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Bio-based targeted chemical engineering education; role and impact of bio-based energy and resource development projects

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Abstract

Avans University of Applied Sciences is redrafting its courses and curricula in view of sustainability. For chemical engineering in particular that implies a focus on 'green' and bio-based processes, products and energy. Avans is situated in the Southwest region of the Netherlands and specifically in that region much development occurs towards 'a bio-based economy'. There is much agriculture based business, small and large companies, important chemical industry and it is situated between major industrial and chemical industry centers and leading international ports. Chemical companies see many opportunities in bio-based products and processes. Connecting the chemical and agro-food sector will lead to unexpected new innovation opportunities.
Biomass has quite other characteristics than oil and gas, in composition, availability, and offers new options with respect to compounds that can be derived from it. So there is a strong need to develop and introduce novel processes, products and production routes based on biomass resources. It requires other technologies and equipment, another approach and another mindset than those chemical engineers are being taught at present. Process design, modeling, and optimization will have to be adapted to the new circumstances. Chemical engineering in its basic knowledge won't be different but in practice students will need other and extra knowledge and therefore get other cases to study in projects.
That transition will be gradually but it starts now. The bio-based economy already asks for new approaches in education, in particular in chemical engineering. Already now we observe an increasing need for personnel with knowledge of biobased issues on site and for a more bio-based oriented chemical engineering curriculum.

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To acquire that new knowledge and to observe what is needed by industries involved in that bio-based economy Avans University of Applied Sciences is actively participating in projects with local companies, other universities and research institutes. For this paper we have taken the international (Interreg) cooperation project 'Energy Conversion Parks' (ECP) in which we partake as example how such projects can and must contribute when developing a 'bio-based chemical engineering curriculum'. Besides attention for the specific types of equipment, processes and compounds involved, it shows that crucial knowledge also concerns the complexity of energetic optimization and the need for economic synergy when using different biomass streams and conversion technologies. Aspects involved are also bio-refinery, bio-cascading (implying use of all biomass components for products with the highest possible value) and optimizing input and output for seasonal variations in availability and demand. It shows the need for special mathematical models to calculate mass and energy balances for integrated bio-based installations, as well as the economical profitability of the different possible combination of biomass inputs and conversion techniques.
The cooperation with industrial partners shows which the important technologies and knowledge for the bio-based oriented chemical engineer are. Students work on cases derived from the projects. The research results increase the knowledge we can teach. Representatives of the various project partners, from industry and research institutes, contribute with lectures based on practice information. In this manner it is possible to develop curricula that are useful for industry and society as a whole and at the same time attractive for the much needed new students.

chemical engineering; biobased economy; biobased education

1. Introduction

1.1. A changing economy

Bio-based economy concerns the transition from production of materials, chemicals and energy based on fossil oil and gas towards one that is based on renewable biological resources. Factors as climate change, dependence on politically unstable regions, and strong price fluctuations of fossil fuels are the driving forces for this. According to the Dutch Green Raw Materials Platform [1], in 2030 30% of the Dutch raw materials and energy needs can and should be supplied by biomass.

The bio-based economy is beneficial for both the agro-food sector and the chemical industry because it leads to new products and markets at the one hand and offers profitable uses for biomass waste streams at the other. Additionally, the transition to a bio-based economy is driven by their need to come to a more sustainable way of production and green image. Examples of some bio-based processes and products are for instance: oil from pyrolysis of waste wood, chemical products from carbohydrates (C6 chemistry), biomass based polymers (e.g. poly-lactic-acid and cellulose derivates), and biogas production via fermentation of manure and green household waste.

People working in the companies that will make this transition will need a different training and knowledge than those which are presently working in the chemical industry. To some extent, that will also be the case for companies that supply for instance equipment, and industries further in the chain using the new products and materials. Engineers, operators and managers alike must understand the complexities and variability of biomass production, and yet can recognize and help advance promising new technologies utilizing biomass as feedstock. Besides, the new type of compounds, processes and equipment used and produced ask for people knowledgeable with these. Workforce development and creative linkages with new sources of human and technological capital are essential to the success of the bio-based economy. Already in 2003, Singh et al. from Tennessee State University, USA [2] discussed a plan to prepare agricultural professionals for working in the bio-based product economy. This educational plan was based on the results of a survey of employers (industry and government) about training needs. Research conducted in the state of California, USA [3] shows an 11% growth rate in the bio-energy employment projection from 2010 to 2013 and reports a level of difficulty hiring qualified workers for the occupations studied. Van der Schot [4] shows some educational initiatives in the Netherlands for the preparation of the required bio-based personnel in areas as chemical engineering, chemistry, agriculture, material sciences, and commercialization. These initiatives are taking place at all educational levels (research universities, universities of applied sciences, and vocational training centers) in close cooperation with industry.

