Working Group #4
Sustainable resources circulation for global environment

Carbon recycling technologies based on microbial electrochemistry

Souichiro Kato

Bioproduction Research Institute (BPRI),
Natl. Inst. of Advanced Industrial Science & Technology (AIST)

Division of Applied Bioscience, Hokkaido Univ.

Research Center for Solar Energy Chemistry, Osaka Univ.

Microbiology for carbon cycling

(Micro)biology

Genetic engineering

Metabolic engineering

Evolutionary engineering

Synthetic biology

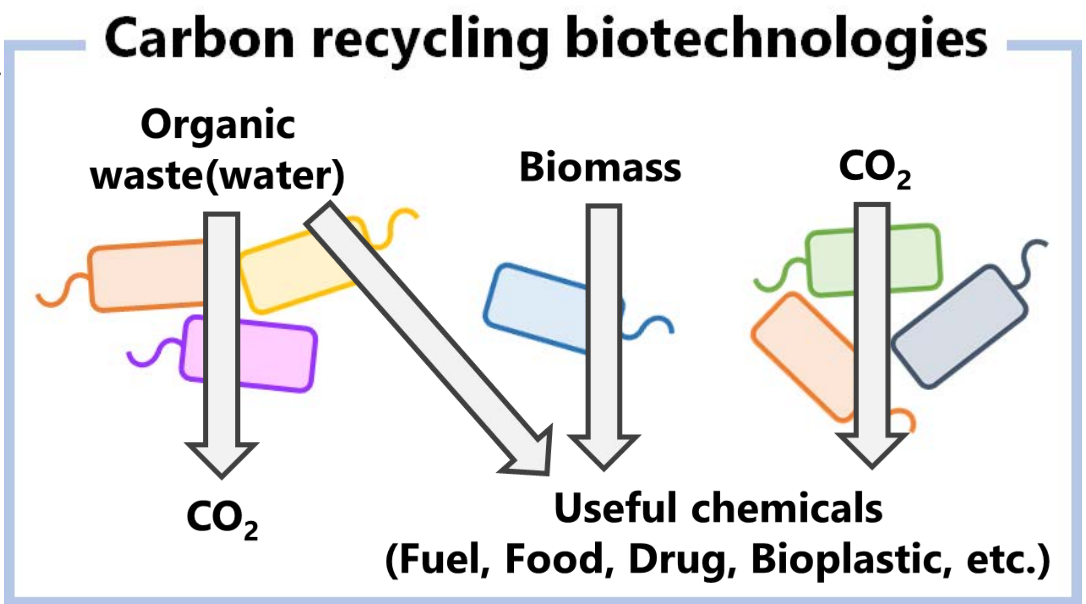
Systems biology

etc.

Information technology

Big data science

Artificial intelligence etc.



