

BIOGRAPHICAL SKETCH

NAME: Malvankar, Nikhil

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POSITION TITLE: Associate Professor

EDUCATION/TRAINING

INSTITUTION AND LOCATION	DEGREE	END DATE	FIELD OF STUDY
Indian Institute of Technology, Mumbai	MS	05/2003	Physics
University of Massachusetts, Amherst	PhD	08/2010	Biophysics
University of Massachusetts, Amherst	Postdoctoral Fellow	06/2015	Microbiology

A. Personal Statement

My research focuses on developing single-cell imaging and on controlling cellular metabolism via protein nanowires. Nanowires are hair-like filaments that eliminate excess electrons produced during metabolism by diverse, environmentally- and clinically-important bacteria and archaea via extracellular electron transfer (EET) to other cells or materials. EET allows cells to grow & survive in harsh environments, such as extreme pH, temperature, pressure, or radiation. Therefore, controlling cell pathophysiology and ecology via EET can mitigate climate change (via lowering methane), pollution (via bioremediation), dysbiosis & diseases.

Despite its importance, the mechanism of long-range ($> 10 \mu\text{m}$) EET was unknown for ~40 years. EET via surface-displayed Type-IV pili (T4P) serving as “nanowires” is hypothesized since 2002, primarily based on genetic studies. My measurements found that surface-displayed filaments confer electrical conductivity to living biofilms rather than monomeric cytochromes (*Nature Nano*’11 & ’14, *Science*’10). But the bioenergetic need for nanowires, their exact composition, and the mechanism of electron flow that could explain EET was unclear.

Our *in situ* structural and functional imaging of metabolism discovered how microbes build & use nanowires for EET (*Nature*’21) (*Cell*’19) by addressing the following: **(1)** How do nanowires enable cell growth? **(2)** What are nanowires made of? and **(3)** How do cells move electrons through nanowires from the cytoplasm to extracellular electron acceptors? **(4)** How can we modulate nanowire conductivity to control cell growth and host colonization?

Our **long-term vision** is to monitor and control cells and enzymes via protein nanowires through the following:

- **Fundamental studies** to elucidate how diverse cells assemble and use various types of nanowires.
- **Repair environmental health** using cellular communities through nanowire-mediated electron exchange.
- **Restore human health** by controlling the growth of cells & neurons by targeting nanowire-mediated EET.
- **Control enzyme catalysis** by electronically imaging & controlling the enzymes bound to protein nanowires.

B. Positions, Scientific Appointments, and Honors

Asst. Professor (7/15-6/22) Molecular Biophysics & Biochemistry, Microbial Sciences Institute, Yale University
Assoc. Professor (7/22-).

2024	Burroughs Wellcome Fund – Climate Change & Human Health Award
2023	Human Frontier Science Program Award
2021-2026	Camille Dreyfus Teacher-Scholar Award
2021-2023	Blavatnik Innovation Award. Highlighted in Yale Magazine (Cover, Inside Cover)
2018-2023	NSF CAREER Award
2017-2022	NIH Director’s New Innovator Award
2017-2020	Hartwell Foundation Individual Biomedical Research Award
2017-2019	Charles H. Hood Foundation Child Health Research Award
2016-2017	Helmsley Interdisciplinary Research Fellowships, Cold Spring Harbor Laboratory
2014-2019	Burroughs Wellcome Fund Career Award at Scientific Interfaces
2009	Rao Biophysics Scholarship, UMass, Amherst
2008	First Prize, Innovation Challenge Elevator Pitch and Business Plan Competition, UMass, Amherst
2008	Entrepreneurship Fellowship, University of Massachusetts, Amherst
2004	Graduate Fellowship, American Alumni Association, India

1. **Electrogenetic control of microbial growth by stimulating nanowire expression using E-fields.**

The ability to monitor and control the growth and colonization of microbes deep inside the Earth and within human cells is central to understanding primary microbial function in their native environments, with various applications. To achieve this, **we are studying proteins that enable the imaging and control of microbial growth and colonization using electrons**. Our discovery enables this work, which shows that diverse microbes use chains of heme or aromatic moieties to export electrons to partner or host cells. This allows microbes to switch their metabolism to respiration and promote growth and colonization in the absence of oxygen or other soluble electron acceptors. We found that microbes use intracellular pili as a switch to secrete nanowires and overexpress nanowire genes by sensing natural electric fields, allowing electronic control of gene expression.

