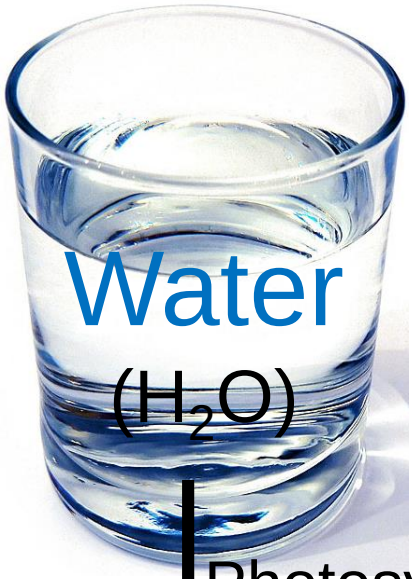
Water photolysis

Photosynthetic organisms generate electricity: how does it work?



+ **Light**

Photosynthetic (oxygenic) organisms

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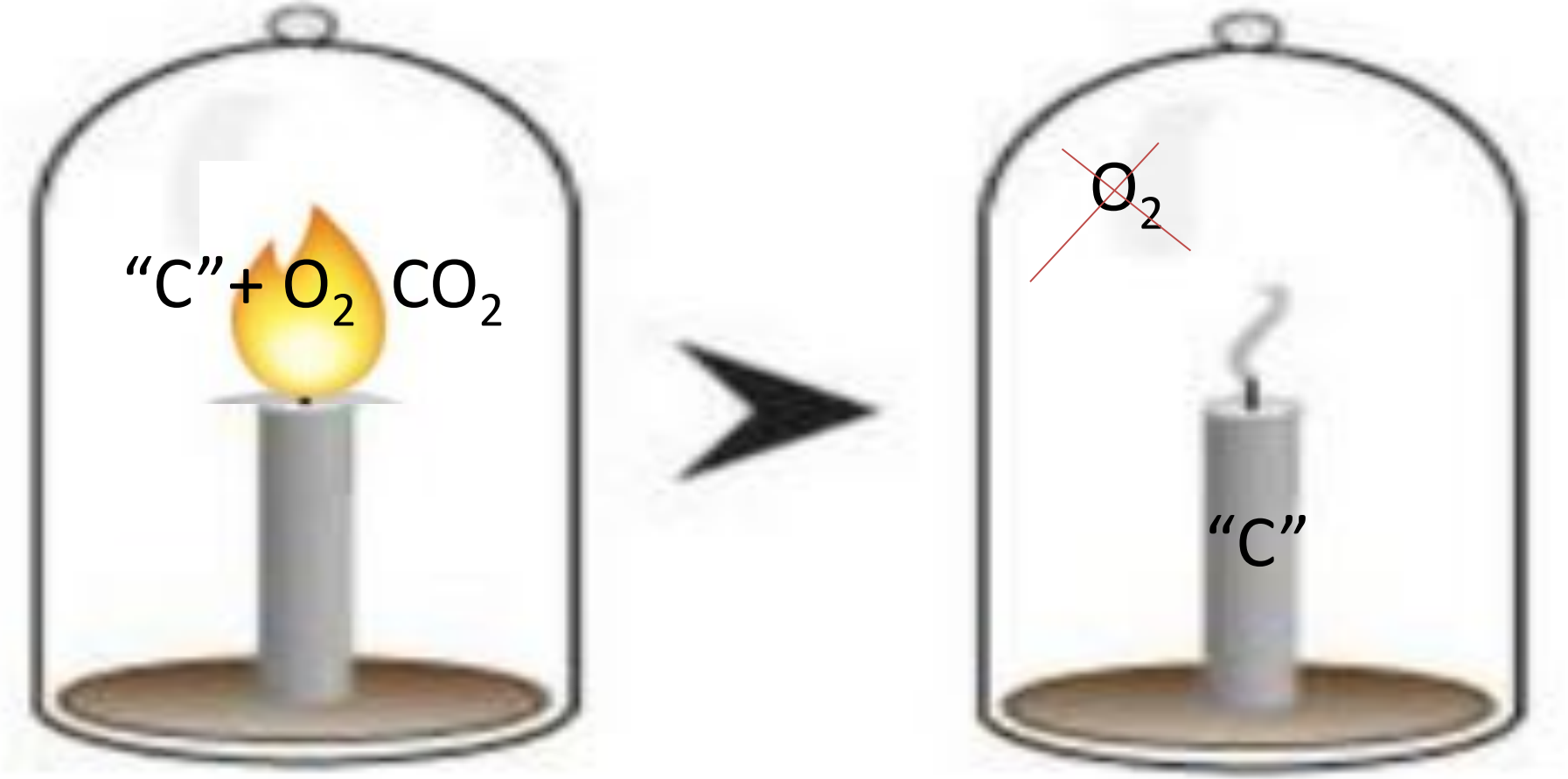
Water photolysis

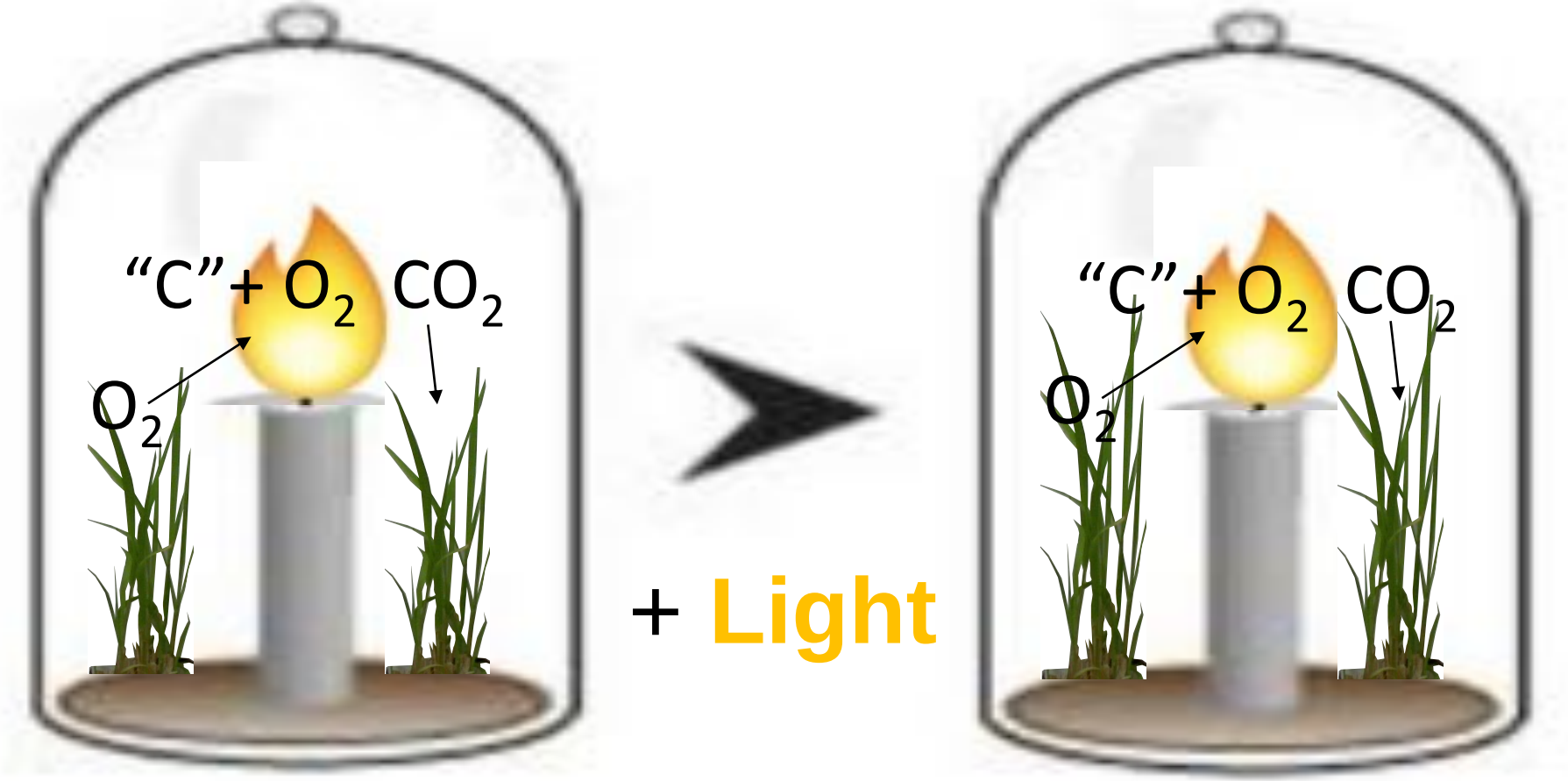
Can I prove that?

