Educating the managers of the bioeconomy

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Abstract

The educational gap for which science is not taught to managers, and management is not taught to scientists, is a significant obstacle to a company's success also in the bioeconomy field. Companies worldwide eagerly seek for new managers, researchers and technologists owning new knowledge and skills in topics spanning from circular production processes through new energy technologies and green chemistry. Most employers, however, have difficulty recruiting qualified professionals due to the shortage of qualified professionals. This shortage includes bioeconomy managers capable to successfully lead bioeconomy companies. Shaping the managers of successful bioeconomy companies, we argue in this study, requires to transfer a closer understanding of the nature of bioeconomy companies and their competitive landscape, as well as identifying the main guiding principles for managing these organizations.

1 Introduction

In the bioeconomy, the production of useful substances and of useful energy starts from biological resources and from renewable energy sources, respectively.[1] The root cause of this shift is closely related to the end of low cost (or "easy to extract") oil which has literally driving the growth of global wealth and human population since the early 1930s.[2,3] Currently, new bioeconomy companies worldwide eagerly seek for new managers, researchers and technologists gifted with new knowledge and skills in topics spanning from circular production processes through new energy technologies and green chemistry. In Canada, for example, in 2008 a labour market report noted that nearly half of companies active in the bioeconomy (at that time chiefly identified with biotechnology) were dealing with a shortage of "skilled/experienced workers" with at least one-quarter of all companies reporting vacant positions.[4]

Thirteen years later, the situation was unchanged, with "nearly two-thirds of employers" surveyed having difficulty recruiting qualified professionals "due to a lack of skilled, experienced talent". As a result, the team found, "bioeconomy employers compete for talent among themselves" and "with other sectors for candidates with technical skills".[5] This shortage includes bioeconomy managers, namely managers capable to lead bioeconomy companies to successfully develop and market new bioderived products and renewable energy services.

Accordingly, a recent (2019) survey of the educational gaps amid 192 bioeconomy companies, in European countries, and mostly in Spain, identified management amid the six main general competences found to be deficitary.[6]

The importance of bioeconomy education is now widely recognized in both economically developed and developing countries. The "outstanding feature of the bioeconomist", wrote Lask and co-workers in 2017, "is interdisciplinary expertise built up from disciplinary expertise".[7] To shape these professionals, the team concluded, requires an interdisciplinary approach and new learning environments. Several universities across the world have launched new Master of Science (MSci) programmes in the bioeconomy.

Examples span from the 2 year Master "Bioeconomy" offered by the University of Hoenheim in Germany since 2014, through the Master in Bioeconomy and the Circular Economy held in Italy since 2017. Though open also to students with a degree in social and economic sciences, these Master programs either aim to educate "the type of scientists needed to successfully make this transition"[8] or provide "a rich combination of theoretical perspectives on life science innovation with a practical focus on the dynamics of the bioeconomy and its value chains".[9]

In general, the educational programs of these Master courses include both scientific and economic topics, in agreement with a 2012 study in which Pagliaro identified the urgency to renew the education of both scientists and managers by closing the "two-cultures" gap.[10] Shaping the managers of successful bioeconomy companies, we highlight in this study, requires to transfer a closer understanding of the nature of bioeconomy companies and their competitive landscape, as well as identifying the guiding principles for managing said companies.

2 Guiding principles for managing bioeconomy companies

Managers of successful bioeconomy companies need first a closer understanding of the nature of bioeconomy companies and their competitive environment.

Producing useful substances and functional materials from biological resources, these companies actually are chemical companies competing with existing chemical manufacturers deriving their products either directly from oil or from oil-derived chemicals. From bioplastics[11] through biobased monomers and fine chemicals, this simple fact explains why in the last thirty years (1990-2020) many bioeconomy companies attempting to produce biobased substances and materials either failed or abandoned the original plans after investing tens or even hundreds of millions of dollars.[12] A few names of a truly long list include Cere plast, Vertellus Specialties, TerraVia, Metabolix and Rennovia in the USA, Bio-On and Mossi Ghisolfi in Italy, BioAmber in Canada, Leaf Resources in Australia, and Bio-Xcell in Malaysia.

