Mikrobe des Jahres

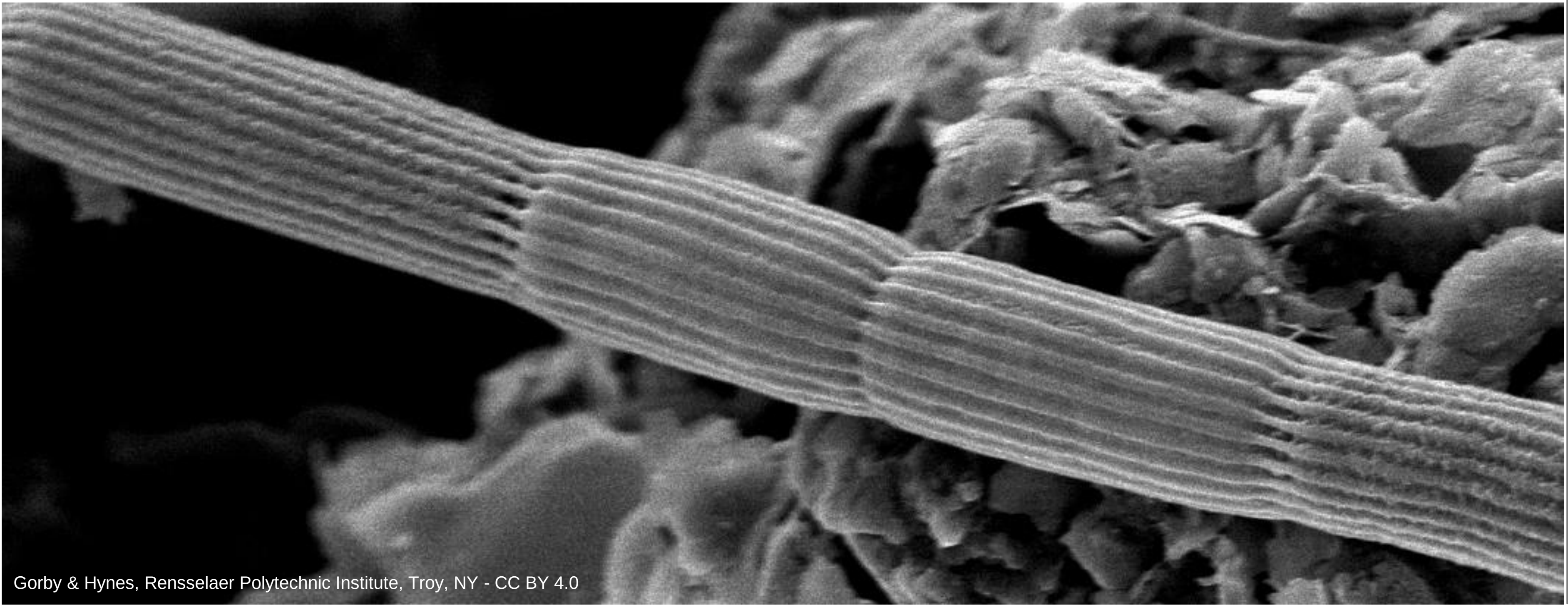
Vereinigung für Allgemeine und Angewandte Mikrobiologie