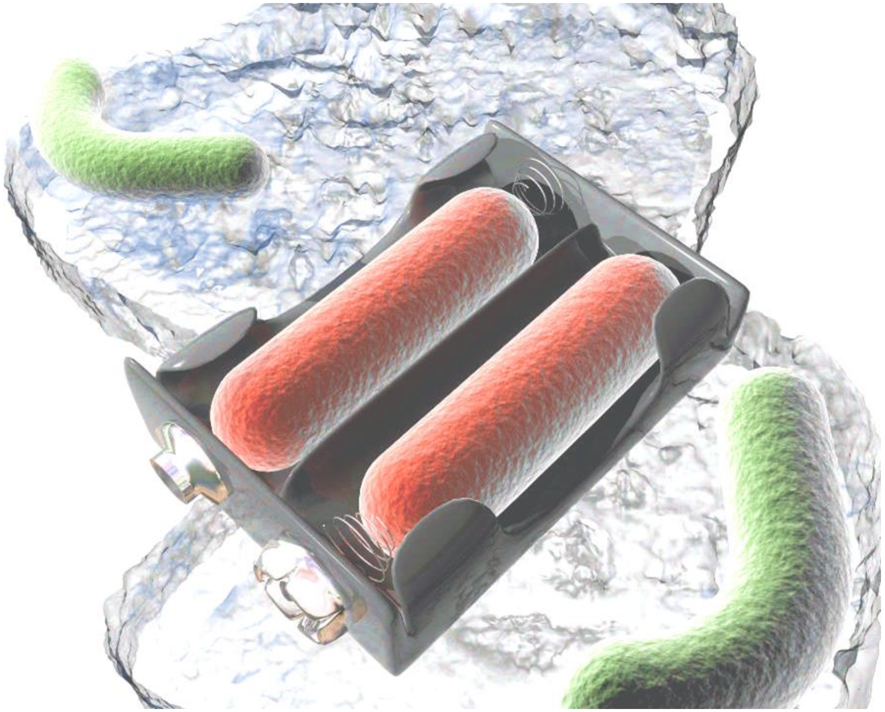
Electrochemistry

Materials science

Microbial electrochemistry

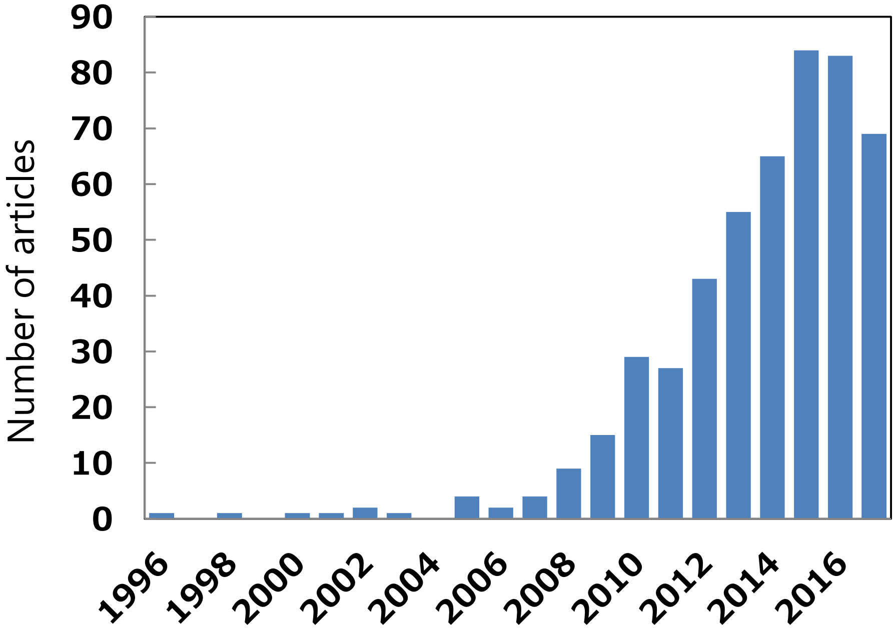
Electrochemically active microorganisms:

acquire energy by electron transfer reaction with conductive solid materials



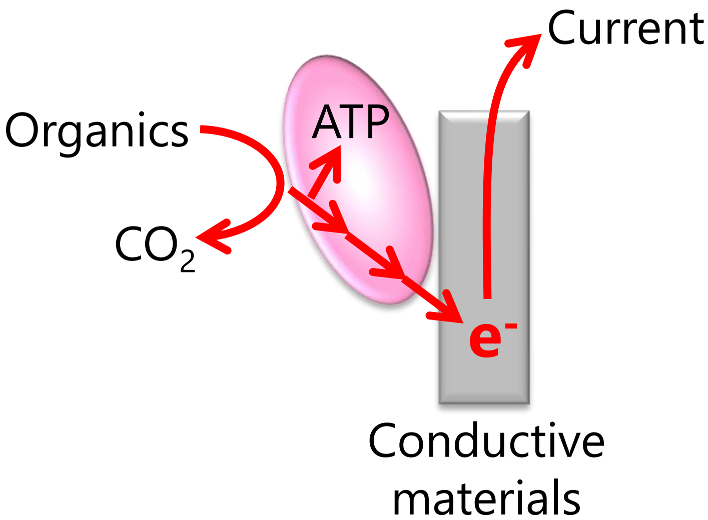
Schubert C., *Nature*. 441: 277-279 (2006)