Together, electron-conducting proteins and electrogenetics are the **electronic analogs of GFP and optogenetics**. **We recently reported the first electrogenetic control of biofilm growth by demonstrating that it is possible to stimulate the expression of nanowire genes deep inside biofilms using an electric field** (*Nature Chem. Bio* '20). This work followed our earlier paper (*Cell*'19), which showed that bacteria overexpress nanowires when grown in an external electric field. These bacterial nanowires conduct electrons at unprecedented, ultrafast (<200 fs) rates over distances 10,000 times the size of a microbe.

Using multimodal functional imaging at the nanoscale that my lab developed, we discovered these nanowires' identity and structure. Remarkably, we showed that despite being made of proteins, nanowires can withstand and function in highly acidic environments where most proteins break down - a **unique opportunity to develop novel sensors and highly resilient materials**. The strength and conductivity of these nanowires, along with bacteria's ability to repair themselves, will help create durable, self-healing electronics composed of living cells.

As this area of research is in its infancy, many of our advancements are made possible by the new methods we develop. For example, the studies described above (*Nature Chem. Bio*'20) also established a **new atomic force microscopy (AFM)-based multimodal imaging** to correlate protein structures with electrical and mechanical properties in response to environmental changes, such as pH and redox potential. Using this platform, we found that the electron-transfer rate in nanowires depends on the environment; it is 100 times faster at lower pH or higher pressure, suggesting a possible path to engineer more conductive protein nanowires.

Furthermore, methodological innovation has been a cornerstone of my lab, as the availability of new methods has enabled us to make unexpected discoveries and challenge thinking in the field. For example, our process for **growing biofilms in electric fields** (*Current Protocols*'16) allowed the first electrogenetic control of biofilm growth (*Nature Chem. Bio*'20). Also, it enabled us to make the initial discovery that bacterial biofilms conduct electricity (*Nature Nano*'11), as before my work, biofilms were thought to be electronically non-conducting.

2. **Discovery of nanowires, identification of their structures, functions, and assembly mechanisms.**

As described above, my lab led the effort to solve the first structure of protein nanowires and discovered an unprecedented polymer of cytochrome OmcS (*Cell*'19). My lab showed that these are the same filaments previously thought to be pili since 2002 and reported the first example of protein 'sequencing' by imaging, enabling the identification of difficult-to-purify proteins by combining cryo-EM, AFM, and mass spectrometry. Now, many labs use this bottom-up structural proteomics method, which is **cited > 600 times in 7 years**.

This paper has greatly impacted the field. It turned Electromicrobiology from a field focused for ~20 years on Type-IV pili or monomeric cytochromes to one focused on polymeric cytochromes that mediate electron transfer from the bacterial periplasm to extracellular acceptors. This insight has guided subsequent work from our lab and many others to understand the molecular mechanisms of microbial respiration via extracellular electron transfer across diverse species and environments. Furthermore, this shift in focus led to the discovery of other cytochromes polymerizing into conductive filaments, thereby establishing a new class of nanowires. The Malvankar lab subsequently found that the cytochromes OmcZ, ExtA, and MacA polymerize into conductive filaments under different growth conditions and perform distinct functions. Three other labs have together found OmcE filaments when omcS was mutated and couldn't form filaments. Based on the structures of two archaeal cytochrome filaments that show a heme arrangement akin to that of OmcE, it has been hypothesized that diverse microbial species could transfer electrons via cytochrome nanowires.

Despite our discovery of high conductivity in *G. sulfurreducens* OmcZ nanowires (*Nature Chem Bio*'20), the molecular mechanism of conductivity was unclear. Our next work established the **first method to obtain highly purified nanowires** using OmcZ (*Nature Micro*'23). Here, we achieved the **first synthetic assembly of nanowires *in vitro***, at high yield and purity. These studies explained how bacteria make nanowires on demand using an environmentally controlled, protease-mediated switch. We reported the highest resolution cryo-EM structure of OmcZ. It revealed the presence of highly linear, closely stacked hemes, in contrast to those in OmcS nanowires. We showed that this unique arrangement of hemes leads to strong excitonic coupling and could explain why OmcZ nanowires exhibit the **highest conductivity** known to date in natural biomolecules.

We also showed that OmcZ nanowires allow bacteria to produce the highest electrical power reported to date. We explained the physiological **role** of nanowires in bacterial survival against extreme environments and their **ecological role** in forming microbial communities in biofilms. This work also demonstrated the **ultrastability of nanowires in highly acidic, protein-denaturing environments, showing that bacteria respond to such conditions by altering** nanowire organization—these studies also present **design principles** for rationally engineering the assembly and conductivity of cytochrome nanowires.

