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# 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. The characteristic aspects of innovation in the bioeconomy contribute to explaining why it is difficult to find managers for bioeconomy companies. In addition, many different sectors in the bioeconomy pose different managerial challenges. Shaping the managers of successful bioeconomy companies 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. Following the analysis of the first thirty years of bioeconomy company attempts to replace chemical productions based on oil-derived feedstocks, including innovation dynamics, in this research we aim to identify the main guiding principles of successful bioeconomy companies engaged in the production of bioproducts.

## 1. Introduction

In the bioeconomy, the production of useful substances and of useful energy starts, respectively, from biological resources and from renewable energy sources (Bugge et al., 2016). The root cause of this shift is closely related to the end of low cost (or "easy to extract") oil which has literally driven the growth of global wealth and human population since the early 1900s (Meneguzzo et al., 2016; Perissi et al., 2021).

Bioenergy today can be considered part of the overall bioeconomy. Indeed, the emergence of advanced technologies and products (jet fuels, renewable or green diesel, maritime fuels, solar or "green" hydrogen, etc.) has made the relationship between bioenergy and other bioproducts stronger (Lago et al., 2019), bringing challenges to the structuring of new businesses.

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 (BioTalent Canada, 2008).

Nearly 15 years later, the situation has barely changed, with nearly two-thirds of employers surveyed again in Canada having difficulty recruiting qualified professionals due to a lack of skilled and experienced talent (BioTalent Canada, 2021). As a result, the team found, "bioeconomy employers compete for talent among themselves" and "with other sectors for candidates with technical skills" (BioTalent Canada, 2021).

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 (Barreira-Corominas et al., 2020).

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" (Lask et al., 1007). 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

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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 sciences, these Master programs either aim to educate “the type of scientists needed to successfully make this transition” (University of Hoenheim, 2021) 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” (Master BioCirce, 2021).

In agreement for example 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 (Pagliaro, 2012), the curricula of these Master courses generally include topics from both natural and social sciences.

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 guiding principles for managing said companies. This is important because “a blatant lack of reflexivity” currently “characterizes the bioeconomy discourse” (Allain et al., 2022). The newly shaped managers, for example, will manage their company’s bioproductions measuring and achieving reduced exploitation of natural resources, aware that rebound effects are possible (Giampietro, 2019), and can be avoided (see below), provided that guiding management principles are clearly identified. Bioenergy challenges, that are quite different when compared to biobased productions, are not studied here and will form the scope of subsequent research.

## 2. Guiding principles for managing bioeconomy companies

Following the analysis of the first thirty years of bioeconomy company attempts to replace chemical productions based on oil-derived feedstocks, including innovation dynamics, in this research we aim to identify the main guiding principles of successful bioeconomy companies engaged in the production of bioproducts.

Managers of successful bioeconomy companies need first a closer understanding of the nature of bioeconomy companies and their competitive environment, and then an understanding of the innovation dynamics of the bioeconomy.

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 (Ciriminna and Pagliaro, 2020) 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 (Next Five Years Could be, 2020). 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 (van Santen, 2017). 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.

One of the world’s largest biorefineries, located in France’s Bazancourt (Fig. 1), 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 €800 million (Allais et al., 2021). 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.

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” (Chauvet, 2021). 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 (Speight, 2011).

This industry, and the closely related but largely different fine chemical industry (Pollack, 2007), are the main (but not the only) competitors of the emerging bioeconomy industry. More in general, the bioeconomy is a complex environment with activities still being structured, involving several established industries (chemical and petrochemical, agro-industry, pulp and paper, food ingredients, oil and gas companies, brand owners) with which the new bioeconomy companies interact and compete.

Hence, the managers of successful bioeconomy companies will first need to acquire an understanding of the innovation dynamics of the bioeconomy. The subsequent cases analyzed are part of this logic of bioeconomy and innovation. According to Bomtempo and Alves who studied the emergence of the biobased industry in Brazil, the industry four key dimensions (raw materials, conversion technologies, products, and business models) structure the industry (Bomtempo and Alves, 2014).

