Preprint

Title: Building Human and Industrial Capacity in European Biotechnology: The Yeast Genome Sequencing Project (1989–1996).

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Abstract

During the years 1989-1996 the European Commission took a leading role in sequencing the yeast genome. The project was completed in April 1996 and celebrated as the success of a European research strategy based on a distributed model of scientific collaboration. Almost one hundred laboratories and private companies dispersed all over Europe took part in the sequencing work sponsored by the European Commission and an industrial platform was created to facilitate the exploitation of the genomic data by companies which were interested in yeast. The yeast genome project was part of the biotechnology strategy developed by the European Commission during the 1980s and 1990s. The Commission expected biotechnology to be relevant in crucial areas of political, economic and social intervention and wanted to promote economic growth and contribute to the process of European integration by developing a community strategy in biotechnology. Due to the strong industrial value of yeast, which is used by agrofood, pharmaceutical and biotechnology companies, sequencing the genome of this microorganism proved an ideal opportunity to pursue the Commission's plans and the paper will examine how the yeast genome project was shaped to build human and industrial capacity in European biotechnology. By investigating capacity building, it will be possible to understand why the European Commission decided to sponsor and coordinate a scientific project in genomics,

but with the real aim to strengthen economic growth in the biotechnology sector and promote integration among new and old member states of the European Economic Community.

Keywords

Yeast; Sequencing; Biotechnology; Capacity; R&D; European Commission

1. Introduction

> The first complete description of a eukaryotic genome, the yeast genome, is nowadays a 'classic' result of a [European] Community's programme. We are rather proud of it. […] In its field, the yeast genome project represented a new way to do research. […] The Europeans proved able to work together not only when they had to build a machine too expensive for the individual countries, but also when it was necessary to reach a critical threshold of human capacity distributed among several laboratories.[1]

With these words, Paolo Fasella, head of the European Commission's Directorate for Science, Research and Development for almost fifteen years, commented the collaborative project to sequence the yeast genome promoted by the European Commission (EC).[2] Dozens of European laboratories and several biotechnology companies based in Europe joined the project that started in 1989 and contributed to sequence over half of the yeast genome. The remaining sequencing work was undertaken by the Wellcome Trust Sanger Centre (UK), Washington University St. Louis (US), Stanford University (US), McGill University (Canada) and RIKEN (Japan) (Goffeau and Vassarotti 1993, p. 35 Table 2) (Fig. 1). The EC was the main project sponsor and also acted as global coordinator of the international network that took part in mapping and sequencing the

[1] Interview with Paolo Fasella (1998), pp. 24-26. Voices on Europe Collection (INT585), Historical Archives of the European Union (http://archives.eui.eu/en/oral_history/INT585). My translation.

[2] Fasella (1930-1999) was a physician by training and a research biochemist by profession. He managed the directorate for Science, Research and Development from 1981 until 1995.

yeast genome.

When the complete sequence was unveiled in April 1996, it was celebrated as the success of a European research strategy based on a distributed model of scientific collaboration (Millet 1996). Almost one hundred laboratories and private companies dispersed all over Europe took part in the project (Goffeau et al. 1996, p. 567). They were based in founding member states of the European (Economic) Community (EEC), such as France and Germany, but also in countries which had only recently joined the EEC, like Spain and Portugal.[3] The microbiologist André Goffeau coordinated the project.[4] He was both a scientist based at the Université Catholique de Louvain (UCL) in Belgium and a civil servant working for the EC in DG XII, the Directorate for Science, Research and Development headed by Fasella. Goffeau managed the project with the support of Alessio Vassarotti, an EC's civil servant in charge of biotechnology projects and a former student of Goffeau (Goujon 2001, p. 556).

For the EC and its civil servants the yeast genome project was much more than an initiative to take part in the race to map and sequence the genome of model organisms and the human genome (Cook-Deegan 1996, Fortun 1999). Unlike other popular model organisms, such as *Drosophila melanogaster* and *C. elegans*, yeast had a strong industrial value, as it was used by the food industry, the fermentation industry, the biotechnology industry and the pharmaceutical industry. It was therefore "appropriate to finance the sequencing of its genome in the context of the [European] community programmes in biotechnology" (Goffeau and Vassarotti 1993, p. 37, my translation), whose implicit focus was on industry (Senker 1998, p. 2). The main EC biotechnology initiatives of the time that sponsored the yeast genome project were the

[3] The European Economic Community was absorbed into the European Union (EU) with the Lisbon Treaty signed in 2009. The denomination European Union began to be used in 1992 with the signing of the Maastricht Treaty.

[4] Goffeau acted also as global coordinator of the project and liaised with the institutions not sponsored by the EC that participated in sequencing the yeast genome. A table with the worldwide contributions to the yeast genome project is published in Levy (1994, p. 1699).

Biotechnology Action Programme (BAP), the Biotechnology Research, Innovation, Development and Growth in Europe Programme (BRIDGE) and the programmes BIOTECH I and II (Table 1). To promote the transition from research to commercial applications the EC also facilitated the creation of industrial platforms in its biotechnology programmes (Aguilar et al. 1998). The first one was the Yeast Industry Platform (YIP), which was created in 1990 by companies sympathetic to the yeast genome project. YIP members had privileged access to the genomic data collected by the laboratories sponsored by the EC and were encouraged to contact the sequencing contractors if interested in the industrial exploitation of the genomic data (Goffeau and Vassarotti 1993, p. 38).

The idea that the yeast genome project must be framed within the biotechnology programmes implemented by the EC during the 1980s and 1990s, and more generally within the biotechnology policy developed in those years, is not new. Philippe Goujon already established such connection in his book *From Biotechnology to Genomes* (Goujon 2001). Unlike Goujon's book, however, the aim of this paper is not "to write the 'little tale' of the European and world effort to sequence the yeast genome" (Goujon 2001, p. xvi). Neither this paper aims to address specific aspects of the yeast genome project, such as its collaborative model (Joly and Mangematin 1997a, 1998), the management of intellectual property rights (Joly and Mangematin 1997a) or the data access policy (Hilgartner 1998; 2017, pp. 171-172).[5] Instead, this paper will examine how the

[5] The historiography on the yeast genome project is not extensive. Apart from the contributions mentioned above (Goujon 2001; Hilgartner 1998, 2017; Joly and Mangematin 1997a, 1997b, 1998), little else – see Cooke-Deegan (1996, p. 201) and Langer (2016, pp. 431–434) – has been written on the yeast genome project by historians of science and STS scholars. On the contrary, the European scientists and civil servants who took part in the project were prolific writers. Their published contributions, alongside reports on the yeast genome project and EC's policy documents are the primary sources on which this paper is based. They are complemented by oral histories and archival documents provided by the Historical Archives of the European Union (HAEU), the National Human Genome Research Institute Archive (NHGRI), the Carlsberg Archive, the Archive of European Integration (AEI), E. J. Louis personal papers.

yeast genome project was shaped to build the human capacity in biotechnology mentioned by Fasella in the opening quotation and why this human capacity and the associated industrial capacity (see, for instance, Senker 1998, p. 160) were part of the EC's plans for economic development and European integration.

