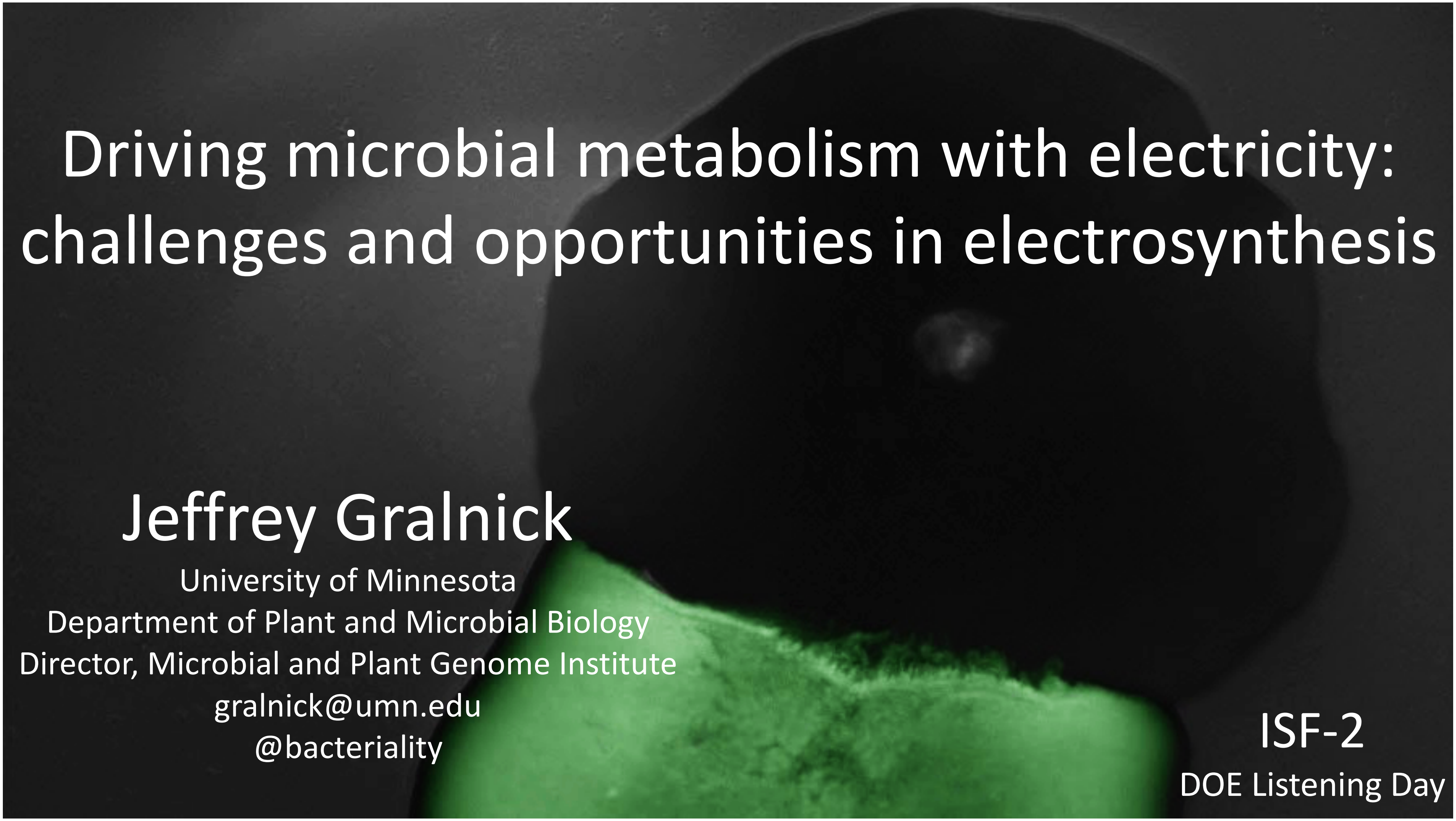

Driving microbial metabolism with electricity: challenges and opportunities in electrosynthesis

Jeffrey Gralnick

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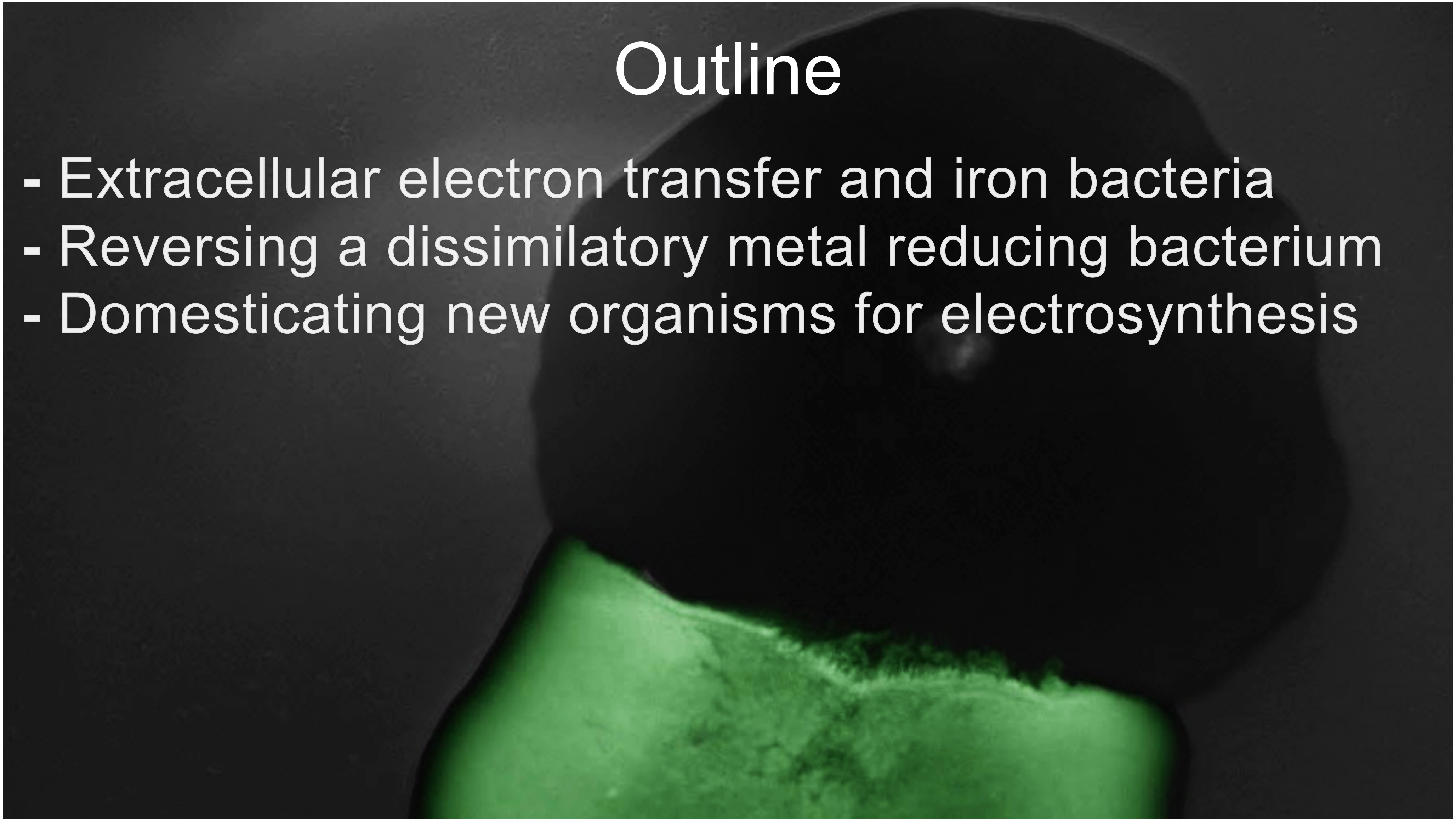
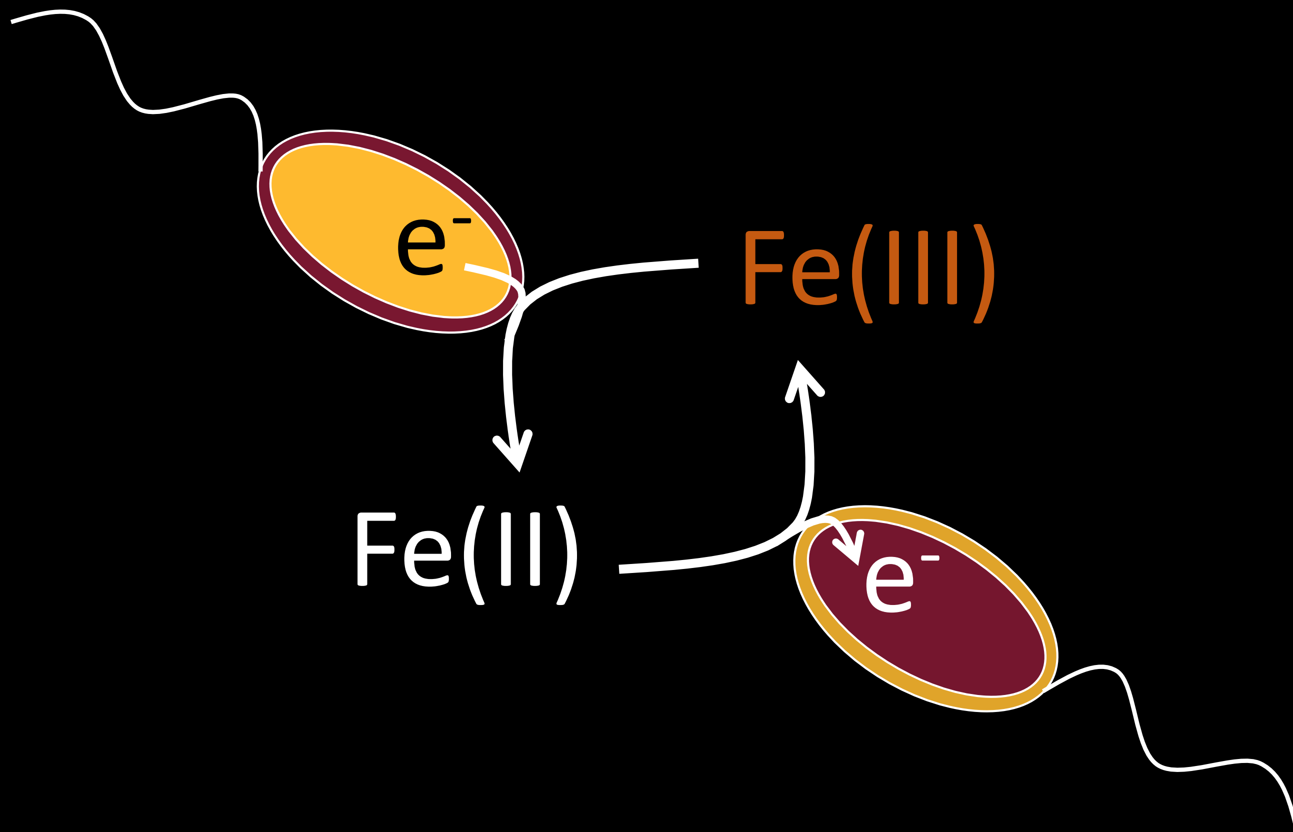
gralnick@umn.edu
@bacteriality

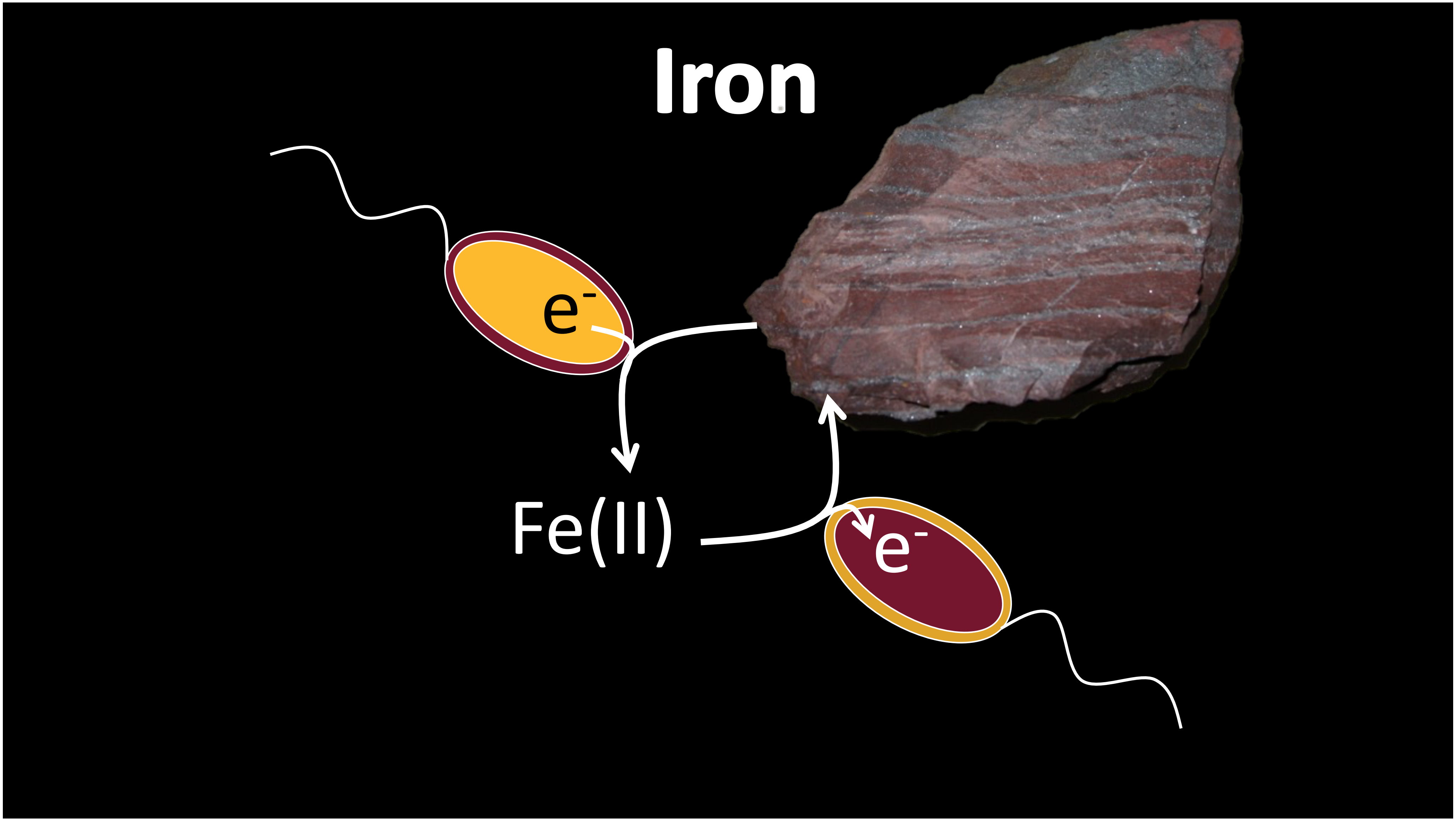
ISF-2

DOE Listening Day


Outline
- Extracellular electron transfer and iron bacteria
- Reversing a dissimilatory metal reducing bacterium
- Domesticating new organisms for electrosynthesis