The core of the Dutch policy vision on the bio-based economy aims at efficient and intelligent use of biomass and sets two conditions for this [5]:

- Biomass must be used in the most efficient manner, both ecologically and economically. Biomass can be converted in various ways into energy or into raw materials for products. In the bio-based economy policy the objective of achieving the highest added value is pivotal (Figure 1). This pyramid principle assumes that first of all, biomass is used for the economically most interesting applications, after which the residuals are used, to the greatest extent possible, for other lower value applications.

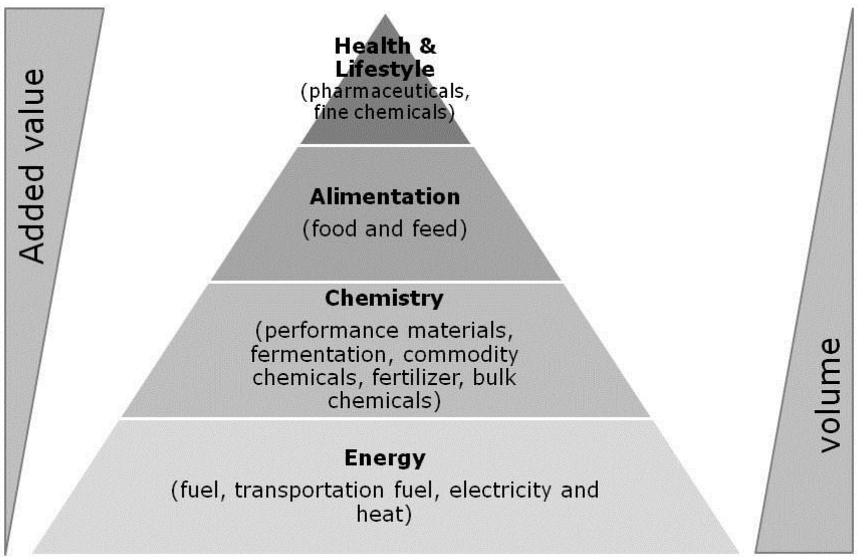

Fig. 1. Bio-based value pyramid (Adapted from [6])

- For economic and sustainability reasons not a single straw of biomass may go to waste. The chains must be closed (Figure 2). If this principle is adhered to, waste no longer exists. All residual flows can be introduced to the chain again with a new function. This reintroduction of raw materials may also take place across different sectors, such as agriculture and the chemical industry.

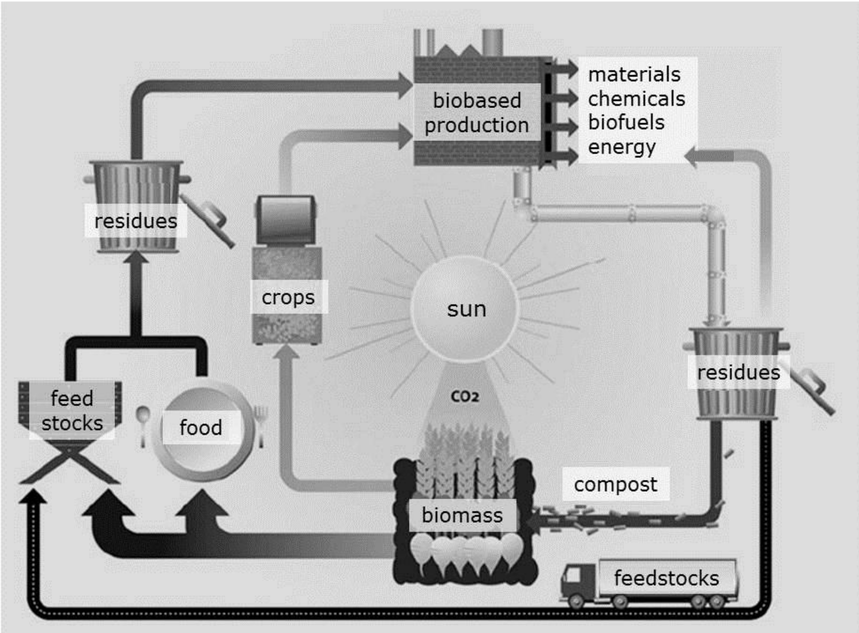

Fig. 2. Closed chain concept (Adapted from [6])

