Survey

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Biological engineering – an engineering discipline crucial to the future of our civilization

Bioingenieurwesen – eine entscheidende Ingenieursdiziplin für die Zukunft unserer Zivilisation

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Abstract: Biological engineering is a new engineering discipline that is paving the way for new products and processes based on findings from biology. These allow for environmentally friendly production, use and disposal while at the same time creating high added value. Like any engineering discipline, biological engineering requires a sound university education, which is already being provided at many North American universities. The aim of the article is to motivate policymakers to take note of this development and to establish comparable departments and degree programs in the EU.

Keywords: biological engineering; synthetic biology; ecological devastation; cyclical economy; increased prosperity

Kurzfassung: Das Bioingenieurwesen ist eine neue Ingenieurdisziplin, die basierend auf den Erkenntnissen der Biologie neuartige Produkte und Verfahren ermöglicht. Diese erlauben eine umweltverträgliche Herstellung, Nutzung und Entsorgung bei gleichzeitig hoher Wertschöpfung. Wie jede Ingenieurdisziplin benötigt auch das Bioingenieurwesen eine fundierte universitäre Ausbildung, wie es sie an vielen nordamerikanischen Universitäten bereits gibt. Ziel des Artikels ist es, Entscheidungsträger auf diese in Nordamerika stattfindende Entwicklung aufmerksam zu machen und die Einrichtung vergleichbarer Fakultäten und Studiengänge in der EU zu motivieren.

Schlagwörter: Bioingenieurwesen; synthetische Biologie; Umweltzerstörung; Kreislaufwirtschaft; Wohlstandsgewinne

1 The historical development of engineering – where does it lead?

Engineering science departments were first founded and became established at colleges and universities during the Industrial Revolution. The design and construction of more and more high-performing and complex devices, buildings, facilities, and systems required professionals with technological training – engineers. The way was paved in civil engineering, for which the École Nationale des Ponts et Chaussées was founded in Paris in 1747 [1]. The first mining engineering academy followed only a few years later [2]. In approximately 1820, the first general engineering schools were established, ultimately resulting in the first mechanical engineering departments [3], [4]. Seventy years later, at the end of the nineteenth century, electrical engineering became established at technical schools, colleges, and later at universities [5]. These institutes provided education and training for the engineers who made widespread provision of electricity possible, culminating in mobile phones today. Another seventy years later, in the 1950s, information technology (IT) and computer science emerged, and the inventions in these fields continue to drive technological progress forward [6]. For special tasks and industries, established engineering disciplines such as mining and metallurgy, process, chemical, and biomedical engineering complement the major disciplines civil, mechanical, and electrical engineering. Figure 1 provides an illustration of this historical development.

Now as before, these are the engineering disciplines which have transformed our material world in the last 200 years in ways that could not previously have been conceived

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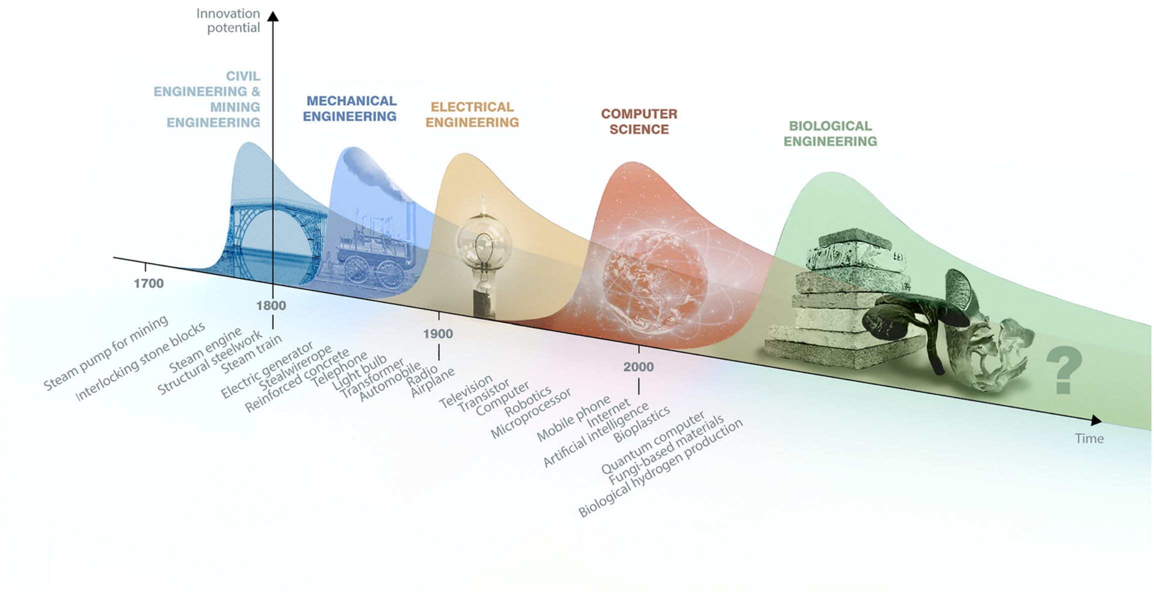

Figure 1: The historical development and the innovation potential of engineering disciplines.

of. From the tunnel connecting England and France to the airplane, space travel, oil rigs capable of drilling several thousand meters, the pacemaker, the Internet, and self-driving cars, they have given humanity an excellent standard of living, high life expectancy, unlimited mobility, and opportunities to communicate, as well as conquering hunger in many parts of the world.

