1 The Historical Origins of the Bioeconomy

Learning Objectives

To understand and be able to critically discuss:

- the role of strategies for building a vision of the future for the transition towards a sustainable bioeconomy.
- the history of the bioeconomy.
- the role of collective innovation strategies for the transition towards the bioeconomy.

1.1 From Today's Bioeconomy to Those of the Past

In its 2012 paper, the European Commission defined the bioeconomy as encompassing 'the production of renewable biological resources and the transformation of these resources and waste streams into value-added products such as food, feed, bioproducts and bioenergy'.[1] It thus gave impetus to a broad movement of thinking, which took the form of the development of national strategies towards the bioeconomy (Lokko et al. 2018; Staffas et al. 2013), which reincorporated earlier exercises dealing with biorefinery.

However, this questioning is not new. We have identified two in particular that could have been moments of development of a bioeconomy. In the United States, the 1920s was a moment of crystallisation during which a social bloc was formed at the initiative of isolationists and agrarianists who joined the project of pioneer scientists, seeking to lift the Deep South out of poverty and its cotton monoculture through the non-food use of other products and co-products of agriculture. They sought to theorise and promote what they called *Chemurgy*. To do so, we have relied on the work of historians of technology (Finlay 1997, 2003) or economic policy (Pursell 1969), the very abundant historical documentation gathered by the American Soybean Information Center (Shurtleff & Aoyagi 2011), as well as documents of the American Chemistry Society.

[1] This document extends the Lisbon strategy adopted in 2000, which launched the 'Knowledge Based Economy' (KBE), which will be declined into a Knowledge Based Bio-Economy (KBBE) in 2007.

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At the end of the 1970s, the crisis in the chemical industry, linked to the oil crisis and the saturation of its markets and the slowdown in its innovations, led to the exploration of sugar chemistry as a vector for new growth. During the foresight exercises of the time (published between 1979 and 1982), a large number of the paths explored today were mentioned, hence our interest in this particular moment of problematisation. Biotechnology was then 'chosen' as one of the two fields in which a return to growth was expected.

During these periods, actors problematised their industry (Jullien & Smith 2012). This means that economic and political actors sought to determine collectively the innovations to be developed to drive the development of their industry. Section 1.2 of this chapter explains the role of actors' expectations in driving the development of an industry and the development of innovations. Section 1.3 is devoted to the presentation of the biorefinery. Section 1.4 is devoted to chemurgy. Section 1.5 details the bioindustry movement.

1.2 Problematisation, Visions of the Future, and Promises

1.2.1 Visions of the Future as a Basis for the Problematisation of Economic Activities

The transition to a sustainable bioeconomy aims to develop an economy that is no longer based on the use of oil but on the use of renewable resources that must respect planetary limits (cf. Chapter 2). This dynamic brings into play visions of the future. That is, the opportunity for a transition to the bioeconomy relies on the need for actors to share common representations (Beckert 2013, 2016; Borup et al. 2006).

These shared representations have the function of accompanying the actors in their activities that are subject to very high uncertainty. This uncertainty is linked to the instability related to production, demand, and the ability to access the natural resources necessary for production. To counter these uncertainties, actors translate their visions of the future into narratives. These narratives are then expressed in speeches, projects, etc.

From this point of view, the transition to the bioeconomy is being played out today under the influence of the futures that the actors represent (Giurca et al. 2022). In doing so, actors act 'as if' this future were true and build their innovation strategies in this direction. Actors are then strongly invested in the definition and propagation of these visions of the future, which may be contradictory. Thus, the actors proceed with *backcasting* exercises. Unlike the scenario method, which starts from the present to identify futures, *backcasting* starts from a vision of the future to identify the transition path to be followed and the technical and economic obstacles to be overcome (Sanders et al. 2010).