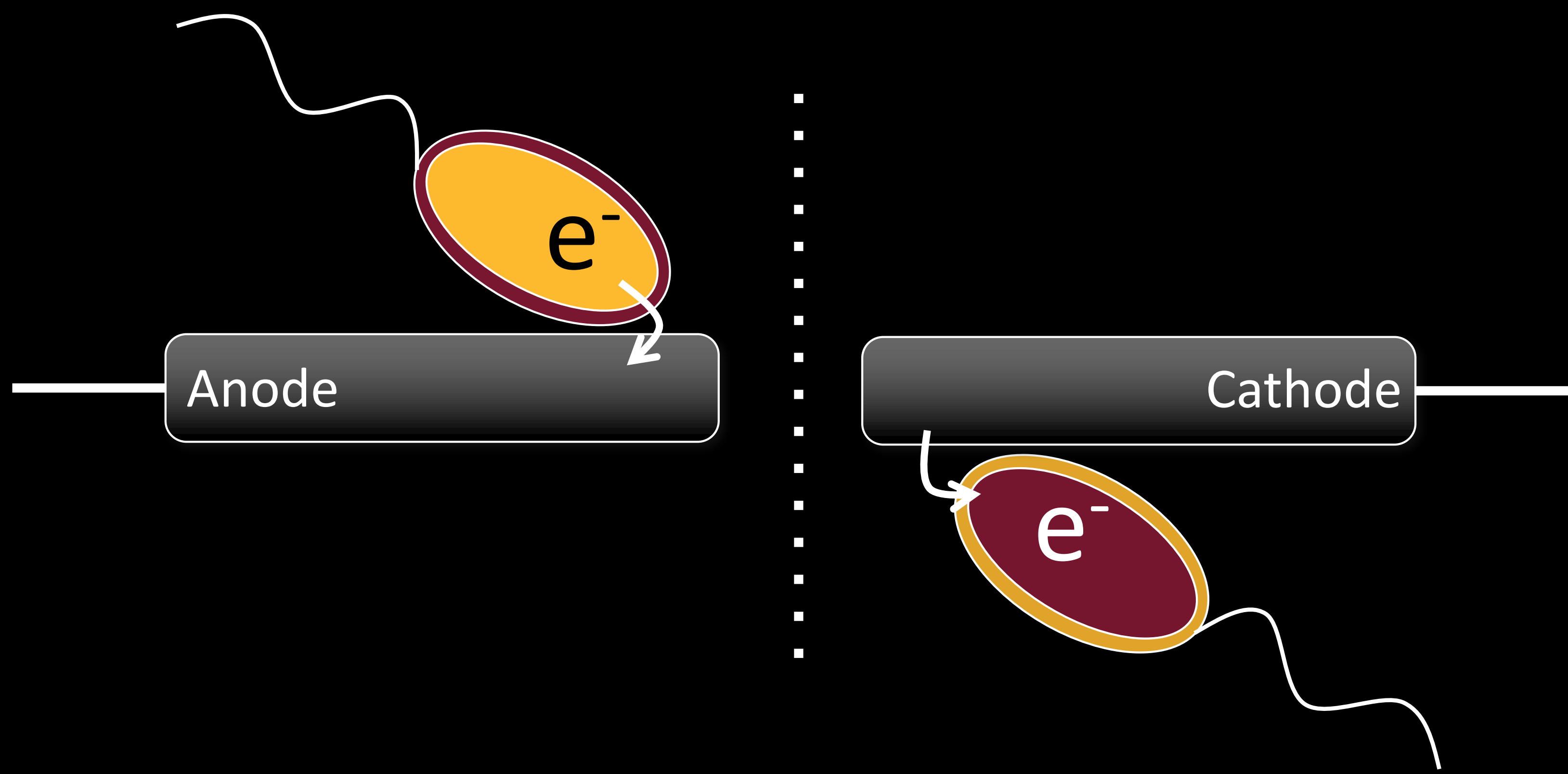
Iron



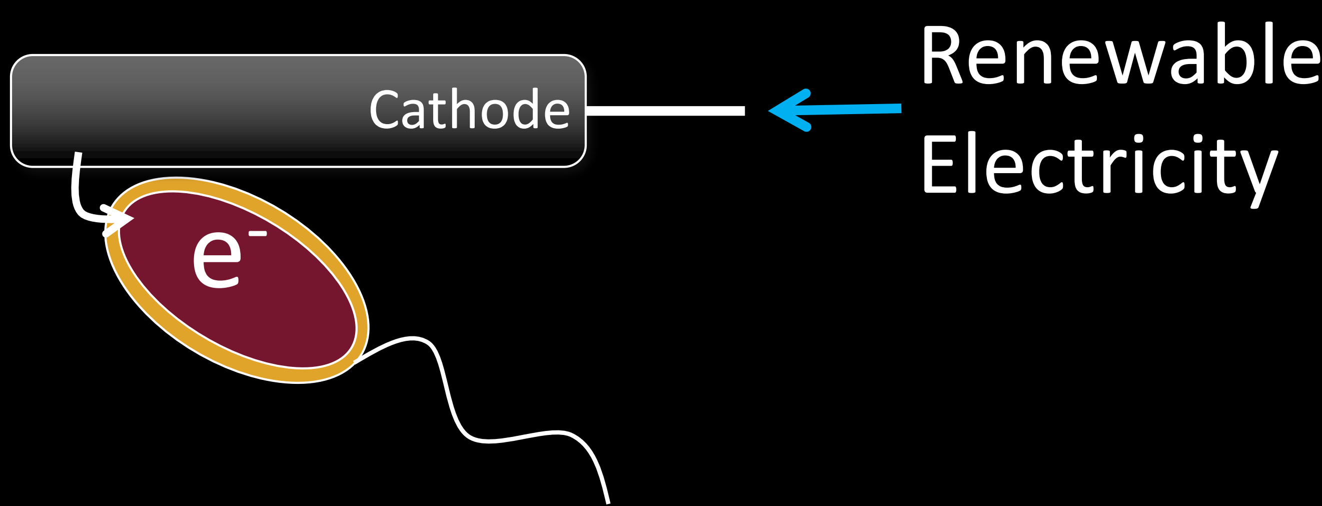


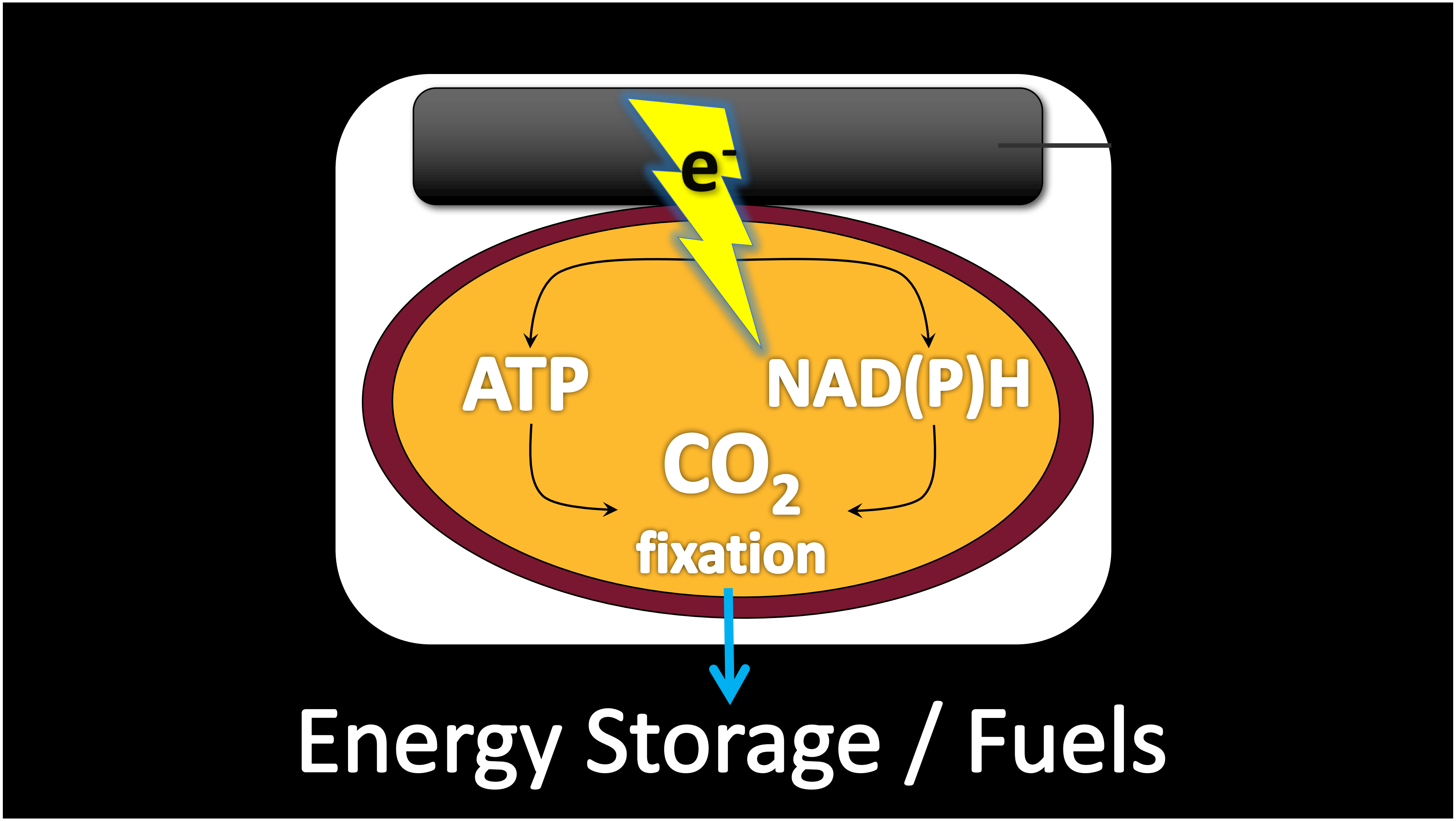
Iron
e⁻
Fe(II)
e⁻

Electrodes



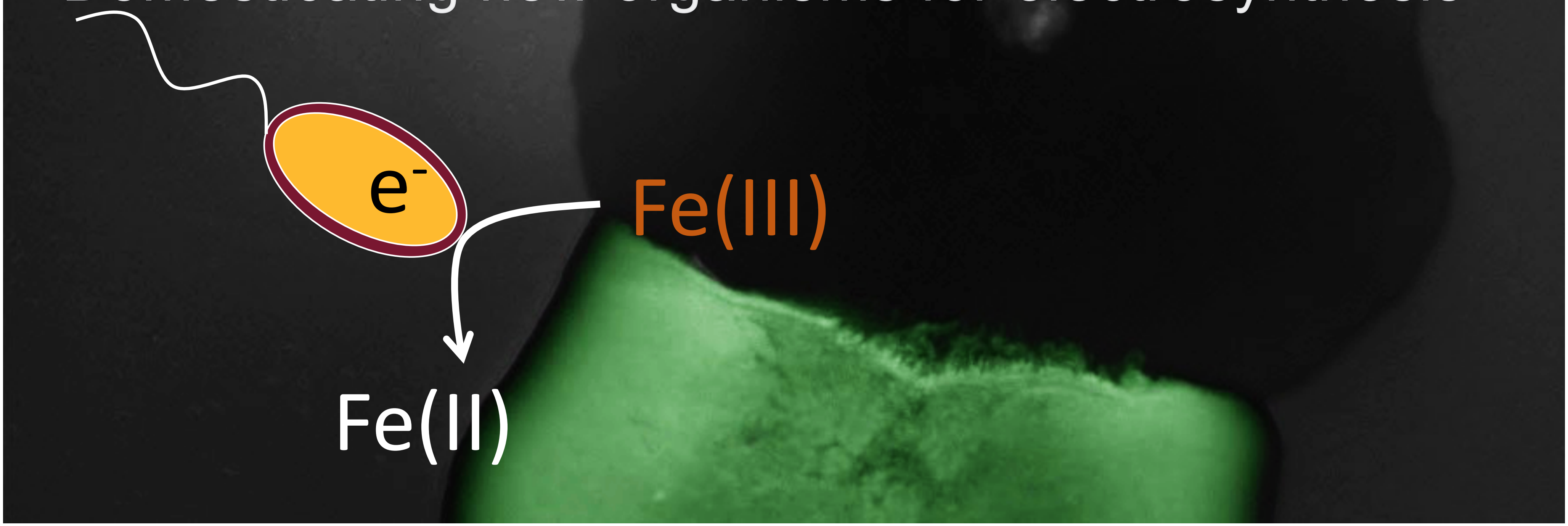
Electrosynthesis

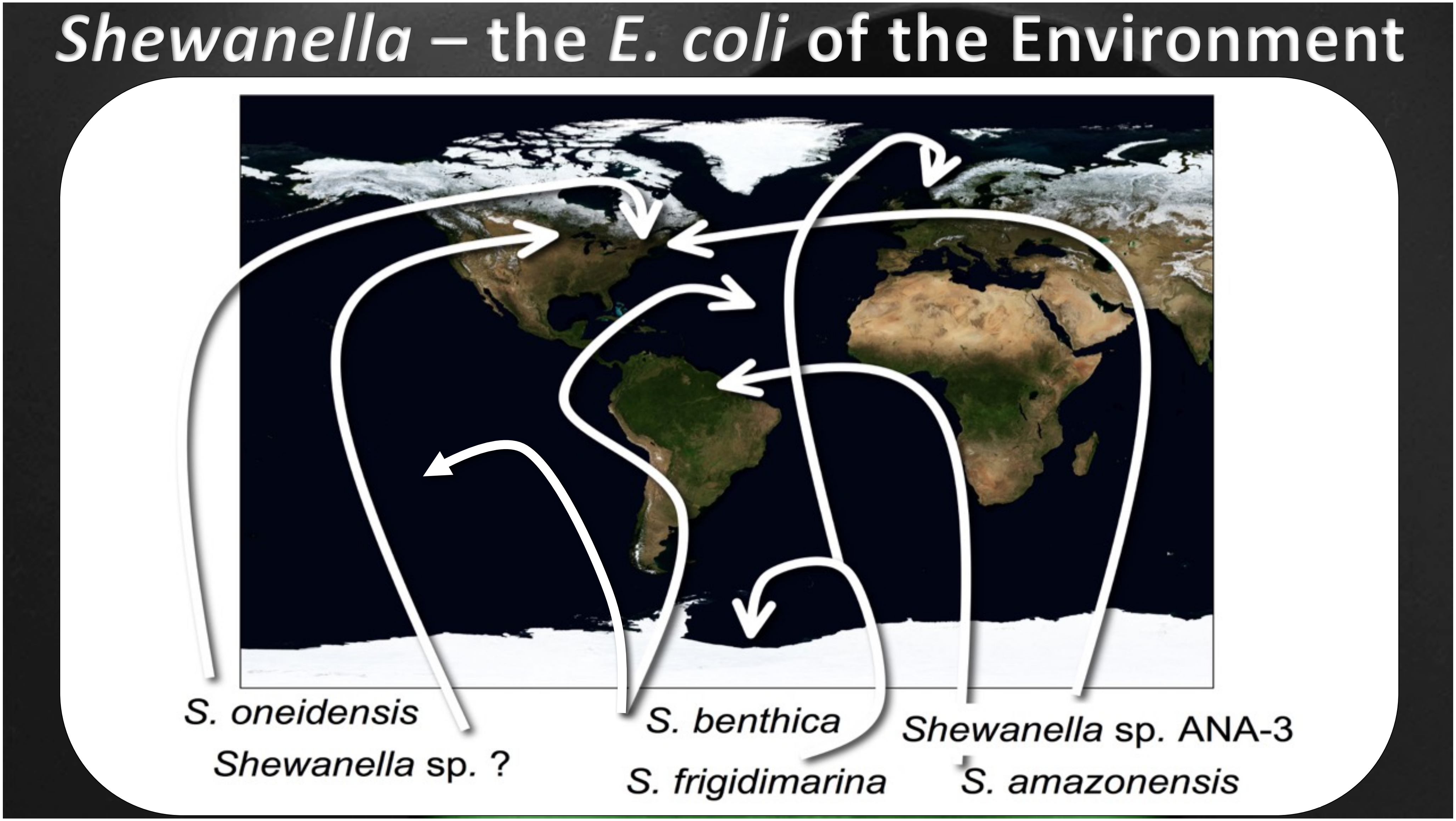


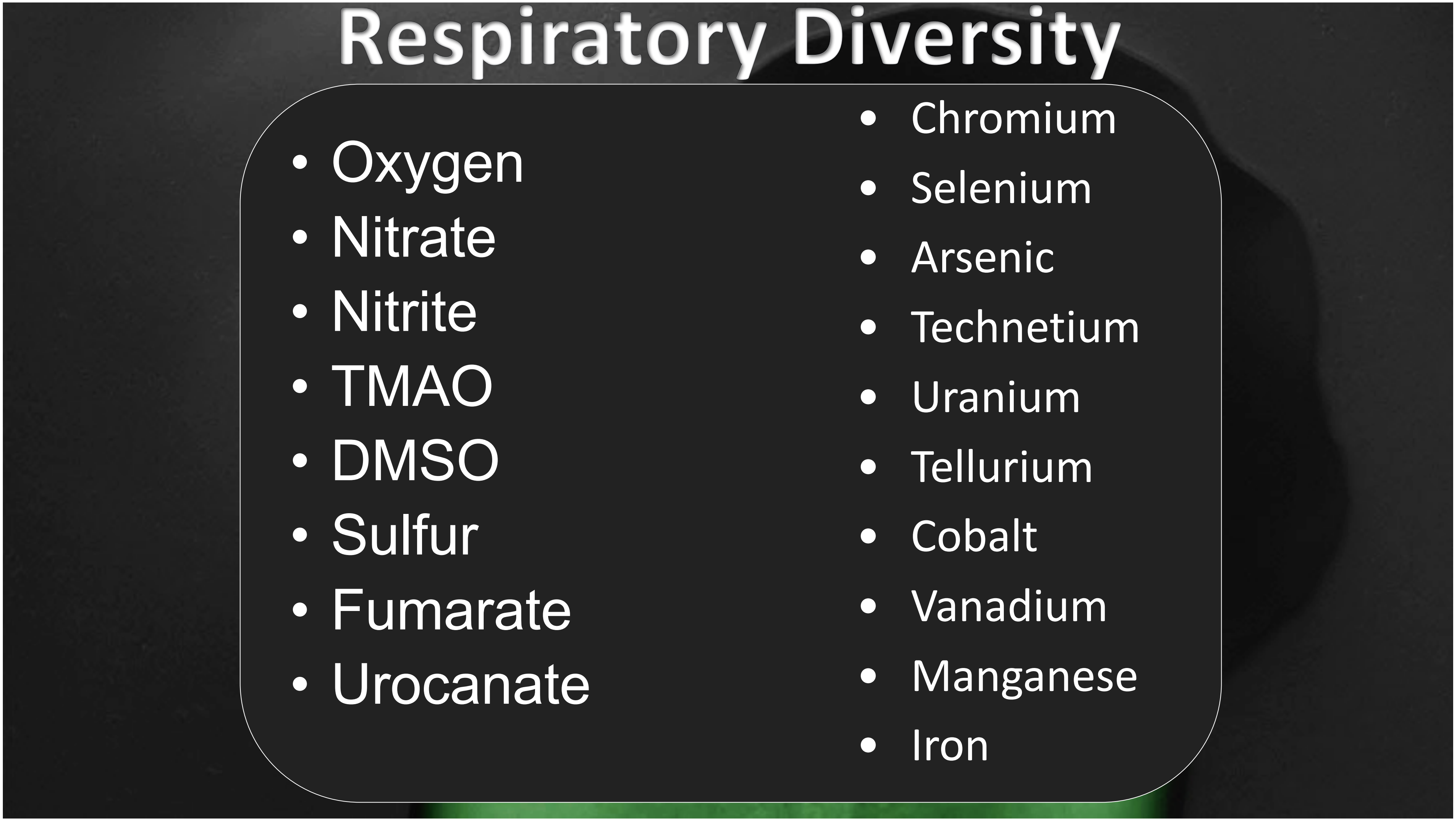

e⁻
ATP
NAD(P)H
CO2
fixation
Energy Storage / Fuels

Outline

- Extracellular electron transfer and iron bacteria
- Reversing a dissimilatory metal reducing bacterium
- Domesticating new organisms for electrosynthesis



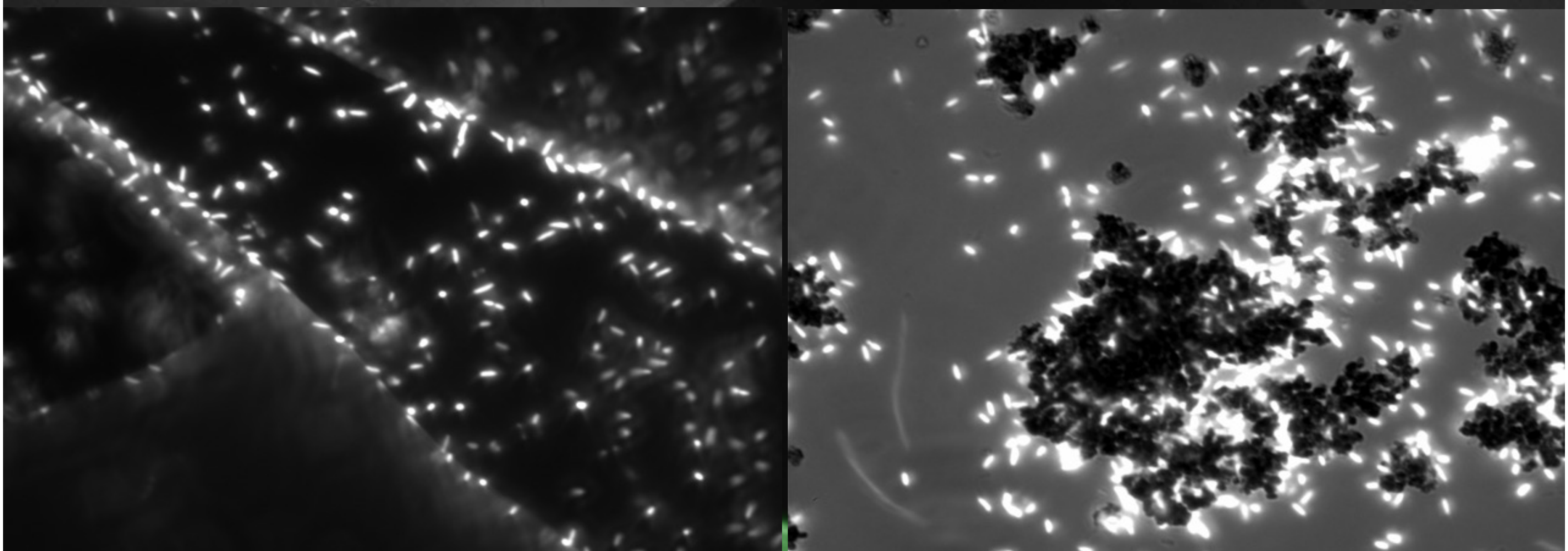

Shewanella – the E. coli of the Environment
S. oneidensis
Shewanella sp. ?
S. benthica
S. frigidimarina
Shewanella sp. ANA-3
S. amazonensis