Number of articles contain the term "extracellular electron transfer"



Electrochemically active microorganisms

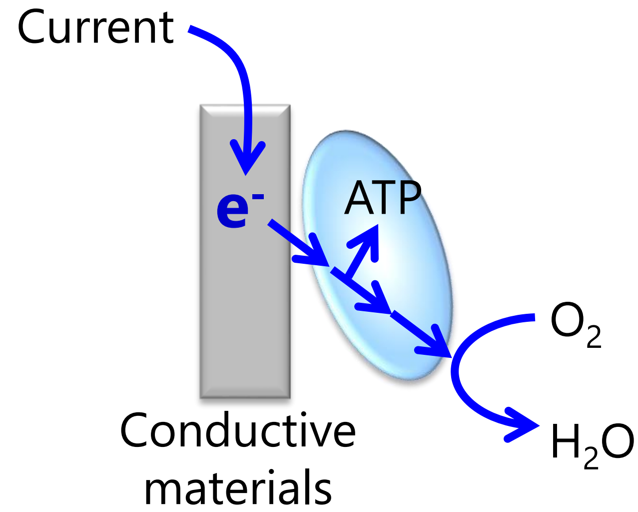
Electricity Generators



Discard **surplus electrons** as **electric current**

(i.e. free electrons in conductors)

Electricity Consumers



Use **electric current**

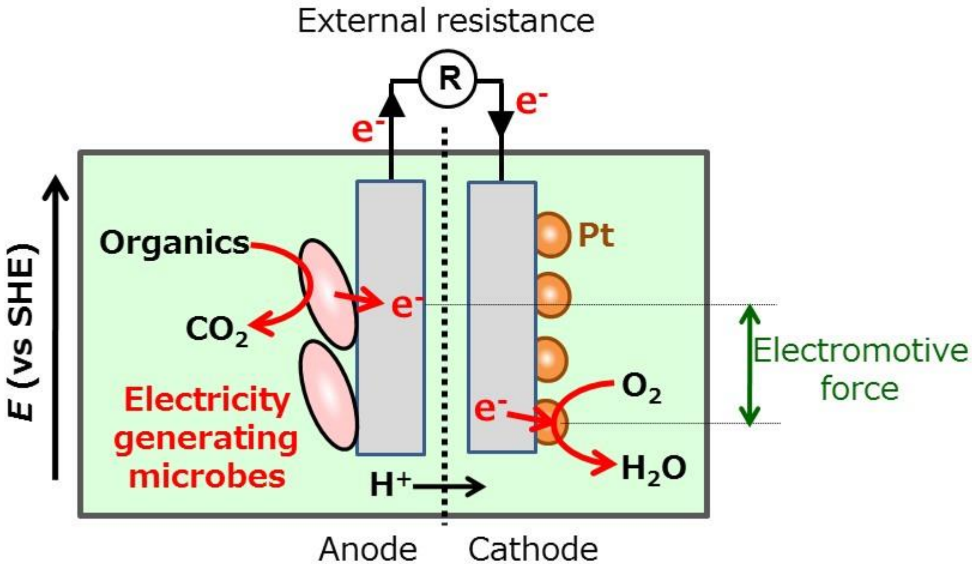
(i.e. free electrons in conductors)

as an **energy source**

Application of electricity generators

Microbial fuel cells (MFC)

Generate electric power using any organic compounds as fuel



NEDO research project (2009-2015)