1.2. A changing education

Changes in the economy ask for changes in education. New knowledge must be taught and paradigms about how we look at production and use of what we need in our economy and society must be learned. Avans University of Applied Sciences is since many years aware of the challenge that education faces in view of the changes that must and already do occur in our society and economy due to the various transitions caused by sustainable development issues. Sustainability is becoming a key aspect of all curricula (7).

Avans is situated in the Southwest region of the Netherlands. In specifically that region much development occurs towards a bio-based economy. There is much agriculture based business, small and large companies, important chemical industry and it is situated between major industrial and chemical industry centers and leading international ports. Avans University of Applied Sciences in general and its School of Life Sciences and Environmental Technology in particular are actively participating in the bio-based economy development in Southwest Netherlands. So Avans has decided to give bio-based processes and products a central place in the development of its new 'sustainable' education, in particular for chemical engineering. Chemical engineers will have a pivotal role in developing a new bio-based industry.

Several research groups within Avans University of Applied Sciences are involved in biomass based projects with local companies and other universities and research institutes. The knowledge and vision generated in these projects can and must benefit education as we organize it. That can be done in different ways.

1.3. This paper

The main objective of this paper is to show how we use this experience in bio-based energy and resource projects in developing a future aimed, more bio-based and sustainable, curriculum for chemical engineering education.

The paper is organized as follows. First is described which specific bio-based issues and knowledge need different and/or additional knowledge compared to 'classic chemical engineering education'. Next, the impact of bio-based energy and resource development projects in the current chemical engineering program within Avans University of applied science is described and the development of a new bio-based chemical engineering program is outlined. Thirdly one of the major projects we are involved in: the Interreg-project 'Energy Conversion Parks', is used to illustrate the knowledge and vision generated in bio-based projects and how this can and must benefit education as we organize it. Finally we present some conclusions and points of attention, which need further discussion. We are quite aware that the bio-based economy is just starting. So a definitive description on what a bio-based chemical engineer will need to learn is of course not possible.

2. Need to know in bio-based

Biomass, seen with a chemical engineers eye, is a quite diverse group of materials, originating from agriculture and forestry, including organic waste from food production. Not plant-originating biomass from animal and fishery waste can also be used. Biomass offers a challenging variety in form, composition, availability, and possible derivatives and uses. So there is a strong need to develop and introduce novel processes, products, and production routes based on biomass resources. Connecting the chemical and agro-food sector will lead to unexpected new innovation opportunities. It requires other technologies and equipment, another approach, and another mindset than those chemical engineers are being taught at present. Students must be trained to handle such a 'systems-approach' for finding sustainable solutions and implementation options for the short and for the long term. It requires multidisciplinary and 'lateral' thinking [7-8].

From our experience we can discern several areas of knowledge and 'insight' which need to be addressed. Some concern basic knowledge a bio-based engineer must know, some are more 'good to be aware of' because it has implications for selecting bio-based resources and for running a bio-based process and industry. Some of the already known important issues are:

- occurrence, characteristics, possible chemical reactions and practical applications of specific compounds in biomass, and for instance an aspect as how fast a compound is 'spoiled' after harvesting;

- specific processes for use in bio-based production (e.g. fermentation, pyrolysis) or adaptations needed in 'classic' oil based products based processes;
- specific types or adaptation of equipment: fermentation, separation, breaking up cells, thermal biomass processes (producing bio-syngas), etc.;
- biomass characteristics important for transport, storage, pretreatment and preparation steps;
- general biology knowledge in topics as: structure and functionality of biological cells/materials, how specific products are built up in a plant and what are the implications for their use, growth potential, genetics and genomics, differences between possible uses of cells/materials from plants, animals, algae, fungi, yeast, etc.;
- general agriculture knowledge in the following aspects: production per ha, seasonality, , agro-economics, logistics;
- business development aspects: introduction and marketing of novel compounds, costs of biomass resources, how important is the option that a bio-based product has a 'green label' and/or is sometimes biodegradable;
- sustainability aspects: land use, need of fertilizers and energy (often underestimated and misunderstood), food versus products.