'Capacity building' is an actors' category for the EC's civil servants and the advisors involved in shaping biotechnology policies during the 1980s and 1990s. They repeatedly use the term (e.g. Cantley 1983; European Commission 1988; Senker 1998), although they never define it explicitly. Reading between the lines of the policy documents, it is evident that the EC's civil servants and policy advisors had in mind a broad strategy of human resources and industrial development when they wrote about Europe's need for "a broadly-based scientific and technological capability to respond to the twin needs of increased competitiveness and a better quality of life", when they assessed the necessity of cost-effective solutions for developing such capabilities and the relevance of basic research in achieving them, and when they stressed the regional differences in R&D capacities across the Community (European Commission 1988, p. 5; p. 10; p. 60).

Besides being an actors' category, capacity building can also act as a useful analytical category for the contemporary historian. By using this concept, it is possible to interconnect the scientific, economic and political agendas that shaped the yeast genome project and made it an experiment in science policy and European integration as much (and probably more) than a contribution to genomics. Used as an analytical category, capacity building resonates with the namesake concept now widespread in the international aid and development literature, and in management and in public policy (Kislov et al. 2014). While it is not the aim of this paper to establish and discuss connections between the capacity building model envisaged by EC's civil servants and policy advisors during the 1980s and 1990s and the modern concept of capacity building, the EC is certainly recognised as an early proponent of the capacity building concept in relation to the economic development of disadvantaged communities (Pence and Benner 2015,

pp. 7–8) and European social fund objectives incorporated the notion already in the 1990s (Harrow 2001, p. 210).[6] Since then the concept has never disappeared from the EC's policy discourse whenever at stake there are research and innovation strategies and their impact on social and political development (see, for instance, Andrés Rodríguez-Pose 2014).

In relation to the yeast genome project, the use of capacity building will allow to understand why a political and administrative entity, the EC, decided to sponsor and coordinate a scientific project in genomics, but with the real aim to strengthen economic growth in the biotechnology sector and promote integration among new and old member states of the EEC. When the yeast genome project started at the turn of the 1990s, "[p]olitical orders that seemed to be rigidly fixed changed within only a few years" (Bornschier 2000, p. 3). The fall of the Berlin Wall in 1989 and the dissolution of the Soviet Union in 1991 marked the end of the Cold War era. At the same time, the European integration process culminated in the Maastricht Treaty and the creation of the European Union in 1992. All these events had an immediate effect on the yeast genome project sponsored by the EC, because the network of participating laboratories constantly expanded from 1989 until the conclusion of the project in 1996.

By examining the yeast genome project as an opportunity to build human and industrial capacities in European biotechnology, the paper will contribute to the growing historiography on the role of science and technology in European integration. It will complement the existing literature on scientific facilities and organisations in Europe (Guzzetti and Krige 1997; Krige 1996, 2002, 2014), and add an history of science perspective to the historiography of technology that has already addressed how "European integration depended on and was shaped by material networks, technical systems, and the circulation of knowledge and artifacts" (Misa and Schot 2005, p. 2). The paper will also contribute to the current literature on biotechnology in the European Union (EU), a literature which is mainly focused on the social conflicts raised by

[6] More information on the early uses of the term capacity building can be found in Craig (2010).

biotechnology and the divisions it produced (e.g. Gottweis 1998; Jasanoff 2005; Montpetit et al. 2006). Conversely, the case of the yeast genome project emphasises how biotechnology could be an opportunity to build political integration and develop policies consistent with European values and standards. The yeast genome project will offer a specific example of how biotechnology became "an occasion for the formation of European culture in action" (Bud 1994, p. 202).

To provide evidence for my argument, I will examine EC's biotechnology policies in the 1980s and 1990s and the role that genomics had in them. I will then describe in detail the organisation of the Yeast Genome Sequencing Network and how it was used to build human and industrial capacity in European biotechnology. In conclusion, I will discuss how the use of capacity building allows to interconnect the scientific, political and business agendas that shaped European biotechnology.

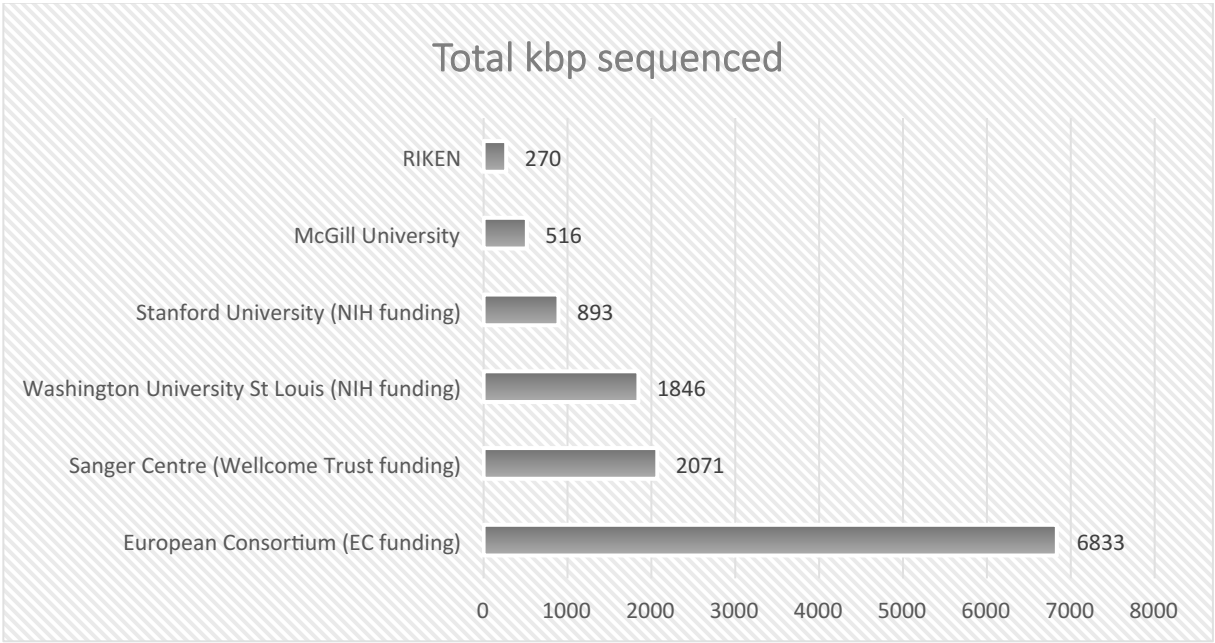

Figure 1

Data source: European Commission 1996, p. 6. There was a total of 377 kbp overlap between DNA fragments allocated to EU, UK, USA, Canada and Japan.