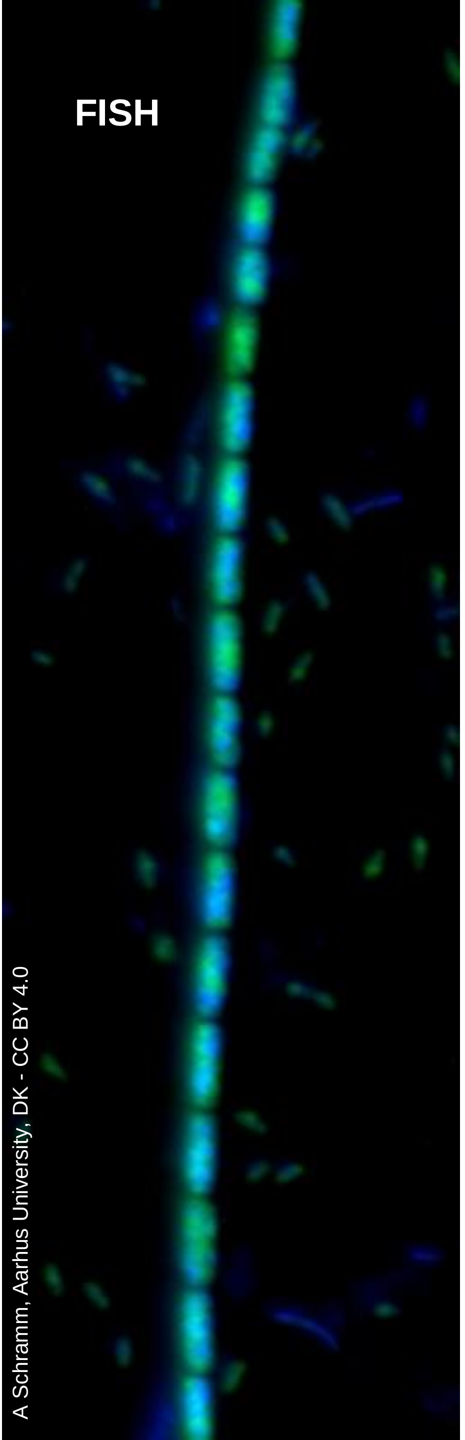
VAAM

Microbe of the year 2024

The Cable Bacterium

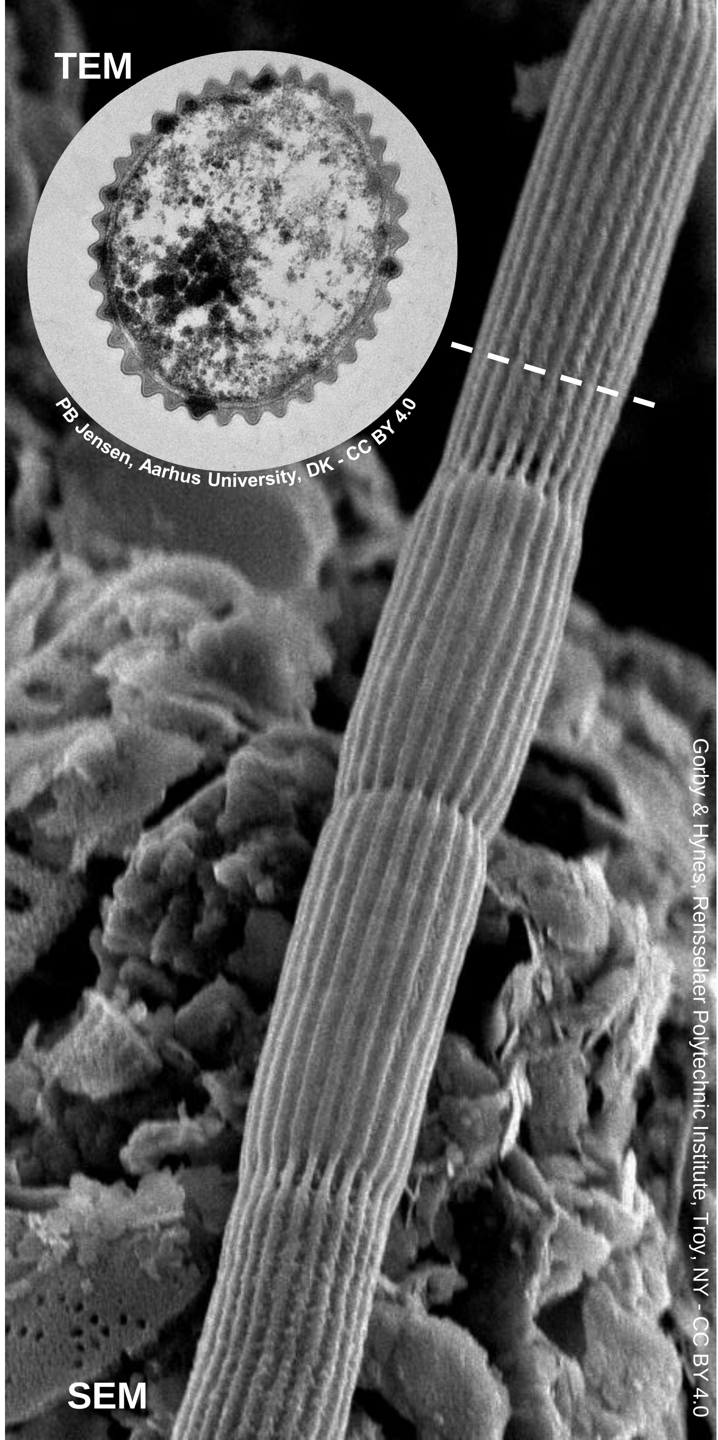
Candidatus Electronema

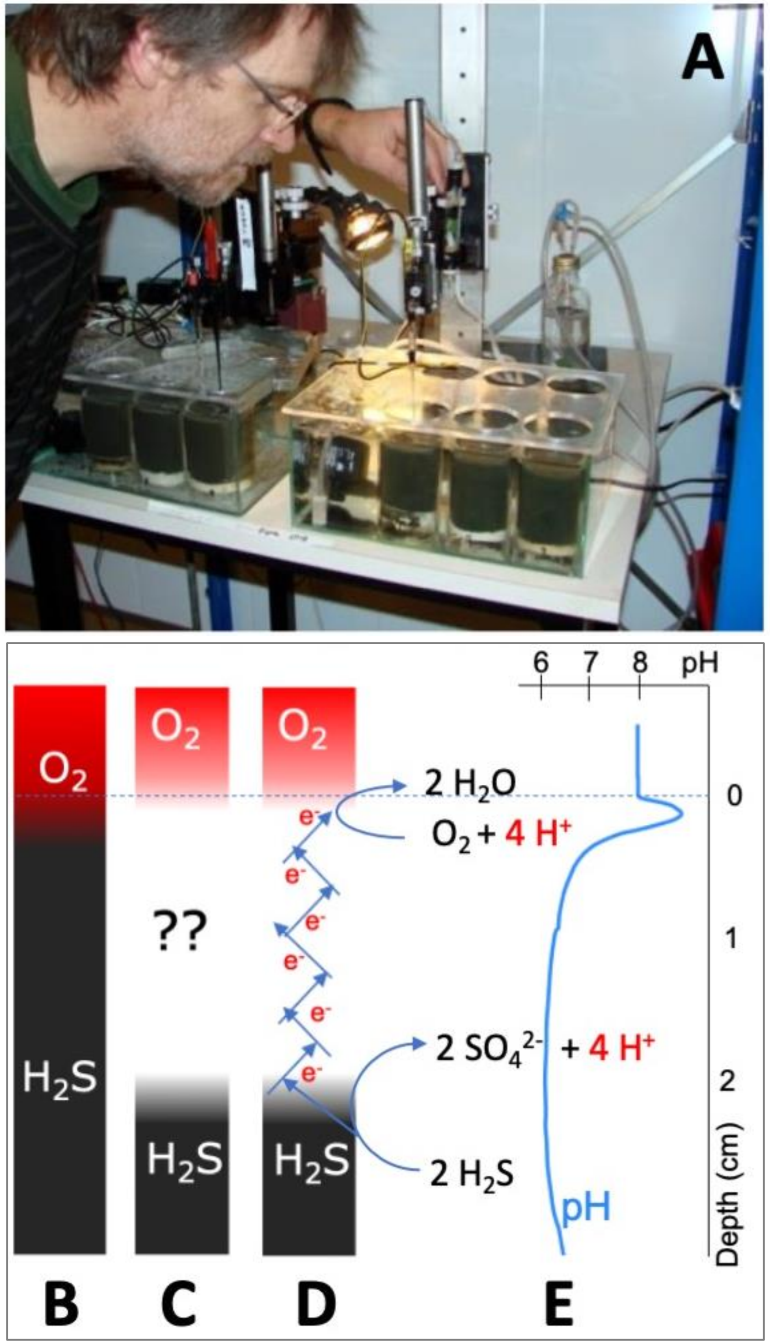




Cable bacteria…

- Occur worldwide in the top few centimeters of marine, coastal and freshwater sediments
- Belong to the *Desulfobacterota*
- Form centimeter-long chains of cells across the oxic-anoxic transition zone in sediments
- Conduct electricity over centimeter-long distances
- Connect oxidation of sulfide in deeper anoxic sediment layers with reduction of oxygen close to surface areas…
- …thereby enabling flow of electrons between different sediment layers
- Are an example for multicellular microorganisms, practising division of labor within the chain of cells
- Have potential for applications in environmental remediation and in bioelectronics





Despite their ubiquitous distribution and formidable size (chains of cells can reach a length of 8 cm!), cable bacteria have been discovered only recently

It was a Danish team of scientists that got on track - by measuring an unusual distribution of O_2, H_2S und pH in the Baltic Sea sediment of the Aarhus bay.