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Furthermore, we found that both OmcS (*Cell Chem Bio*'25) and OmcZ (*Nature Micro*'23) **nanowire assembly machinery is widespread** in both methane-producing and methane-consuming microbes. Remarkably, methanogens release half of the atmospheric methane, whereas methane-consuming microbes that harbor nanowire genes consume 80% of the methane flux from the ocean sediments. With the Banfield lab (UC Berkeley), we identified the OmcZ gene cluster in *Methanoperedens* and its giant (>1 Mb) extrachromosomal elements, called Borgen, hypothesized to increase methane-consuming capacity. In this work, our lab discovered the *omcZ* gene cluster in these samples and showed its potential to form nanowires. Several other groups confirmed our finding that electricity-producing archaea overexpress OmcZ homologs. This finding of OmcZ-like nanowires in archaea suggests an intriguing possibility that nanowires play a role in regulating atmospheric methane levels and, thus, global climate. Using samples from Welte (Netherlands) and Wagner (Germany), we solved the structures of the filaments produced by these microbes. These filaments show closer heme spacing than OmcZ nanowires, suggesting it could be the most conductive protein found to date.

3. Discovery of intracellular pili involved in cytochrome secretion, and engineering pili as nanowires.

The involvement of filaments in microbial electron export was first reported over two decades ago. These structures were referred to as type 4 pili in thousands of papers. My lab combined structural, functional, and localization studies to establish that these pili cannot function as nanowires and instead function as **pseudopili-like pistons to secrete polymerized cytochromes** (*Nature*'21). Furthermore, we found that instead of being extracellular as widely believed, they remain intracellular and display **unique heterodimeric pili**.

Our subsequent detailed genetic, biochemical, structural, and imaging studies of transfer with *pilA* mutants further established this discovery. These studies showed a direct relationship between *pilA* mutants and the secretion of OmcS and OmcZ nanowires. Furthermore, electron transfer imaging confirmed that cells transfer electrons via cytochrome nanowires, not pili. We also combined genetic studies with cryo-electron tomography in collaboration with Liu's lab (Yale). This further confirmed that *G. sulfurreducens* pili are not surface-displayed like Type-IV pili (T4P) and thus cannot function as nanowires. We discovered that these pili exhibit a novel secretion system that combines T4P and Type-II secretion system components.

The discovery of *Geobacter* pili showing low conductivity and functioning akin to secretion pseudopili to translocate cytochrome nanowires has received pushback from Derek Lovley (UMass, Amherst), who proposed the pili hypothesis, and Malvankar lab's former postdoc, Matthew Guberman-Pfeffer, who is now working with Lovley lab. Their critiques have been addressed in prior reviews. Several other labs have also supported our work through multiple articles.

Over the past seven decades, numerous publications on protein conductivity have been published, and contact resistances have dominated measurements in all of them. Therefore, measuring the intrinsic conductivity of proteins by isolating the contribution of contact resistance has long been a major challenge in the field.

Our novel method enabled the **first measurement of intrinsic electron conductivity in proteins**, revealing high conductivity at physiologically relevant potentials in the absence of metal cofactors. Using these new principles, we introduced natural and non-natural aromatic residues in *E. coli* pili to confer high electron conductivity (*Nature Comm.*'22). These studies thus provide design principles in engineering electron conductivity in bacterial filaments and developing novel chassis to secrete nanowires on bacterial surfaces.

Although *G. sulfurreducens* pili are intracellular, the Malvankar lab has found that diverse pathogens use surface-displayed Type 4 pili for extracellular electron transfer, enabling switching metabolism to fast-growing respiration and host-cell colonization despite their low conductivity (*Nature Micro.* in revision). This is owing to highly conserved aromatic amino acids that serve as a novel electron escape route to avoid oxidative damage (*PNAS*'20). With the Eisenberg lab (UCLA)'s short peptides and structures and the Batista lab (Yale)'s computations, the Malvankar lab showed micrometer-long electron transfer through tyrosines due to a proton-rocking mechanism, whereby the energetics and proximity of the proton acceptor control electron transfer. We also introduced natural and non-natural aromatic residues into *E. coli* Type I pili, using click chemistry, to enhance conductivity by 100-fold. (*Nature Commun.*'22). The Malvankar lab members purified, imaged, modeled, and measured the conductivity of pili. The Isaacs and Batista labs (Yale) guided genetics and modeling, respectively.