Table 1: EC Biotechnology Programmes that funded the Yeast Genome Sequencing Project

Programme name	Total budget (in million ECU)	Programme duration	Yeast chromosomes mapped/sequenced
Biotechnology Action Programme (BAP) and revision	75	1985-1990	III
Biotechnology Research for Innovation, Development and Growth in Europe (BRIDGE)	100	1990-1993	II, X, XI
BIOTECH I	184.14	1992-1996	IV, VII, X, XIV, XV
BIOTECH II	595.50	1994-1998	IV, VII, XII, XV, XVI

Data source: Hoeveler and Cresti (1997). The budget figures are extracted from the EU Parliamentary question E-0206/1998.

2. The EC's strategy in biotechnology during the 1980s and 1990s

> The Community's research activities in biotechnology have a long history starting from radiation biology in EURATOM, arguments in the 1970s about recombinant DNA regulation, and the long debate which led in 1981 to adoption of a first and modest (15 MECU, 1982-86) "Biomolecular Engineering Programme (BEP)", covering elements of genetic engineering and enzymology. (European Commission 1991 Annex II)[7]

This is the genealogy of biotechnology research in the EEC, as reconstructed by EC's civil servants in the early 1990s (see also Cantley and de Nettancourt 1992). This genealogy has crystallized and it is still adopted in recent accounts of biotechnology written by EC's civil servants (Aguilar et al. 2013). This linear narrative that connects early work in radiation biology to biotechnology reflects the career path of many amongst the most influential people involved in biotechnology during the 1980s and 1990s. It is certainly the case for Dreux de Nettancourt, who advanced "a possible action of the European Communities for the optimal exploitation of the fundamentals of the new biology in applied research" in the 1970s and went on to become

[7] The ECU (European Currency Unit) was used by the EC as an internal accounting unit until 1999, when it was officially replaced by the Euro.

head of the EC's biotechnology division during the BEP programme in the early 1980s.[8] André Goffeau, a close associate of de Nettancourt for many years and the coordinator of the yeast genome project, also moved from the radiation protection projects sponsored by the Community to work on the EC's biotechnology programmes (Goujon 2001, p. 94).

However, this account that connects the EURATOM radiation biology programmes to biotechnology fails to explain the revolutionary claims that EC's policy documents formulated about biotechnology in crucial areas of political, economic and social intervention, such as chemicals, food, health, energy and the environment (Cantley 1983; European Commission 1983, 1994). The radiation biology programmes promoted by EURATOM were very limited in scope and aimed only at the creation of common standards in European nuclear research and protection.[9] By contrast, the EC's vision for biotechnology "expressed a grand design interfacing R&D policies, industrial policies, and regulatory politics" (Gottweis 1998, p. 171). To realise this "grand design" it was necessary to increase the resources available and the budget of the biotechnology programmes rose steeply from the modest BEP budget of 15 million ECU to the almost 600 million ECU of BIOTECH II, the biotechnology programme that sponsored the final stages of the yeast genome project (see Table 1).

However, money alone would not have been enough to sustain the EC's grand design for European biotechnology, if this enterprise had not been recast as a "European project" in need of a supranational strategy (Gottweis 1998, p. 174). Already in 1983, Mark Cantley, an EC's civil servant who worked for many years on shaping biotechnology policies, stressed the necessity of "political confidence in a Community approach, and some de facto sharing of costs, risks, and benefits at European scale" (Cantley 1983, p. 65). In this scenario, the objectives of the EC's

[8] Cold Spring Harbour Laboratory Archives Ref. SB/1/2/206/3.

[9] On the EURATOM research programmes see Fasella's interview (pp. 6-8), Historical Archives of the European Union, Ref. INT585. The most ambitious goal of the EURATOM Treaty was the development of a common strategy in the industrial exploitation of nuclear energy, a common strategy which never materialised.

biotechnology R&D policy had to be "compatible with and supportive of other community policies" related to economic growth, industry, education, health, agriculture, development, environmental issues, etc. (Cantley 1983, pp. 74–75). The first FAST (Forecasting and Assessment in Science and Technology) programme also officially concluded that the interdisciplinary nature of biotechnology, the diversity of its applications and its expected potential made "valuable to look at the whole biotechnology problem at European level" and the analysis required "had to go beyond the scientific and industrial aspects and take account of the political and social implications" (European Commission 1983, p. 21).

Concertation became a major concern within EC's biotechnology policy "with the objectives of improving standards and capabilities in the life sciences, and enhancing the strategic effectiveness with which these are applied to the social and economic objectives of the Community and its Member States".[10] As argued by Sheila Jasanoff,

> biotechnology policy became a site of interpretive politics, in which important elements of European identity were debated along with the goals and strategies of European research. [...] to answer what Europe should strive to achieve in the field of biotechnology, it proved necessary to address what kind of union Europe was – or wanted to be – both in relation to its member states and as a player on the world stage. (Jasanoff 2005, p. 92)

The EC gained the legislative tools to become a key player in the promotion of biotechnology with the enforcement of the Single European Act (SEA) (Cantley 1995, p. 518).[11] The SEA completed the constitution of the internal market, strengthened political integration and expanded community powers in relation to research and development, environmental issues and common foreign policy. This treaty marked a qualitative shift in European integration because

[10] Quotation taken from Cantley (1995, p. 539). In 1984 a secretariat known as Concertation Unit for Biotechnology in Europe (CUBE) was created within DG XII redeploying the staff involved in the biotechnology activities of the FAST programme. Cantley managed this secretariat until it was dissolved in 1992.

[11] The Single European Act was signed in 1986, but came into effect in July 1987.

regulated "policy cooperation at European level" (Bornschier 2000, p. xii). In the case of biotechnology it enabled the EC to act as a "political entrepreneur" promoting research programmes and the creation of "an industry-friendly legal environment" (Nollert 2000, p. 243).[12] These actions were lobbied for by the transnational European business elite that "were pushing to have the same opportunities as their global competitors by broadening their home base (allowing for greater economies of scale) and by getting support from strategic technology policy" (Bornschier 2000, p. 29). However, if transnational were the business stakeholders and national the governments and institutions that took part in and benefitted from the EC's R&D programmes in biotechnology, it was the supranational dimension of the Commission, which was influenced but not driven by national ambitions, that made political entrepreneurship possible and transformed the yeast genome project in an opportunity to increase human and industrial capabilities in European biotechnology.

