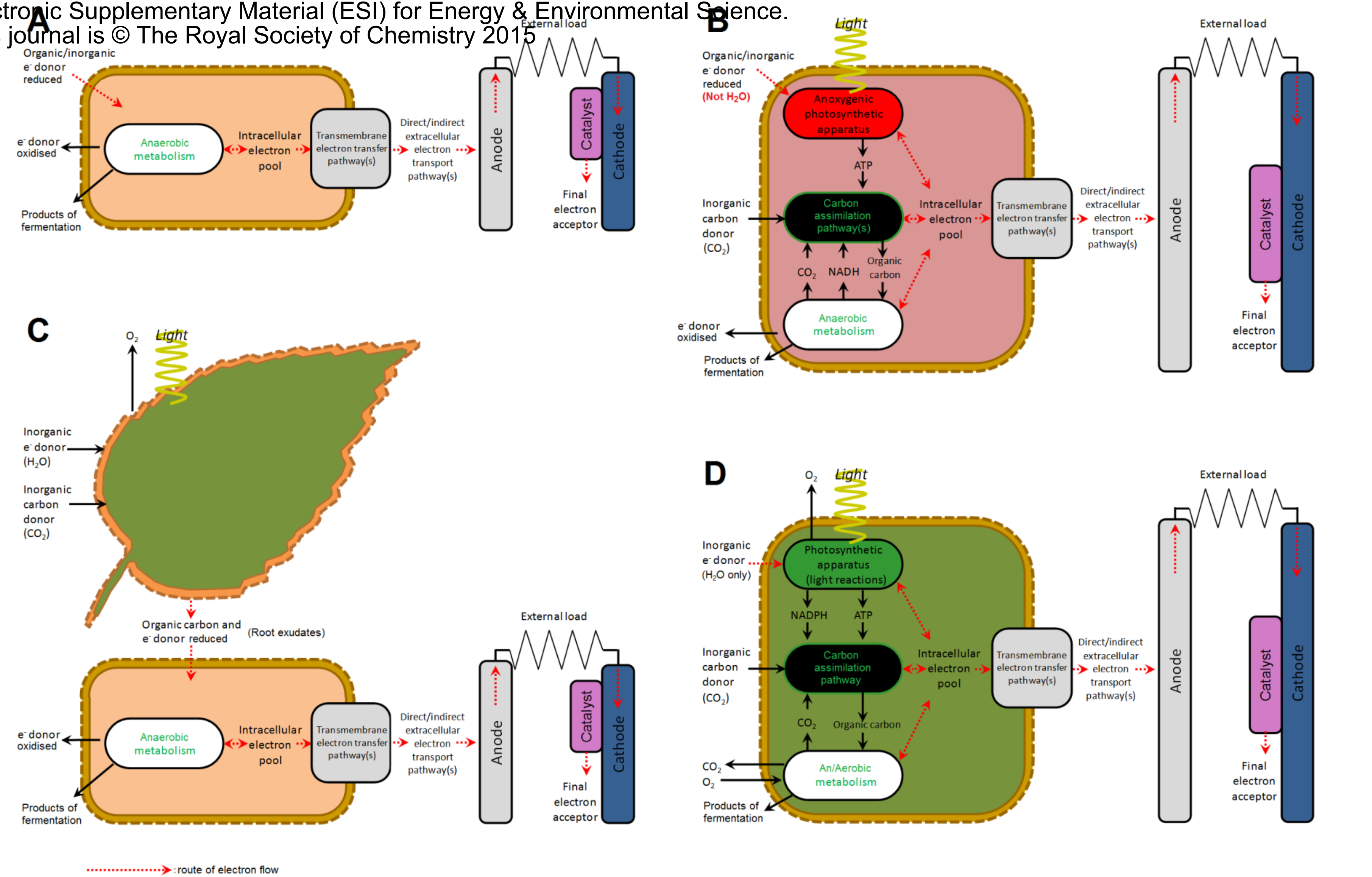
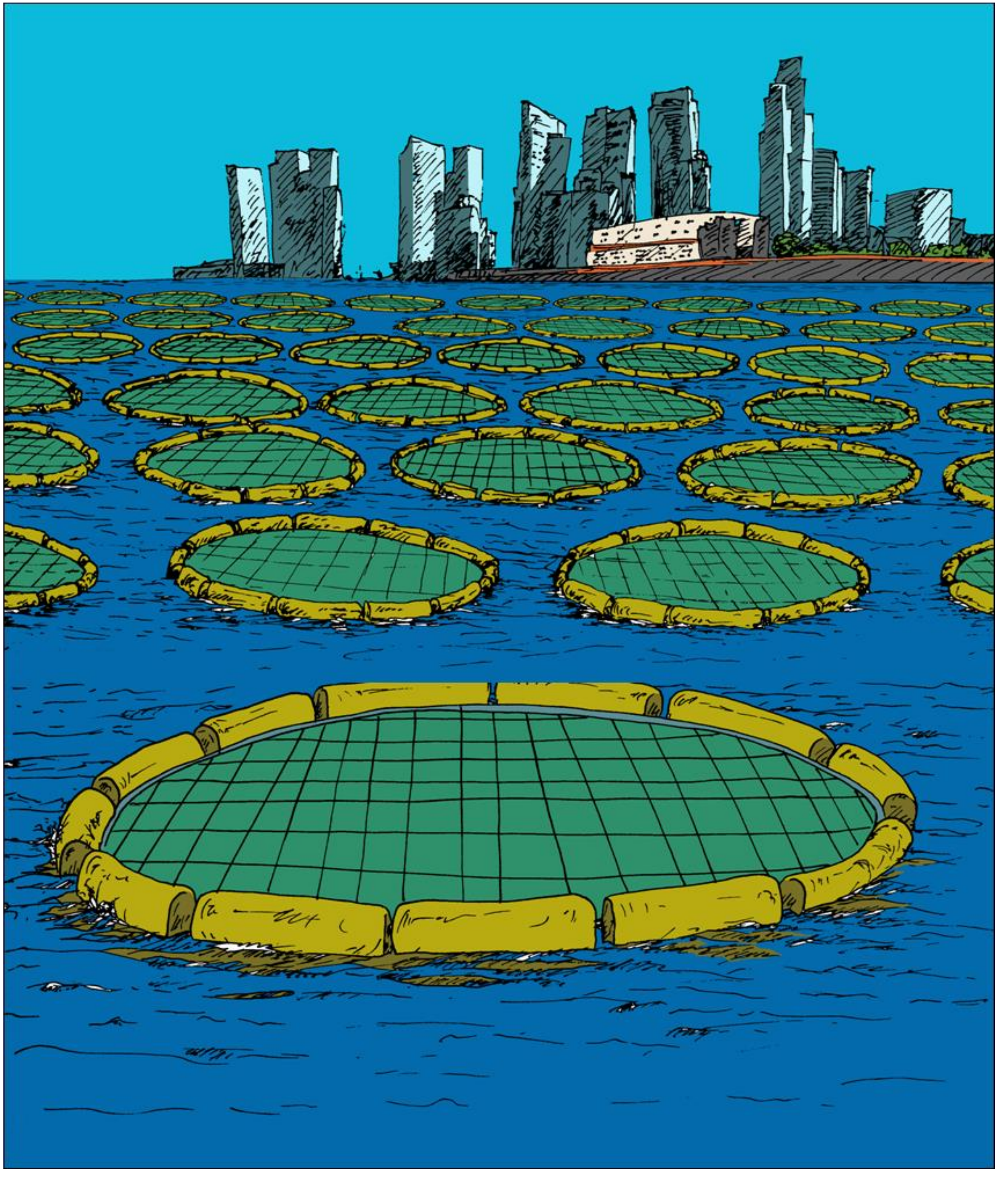