1.2.2 The Role of Innovation Commons

Innovations have a role to play in the transition to the bioeconomy because the aim is to use new raw materials and develop new processes, new products, new outlets, or new forms of organisation. These innovations can aim to replace existing products (e.g. biodegradable plastics aim to replace single-use plastics) or to fulfil new functions (e.g. because of its lightness and strength, hemp can be used to produce high-speed train bodies).

We often think that innovations are the result of an individual process driven by a particularly inspired entrepreneur. However, in order to emerge, all innovation projects rely on the production of common knowledge that the actors share. These particular forms of innovation are called innovation commons (Potts 2018).

These common resources appear when actors seek to solve a common problem (here, how to industrialise the production of bio-based products). Thus, this governance tool allows actors to give themselves a common vision and to co-ordinate their activities. To do so, the actors share not only technologies and demonstrative objects but also information guiding the discovery of entrepreneurial opportunities. This collective action makes it possible to defend innovations under development from the pressures of established actors. Nevertheless, these commons are bound to disappear in the future.

1.3 A Bioeconomy Based on Biorefinery?

After the first oil crisis in 1973, the agro-industry and the paper industry put the idea of renewable-based industrial production back on the public policy agenda. The pressure of agricultural surpluses and overcapacity in the paper industry led them to define the range of products that could be produced, based on a theorisation of the biorefinery object and a strategy for disseminating its model in various areas (Cherubini et al. 2009).

By analogy with the oil refinery, the biorefinery will be conceived as the functional unit carrying out the cracking of raw materials of plant or animal origin of various natures and qualities, in order to reduce them to liquid fuels, and a small number of large chemical intermediates, allowing the preservation and continuation of carbon chemistry. Like the petroleum refinery, which generates the bulk of commodity chemistry from steam cracking in five major intermediates,[2] the prospective study conducted by the US Department of Agriculture (Werpy & Petersen 2004) proposes to target twelve major intermediates selected on the basis of expert opinion by crossing the technological expectations of rapid substitution and the size of the markets (a list reduced to a top ten by Bozell & Petersen (2010)). Although this vision is contested because of its reductive aspect or its lack of

[2] Ethylene, propylene, butadiene, toluene, and benzene.

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attention to its sustainability, it is indeed the one that has become dominant in the bioeconomy landscape (Morone et al. 2019).

This dominant representation of the future of plant-based chemistry comes from commodity chemistry, from small light molecules such as diacids, and making it possible to reform *chemical structures identical* to those of products derived from fossil carbon. However, this is debated, as other avenues for future exploration exist. Colonna et al. (2015) identified two other paradigms: the search for molecules of renewable origin with different structures, but providing the same functions, and the search for new functionalities that can be achieved, thanks to the complex structures that living organisms have been able to produce – and which it is important not to destroy in the cracking process. Nevertheless, the bioeconomy is based on two objectives that are difficult to reconcile: increasing the use of natural resources through technical progress and ensuring the sustainable use of these resources through controlled pressure on ecosystems (Levidow et al. 2013).

1.4 The *Chemurgy*, Problematisation of a Development Path

1.4.1 Chemurgy as a Social Movement for the Use of Renewable Resources

When it emerged in the 1920s, *chemurgy* brought together very contrasting characters. G. W. Carver, son of a black slave with an uncertain birth date, sought from the 1890s to develop new agricultural production and their valorisation in order to lift the black farmers of the 'Deep South' out of its endemic poverty. Although he was excluded from federal research grants because of the racism of Alabama's laws, this did not prevent him from finding more than a hundred non-food applications for soybeans and peanuts, from seeking to valorise all waste products on the farm, from finding other ways than those of pesticides and chemical fertilisers, and from protecting soils from erosion and monoproduction. Carver's pre-World War I 'creative chemistry' (Abrams & Adair 2009) is dreamlike in its proximity to the uses expected today: the use of food co-products for the manufacture of insulating panels, paints, dyes, industrial alcohol, various types of plastic, carpets, mats and fabrics, oils, gums and waxes, etc. He became famous at the end of World War I by proposing a process for producing rubber from sweet potatoes.