4. Mechanism of electron transfer in nanowires - Light and cooling accelerate electron export.

We combined experiments with computations to establish that quantum effects confer extremely high conductivity to nanowires and living biofilms at ultrafast (~200 fs) rates over micrometer distances, a phenomenon not previously reported for natural biomolecules. This quantum control could be important because it may explain light- and temperature-activated (*Science Adv.*'22) control of cell growth and biofilm formation. To our knowledge, this is the first time such ultrafast electron transfer is observed in non-photosynthetic proteins.

This work elucidated the structural features and conditions that could increase conductivity. Transient absorption (TA) spectroscopy revealed ultrafast (~200 fs) electron transfer between nanowire hemes upon photoexcitation, enhancing electron density and mobility. Photoconductive atomic force microscopy showed a 100-fold increase in photocurrents in nanowires. Photocurrents respond rapidly (<100 ms) to the excitation and persist reversibly for hours. Furthermore, nanowires and biofilms showed that cooling accelerates electron transport by 300-fold (*Science Adv.*'22). These behaviours contrast with the commonly known hopping model for electron transfer.

Efforts led by the Malvankar lab's postdoc, Guberman-Pfeffer, to model the heme redox potential and conductivity of nanowires computationally yielded up to a million-fold lower conductivity than observed experimentally. This discrepancy is not due to variations in conductivity measurements, as multiple researchers in different labs have measured nanowire conductivity across various buffers and hydrations and found similar values. Measurements of fully-hydrated or air-dried OmcS nanowires (*Science Adv.*'22) showed identical structural features and conductivity to that measured in the Lovley lab, which we showed to be OmcS. Similarly, the Malvankar lab's conductivity measurements of air-dried OmcZ nanowires (*Nature Chem. Bio.*'20) showed structural features and conductivity similar to those measured in the Lovley lab, which we showed to be OmcZ.

This discrepancy between measurements and computations could be due to the nanowires' conformation changing upon binding to electron acceptors. Our simulations showed a large structural changes in OmcS upon binding to the gold electrode, altering the heme redox potentials and enhancing conductivity by 100-fold.

High nanowire conductivity also raises the possibility of a fundamentally different mechanism. Our and other groups' computations suggest the role of quantum effects in OmcS/Z nanowires (*JPCL*'25). We have also measured these effects directly in individual OmcS nanowires. In this work, we found that nanowires show 30,000-fold higher magnetoconductance with (>99%) spin polarization at physiological B-fields (<0.5 Tesla) and potentials (<0.1 V), with the metal-like temperature dependence of conductivity. Surprisingly, we found that substituting iron heme with zinc did not change nanowire conductivity. Therefore, the classical iron-to-iron hopping model does not apply to these nanowires. Quantum computations by the Anantram group (UW Seattle) could partly explain the high spin polarization in nanowire magnetoconductance. The substitution of Fe with Zn in nanowires could enable efficient exciton transport over micrometer distances, which is critical for efficient solar energy conversion and energy storage technologies as well as biomedical imaging applications.

Protein nanowires could provide non-photosynthetic protein analogs for flexible testbeds for studies of quantum processes in which the monomer structure and nanowire assembly can be controlled at the atomic and mesoscales. In contrast to most synthetic quantum materials that require very low temperatures to function, these proteins could have evolved to optimize ultrafast electron transfer in aqueous environments at physiological temperatures. Understanding how to optimize systems' electron transfer may have implications for designing protein nanowire-based quantum sensors and developing new quantum computing applications.

Our efforts to computationally model the heme redox potential and conductivity of nanowires yielded up to a billion-fold lower conductivity than observed experimentally, illustrating that existing computational models based on the electron-hopping assumption fail to capture electron transfer in biological nanowires. This raises the possibility that biological nanowires employ a fundamentally different, currently unknown mechanism. Thus, existing models predict the same conductivity for all nanowires with computed timescales for heme-to-heme electron transfers (100 ns), million-fold lower than that measured using transient absorption spectroscopy (*Nature Commun.*'22) and conductivity for fully hydrated or air-dried nanowires (*Science Adv.*'22).

We are now directly measuring the role of electron delocalization and spin polarization in nanowire conductivity. Our work will advance the basic biological and physical understanding of nanowires and have a major impact, eventually enabling us to predict and control the microbial electron export to transport and store energy.