However, as we know, there have been downsides to this enormous and extremely rapid technological progress: climate change, environmental pollution, and loss of species and biodiversity are currently viewed by most scientists as urgent dangers facing human civilization. The traditional major engineering disciplines – civil, mechanical, and electrical engineering – have recognized these issues and are developing solutions aimed at environmental protection, new energy sources, and sustainable construction. But on their own, these three major fields and their capabilities are not sufficient to solve the problems named above.

2 A new engineering discipline – why?

Physics is the science underlying today's main engineering disciplines, i.e. civil, mechanical, and electrical engineering, along with the industries they have spawned. Process and chemical engineering are based on chemistry as well. Since their foundation, they have implicitly worked according to a linear concept by which raw materials are extracted from the Earth, made into products with a limited lifespan, and are finally discarded. It is not only waste such as the plastics that end up in the world's oceans which present a problem [7], [8]; it is also the undesired byproducts of production processes, such as carbon dioxide emissions yielded by cement manufacture [9].

Problems of this kind can potentially be solved by modifying usage and production chains; apart from this, certain processes can be transformed into cyclical (as opposed to linear) economies. One example we can name is the production of insulation material for buildings. The standard practice is to use petroleum-based insulation materials such as polystyrene. Alternatively, insulation materials of comparable or even higher quality can be produced using special fungi and biological waste products, which can be composted at the end of their lifetime as insulating materials [10].

Although the traditional engineering sciences can help to solve the environmental problems that they themselves have in a sense created, ultimately their contributions will not be sufficient, because the fundamentals of human life are biologically based. Mechanical, civil, and electrical engineers who have successfully completed a degree program generally have no training or expertise in this field. Biology as a natural science itself is, on its own, incapable of setting up sustainable production methods and a cyclical economy aiming to preserve human beings' natural living requirements in the long term; this would necessitate a highly technological implementation. To put insights from biology into practice in industry and on a large technological scale, engineers would have to acquire scientific knowledge and technical skills which – naturally – are not imparted to students of biology as part of their degree programs.

However, we are not motivated solely by the environmental aspects of a biologically based engineering discipline; it would additionally offer the opportunity to develop innovative materials and processes with entirely new characteristics. This could be accomplished by drawing inspiration from biological systems for engineering solutions, and by integrating engineering-inspired concepts into biological processes. Examples include biological hydrogen production, sustainable construction, neuromorphic computing, integrated biosensors to compute the internet of molecules, carbon dioxide sequestration by algae, bioelectronic devices for augmented bio-reality, biomaterials, an engineering theory of evolution, micro-biorobots, etc. The articles in this issue present numerous examples of applications of this type, illustrating the diversity of this new engineering discipline.

The obvious solution is to combine biology and technology into a new engineering discipline – biological engineering – with independent departments and degree programs based on biology as the underlying science [11]–[13]. As shown in Figure 2, biological engineering would unite all of the currently existing biological-technical fields of research, such as biomaterials, bionics, biological agriculture, biomimetics, synthetic biology, biotechnology, etc. [14], [15]. In some cases, biomedical engineering could also fall into this category, although it is more of an independent discipline in terms of its scope and affiliation to medicine.

3 The current situation – who will take this on?

In recent years, the use of biologically based methods in civil, mechanical, electrical, chemical, and biomedical engineering has been continuously on the rise. In many cases, these have been the result of research collaborations between biology and the engineering sciences. To train and educate suitable professionals, a raft of degree programs has been established at many universities, including programs in synthetic biology, biotechnology, biomaterials, and bionics. However, these have simply been added to the traditional engineering departments, or to biology, in the case of synthetic biology. This means that either the biologically based education or the engineering aspects are insufficiently addressed.

American universities such as the Purdue University, UC Berkeley, the Massachusetts Institute of Technology (MIT), and Cornell University have recognized this problem and established schools and departments with corresponding undergraduate, graduate, and PhD degree programs to create an entirely new type of engineering based on biology that aims to create new processes and products in all areas of human life [11]. MIT calls this new engineering discipline biological engineering. A large number of American, Canadian, and British universities also use this term, without offering a similarly wide-ranging engineering education based on biology [16]. Outside of the United States, particularly in the European Union, comparable steps toward biology-based engineering education have not yet been taken at the level of university departments.