**Supp. Figure 1.** Illustrative diagrams of bioelectrochemical systems (BESs) and light-dependent BESs outlined in Figure 2. The figure shows, in more metabolic detail, microbial fuel cells (MFCs) (**A**), cellular photosynthetic microbial fuel cells (cellular photoMFCs) (**B**), complex photoMFCs (here shown as a plant MFC) (**C**) and cellular biophotovoltaic systems (BPVs) (**D**).



**Supp. Figure 3**. Illustration of a potential marine BPV power station. The bay hosts several floating BPV devices.

**Supp. Table 1.** Complete listing of BES studies reviewed

| Classification | Device name | Photosynthetic material | | Electrode material | | Electron source (feedstock) to anode | Mechanisms for electron export | Main electron acceptor (catalyst) at cathode | OCP | Peak power | Current at peak power | Reference | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Type | Location (with respect to anode, unless stated) | Anode | Cathode | | | | mV | mW $m^{-2}$ | mA $m^{-2}$ | First author | Date | Journal |
| BPV (sub-cellular) | | PSII | Immobilised | Au | | $H_2O$ | 2,6-dimethyl-1,4-benzoquinone | | | | | Badura | 2006 | Photochem. Photobiol. |
| BPV (sub-cellular) | | PSII | Immobilised | Au | | $H_2O$ | Hydrogel | | | | | Badura | 2008 | Electroanalysis |
| BPV (sub-cellular) | | Chloroplasts | Immobilised | Au | | DCIP | FMN | FMN | 515 | 480 | 5000 | Bhardwaj | 1981 | Nature |
| BPV (sub-cellular) | Photosynthetic electrochemical cell | Thylakoids from *Spinacia oleracea* | Immobilised | Multiwalled C nanotubes (thylakoid-MWNT composite) | Multiwalled C nanotubes (laccase-MWNT composite) | $H_2O$ | Mediator-less | $O_2$ (laccase) | 350 | 53 | 250 | Calkins | 2013 | Energy Environ. Sci. |
| BPV (sub-cellular) | Photoelectrochemical cell | Thylakoids from spinach | Suspension | Pt | Pt | $H_2O$ | Ferricyanide | Ferricyanide | | | | Carpentier | 1989 | J. Electroanal. Chem. |
| BPV (sub-cellular) | | Chloroplasts from spinach | Suspension | Pt | Pt | $H_2O$ | Diaminodurene | Diaminodurene | 75 | | | Haehnel | 1979 | Bioelectrochem. Bioenerg. |
| BPV (sub-cellular) | Photoelectrochemical cell | Reaction center complexes from *Rhodopseudomonas sphaeroides* R-26 | Immobilised | $SnO_2$ electrode | Pt | $H_2O$ | Hydroquinone | Hydroquinone | 70 | | | Janzen | 1980 | Nature |
| BPV (sub-cellular) | Micro-electrochemical cell | Thylakoids from spinach | Immobilised | Pt with poly-vinylalcohol bearing styrylpyridinium groups | Pt | $H_2O$ | Mediator-less | $O_2$ (Pt) | | | | Laberge | 2000 | Enzyme Microb. Technol. |
| BPV (sub-cellular) | Photosynthetic electrochemical cell | Thylakoids from spinach | Immobilised | Gold | | $H_2O$ | Cystamine and pyrroloquinoline quinone | $O_2$ | | | | Lam | 2006 | J. Microelectromech. Syst. |
| BPV (sub-cellular) | Photosynthetic electrochemical cell | Thylakoids from spinach | Suspension | Cr/Au | Cr/Au | $H_2O$ | Ferricyanide | Ferricyanide | 470 | | 11 | Lam | 2006 | Sens. Actuators, B |
| BPV (sub-cellular) | Bio-chemical sensor | Thylakoids from baby spinach | Deposited and in suspension | Polypyrrole on Cr/Au | | $H_2O$ | Mediator-less | $O_2$ | | | | Lin | 2006 | IEEE Int. Conf. Nano/Micro Eng. Mol. Syst. |
| BPV (sub-cellular) | Biosensor | PSII particles from *Synechococcus bigranulatus* | Physically adsorbed | Poly-mercapto-p-benzoquinone coated Au | Au | $H_2O$ | Mediator-less | $O_2$ | | | | Maly | 2005 | Biosens. Bioelectron. |
| BPV (sub-cellular) | Photoelectrochemical cell | PSII from spinach chloroplasts | Immobilised | TiO2 | Pt | $H_2O$ | Benzoquinone | Benzoquinone | | | | Rao | 1990 | J. Photochem. Photobiol. |
| BPV (sub-cellular) | Microphotoelectrochemical cell | Thylakoid membranes from *Spinacia oleracea* L | Entrapped | Pt with poly-vinylalcohol bearing styrylpyridinium groups | Pt | $H_2O$ | Mediator-less | $O_2$ (Pt) | | | | Rouillon | 1995 | Sens. Actuators, B |
| BPV (sub-cellular) | Multi-biosensor | Thylakoids from *Spinacia oleracea* L and *Senecio vulgaris* | Immobilised | Graphite with albumin-glutaraldehyde matrix | | $H_2O$ | Duroquinone | Duroquinone | | | | Touloupakis | 2005 | Biosens. Bioelectron. |
| | | | | | | | | | | | | | | |
| BPV (cellular) | Bio-photovoltaic | *Chlamydomonas reinhardtii* | Suspension | ITO coated polyethylene terephthalate | Pt | $H_2O$ | Ferricyanide | $O_2$ (Pt) | | | | Anderson | 2015 | Plant Biotech. J. |
| BPV (cellular) | Bio-photovoltaic | *Synechocystis* sp. PCC 6803 | Suspension | ITO coated polyethylene terephthalate with Cu strip | Nafion-C/Pt | $H_2O$ | Ferricyanide | $O_2$ (Pt) | 262 | 1.2 | 7.75 | Bombelli | 2011 | Energy Environ. Sci. |
| BPV (cellular) | Bio-photovoltaic | *Pseudanabaena limnetica* | Biofilm | ITO coated polyethylene terephthalate with Cu strip | C/Pt | $H_2O$ | Mediator-less | $O_2$ (Pt) | 183 | 0.024 | 0.246 | Bombelli | 2012 | Phys. Chem. Chem. Phys. |
| BPV (cellular) | Bio-photovoltaic | *Synechocystis* sp. PCC 6803 | Deposited | InSnBi | Pt | $H_2O$ | Mediator-less | $O_2$ (Pt) | 350 | 105 | 1050 | Bombelli | 2014 | Adv. Energy Mater. |
| BPV (cellular) | Bio-photovoltaic | *Synechocystis* sp PCC 6803 triple mutant | Suspension | ITO coated polyethylene terephthalate | C-Pt | $H_2O$ | Ferricyanide | $O_2$ (Pt) | 115 | 0.181 | 2.549 | Bradley | 2013 | Phys. Chem. Chem. Phys. |
| BPV (cellular) | Bio-photovoltaic | *Synechocystis* sp. PCC 6803 and mutants | Biofilm | Carbon cloth | Pt | $H_2O$ | Mediator-less | $O_2$ (Pt) | | | 4 | Cereda | 2014 | PLoS One |
| BPV (cellular) | Photo-bioelectrocatalytic / photo-biological fuel cell | Mixed photosynthetic consortia | Suspension | Graphite plate | Graphite plate | $H_2O$ and acetate | Mediator-less | $O_2$ | | | | Chandra | 2012 | Bioresour. Technol. |
| BPV (cellular) | | *Tetraselmis subcordiformis* | Incorporated | Silica sol on C paper | Pt | $H_2O$ (hydrogen produced) | P-benzoquinone | $O_2$ (Pt) | | | | Chen | 2013 | Int. J. Hydrogen Energy |
| BPV (cellular) | Miniature photosynthetic electrochemical cell | *Anabaena* sp. | Suspension | Au | N-Au - csc | $H_2O$ | methylene blue | $O_2$ | 500 | 0.0004 | | Chiao | 2006 | J. Micromech. Microeng. |
| BPV (cellular) | Photosynthetic microbial fuel cell | *Spirulina platensis* | Biofilm | Pt | Pt | | Mediator-less | | 390 | 1.64 | 17.5 | Fu | 2009 | Bioresour. Technol. |
| BPV (cellular) | Photosynthetic microbial cell | *Spirulina platensis* | Dense layer | Pt | Pt | $H_2O$ | Mediator-less | $O_2$ (Pt) | 400 | 6.5 | 56 | Fu | 2010 | Biochem. Eng. J. |