Respiratory Diversity
Oxygen
Nitrate
Nitrite
TMAO
DMSO
Sulfur
Fumarate
Urocanate
Chromium
Selenium
Arsenic
Technetium
Uranium
Tellurium
Cobalt
Vanadium
Manganese
Iron

Respiratory Diversity

- Oxygen
- Nitrate
- Nitrite
- TMAO
- DMSO
- Sulfur
- Fumarate
- Urocanate
- Chromium
- Selenium
- Arsenic
- Technetium
- Uranium
- Tellurium
- Cobalt
- Vanadium
- **Manganese**
- **Iron**

Respiration of insoluble substrates



Iron Oxide

Manganese Oxide

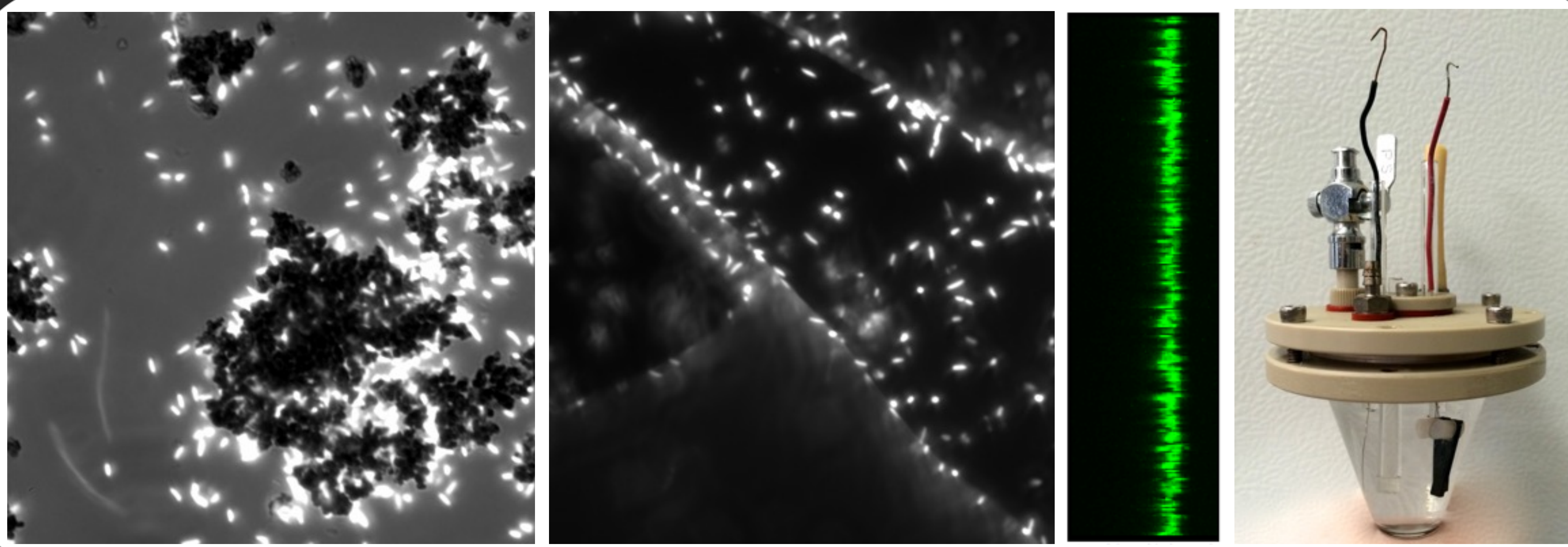
"Extracellular Electron Transport"

Why is Extracellular Electron Transport Importar

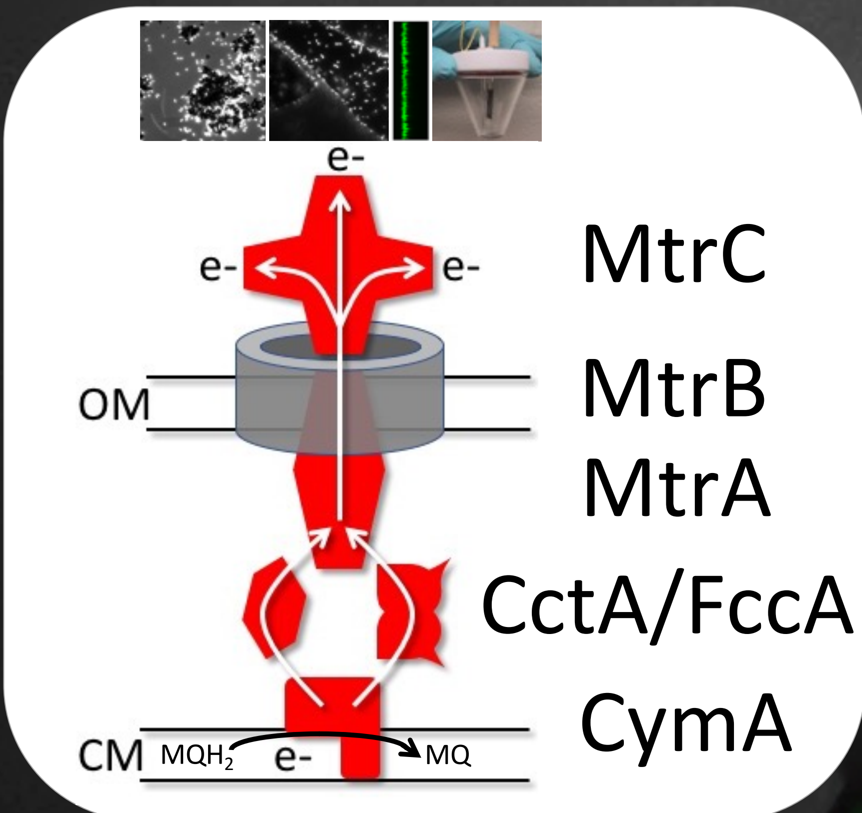
- Respiration of *insoluble* substrates requires novel electron transfer pathways.