5. Quantitative imaging of electron export correlated with protein structure and mechanical properties

Beyond conceptual innovations in protein nanowires and a novel mechanism of electron transfer, my lab has also contributed to technological innovations in bottom-up proteomics using cryo-EM and mass spectrometry, and in imaging of electron export in individual nanowires.

Recently, we focused on developing nanoscopic imaging techniques to address major bottlenecks in the field by quantitatively visualizing electron export via protein nanowires in living, diverse, environmentally, and clinically important bacteria at the single-cell level. For example, a major challenge in studying how the metabolic switch from slow-growing fermentation to fast-growing respiration is the lack of methods to follow individual bacteria in their environmental context. We have found that niche dictates a metabolic switch by tracking bacterial electron export and niche behaviors at single-cell resolution over extended periods in real time.

Further findings indicate that electron transfer via nanowires modulates microbe-to-microbe direct interspecies electron transfer that promotes methane production, a critical step in global warming. We have reduced bacterial growth and adhesion by diverting metabolic electrons through small-molecule electron acceptors. Our expertise in the bacterial metabolic niche, therefore, uniquely positions us to address the causes of infection and the rising temperatures driven by elevated methane levels.

Our nanoscopic imaging methods are **widely applicable to diverse biological systems**. For example, my lab has applied these imaging methods to nanoscopic visualization of water binding to minerals (Sci. Adv. 2020). We revealed that, instead of growing layer by layer as previously thought, water growth starts near the edges before surface tension takes over, engulfing the surface and forming droplets. My lab's methodology allows us to visualize directly how bacteria export electrons via nanowires to minerals and electrodes.

Many labs are contacting us to apply these methods to systems as diverse as pathogenic biofilms, brain cells, and diabetic cells. For example, with the Yaldiz lab (UCSZ), we have applied these nanoscale imaging methods to help discover how pathogenic bacteria form biofilms using vesicle packaging proteins (*mBio*'24). With Kahle lab (Yale and Harvard Medical School), we also found how fluid-filled brain cavities (hydrocephalus) arise due to reduced stiffness of brain tissue (*Nature Neuro.*'22). Moreover, in collaboration with Kyriakides' lab (Yale Biomedical Engineering and Medical School), we showed that diabetes increases fibroblast stiffness, which is critical for wound healing (Sci. Reports 23). The Malvankar lab members performed all nanoscale imaging, biomechanical measurements, and data analysis for these studies.

Our lab is also collaborating with several other labs at Yale and beyond to perform similar electrical and mechanical measurements on diverse systems, ranging from zebrafish to neuronal cells. This paper establishes multimodal imaging of biosystems for the simultaneous analysis of structural, electrical, mechanical, and optical properties. For example, we later found that OmcS nanowire photoconductivity increased 100-fold.

D. Most Significant Publications *corresponding author #Lab member %Undergrad from lab, †equal contribution

Z. Summers, H. Fogarty, C. Leang, A. Franks, N. Malvankar and D. Lovley. Cooperative exchange of electrons within evolved syntrophic co-culture. **Science** 330,1413-1415 (2010). (> 1200 citations) Press: [EurekAlert!](#)

N. Malvankar et al. Tunable metallic-like conductivity in microbial nanowire networks. **Nature Nanotechnology** 6, 573 (2011). In 99 percentiles across all journals, (Ranked 1st in the journal) (> 1125 citations) News & Views,

Morita, M., N. Malvankar et al. Lovley Potential for direct interspecies electron transfer in methanogenic wastewater digester aggregates. **mBio** 2 (4), e00159-00111 (2011). (> 600 citations)

F Liu, A Rotaru, P Shrestha, N. Malvankar K Nevin, D Lovley. Promoting direct interspecies electron transfer with activated carbon. **Energy & Environmental Science**, 5, 8982 (2012). (> 1050 citations)

Chen..N. Malvankar..Lovley Interspecies electron transfer with biochar **Sci. Rep.** 4, 5019 (2014). (>850 citations)

N. Malvankar*, et al. D. Lovley. Visualization of charge propagation along individual pili using electrostatic force microscopy. **Nature Nanotechnology** 9, 1012-1017 (2014). (> 265 citations). Press: [EurekAlert!](#)

F. Wang[†] & Y. Gu^{†#}, et al. N. Malvankar*. Structure of microbial nanowires reveals stacked hemes that transport electrons over micrometers. **Cell** 177, 1-9 (2019). (Citations > 650) Press: [New York Times](#), [Protein Data Bank's Molecule of the Month](#), [Proteopedia](#), [Yale News](#); [EurekAlert!](#) [Nature Chemical Biology](#), [Yale Scientific](#),

