Editorial to Special Issue of *Engineering in Life Sciences* Emerging biotechnologies viewed by emerging bioengineers (EBEB)

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From emergence to consolidation or peaks: Riding the waves of bioengineering

As a graduate student, PhD student, or even a PostDoc, one is standing at the shores of the ocean of science. This is certainly a very overwhelming time. Its beauty and hidden treasures gave rise to the desire to set the sails of curiosity and investigation. Yet at that time, its riffs and reefs we could not foresee nor its wakes and unpredictability may have triggered the rationale thinking to turn around and settle down on solid ground. The fact is that nowadays this ground can turn out not to be rocksolid, but quicksand which is another story.

After having sailed these first miles with the shores still in sight, we briefly want to address two questions by light of the burning sun:

- What motivates young people to set the sails for an academic career in bioengineering?
- How are the ships and the course selected for riding the waves of bioengineering?

Tipping points of life and disciplines

When we as scientists or engineers look in retrospect to our first steps in education (which might be a little early in our careers but sometimes it feels like ages ago) almost every step since then may seem like a logical, almost natural succession. Clearly it was not! What brought us into science and made us staying there (so far) was a mixture of decisions by us and others as well as chance. When distilling our limited ex-

perience down we consider the following three factors to be most important: 1) We followed our interests on fascinating topics and not a fashion; 2) The people that we met and that supported our development, e.g. mentors providing academic freedom or excellent co-workers and students; 3) We aimed at getting things done (and not just talking about that things should have been done) and were stubborn as well as frustration tolerant.

Epistemological questions are made relevant through scientific academics which inherently gives rise to scientific researchers. This is based on multiple factors. As a result of this relationship, the emergence of specific trends in research (historic, contemporary, and novel) and specific fields of research lay the ground work for new science-based technologies. Our forefathers and mothers made historic discovery which developed our way of thinking about science in the physical world, yet today none of these would be considered breakthrough technologies. This may be explained through a multitude of factors ranging from the lack of adequate methods and tools, the continued shortfall of knowledge in the scientific method, and the sociopolitical framework at these points of history. For instance, the first reports on electrical interactions of electrodes and microbes can be dated back more than 100 years yet the first virtually ready technical systems were not available until the 1950s. Moreover, the field of electrobiotechnology is emerging only within the last decade. Today, electrobiotechnology is on the cusp of its first practical applications and as a result the field is on its way to consolidation. Generally speaking, microbiology and enzymology are forming the base of current biotechnology applications. These fields have been studied and re-

searched for more than 100 years, with several established process applications in the food industry and chemical industry. Biotechnology is accelerating its pace by the emerging field of synthetic biotechnology, but still a huge potential for improvement exists. For instance, exploiting enzymatic cascade reactions or microbial polymer production shows impressive scientific promise but they still require much scientific improvements. One may summarize that following one's interest for these specific topics would have certainly lead to a dead end career or very narrow academic niche in earlier times of bioengineering, but today it's expected.

The waves of science: From big ships to small boats

In summary, we are confident that academic careers as well as emerging disciplines can hardly be planned. However, we believe that a framework combining academic freedom and early independence with (a certain share of) mid- to long-term planning capacity can set an adequate environment. An environment that does not punish failures and honors those who take a risk stimulates not only the emergence of unpredictable fundamental insights, but also leads to innovative products and processes down the line. Without providing this combination framework, it is likely to lead to the loss of bright minds (especially women), the loss of clever ideas, or the loss of "the next big thing". Therefore, we are confident that the present individualized framework not only should, but has to be improved.

When standing on the navigation bridge and looking around we may see all across the ocean that there are emerging bioengineers, which already sailed

a long way across. They all started on big ships and (more or less recently) headed off with their own small or even already medium sized sailing boats. Yet, it is not the size of the sailing vessels that matters - too huge tankers are often not flexible enough. Rather it are specialized vessels and its crews with bright minds, skilled hands, and hearts in the right place as well as the communication and collaboration of its captains that will be decisive more than in the past for discovering new land, seizing its beauty, and salvaging its treasures. Or in other words: As the boarders between disciplines are more and more permeable and neither a single person nor entity can cover the expertise needed for multidisciplinary research we believe that the key to successful future developments is based on communication and collaboration of experts. The compilation of articles of this special issue - certainly not even touching a glimpse of all emerging biotechnologies and only covering a very few of the emerging bioengineers - illustrates that the core of all future developments is interdisciplinary collaboration.

The following articles represent some of the emerging research fields closely related to microbiology and bioprocess engineering mostly in a highly interdisciplinary way:

Fueling the future with biomass: processes and pathways for a sustainable supply of hydrocarbon fuels and biogas: Sustainability and bioeconomy are the driving forces of the 21st century striving for renewable sources of energy and materials by exploiting a plethora of technologies. One of the most challenging sectors is mobility. This review combines engineering as well as genetic aspects to culminate a sustainable biobased research area.

Zero-growth bioprocesses – A challenge for microbial production strains and bioprocess engineering: Fermentation represents a well-established tool in biotechnology, but still bears a high po-

tential for optimizing production processes. This article highlights the emerging attractiveness of coupling aerobic and anaerobic process conditions to ride the next wave of fermentation processes.

Metabolic response of Pseudomonas putida to increased NADH regeneration rates: Fundamental monitoring of cellular processes under different environmental conditions is realized by the latest technologies such as omics approaches and highly sophisticated analysis devices. This manuscript deals with the flux analysis of the biotechnological work horse *Pseudomonas putida*.

Real-time monitoring of fungal growth and morphogenesis at single-cell resolution: Visualization and targeted analysis of single cells is one of the fastest emerging fields in biotechnology in order to obtain enhanced insights in process conditions and cellular response. In addition to bacteria and yeast cells, filamentous fungi such as *Paenicillium* sp. represent the next wave of complexity.

The following articles represent the tip of the iceberg but display the groundbreaking development in synthetic biology and closely related application driven fields.

Polymersomes for biotechnological applications: large-scale production of nano-scale vesicles: Synthetic reaction compartments such as highly robust polymersomes are used in synthetic biology approaches, but still lack large scale production which is needed for further boosting them towards economical applications. In this manuscript, the successful up-scale application of polymersome production is presented.

Next generation gene synthesis: from microarrays to genomes: Gene synthesis rode the first wave of synthetic biotechnology by *in-vitro* DNA synthesis and it still faces an accelerated development by use of microfluidics and automatization. This review covers the development in gene synthesis by employees of one of the leading companies in the field.

Engineering bacterial microcompartments with heterologous enzyme cargos: The use of heterologously filled bacterial microcompartments can massively enhance *in-vivo* conversion of novel and synthetic process routes, which is addressed in this highly up-to-date article.

The next two articles are devoted to the emerging field of enzyme based and microbial electrobiotechnology.

Towards electro enzymatic processes involving old yellow enzymes and mediated cofactor regeneration: Electricity driven enzyme reactions need a sustainable co-factor recycling, which is addressed in this timely and innovative article.

Paving the way for Bioelectrotechnology: Integrating Electrochemistry into Bioreactors: For riding the next wave of microbial electrobiotechnology bioreactors with integrated electrodes and compartmentalization which allows scaling as well as benchmarking are needed. Here one of the first of its kind for this purpose is presented.

We are aware that emerging disciplines will vanish, whereas others - some of which we now do not yet even consider - will consolidate or even escalate. The same holds true for emerging researchers. Yet, we remain optimistic that those who have learned to navigate their own boats of science will not only survive in uncharted waters but master the next waves of bioengineering.

Yours,

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