In the mid-1920s, an unexpected actor emerged: the railroad companies. Stricken by the post–World War I crises of overproduction, they sought to plan a regional development likely to bring them business, based on the presence of an agro-industry 'on the farm' (Finlay 1997). The unlikely meeting between the agro-ecologist son of a slave and Henry Ford is probably because the latter was seeking to circumvent the steel cartel by producing his car bodies and some of his car parts from renewable

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resources. He dreamt of vertically integrating all the raw materials, processes, and components necessary for his automobile production:

> In May 1935, Ford brought together over 300 leaders of agriculture, education, industry, and science in Dearborn, Michigan, for the first Dearborn Conference of Agriculture, Industry, and Science. Here the Farm Chemurgic Council was established, with Francis Garvan and the Chemical Foundation (a non-profit group dedicated to advancing the position of industrial chemistry) promising to support the group for the first year. (Permeswaran (2010), p. 97)

The Great Depression, if it strengthened the interest in *chemurgy*, was above all a moment of conflict between the isolationists and agrarians and the Roosevelt presidency because the former claimed that the ‘free’ development of *chemurgy* was a sufficient alternative to the interventionist measures of the New Deal; nevertheless, they ended up accepting the creation by Roosevelt in 1938 of four regional laboratories of the US Department of Agriculture dedicated to *chemurgy*. Thus, the emergence of *chemurgy* took shape through the conjunction of three phenomena: (i) the growing interest in a new industrialisation of chemistry (Galambos et al. 2007), (ii) the existence of agricultural production surpluses, and (iii) a political debate between isolationists and agrarians.

1.4.2 Promises of Chemurgy and the Constitution of Networks of Actors

The end of *chemurgy* can be explained by the cessation of large-scale projects, the victory of oil over the use of renewable resources, and the opposition to *chemurgy* by leaders of the American agricultural world, who favoured specialisation in commodity agricultural products rather than a strategy of diversification towards non-food biomass (Finlay 2003). However, two elements must be kept in mind to understand the contemporary dynamics.

On the one hand, the formation of a specific meso-economic space is a meeting place for heterogeneous actors around technical objects. Within this space, actors set up reflections on all the knowledge to be produced, the resources to be assembled, and the political alliances to be built to support the industrial effort. Through reality checks, they seek to make stable a particular regime of knowledge production and economic activities.

On the other hand, the technical and economic promises required *the production of demonstrative objects* to support the development stories. The various products proposed by Carver (often with little commercial success but always well publicised to the point that we find traces of them in major films of the time), or at Ford the prototype cars with bodies made of thermosetting plastics from renewables, fulfil this function. It is therefore interesting to focus on these promises by projecting them onto the current situation (see Table 1.1).

Table 1.1 Comparison of the techno-economic promise of chemurgy and current chemurgy

	Raw materials and targeted products	Products still targeted at present
1920–1934	– Soy milk → paints, lubricants, automotive plastics – Corn cob, pine waste, sweet potato, hemp, and various grains → raw materials – Natural alcohol (ethanol) → energy and gasoline/ethanol blends – Cellulose, starch, lignin, fructose →sugars and fibres	– Soybean oils for lubrication (e.g. biopress) – Pine waste such as bark for the production of insulating foams – Hemp-based materials and wheat for the production of PHA (high value-added biodegradable plastic) – Incorporation rate already existing, generalisation of biofuel production – Lignin (materials vs. energy), starch (materials vs. chemistry of molecules), cellulose in materials, and hygiene (e.g. toothpaste)
1935–1939	– Use of sawmill waste → production of materials and plastics – Beet sugar, artichoke waste, farm waste → butanol, acetone – Hemp, flax, rice → paper – Rice → furfural and glycerine – Sweet potato → starches – Cane sugar, sorghum, sweet potatoes → ethanol – Pines, tung → newspapers – Cellulose → synthetic fibres, automotive materials	– Reuse of sawmill waste for materials and not just energy – Bio-based butanol – Furfural – Generalisation of ethanol – Cellulosic extraction techniques
1939–1945	– American rubber sources – Molecules → pharmacy – Wheat → adhesives – Sugar cane → fat – Casein → clothing, fibres – Fermentation → production of antibiotics	– Reintroduction of natural rubber (Michelin) – Cardboard and adhesives by wheat starch (arugula) – Fermentation techniques
1945–1972	– Vegetable oils → lecithin, glycerine, plastics, adhesives, flame retardants – Fermentation using lactic, citric, gluconic acid	– Polyurethanes from vegetable oils – PLA from lactic acid fermentation