However, in Europe biotechnology was not only associated to positive images of economic growth, more employment and increased industrial competitiveness. Ethical issues, environmental and health risks and unsettling transformations of the labour market were seen as potential negative outcomes produced by biotechnology and requiring regulation at national and transnational level. The establishment of a regulatory framework for biotechnology (Cantley 1995) was indeed one of the areas in which the EC became very active during the 1980s and 1990s, alongside the protection of intellectual property rights associated to biotechnology inventions (see Directive 98/44/EC on the legal protection of biotechnology inventions) and the monitoring of the public perception of biotechnology, for instance through the Eurobarometer

[12] The EC is both a political and an administrative entity (Christiansen 1997). Its ambiguous role stems from its tasks and its organisation. While president, vice-presidents and members of the Commission are politically nominated, the thousands of EC's civil are not, but they all together participate in the highly politicized tasks of the Commission which consist in proposing legislation and supervising the implementation of policies and (when necessary) their renegotiation at national scale.

surveys (Jasanoff 2005, pp. 85–89).

In shaping its R&D biotechnology policy, the EC decided to limit its intervention to 'pre-competitive' research. The Community facilitated the creation of links between academic and industrial research and stimulated associations among private companies for dealing with investigations not directly connected to marketable products. The leap from pre-competitive investigations to near-market research was instead left "to the companies themselves so as to maintain the incentive for them to compete through innovation" (European Commission 1991, p. 15). The EC took also upon itself the tasks "to develop in biotechnology the habit of transnational collaboration between [academic] laboratories within Europe" (European Commission 1991 Annex 2). A successful initiative in this pursuit was the creation of "open-ended, transnational association[s] of cooperating European groups with a common commitment to target-oriented multidisciplinary research" (van der Meer et al. 1987, p. 318). These associations, called European Laboratories Without Walls (ELWWs), were launched in the context of the BAP programme and brought together researchers working in industry and academia in a free exchange of methods, materials and results (European Commission 1988, p. 242). The pilot phase of the yeast genome project, the sequencing of chromosome III, was one of such ELWWs. The project, sponsored by the Commission with over 2.5 million ECU, was able to bring together "most of the best European laboratories working on yeast molecular biology" (Vassarotti and Magnien 1990, p. 12) and proved the feasibility of the EC's network approach and its effectiveness in building human capabilities across the EEC. Apart from stimulating precompetitive research, the EC also provided training opportunities, especially "in Member States which recently joined the Community or where stronger foundations in basic biotechnology must be prepared" (European Commission 1991 Annex 3).

The expected outcome of this strategic investment in biotechnology was to make the EEC, as a supranational organisation, competitive with United States and Japan. Hardly any EC's document on biotechnology written during the 1980s and 1990s fails to mention US and

Japanese performances in biotechnology and to compare them with the European effort (see, for instance, European Commission 1984). Regulatory frameworks, policy attitudes, long and short-term investment strategies were examined in detail to understand whether there were lessons to be learnt and pitfalls to be aware of in the competition with US and Japan. The EC expected biotechnology to provide two million jobs by the year 2000 (European Commission 1991, p. 3). But worldwide competition was especially tough in biotechnology because multinational companies could relocate their R&D activities where they expected to find the best regulatory and economic conditions, and knowledge-intensive jobs could shift from one country to another. The German chemical industry BASF, for instance, moved its main R&D biotech activities to Massachusetts, when Germany adopted EC's regulations on genetically modified organisms that were deemed too restrictive (Mackenzie 1993). The biotechnology strategy that the EC promoted in those years, therefore, was shaped by two equally important ambitions. The first ambition was to build a transnational biotechnology community in Europe. This community involved not only the member states of the EEC, but also COST-participants and EFTA countries that took part in the EC's biotechnology programmes, starting with the BRIDGE programme.[13] This transnational approach within Europe had to coexist with the EC's second ambition to make European biotechnology a global player, able to both compete and collaborate with partners based in US and Japan. To become a global player in biotechnology, Europe needed both the human capacity generated by EC's training opportunities and cooperation schemes, such as the ELWWs, and the industrial capacity that clear regulations on biotechnology inventions and stronger links between academic laboratories and private companies could stimulate.

[13] COST (European Cooperation in Science and Technology) is an intergovernamental network for the promotion of scientific and technological exchange founded in 1971. The European Free Trade Association (EFTA) was founded in 1960 by Norway and Switzerland. Iceland and Liechtenstein have also joined this association.

3. Genomics in EC's biotechnology

Genome mapping and sequencing projects had a role in EC's biotechnology strategies since the 1980s. "The characterization of the structure and expression of microbial, animal and plant genomes" was officially presented as a priority area of intervention already in the BEP programme (Davignon 1983). Genome analysis remained central to EC's biotechnology throughout the 1980s and 1990s. Within the BAP, BRIDGE and SCIENCE programmes, mapping and sequencing activities on the genomes of model organisms – yeast, *Arabidopsis thaliana*, *Bacillus subtilis*, *Drosophila melanogaster* – and on the mouse and porcine genome were funded (Vassarotti et al. 1990, p. 87 (Table)). In 1990 also a dedicated programme for the human genome, the Human Genome Analysis Programme, was adopted by the EC (Hallen and Klepsch 1995). These genomic projects facilitated transnational collaboration in Europe and international cooperation with the US and Japan at the same time. As mentioned above, the yeast genome project involved laboratories based in the EEC, EFTA and COST countries alongside institutions in the US, Canada and Japan. The same pattern – with the exclusion of Canadian laboratories – was used for the *Arabidopsis thaliana* project (Delseny et al. 1997). The genome of *Bacillus subtilis* was sequenced by a consortium of European (EEC and EFTA) laboratories in association with Japanese laboratories (Kunst et al. 1995).

Despite the cooperation with US and Japan, however, the EC approach to genome analysis of model organisms remained markedly 'European'. Both the US and Japan invested in the development of sequencing technology and in the creation of dedicated centres able to undertake large-scale sequencing work. For instance, the RIKEN centre in Tsukuba, Japan, which sequenced chromosome VI of the yeast genome, heavily invested in the automation of DNA sequencing (Cook-Deegan 1996, p. 217). The same emphasis on technology was placed in the US and, with a certain disconcert, a US commentator returning from an EC meeting on genomics pointed out that "the Europeans do not appreciate our emphasis on development of sequencing technology as a prerequisite for funding of sequencing projects of important model

organisms". While model organisms were part of the Human Genome Project in the US, in Europe they were studied for their "economic implications", as already mentioned for yeast, and community-based efforts were deemed compatible with the decision to use state-of-the-art-methods, and entrust the sequencing laboratories also with the functional analysis.[14]

When called to decide whether to invest in new technology or in increased human capability, the choice of the EC always favoured the latter against the former during the 1980s-1990s. This is the reason why the mapping and sequencing projects of model organisms sponsored by the EC turned into capacity building exercises in both academia and industry, as I argue for the yeast genome project. That is also the reason why these projects could not be reproduced later in time, when artisanal skills in sequencing had been completely outdated by the factory-style work carried out in dedicated centres. At most, small laboratories could be called upon "to sort out problem regions where their specialist knowledge of the organism involved may be of assistance" (Goffeau et al. 1996, p. 567). A change in the EC's biotechnology strategy in genomics was therefore required in the second half of the 1990s, but its investigation falls beyond the scope of this paper.