To prove that photosynthetic organisms generate oxygen (and therefore electrons)



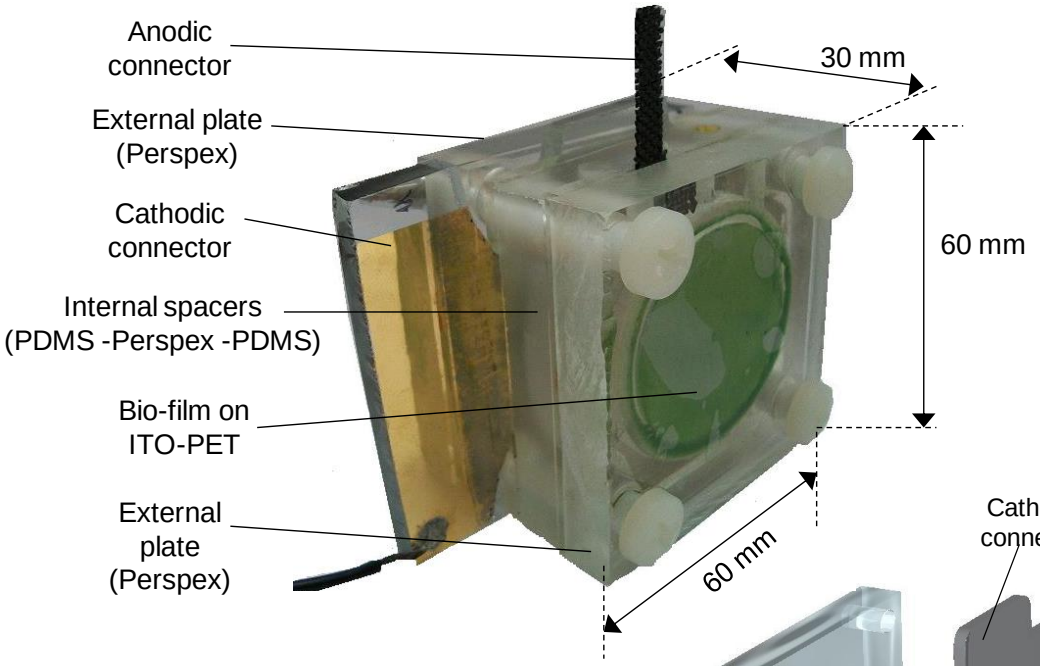
Priestley's experiment

To prove that photosynthetic organisms generate oxygen (and therefore electrons)

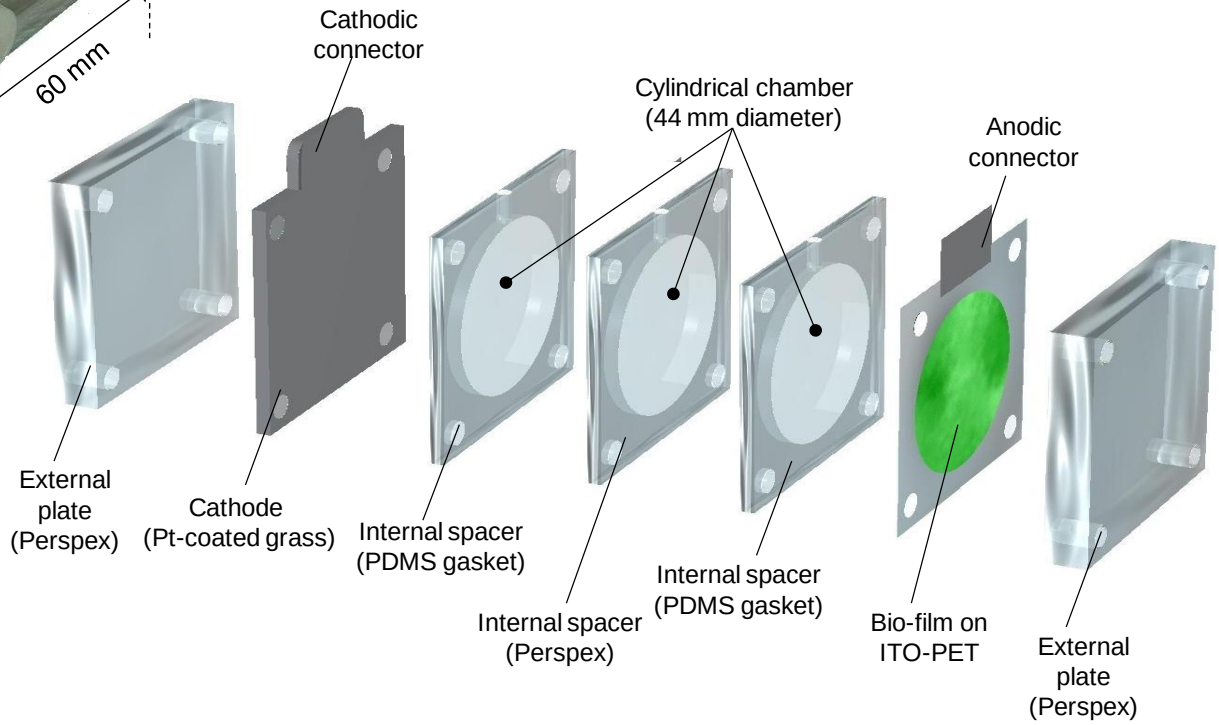


Priestley's experiment

Photosynthetic bio electrochemical systems (photosynthetic-BES)

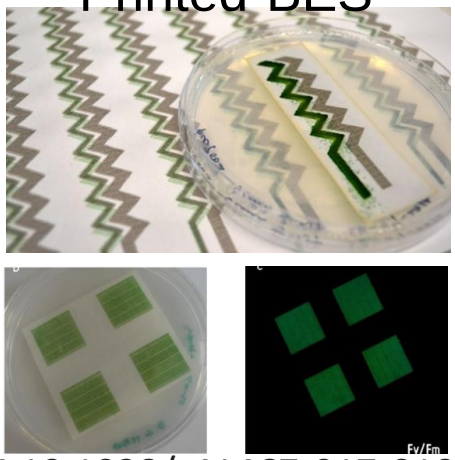


McCormick *at al*. 2011
Energy Environ. Sci., 2011,**4**, 4699-4709



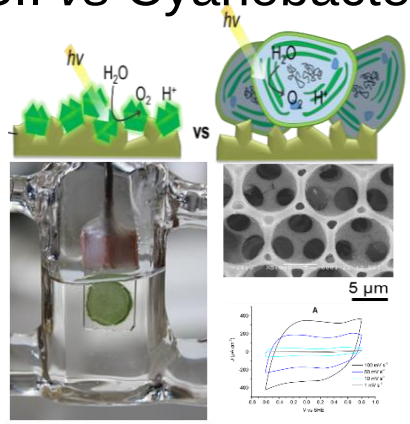
Photosynthetic bio electrochemical systems (photosynthetic-BES)

Printed-BES



DOI:10.1038/s41467-017-01084-4
Nature Communications, 2017

PSII *vs* Cyanobacteria

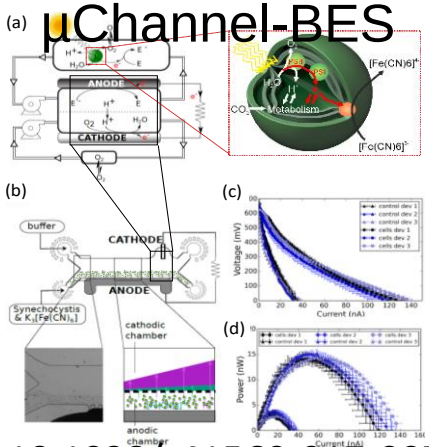


DOI: 10.1021/jacs.7b08563
J. Am. Chem. Soc., 2017

Electricity from rice

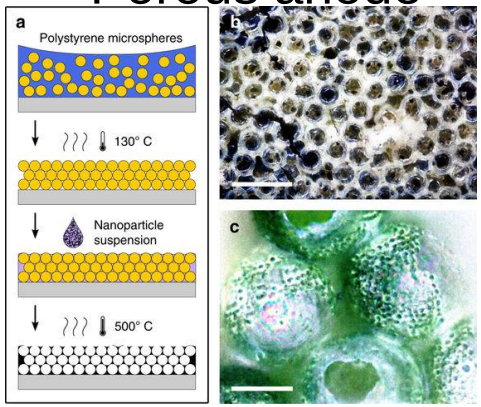
DOI: 10.1007/s00253-012-4473-6
Ap. Microb. and Biotech., 2013

µChannel-BES



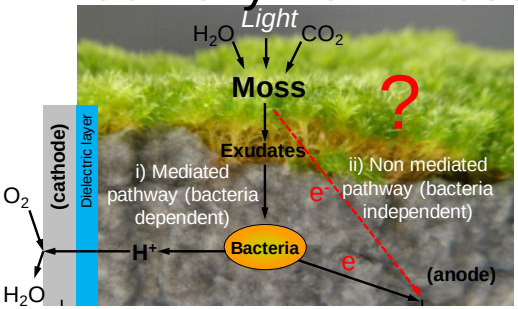
DOI:10.1038/s41560-017-0073-
Nature Energy, 2018

Porous anode



DOI: 10.1038/s41467-018-03320-x
Nature Communications, 2018

Electricity from moss



DOI: 10.1098/rsos.160249
Royal Society j. *Open Science*, 2016

Photosynthetic-BESs:

are they feasible for actual applications?

