however, not sure whether it is mainly a ‘I believe’ or ‘I hope’ – but perhaps it is both as described below.

The future of microbial ecology will provide many exciting things to the engineers and – what many tend to forget – also visa versa: New microbial processes have in the past been discovered in engineered systems, e.g. the process for removal of the nitrogen by anaerobic ammonium oxidation (anammox) and enhanced biological removal of phosphorus. In case of the anammox organisms, they proved not just to be important in engineered systems, but central to the whole global N-cycle. The next decade will undoubtedly reveal several new organisms or microbial consortia that can be developed into useful full-scale processes in water and wastewater treatment or in the recovery and reuse of non-renewable recourses, such as phosphorus and production of bioplastic.

In order to manage the microbial ecosystems, microbial ecology needs to provide engineers with better models and theories about how these complex ecosystems work. Many wastewater treatment plants are still run as a ‘black box’ with a minimum of knowledge about the functioning ecosystem that lies behind. In the not too distant future I see the development of representative ‘model ecosystems’ where a detailed understanding of the underlying organization of the ecosystem has been obtained. Bill Sloan and Tom Curtis have initiated to incorporate the huge microbial diversity into relatively simple models that take the first steps at elucidating the general rules for the assembly of microbial ecosystems (Ofitery *et al*., 2010). I see a further development of such ‘top down’ models and a meeting of these with the deterministic ‘bottom up’ metabolic models and mass transfer models, e.g. by advanced 3-D biofilm models as developed by Cristian Picioreanu and Mark van Loosdrecht (Graf von der Schulenburg *et al*., 2009). It will be interesting to see these approaches merge in the future.

Metagenomics and other ‘–omics’ methods are extremely useful to obtain lots of information about specific ecosystems. The number of studies of engineered systems – although is still few – have given invaluable new knowledge, but have mainly been limited to the sequencing of genomes of uncultured organisms such as the anammox bacteria, polyphosphate-accumulating organisms and nitrifiers obtained from highly enriched cultures. Metagenomes of entire model ecosystems will characterize the diversity and potential function of the entire community and are now becoming practically possible because of rapidly improving sequencing and bioinformatics capacity. A deeper understanding of ecosystems must combine these approaches with transformation rates to characterize the overall function of the system. These advances will be combined with advances in single cell techniques that link the genomic information with species-related morphology, surface properties, 3-D organization in the aggregates and other functional details. The combination of ‘-omics’ with single-cell studies is extremely important – just ask a plant operator where the entire treatment plant is covered by a thick foam layer caused by a certain filamentous bacterium excreting hydrophobic surface components! My crystal ball sees these studies eventually developing an easy and fast community fingerprint of structure and function that contains both a diagnosis of problems and suggestions for corrective actions of relevance for the operation of the system.

Is the microbial diversity in engineered systems so high that it is beyond our reach to cope with? Fortunately, not so! We have been studying in a large number of Danish wastewater treatment plants with enhanced biological phosphorus removal and discovered a surprising similar composition of the microbial communities (Nielsen *et al*., 2010). However, indications are strong that the microdiversity among the different species or genera is very large in the individual plants and perhaps partly decisive for plant function and stability – which should be resolved in near future.

The exciting new microbial ecology and ‘Systems Biology’ will go hand in hand with the next generation of ecosystem theories and modelling and – not to forget – the developing of new technologies in water engineering. This will require more co-ordination and cross-disciplinary collaboration – already at the university and during post-graduate training. Strangely, this aspect of the future is – in my crystal ball – still unclear. I certainly hope that this wish will also come true.

References

Graf von der Schulenburg, D.A., Pintelon, T.R.R., Picioreanu, C., Van Loosdrecht, M.C.M., and Johns, M.L. (2009) Three-dimensional simulations of biofilm growth in porous media. *AIChE J* **55:** 494–504.

Nielsen, P.H., Mielczarek, A.T., Kragelund, C., Nielsen, J.L., Saunders, A.M., Kong, Y., *et al*. (2010) A conceptual ecosystem model of microbial communities in enhanced biological phosphorus removal plants. *Wat Res* **44:** 5070–5088.

Ofitery, I., Lunn, M., Curtis, T.P., Criddle, C., Francis, C.A., and Sloan, W.T. (2010) Combined niche and neutral effects in a microbial wastewater treatment community. *Proc Natl Acad Sci USA* **107:** 15345–15350.