As mentioned in the introduction, the yeast genome project was compatible with the EC's biotechnology programmes because its scientific interest for yeast as model organism went hand in hand with the industrial value of yeast. A successful strategy in biotechnology required to "establish a much closer and more interactive relationship between fundamental research and commercial production" (European Commission 1988, p. 27) and the yeast genome project enforced this vision by bringing together academic research and industrial R&D. If the majority of the European laboratories that sequenced the yeast genome were based in academic institutions, nonetheless private companies were systematically involved in the project either as (paid) contributors to the sequencing work or as members of the YIP.

[14] Linda Engels, Report on the Genome Analysis in the EC Meeting, May 1991, National Human Genome Research Institute (NHGRI) Archive, file ref. 1219_007.

Aside from the industrial implications, the project was considered value for money because the yeast genome was compact and with very little non-coding DNA, it acted as a model for other eukaryotic genomes, including the human genome, and offered an opportunity to identify rapidly the function of unknown genes through targeted disruption. "Translated in plain economic terms this signifies that we are dealing with the best 'scientific output/resources invested' ratio available on the 'market'", argued Goffeau and Vassarotti (Goffeau and Vassarotti 1990, p. 30). The economic evaluation of the project is indicative of the EC's approach to genome analysis and suggestive of how the EC, as a promoter of science and technology, never forgot to be first and foremost a political body whose accountability was to multiple stakeholders, not to the EEC's scientific community alone. In this sense, another aspect of the project fulfilled the EC's needs. Sequencing the yeast genome did not pose any ethical concern (Vassarotti et al. 1995, p. 131).[15] This was crucial in the European context where biotechnology remained a contested field of research and social anxieties about biotechnologies were considerable and could hinder scientific research and industrial R&D.

4. The Yeast Genome Sequencing Network

During the years 1989-1996 the EC invested about 20 million ECU in the yeast genome sequencing project (European Commission 1996, p. 6).[16] The initial funding was provided in the context of the BAP programme and sponsored the sequencing of chromosome III (January 1989–December 1990). The remaining mapping and sequencing activities sponsored by the EC were related to chromosomes II, IV, VII, X, XI, XII, XIV, XV, XVI (Fig. 2) and were undertaken from 1990 to 1996. The Université Catholique de Louvain, Goffeau's own

[15] At the conclusion of the yeast genome project the civil servants in DG XII re-evaluated the ethical and legal implications of the project (DG XII 1996).

[16] EC funding was often integrated by national funding, thus the overall estimation of the money spent on the project is difficult (Joly and Mangematin 1998, p. 82).

institution, acted as financial and administrative coordinator redistributing the funding provided by the EC to the participating laboratories. For each of the chromosomes sequenced (in full or in part) with funding provided by the EC there was a designated coordinator (Fig. 2), who was in charge of the preparation of a cosmid library and the creation of a physical map of the chromosome.[17] The coordinator was also tasked with redistributing to the participating laboratories the cosmids to be sequenced, he was in charge of quality control on the submitted sequences and had to assemble the final sequence (Joly and Mangematin 1998, p. 79 Figure 5.1). The sequencing data produced by the European network were collected, managed and preliminarily analysed by a single informatics centre, the Martinsried Institute for Protein Sequences (MIPS), based near Munich. The molecular geneticist Piotr Slonimski coordinated the functional analysis of the yeast genome.[18]

To ensure that the "challenging team-work" was "carried out in a spirit of collaboration, trust and openness", clear rules were set out on the distribution of the cosmids to be sequenced, the payments, the intellectual property rights and the validation and sharing of the sequencing data.[19] Each participating laboratory (sub-contractor) was to receive a sequencing unit of fixed length from the chromosome coordinator and had the duty to sequence it and carry out basic verification procedures. The sub-contractor's retribution was proportional to the amount of base pairs sequenced and, apart from the first initial payment, all the following payments were subject to timely progress in sequencing and adequate quality of the results. For the pilot project all the participating laboratories were assigned 8 kb sequencing units and paid 5 ECU/bp (Vassarotti et al. 1990, p. 89). During the progress of the sequencing project the length of the sequencing units constantly increased, while the payment decreased. For the BIOTECH I programme, for instance, sub-contractors who did 'small scale sequencing' were

[17] The genomic libraries used in the pilot project were courtesy of US researchers. Subsequently the European researchers took upon themselves the tasks of building appropriate libraries. These libraries circulated among the laboratories of the European chromosome coordinators and were also shared with the Canadian laboratory that contributed to sequencing the yeast genome (Dujon 1993, p. 359).

[18] For Slonimski's contribution to the yeast genome functional analysis see Annex 1 of the contract for sequencing Yeast Chromosome III (Carlsberg Archive). On Slonimski's contribution to yeast genetics see Dujon (2009).

[19] Annex 1, Sequencing Yeast Chromosome III (Carlsberg Archive).

expected to sequence contiguous fragments of at least 25 kb/year and were paid 2 ECU/bp, as during the BRIDGE programme, while the contractors involved in medium scale sequencing were expected to sequence contiguous fragments of at least 100 kb and were paid 1.6 ECU/bp. The payment per base pair further decreased in 1996 (1 ECU/bp) (Vassarotti and Magnien 1996). Provisions were also made for the construction of cloning libraries (0.1 ECU/bp) and information coordination (0.05 ECU/bp).[20]

Each sub-contractor could adopt their preferred sequencing strategy, as long as results were accurate and the laboratory met the sequencing targets. Once a sequencing unit had been completed and was submitted to the informatics centre, a laboratory could request a new one. Distribution was done "on a first come first serve basis" (Vassarotti et al. 1995, p. 133) rewarding the most enterprising subcontractors, but the tapering rates avoided excessive concentration of sequencing work in the hands of only a few contractors (Joly and Mangematin 1998). Each assigned portion of the sequence became "property" of the sub-contractor for the duration of the sequencing programme (Vassarotti et al. 1995, p. 133). Sub-contractors had the opportunity to analyse, publish and even patent the DNA segments sequenced.[21] The coexistence of genome sequencing and data analysis was possible because the network mainly involved contractors that had scientific expertise in yeast genetics rather than "highly specialised [in sequencing] scientists and technicians who may never have seen a yeast outside of a bottle of doubly fermented beer" (Goffeau et al. 1996, p. 566).[22] From 1991, when the first sequences related to chromosome III became available, until 1996, when the complete genome sequence was made public, the journal *Yeast* published 226 papers reporting on sequenced yeast genome fragments (Goffeau 1996, p. 1603).[23] The journal published both *Yeast Sequencing Reports* for the rapid presentation of sequencing data and *Functional Analysis Reports* for the systematic analysis of the function of novel genes discovered as a result of genome sequencing.[24]

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[20] For the payment rates during the BIOTECH programme see Gordon Adam Papers, Historical Archives of the European Union, Ref. 33/2/ii.