Studying the literature on technology and innovation management

**Fig. 1.** Europe’s largest biorefinery in France’s Bazancourt occupies an area of more than 260 ha [Reproduced from Allais et al. (2021), Creative Commons License].

in bioeconomy companies and building on a previous study of Golembiewski and co-workers (Golembiewski et al., 2015), 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 (van Lancker et al., 2016).

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 (Pagliaro et al., 2021). 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 (Pizzi, 2019). 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". (Pizzi).

Another example is pectin. Currently manufactured at 70,000 t/a rate, this biopolymer is the most valued food hydrocolloid (Seisun and Zalesny, 2021). 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 (Ciriminna et al., 2016a). 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 (Ciriminna et al., 2002). Once a low cost, high-throughput production process will be discovered and industrialized, for example based on emerging hydrodynamic (Meneguzzo et al., 2019) or acoustic (Wang et al., 2017) 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). (Tsay et al., 2011).

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. This fact in its turn demands that bioeconomy managers understand the nature (and the history) of the aforementioned branches (bulk and fine) of the chemical industry.

**Table 1**
Five main factors and requirements affecting the implementation and management of innovation development processes in bioeconomy companies according to van Lancker et al. (2016), 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, ecology, food science, social science, biotechnology, nanotechnology, information and communication technologies and engineering |
| Enhanced degree of cooperation with external actors | Cooperation with suppliers, universities and research centres, customers and distributors |
| Enhanced commercialization efforts | New communication to convince customers to adopt new biobased products, often obtained from previous waste streams |
| Complex and fragmented policy schemes | New products and new processes expected to comply to a number of different regulations from different administrative levels; biomass cascade steps often forbidden by current policy |

### 2.1. Low volume, high margin bioproducts

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.

Management consultants studying companies using synthetic biology production processes (*i.e.*, fermentation) (HewageLux Research, 1015), 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. 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 (HewageLux Research, 1015).

### 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. 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 (Ciriminna et al., 2021a).

In this shift (Fig. 2), 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 (Pagliaro, 2019). 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

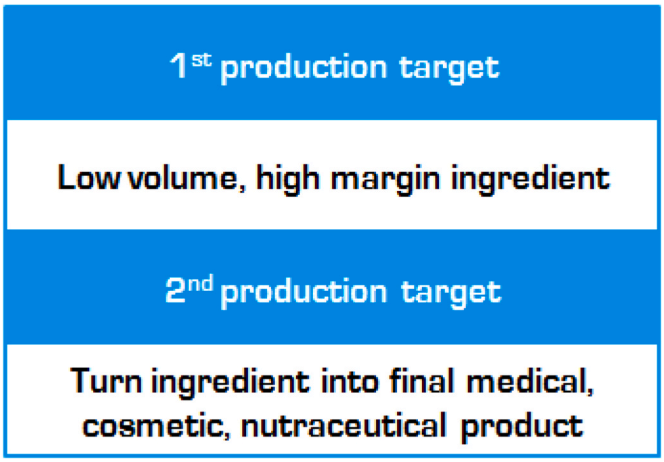


**Fig. 2.** Production targets of successful bioeconomy companies: low volume, high margin functional ingredients, and functional formulations.

chemical synthesis, and thus rely on heterogeneously catalytic processes taking place in small, high-throughput flow reactors (Ciriminna et al., 2021b); or can be based on new, waste-free extraction routes of natural products (Chemat and Strube, 2015).

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 (Liao and Wang, 2021). 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 (Sundus et al., 2021).

### *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 (Golembiewski et al., 2015).

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 (Chapman, 2008).

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” (Govindasamy et al., 2007).

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 (Seisun and Zalesny, 2021).

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 (Fig. 3) increasing at 12.7% annual growth rate (Mast et al., 2021).

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 (Ariyawardana 2009).