| BPV (cellular) | Photosynthetic algal microbial fuel cell | *Chlorella vulgaris* | Immobilsed in alginate beads (cathodic chamber) | Graphite felt | Pt containing C cloth | Glucose | Mediator-less | $O_2$ (Pt/Algae) | 730 | | | He | 2013 | Bioprocess Biosyst. Eng. |
| BPV (cellular) | Photosynthetic microbial fuel cell | *Arthrospira maxima* | Biofilm | ITO coated glass | Pt coated C paper | $H_2O$ | Mediator-less | $O_2$ (Pt) | 170 | 0.0248 | 0.337 | Inglesby | 2013 | Phys. Chem. Chem. Phys. |
| BPV (cellular) | Photo microbial fuel cell | *Chlamydomonas reinhardtii* transformation F5 | Suspension | Pre-treated graphite | Pre-treated graphite | $H_2O$ | Mediator-less | Hexacyanoferrate (III) | 270 | 12.95 | 117.7 | Lan | 2013 | Biochem. Eng. J. |
| BPV (cellular) | Photosynthetic microbial fuel cell | *Spirulina platensis* | Biofilm | Au mesh | Graphite cloth | $H_2O$ | Mediator-less | $O_2$ | 490 | 10 | 70 | Lin | 2013 | Bioresour. Technol. |
| BPV (cellular) | Photosynthetic microbial fuel cell | *Paulschulzia pseudovolvox* | Biofilm | C paint with polypyrrole | Pt containing C fiber cloth | $H_2O$ | Mediator-less | $O_2$ (Pt) | 160 | 6.2 | | Luimstra | 2013 | J. Appl. Phycol. |
| BPV (cellular) | Microbial fuel cell | *Synechocystis* sp PCC 6803 | Biofilm | C fiber | C fiber | $H_2O$ | Mediator-less | $O_2$ | | 0.27 | | Madiraju | 2012 | Bioresour. Technol. |
| BPV (cellular) | Microbial fuel cell | *Synechocystis* sp PCC 6803 | Attached | Ideal surface (modelled) | Ideal surface (modelled) | $H_2O$ | Mediator-less | $O_2$ | | | | Mao | 2013 | J. Ind. Microbiol. Biotechnol. |
| BPV (cellular) | | *Synechococcus* PCC 6301 | Immobilised | C paste | Pt | $H_2O$ | Diaminodurene | Diaminodurene | | | | Martens | 1994 | Photochem. Photobiol. |
| BPV (cellular) | Bio-photovoltaic cell | *Synechococcus* sp. WH 5701 | Biofilm | ITO coated polyethylene terephthalate | Pt coated C paper | $H_2O$ | Mediator-less | $O_2$ (Pt) | 550 | 10 | 50 | McCormick | 2011 | Energy Environ. Sci. |
| BPV (cellular) | Bio-photoelectrolysis cell | *Synechocystis* sp PCC 6803 | Suspension | ITO coated polyethylene terephthalate | Pt-titanium | $H_2O$ | Ferricyanide | $H_2$(Pt) | | | 61.4 | McCormick | 2013 | Energy Environ. Sci. |
| BPV (cellular) | | Mixed photosynthetic biofilm consortium | Biofilm | Carbon paint anodes coated with polypyrrole | Pt-carbon | $H_2O$ | Mediator-less | $O_2$ (Pt) | 250 | 5.9 | 45 | Pisciotta | 2010 | PLoS One |
| BPV (cellular) | | Lyngbya sp. (CCMP2520) and Nostoc sp. (CCMP2511) | Biofilm | Nanostructured fibrillar polypyrrole coated C fiber | Pt-carbon | $H_2O$ | Mediator-less | $O_2$ (Pt) | | | | Pisciotta | 2011 | Appl. Microbiol. Biotechnol. |
| BPV (cellular) | Photo microbial fuel cell | *Chlamydomonas reinhardtii* transformation F5 | Suspension | Pre-treated graphite | Pre-treated graphite | $H_2O$ | Mediator-less | Hexacyanoferrate (III) | 342 | 0.82 | 2.83 | Raman | 2012 | Appl. Energy |
| BPV (cellular) | | *Chlamydomonas reinhardtii* | Immobilised single cell | Au nanoscale probe, AFM compatible | | $H_2O$ | Mediator-less | | | | | Ryu | 2010 | Nano Lett. |
| BPV (cellular) | Photosynthetic-plasmonic-voltaic cell | *Synechococcus bacillaris (CCAP WH5701)* | Immobilised single cell | 50-nm gold-on-glass electrode | Platinum coated carbon paper | $H_2O$ | Mediator-less | $O_2$ (Pt) | 37 | 0.012 | 0.15 | Samsonoff | 2014 | Appl. Phys. Lett. |
| BPV (cellular) | Photo-bioelectrochemical cells | *Nostoc sp. ATCC 27893* | Immobilised cell | Carbon nanotube | Carbon nanotube/laccase | $H_2O$ | 1,4-benzoquinone | $O_2$ | 500 | 100 | 1500 | Sekar | 2014 | Phys. Chem. Chem. Phys. |
| BPV (cellular) | Oxygenic photo-bioelectrocatalytic fuel cell | Mixed photosynthetic consortia | Suspension | Graphite plate | Graphite plate | $H_2O$ and glucose | Mediator-less | $O_2$ | 45 | 0.0036 | 0.15 | Subhash | 2013 | Bioresour. Technol. |
| BPV (cellular) | Bioelectrochemical fuel cell | *Anabaena variabilis* M-2 | Suspension | | | $H_2O$ | 2-hydroxy-1,4-napthoquinone | Ferricyanide | | | | Tanaka | 1988 | J . Chem. Tech. Biotechnol |
| BPV (cellular) | Photo-microbial fuell cell | *Chlorella vulgaris* | Biofilm | FTO coated glass | C cloth | $H_2O$ | Ferricyanide | $O_2$ | 340 | 24 | 110 | Thorne | 2011 | J. Mater. Chem |
| BPV (cellular) | | *Chlorella vulgaris* | Suspension | FTO coated glass | C cloth | $H_2O$ | Ferricyanide | $O_2$ | | | | Thorne | 2014 | Phys. Chem. Chem. Phys. |
| BPV (cellular) | Photo-electrochemical cell | *Synechococcus* sp PCC 7942 | Incorporated | C paste incorporating DMBQ | Pt | $H_2O$ | 2,6-dimethyl-1,4-benzoquinone | $O_2$ (Pt) | | | | Torimura | 2001 | J. Electroanal. Chem. |
| BPV (cellular) | Photosynthetic bioelectrochemical cell | *Synechococcus* sp. PCC 7942 | Suspension | C felt | C felt | $H_2O$ | 2,6-dimethyl-1,4-benzoquinone | 2,2'-Azinobis-(3-ethylbenzthiazoline-6-sulfonate) (BOD) | 600 | 289 | 1111 | Tsujimura | 2001 | Enzyme Microb. Technol. |
| BPV (cellular) | Bioelectrochemical system | *Desmodesmus* sp. | Suspension | C felt | C felt | $H_2O$ | Mediator-less | $O_2$ | | | | Wu | 2013 | PLoS One |
| BPV (cellular) | Photoelectrochemical cell | *Synechocystis* PCC 6714 | Suspension | C cloth | Pt powder loaded C cloth | $H_2O$ | Vitamin K-3 | $O_2$ (Pt) | | 24.8 | 78.75 | Xie | 2011 | J. Chem. Technol. Biotechnol. |
| BPV (cellular) | Bioelectrochemical fuel cell | *Synechocystis* sp. M-203 | Suspension | C cloth | C cloth | Glucose | 2-hydroxy-1,4-napthoquinone | Ferricyanide | 800 | 288 | 600 | Yagishita | 1997 | Bioelectrochem. Bioenerg. |
| BPV (cellular) | Biofuel cell | *Synechococcus* sp. (UTEX 2380) | Suspension | | | $H_2O$ | 2-hydroxy-1,4-napthoquinone | Ferricyanide | 800 | | | Yagishita | 1993 | J. Chem. Tech. Biotechnol |
| BPV (cellular) | Photosynthetic electrochemical cell | *Anabaena variabilis* M-3 | Immobilised in alginate beads (suspended in anode chamber) | C cloth | C cloth | $H_2O$ | 2-hydroxy-1,4-napthoquinone | Ferricyanide | | 800 | 1000 | Yagishita | 1998 | J. Ferment. Bioeng. |
| BPV (cellular) | Photosynthetic electrochemical cell | *Synechocystis* sp. PCC 6714 | Suspension | C cloth | C cloth | Glucose | 2-hydroxy-1,4-napthoquinone | Ferricyanide | | 121 | 275 | Yagishita | 1999 | J. Biosci. Bioeng. |
| BPV (cellular) | Photosynthetic electrochemical cell | *Synechococcus* sp. (UTEX 2380) | Suspension | C cloth | C cloth | $H_2O$ | 2-hydroxy-1,4-napthoquinone | Ferricyanide | 800 | | 4000 | Yagishita | 1997 | Solar Energy |