[21] Contractors had to sign a "Confidential declaration concerning the information and other results, patentable or not, arising from a cost-sharing research contract concluded with the Commission of the European Communities" (Carlsberg Archive).

[22] All the thirty-five laboratories that took part in the pilot project already had a consolidated expertise in yeast genetics. Only later in the project the EC accepted sub-contractors, mainly the biotechnology companies, that did not have a specific commitment to yeast research, but could offer increased rates of sequencing work.

[23] A few more reports were published also in 1997.

[24] *Yeast*, Notes for Contributors.

Sequences deposited in the MIPS database, but not immediately published by the sub-contracting laboratory, were confidential, although third parties – for instance the other sub-contractors and the companies who were members of the YIP – could have a limited and controlled access to them, before they were made available to everyone with the publication of the complete chromosome sequence in a open access database (Vassarotti et al. 1995, p. 134; Joly and Mangematin 1998, pp. 81–82). Before this final publication, the sequence data were checked to reduce the error rate, and assembled. Some re-sequencing was also undertaken for verification purposes by the participating laboratories, as part of their contractual obligations. The publication of the complete chromosome sequence had to follow the conclusion of the data collection process within six months and, at that point, previous intellectual property rights were lost and the sequencing laboratories were "liable for free distribution of DNA material and other biological materials to third parties" (Vassarotti et al. 1995, p. 136). Yeast geneticists shared a deep communitarian ethos, and if the European yeast genome network had to break this tradition to stimulate rapid analysis of the genomic data, it had also to reinstate it eventually, as the project itself had benefitted from this ethos in the acquisition of the original genomic libraries, donated by the US researchers Maynard Olson, Linda Riles and Carol Newlon (Dujon 2015).[25]

[25] During the 1980s, Maynard Olson, based at the University of Washington St Louis, worked on building a complete physical map of the yeast genome. By the time the yeast genome project started in 1989, however, Olson was moving away from this institution and did not want to be involved in the project (Olson, personal communication). Linda Riles, who was Olson right-hand person on the yeast mapping project, took instead part in the project, as she continued to work on yeast mapping in the same institution, but in Mark Johnston's laboratory. In the US, Johnston's laboratory was the centre that did most of the sequencing work for the yeast genome project. Carol Newlon worked on mapping yeast chromosome III. She collaborated with the European network in the pilot phase of the project and she is listed as one of the co-authors in the publication that presented the complete sequence of chromosome III (Oliver et al. 1992).

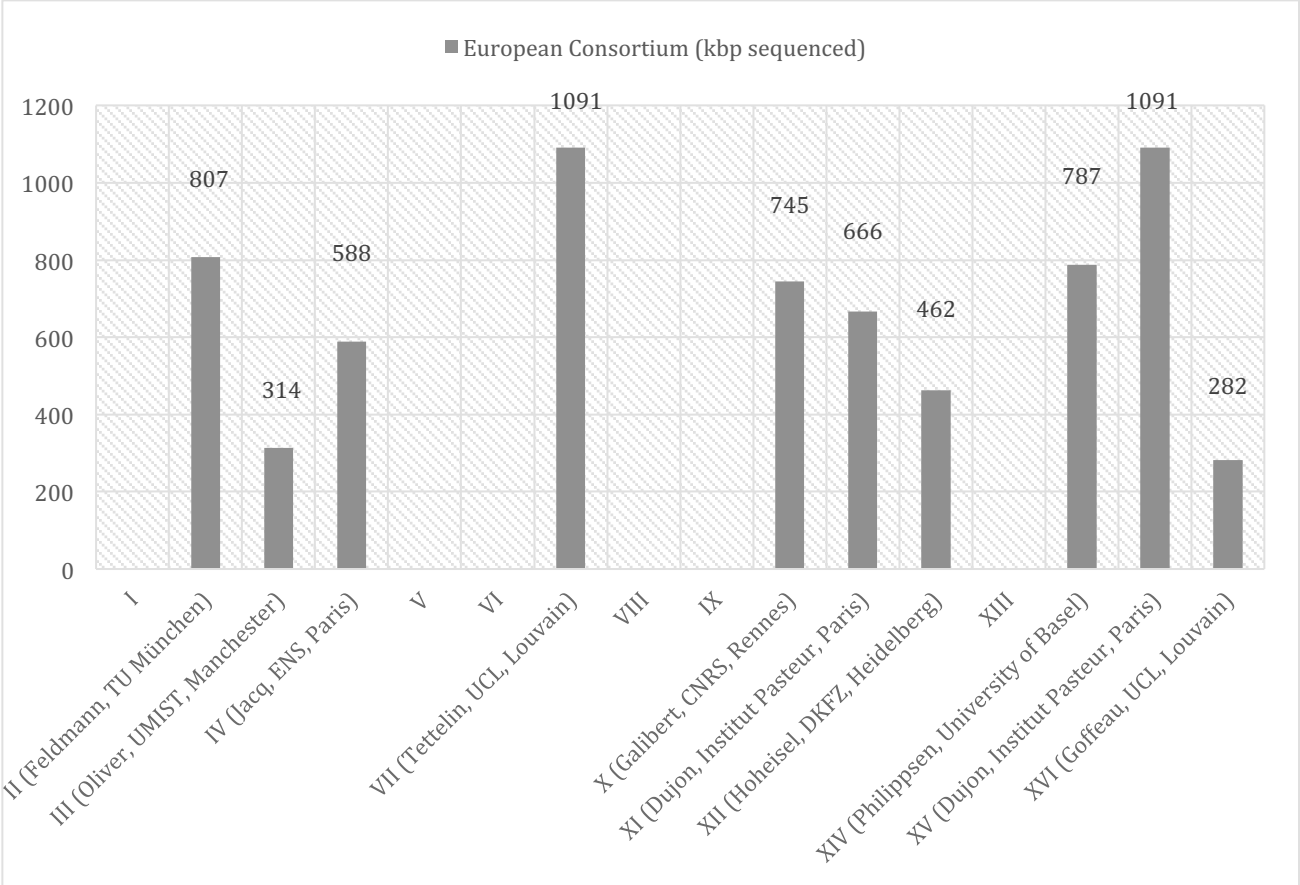

Figure 2

Data source: European Commission 1996, p. 6. In brackets the name of the chromosome coordinator and his affiliation.