The highly integrated petrochemical industry, indeed, not only starts its productions from self-produced feedstocks obtained from oil transferred from its oil ("petro") division, but also relies on highly efficient, heterogeneously catalyzed continuous processes.[13] This allows the industry to produce virtually all synthetic polymers (invented between the 1930s and the late 1960s) at very low cost and in huge amounts. Furthermore, the industry has not been harmed by oil price volatility because when oil price is high, revenues from fuel sales increase and largely compensate reduced sales of petrochemicals due to higher selling prices. Under these conditions, it is necessary for bioeconomy company managers to learn from the few examples of successful companies.

2.1 Low volume, high margin bioproducts

Management consultants studying companies using synthetic biology production processes (*i.e.* , fermentation) lately identified three approaches common to successful companies, namely *i*) target low volume, high margin products; *ii*) license technology; and*iii*) adopt modular manufacturing using multiple small fermenters distributed globally, in place of a large fermenter in one facility, to flexibly meet demand from different regions.[14]Examples identified by the consultants include France-based Global Bioénergies now producing cellulosic isobutene for cosmetic products rather than for making fuels, and USA-based Genomatica licensing its sugar fermentation route to 1,4-butanediol to Italy's Novamont and to Germany's BASF.[14]

2.2 From ingredients to complete formulations

More generally, after targeting the production of one or more low volume, high margin bioproducts, successful bioeconomy companies will target the production of the functional formulation using the same ingredient or combination of ingredients. An exemplary case are the China-based companies manufacturing hyaluronic acid via microbial fermentation.

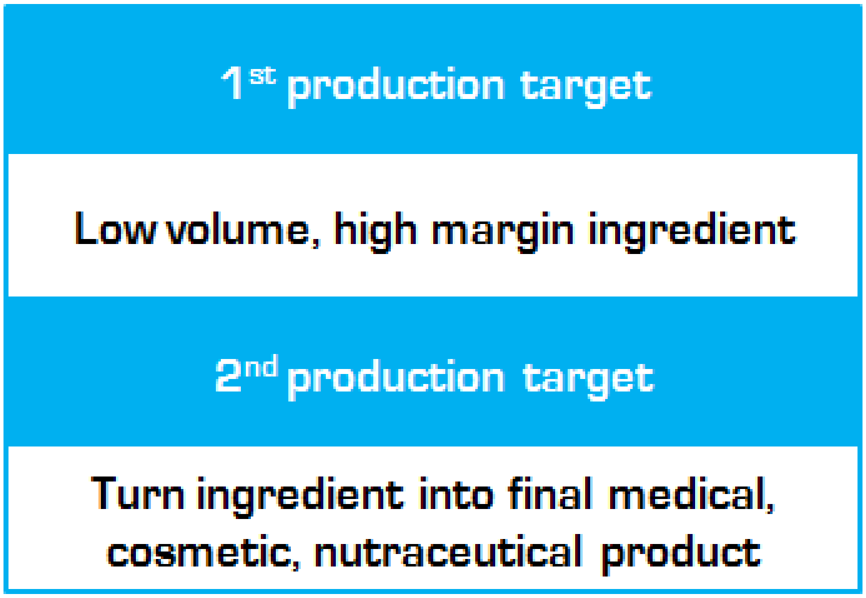

Figure 1: Production targets of successful bioeconomy companies: low volume, high margin functional ingredients, and functional formulations.

After the first few years in which they supplied the ingredient to cosmetic and biomedical companies based in western Europe or North America, they became supplier of the medical and cosmetic formulations widely used in China and across the world as dermal fillers.[15] In this shift (Figure 1), the "vertically integrated" company will earn the huge difference in revenues existing between active ingredients and the final functional products sold on the rich healthcare, cosmetic, nutraceutical and pharmaceutical markets.