SE Yalcin^{##}, J. O'Brien^{##}, et al. N. Malvankar* Electric field stimulates highly conductive microbial OmcZ nanowires. **Nature Chemical Biology** 16, 1136–1142 (2020). (Citations > 225) News & Views; Press: [PDB's Molecule of the Month](#). [Yale](#), [Scientific American](#), [Live Science](#), [Oxford Instruments](#), [Nature Portfolio](#), [NBC-SYFY](#), [Yale Today](#), [Yale News](#), [Behind the Paper American Society of Microbiology Podcast](#) (@ 16:30 min.)

C. Shipps[#], et al. N. Malvankar*. Intrinsic electronic conductivity in atomically resolved amyloid crystals reveals micrometer-long hole hopping via stacked tyrosines. **PNAS** 118, e2014139118 (2021).(Citations > 80)

Y. Gu^{##}, V. Srikanth^{##}, et al. N. Malvankar* Structure of *Geobacter* pili reveals secretory rather than nanowire behavior. **Nature** 597, 430 (2021) (Citations >230) [Tweeterial](#); [News & Views](#), [Structure Tour](#). Press: [Molecule of the Month](#). [Proteopedia](#), [EurekAlert!](#) [Live Science](#), ,Recommended by [Faculty Opinions](#) as *Exceptional*.

D. Shapiro[%], et al. N. Malvankar^{*†}. F. Isaacs^{*†} (co-last) Protein nanowires with tunable functionality & assembly using sequence-controlled synthesis **Nature Comm.** 13, 829 (2022). (Citations > 90) Press: [Yale Scientific](#).

P. Dahl[#], et al. N. Malvankar* A 300-fold conductivity increase in microbial nanowires due to temperature-induced restructuring of hydrogen bonding networks. **Science Adv.** 8, eabm7193 (2022). (Citations > 90). Press: [EurekAlert!](#), [International Center for Theoretical Physics](#), [Yale Scientific](#), Selected for Monthly [Yale News](#).

J. Neu^{##}, et al. N. Malvankar* Microbial biofilms as living photoconductors due to ultrafast electron transfer in cytochrome OmcS nanowires. **Nature Comm.** 13, 5150,1-12 (2022). (Citations > 75) Press: [Yale Today](#), [Interesting Engineering](#), [Yale Highlight](#), [Brookhaven National Lab Dutch New Scientist](#) (translation). [Interesting Engineering](#) (PDF). [Yale Today](#) and [Chemistry World](#). Selected as [Editor's Highlight](#) among the 50 best papers.

D. Phan...P. Dahl[#].. N. Malvankar .. K. Kahle* Impaired neurogenesis alters brain biomechanics in a neuroprogenitor-based genetic subtype of congenital hydrocephalus. **Nature Neuroscience** 25, 458–473 (2022). DOI: 10.1038/s41593-022-01043-3 (Citations > 100) Press: [News-1,2](#), [Boston Children's Hospital](#)

Y. Gu^{##}, et al N. Malvankar*. Structure of *Geobacter* cytochrome OmcZ identifies mechanism of nanowire assembly & conductivity. **Nature Microbiology** 8, 284–298 (2023) (Citations > 150) Press: [Protein Data Bank's Molecule of the Month](#). [EurekAlert!](#) [Scientias](#) (English). [Interesting engineering](#) (Full article). [Behind the Paper](#)

P. Portela^{##},et al N. Malvankar*. Widespread extracellular electron transfer pathways for charging microbial cytochrome nanowires via periplasmic cytochromes PpcABCDE **Nature Comm.** 15, 2434 (2024) Press: [EurekAlert!](#) [Yale Insights](#), [Popular Mechanics](#), [SciTechDaily](#), [Physics World](#). [Behind the Paper](#) (Citations > 90)

C. Shen[#], et al., N. Malvankar*. A widespread bacterial machinery assembles cytochrome omcS nanowires for extracellular electron transfer. **Cell Chem. Bio.** 32, 239-254.e7 (2025). [Cover](#). [Tweeterial](#) [Yale Highlight](#)

W. Parson*, P. Dahl[#] & N. Malvankar Coherent electron transfer in cytochrome nanowires at 300K. **Journal of Physical Chemistry Letters** 16, 8037–8045 (2025) [Cover](#). [Yale Highlight](#) [Yale Today](#) , [Bioengineer.org](#)