In 2010, Lars Peter Nielsen (Fig. A) and co-workers postulated a possible explanation for the observed anomalies: microorganisms capable of conducting electricity („long-distance electron transport“), which connects spatially distant redox reactions and allows energy gain for the microbes (Fig. B-E).

2010

Vol 463 | 25 February 2010 | doi:10.1038/nature08790 nature

LETTERS

Electric currents couple spatially separated biogeochemical processes in marine sediment

Lars Peter Nielsen[1], Nils Risgaard-Petersen[2], Henrik Fossing[3], Peter Bondo Christensen[3] & Mikio Sayama[4]

Inspired by this idea, in 2012 a team led by Andreas Schramm, Nils Risgaard-Petersen and Lars Peter Nielsen discovered the organisms responsible for this process: long threads consisting of thousands of bacterial cells.

ARTICLE **2012**

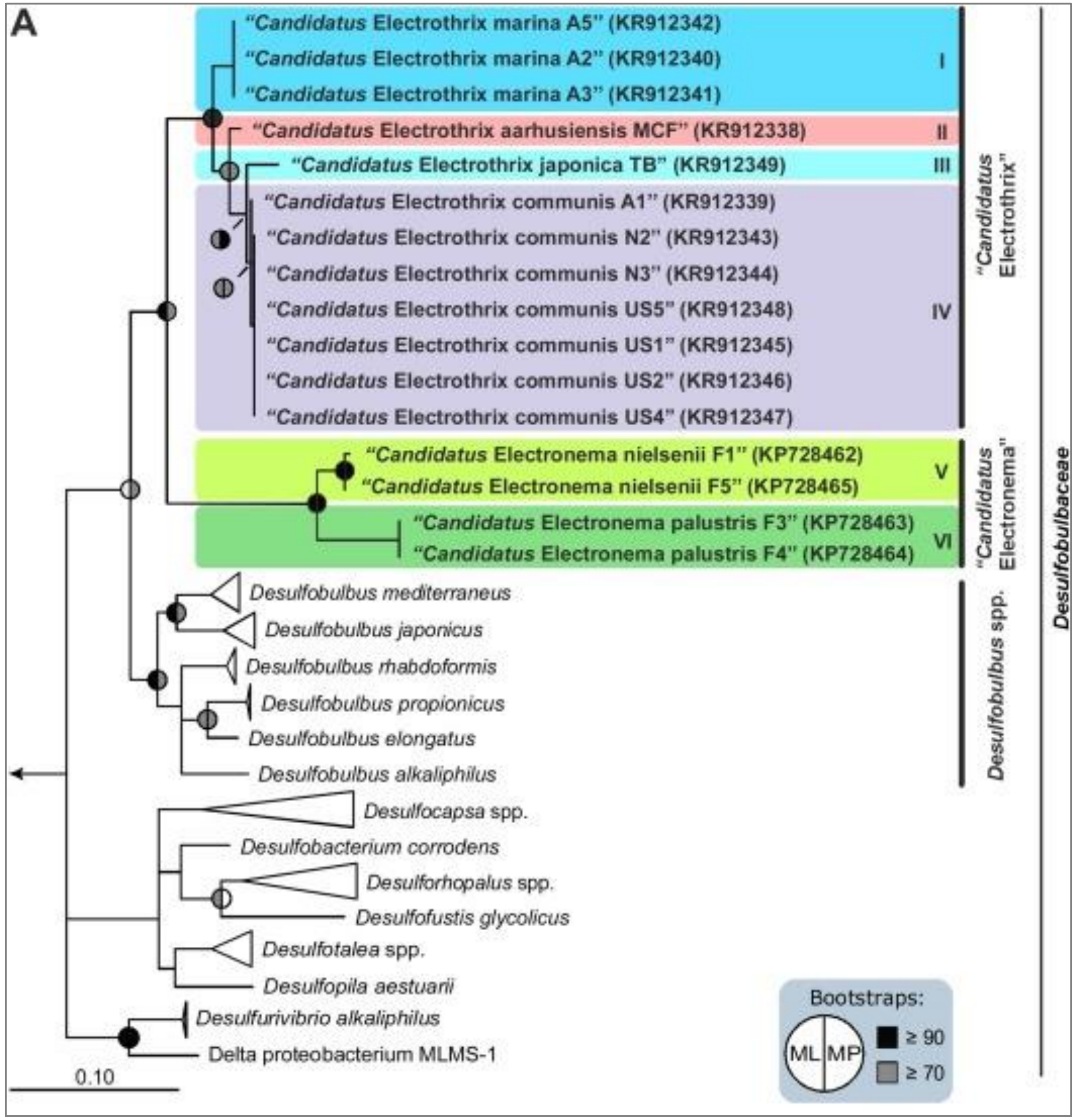
nature doi:10.1038/nature11586

Filamentous bacteria transport electrons over centimetre distances

Christian Pfeffer[1], Steffen Larsen[2], Jie Song[3], Mingdong Dong[3], Flemming Besenbacher[3], Rikke Louise Meyer[2,3], Kasper Urup Kjeldsen[1], Lars Schreiber[1], Yuri A. Gorby[4], Mohamed Y. El-Naggar[5], Kar Man Leung[4,5], Andreas Schramm[1,2], Nils Risgaard-Petersen[1] & Lars Peter Nielsen[1,2]