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It depends from the
given conditions

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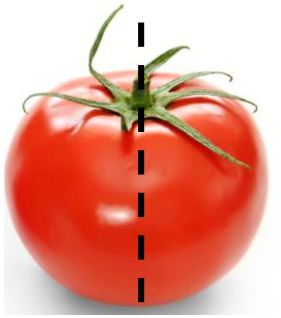
Palermo (Sicily)

Summer

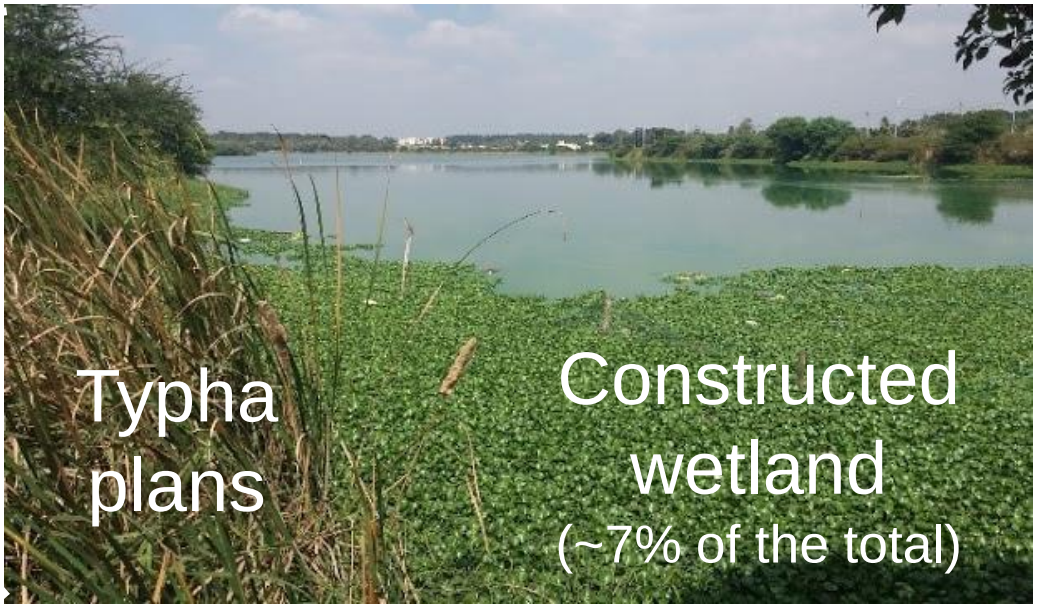


Glasgow (Scotland)

Winter

Photosynthetic-BES combined with wastewater treatment

Jakkur lake ~160-acre (~647,000 m2)



Priyanka Jamwal

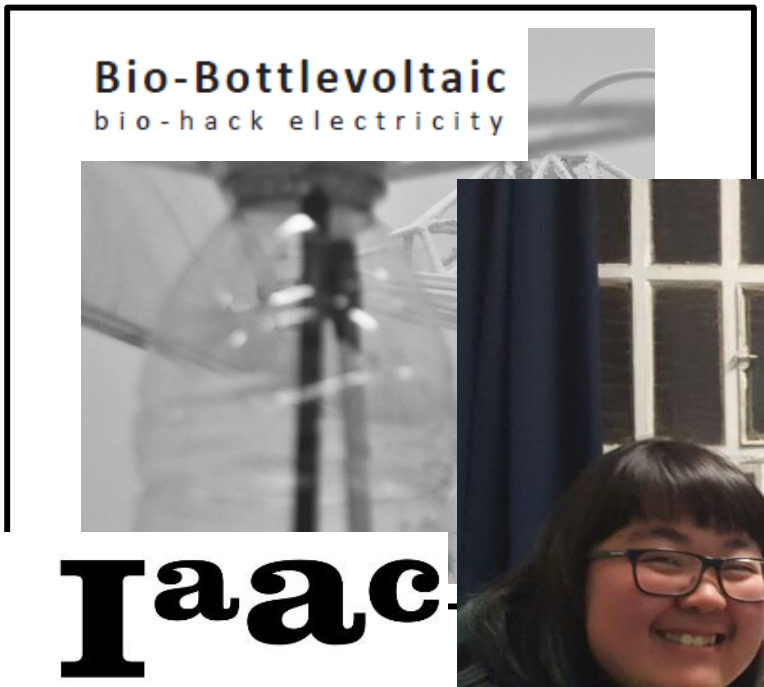
Sue Harrison

Bengaluru

Population (2017): ~12M

ASHOKA TRUST FOR RESEARCH IN ECOLOGY AND THE ENVIRONMENT

Photosynthetic-BES as educational toolkit



Lara Allen

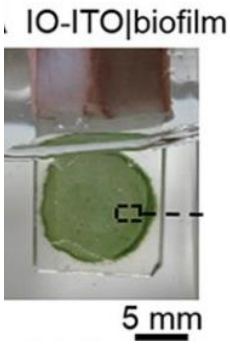
Centre fo
Global
Equality

http://www.iaacblog.com/programs/bio-bottle-voltaic-bbv/

Photosynthetic-BES as tool of investigation for lab work

e.g., to investigate the mechanism of electron transport

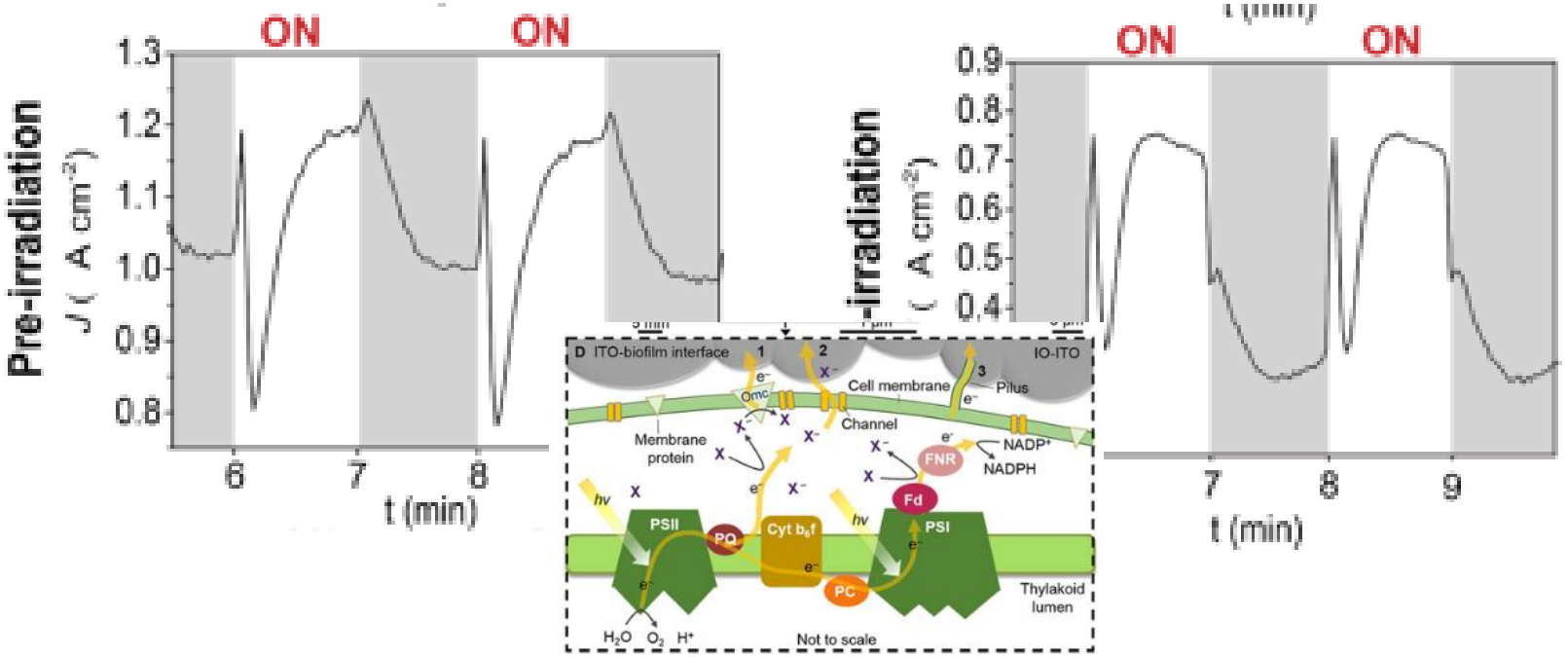
J. Am. Chem. Soc., 2017
DOI: 10.1021/jacs.7b08563