A key issue is that bio-based is even more 'multi and interdisciplinary' than chemical engineering already is. As we observed, in research and in industry those people who have a broad interest and network, and are not to reluctant to join efforts with quite different types of industries and expertise, are often the most innovative and successful ones. As example, in de Energy Conversion Parks project, which will be discuss later in more detail, an important issue has been the options for 'green gas' production based on wet biomass residues and animal manure fermentation. Issues as selection of biomass processing process, possibilities to hydrolyze cellulosic materials, and process selection to upgrade biogas to different products; proved to be a very complicated matter which requires much more and broader knowledge (technical, agricultural, biological, and economical) than present chemical engineering students normally acquire.

3. Impact of bio-based energy and resource development projects in the current chemical engineering program

At Avans School of Life Sciences and Environmental Technology, the 4-year chemical engineering program is divided in different phases: orientation, deepening, specialization, and graduation phase. Already in the orientation phase (first year), the students are involved in small projects related to the implementation of the Dutch transition of energy supply to renewable energy and for bio-based economy.

During the specialization phase (third year), the students follow the compulsory minor Sustainable Technology. Within this minor students participate for 20 weeks on actual business cases for local companies, small and medium size enterprises which are active in the bio-based economy. During the execution of these projects the students broaden their knowledge and vision concerning chemical engineering in practice, experience working for and with external stakeholders, and learn to actively apply project management and experience the effect on output and quality of their work. Examples of some project topics are:

- Processing valuable components from algae;
- Valorization of waste streams;
- Connecting CO2-streams.

The optional minor Biopolymers is offered to last year chemistry, chemical engineering and mechanical engineering students. In this minor de students do practical research projects for local companies that are active in the bio-materials sector. The projects are executed by multidisciplinary teams. In this minor de students learn about topics as design of experiments, multidisciplinary approach to problems, and relationship between bio-polymer chemical structure, processing conditions and final product properties. In both minor projects and interactive and problem oriented learning method is applied. Examples of some project topics in the minor Biopolymers are:

- Tailoring polymer degradability properties;
- Utilization of agro-waste streams for production of bio-composites;
- Bio-polymers synthesis.

3.1. A new educational program: major BioBased TeCh

A new development is the initiative to start a 4-year bio-based major in 2012. It is named Biobased TeCh, where TeCh stands for chemical technology and chemistry. This major offers two specialization options: a bio-chemistry oriented route and a bio-chemical engineering oriented route.

Students start with an overall first-year program (orientation phase) that is also, with some slight variations, followed by the current chemistry, chemical engineering, environmental and biomedical students. Some first-year specific courses for the Biobased Tech program, that are not included in the classical chemical engineering program, are: microbiological techniques, cell biology, 'green' synthesis, and bio-technology.

The study program for the deepening, specialization, and graduation phases is under development. It is expected that in these following phases the differentiation with the classical chemical engineering program will be larger. The following minors will be offered: Biobased Technology, Biobased Chemistry, and Biobased Economy.

3.2. Further approaches

Avans University of applied science organizes multidisciplinary-minor weeks with students from different educational programs (chemical engineering, industrial engineering, civil engineering, etc.). In this one-week activity, multidisciplinary groups of students work at a company location on a business case. Activities like this help the students to think and work in a creative manner. A typical example of such one-week project is to explore the opportunities to produce and sell dried algae biomass and produce one or several algae-based products.

Representatives of the various project partners from industry and research institutes, in which Avans is involved, participate actively in our educational programs with lectures based on practice information and case studies in the minors' projects.

The Avans School of Life Sciences and Environmental Technology has recruited, as part time professor from industry, two experts who are involved in the latest developments in bio-based energy and bio-based products respectively. This school also wants to organize master classes for students and people from industry. During these master classes experts explain different bio-based topics and how to handle them.

All these initiatives take place because 'practical research skills' (not fundamental research) are an increasingly important competence for a bachelor degree. This is the result of the rapid developments, and here in particular in bio-based science and sustainability: Universities of Applied Sciences should train students' critical and reflective skills.