## 3. Discussions and conclusions

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 need *i*) to focus on low volume, high-margin bioproducts made *ii*) in small, flexible plants according to customer demand, with the aim *iii*) to evolve from suppliers of biobased ingredients

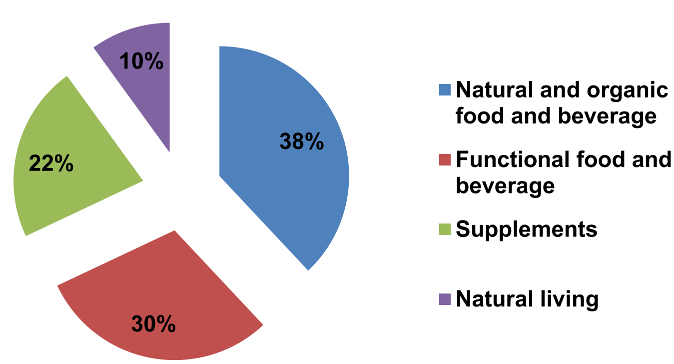


**Fig. 3.** Structure of the natural and organic products industry in the United States of America in 2020. [Adapted from Mast et al. (2021), with kind permission].

to producers of valued formulations, having care *iv*) to turn suppliers of the raw biomaterials into real business partners.

Referring to tannin and pectin, we have illustrated a unique trait of bioeconomy productions, namely the virtually unlimited market for many bioproductions once a technically and economically viable production process is industrialized. This fact is due to the unique versatility of many small and large biomolecules, which creates room for diverse potentially large-scale applications.

As mentioned in the introduction, these newly educated managers will be aware that rebound effects are possible (Giampietro, 2019), and can be prevented. For instance, 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 prove the concept. Recently demonstrated in the case of the most fished species across the seas (the anchovy), concomitant production of both fish oil (Ciriminna et al., 2019) rich in omega-3 lipids and high performance organic fertilizer (Muscolo et al., 2022) can now rely on fish processing waste rather than fish itself. This closes the material cycle through a green chemistry technology (lipid extraction with biobased and antimicrobial solvent limonene) and converts anchovy waste into a highly valued resource. The discovery will reduce pressure on the anchovy stocks, by finally valorising biowaste amounting to >50% in weight of the fish catched that so far has been mostly landfilled or, at best, used for the production of compost.

The same holds true for the energy-efficient continuous flow productions 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) (Sorrell, 2009). Aware that the economies of flow, rather than economies of scale, maximize value and minimize waste (Seddon and Caulkin, 2007), managers of such successful organizations will also be trained in energy management. Energy, indeed, is no longer a technical issue that can be left substantially unmanaged passively paying the natural gas or electricity bills, but a central management issue to be proactively managed by Energy managers educated with a new approach in which science and technology are given equal importance to economic and financial aspects (Ciriminna et al., 2016b).

Energy, indeed, plays a significantly more important role in driving economic growth than is conventionally assumed (Sorrell, 2009).

Again, one example suffices to provide evidence supporting this claim. From Clermont-Ferrand's 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 (Meneguzzo et al., 2017). There is no rebound or "backfire" effect. Owners of the lighting systems for at least two decades will receive no electricity bill having to face nearly negligible maintenance costs. 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) (Meneguzzo et al., 2017) than conventional lighting systems using older technology with electricity supplied from the grid.

From India (Goyal et al., 2021) through Germany (Wagner, 2010) and the USA (Raelin, 2009), the 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. Education of the bioeconomy managers 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" (Raelin, 2009).

While the present study presents the guiding principles for managing bioeconomy companies to widen and improve the education of bioeconomy company managers, it does not specify the curriculum of a typical new course. Said curriculum and the case studies relevant to widely different world's areas and countries will be the object of a new study. Furthermore, the few examples discussed could be extended to a greater variety of companies (for example, the transformation processes of established companies such as Neste, Stora Enso, UPM, DSM, and others) and products (alternative proteins, for example). Again, this will form the topic of the detailed study describing the curriculum of a new course aimed at shaping bioeconomy managers.

## CRediT authorship contribution statement

**Rosaria Ciriminna:** Methodology, Data curation, Writing – review & editing. **Lorenzo Albanese:** Investigation, Writing – review & editing. **Francesco Meneguzzo:** Methodology, Writing – review & editing. **Mario Pagliaro:** Conceptualization, Writing – original draft, preparation.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## References

Allain, S., Ruault, J.-F., Moraine, M., Madelrieux, S., 2022. The 'bioeconomics vs bioeconomy' debate: beyond criticism, advancing research fronts. Environ. Innov. Soc. Transit. 42, 58–73. https://doi.org/10.1016/j.eist.2021.11.004.