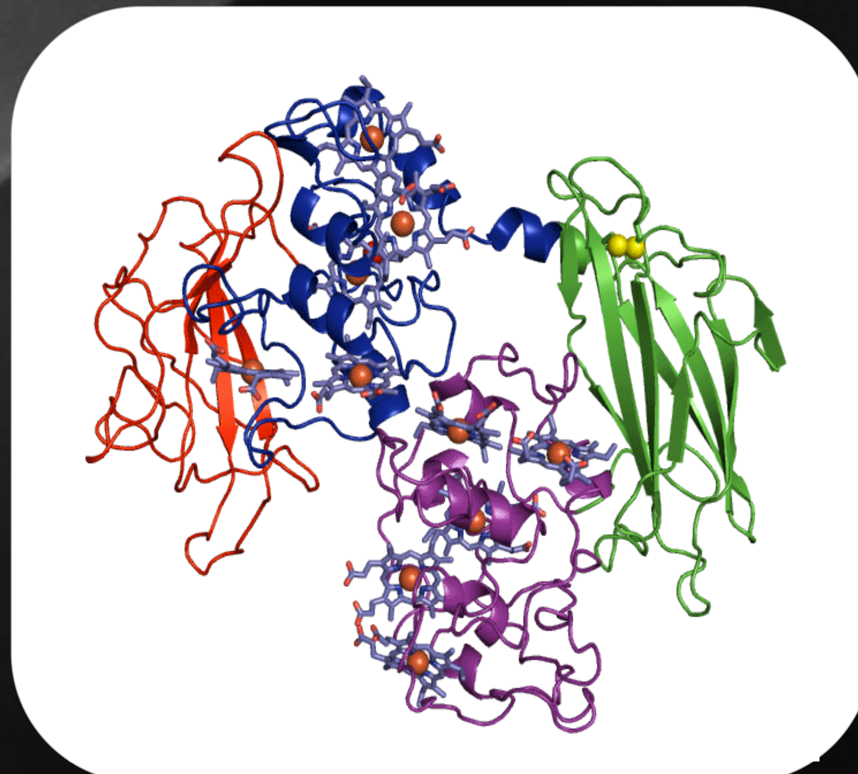
- EET allows the cell to respire electrodes to generate electricity, can also reverse flow *into* cells: **electrosynthesis.**

Respiration of insoluble substrates



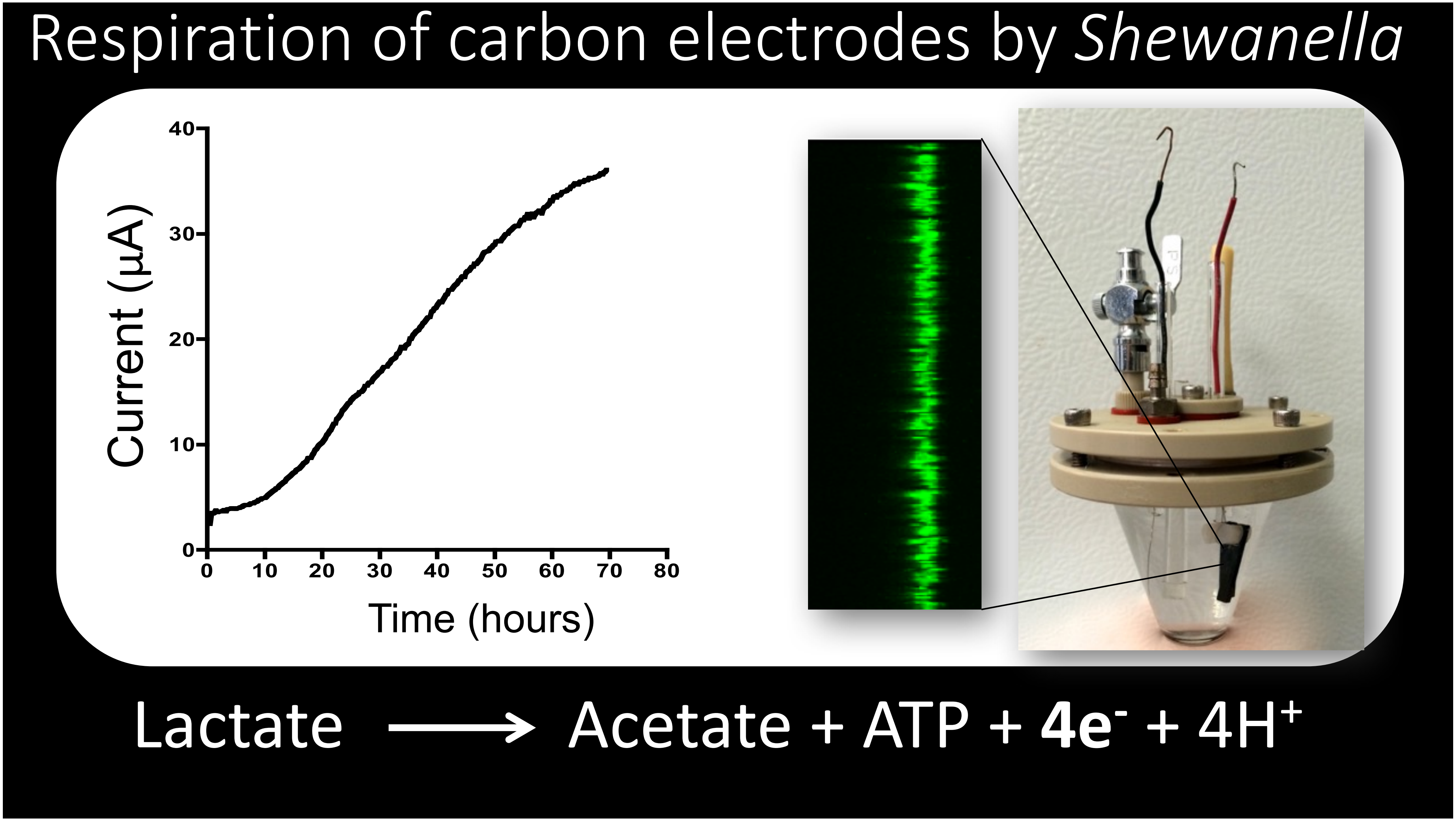
Core conduit for EET in *Shewanella*





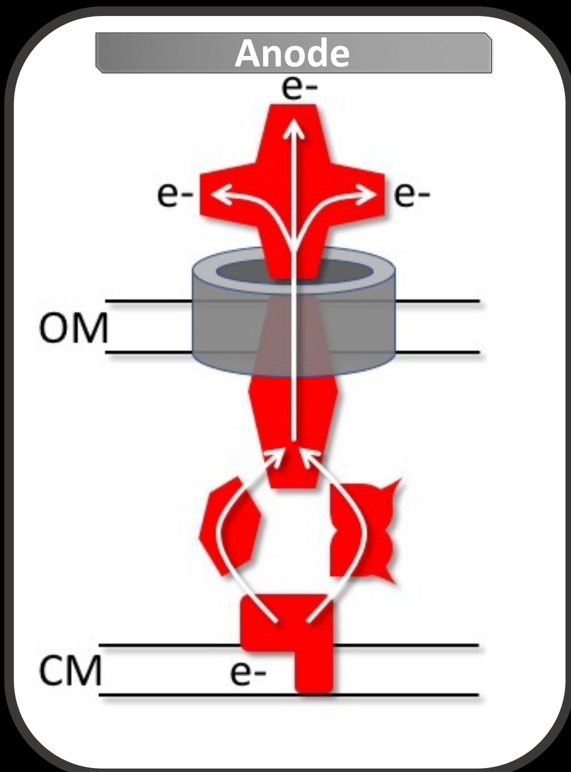
MtrF – a paralog of
MtrC in *S. oneidensis*

Clarke et al., 2011 PNAS Jun 7;108(23):9384-9

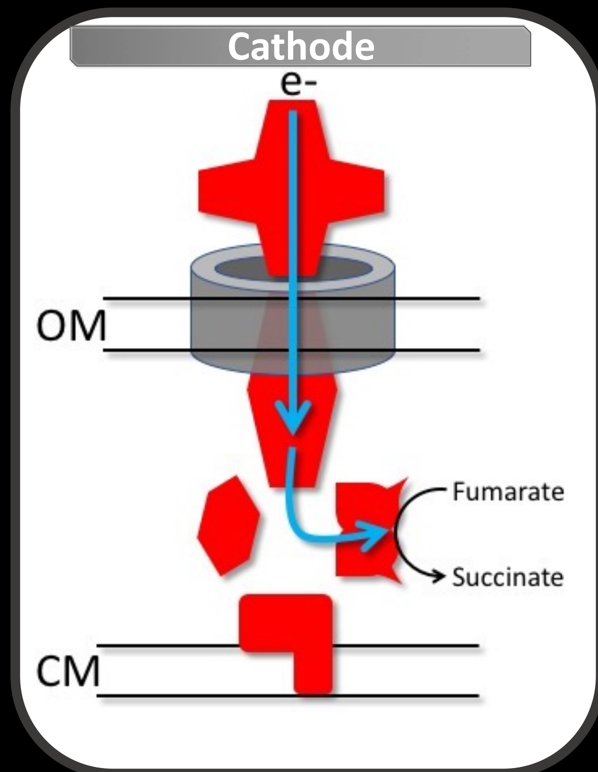


Respiration of carbon electrodes by *Shewanella*
Current (μA)
0
10
20
30
40
Time (hours)
0
10
20
30
40
50
60
70
80
Lactate → Acetate + ATP + **4e⁻** + 4H⁺