| BPV (cellular) | Photosynthetic microbial fuel cell | Mixed photosynthetic consortia | Biofilm | Polypyrrole coated C | Pt-carbon | $H_2O$ | Mediator-less | $O_2$ (Pt) | 125 | 1.3 | 15 | Zou | 2009 | Biotechnol. Bioeng. |
| BPV (cellular) | Photosynthetic microbial fuel cell | Mixed photosynthetic consortia | Biofilm | Nanostructured fibrillar polypyrrole coated C fiber | Pt-carbon | $H_2O$ | Mediator-less | $O_2$ (Pt) | 270 | 5.9 | 46.6 | Zou | 2010 | Bioelectrochemistry |
| | | | | | | | | | | | | | | |
| PhotoMFC (sub-cellular) | | PSI | Immobilised | Au | | Os complexe | Hydrogels | Methyl viologen | | | | Badura | 2011 | Energy Environ. Sci. |
| PhotoMFC (sub-cellular) | Biomimetic photonic energy conversion system | PSI from baby spinach thylakoids | Immobilised | Nanoporous Au leaf | Pt mesh | Sodium ascorbate | Dichloroindophenol | | | | | Ciesielski | 2008 | ACS Nano |
| PhotoMFC (sub-cellular) | Biohybrid photoelectrochemical cell | PSI from baby spinach thylakoids | Dense layer (cathode) | ITO coated polyethylene terephthalate with Cu strip | Au | Ascorbic acid | Dichloroindophenol | Dichloroindophenol | 135 | | | Ciesielski | 2010 | Bioresour. Technol. |
| PhotoMFC (sub-cellular) | Photo-bioelectrochemical cell | PSI and PSII from *Mastigocladus laminsus* | Incorporated in layers in anode composite | ITO coated with PSI/Cyt c/PSII composite | Pt | $H_2O$ | Mediator-less | $O_2$ (Pt) | | | | Efrati | 2013 | Energy Environ. Sci. |
| PhotoMFC (sub-cellular) | | PSI bipolar mutant (single protein) | Immobilised (covalently bound) | Au | Au scanning near-field optical microscopy tip | $H_2O$ | Mediator-less | $O_2$ | | | | Gerster | 2013 | Nat. Biotechnol. |
| | | | | | | | | | | | | | | |
| PhotoMFC (cellular) | Microbial fuel cell | Mixed phototrophic consortia | Biofilm (cathode) | Graphite felt | Graphite felt | Acetate | Mediator-less | $CO_2$ (algae/bacteria) | 650 | 750 | 2500 | Cao | 2009 | Energy Environ. Sci. |
| PhotoMFC (cellular) | Solar-powered microbial fuel cell | *Rhodobacter sphaeroides* | Biofilm | C paper | C paper/Pt | Succinate or propionate | Mediator-less | $O_2$ | 780 | 750 | 3300 | Cho | 2008 | J. Pure Appl. Microbiol. |
| PhotoMFC (cellular) | Flat plate microbial fuel cell | *Rhodopseudomonas palustris* | Suspension | Stainless steel | Stainless steel | Acetate | Ferricyanide | Ferricyanide | | | | Inglesby | 2012 | RSC Adv. |
| PhotoMFC (cellular) | | *Shewanella oneidensis* MR-1, modified to express proteorhodopsin | Biofilm | Graphite | | Lactate, fumarate | Mediator-less | | | | | Johnson | 2010 | Appl. Environ. Microbiol. |
| PhotoMFC (cellular) | Direct photosynthetic/metabolic bio-fuel cell | *Rhodopseudomonas palustris* (H2 emission suppressed) | Biofilm | Polyaniline on C | | PYS medium | Mediator-less | $O_2$ | 140 | 183 | | Morishima | 2007 | J. Micromech. Microeng. |
| PhotoMFC (cellular) | Photobiological fuel cell | *Rhodobacter sphaeroides* | Suspension | PEDOT on Pt mesh | Graphite rod | Lactate | Mediator-less | Ferricyanide | 850 | 182.5 | 400 | Rosenbaum | 2005 | Environ. Sci. Technol. |
| | | | | | | | | | | | | | | |
| Plant MFC | Vascular plant bio-photovoltaic system | *Oryza sativa* | Planted | C fiber | Stainless steel | $H_2O$/Rhizodeposits | Mediator-less | Ferricyanide | 249 | 3.39 | 25.5 | Bombelli | 2012 | Appl. Microbiol. Biotechnol. |
| Plant MFC | Sediment microbial fuel cell | *Oryza sativa* L | Planted (roots contacting cathode) | Graphite mat | Graphite mat | $H_2O$/Rhizodeposits | Mediator-less | $O_2$ (Root) | 780 | 1.3 | | Chen | 2012 | Bioresour. Technol. |
| Plant MFC | Eco-electrogenic system | Hydroponic plants consortium | submerged and emergent macrophyte | Non catalyzed graphite | Non catalyzed graphite | $H_2O$/Rhizodeposits/Organics | Mediator-less | | 780 | 110 | 250 | Chiranjeevi | 2013 | Ecological Engineering |
| Plant MFC | Microbial fuel Cell | *Oryza sativa ssp* | Planted | Graphite mat | Graphite mat or graphite | $H_2O$/Rhizodeposits | Mediator-less | Ferricyanide and $O_2$ | 760 | 33 | | DeSchamphelaire | 2008 | Environ. Sci. Technol. |
| Plant MFC | Microbial fuel Cell | *Ipomoea aquatica* | Planted | Granular activated carbon | Granular activated carbon | $H_2O$/Rhizodeposits/Organics | Mediator-less | $O_2$ | 610 | 11.2 | 29.8 | Fang | 2013 | Bioresour. Technol. |
| Plant MFC | Biofuel cell | *Mytillocactus* | Electrodes implanted inside leaf | Glassy C | Glassy C | Glucose | Mediator-less | $O_2$ (BOD) | | 90 | 225 | Flexer | 2010 | Anal. Chem |
| Plant MFC | Plant-microbial fuel cell | *Spartina anglica* | Planted | Graphite granules and graphite rod | Graphite felt | Rhizodeposits | Mediator-less | Ferricyanide | | 222 | | Helder | 2010 | Bioresour. Technol. |
| Plant MFC | Plant-microbial fuel cell | *Spartina anglica* | Planted | Graphite felt | Graphite felt | Rhizodeposits | Mediator-less | Ferricyanide | | 211 | 469 | Helder | 2012 | Biotechnol. Biofuels |
| Plant MFC | Plant-microbial fuel cell | *Spartina anglica* | Planted | Graphite felt | Graphite felt | Rhizodeposits | Mediator-less | Ferricyanide | 600 | 440 | 1600 | Helder | 2012 | Bioresour. Technol. |
| Plant MFC | Direct photosynthetic plant fuel cell | *Lemna minuta* | Spread on surface | C felt | Graphite granules | $H_2O$ | Mediator-less | $O_2$ | 750 | 380 | 900 | Hubenova | 2012 | Bioelectrochemistry |
| Plant MFC | Direct photosynthetic plant fuel cell | *Lemna valdiviana* | Spread on surface | C felt | Graphite granules | $H_2O$ | Unknown | $O_3$ | 550 | 140 | 650 | Hubenova | 2014 | Bioelectrochemistry |
| Plant MFC | Paddy field electricity generation system | Rice paddy field | Electrodes within rice paddy | Graphite felt | Graphite felt | Rhizodeposits/Acetate | Mediator-less | $O_2$ | 428 | 5.85 | 29.6 | Kaku | 2008 | Appl. Microbiol. Biotechnol. |
| Plant MFC | Microbial fuel cell coupled constructed wetland system | *Ipomoea aquatica* | Planted | Granular activated C | Stainless steel mesh | Rhizodeposits | Mediator-less | $O_2$ | 740 | 12.42 | 31 | Liu | 2013 | Int. J. Photoenergy |
| Plant MFC | | *Ficus benjamina* | Anode inserted into xylem | Pt | Pt | | Mediator-less | $O_2$ (Pt) | 275 | | | Love | 2008 | PLoS One |
| Plant MFC | Miniatured floating macrophyte based ecosystem | Hydroponic plants consortium | Grown | Non catalysed graphite | Non catalysed graphite | $H_2O$/Rhizodeposits/Organics | Mediator-less | $O_2$ | 792 | 80.08 | 180 | Mohan | 2011 | Bioresour. Technol. |
| Plant MFC | Plant microbial fuel cell | *Glyceria maxima* | Planted | Graphite felt and graphite granules | Graphite felt | Rhizodeposits | Mediator-less | $O_2$ | | 67 | 265 | Strik | 2008 | Int. J. Energy Res. |