Allais, F., Lescieux-Katir, H., Chauvet, J.-M., 2021. The continuous evolution of the Bazancourt–Pomacle site rooted in the commitment and vision of pioneering farmers. When reality shapes the biorefinery concept. EFB Bioecon. J. 1, 100007 https://doi.org/10.1016/j.bioeco.2021.100007.Ariyawardana, 2009 Ariyawardana, A., Govindasamy, R., Simon, J.E., 2009. The natural products industry: a global and African economic perspective. In: Juliani, H.R., Simon, J.E., Ho, C.-T. (Eds.), African Natural Plant Products: New Discoveries and Challenges in Chemistry and Quality, 1021, pp. 7–28. https://doi.org/10.1021/bk-2009-1021.ch002. ACS (Am. Chem. Soc.) Symp. Ser.

Barreira-Corominas, A., Gairí, J., Tienda, D., 2020. *Report about the Analysis of Educational Gaps Identified in the Different Regional Contexts and Action Fields*, UrBIOfuture-Boosting Future Careers, Education and Research Activities in the European Biobased Industry. Madrid. https://www.bioeconomy-library.eu/wp-content/uploads/2020/02/D3.3_Report_about_the_analysis_of_educational_gaps_identified.pics_.pdf. (Accessed 6 June 2022).

BioTalent Canada, 2008. Segmenting the Data. Ottawa. https://www.biotalent.ca/wp-content/uploads/2008/09/Segmenting_the_data_E_Sept19_08.pdf. (Accessed 6 June 2022).

BioTalent Canada, 2021. Close-up on the Bio-Economy. Ottawa. https://www.biotalent.ca/wp-content/uploads/BioTalent-Canada-LMI-DemandandSupply-13OCT2021-1.pdf. (Accessed 6 June 2022).

Bomtempo, J.V., Alves, F., 2014. Innovation dynamics in the biobased industry. Chem. Biol. Technol. Agric. 1, 19. https://doi.org/10.1186/s40538-014-0019-8.

Bugge, M.M., Hansen, T., Klitkou, A., 2016. What Is the bioeconomy? A review of the literature. Sustainability 8, 691. https://doi.org/10.3390/su8070691.

Chapman, R., 2008. Indena and Kanebo Present Olive Fruit Extract. Cosmetics & Toiletries. October 31. https://www.cosmeticsandtoiletries.com/cosmetic-ingredients/actives/news/21839496/indena-and-kanebo-present-olive-fruit-extract. (Accessed 6 June 2022).

Chauvet, J.-M., 2021. Biorefinery of Bazancourt. https://www.francechimie.fr/media/51b/bazancourt.pdf. (Accessed 6 June 2022).

Chemat, F., Strube, J., 2015. Green Extraction of Natural Products. Wiley-VCH, Weinheim.

Ciriminna, R., Pagliaro, M., 2020. Biodegradable and compostable plastics: a critical perspective on the dawn of their global adoption. ChemistryOpen 9, 8–13. https://doi.org/10.1002/open.201900272.