Oxygen consumption in marine sediments is often coupled to the oxidation of sulphide generated by degradation of organic matter in deeper, oxygen-free layers. Geochemical observations have shown that this coupling can be mediated by electric currents carried by unidentified electron transporters across centimetre-wide zones. Here we present evidence that the native conductors are long, filamentous bacteria. They abounded in sediment zones with electric currents and along their length they contained strings with distinct properties in accordance with a function as electron transporters. Living, electrical cables add a new dimension to the understanding of interactions in nature and may find use in technology development.

Ca. Electronema: the first „unculturable“ microbe of the year



Trojan et al., Syst. Appl. Microbiol. 39: 297-306 (2016) 126236 (CC-BY-NC-ND)

So far, cable bacteria cannot be isolated in classical pure culture.

Therefore, they have been described based on genomic, morphological and functional traits as „***Candidatus***“-species in 2016.

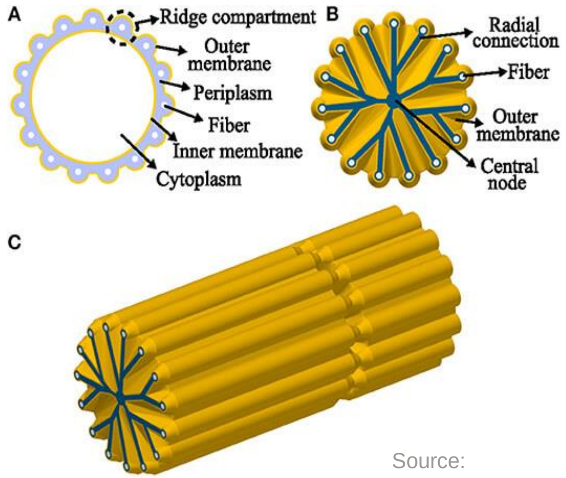
Representatives belong to the two sister genera *Ca.* Electrothrix and *Ca.* Electronema (family *Desulfobulbaceae)*

2021: first stabile enrichment of a cable bacteria species:

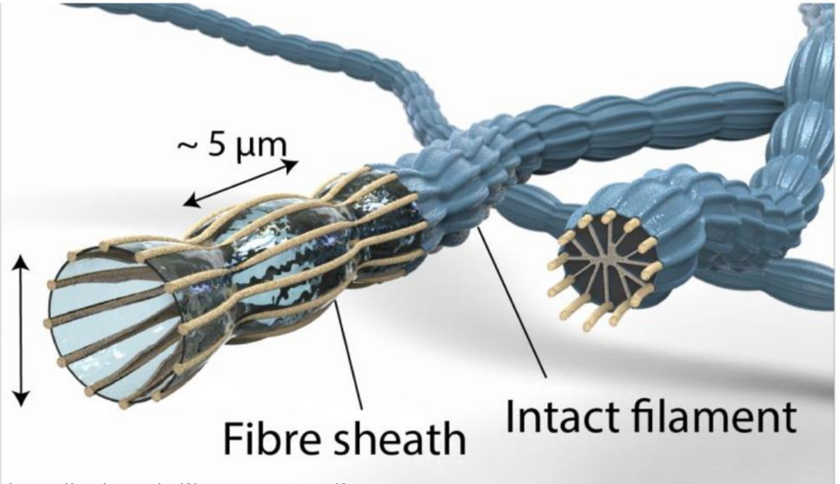
***Ca*. Electronema** aureum, microbe of the year 2024

Thorup et al., Syst. Appl. Microbiol. 44 (2021) 126236

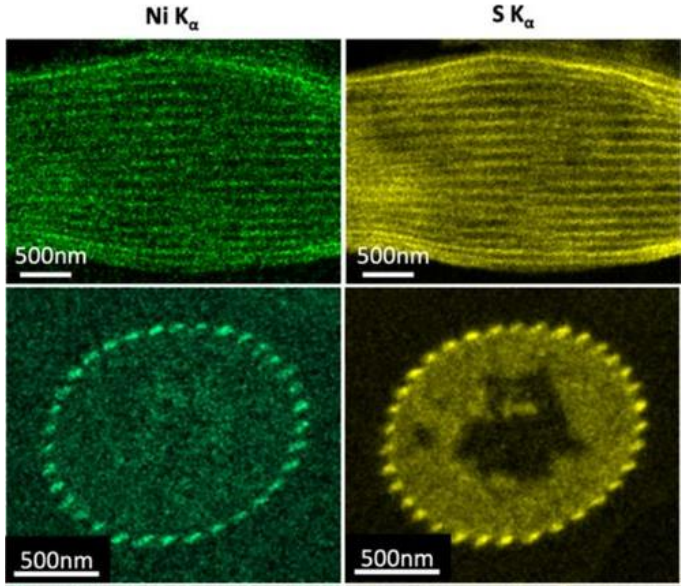
Unique cell biology: periplasmic „power lines“ and novel Ni-S-cofactors



Source: Wikimedia.