2.3 Lean production in small, flexible plants

The key technologies that will enable economically convenient and actually highly profitable bioeconomy productions are similar to those that are eventually enabling a major shift in the global chemical industry.[16] An in-depth knowledge and understanding of these technologies and their possibilities is therefore required for biobased productions to thrive. The aforementioned productions can be based on chemical synthesis, and thus rely on heterogeneously catalytic processes taking place in small, high-throughput flow reactors;[17] or can be based on new, waste-free extraction routes of natural products.[18]

In both cases, the new continuous high-throughput productions are conducted in digitally controlled small, modular plants rather than in huge plants requiring both large capital expense and large operational costs. This, *inter alia* , allows to flexibly adapt productions to customer demand in various regions of the world.[19]Besides cutting the cost of shipping, this will end the reliance on foreign suppliers for substances that can be of vital importance for entire countries, as shown by the prolonged shortage of active pharmaceutical ingredients (APIs) not only in low-income countries but also in industrially developed countries such as the USA, European and Oceania countries.[20]

2.4 From suppliers to business partners

In bioeconomy productions, suppliers necessarily turn into business partners. The fact that value chains of the agri-food and industrial products converge "due to the shift to bio-based raw materials leading to a mutual dependence and triggering new material flows and food processing technologies" was identified in the early studies on technology and innovation management in the bioeconomy.[21] In practice, learning that their by-products supplied at low cost are used for the production of high value substances and materials, farming, forestry or fishing companies will increase prices with the risk to undermine the economic convenience of said bioproductions.

Rather than trying to fix prices with easily broken long-term supply contracts, successful bioeconomy companies have two management options. They will either enter into partnership with their suppliers by establishing jointly owned production plants, thereby sharing revenues and profits, or they will become owners of plantations, forests or fishing companies.

Italy's Indena, for instance, owns several hectares of olive orchard plantations in southern Italy from which it sources the olives used to produce phenolic extracts rich in hydroxytyrosol and verbascoside to be turned into valued cosmetic applications (skin protection and skin antiaging topical and oral formulations). This way, a specific olive variety was selected amid more than 300 existing varieties, while botanists chose the best harvesting period to ensure high levels of verbascoside and other biophenols.[22]

Relying on seasonally dependent biological resources used as raw materials, the manufacturing of biobased products requires establishing mutually beneficial relationships with the suppliers of the raw materials, which generally are agriculture, agrifood, forestry or fishing companies. Gone are the days in which plants or flowers grown by poor farmers were collected in African regions with "most of the benefits captured by the retailers".[23]

The scale of biobased productions and the need to assure the quality of the biological resources supplied requires the development, often from scratch, of a complete supply chain starting from harvest, followed by appropriate handling, storage and delivery of the required biological raw materials. For example, facing a huge increase in demand and production in the last decade (2010-2020), the pectin industry could not rely any longer on slow and highly variable supply of dried lemon peel chiefly sourced from Argentina. Hence, large pectin manufacturers opted to build new production plants in Brazil next to plantations of orange, lemon and lime.[24]

Among other benefits, the immediate supply of waste citrus peel after fruit squeezing allowed preventing microbial spoilage of the fresh peels, which could be readily processed to extract the valued hydrocolloid.

The natural products industry, which originally supplied costly flavour and fragrance ingredients such as vanillin to the food and perfume industries, currently supplies a huge variety of ingredients to the so called "natural and organic industry", namely a sector comprising food supplements, natural organic food and beverage, functional food and beverage, and natural living (personal care, household cleaning and pet products). In 2020, only in the USA such industry enjoyed $259 billion revenues (Figure 2) increasing at 12.7% annual growth rate.[25]

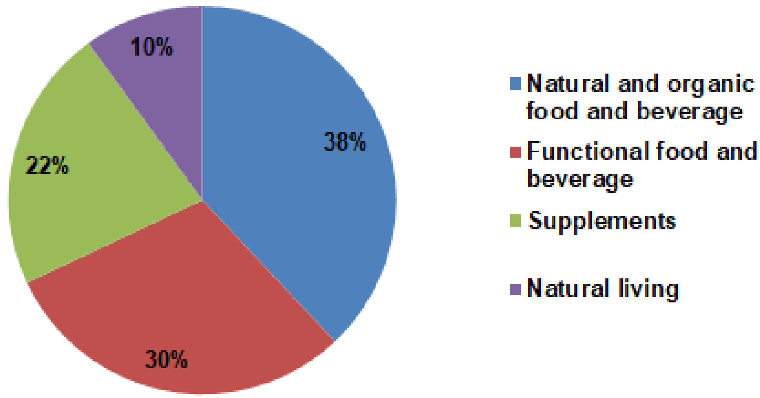

Figure 2: Structure of the natural and organic products industry in the USA in 2020. [Reprorduced from Ref.25, with kind permission]

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Chiefly comprised of European and North American companies, the natural products industry mostly sources natural products from plants, algae and fish. Plants and algae are either collected from the wild in rural areas of Africa, Asia and Latin America or purposefully grown. The active ingredients are then extracted and isolated as standardized extracts in dedicated plants based in France, Italy, Switzerland, Germany, Spain, USA and Canada and then sold to a number of different industries for their pharmaceutical, nutraceutical, cosmetic and health applications.