Electrode-dependent fumarate reduction

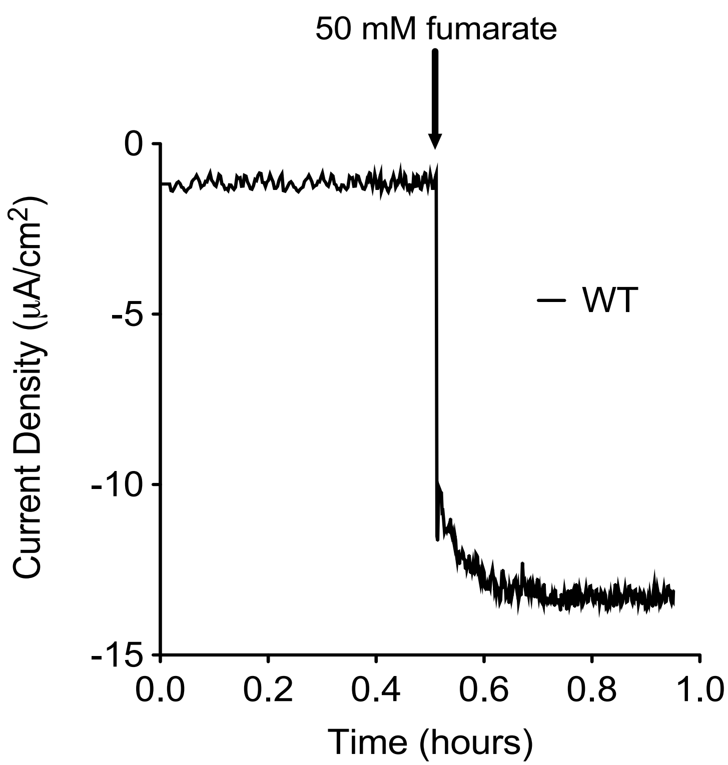


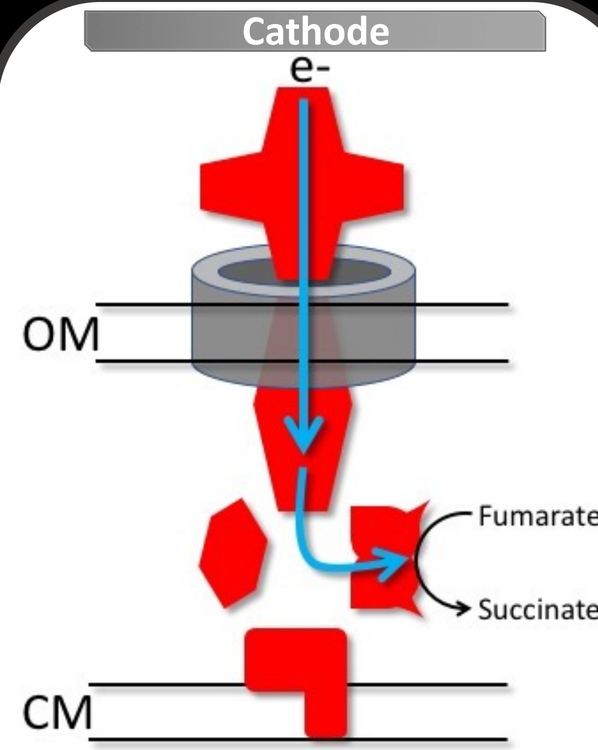
Outward Electron Flow



Reverse Electron Flow

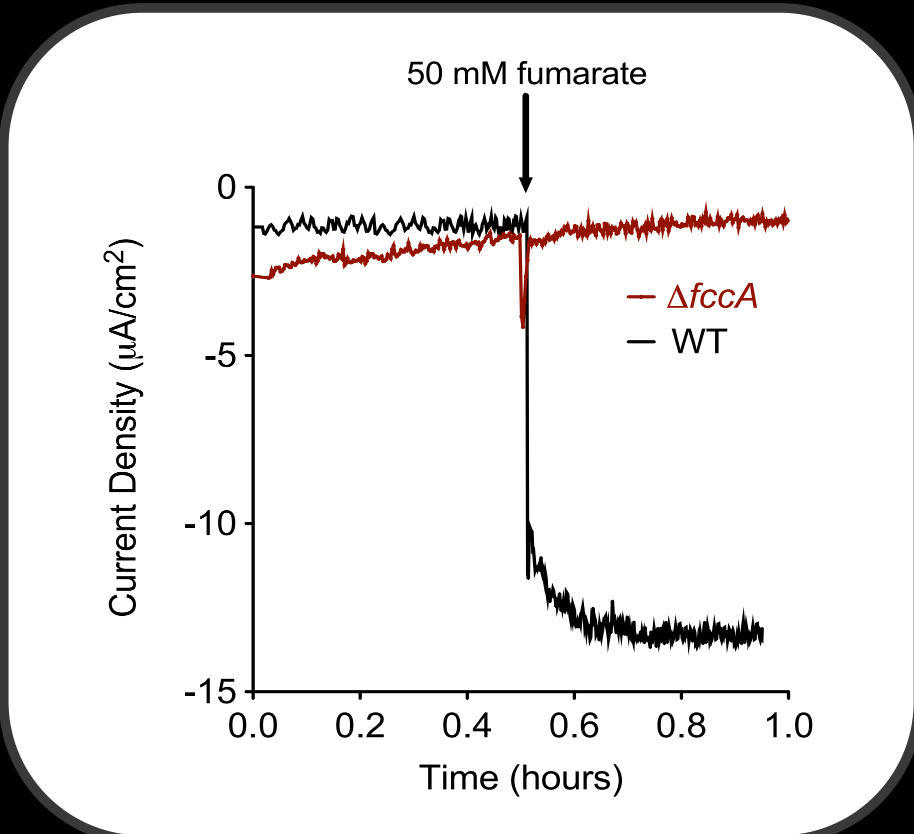
Electrode-dependent fumarate reduction

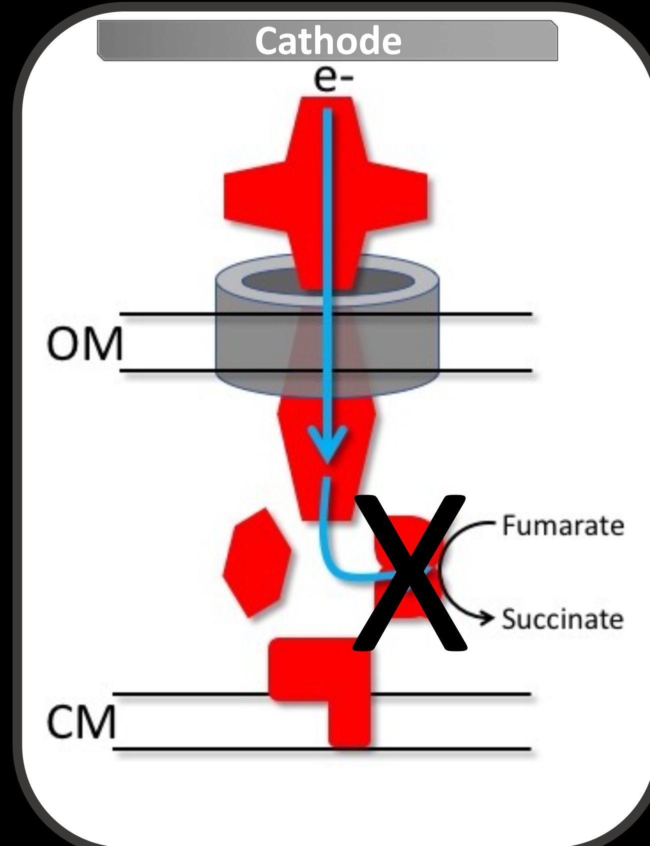




Ross et al., PLoS One, 2011

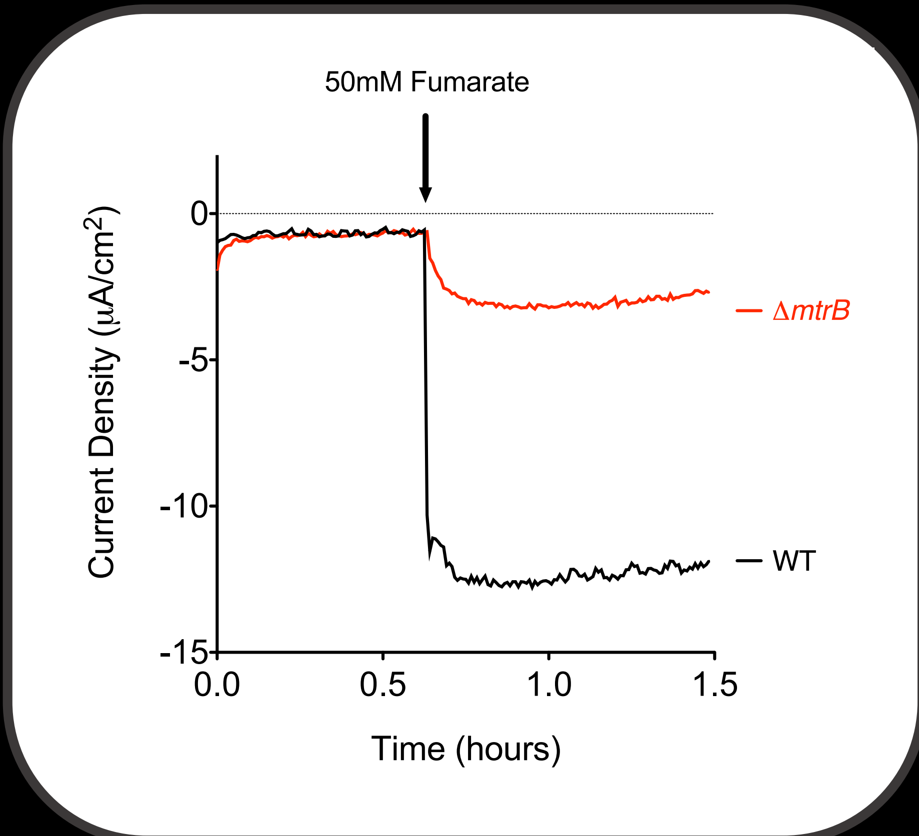
Electrode-dependent fumarate reduction requires FccA (the fumarate reducatase)

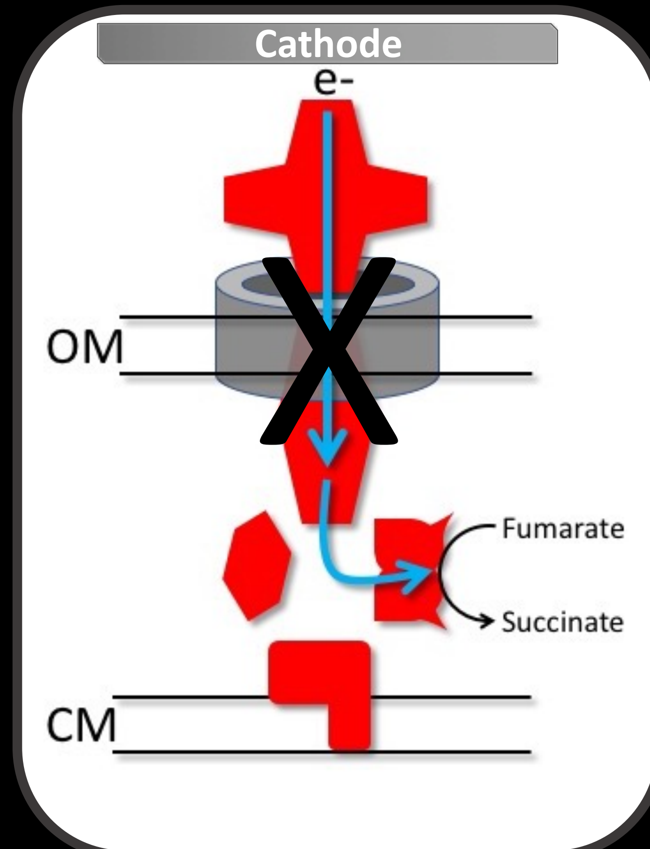




Ross et al., PLoS One, 2011

The Mtr respiratory pathway catalyzes reversible electron transfer





Ross et al., PLoS One, 2011

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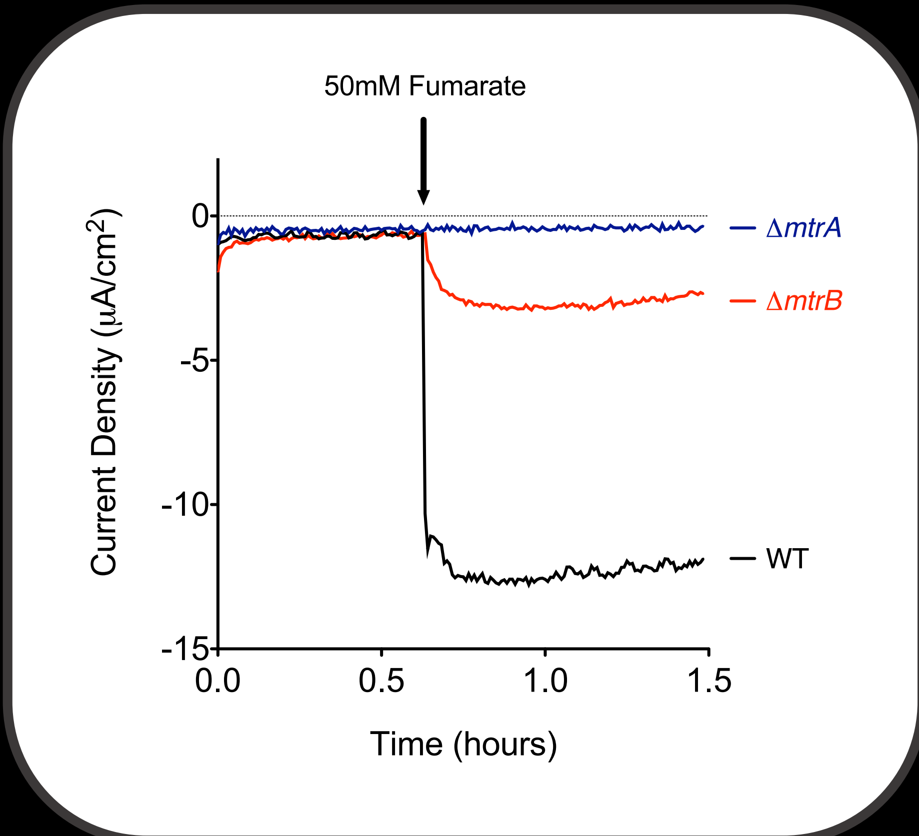
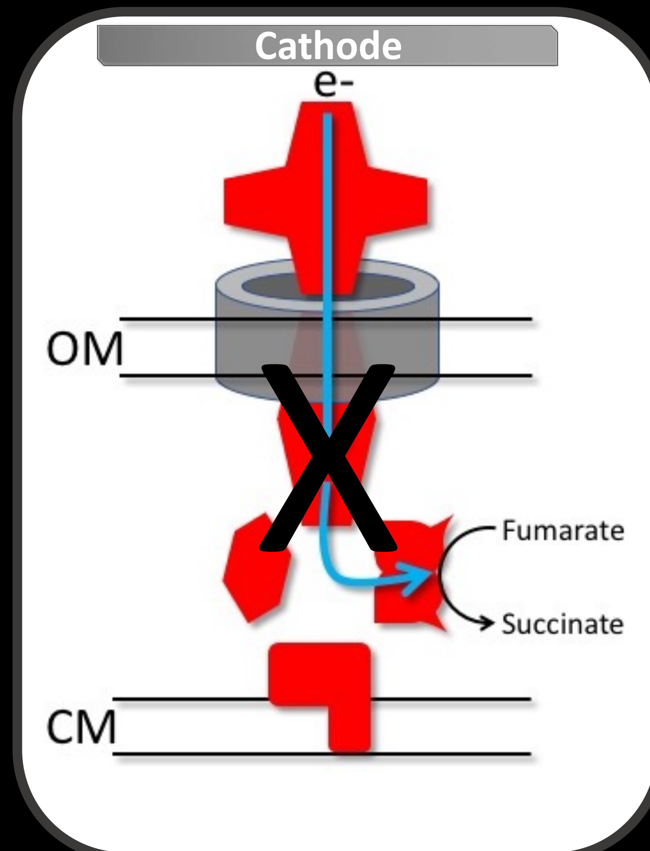
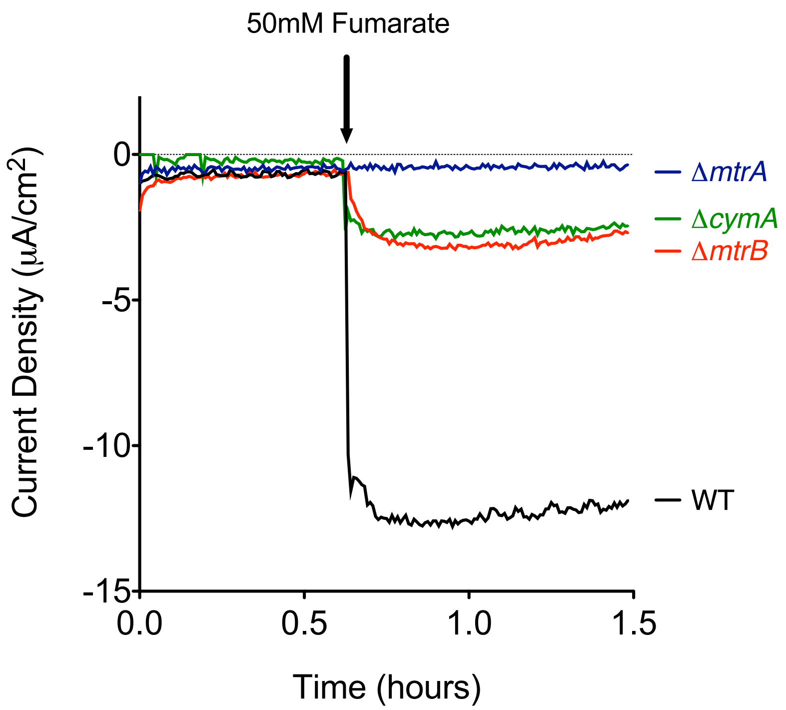
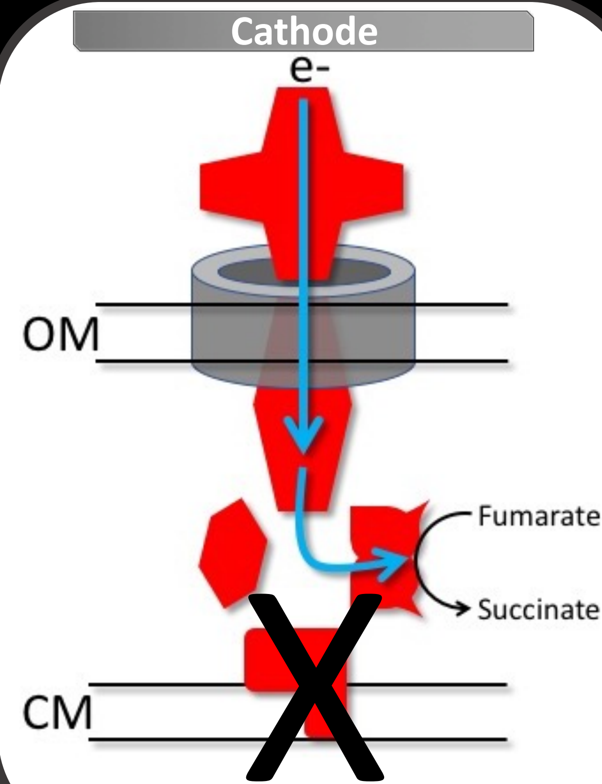