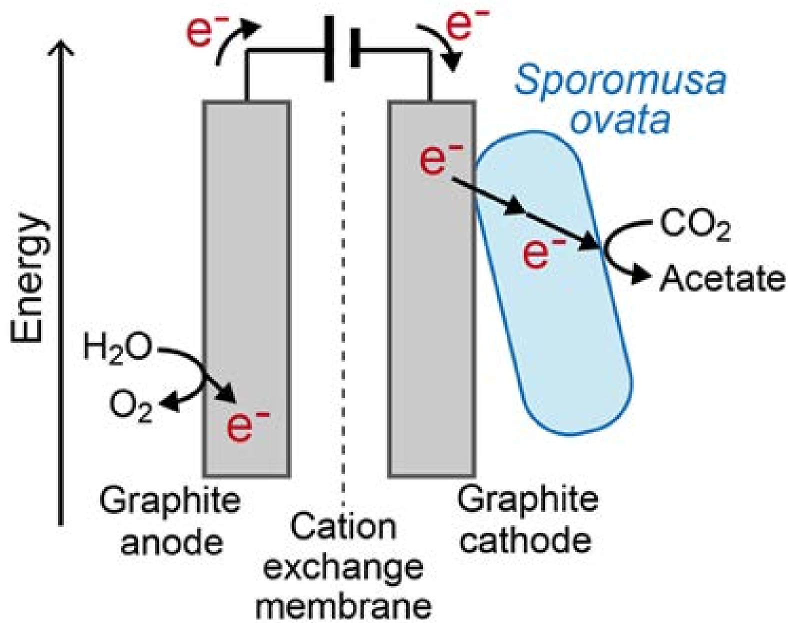
- m^3-scale pilot reactor
- Achieved 80% reduction in power input & waste sludge

- **Application for wastewater treatment is almost practical**
- **Many challenges remain for use as a power source**

Application of electricity consumers

Microbial electrosynthesis

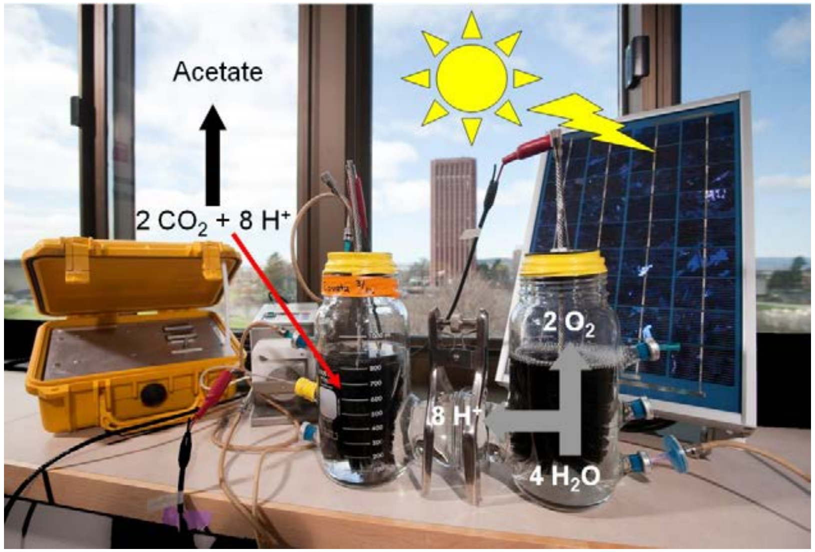
Convert CO_2 into organic compounds using electric power



Sasaki K, Kato S. *Curr Opin Biotechnol*. 50:182-188 (2018)

Microbial electrosynthesis: feeding microbes electricity to convert carbon dioxide and water to multicarbon extracellular organic compounds.

Nevin KP. *et al. mBio*. 1: e00103 (2010)