For comparison, in 2009 the industry, including the key sub-sectors of food and beverages, cosmetics, herbal medicines and pharmaceuticals, had $65 billion revenues.[26]

2.5 Managing the innovation process

Studying the literature on technology and innovation management in bioeconomy companies and building on a previous study of Golembiewski and co-workers,[21] van Lancker and co-workers in 2016 identified five main factors driving the innovation process in the bioeconomy (Table 1), suggesting that an open innovation approach naturally fits the bioeconomy.[27]

Table 1 . Five main factors and requiriments affecting the implementation and management of innovation development processes in bioeconomy companies according to van Lancker et al. (Adapted from Ref.27, with kind permission)

Factor	Requirement
Disruptive innovations	Redesigned business models, reconfigured supply chains, etc.
Complex knowledge base	Variety of sciences and technologies such as life sciences, agronomy, (
Enhanced degree of cooperation with external actors	Cooperation with suppliers, universities and research centres, custon
Enhanced commercialization efforts	New communication to convince customers to adopt new biobased p
Complex and fragmented policy schemes	New products and new processes expected to comply to a number of

Five years later, all these factors and the fact that innovation processes in the bioeconomy are cross-disciplinary, and include a network of diverse stakeholders, are still relevant to managers of bioeconomy organizations, irrespective of the specific production.

The most important and unique trait of bioeconomy productions, however, is the virtually unlimited market for many said productions once an economically viable production process has been identified. This is due to the unique versatility of many biomolecules, independent of their size (e.g. small biomolecules or large biopolymers), which creates room for diverse potentially large-scale applications.

Two examples out of many possible ones nicely illustrate the concept. Tannin is the name given to a mixture of high molecular weight biophenols extracted from certain woods and bark and increasingly used for widely different applications, including as an environmentally friendly agrochemical.[28] Due to an expensive and energy-demanding production process, the current annual production of commercial tannins amounts to about 230,000 tonnes. Tannin, however, has a high-value chemical application as a building block in the preparation of adhesives and resins.[29] The limiting factor for its utilization on the million tonne per year scale, has been and continues to be its limited supply and high cost. In the words of the father of the technology, "the potential is enormous, but it is not realized".[30]

Another example is pectin. Currently manufactured at 70,000 t/a rate, this biopolymer is the most valued food hydrocolloid.[31] Though increasing since more than a decade at 4-6% annual growth rate, its production from citrus peel (and apple pomace) is intrinsically limited by the high capital and operational expenses of conventional production plant and process, respectively.[31] From biobased aerogels of exceptional thermal insulating power through superior food and beverage texturizer and emulsifier, pectin has a number of potential applications that so far were constrained by its limited supply.[24] Once a low cost, high-throughput production process will be discovered and industrialized, for example based on emerging hydrodynamic[32] or acoustic[33]cavitation extraction of citrus waste peel, its potential will be realized and the usage rate will increase to several hundreds of thousand tonnes per year.

Aware of the potentially enormous demand for the above-mentioned and many other bioproducts, bioeconomy companies owner of new process technologies should partner with other companies and license their proprietary technology so as to increase supply and lower the cost of these biobased ingredients, while increasing customer confidence in the biobased alternatives.

This will lead to major uptake of these products in place of competing, less performing – but until now much cheaper – oil-based or biobased alternatives, such as starch or gelatine in the case of pectin. In selecting the partner companies, however, bioeconomy company managers working in a highly competitive context should avoid to be naïve (as well as to be too cynical, opposite side of the same problem).[34] Whether sourcing raw materials from oil-based feedstocks or from biological resources, existing chemical companies are (and will be) the main competitors of new bioeconomy companies. In other words, the biorefinery is not the evolution of the oil refinery, but rather its competitor.