Ross et al., PLoS One, 2011

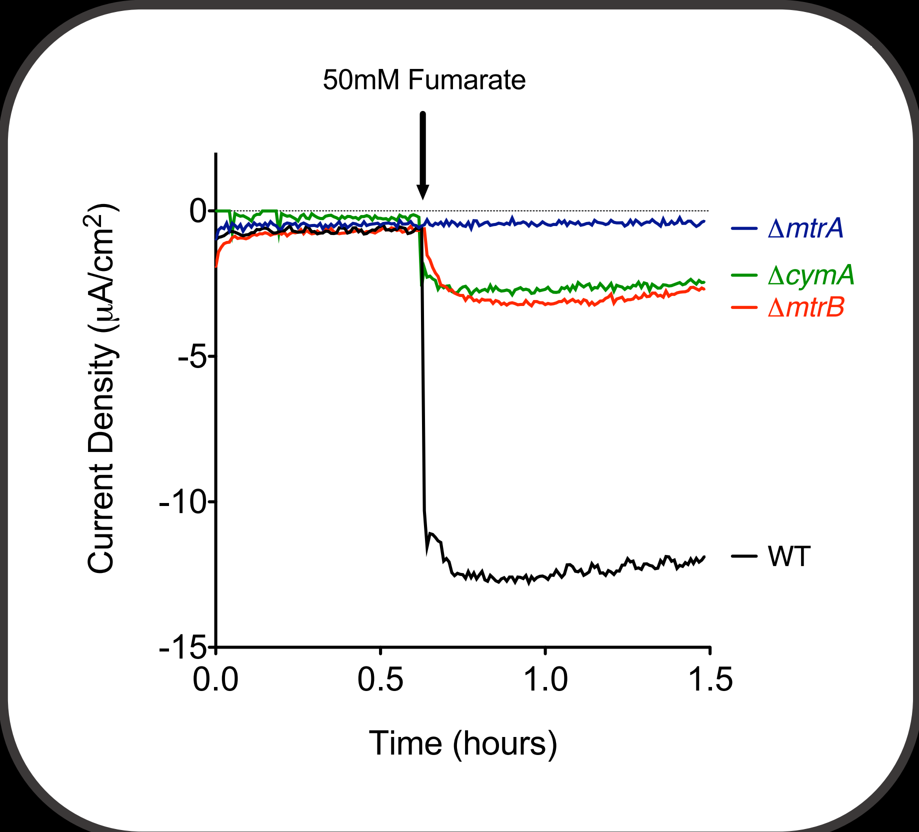
The quinone oxidoreductase CymA is required for robust inward electron flow

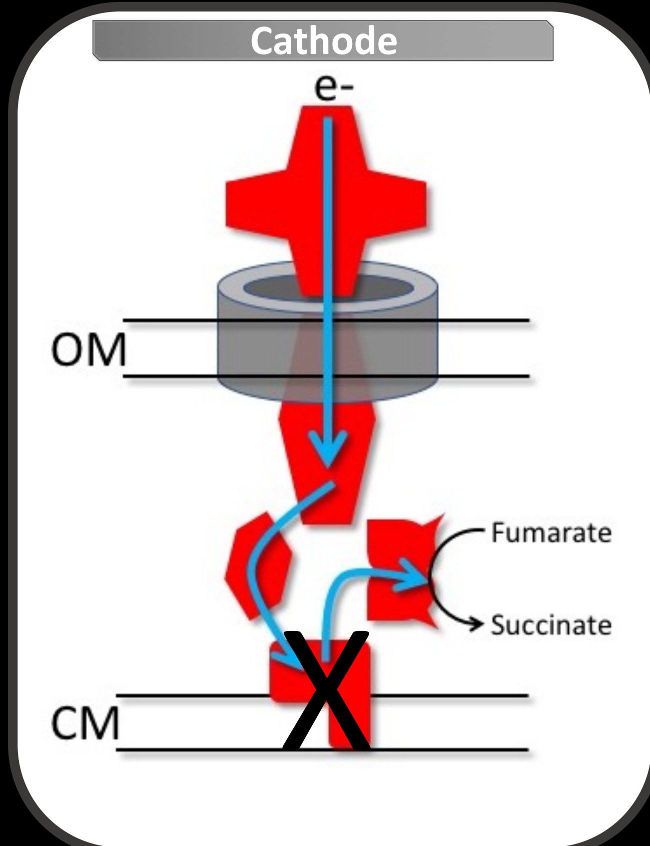




Ross et al., PLoS One, 2011

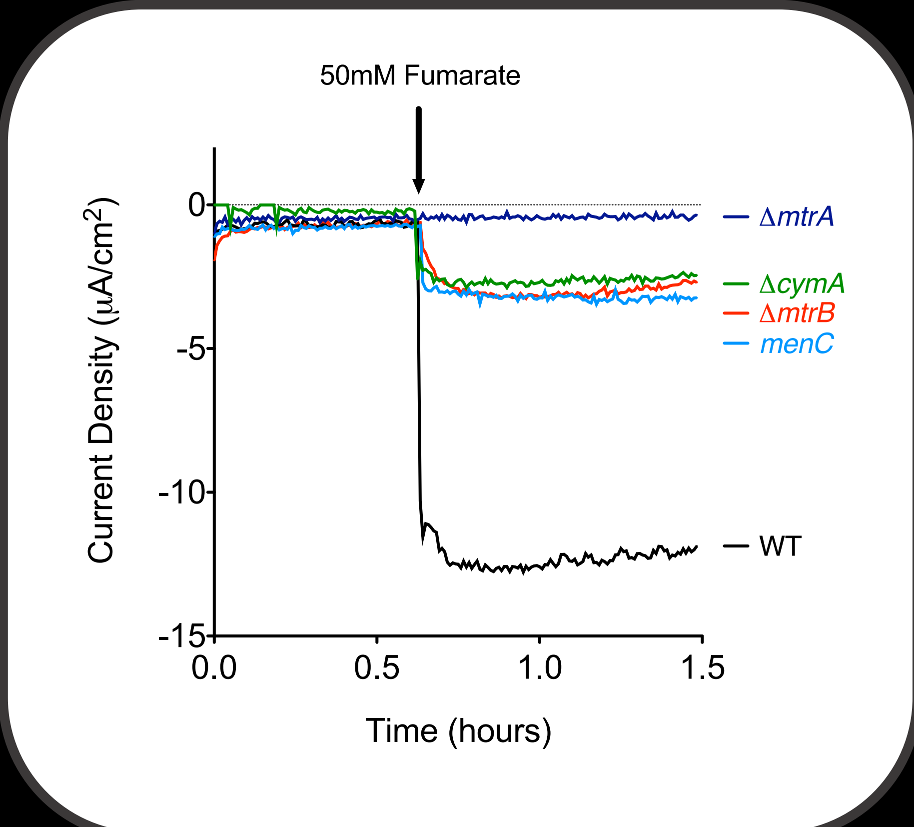
The quinone oxidoreductase CymA is required for robust inward electron flow