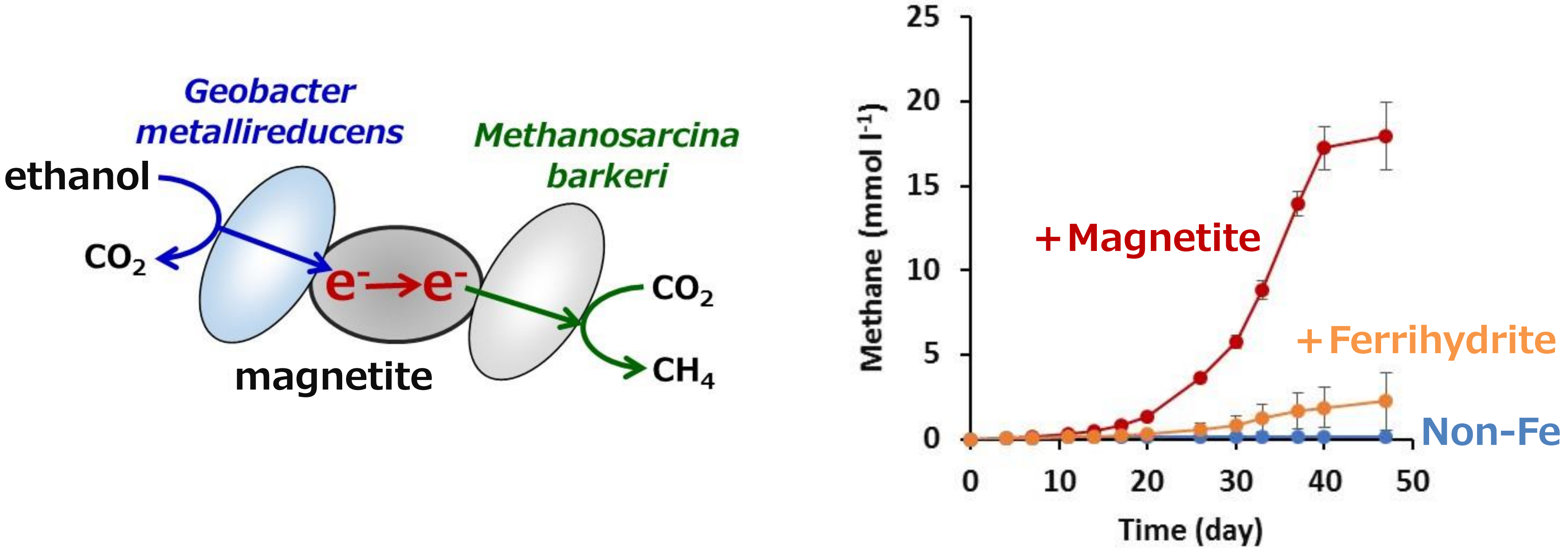
■ **Research for practical use is still limited**

Symbiosis of electricity generator/consumer

Microbial interspecies electron transfer via electric currents through conductive minerals

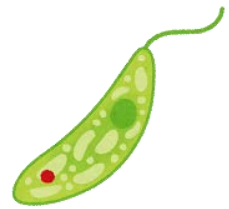
Souichiro Kato[a,1], Kazuhito Hashimoto[a,b,c,2], and Kazuya Watanabe[a,b,d,2]

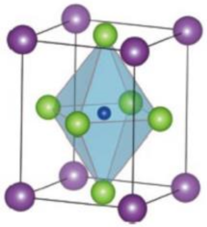
PNAS 109: 10042-10046 (2012)



■ **Symbiotic interactions can be promoted/created by adding conductive particles**

Biotechnology vs. Materials science



	Living organisms (Photosynthesis)	Inorganic materials (Artificial photosynthesis)
Production of organics	○ Can produce various, complex organics	× Difficult to produce complex organic matters
Environmental compatibility	○ Ambient conditions, self propagation/organisation	× Harsh conditions, use toxic/rare metals, etc.
Reaction rates	× Low	○ High
Energy efficiency	× Low (~0.1%)	○ High (~10%)