https://arxiv.org/pdf/1912.06224.pdf



STEM-EDX detection of Ni and S in the wire of a *Ca.* Electronema aureum cell (top) and cross-section (bottom). Digel et al, bioRxiv 2023, https://doi.org/10.1101/2023.05.24.541955

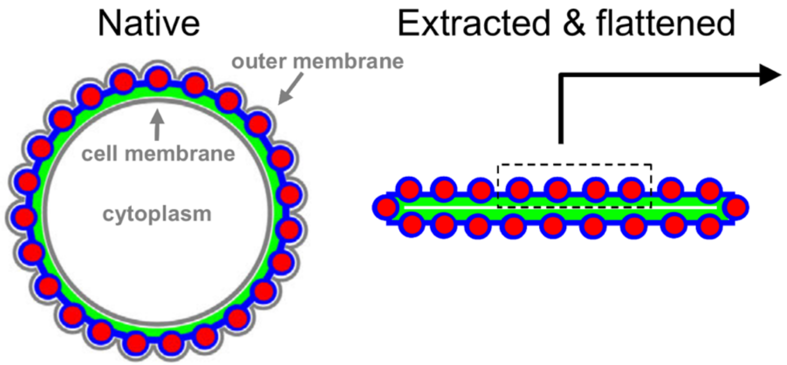
„Cable“ like morphology: shared outer membrane + continuous fiber-like periplasmic structures consisting of nickel-sulfur-proteins and polysaccharides

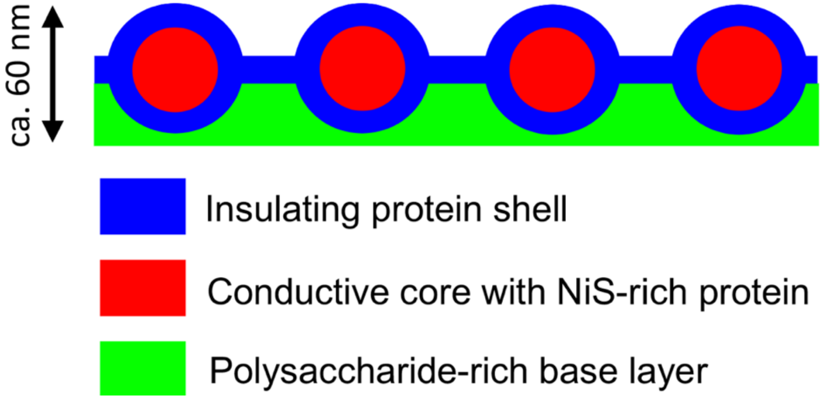
- **Electric current density of 10^6 A m^{-2}: similar to a copper cable!**
- **Conductivity > 20 S cm^{-1}: new record for a biological polymer!**

NATURE COMMUNICATIONS | (2021)

Efficient long-range conduction in cable bacteria through nickel protein wires

Henricus T. S. Boschker[1,2], Perran L. M. Cook[3], Lubos Polerecky[4], Raghavendran Thiruvallur Eachambadi[5], Helena Lozano[6], Silvia Hidalgo-Martinez[2], Dmitry Khalenkow[7], Valentina Spampinato[8], Nathalie Claes[9], Paromita Kundu[9], Da Wang[9], Sara Bals[9], Karina K. Sand[10], Francesca Cavezza[11], Tom Hauffman[11], Jesper Tataru Bjerg[2,12,13], Andre G. Skirtach[7], Kamila Kochan[3], Merrilyn McKee[3], Bayden Wood[3], Diana Bedolla[14], Alessandra Gianoncelli[14], Nicole M. J. Geerlings[4], Nani Van Gerven[15,16], Han Remaut[15,16], Jeanine S. Geelhoed[2], Ruben Millan-Solsona[6,17], Laura Fumagalli[18,19], Lars Peter Nielsen[12,13], Alexis Franquet[8], Jean V. Manca[5], Gabriel Gomila[6,17] & Filip J. R. Meysman[1,2]