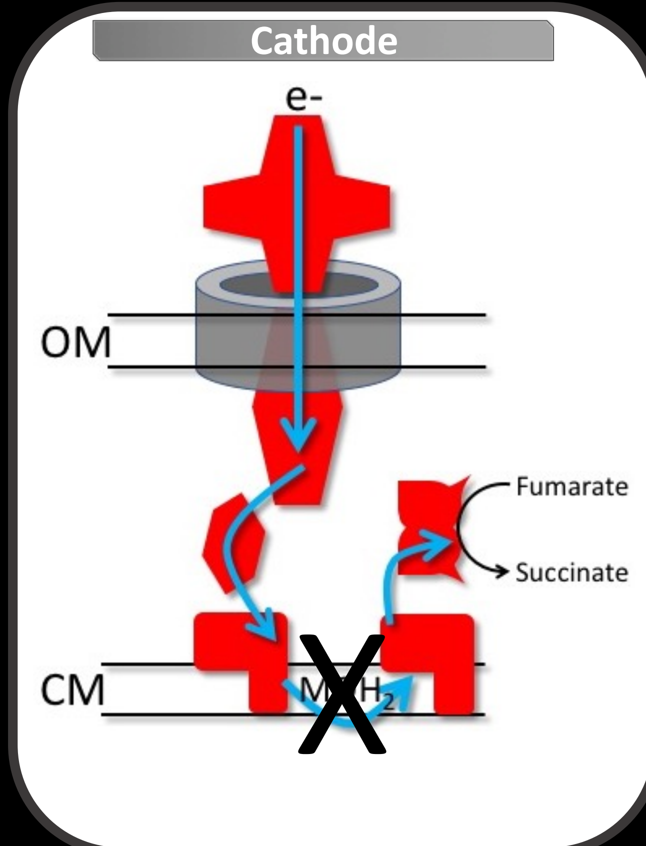




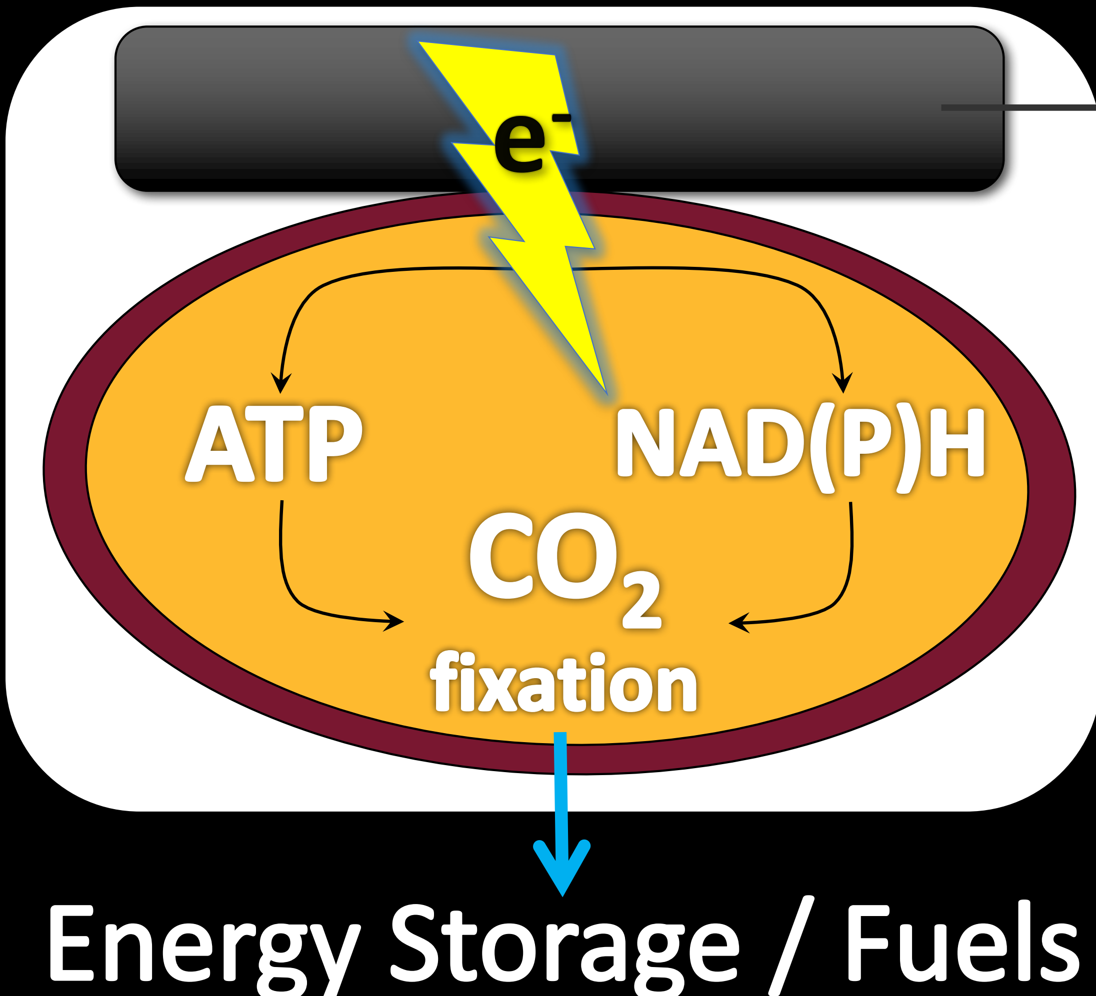
Ross et al., PLoS One, 2011

Menaquinone is important for robust inward electron flow





Ross et al., PLoS One, 2011

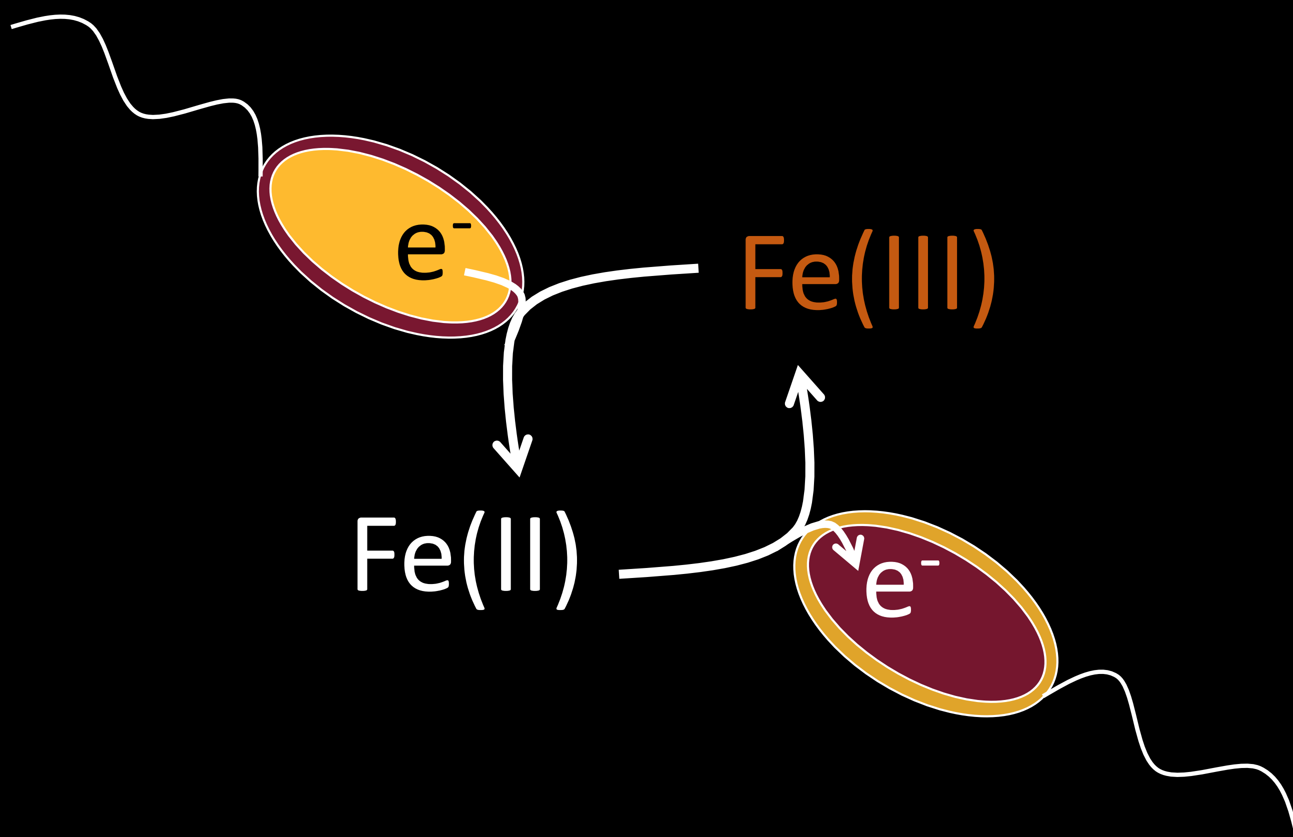


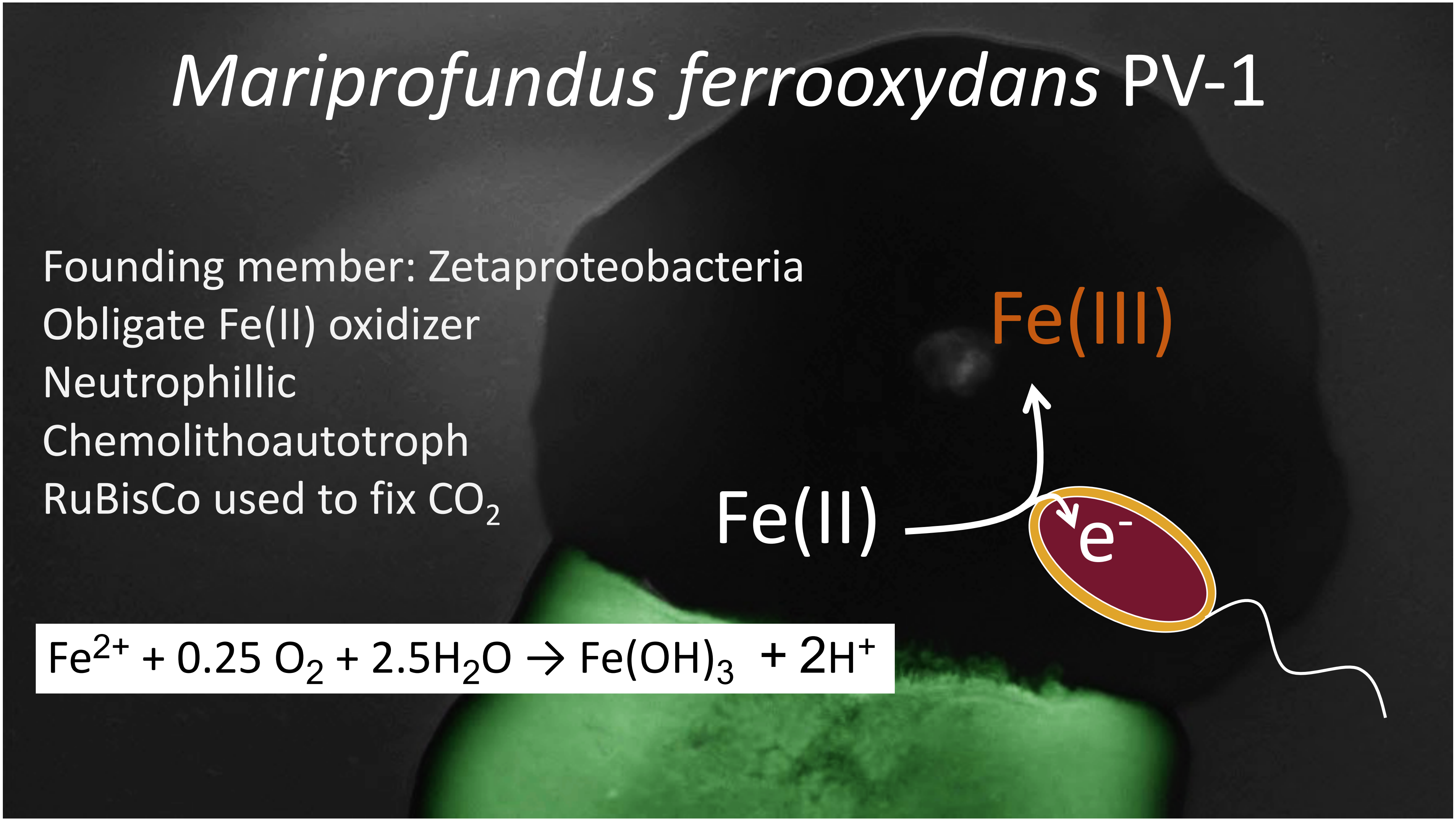
Shewanella cannot fix CO_2

Robust ATP and NAD(P)H production would require O_2 as an electron acceptor. Anaerobic metabolism and EET are HIGHLY repressed by O_2.

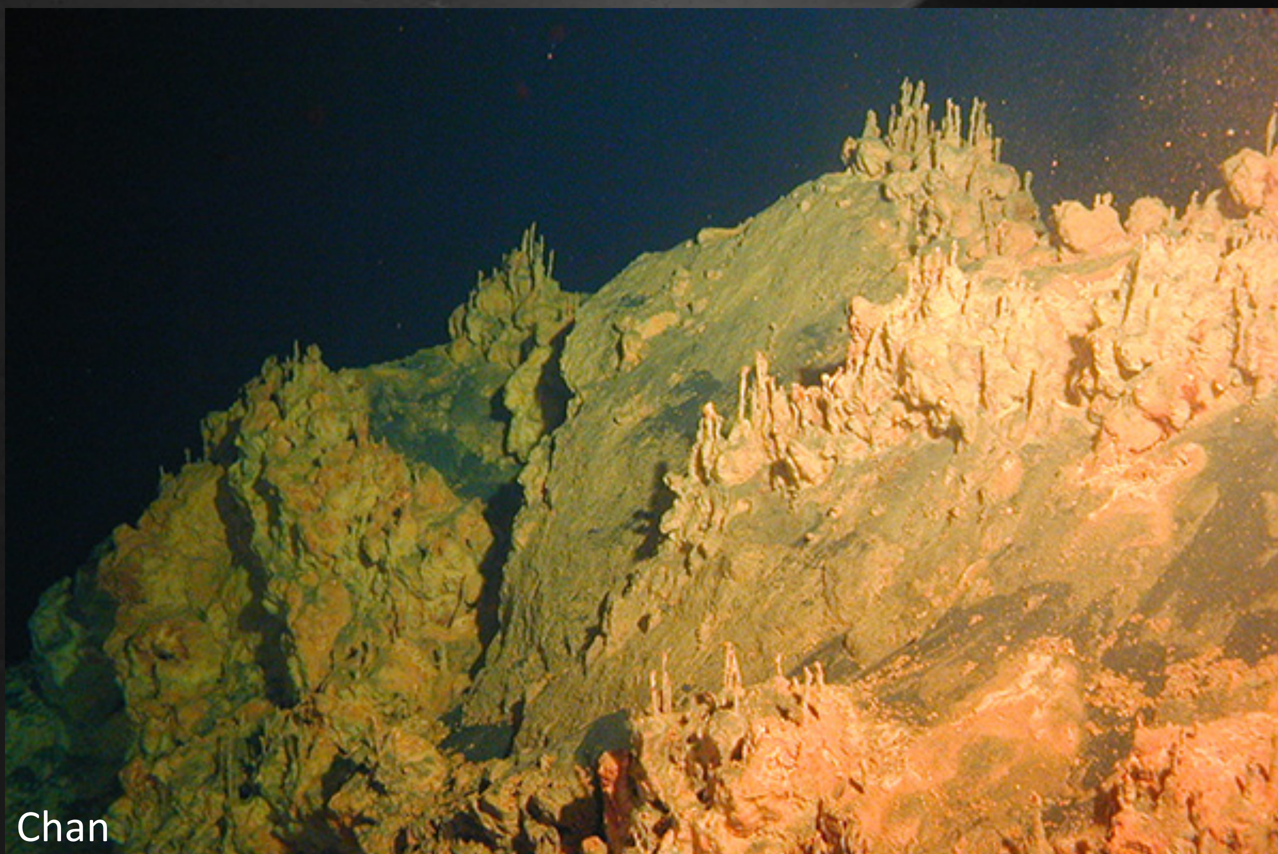
Iron respiration is thought to be one of the earliest forms of respiration on Earth – that's a lot of selection for sending electrons OUT of the system rather than in.

Iron

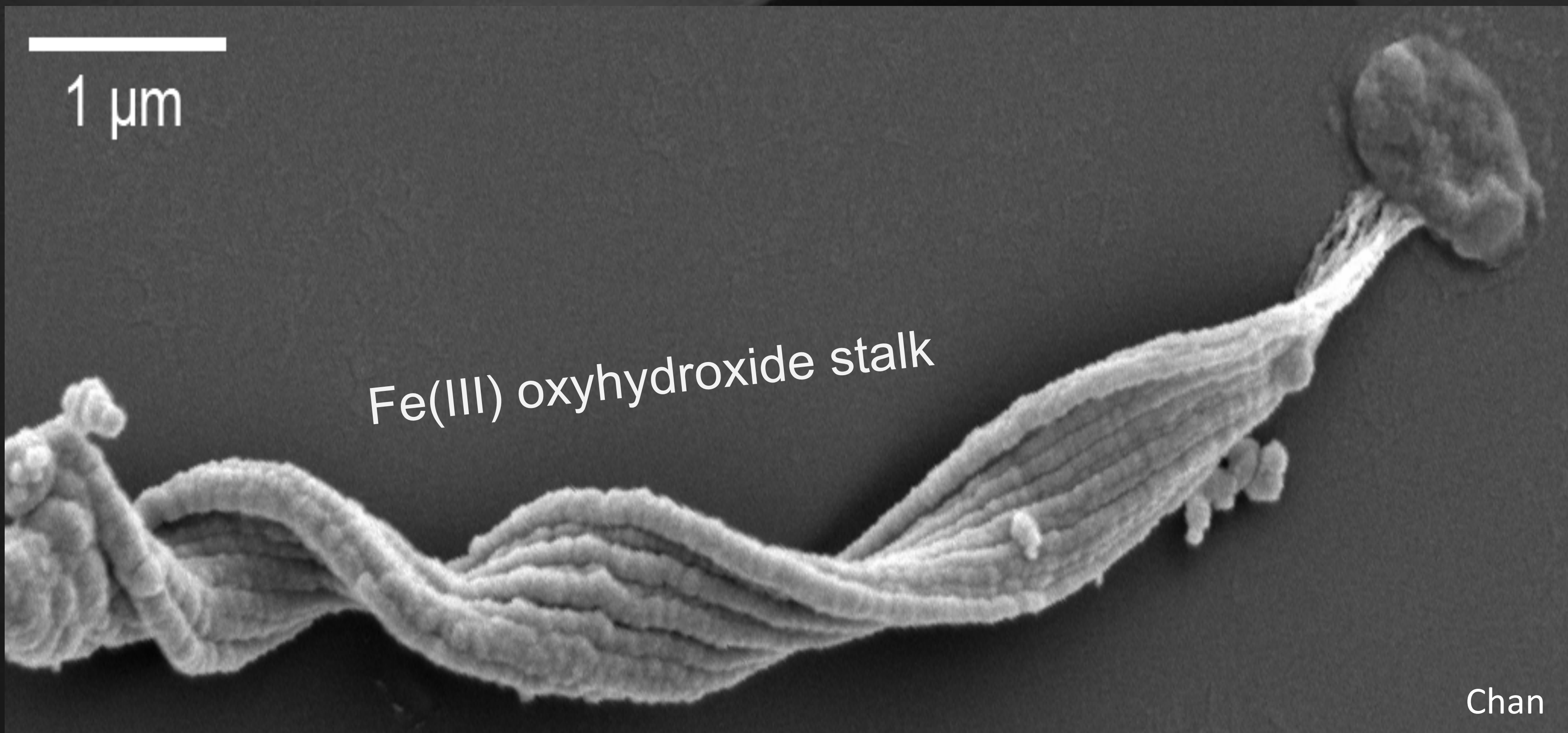



Mariprofundus ferrooxydans PV-1
Founding member: Zetaproteobacteria
Obligate Fe(II) oxidizer
Neutrophillic
Chemolithoautotroph
RuBisCo used to fix CO_2
Fe(III)
Fe(II)
e^-
$Fe^{2+} + 0.25\ O_2 + 2.5H_2O \rightarrow Fe(OH)_3 + 2H^+$