| Plant MFC | Rice-paddy microbial fuel cell | Rice paddy field | Electrodes within rice paddy | Graphite felt | Pt modified graphite felt | Rhizodeposits | Mediator-less | $O_2$ (Pt) | 350 | 14.44 | 70 | Takanezawa | 2010 | Biosci. Biotechnol. Biochem. |
| Plant MFC | Plant microbial fuel cell | *Spartina anglica* | Planted | Graphite granules | Graphite felt | Rhizodeposits | Mediator-less | Ferricyanide | | 100 | 331 | Timmers | 2010 | Appl. Microbiol. Biotechnol. |
| Plant MFC | Plant microbial fuel cell | *Glyceria maxima* | Planted | Graphite granules | Graphite felt | Rhizodeposits | Mediator-less | $O_2$ | | 80 | 164 | Timmers | 2012 | Appl. Microbiol. Biotechnol. |
| Plant MFC | Plant microbial fuel cell | *Glyceria maxima* | Planted | Graphite granules | Graphite felt | Rhizodeposits | Mediator-less | $O_2$ | 260 | 390 | 1900 | Timmers | 2012 | Electrochim. Acta |
| Plant MFC | Plant microbial fuel cell | *Glyceria maxima* | Planted | Graphite granules | Graphite felt | Rhizodeposits | Mediator-less | $O_2$ | | | | Timmers | 2012 | Bioresour. Technol. |
| Plant MFC | Constructed wetland microbial fuel cell | *Phragmites australis* | Planted | Graphite | Graphite | Rhizodeposits | Mediator-less | $O_2$ | | 43 | 37 | Villasenor | 2013 | Water Research |
| Plant MFC | Plant microbial fuel cell | *Spartina anglica* | Planted | Graphite felt | Graphite felt (biocathode) | Rhizodeposits | Mediator-less | $O_2$ | | 679 | 1370 | Wetser | 2014 | Appl. Energy |
| Plant MFC | Wetland microbial fuel cell | *Canna indica* | Planted | | | $H_2O$/Rhizodeposits/Organics | Methylene blue | | | 15.73 | 69.75 | Yadav | 2012 | Ecological Engineering |
| Plant MFC | Constructed wetland microbial fuel cell | *Phragmites australis* | Planted | Graphite plate | Graphite plate | Rhizodeposits | Mediator-less | $O_2$ | | 9.4 | | Zhao | 2013 | Chem. Eng. J. |
| | | | | | | | | | | | | | | |
| Complex PhotoMFC | Microbial electrochemical cell | Mixed phototrophic consortia dominated by green sulphur bacteria | Biofilm | Graphite rod | | Acetate and sulfide | Mediator-less | | | | | Badalamenti | 2013 | Biotechnol. Bioeng. |
| Complex PhotoMFC | Bioelectrochemical cell | Blue green algae (Oscillatoriacae) and *Rhodospirillum rubrum* | Biofilm (cathode) and suspension (anode) respectively | Sandblasted Pt | Sandblasted Pt | Malate | Mediator-less | $O_2$ (Pt/algae) | 960 | | | Berk | 1964 | Applied Microbiology |
| Complex PhotoMFC | Bio-electrochemical system | *M. aeruginosa* IPP and Cyanobacteria | | Carbon paper | Carbon paper (biocathode) | | Mediator-less | $O_2$ | 500 | 0.007 | 0.067 | Cai | 2013 | Biosens. Bioelectron. |
| Complex PhotoMFC | Microbial fuel cell with an algae-assisted cathode | Sludge from a wastewater (anode) and *Chlorella vulgaris* (cathode) | Biofilm | | | Sugar | Mediator-less | $O_2$ (algae) | | 13.5 | | Campo | 2013 | J. Power Sources |
| Complex PhotoMFC | Algal growth-anaerobic digestion-microbial fuel cell | Mixed algal consortia | Effluent from digested algae (anode) and in suspension (cathode) | Graphite granules | Graphite mat | Algal effluent | Mediator-less | $O_2$ (algae) | | | | De Schamphelaire | 2009 | Biotechnol. Bioeng. |
| Complex PhotoMFC | Microbial fuel cell | Mixed algal consortia | Biofilm (cathode) | Carbon veil | Carbon veil | Acetate | Mediator-less | $O_2$ (algae) | | 7 | 12 | Gajda | 2013 | Int. J. Hydrogen Energy |
| Complex PhotoMFC | Sediment phototrophic microbial fuel cell | Mixed phototrophic consortia | Biofilm (anode and cathode) and sediment | Graphite felt | Graphite plate | Photosynthetic products | Mediator-less | $O_2$ (algae/bacteria) | | 1.28 | 12.8 | He | 2009 | Environ. Sci. Technol. |
| Complex PhotoMFC | Lagooning microbial fuel cell | Mixed algal consortia | Biofilm/suspension (cathode) | C cloth | C cloth | Glucose | Mediator-less | $O_2$ (algae) | | 12.6 | | Lobato | 2013 | Appl. Energy |
| Complex PhotoMFC | Microbial photoelectrochemical solar cell | Mixed phototrophic consortia | Biofilm/suspension (anode and cathode) and sediment | Grpahite plate | Grpahite plate | Photosynthetic products | Mediator-less | $O_2$ (algae/bacteria) | | 17 | 113 | Malik | 2009 | Energy Environ. Sci. |
| Complex PhotoMFC | Biological energy-conversion system | Mixed phototrophic consortia (hot spring mat) | Biofilm | Graphite felt | Pt on PET | Photosynthetic products | Mediator-less | $O_2$ (Pt) | 320 | 9.2 | 50 | Nishio | 2010 | Appl. Microbiol. Biotechnol. |
| Complex PhotoMFC | Microbial solar cell | *Chlamydomonas reinhardtii* | Suspension | Graphite felt | Pt on PET | Formate (algae) | Mediator-less | $O_2$ (Pt) | 620 | 41 | 75 | Nishio | 2013 | J. Biosci. Bioeng. |
| Complex PhotoMFC | Solar energy powered microbial fuel cell | Mixed phototrophic consortia | Biofilm (cathode) | Graphite felt | Graphite felt | Acetate | Mediator-less | $O_2$ (algae/bacteria) | | 41 | 100 | Strik | 2010 | Environ. Sci. Technol. |
| Complex PhotoMFC | Microbial fuel cell | *Chlorella vulgaris* (powdered) | Suspension | Graphite fiber brush | Pt containing cathode | Algal biomass | Mediator-less | $O_2$ (Pt) | 850 | 950 | 2300 | Velasquez-Orta | 2009 | Biotechnol. Bioeng. |
| Complex PhotoMFC | Microbial fuel cell | *Chlorella vulgaris* | Biofilm | Carbon felt | Carbon paper/Pt | Organics | Mediator-less | $O_2$ (Pt) | 550 | 24.4 | | Wu | 2014 | Appl. Biochem. Biotechnol. |
| Complex PhotoMFC | Photomicrobial fuel cell | *Chlorella vulgaris* (cathode) | Suspension (cathode) | C paper | Pt containing C paper | Acetate | Mediator-less | $O_2$ (Pt/algae) | | 98 | | Zhang | 2011 | Energy Environ. Sci. |
| | | | | | | | | | | | | | | |
| Review | Bioelectrochemical device | | | | | | | | | | | Badura | 2011 | Energy Environ. Sci. |
| Review | Biomimetic solar energy conversion device | | | | | | | | | | | Boghossian | 2011 | Energy Environ. Sci. |
| Review | Photoelectrochemical cell | | | | | | | | | | | Bora | 2012 | Energy Environ. Sci. |
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| Review | | | | | | | | | | | | Faunce | 2013 | Energy Environ. Sci. |
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| Review | | | | | | | | | | | | Rasmussen | 2014 | J. Electrochem. Soc. |
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| Review | Microbial solar cell | | | | | | | | | | | Strik | 2011 | Curr. Trends Biotechnol. |
| Review | Dye-sensitized solar cell | | | | | | | | | | | Wang | 2010 | Energy Environ. Sci. |