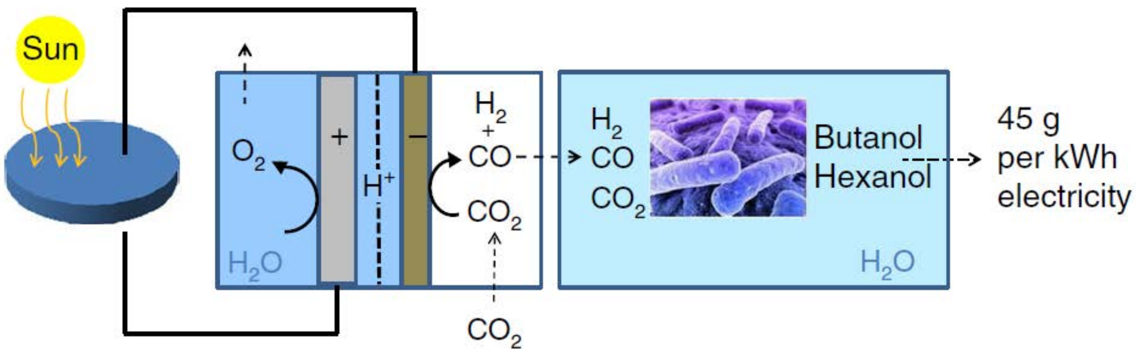
■ **We can develop better systems by hybrid of the two technologies (semi-artificial photosynthesis)??**

Ex. 1) Semi-artificial photosynthesis

ARTICLES
https://doi.org/10.1038/s41929-017-0005-1
1:32-39 (2018)
nature catalysis

Technical photosynthesis involving CO_2 electrolysis and fermentation

Thomas Haas[1], Ralf Krause[2], Rainer Weber[3], Martin Demler[1] and Guenter Schmid[2]*



PV cells

EE up to 20%

Price of 1 kWh PV electricity
= 2.5 cents

CO_2 and H_2O electrolyser

EE-CO up to 47%
EE-H_2 up to 70%
FE-CO + FE-H_2 near 100%

Fermenters
Clostridium autoethanogenum +
Clostridium kluyveri

EE near 80%
FE near 100%

Price per 45 g alcohol
= 5.4 cents

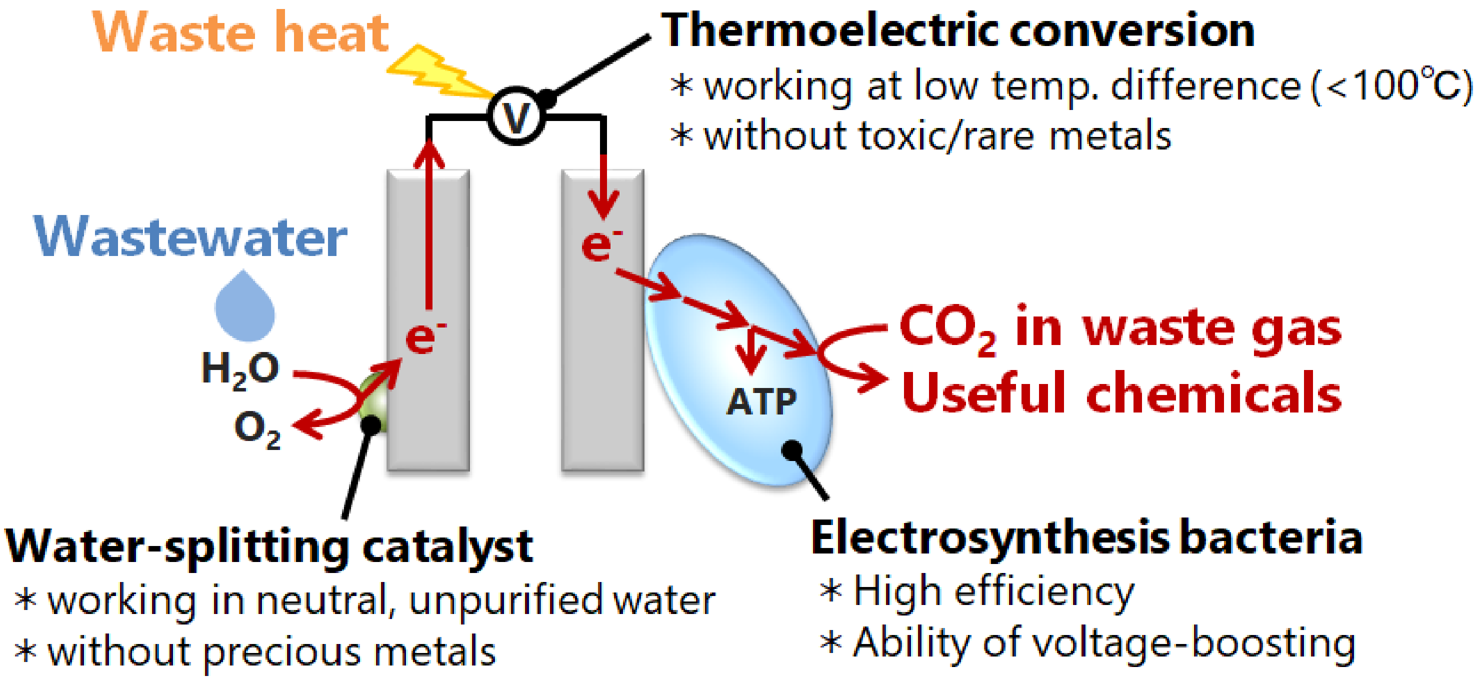
←total energy efficiency of ~7.5%
could work >50 days
←has economic rationality