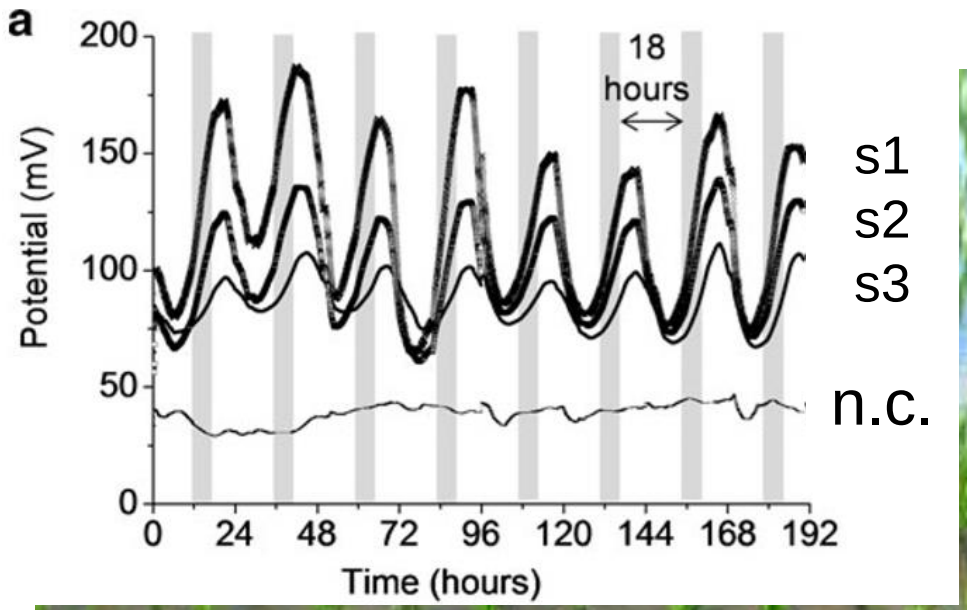
Jenny Zhang

Laura Wey

Chronoamperommetry



Photosynthetic-BES as tool of investigation for agricultural work

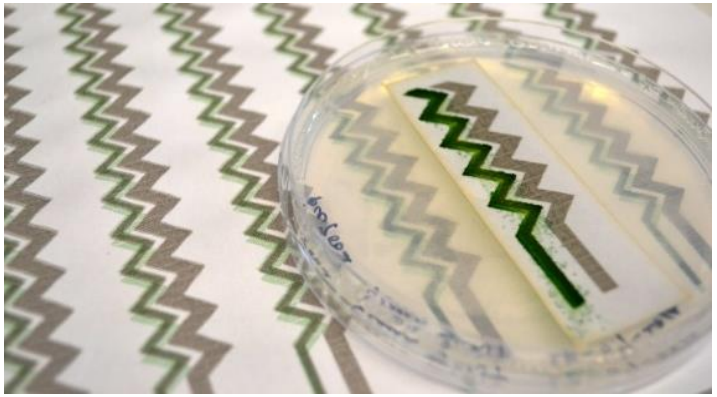


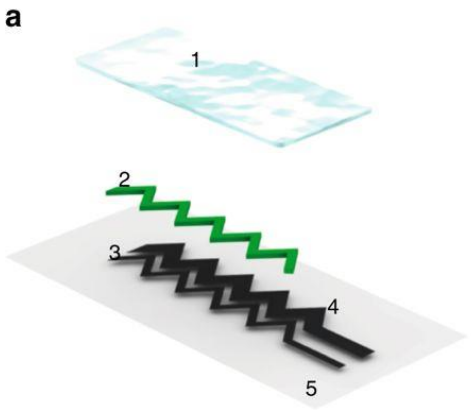
Appl Microbiol Biotechnol doi: 10.1007/s00253-012-4473-6

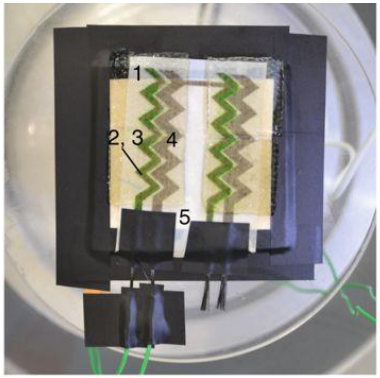
Photosynthetic-BES used to run μ-chip

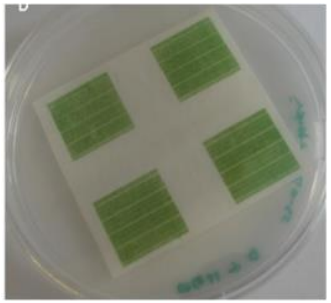
Anand Savanth

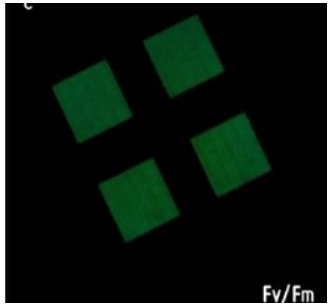
Emre Ozer











Andrea Fantuzzi

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Marin Sawa

DOI:10.1038/s41467-017-01084-4
Nature Communications, 2017

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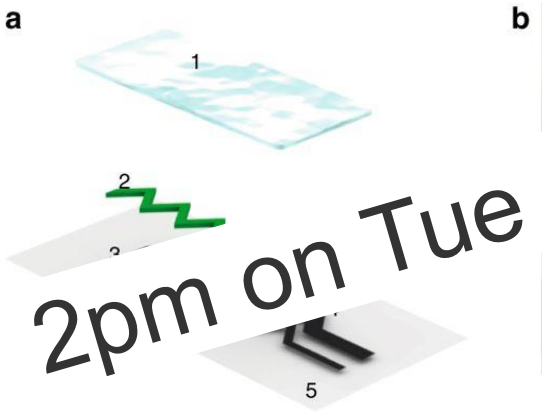
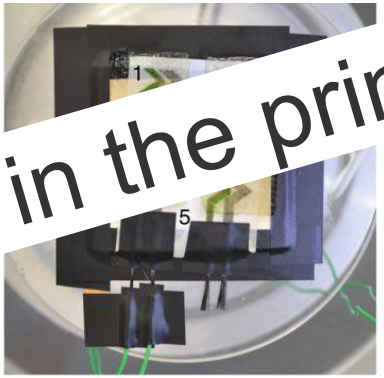
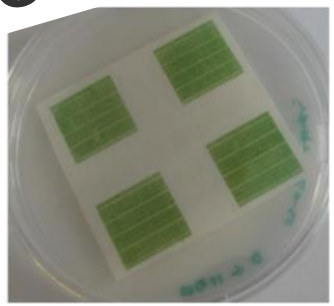
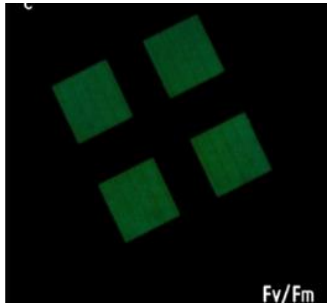
Photosynthetic-BES used to run µ-chip









2pm on Tue in the printed electric session

DOI:10.1038/s41467-017-01084-4
Nature Communications, 2017

Imperial College London

Andrea Fantuzzi

Peter Nixon

Marin Sawa

Photosynthetic-BES used to run environmental sensor in remote locations (e.g., tropical forest)

ZSL
LIVING CONSERVATION

Alasdair Davies Rachael Kemp

Photosynthetic-BES used to run environmental sensor in remote locations (e.g., tropical forest)

The environmental sensor requires:
5000 mC (@ 5V) per day

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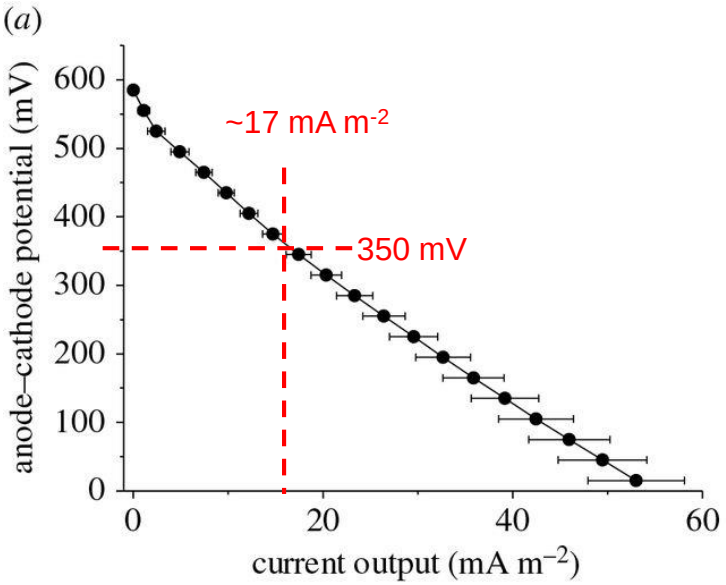