5. Building Human Capacity

The EC's civil servants who coordinated the yeast genome project, Goffeau and Vassarotti, envisaged in the network model several advantages. Some of these advantages were of a general scientific nature, for instance the rapid exploitation of the sequencing data made possible by the expertise in yeast research of the laboratories involved in the network, or the technological and methodological innovations facilitated by the sharing of ideas and experiences among the contractors. But there were also advantages that were peculiar to the European situation. The network approach, in fact, offered the opportunity of a "parallel gain of expertise and information spread over all the European Community" and "facilitated access to European

scientific competences" as the European laboratories "recorded their specific competences in order to assist each other in specific problems" (Goffeau and Vassarotti 1990, p. 30).

Indeed, the network participants pursued very different kinds of research. Among the participating institutions were laboratories dedicated to basic research in microbiology, genetics, biochemistry, molecular biology, but also institutions devoted to agricultural and food research (e.g. the French Institut National Agronomique Paris-Grignon or the British Food Research Institute in Norwich), biotechnology (for instance, the French company Pharmacia Biotech in Orsay), and medicine (e.g. DKFZ, a German centre for cancer research located in Heidelberg). This plurality of interests in yeast research did not materialise by chance. The sequencing laboratories were not randomly recruited by the chromosome coordinators among their personal networks, but they were selected according to the Community's evaluation procedures among the laboratories that had applied "in the frame of a relevant EC research programme" (Vassarotti et al. 1995, p. 132). If biotechnology was to answer societal challenges related to agriculture, environment, health and energy, as envisioned by the EC's policymakers, it was certainly necessary to grow expertise in both basic and applied research and to distribute it across a variety of disciplines, ranging from medicine to enzymology, as in the case of the yeast sequencing network.

Alongside the disciplinary diversity of the yeast genome sub-contractors, their geographic distribution also deserves some attention. Except for Luxembourg, all the EEC countries were involved in the network with at least one laboratory. Belgium, France and, especially, Germany had the lion's share, but also countries like Spain, which had joined the EEC only in 1986, were well represented. In the sequencing work sponsored by the BRIDGE and BIOTECH programmes, contractors were also recruited among EFTA and COST-member countries. Nations that have never joined the EEC, like Switzerland and Norway, or nations that joined the EU much later, such as the Czech Republic and Poland, featured in the yeast genome project.

Care was taken to avoid the creation of national subnetworks in the sequencing work, as explained by Goffeau to the staff of the Carlsberg Laboratory involved in the project:

> In order to avoid national (or any other) clubs in the "sequencing crews" of the two DNA coordinators, we have made arbitrary assignments and will request switching to a clone from chromosome II after determination of your first cosmid from chromosome XI.[26]

The yeast genome project had to build competencies all over Europe because transnational was the biotechnology strategy of the EC. Indeed, the targets of the yeast genome network were "happy DNA sequencing" as much as "merry collaboration" among the European countries.[27]

As a truly transnational initiative, the yeast genome network satisfied the cooperative scheme of the European Laboratories Without Walls envisaged by the EC, but in this case it was not just a matter to promote circulation of people or pooling of established knowledge, materials and methods. Rather, the yeast genome project was designed to progressively increase sequencing competences all over Europe. The number of participating laboratories steadily rose in time: thirty-five European contractors took part in the pilot project, thirty-six in the successive BRIDGE-funded research, fifty-six in the activities sponsored by the BIOTECH I programme and seventy-four in the final sequencing carried out under the BIOTECH II programme (Goujon 2001, pp. 461–464). Among these laboratories, a few – for instance, Goffeau's UCL laboratory or the German DKFZ in Heidelberg – became systematically involved in the project and had a role in the sequencing of all, or almost all, the chromosomes tackled by the European network. Many more institutions, instead, just took part in the sequencing of one or two chromosomes and were content with the sequencing skills so learnt. As each contractor could choose the preferred sequencing strategy, there was no technological barrier that prevented access to the project and even the laboratories that still adopted manual methods had the opportunity to join the sequencing network. Indeed most of the contractors in the yeast genome

[26] Letter from A. Goffeau to D. von Wettstein, 29th November 1990 (Carlsberg Archive).

[27] Ibid.

project relied on manual sequencing methods, and only a few, like Fritz Pohl's laboratory (Universität Konstanz) in Germany, systematically invested in the development of new and more efficient sequencing technology, even making a family business of it (Oliver 1995).

However, as financial contributions constantly decreased and were subject to the timely completion of the work, the contractors who were associated for longer with the project had constantly to improve efficiency and cost-effectiveness of their sequencing methods to make the venture profitable (Joly and Mangematin 1998, p. 80). The EC's economic contribution could further decrease in special circumstances. For instance, the contractors that sequenced the left arm of chromosome XII were paid only 1.4 ECU/bp because the coordinator, Jörg Hoheisel, prepared plasmid sub-libraries to facilitate the work of the sequencing laboratories. This was again an attempt to improve the efficiency of the European network by assessing how the ordering of clones could speed up the work of the contractors that were warned "not to leave the clones sitting in the freezer while finishing off something else".[28]

To facilitate the growth of the contractor's sequencing capabilities, the EC also offered opportunities to the participating laboratories to exchange ideas and learn from each other's work. From 1989 until 1996, eight contractors' meetings took place sponsored by the EC. In the meetings the participants discussed their practical experiences. Some complained that the lambda clones received from the DNA coordinator did not show the expected restriction pattern (e.g. Wilson et al. 1989), some presented results on the preliminary analysis of the sequence obtained (e.g. Cziepluch et al. 1994) and others discussed methodologies for the functional analysis of the yeast genome (Fey et al. 1995). The EC also sponsored training courses where necessary. For instance, P. Slonimski, in charge of the functional analysis, organised a practical course during the early stages of the pilot project. Course participants could bring their own 'disruptants' to study the function of a specific yeast gene and they could analyse them during the course (Goffeau and Vassarotti 1990, p. 30).

[28] Letter from J. Hoheisel to the contractors of chromosome XI, 27 January 1995. E. J. Louis personal papers.