A characteristic of the founding of technological departments at universities is that they are motivated by a technology which has been newly developed in society and industry. They take on the necessary role of educating engineers for these new technologies, enabling industrial production and introduction of the technologies on a large scale. Each engineering science has had its period of great flourishing in which it has shaped the technological and thus also the societal structures of an era. During the Industrial Revolution, these fields were construction and mechanical engineering. Steel structures, engine-driven ships, automobiles, and airplanes changed the world. After this, electrical engineering opened up new opportunities to the world with electrification, the radio, and digital processors. Today, it is the field of IT which is beginning to change our lives via automated data processing, the Internet, and artificial intelligence. Figure 1

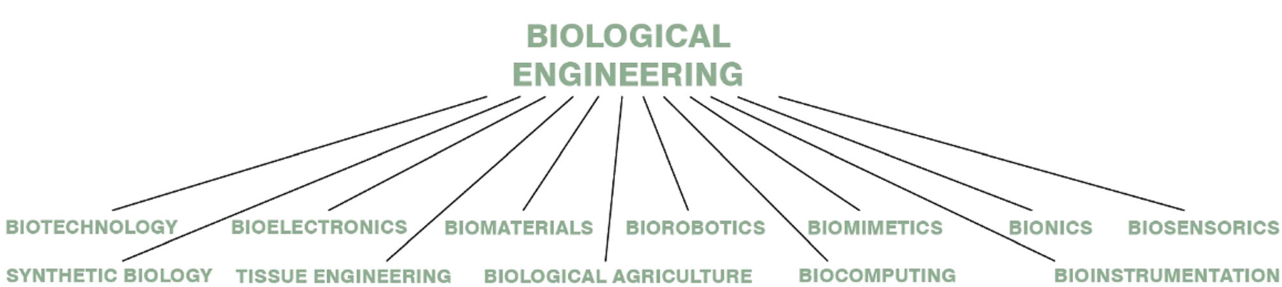

Figure 2: Biological engineering is the generic term for all biology-based engineering disciplines.

illustrates this sequence of ever-newer technological disciplines, posing the question of which engineering discipline will be the next to change our world. Will it be biological engineering?

4 Potential – what are the possible benefits?

For biological engineering as a science, there are two benefits: firstly, biological engineers would be able to solve important environmental issues by gradually replacing traditional production chains with sustainable ones, or by developing new products and the production processes that go along with them. Examples include the large-scale technological implementation of new biologically based procedures for generating hydrogen, biologically degradable plastics, and carbon dioxide storage using algae. Discoveries from biological engineering and their large-scale technological implementation could thus make a major contribution to ameliorating or even solving the central problems of our time: climate change, environmental pollution, and loss of biodiversity. In addition, innovative materials and processes with entirely new characteristics would lead to advances in numerous areas of human life.

Secondly, new large-scale industries would emerge which would contribute to the productivity of our economy and to ensuring and increasing prosperity within society. These would not only be the industries which are already being established, but many which have not even been yet conceived. Here it is important to mention that the European economies, and the German economy especially, are largely based on inventions and technological fields which date back to the late nineteenth and early twentieth centuries. Other parts of the world have caught up with the necessary skills, so that the question of European competitiveness is being asked with increasing urgency [17]. New technologies and inventions emerging from biological engineering would open up new economic opportunities.

5 Acceptance – who wants this new discipline?

We can assume that there will be broad public acceptance for the transition to a more environmentally friendly economy and a safeguarded prosperity, as mentioned above. Most people and institutions have recognized the environmental problems of our time and are looking for solutions, one of which could be biological engineering. Many young people about to choose a career express great interest in choosing degree programs and meaningful professions which could contribute to solving the problems of our time and improving human civilization. In contrast, the traditional engineering degree programs are increasingly becoming less attractive, which is reflected in the dramatic fall in the rates of matriculating students in Germany [18]–[20]. Without a sufficient number of engineers, however, a modern society will be unable to ensure its productivity or its prosperity. Biological engineering as a science, and the industries resulting from it, would offer opportunities in this regard.

6 Suggestions

Time is running out to launch and establish biological engineering as an engineering discipline in Europe's universities, research institutes, and industry in good time [21]. There are two reasons for this. On the one hand, this engineering discipline could help to mitigate or solve pressing environmental problems. Secondly, because biological engineering is already established in the United States, an innovative development is underway in which Europe will only be able to participate if it also creates a corresponding university education in this field. It is important for us not to lose touch with this development. The authors and editors of this issue therefore propose three changes:

1. Setting up biological engineering departments at universities in the EU,
2. Setting up degree programs that teach the entire breadth of biological engineering,
3. Fostering company start-ups with the aim of introducing biological engineering processes and products into industry and everyday life.

7 Summary

Biological engineering, the engineering discipline introduced in the United States, complements the traditional engineering disciplines of civil, mining, mechanical, chemical, and electrical engineering and makes it possible to develop entirely new products and processes, and to implement them on a large scale. In doing so, it can provide the foundation for innovative environmentally friendly industries which would ensure prosperity and enjoy widespread societal acceptance. To implement this concept, we need to follow the example of the United States by establishing biological engineering departments and degree programs, and by fostering and supporting the implementation of their research results in industry. This special issue is intended to point out the opportunities this would open up.

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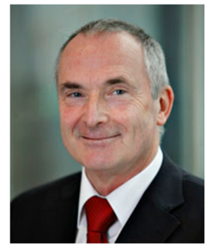

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