Royal Society journal *Open Science*, 2016 **DOI**: 10.1098/rsos.160249

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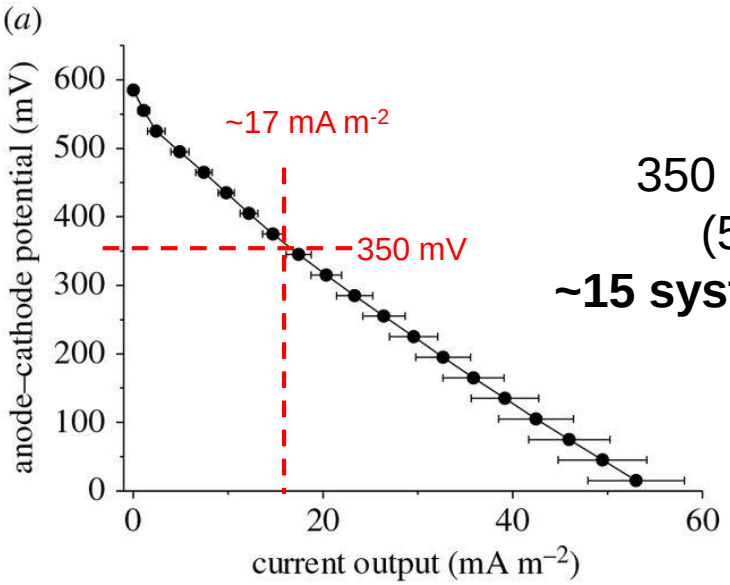


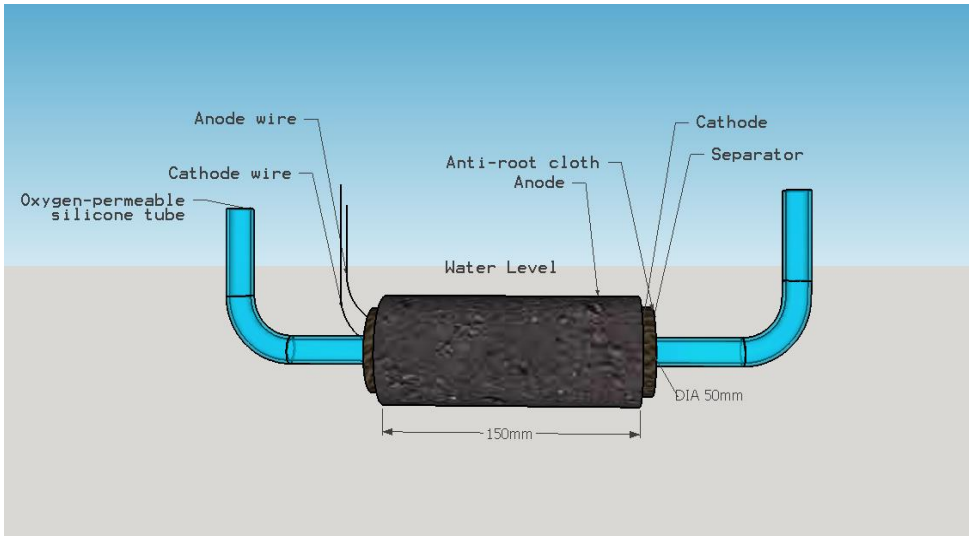
Potential:
350 mV per system
(5V / 0.35V)=
~15 system to provide 5V

Royal Society journal *Open Science*, 2016 **DOI**: 10.1098/rsos.160249

Current:
17 mA m^{-2} = 1.7 µC s^{-1} cm^{-2}
1.7 µC s^{-1} cm^{-2} = 146.9 mC cm^{-2} per day
5000/146 = ~ **34 cm^{-2}**

Photosynthetic-BES used to run environmental sensor in remote locations (e.g., tropical forest)

The real device might look like this



+ plants…..

In conclusion

photosynthetic-BES could be a feasible tool to:

power environmental sensor in remote locations (e.g., tropical forest)

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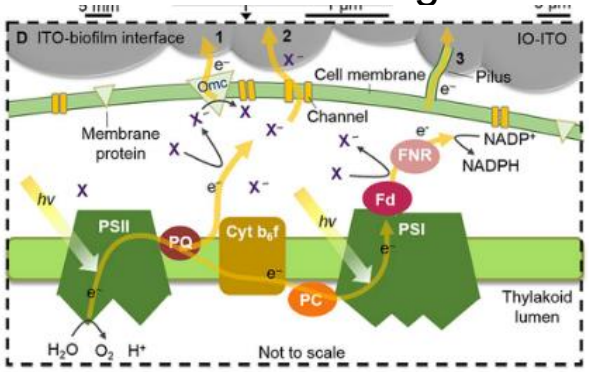
photosynthetic-BES could be a feasible tool to:

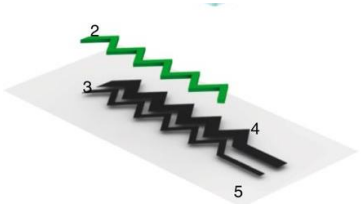
Tool of lab investigation



power environmental sensor in remote locations (e.g., tropical forest)

power autonomous µ-chip

arm



Develop educational tool-kit

Centre for Global Equality

Be a living sensor for agricultural application

Combined with wastewater treatment

ZSL
LIVING CONSERVATION

Acknowledgments

Howe's lab

- **<u>Chris Howe (Group Leader)</u>**
- Jack Hervey (Graduate Student)
- Isabel Nimmo (Postdoctoral Researcher)
- Ellen Nisbet (Senior Research Associate)
- Elfadil Osman (Graduate Student)
- Stephen Rowden (Graduate Student)
- Barnaby Slater (Graduate Student)
- Laura Wey (Graduate Student)
- Wendy Gibson (Lab Manager)

UNIVERSITY OF CAMBRIDGE

Acknowledgments

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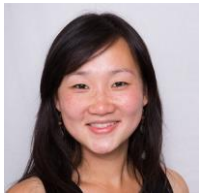
Chris Howe 

Jenny Zhang 

Imperial College London

Bill Rutherford 

Andrea Fantuzzi 

Peter Nixon 

Marin Sawa 

Alison Smith 

Erwin Reisner 

ZSL LIVING CONSERVATION

Alasdair Davies 

Rachael Kemp 

Tuomas Knowles 

AIrEE

Priyanka Jamwal 

arm

Anand Savanth

Emre Ozer

Lara Allen 

Centre for Global Equality

CeBER

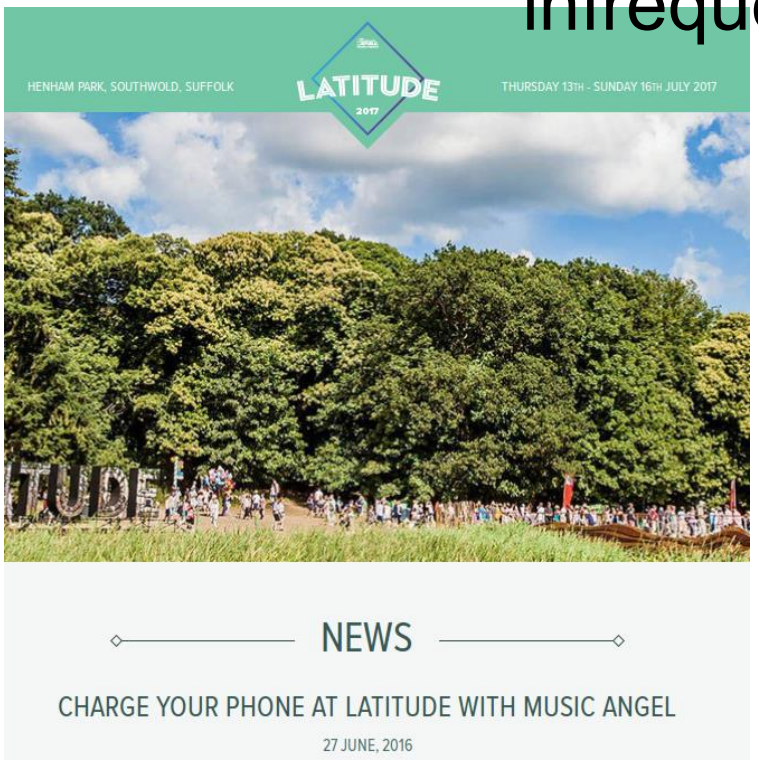
Sue Harrison 

Acknowledgments

Acknowledgments

Thank you for your attention

Photosynthetic-BES to power small device in “infrequent” location/event



Music Angel Social Power: Li - ion battery (@5v)

Music Angel Mobile Charging are at the festival this year to keep you topped up with power. For £20 on pre-order, you get a Social Power battery that comes with an unlimited charging wristband – meaning you can swap the battery as many times as you like over the festival.

It takes 2 hours to charge an iPhone 6. For this phone, the battery has a voltage of 3.82V and the capacity is 1810 mAh. For a total of 6.91Wh.

At the festival the charging station are open from 9am to 11pm (14h). Therefore we could extimate up to (14/2)= 7 cycles to charge per day.