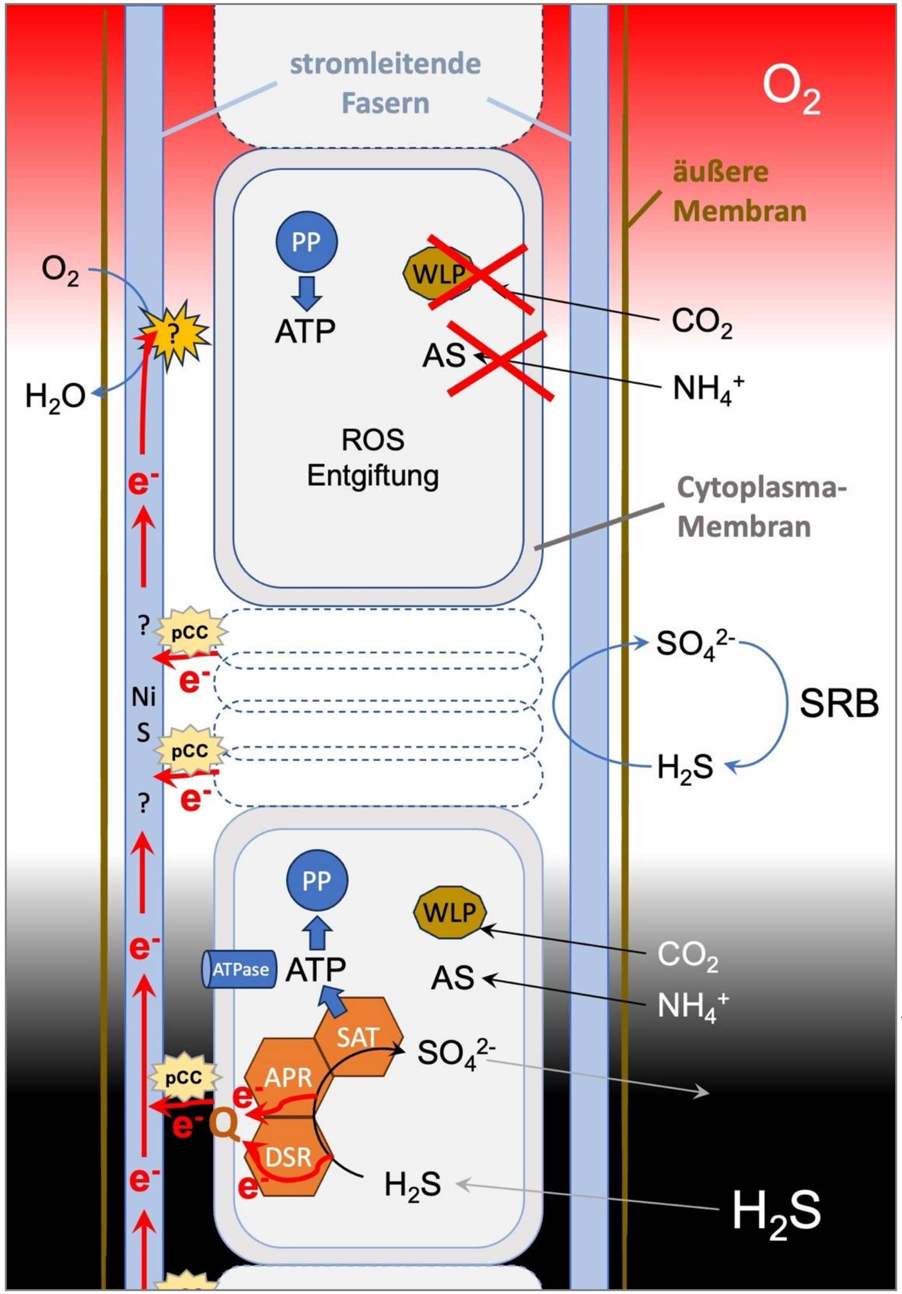


Evolution and Metabolism of Cable Bacteria

Insights through studies on enrichments of *Ca*. Electronema-bacteria and analysis of their genome sequences:

- Descendants of sulfate reducing bacteria, reverse the path of dissimilatory sulfate reduction (DSR) for sulfide oxidation
- **Division of labor:**
  - >80% of the cells in the filament provide electrons through oxidation of sulfide, only few cells are in contact with O_2 and consume electrons
  - Energy conservation, cell division and assimilation of C & N occurs only in anoxic cells

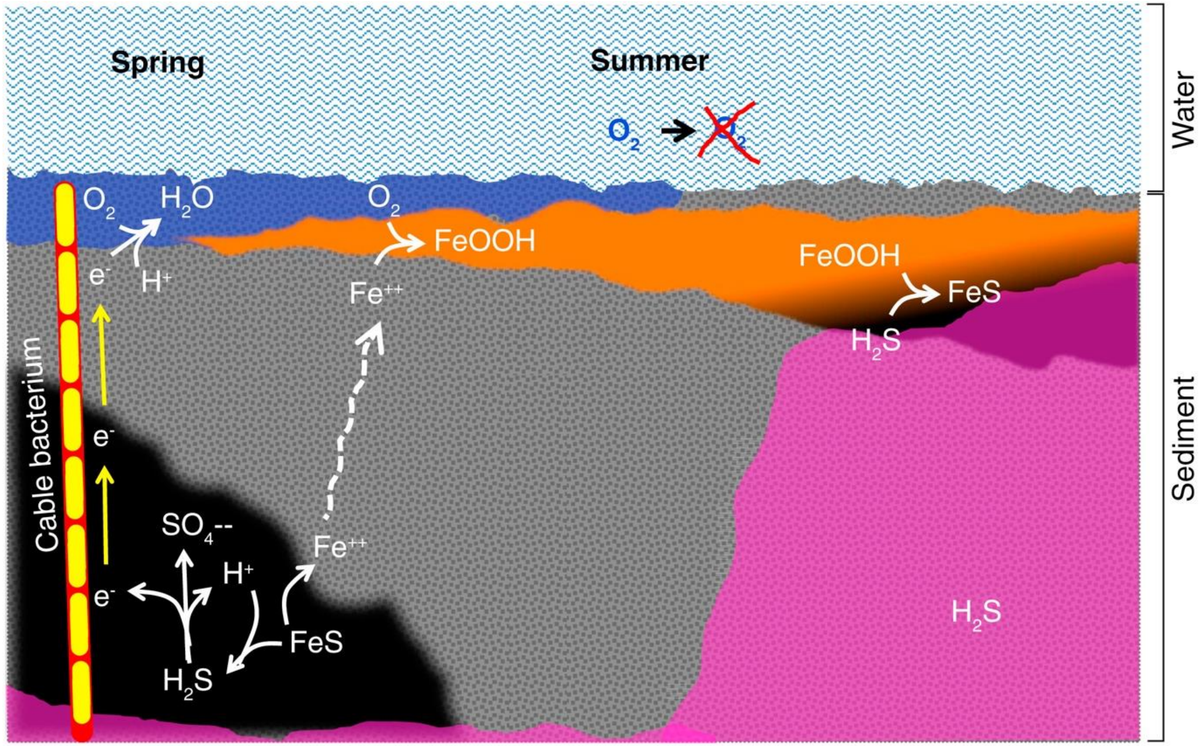
Kjeldsen et al. PNAS 2019, Geelhoed et al. PNAS 2020



Metabolism of *Ca.* Electronema in an oxygen-sulfide gradient (O_2 red - H_2S black).
An oxic cell (above) and an anoxic cell (below) are shown, in between there are hundreds to thousands additional, mostly anoxic cells (indicated by dashed lines).