1.5 The Late 1970s: Towards a Bioindustry?

This second moment of problematisation appeared to the experts to be a deeper crisis than the oil shocks of 1973 and 1979 alone. In what follows, three observations that emerged from several documents published during this period will be discussed (Section 1.5.1). Then, the French foresight exercise on the bioindustry will be presented (Section 1.5.2). Finally, the European position on the subject, resulting from the Framework about SusTainability (FAST) program of DG XII of the EEC, will be analysed (Section 1.5.3).

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1.5.1 Three Observations at the Origin of the Reflection on the Development of Bioindustries

The first observation is the clear slowdown in the pace of innovation in the chemical industry compared to the 1950s–60s, as attested by subsequent econometric studies, such as that of Achilladelis et al. (1990).

The second observation is the saturation of large markets built through property rights monopolies and the so-called *ultimate plant* strategy, theorised by the Dupont de Nemours company. In this strategy, productivity investments allowed for a drastic reduction in production costs in order to dissuade the entry of competitors. The downside of such a strategy is the creation of structural rigidities that are ill-equipped to cope with the new instability caused by market saturation and the instability of upstream and downstream prices.

The third observation is that the United States of America, in association with the large chemical companies concerned by the crisis of the large chemical production units (and the European Commission), would have developed state-of-the-art and prospective hypotheses on the fields likely to revive growth and innovation (van Laer 2010). These states of the art are constitutive of the work that the actors carry out around technological promises, as well as the place where common resources are constituted.

1.5.2 Chemistry and 'Classical Bioindustries' at the Heart of European Reflection

During this period, several reports and journal special issues were published. With the support of policymakers, they outlined the stakes in terms of industrial exploitation of the scientific revolution of genetic engineering in a complementary way with 'classic' bioindustries. The 'classical' bioindustries and chemistry are at the heart of the development of an engineering science of continuous processes, an essential condition for achieving productivity gains in large refineries (Danielou & Broun 1981). Beyond the product innovations introduced by genetic engineering, it is the capacity to propose catalytic reactions that is the most appreciated quality of biotechnologies. Indeed, these allow us to envisage an improvement in the efficiency of processes. However, it appears that industrialists will only adopt biotechnologies when they succeed in challenging the existing process (Penasse 1981). Between the two polar situations (domination of the classical chemical process *vs.* that of a biotechnological process), the authors of the reports and journals mentioned above saw a set of technological paths qualified as *hemisynthesis* (coupling or cascade use of chemical and biotech reactions) creating a set of new economic opportunities.

The authors did not envisage the disappearance of thermochemical processes from the bioindustry landscape in favour of biotechnological processes. Thus, in order to locate themselves in the space of competing trajectories, the actors produced analytical diagrams of the main sectors. These show that the current landscape was already mapped out in 1981. For example, Chesnais (1981) already listed the raw materials under discussion today, from oil shale to biomass or waste. Biomass is transformed in processes that go either towards synthesis gases (thermochemistry) imitating petroleum chemistry or towards fermentation processes that loop back on it from ethanol or diacids. It is the same carbon chains as those from 'king oil' that are targeted. Hence, there is confusion between bioindustries mobilising a biotechnological process and those mobilising biomasses, whatever the process.