2.6 Understanding the competitive landscape

As mentioned above, bioeconomy managers need a better understanding of the competitive landscape in which their companies operate, namely the global chemicals market.

One of the world's largest biorefineries, located in France's Bazancourt (Figure 3), converts more than 4 million tons of biomass per year (3 million tons of sugarbeet + 1 million tons of wheat + 400,000 tons of other biomasses such as alfalfa and woody materials) into sugar, glucose, starch, food or pharmaceutical alcohol, ethanol fuel, cosmetic actives, etc., with annual revenues exceeding \euro800 million.[35] The site currently hosts eight companies (ADM, Air Liquide, A.R.D., Cristal Union, Cristanol, Givaudan, Procethol 2G, Futurol project, Vivescia), none of which is a petrochemical company. Out of 1,200 workers, 1,000 are permanent staff and 200 on-site scientists.

Figure 3: Europe's largest biorefinery in France's Bazancourt occupies an area of more than 260 hectares [Reproduced from Ref.35, with kind permission]

The biorefinery, reads a succinct presentation, offers "opportunities for synergies between stakeholders at the site" with "flows and interconnections made possible through locations upstream or downstream of existing facilities".[36] In reality, this is exactly what the petrochemical industry does: integrating "upstream" oil and natural gas extraction with "downstream" refining and production of oil-derived and natural gas-derived "feedstocks", basically ethylene, propylene, butadiene, aromatics, and synthesis gas ($CO + H_2$), from which virtually all petrochemicals are derived, including ammonia and methanol.[37]

This industry, and the closely related but largely different fine chemical industry,[38] are the main competitors of the emerging bioeconomy industry. Hence, the managers of successful bioeconomy companies will first study the nature (and the history) of the aforementioned branches of the chemical industry. Willing to enter the chemicals markets with biobased alternatives, the same managers should be aware that customers will buy their products driven only by higher product performance (quality), lower prices and reliable (stable and smooth) supply; and not by "green" or "bio" allures of their company's productions.

This, in turn, requires to systematically adopting the model of lean production in small, flexible plants, which is the only model capable of producing low amounts of high value products at low production cost, following the highly variable customer demand.

3 Conclusions and perspectives

Starting from the need to transfer a closer understanding of the nature of bioeconomy companies and their competitive landscape, this study identifies the guiding principles for managing said companies. These include the key enabling technologies of the bioeconomy, the factors affecting the management of innovation in bioeconomy companies, the need to turn suppliers into real business partners, and to focus on low volume, high-margin bioproducts with the final aim to evolve from suppliers of biobased ingredients to producers of the final formulations reaching the retail marketplace.

Referring to tannin and pectin, we illustrated a unique trait of bioeconomy productions, namely the virtually unlimited market for many bioproductions once an economically viable production process has been identified and industrialized. This is due to the unique versatility of many small and large biomolecules, which creates room for diverse potentially large-scale applications. In an opposite fashion to the "blatant lack of reflexivity" that "characterizes the bioeconomy discourse",[39] these newly shaped managers will manage their company's bioproductions measuring and achieving reduced exploitation of natural resources, aware that rebound effects are possible,[40] and can be avoided. Decoupling of biological material resource use and economic growth is possible both at the level of resource stocks, and at the level of biological renewability.

A single example suffices to render the idea. Recently demonstrated in the case of the most fished species across the seas (the anchovy), concomitant production of both fish oil[41] rich in omega-3 lipids and high performance organic fertilizer[42] can now rely on fish processing waste rather than fish itself. This closes the material cycle through a green chemistry technology (extraction with biobased and antimicrobial solvent limonene) and converts anchovy waste into a highly valued resource. Clearly, this discovery should not lead to increase pressure on the anchovy stocks, but rather to diminish it by finally valorising the biowaste amounting to >50% in weight of the fish catched and so far landfilled or, at best, used for the production of compost.