PP: polyphosphat
WLP: Wood-Ljungdahl-Pathway
AS: amino acids
ROS: reactive oxygen species
pCC: periplasmic cytochromes
Q: quinone pool
DSR, APR, SAT: complexes of the DSR-path
SRB: sulfate reducing bacteria (responsible for continuous sulfide supply to cable bacteria in suboxic sediments)

Cable Bacteria as „ecosystem engineers“: effects on C, N, S, P, Fe and trace metals

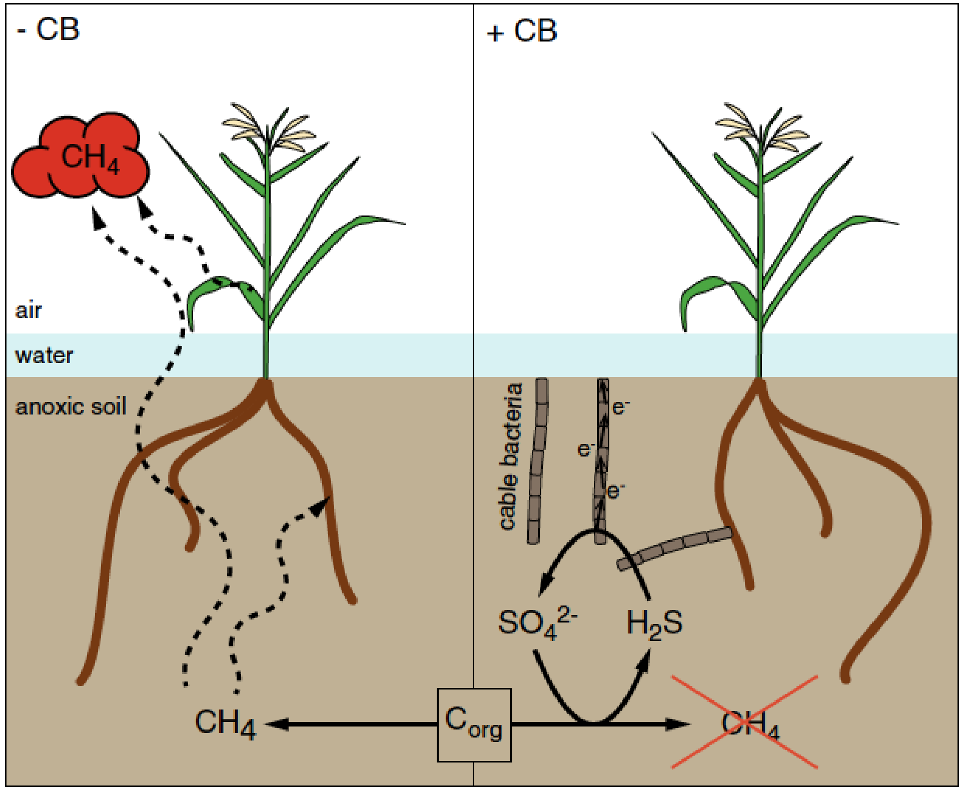


Current Biology

Activities of cable bacteria lead to oxidation of H_2S and to dissolution of FeS; released Fe^{2+} migrates upwards in the electric field and precipitates as Fe-oxide which can act as shield against H_2S in case the aquatic sediment turns anoxic during seasonal changes.

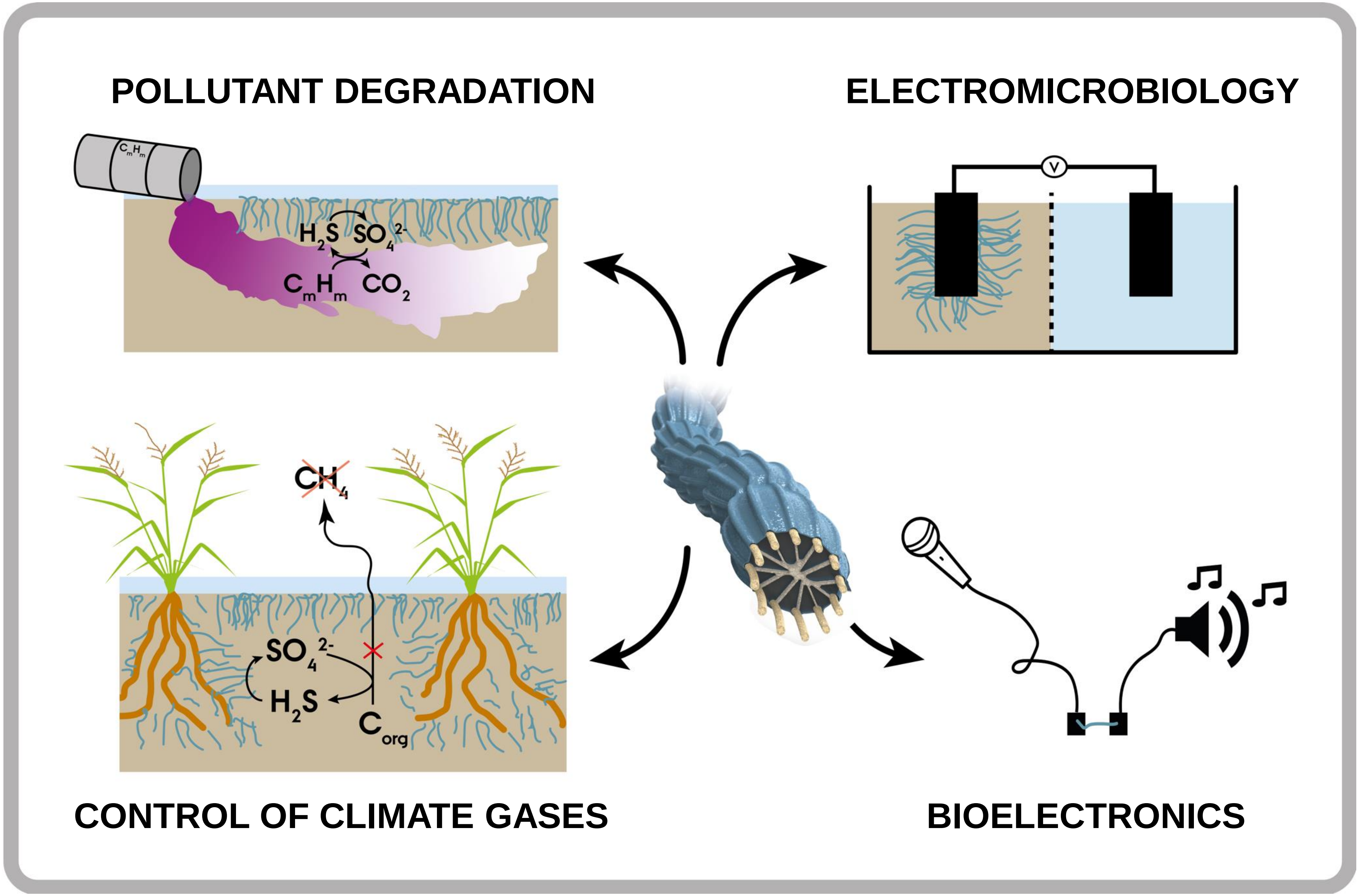
Nielsen, L.P. Current Biology (2016) https://doi.org/10.1016/j.cub.2015.11.014