The problematisation exercise then focuses on Schumpeterian ruptures within existing agro-industries and brings to light two elements that seem to us to be structuring today. On the one hand, innovation leads to the development of hyper-competition between biosourced raw materials as soon as scientific advances in biotechnologies can become continuous industrial processes (Zitt 1983, p. 42). On the other hand, biotechnological innovation[3] makes it possible to reconfigure the value chain to obtain control of the 'global supply chain' from intermediate products: 'Finally, this mixed process-product innovation is significant for major trends in technological evolution in the bioindustries: the development of markets for intermediate products freed from a single agricultural source, and the emergence of a new technical operator, "immobilised enzymes", of which the production of isoglucose is the most important industrial application to date' (Ibid., p. 42).

From this point of view, the key variable of change is economic since, in theory, most petroleum chemical products can be produced from a biotechnological process. Research in biotechs is therefore oriented in a precise direction: to challenge each existing chemical or thermochemical process, in order to consider whether it is possible to envisage a substitution of these processes, with an *identical* product or final function (e.g. sweetness). This type of orientation based on a vision of the future of chemistry hybridised with biotechnologies thus generates a particular regime of knowledge production – and of the resulting economic activities (Cohendet et al. 1987). This is dedicated to the enrichment of commons that are also specific, without the knowledge of thermochemistry targeted by the substitution disappearing for all that.

1.5.3 What Structure(s) for a Bioindustry-Based Chemistry?

The work of the Organisation for Economic Co-operation and Development (OECD) in 1978–79 and of the FAST EUR7767 program of the European Commission (DG XII), which brought together researchers and large chemical firms on the prospects for chemistry in Europe (well-known from the publications of the BETA laboratory in Strasbourg); Ancori & Cohendet (1984) had a definite influence on the development of the European chemical industry. These research programs identified four main themes around which it was proposed to articulate the innovation policy on a European scale: the chemistry of small molecules[4] (linked to the renewal of carbochemistry), the chemistry of sugars, the chemistry of new materials, and the chemistry of function.

[3] Let us specify that we are talking about industrial biotechnologies that we would qualify today as classical in the sense that they involve preparing enzymes for use in industrial conditions and not 'new biotechs' based on genetic engineering manipulations.

[4] 'Small molecule chemistry' refers to the chemistry related to the production of chemical molecules with a low number of carbon atoms (one to three carbon atoms), whereas sugars contain more. This classification is structuring for the reflection on the transition of a sustainable chemistry.

However, this way of organising these themes would suggest that the bioindustry would be reserved for sugar chemistry, which is not the case, as we will show. The challenges of small molecule chemistry are discussed as those of a renaissance of coal chemistry. The core of the promise of the bioindustry core lies in the fact that one could imagine substituting for the intermediates derived from petrochemistry, an intermediate derived from gasification of the carbon chains of coal – that is, methanol – on which it is possible to base a set of technological hopes. Like the five basic petrochemical intermediates,[5] 'the downstream chemistry of methanol is very rich' (Cohendet 1982, p. 17). It allows the reformation of fuels and acetic acid, which serves as a base for plastics (PET), solvents, paints, and varnishes (Box 1.1).

However, biosourced routes for materials chemistry and functional chemistry have also been documented. It is therefore in the four themes of the report on the prospects for chemistry in Europe that we must look for traces of a problematisation of the bioindustry and not in only one, that of sugar chemistry. This observation is not surprising if we follow the work of Colombo, who was to be the founder of Novamont, a leading company in the conversion of Italian chemistry to renewables. In his 1980 article, based on a report for the OECD while he was in charge of R&D at Montedison, Colombo defended the need for a kind of technological pluralism, identifying the fields of activity where it is relevant to intervene with this or that technology, with the idea of achieving a better balance between centralised production (around the ultimate plants) and decentralised production (Colombo 1980).