Ex. 2) Semi-artificial *THERMO*synthesis

Development of a novel energy conversion system by hybrid of inorganic materials and microorganisms

Souichiro Kato (AIST) and Ryuhei Nakamura (RIKEN), in the AIST-RIKEN joint research project

Production of organics only from wastewater, waste heat & waste gas (semi-artificial thermosynthesis)

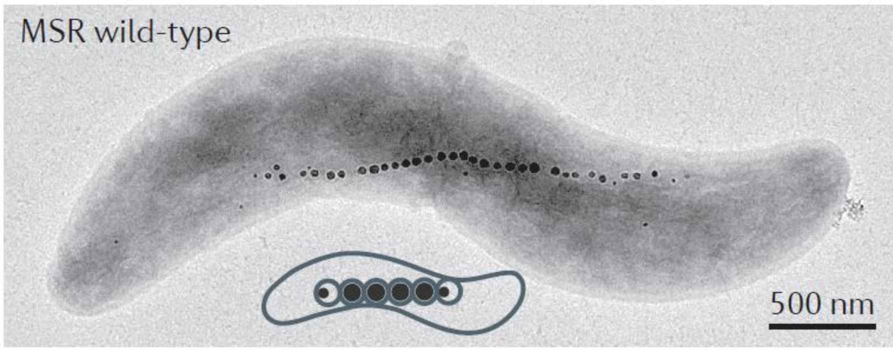


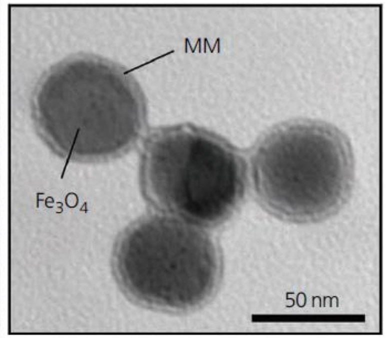
Ex. 3) Photosynthetic "Cyborg" bacteria

Uebe R, Schüler D. *Nat Rev Microbiol*. 14:621-637 (2016)

Magnetotactic bacteria :