| | Oslo (60°N) | | Rijadh (25°N) | | Details |
|---|---|---|---|---|---|
| **Power input based on SRG (mW $m^{-2}$)** | 103000 | | 263000 | | Provided by SolarGIS (http://solargis.info/) |
| **Light photon flux (µE $m^{-2}$ $s^{-1}$)** | 481 | | 1228 | | Based on the power input at the midpoint wavelength (560 nm) of the PAR range. |
| **Light photon flux in the PAR range (µE $m^{-2}$ $s^{-1}$)** | 241 | | 614 | | Available light for photosynthesis (50% lost). |
| **Intercepted light photon flux (µE $m^{-2}$ $s^{-1}$)** | 216 | | 553 | | Losses during linear photosynthetic electron transport (10% lost). |
| **Generation of electrons (µmol $e^-$ $m^{-2}$ $s^{-1}$)** | 86.6 | 108.2 | 221.0 | 276.3 | Estimate of either 4 or 5 photons per 2 electrons for 1 NADPH. |
| **Remaining after metabolic losses (µmol $e^-$ $m^{-2}$ $s^{-1}$)** | 58.0 | 105.0 | 148.1 | 268.0 | Either 33% or 3% of electrons generated by the photosynthetic light reactions are used for cellular metabolic processes. |
| **Coulumbic efficiencies (µmol $e^-$ $m^{-2}$ $s^{-1}$)** | 34.8 | 99.7 | 88.9 | 254.6 | 60% or 95% or of the remaining electrons available for export. |
| **Current output (mA $m^{-2}$)** | 3359 | 9624 | 8575 | 24570 | Remaining electrons x the Faraday constant (96500 C $mol^{-1}$) / 1000 = mC $m^{-2}$ $s^{-1}$ = mA $m^{-2}$ |
| **Power output (mW $m^{-2}$)** | 715 | 3032 | 1826 | 7740 | Power outputs based on the averaging potential drop (213 mV) from 26 BPV studies (Supp. Table 1) or on the potential drop demonstrated by Xie et al.[118] (315 mV). mV x mA $m^{-2}$ = mW $m^{-2}$ |
| **% of the initial power input** | 0.7% | 2.9% | 0.7% | 2.9% | Final power output / initial solar input x100 |