Box 1.1 Acetic Acid from Ethylene (Reconstituted by us from the Article 'Acetic Acid' Ulmann's Encyclopaedia of Industrial Chemistry, vol. 1, pp. 209)

Acetic acid, produced from petroleum ethylene, methanol from coal chemistry, or by biological means (the good old vinegar), can be used as a:

- solvent: miscible with water and various organic solvents such as ethanol, diethyl ether, and glycerol, but insoluble in carbon sulphide; it is also a good solvent for gums, resins, phosphorus, sulphur, and halogenated acids;
- production of acetic anhydride, cellulose acetate, vinyl acetate monomer, and other acetates, as well as medicines, pesticides, dyes, and products of the photographic industry;
- food (production of fruit vinegars, food additive);
- textiles;
- cleaning agent (e.g. for semiconductors);
- coagulant (from natural latex);
- bacteriostatic (in solution);
- in the manufacture of plastics such as polyethylene terephthalate (PET) or cellulose acetate, useful in the production of vinyl acetate (paints, adhesives) and organic solvents; and
- additive in tobacco products (flavouring).

[5] Ethylene, propylene, butadiene, toluene, benzene.

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1.6 Conclusion: What Lessons Can Be Learnt from the Study of the Current Bioeconomy?

This chapter focuses on the study of two moments of problematisation of the future. In these two particular moments, actors sought to construct visions of the use of renewable resources. Table 1.2 compares the characteristics of the *chemurgy*, the "bioindustry" of the 1980s and what is now called the bioeconomy. It shows the great permanence of the resources mobilised, the qualification and co-ordination mechanisms, and the underlying collective production issues. We have pointed out the dominant role of small molecule chemistry in the visions of the future of bioindustries, a result that has been found in the current bioeconomy. Indeed, this chemistry was first established in that of fossil materials, associated with large production units, providing large intermediates to the basic chemistry. This model will significantly orient biorefinery research on the small molecules of the renewable known since the chemurgy era. Today, however,

Table 1.2 The structure of the chemurgy, bioindustry, and bioeconomy innovation commons

	Chemurgy	Bioindustry	Bioeconomy
Material and immaterial resources	– Co-products of food and agriculture		– Heterogeneous knowledge bases
	– Agricultural production surplus	– Government funding of prospective projects	– Project financing
	– Advances in the industrialisation of chemistry	– Opportunities offered by the emergence of new processes	– Biomass from agro-industrial agriculture
	– Regional laboratories for *chemurgy*		
Knowledge production and diffusion among members of the community	– Formation of a social bloc linking isolationists and agrarians	– State-of-the-art qualifying technologies	– Definitions of the bioeconomy
	– Farm Chemurgic Council	– Possibility of competing with an existing process	– Financing of projects aiming at non-food valorisation
	– Integration of *chemurgy* projects in large companies (Ford)		– The use of renewable resources, if possible, in a sustainable way
Common understanding of entrepreneurial opportunities	– Chemurgic Council	– Think tanks and foresight groups	– Biorefinery and industrial pilots
	– Development of production units	– Small molecule chemistry	– Platform molecules *vs.* new functionalities
	– Demonstration of emblematic products	– Emblematic products	– Promise of transition carried by the bioeconomy and its products
		– Centralised *vs.* decentralised production	

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we also find a more complex macromolecular chemistry that is more closely linked to materials science, suggesting the opportunity for a more decentralised bioeconomy – also present in the *chemurgy* or at the turn of the 1980s.

Take-Home Message

- The bioeconomy is the new name for an old dynamic.
- The development of innovations in the bioeconomy is the product of the interaction between groups of actors, the development of knowledge, and the formation of promises.
- The development of non-food uses of biomass is currently concentrated around emblematic products (e.g. biofuels, biodegradable plastics).

Learning Exercises

1. What are the periods of development of non-food uses of the biomass?
2. From the presentation of the old products, what is taken back today?
3. What are the differences between each period?

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