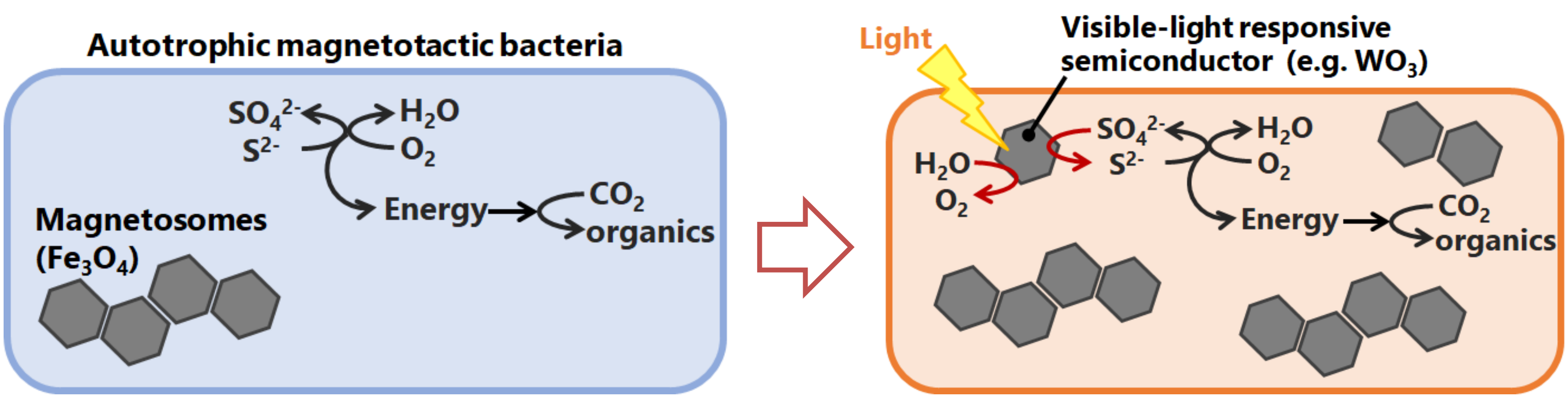
produce nano-particles of magnetite (Fe_3O_4) to sense the terrestrial magnetism





- Some strains can fix CO_2
- Size/number of the magnets can be modified
- Mn/Co can be doped

"Cyborg" magnetotactic bacteria doing photosynthesis??



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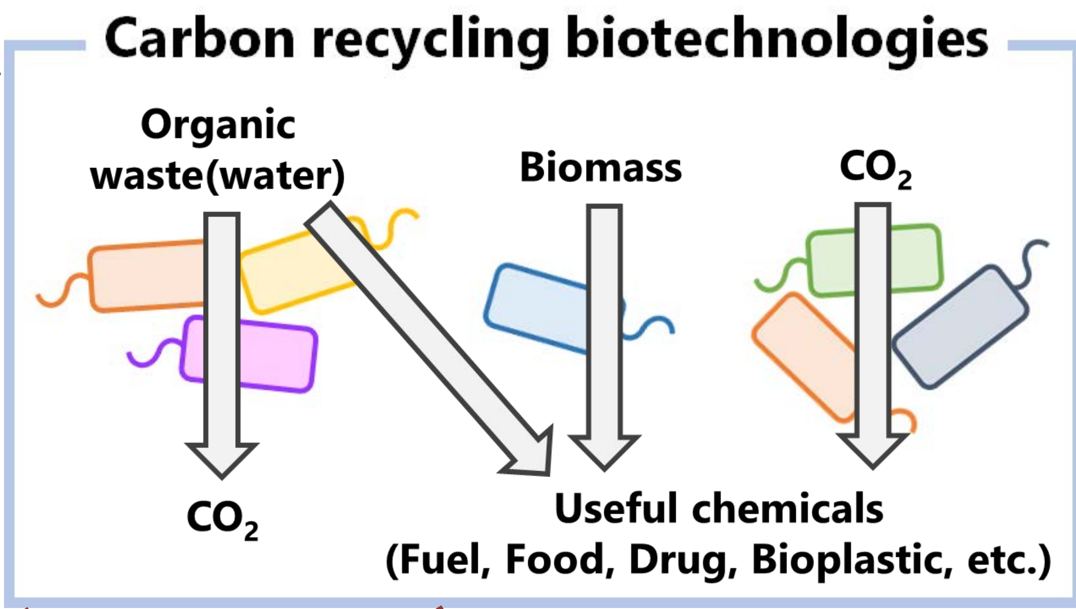

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Electrochemistry

Materials science

Nano-technology
Quantum mechanics
Economics, Sociology, etc.