Ciriminna, R., Fidalgo, A., Scurria, A., Ilharco, L.M., Pagliaro, M., 2002. Pectin: new science and forthcoming applications of the most valued hydrocolloid. Food Hydrocolloids 127, 107483. https://doi.org/10.1016/j.foodhyd.2022.107483.
Ciriminna, R., Fidalgo, A., Delisi, R., Ilharco, L.M., Pagliaro, M., 2016a. Pectin production and global market. Agro Food Ind. Hi-Tech 27 (5), 17–20.
Ciriminna, R., Pecoraino, M., Meneguzzo, F., Pagliaro, M., 2016b. Reshaping the education of Energy managers. Energy Res. Social Sci. 21, 44–48. https://doi.org/10.1016/j.erss.2016.06.022.
Ciriminna, R., Scurria, A., Avellone, G., Pagliaro, M., 2019. A circular economy approach to fish oil extraction. ChemistrySelect 4, 5106–5109. https://doi.org/10.1002/slct.201900851.
Ciriminna, R., Scurria, A., Pagliaro, M., 2021a. Microbial production of hyaluronic acid: the case of an emergent technology in the bioeconomy. Biofuel Bioproc. Bioref. 15, 1604–1610. https://doi.org/10.1002/bbb.2285.
Ciriminna, R., Pagliaro, M., Luque, R., 2021b. Heterogeneous catalysis under flow for the 21$^{st}$ century fine chemical industry. Green Energy Environ. 6, 161–166. https://doi.org/10.1016/j.gee.2020.09.013.
Giampietro, M., 2019. On the circular bioeconomy and decoupling : implications for sustainable growth. Ecol. Econ. 162, 143–156. https://doi.org/10.1016/j.ecolecon.2019.05.001.
Golembiewski, B., Sick, N., Bröring, S., 2015. The emerging research landscape on bioeconomy: what has been done so far and what is essential from a technology and innovation management perspective? Innovat. Food Sci. Emerg. Technol. 29, 308–317. https://doi.org/10.1016/j.ifset.2015.03.006.
Govindasamy, R., Hitimana, N., Puduri, V.S., Juliani, H.R., Simon, J.E., 2007. Constraints and perceptions of natural products trade in Rwanda. Acta Hortic. 756, 413–423. https://doi.org/10.17660/ActaHortic.2007.756.44.
Goyal, J.K., Daipuria, P., Jain, S., 2021. An alternative structure of delivering management education in India. J. Educ. Technol. Syst. 49, 325–340 https://doi.org/10.1177%2F0047239520958612.
Hewage, G., Lux Research. Surviving and thriving in renewable chemicals. https://www.bio.org/sites/default/files/legacy/bioorg/docs/1015%20Hewage.pdf. (Accessed 6 June 2022).
Lago, C., Herrera, I., Caldés, N., Lechón, Y., 2019. Nexus bioenergy–bioeconomy. In: Lago, C., Caldés, N., Lechón, Y. (Eds.), The Role of Bioenergy in the Bioeconomy. Academic Press, Cambdridge (MA), pp. 3–24. https://doi.org/10.1016/B978-0-12-813056-8.00001-7.
J. Lask, J. Maier, B. Tchouga, R. Vargas-Carpintero, The bioeconomist in bioeconomy, I. Lewandowski (Ed.), https://doi.org/10.1007/978-3-319-68152-8_12; pp.343-356.
Liao, M.H., Wang, C.T., 2021. Using enterprise architecture to integrate lean manufacturing, digitalization, and sustainability: a lean enterprise case study in the chemical industry. Sustainability 13, 4851. https://doi.org/10.3390/su13094851.
Mast, C., Peters, K., McCoy, N., 2021. The state of our natural & organic industry today, natural products east 2021. https://www.newhope.com/sites/newhope360.com/files/NPEE21%20State%20of%20Natural_Master%20%20Organic%20Presentation.pdf. (Accessed 6 June 2022).
Master BioCirce, Program Overview, 2021. https://masterbiocirce.com/program-overview/. (Accessed 6 June 2022).
Meneguzzo, F., Ciriminna, R., Albanese, L., Pagliaro, M., 2016. The Energy-Population Conundrum and its Possible Solution, 1610.07298. *arXiv*. https://arxiv.org/abs/1610.07298v1.
Meneguzzo, F., Ciriminna, R., Albanese, L., Pagliaro, M., 2017. Solar street lighting: a key technology *en route* to sustainability. Wiley Interdiscip. Rev. Energy Environ. 6, e218. https://doi.org/10.1002/wene.218.
Meneguzzo, F., Brunetti, C., Fidalgo, A., Ciriminna, R., Delisi, R., Albanese, L., Zabini, F., Gori, A., dos Santos Nascimento, L.B., De Carlo, A., Ferrini, F., Ilharco, L.M., Pagliaro, M., 2019. Real-scale integral valorization of waste orange peel via hydrodynamic cavitation. Processes 7, 581. https://doi.org/10.3390/pr7090581.