Therefore, the total electrical energy consumed per day could be up to (6.91 x 7)= 0.048 kWh per day.

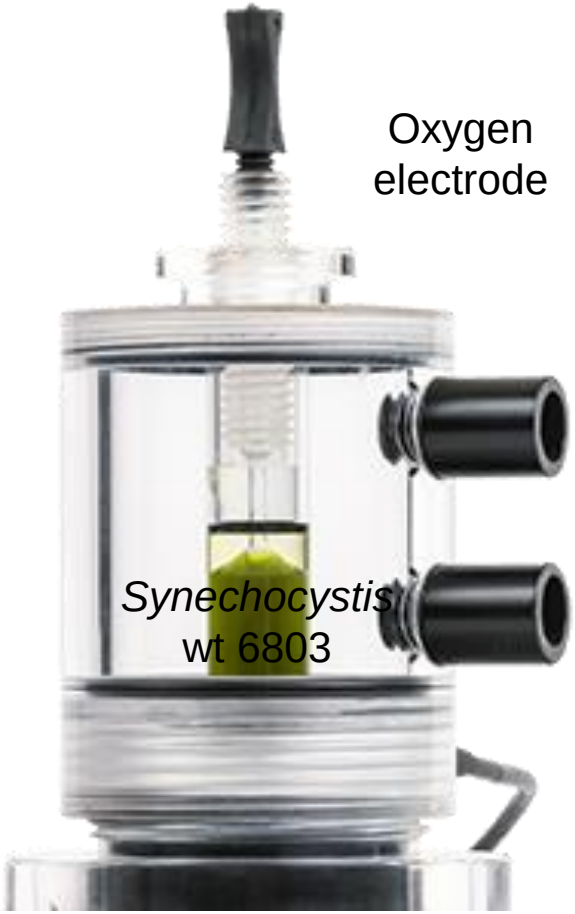
Latitude operates for 4 days, therefore at most you could consume (0.048x4)= 0.194 kWh

During the festival, you will pay the electrical energy to charge your mobile (20/0.194)= £ 103 per kWh

http://www.musicangelsocialpower.com/

http://www.latitudefestival.com/news/charge-your-phone-latitude-music-angel

To prove that photosynthetic organisms generate oxygen (and therefore electrons)



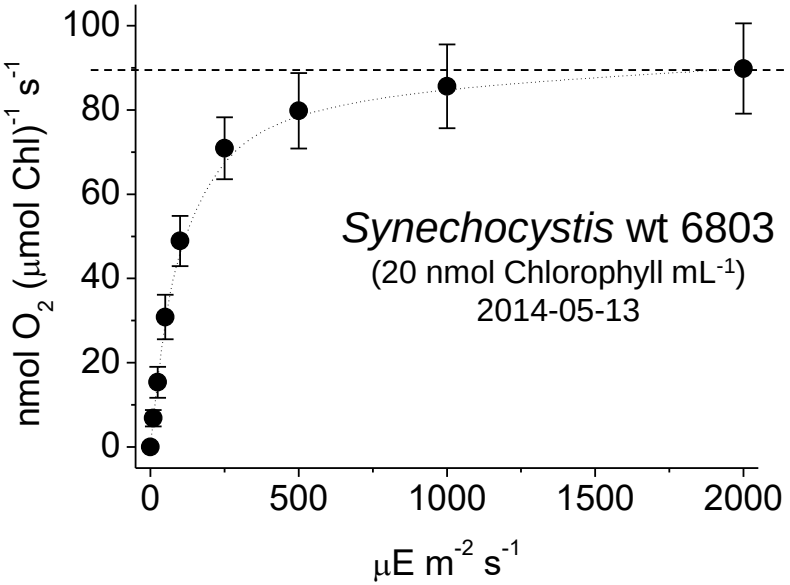
Ø: 1 cm

Top area : 0.79 cm^2

h: 2.5 cm (for 2 mL)

Front area: 2.5 cm^2

~90 nmol O_2 (µmol Chl)$^{-1}$ s^{-1} (@ 2000 µE m^{-2} s^{-1})



20 nmol Chlorophyll mL^{-1} x 15 mL = 300 nmol Chlorophyll

Photosynthetic oxygenic activity: ~90 nmol O_2 (µmol Chl)$^{-1}$ s^{-1}

(90 nmol O_2 (µmol Chl)$^{-1}$ s^{-1}) x 300 nmol Chlorophyll = 27 µmol O_2 s^{-1}

Given: $H_2O \rightarrow O_2 + 4H^+ 4e^-$ (27 µmol O_2 s^{-1}) x 4 = 108 µmol e^- s^{-1}

Given: Coulomb = charge x F 108 µmol e^- s^{-1} x F = 10.4 mC s^{-1}

= 10.4 mA

~ 250 mAh day^{-1}

Ni-Cd AAA (300 mAh)

pBES in school

Hills road sixth form college (Cambridge)
http://www.hillsroad.ac.uk/

University Technical College (Cambridge)
Alistair Easterfield
aeasterfield@utccambridge.co.uk

http://www.etoncollege.com/
Karl Frearson Head of Science
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Marketa Cechova (Prague, Czech Republic).
http://www.nordangliaeducation.com/our-schools/prague
Marketa.Cechova@eisp.cz

Marlboro College (USA)
(self-directed liberal arts education)
https://www.marlboro.edu/
danielm@marlboro.edu

Jeff Roth-Vinson
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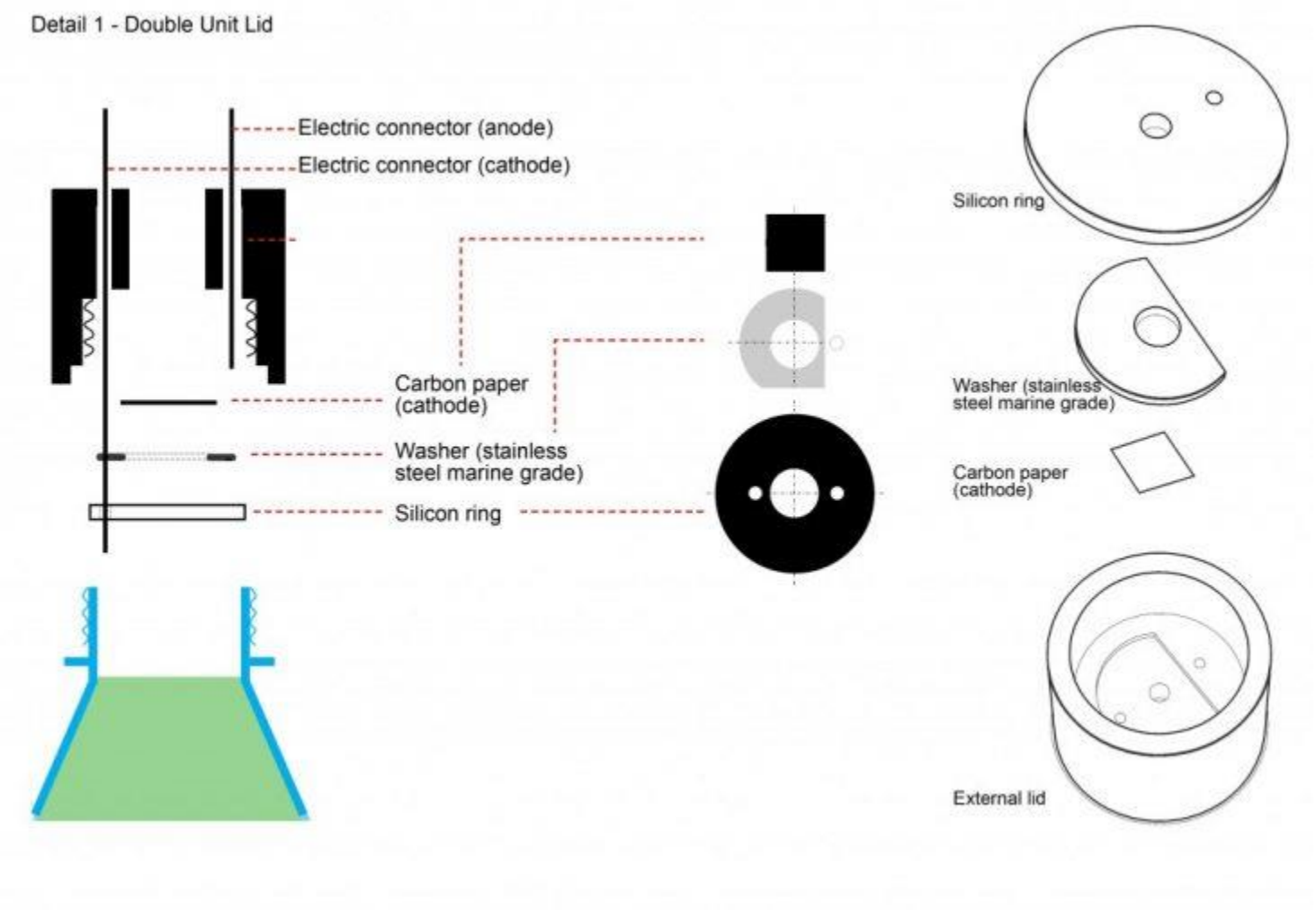
Filipa de Vilhena HighSchool in Oporto, Portugal.
http://www.filipa-vilhena.edu.pt/
JoÃo Campos Grancho jcgrancho@gmail.com

pBES as educational tool-kit



http://www.iaacblog.com/programs/bio-bottle-voltaic-bbv/

pBES as educational tool-kit

biology

MDPI

Article

Electrochemical characterisation of BBV systems operated with algae and built with recycled materials

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Plant-BES in school

Filipa de Vilhena
Mais informados, mais capazes, mais livres.