Switch on the bugs! (Where Environmental Engineering meets Synthetic Biology)

Korneel Rabaey, Advanced Water Management Centre, The University of Queensland, Brisbane, QLD, Australia

Microbial respiration is a form of internal electricity generation. In 1962 Davis and Yarbrough elegantly exploited this in the first true MFC: electrical power was produced from organic conversion and sunlight (Davis and Yarbrough, 1962). In 1979 the process was reversed, electricity was given to a fermenting organism and its product spectrum changed (Hongo and Iwahara, 1979). While MFCs resurfaced strongly in the past years, we now know that effective power production at scale is challenging, and that the economic and environmental drivers for this bioelectricity are limited. Aside from developing advanced bioremediation approaches, many researchers are now refocusing towards the production of chemicals and fuels with this technology (‘bioelectrochemical systems’). Electrical current can indeed be used to drive microbial metabolism for bioproduction, by changing the outcome of fermentation, or by driving respiration (‘microbial electrosynthesis’) (Nevin *et al*., 2010; Rabaey and Rozendal, 2010).

Producing (bio)chemicals starting from electricity and CO_2 or substrate organics could have many advantages, such as high-production density, CO_2 capture, facilitated storage and ‘transport’ of electricity. Particularly attractive is the combination with wastewater. Although its supply is limited and localized, wastewater organics can provide an energy-efficient source of the electrical current and CO_2 (anode), while the wastewater nutrients can support the growth of producing organisms (present at the cathode). Principally, microbial electrosynthesis uses microorganisms to convert mixed organics into electrical current, and converts electrical current into specific organics of interest. Biorefining in one reactor!

What is needed to make this work is a good technology platform (including electrode materials), microbial populations to degrade the wastewater organics and effective production strains to convert the electrical current into the desired product. We have none of these today. This is hence where environmental engineering meets synthetic biology. Breakthroughs are needed to create biocompatible, low-cost electrode materials, combining surface area with surface charge and functionality. We need to engineer microorganisms that effectively produce biochemicals using electrical current as electron donor. And, we need to develop a technology that brings this process to scale, in a wastewater context or in a straight bioproduction context. Quite some walls between microbiologists and engineers need to be torn down, and the challenging creation of a common language will be part of this.

If we succeed, we will extract sufficient value from wastewater to turn it from a waste into a resource, with a positive value. Wastewater treatment can thus be professionalized to the level of true biorefining, where water, organics/energy and nutrients are extracted and brought back to the market. Outside the wastewater context, the sun can (via photovoltaics) drive microbial electrosynthesis, and thus enable bioproduction in areas that are not suitable for agriculture. Areas such as the Australian outback and the Arizona desert suddenly provide a tremendous opportunity for large-scale biorefining. So if all goes well, you may find that someday your wastewater will go to the highest bidder, and that you can fuel your car not only in the Saudi-Arabian desert . . .

References

Davis, J.B., and Yarbrough, H.F. (1962) Preliminary experiments on a microbial fuel cell. *Science* **137:** 615–616.

Hongo, M., and Iwahara, M. (1979) Electrochemical studies on fermentation. 1. Application of electro-energizing method to L-glutamic acid fermentation. *Agric Biol Chem* **43:** 2075–2081.

Nevin, K.P., Woodard, T.L., Franks, A.E., Summers, Z.M., and Lovley, D.R. (2010) Microbial electrosynthesis: feeding microbes electricity to convert carbon dioxide and water to multicarbon extracellular organic compounds. *mBio* **1:** e00103–00110.

Rabaey, K., and Rozendal, R.A. (2010) Microbial electrosynthesis – revisiting the electrical route for microbial production. *Nat Rev Microbiol* **8:** 706–716.

Giving a little help to our prokaryote friends

Bruce E. Rittmann, Center for Environmental Biotechnology, Biodesign Institute at Arizona State University, Tempe, AZ, USA

Because of their small size and simple physiology, prokaryotes are especially capable of exploiting an amazingly wide range of metabolic niches that also provide wonderful services to society. I illustrate the amazing variety by giving a few examples of prokaryotic physiologies that are relatively recent discoveries and that hold promise for providing important services:

- Certain bacteria are able to carry out respiration via extracellular electron transport through a conductive biofilm matrix (Torres *et al*., 2010). These anode-respiring bacteria offer promise for producing renewable electricity, hydrogen gas and other materials from biomass organics.
- Species of *Dehalococcoides* are able to reductively dechlorinate organic solvents, such as trichloroethene, to harmless end-products in another unique form of respiration (Löffler *et al*., 2005). *Dehalococcoides* already are being used commercially for bioremediation of solvent-contaminated sites.
- The ANAMMOX planktomycete is able to oxidize ammonium while respiring nitrite, creating a novel form of anaerobic ammonium oxidation (Strous *et al*., 1999). This startling discovery is being pursued for the treatment of high-ammonium waste streams (Van Loosdrecht *et al*., 2004).