4. Bio-based research projects within Avans University of Applied Sciences

Avans University of Applied Sciences has an Expertise Center for Sustainable Innovation (EDI in Dutch). In this center, technical specialists, researchers, lecturers, and students work together to come to practical sustainable innovations. The EDI focuses on applied research and implementation projects which respond to actual needs and requests of companies, municipalities and other organizations. The bio-based energy group within EDI concentrates on bio-based energy and production related issues. Presently they are involved in 8 projects, some of them of international character. For this paper we will take as example the project 'Energy Conversion Parks' within the European Interreg cooperation program.

4.1. Project 'Energy Conversion Parks' (ECP)

In the ECP project a consortium of Belgian and Dutch research institutes (VITO, Avans University of Applied Sciences, Wageningen University and Research, University Hasselt, and University of Applied Sciences Zeeland) is analyzing whether an economically viable concept can be achieved to valorize locally available biomass (waste) streams, through the use of synergies between different biomass streams, conversion technologies, and outputs. The idea is to maximize the valorization of intrinsic values of the biomass and thereby improving its business case [9].

A biomass energy conversion park (ECP) is defined as a synergetic multi-dimensional biomass conversion site with a highly integrated set of conversion technologies in which a multitude of regionally available biomass (residue) sources are converted into energy and materials. Important starting point is the presence and availability of biomass streams (types of biomass and availability in the region of the pilot), other industrial activities that can be linked to or other nearby companies that can exchange energy. Both in biomass resources, conversion technologies and applications, smart combinations and links can be achieved, leading to very efficient and cost effective solutions. Figure 3 shows a schematic representation of an ECP.

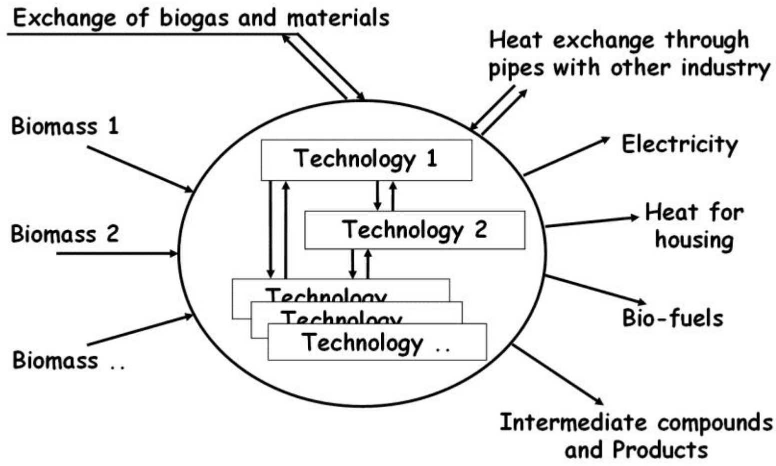

Fig. 3. Schematic representation of an ECP

The design and implementation of an ECP involves different aspects:

- Related to the biomass: classification, composition, how to inventory the locally available streams, season fluctuation, market price fluctuation, transportation, among others.
- Technical: involves optimization of the possible synergies when using different biomass streams and conversion technologies. Aspects involved are maximal energy integration, bio-cascading (implying use of all biomass components for products with the highest possible value), and optimizing input and output for seasonal variations in availability and demand.
- Economical: influence of government subsidies, market price variation of biomass and bio-based energy and products in the economical profitability of the ECP.
- Logistical: determination of the ECP location considering (i) local biomass potential, (ii) local energy demand and exchange possibilities, (iii) existing biomass conversion installations and (iv) accessibility, industrial space and the acceptance by local communities.
- Legal: related to the transport, processing, and buying/selling of biomass and bio-based energy and products.
- Others: cooperation between different companies that can be competitors in the market, sustainability of biomass utilization, social context.

As figure 4 shows all these aspects are interdependent, which implies that chemical engineers involve in this kind of projects should not only have a strong technical background in bio-refinery (integrated biomass conversion process resulting in multiple products of semi-manufactures without waste production) but also knowledge on the other ‘dimensions’ of the bio-based processes (logistical, legal, social aspects). It is a highly interdisciplinary activity and the engineers involved have to be able to gather, understand, and use the information from quite different fields of science and engineering.