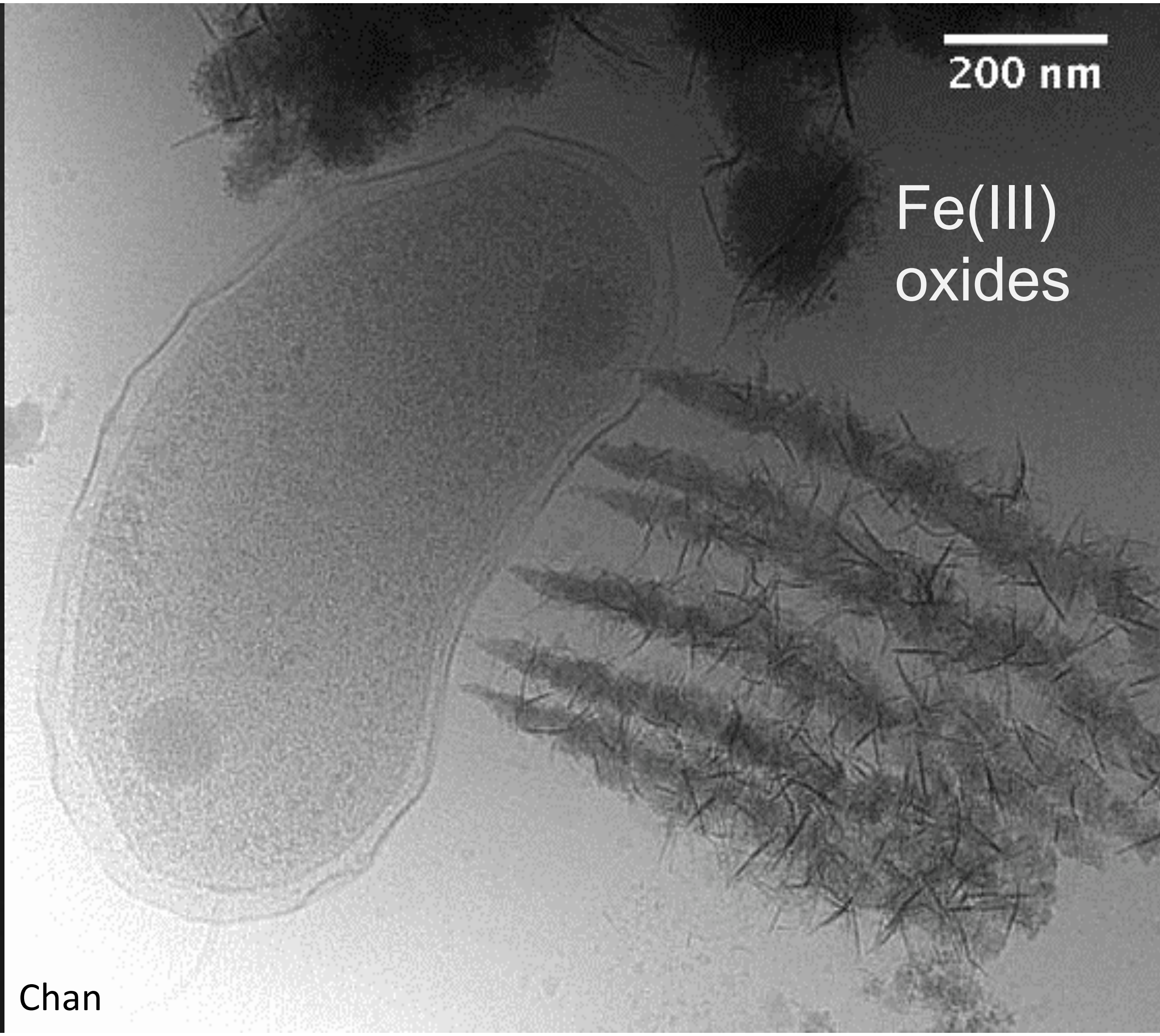
Mariprofundus ferrooxydans PV-1



Mariprofundus ferrooxydans PV-1

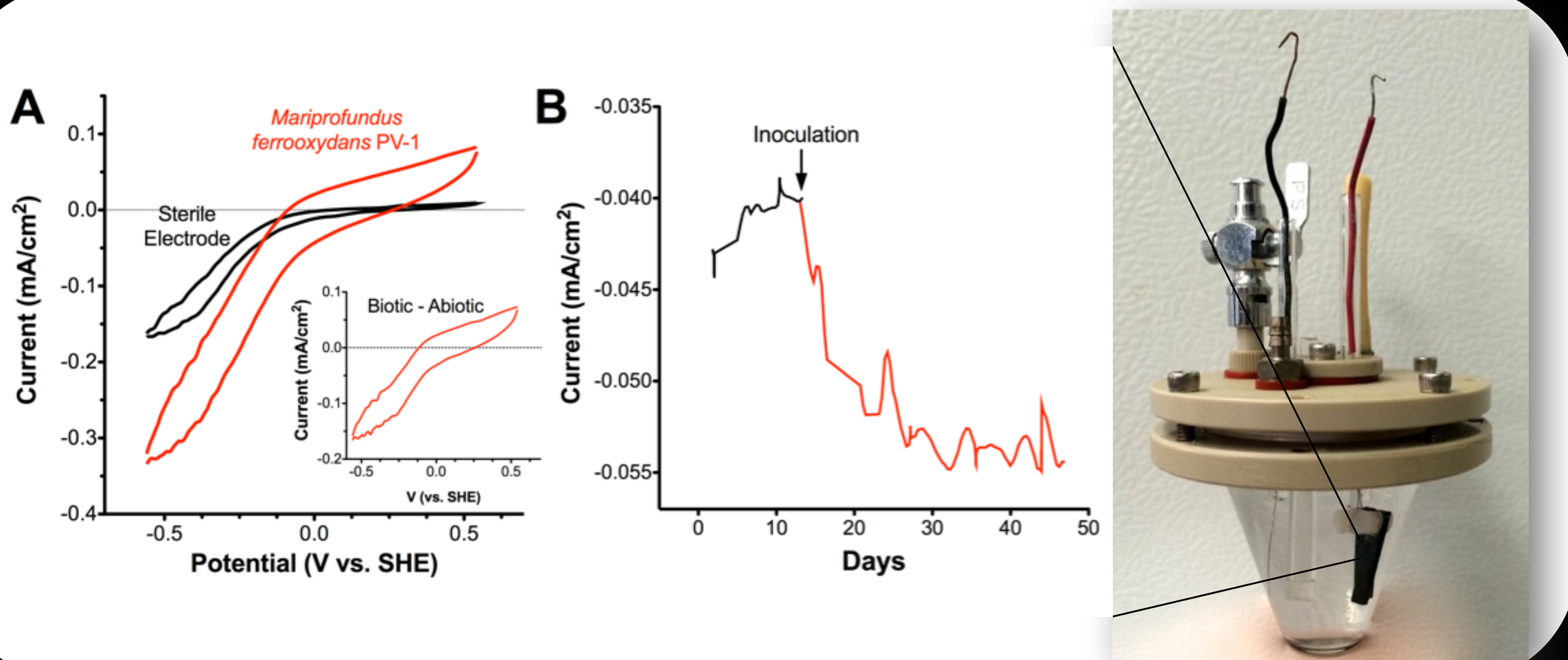


$Fe^{2+} + 0.25\ O_2 + 2.5H_2O \rightarrow Fe(OH)_3 + 2H^+$



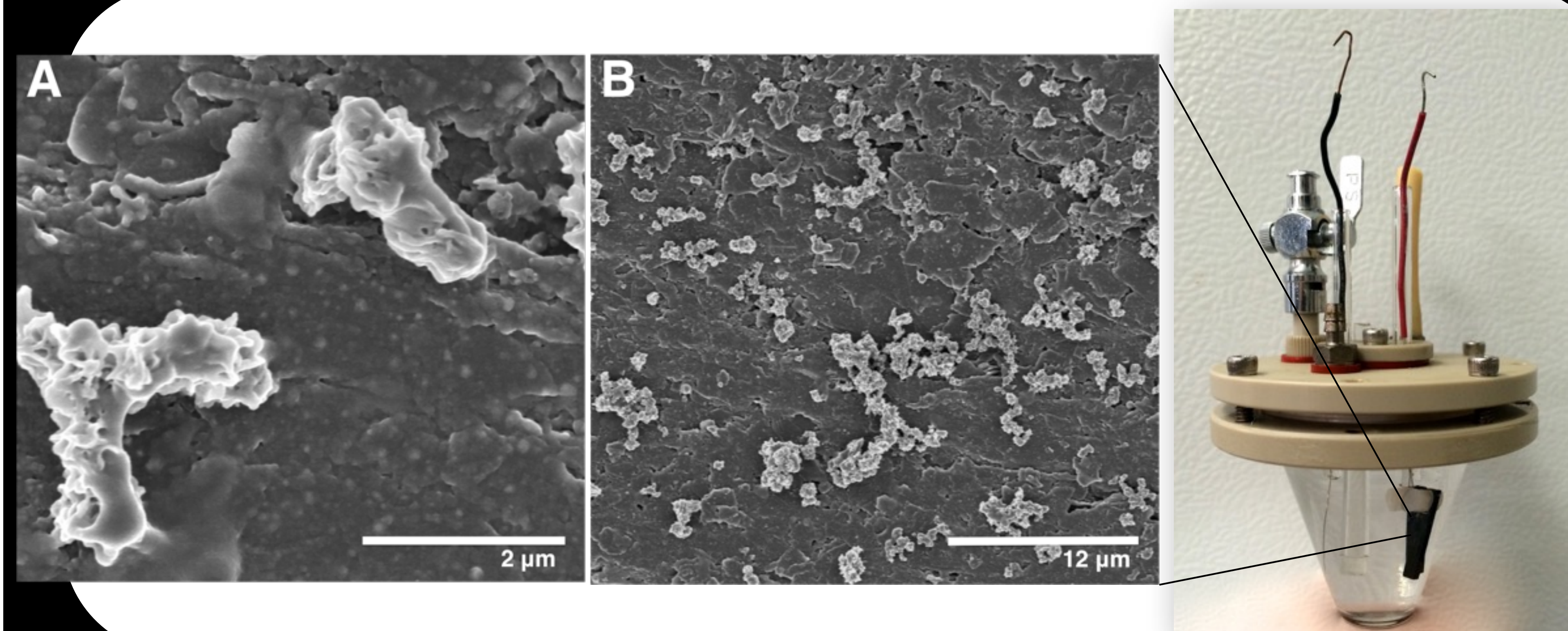
If the mechanism of obtaining e^- from Fe(II) is extracellular, we should be able to replace Fe(II) with a cathode.

Growth of *Mariprofundus* using a cathode



Summers et al., mBio, 2013

Growth of *Mariprofundus* using a cathode

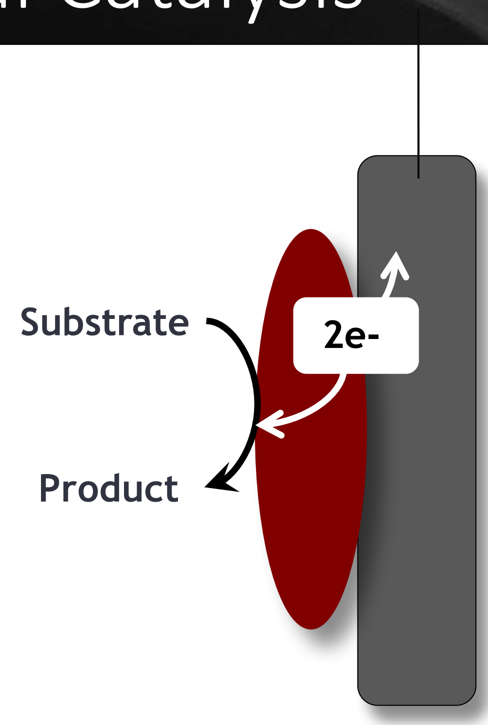


Summers et al., mBio, 2013

Bioelectrochemical Catalysis

Microbial Biocatalysis

- Self-sufficient
- Self-replicating
- Self-contained
- Self-optimizing
- Can be manipulated using synthetic biology and genetics



Bioelectrochemical catalysis

@bacteriality

Acknowledgements

- Clara Chan, University of Delaware
- Daniel Bond, University of Minnesota