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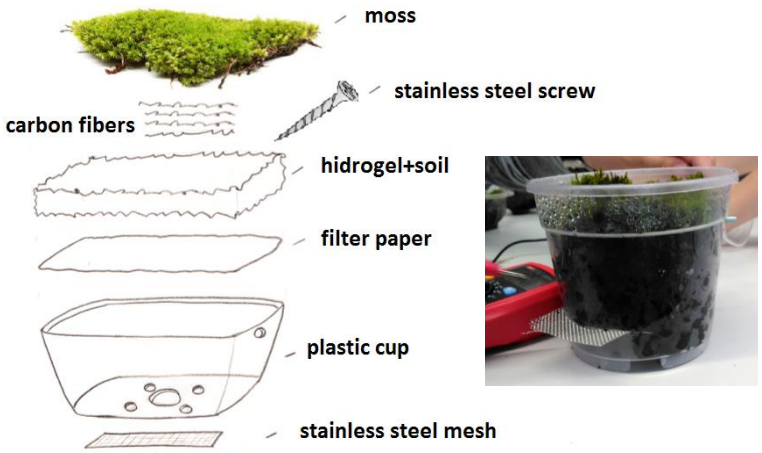
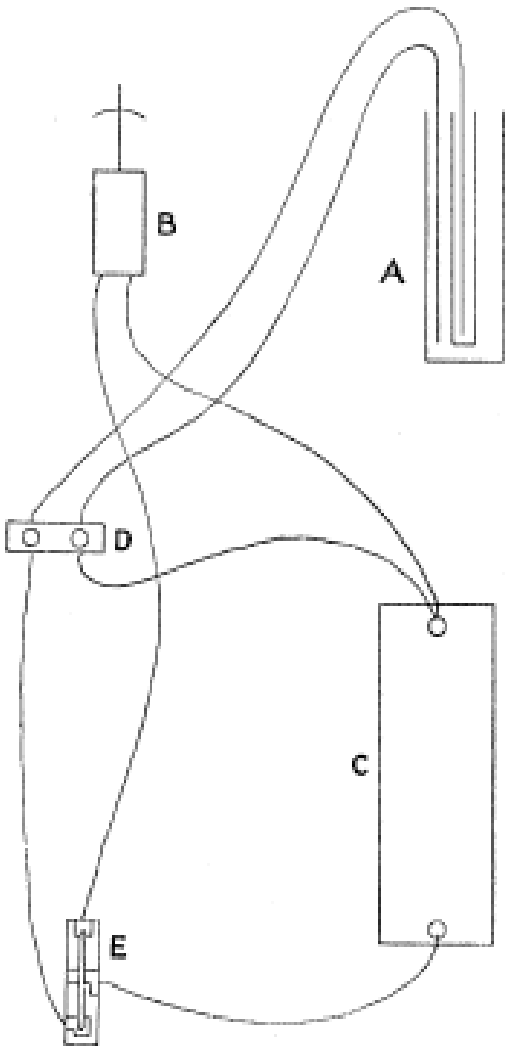


CÉLULA	DIFERENÇA DE POTENCIAL / mV			
	16 maio	17 maio	18 maio	19 maio
controlo	109,4	108	100,4	69,6
1	447	503	504,2	501,2
2	239	386,2	302,8	303
3	269	249,1	250,4	249,3
4	183,4	225,6	226,3	227
5	178,5	140	196,4	195,3
6	171,9	161	172,1	172,2
7	189,1	194,2	200,2	201,3
8	177,7	172,1	178,1	184
9	282,4	302,3	304	304
10	190,2	201,2	203	213,4

Bio Electrochemical System (BES): is this concept new?