The same holds for the high energy efficient continuous flow productions that will be used by successful bioeconomy companies, avoiding the Jevons' paradox for which, since machines were more productive and economical, this led to increased use and increased consumption of energy (coal).[43] Aware that the economies of flow, rather than economies of scale, maximize value and minimize waste,[44] managers of such successful organizations will be trained in energy management too. The reason is that energy is no longer a technical issue left unmanaged, but a central one to be taken in charge by fully trained Energy managers working in the top management of the company to effectively achieve higher levels of energy efficiency and renewable energy penetration.[45]

Energy, indeed, plays a significantly more important role in driving economic growth than is conventionally assumed.[43]

Again, one example suffices to provide evidence supporting this claim. From Clermont-Ferrand hospital parking through Algeria's coastal roads using each hundreds of off-grid solar lighting systems based on energy-efficient light emitting diodes, photovoltaic modules and Li-ion batteries, thousands of roads, parks, parking areas and squares today are lit thanks to solar lighting.[46] Owners of the lighting systems receive no electricity or maintenance bills, while light is supplied every year's night to citizens in both economically developed and developing regions. There is no rebound or "backfire" effect. The white light supplied is generally of much higher quality (devoid of UV and IR radiation, with the right colour temperature and with minimal light pollution thanks to advanced optics) than conventional lighting systems using older technology with electricity supplied from the grid.

In conclusion, from India[47] through Germany[48] and the USA,[49] everywhere from across the world a critical analysis of research in management education and Masters in business administration suggest to re-design management education curricula to make education more practice-oriented, and based on theory tested and tried in the field. Educating the managers of the bioeconomy is no exception. This study suggests avenues to plan and develop such a practice-oriented course developed in accord to sound guiding management principles originating from a careful analysis of successful and unsuccessful bioproductions in the first two decades (2000-2020) of the bioeconomy. Eventually, as put it by Raelin, this and related courses will be able to educate and develop managers "who understand the meaning inherent in the current organizational context rather than exporting young visionaries from the outside".[49]

Conflicts of interest

There are no conflicts to declare.

Acknowledgements

This study is dedicated to the memory of solar energy pioneer Hermann Scheer (1944-2010), who reminded throughout his entire professional life the importance of practice-oriented education.

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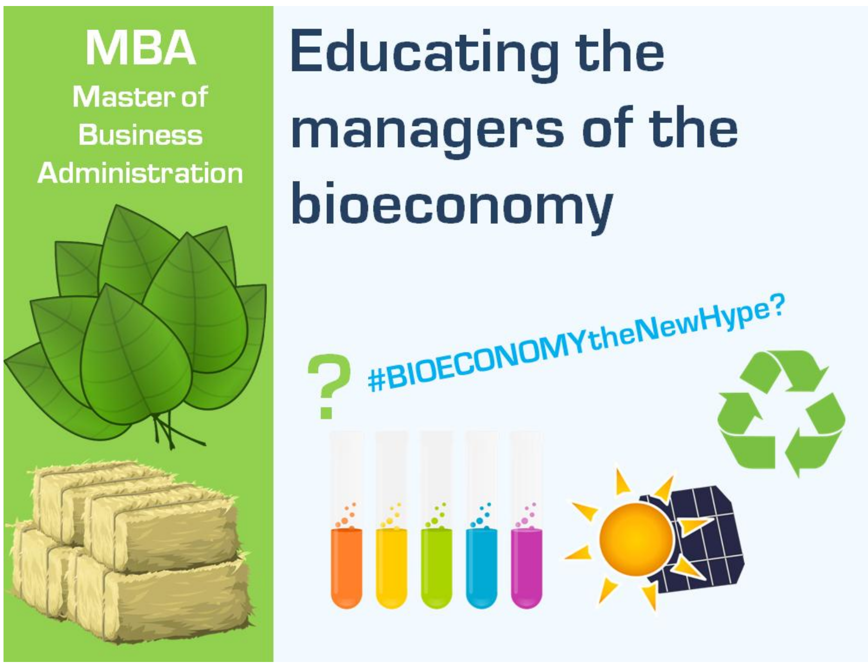

Educating the managers of the bioeconomy

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Shaping the managers of successful bioeconomy companies, we argue in this study, requires to transfer a closer understanding of the nature of bioeconomy companies and their competitive landscape, as well as identifying the main guiding principles for managing these organizations.