Muscolo, A., Mauriello, F., Marra, F., Calabrò, P.S., Russo, M., Ciriminna, R., Pagliaro, M., 2022. AnchoisFert: a new organic fertilizer from fish processing waste for sustainable agriculture. Global Chall. 6, 2100141 https://doi.org/10.1002/gch2.202100141.
Next five years could be pivotal for bioplastics. Plast. Today, 2020. https://www.plasticstoday.com/packaging/next-five-years-could-be-pivotal-bioplastics (accessed April 20, 2022).
Pagliaro, M., 2012. Science and management: a new alliance within the unifying context of culture. Adv. Manag. Appl. Econ. 2, 1. https://bit.ly/3cRidvu.
Pagliaro, M., 2019. Angew. Chem. Int. Ed. 58, 11154–11159. https://doi.org/10.1002/anie.201905032.
Pagliaro, M., Albanese, L., Scurria, A., Zabini, F., Meneguzzo, F., Ciriminna, R., 2021. Tannin: a new insight into a key product for the bioeconomy in forest regions. Biofuel Bioproc. Bioref. 15, 973–979. https://doi.org/10.1002/bbb.2217.
Perissi, I., Lavacchi, A., Bardi, U., Ulgiati, S., Casazza, M., Lomas, P.L., 2021. The role of energy return on energy invested (EROEI) in complex adaptive systems. Energies 14, 8411. https://doi.org/10.3390/en14248411.
Prof A. Pizzi, cit. In Ref.24.
Pizzi, A., 2019. Tannins: prospectives and actual industrial applications. Biomolecules 9, 344. https://doi.org/10.3390/biom9080344.
Pollack, P., 2007. Fine Chemicals: the Industry and the Business. Wiley, New York.
Raelin, J.A., 2009. The practice turn-away: forty years of spoon-feeding in management education. Manag. Learn. 40, 401–410. https://doi.org/10.1177/2F1350507609335850.
Seddon, J., Caulkin, S., 2007. Systems thinking, lean production and action learning. Action Learn. Res. Pract. 4, 9–24. https://doi.org/10.1080/14767330701231438.
Seisun, D., Zalesny, N., 2021. Strides in food texture and hydrocolloids. Food Hydrocolloids 117, 106575. https://doi.org/10.1016/j.foodhyd.2020.106575.
Sorrell, S., 2009. Jevons' Paradox revisited: the evidence for backfire from improved energy efficiency. Energy Pol. 37, 1456–1469. https://doi.org/10.1016/j.enpol.2008.12.003.
Speight, J.G., 2011. Hydrocarbons from Petroleum in *Handbook of Industrial Hydrocarbon Processes*. Gulf Professional Publishing, Houston, pp. 85–126. https://doi.org/10.1016/B978-0-7506-8632-7.10003-9.
Sundus, S., Fatima, Z., Khezar, H., Amna, S., Ali Hassan, G., Sumaira, O., Shuchen, H., Zaheer-Ud-Din, B., Yu, F., Caijun, Y., 2021. Drug shortage: causes, impact, and mitigation strategies. Front. Pharmacol. 12, 1772. https://doi.org/10.3389/fphar.2021.693426.
Tsay, C.-J., Shu, L.L., Bazerman, M.H., 2011. Naiveté and cynicism in negotiations and other competitive contexts. Annals 5, 495–518. https://doi.org/10.5465/19416520.2011.587283.
University of Hoenheim, bioeconomy, master of science. https://www.uni-hohenheim.de/fileadmin/uni_hohenheim/Studiengaenge/bioecon/Flyer_msc_bioecon.pdf, 2021–. (Accessed 6 June 2022).
van Lancker, J., Wauters, E., Van Huylenbroeck, G., 2016. Managing innovation in the bioeconomy: an open innovation perspective. Biomass Bioenergy 90, 60–69. https://doi.org/10.1016/j.biombioe.2016.03.017.
van Santen, R.A., 2017. Modern Heterogeneous Catalysis: an Introduction. Wiley-VCH, Weinheim, pp. 15–58. https://doi.org/10.1002/9783527810253.ch2.
Wagner, R., 2010. The Effects of Management Education upon Strategic Practice and Performance: the Case of the German SME Machinery and Equipment Sector. PhD thesis. University of Glasgow. http://theses.gla.ac.uk/id/eprint/1838. (Accessed 6 June 2022).
Wang, W., Wu, X., Chantapakul, T., Wang, D., Zhang, S., Ma, X., Ding, T., Ye, X., Liu, D., 2017. Acoustic cavitation assisted extraction of pectin from waste grapefruit peels: a green two-stage approach and its general mechanism. Food Res. Int. 102, 101–110. https://doi.org/10.1016/j.foodres.2017.09.087.