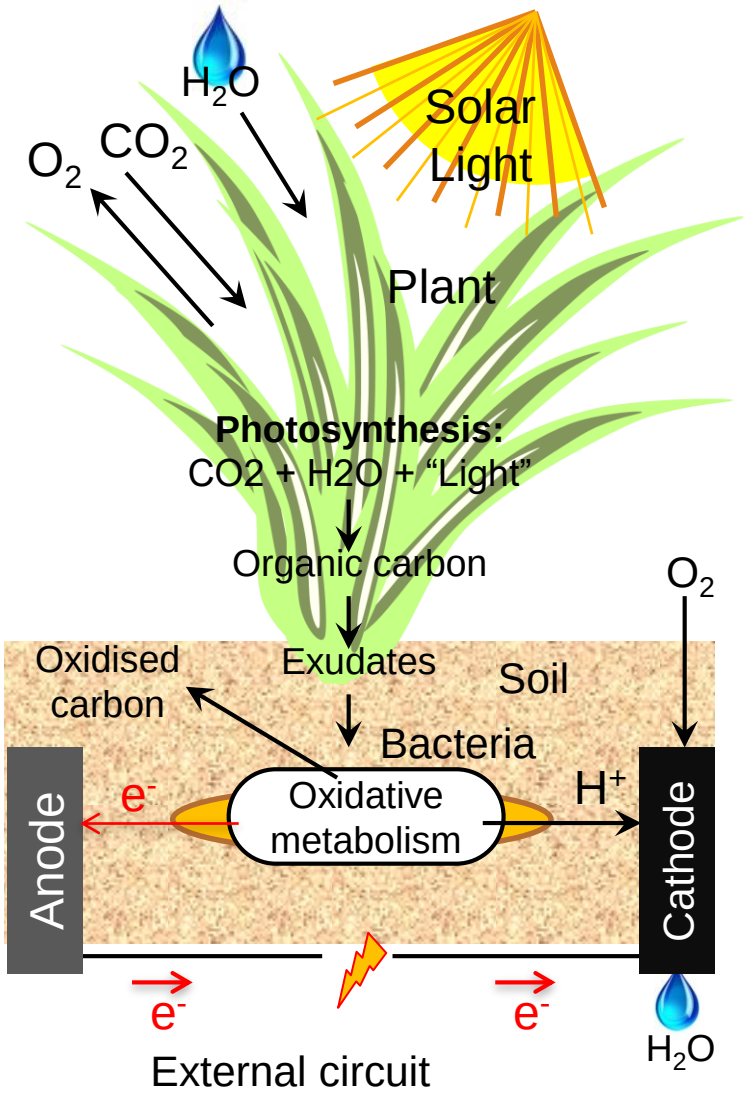


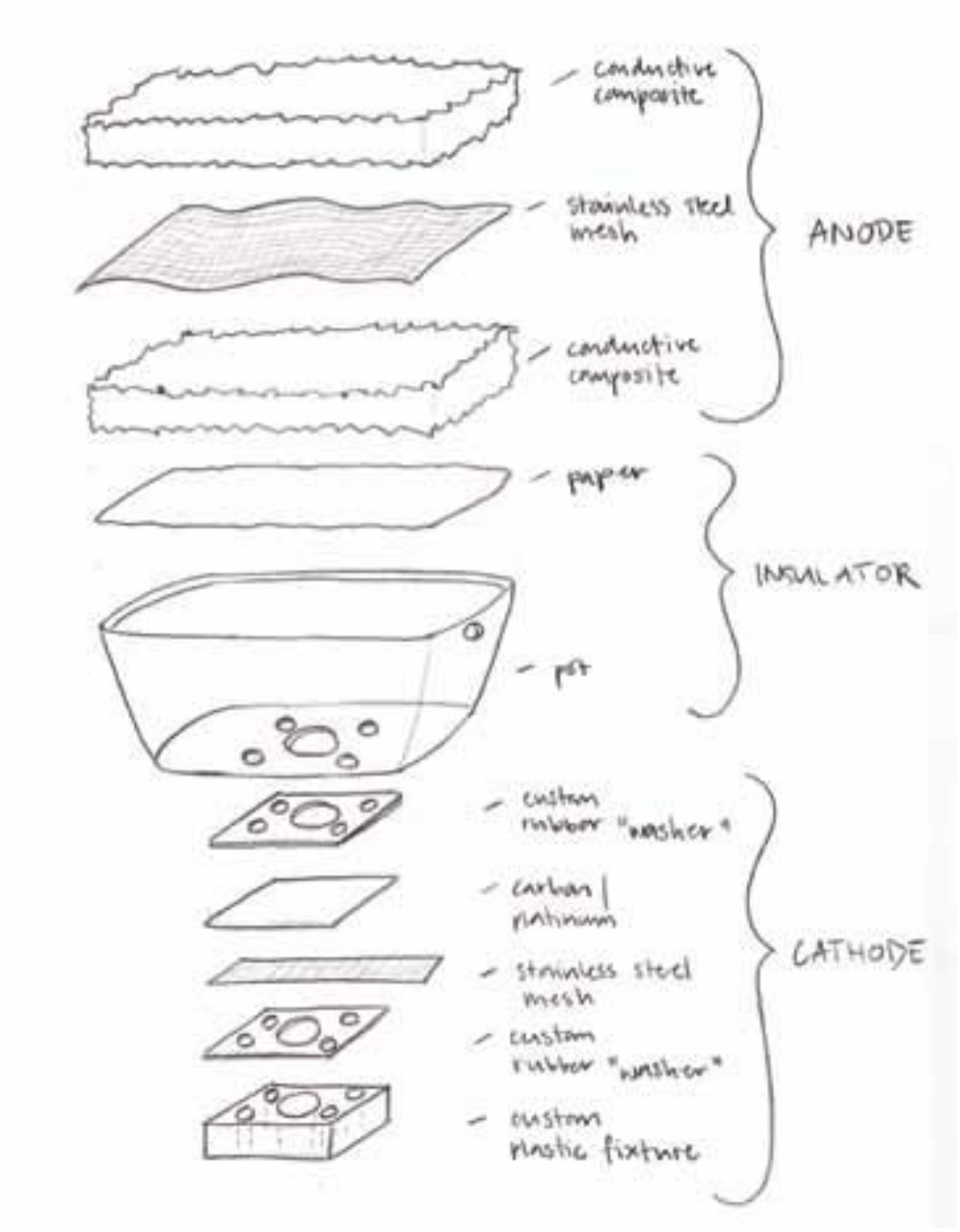
A, The cell.
B, Galvanometer.
C, Condenser.
D, Mercury cup
facilitate connec
with different c
E, Morse key.

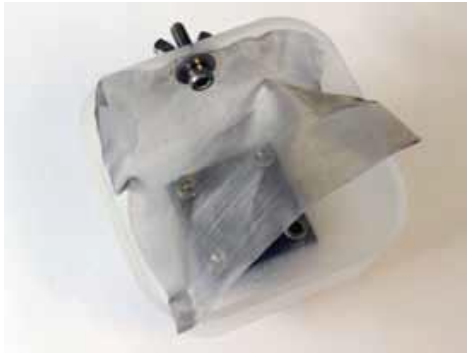
Proceedings of the Royal Society of London. Vol. 84, N.571 (**Sep. 14, 1911**) pp.260-276

M. C. Potter
University of Durham
(Professor of botany)

Electrons from plants: how does it work?







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Electrons from plants: what could we power?

~ 2000 W

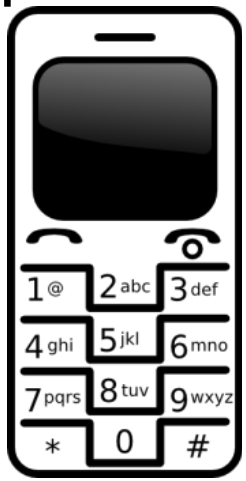
Electrons from plants: what could we power?

Environmental sensors (e.g., humidity, temperature, light)

1-50 mW

Indeed

Mobile phones



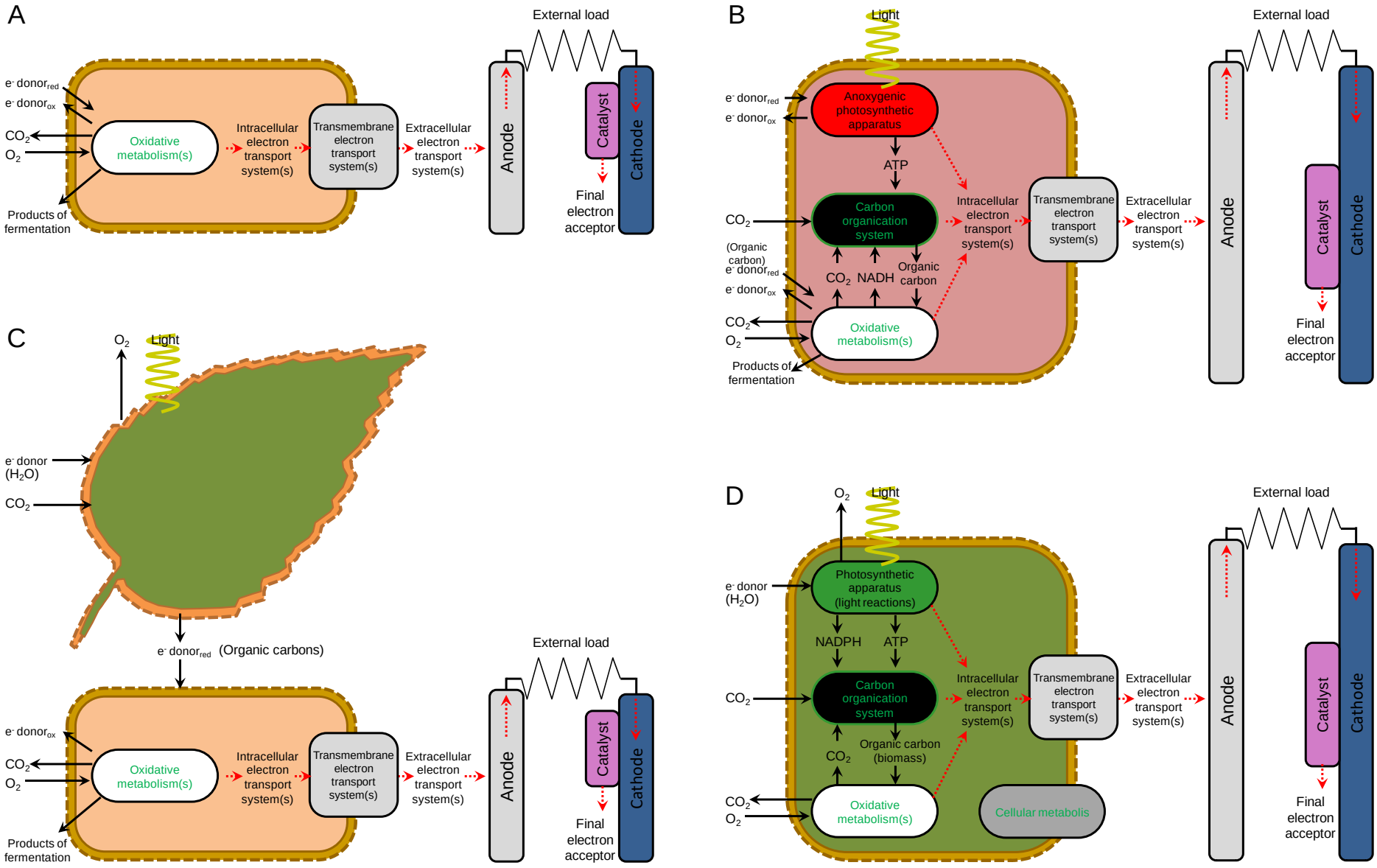
100-500 mW

Almost there…

PCs

1-10 W

Maybe…


A
e- donor red
e- donor ox
CO2
O2
Oxidative metabolism(s)
Products of fermentation
Intracellular electron transport system(s)
Transmembrane electron transport system(s)
Extracellular electron transport system(s)
Anode
External load
Catalyst
Cathode
Final electron acceptor
B
Light
e- donor red
e- donor ox
Anoxygenic photosynthetic apparatus
ATP
CO2
Carbon organication system
(Organic carbon)
e- donor red
e- donor ox
CO2
NADH
Organic carbon
CO2
O2
Oxidative metabolism(s)
Products of fermentation
Intracellular electron transport system(s)
Transmembrane electron transport system(s)
Extracellular electron transport system(s)
Anode
External load
Catalyst
Cathode
Final electron acceptor
C
O2
Light
e- donor (H2O)
CO2
e- donor red
(Organic carbons)
e- donor ox
CO2
O2
Oxidative metabolism(s)
Products of fermentation
Intracellular electron transport system(s)
Transmembrane electron transport system(s)
Extracellular electron transport system(s)
Anode
External load
Catalyst
Cathode
Final electron acceptor
D
O2
Light
e- donor (H2O)
Photosynthetic apparatus (light reactions)
NADPH
ATP
CO2
Carbon organication system
CO2
Organic carbon (biomass)
CO2
O2
Oxidative metabolism(s)
Cellular metabolis
Intracellular electron transport system(s)
Transmembrane electron transport system(s)
Extracellular electron transport system(s)
Anode
External load
Catalyst
Cathode
Final electron acceptor

BES in the context of PV and FC