Activities of cable bacteria stimulate sulfate reducing bacteria, which in turn deprive competing methanogenic microorganisms of nutrients (electrons). This can suppress the release of the climate gas methane, e.g., in rice paddies. On the other hand, it can also accelerate degradation of organic material and pollutants, e.g., oil contaminations.



Scholz et al., Nat. Comm. (2020) https://doi.org/10.1038/s41467-020-15812-w

Potential Applications of Cable Bacteria



Vincent Scholz & Tillmann Lüders, BIOspektrum 1/24

Springer Spektrum www.biospektrum.de

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Das Magazin für Biowissenschaften

Kabelbakterium Electronema – Mikrobe des Jahres 2024

01

Februar 2024
30. Jahrgang

- RNA-Forschung
- Innovative Kulturmethoden
- Special: Genomics & Genetic Engineering

Kabelbakterium Electronema – Mikrobe des Jahres 2024

Lebende Stromkabel mit überraschender Arbeitsteilung

ANDREAS SCHRAMM
SEKTION FÜR MIKROBIOLOGIE & CENTER FOR ELECTROMICROBIOLOGY, UNIVERSITÄT AARHUS, DÄNEMARK

Centimeter-long, multicellular bacteria that form electric wires as good as semiconductors? That split their energy-conserving redox reaction into two half reactions, performed in distant parts of their filamentous "body", so some cells "eat" while other cells "breathe"? Sounds like science fiction, doesn't it? And yet that's what "cable bacteria" do. Here's their story, from their surprise discovery 12 years ago to the selection of the candidate genus Electronema as Microbe of the Year 2024.

DOI: 10.1007/s12268-024-2077-1

konnten sie ebenfalls ausschließen. Anstatt die rätselhaften Daten als Messfehler abzutun, kam Lars Peter Nielsen auf eine radikale Erklärung: eine elektrische Verbindung zwischen Sulfidoxidation in der Tiefe und Sauerstoffreduktion an der Sedimentoberfläche (**Abb. 1**). Dabei würden Protonen in der Tiefe produziert und an der Oberfläche verbraucht – und tatsächlich war diese vorhergesagte pH-Anomalie im Sediment messbar und bestätigte die elektrischen Ströme im Meeresboden [1]. Nur welche Mikroorganismen daran beteiligt waren, blieb völlig unklar, da alle bekannten „elektrischen" Bakterien Elektronen maximal ein paar Mikrometer extrazellulär transportieren konnten. nicht aber mehrere Zentimeter.

Kabelbakterium Electronema – Mikrobe des Jahres 2024

Anwendungen der Kabelbakterien in der Umwelt- und Biotechnologie

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[2] LEHRSTUHL FÜR ÖKOLOGISCHE MIKROBIOLOGIE, UNIVERSITÄT BAYREUTH

Cable bacteria are living electric wires, exerting remarkable effects on their surroundings. Despite still refusing pure culture isolation, their biological conductivity and their impact on aquatic sediments give rise to interesting application prospects in environmental and bio-engineering, including bioremediation, the mitigation of greenhouse gas emissions, and bioelectronics. Here, we summarize how research is currently striving to realize the very versatile application potential of these fascinating bacteria.

DOI: 10.1007/s12268-024-2076-2

ponenten einer weiterführenden bio- und elektrochemischen Untersuchung zuführen. Die (immer noch) nicht in Labor- oder gar großtechnischer Kultur befindliche Mikrobe des Jahres kommt – anders als ihre Vorgänger – natürlich noch nicht großtechnisch in der Biotechnologie oder Lebensmittelindustrie zum Einsatz. Dennoch sind die Kabelbakterien seit ihrer Entdeckung [2] nicht nur mikrobiologisch und biogeochemisch eine Sensation; ihre Erforschung war stets und ist zunehmend ebenso motiviert durch äußerst spannende Perspektiven auf mögliche Anwendungen (**Abb. 1**). Diese haben sogar bereits zur Gewährung von Patenten auf ihre elektrisch leitfähigen Strukturen geführt [3, 4]. Die Anwendungs-

MIKROBIOLOGIE

Kabelbakterien – Leben in Himmel und Hölle

Mikroben vermögen eine Unzahl verschiedener Verbindungen bis hin zu kleinsten Metallionen mit der Umwelt auszutauschen. Seit einigen Jahren weiß man, dass Bakterien selbst Elektronen unmittelbar auf Festkörper und andere Zellen übertragen können. Diese Fähigkeit haben Kabelbakterien perfektioniert – sie leiten Strom über weite Strecken und schaffen damit eine direkte Verbindung zwischen oxischen und anoxischen Zonen im Sediment von Gewässern.

Harald Engelhardt
BIUZ, 2020

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