**Supp. Table 2.** Achievable current and power outputs for a BPV system. Estimates are shown for constant solar radiation at ground level (SRG) inputs at two city locations (Oslo and Riyadh). SRG utilisation is shown through photosynthetic light capture (white) and then under conservative (red) or optimistic (green) downstream energy loss processes.

| Crop | Location | L ha$^{-1}$ y$^{-1}$ (Kg ha$^{-1}$ y$^{-1}$ ) | MJ L$^{-1}$ (MJ Kg$^{-1}$) | PDO GJ ha$^{-1}$ y$^{-1}$ | PDO mW m$^{-2}$ | Reference |
|---|---|---|---|---|---|---|
| Palm oil | Malaysis | (4900) | (40) | 196 | 621 | L. Reijnders , M.A.J. Huijbregts, J. Cleaner Prod., 2008, **16**, 477-482. |
| Hybrid palm oil | Brazil | 6500 | 37.3 | 242 | 769 | R.C. Costa, Biomass Bioenergy, 2004, **26**, 405-415. |
| Palm oil | Brazil | 4250 | 37.3 | 159 | 503 | R.C. Costa, Biomass Bioenergy, 2004, **26**, 405-415. |
| Coconut oil | Brazil | 2500 | 37.3 | 93 | 296 | R.C. Costa, Biomass Bioenergy, 2004, **26**, 405-415. |
| Avocado oil | Brazil | 1500 | 37.3 | 56 | 177 | R.C. Costa, Biomass Bioenergy, 2004, **26**, 405-415. |
| Castor oil | Brazil | 450 | 37.3 | 17 | 53 | R.C. Costa, Biomass Bioenergy, 2004, **26**, 405-415. |
| Sunflower oil | Brazil | 425 | 37.3 | 16 | 50 | R.C. Costa, Biomass Bioenergy, 2004, **26**, 405-415. |
| Peanut oil | Brazil | 780 | 37.3 | 29 | 92 | R.C. Costa, Biomass Bioenergy, 2004, **26**, 405-415. |
| Soybean | Brazil | 400 | 37.3 | 15 | 47 | R.C. Costa, Biomass Bioenergy, 2004, **26**, 405-415. |
| Rapeseed | Germany | 1590 | 37.3 | 59 | 188 | FNR (Fachagentur Nachwachsende Rohstoffe), 2006. Biokraftstoffe - eine vergleichende Analyse. Gülzow, Germany |
| Soybean | Germany | 640 | 37.3 | 24 | 76 | FNR (Fachagentur Nachwachsende Rohstoffe), 2006. Biokraftstoffe - eine vergleichende Analyse. Gülzow, Germany |
| Rapeseed | Austria | 1090 | 37.5 | 41 | 130 | IEA-Bioenergy: Biodiesel and Environment in Austria, IPTS data gathering & analysis |
| Switchgrass and Miscanthus | USA | 3310 | 37.5 | 124 | 393 | Economic Impact Advanced Biofuels (2012) |
| - | - | - | - | **82** | **261** | **Average** |
| - | - | - | - | *23* | *72* | *Standard error* |

