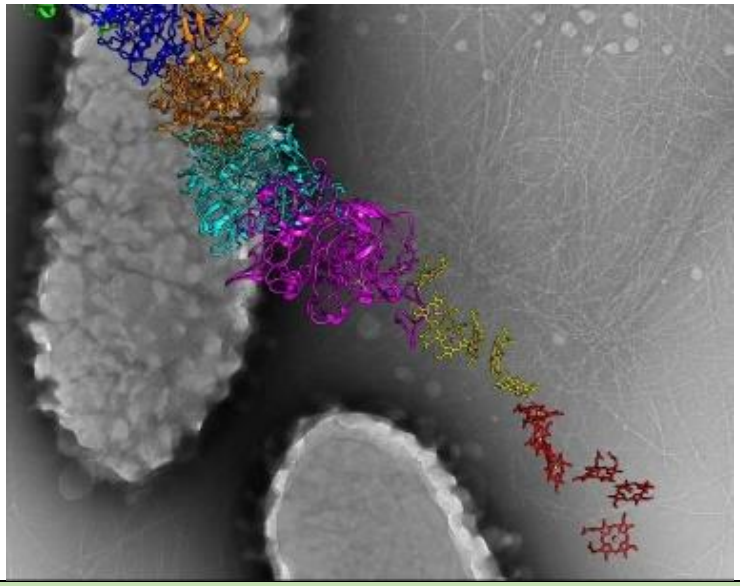
生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	細菌蛋白導電 (Bacterial Proteins Conduct Electricity)
生物系統 LIVING SYSTEM	土桿菌硫還原劑 (*Geobacter sulfurreducens*)
功能類別 FUNCTIONS	#調節細胞代謝　#改變電子傳遞 # Regulate Cellular Processes　# Modify Electron Transport
作用機制標題	微生物建構「奈米線」的外部蛋白網路，以輸出電子到細胞外 Microbes build external protein networks of "nanowires" to export electrons outside their cell walls.
生物系統/作用機制示意圖 (確認版權、註明出處；畫質)	

作用機制摘要說明 (SUMMARY OF FUNCTIONING MECHANISMS)

為了獲得能量以生存和成長，有些細菌建立了比人類頭髮細十萬倍的電線，它們將這些奈米線延伸到細胞壁外並在周圍環境形成微觀電網，這些奈米線讓細菌可以利用金屬代替氧氣呼吸。

生物透過一系列稱為細胞呼吸的化學反應將較大的化合物分解成較小的化合物來產生能量。在每次反應中，化學鍵被破壞並釋放電子，被釋出的電子會在一個接一個的化合物中被傳遞，並在傳遞過程中逐漸減少能量。這些能量提供給細胞進行生存所需的運作，最後能量減少的電子會在原子軌域或化合物上找到安身之處。

鐵、錳和砷等金屬，甚至具有放射性的鈾，都很容易接受多餘的電子，且它們通常存在於土壤中。但問題是：細菌不能將金屬帶入細胞壁，因為金屬太大，對細菌有毒，或者會黏在其他表面上。因此，細菌必須藉由細胞外呼吸將其多餘的電子向細胞壁外輸出。

此即奈米線的用處，細菌利用蛋白質建構直徑 3 到 5 奈米的細小結構，約為人類一股 DNA 的大小。這些奈米線延伸到細胞壁外連接周圍沉澱物或水中的金屬。通常，許多的細菌會形成一個黏糊的薄膜涵蓋整個奈米線網路。

To get energy to live and grow, some bacteria build electrical “wires” 100,000 times thinner than a human hair. They extend these nanowires outside their cell walls and create a microscopic electrical grid in the surrounding environment. The nanowires allow the bacteria to “breathe,” using metals instead of oxygen.

Living things generate energy by breaking down bigger chemical compounds into smaller ones through a series of chemical reactions known as cellular respiration. In each reaction, chemical bonds are broken, releasing electrons that are transported from compound to compound. At each step, the electrons give up a little more of their energy, which is siphoned off to do work that keeps cells alive. At the end of this cascade, the energy-reduced electrons must find a final resting place in the atomic orbit of some element or compound.

Metals such as iron, manganese, and arsenic—and even radioactive uranium—readily accept excess electrons, and they are commonly found in soil. But here’s the hitch: Bacteria can’t bring metals inside their cell walls, because the metals are too big, or toxic to the bacteria, or stuck to other surfaces. So the bacteria have to export their excess electrons outside, in a process known as extracellular respiration.

That’s where the nanowires come in. The bacteria use proteins to build thin structures 3 to 5 nanometers in diameter, about the size of a strand of human DNA. These nanowires extend beyond the bacterial cell walls, where they connect with the metals in surrounding sediments or water. Often, multitudes of bacteria assemble into a slimy biofilm, which can contain a whole network of nanowires.

文獻引用 (REFERENCES)

「Reguera 等人 (2005) 在 *Geobacter sulfurreducens* 細胞外發現可以導電的蛋白質奈米線，並將其命名為 microbial nanowires (MNWs)。這項發現為奈米學和微生物學提供新的研究途徑…一些厭氧呼吸的細菌可以利用細胞外呼吸將電子轉移到細胞外的電子接器…MNWs…作為細胞和遠方受質的導電管。

“Reguera et al (2005) discovered extracellular electrically conductive protein nanofilaments in Geobacter sulfurreducens and termed them microbial nanowires (MNWs). This discovery opened many new avenues of research in nanotechnology and microbiology … As a part of anaerobic respiration, some bacteria are capable of transferring electrons to extracellular electron acceptors in a process termed extracellular respiration. … MNWs … act has a conduit of electrons between cell and distant substrates.”

參考文獻清單與連結 (REFERENCE LIST) **Harvard 或 APA 格式**

Microbiology/Microbiology Society | December 21, 2016 | Sandeep Sure, M. Leigh Ackland, Angel A. J. Torriero, Alok Adholeya, Mandira Kochar
(https://www.microbiologyresearch.org/content/journal/micro/10.1099/mic.0.000382)
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生物系統延伸資訊連結 (LEARN MORE ABOUT THE LIVING SYSTEM/S)

https://asknature.org/innovation/renewable-energy-generator-inspired-by-bacteria/

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https://asknature.org/strategy/bacterial-proteins-conduct-electricity/

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