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EDITORIAL

How can we transfer scientific discoveries to engineered systems?: An example of exploring unknown bacteria

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Clean technologies for air, water and soil are substantially supported by biocatalysts enclosed in a cell of microbes emerging 3.7 billion years ago on this planet [Nutman et al. (2016) *Nature* 537 (7621): 535–538]. The number of prokaryotic cells on this planet is estimated at roughly 10^{30}, and the mass of a single cell is roughly in the order of 10^{-13} g. Taking the world population (approximately 7.3 billion) and an average mass of a human being (rough estimate of 70 kg) into account, the total mass of prokaryotes on this planet is ca. 200 times as high as that of human beings. Needless to say, this plant is overwhelmed by the presence of prokaryotes and we are currently utilizing their powers for clean technologies. Nevertheless, most of bacteria and archaea are still unexplored and await new discovery.

The application of a high-throughput DNA sequencing technology has opened a new window of environmental microbiology and biotechnology. According to the previous report [Hayden (2014) *Nature* 507: 294–295], cost of DNA sequencing has significantly reduced, as often mentioned, to "$1000 genome." The numerous amount of sequencing data by a high-throughput DNA sequencing technology helps to understand physiological and phylogenetic traits of unexplored bacteria which have been present but hidden. Attaining genomes of unexplored bacteria accelerates the discovery of their amazing functions. Of particular importance in the field of wastewater engineering are bacteria responsible for nitrogen transformation, e.g., (1) anaerobic ammonia-oxidizing bacteria (anammox) [Strous et al. (2006) *Nature* 440 (7085): 790–794]; (2) denitrifying methane-oxidizing bacteria [Ettwig et al. (2010) *Nature* 464 (7288): 543–548]; and (3) complete ammonia oxidizer (comammox) [Daims et al. (2015) *Nature* 528 (7583): 504–509; van Kessel et al. (2015) *Nature* 528 (7583): 555–559]. These bacteria can be key players in the next-generation environmental technologies.

It is about time for engineers to perceive this momentum. They are expected to consider how to harness these bacterial functions in engineered systems. The world still suffers from soil, water and air pollution and greenhouse gas emissions. Hence, decomposition of pollutants and mitigation of greenhouse gases are highly desirable. Currently, anammox-based nitrogen removal systems for wastewater treatment have been implemented in practice. The systems allow lower operation cost for nitrogen from wastewater stream, and more than 100 wastewater treatment facilities have employed anammox-based technologies [Lackner et al. (2014) *Water Res* 55: 292–303]. Except this case, newly discovered bacteria have not sufficiently been applied so far. The control of these activities is imperative to be able to fully exploit their potentials. But how can we design and control a process to exert their potentials? The holistic approach by incorporating knowledge from environmental microbiology to process engineering would be very important.

Resource recovery from wastewater has become a more popular option. Biogas and phosphorus recoveries have been utilized and implemented in practice. In addition to these matured processes, recovery of protein by use of hydrogen-oxidizing bacteria likely paves the way for a new paradigm of nitrogen transformation [Matassa et al. (2016) *Water Res* 101: 137–146]. Likewise, versatility of

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methane-oxidizing bacteria in terms of synthesis of valuable products could be promising [Strong et al. (2016) *Biores Technol* 215: 314–323]. These functions suggest that wastewater treatment is not only a process for prevention of environmental pollution but also a process generating something valuable.

So far, there are some challenges remaining for implementation of these bacteria in practice. Can we reduce risk of pathogens contamination in recovered biomass? Are required area, energy and budget affordable? To exploit these bacteria always requires discipline of process/system engineering. This could be an area where researchers/engineers interested in *Clean Technologies and Environmental Policy* can play a pivotal role. I sincerely hope that, in addition to broad ranges of clean technologies and relevant policies, this journal could bridge scientific findings on environmental microbiology to engineering application for better environment and sustainable future.