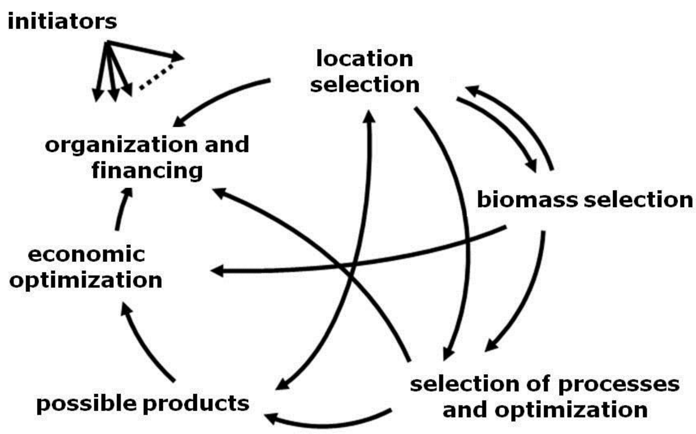

Fig. 4. Implementation of an ECP: some issues that need attention and how they depend on each other

The aim of the project is the development of a technological concept and a business plan for five such integrated Energy Conversion Parks as ‘proof of principle’ in the South of the Netherlands and in Flanders (Belgium). Additionally, a knowledge system is developed which makes the knowledge public and can stimulate the implementation of similar ECP concepts in other locations. The mathematical models developed within this project to calculate mass and energy balances as well as the economical profitability of the different possible combination of biomass inputs and conversion techniques are an important part of the knowledge system.

This project made (again) clear that new knowledge and paradigms have to be taught to students. The various issues given above, in chapter 2 ‘under need to know’, proved to be complex and not just easily handled even by experienced engineers from the institutes involved in the project. Specific aspects which proved to be ‘non classic chemical engineering’ were for instance:

- inventory and selecting best options of biomass resources: changing composition, season influences, other potential uses;
- good understanding of which resource needs which technology;
- process simulation with biomass as input and specific biomass processes and technologies (standard tools do not exist for this purpose);
- uncertainties and variability of availability, supply and consumer demand, which requires a design optimization which reckons with such fluctuations (robust design which is not the classic lean design);
- looking for extra products (and therefore value and income) from the biomass streams that are available by good insight in what the biomass contains (proteins, fibers, sugars, specific compounds etc.);
- the ‘bio-refinery’ concept: which is a high tech complicated set of processes, during which the specific compounds should not be ‘downgraded’ e.g. because of too high temperature and such. (Natural compounds are often, at least initially, rather unstable).

A well prepared bio-based chemical engineer should be able to handle all these topics.

5. Conclusions and recommendations

The knowledge and vision generated in bio-based energy and resource development projects can and must benefit education as we organize it. The actual involvement in practical projects and the cooperation therein with industrial partners shows what the important technologies and knowledge for the bio-based oriented chemical engineer are.

Our approach in setting up such bio-based energy and products oriented courses is very practical. Students work on cases derived from the projects. The project experiences and results increase the knowledge we can teach. Representatives of the various project partners, from industry and research institutes, contribute with lectures based on practice based information. We get a feeling for what a bio-based chemical engineer should know and be able to do. Nevertheless the transition towards the bio-based economy has just started. So the content and the form of the courses will shift continuously. A major point is the fact that due to new type of molecules and processes, total new and quite novel product chains and applications will arise just as the oil-based chemistry did in the beginning of the 20^{th} century.

That leads to the main recommendation: bio-based oriented course and curricula should always and very stringently be mirrored against the developments in the field, nearly on a ‘daily basis’. To that aim, involvement of the staff and the students in actual projects with industrial and research partners is crucial. Also applied sciences can have their ‘ivory towers’.

A specific recommendation concerns the further development of the modeling tools to design and optimize processes and installations. They are not sufficiently developed to handle integrated bio-based industrial complexes. And in general, training and teaching materials should be made for bio-based chemical engineering education. As yet ‘oil-based’ is still the norm.

What we observe is that sustainability, and within that, the bio-based economy transitions, is causing much new development within chemistry and chemical engineering, as it is in other areas. As such, it is a welcome challenge. And not unimportant, the quite novel (green and clean) developments and often high (bio)tech processes attract a new group of students for whom the ‘old’ chemical engineering seems unappealing, rusty and dirty, and certainly not novel.

Acknowledgements

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