**Supp. Table 3.** Photobiological production of bio-diesel.

| Crop | Dry Ton $ac^{-1} y^{-1}$ | Biogas Yield m3/DTon | $m^3$ of biogas $ha^{-1} y^{-1}$ | GJ $ha^{-1} y^{-1}$ | mW $m^{-2}$ | Reference |
|---|---|---|---|---|---|---|
| Corn | 4.2 | 205.0 | 861 | 31 | 98 | Increasing Biofuels Feedstock Production (2007) |
| Corn | 4.2 | 450.0 | 1890 | 68 | 216 | Increasing Biofuels Feedstock Production (2007) |
| Grain sorghum | 1.8 | 295.0 | 531 | 19 | 61 | Increasing Biofuels Feedstock Production (2007) |
| Grain sorghum | 1.8 | 372.0 | 670 | 24 | 76 | Increasing Biofuels Feedstock Production (2007) |
| Barley | 1.5 | 353.0 | 530 | 19. | 60 | Increasing Biofuels Feedstock Production (2007) |
| Barley | 1.5 | 658.0 | 987 | 36 | 113 | Increasing Biofuels Feedstock Production (2007) |
| Sugar beets | 23.8 | 236.0 | 5617 | 202 | 641 | Increasing Biofuels Feedstock Production (2007) |
| Sugar beets | 23.8 | 236.0 | 5617 | 202 | 641 | Increasing Biofuels Feedstock Production (2007) |
| Miscanthus | 13.0 | 179.0 | 2327 | 84 | 266 | Iowa State University, Department of Agronomy |
| Miscanthus | 13.0 | 218.0 | 2834 | 102 | 323 | Iowa State University, Department of Agronomy |
| Sugar beets | 28.3 | 236.0 | 6677 | 240 | 762 | R. Limb, Proc. S. Afr. Sug. Technol. Ass., 2008, **81**, 107-115. |
| Sugar beets | 28.3 | 381.0 | 10782 | 388 | 1231 | R. Limb, Proc. S. Afr. Sug. Technol. Ass., 2008, **81**, 107-115. |
| - | **12.1** | **318.3** | **3277** | **118** | **374** | **Average** |
| - | *3.4* | *41.0* | *973* | *35* | *111* | *Standard error* |

**Supp. Table 4.** Photobiological production of bio-gas.

| Crop | L $ha^{-1}$ $y^{-1}$ | MJ $L^{-1}$ | GJ $ha^{-1}$ $y^{-1}$ | mW $m^{-2}$ | Reference |
|---|---|---|---|---|---|
| Sugar cane | 7500.0 | 25 | 188 | 594 | Y. Chisti, Trends Biotechnol., 2008, **26**, 126-131. |
| Sugar beet | 5800.0 | 25 | 145 | 460 | H. Langeveld, G. van de Ven, S. de Vries, L. van den Brink, C. de Visser, 8th European IFSA Symposium, 2008, Clermont-Ferrand (France) 735. |
| Maize | 3500.0 | 25 | 88 | 277 | I.G. Anemaet, M. Bekker, K.J. Hellingwerf, Mar. Biotechnol, 2010, **12**, 619-629. |
| Sugar cane | 4900.0 | 25 | 123 | 388 | M. Balat, H. Balat, Applied Energy, 2009, **86**, 2273-2282. |
| Cassava | 6000.0 | 25 | 150 | 476 | M. Balat, H. Balat, Applied Energy, 2009, **86**, 2273-2282. |
| Sweet sorghum | 2800.0 | 25 | 70 | 222 | M. Balat, H. Balat, Applied Energy, 2009, **86**, 2273-2282. |
| **-** | **5083.3** | **-** | **127** | **403** | **Average** |
| - | *771.9* | - | *19* | *61* | *Standard error* |

**Supp. Table 5.** Photobiological production of bio-ethanol.

| Crop | Dry mass Tonne $ac^{-1}\,y^{-1}$ | GJ $ha^{-1}\,y^{-1}$ | mW $m^{-2}$ | Reference |
|---|---|---|---|---|
| Corn | 4.2 | 156 | 494 | Increasing_Biofuels_Feedstock_Production (2007) |
| Grain sorghum | 1.8 | 67 | 212 | Increasing_Biofuels_Feedstock_Production (2007) |
| Barley | 1.5 | 56 | 176 | Increasing_Biofuels_Feedstock_Production (2007) |
| Sugarcane | 32.7 | 1212 | 3842 | Increasing_Biofuels_Feedstock_Production (2007) |
| Sugar beet | 23.8 | 882 | 2796 | Increasing_Biofuels_Feedstock_Production (2007) |
| Soybeans | 1.3 | 48 | 153 | Increasing_Biofuels_Feedstock_Production (2007) |
| Miscanthus | 13.0 | 482 | 1527 | Iowa State University, Department of Agronomy |
| Switchgrass | 6.0 | 222 | 705 | USDA Agriculture Research Services, Madison, Wisconsin |
| Sugarcane | 35.1 | 1301 | 4124 | University of Minnesota |
| Sugar beet | 28.3 | 1049 | 3325 | R. Limb, Proc. S. Afr. Sug. Technol. Ass., 2008, **81**, 107-115. |
| - | **14.8** | **548** | **1735** | **Average** |
| - | *4.6* | *171* | *541* | *Standard error* |

**Supp. Table 6.** Photobiological production of biomass.

| PV power station | Geographical coordinates | Area (Tot.) hactare | PDO GJ $y^{-1}$ $ha^{-1}$ | PDO mW $m^{-2}$ |
|---|---|---|---|---|
| Eggebek Solar Park (Germany) | 54°N 9°E | 160.0 | 2327 | 7376 |
| Sarnia Photovoltaic Power Plant (Canada) | 42°N 82°EW | 445.2 | 970 | 3075 |
| Agua Caliente Solar Project (US-Arizona) | 32°N 113°W | 971.7 | 2320 | 7355 |
| Gujarat Solar Park (India) | 24°N 71°E | 2000 | 1562 | 4951 |
| **Average** | **-** | **-** | **1795** | **5689** |
| *Standard error* | - | - | *379* | *1203* |

**Supp. Table 7**. Power density outputs (PDOs) obtained from four recently built solar power stations located in Germany, Canada, India and the USA (Arizona).

**Additional References for Supp. Tables 3-7**


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