The yeast genome network implemented these strategies to reach the "critical threshold of human capacity, distributed among several laboratories" mentioned by Fasella in his interview.[29] This 'human capacity' had a name and a surname, as remarked by the choice to publish the full list of the project participants in the *Yeast Genome Directory*, the overview of the entire genome sequence published as a supplement to the journal *Nature* ('Yeast Genome Directory' 1997). It is difficult, however, to define precisely what the EC's civil servants had in mind when talking about capacity and capabilities in relation to the yeast genome project, and more generally, in relation to biotechnology strategies, because they never provide an explicit definition.[30] This absence of a precise definition is not peculiar to the use of capacity building as an actors' category in European biotechnology. Even used as an analytical category in contemporary policy discourse, capacity building lacks a clear definition and assumes a multiplicity of meanings (Harrow 2001). According to the current literature on capacity building, "the problem with capacity building as a concept, like community participation, human resources development and training, is that it is nothing more than a strategy somewhere in between an existing situation and a better one, between the formulation of an objective and achieving it." (Mengers 2000, p. 378). Yet, even without a precise definition, it is somehow all there, in the image that capacity building suggests and that encompasses human resources development, networking skills and community construction, all elements that featured in the policy documents written by the EC's civil servants involved in biotechnology. Addressing all these issues was a prerequisite for building the industrial capacity I am now going to examine.

6. Building industrial capacity

[29] Interview with Paolo Fasella (1998), Historical Archives of the European Union, Ref. INT585.

[30] Not even Mark Cantley, who was involved for many years in shaping European biotechnology policies and has been frequently interviewed (e.g. Jasanoff 2005) and written contributions on the topic (Cantley 1983, 1995; Cantley and de Nettancourt 1992), gives any definition of capacity and capabilities in this context.

"[W]ho says that progress in biotechnology doesn't create employment?" (Cantley 1996). With this rhetorical question Mark Cantley closed the talk he gave at the Final European Conference of the Yeast Genome Sequencing Network. The talk had started comparing the 'flagship' genomic project on yeast to the sea voyages of the late fifteenth and sixteenth century. The findings of these voyages were celebrated as discovery, but the real motivations were political and commercial, reminded Cantley who knew only too well the ambitions that the EC harboured for its biotechnology strategy. These ambitions promoted the systematic involvement of industrial partners in the yeast genome project. Indeed, "the selection of the yeast genome sequencing projects as flagships of the [EC's biotechnology] programmes was based on the fact that yeast was a model for many other industrially relevant genomes. It was considered less important that the research funded was primarily academic, than that the results would become available to all interested parties, and in particular to industry" (Senker 1998, p. 2).

The yeast genome project pursued the creation of industrial partnerships in relation to both sequencing and exploitation of genomic data. The industrial laboratories of the brewing companies Carlsberg and La Cruz del Campo contributed to both sequencing and analysis of the genomic data. These laboratories shared the sequencing work with the other European contractors (Bojko et al. 1989; Navas et al. 1989), but they also had an interest in the functional analysis of the yeast genome (e.g. Ronnow and Kielland-Brandt 1993). Aside from these industrial laboratories that had a high degree of specialisation in yeast genetics, the other industrial contractors that took part in sequencing the yeast genome were biotechnology companies located in Belgium (1), France (1), Switzerland (1) and Germany (8) (Appendix A, in bold). These companies were "the experts on macro-sequencing and automatic equipment", whose services the EC enrolled to enhance the efficiency of the sequencing networks it sponsored in the 1990s (Vassarotti et al. 1990, p. 87). The companies had the same contractual obligations of the other project participants in terms of payments, timely completion of the work and data quality, but, unlike the laboratories that specialised in yeast research, they were not

interested in functional analysis. On the other hand, they usually had more sequencing capability than the specialised laboratories, as almost all of them employed automatic techniques.[31] The biotechnology companies that participated in sequencing the yeast genome were mainly based in Germany. These German companies were founded between the mid-1980s and the mid-1990s, the period in which the EC began to sponsor genomic projects.[32] They were connected to academic settings: QIAGEN, for instance, was established by a team of scientists based at the Heinrich-Heine-Universität in Düsseldorf, Genotype GmbH was a spin-off of the German cancer centre DKFZ in Heidelberg, TIB MolBiol was again a spin-off of academic research founded by two PhD students, GATC was the company founded by the already mentioned Fritz Pohl, the Labor für DNA-Analytik was created by a researcher in Freiburg, and MediGene GmbH was a spin-off of the Munich Gene Centre. The EC contracts for sequencing the yeast genome helped these young companies to grow and expand their business, and favoured, at the same time, their continued connection to academic research, because the companies' representatives attended the contractors' meetings and had access to the confidential information exchanged during these events.

Among the biotechnology companies that took part in the yeast genome project, GATC is of special interest. The company was set up in 1990 by Fritz Pohl (Universität Konstanz) in association with his three sons. GATC soon became "the most productive sequencing lab" in the European network (Oliver 1995, p. 392) and provided shotgun libraries also to several other contractors in the project. The company exploited the direct blotting electrophoresis method

[31] See, for instance, the book of abstracts produced for the meeting of the European contractors held in Lisbon in June 1995 (European Commission 1995). For each contractor the sequencing methodology adopted is recorded. At that time the only biotechnology company that still adopted manual methods (standard dideoxy reactions) was Genotype GmbH. The other contractors relied on equipment produced by Applied Biosystems or EMBL.

[32] For instance, QIAGEN was founded in 1984, Genotype GmbH in 1987, TIB MolBiol in 1990, GATC in 1990, Labor für DNA-Analytik in 1993 and MediGene GmbH in 1994.

(and machinery) patented by Fritz Pohl and perfected by his son Thomas who managed GATC for many years. GATC provided a sequencing service, but it was not interested in yeast genetics *per se*.[33] The expertise gained in the yeast genome project, however, allowed the company to take part also in other EC-sponsored sequencing projects (for instance, the one related to *Arabidopsis thaliana*). During its first decade of life GATC effectively grew thanks to these sequencing contracts and established itself on the biotech market, where it still competes.[34] This company is an example of the dedicated biotechnology firms that the EC's policymakers wanted to strengthen in Europe (Senker 1998). The sequencing projects, and in particular the yeast genome project, contributed to the achievement of this goal because they provided a steady income in critical stages of these companies' development. However, the strategy was successful only to some extent, because the payment received for each base pair by the EC was enough to make profit, but not to invest in the development of new sequencing technology.[35]

The EC's effort to build industrial capacity in biotechnology was not limited to the direct involvement of industrial laboratories and biotechnology companies in the sequencing activities. This type of support, although helpful to specific companies, failed to address what was considered a major weakness in the European system, that is the scarce success in the systematic transformation of scientific discoveries into industrial applications (Senker 1998). Therefore, the EC tried to facilitate the exploitation of research results and improve academic-industrial collaboration by creating industrial platforms, such as YIP (Aguilar et al. 1998). YIP gathered together biochemical, agrofood and pharmaceutical industries interested in yeast (Table 2). In

[33] Thomas Pohl was a skilled technician, not a research scientist. He did not have a university education, but training as professional assistant technician and started working at the EMBL, where he remained for six years before setting up the company with his father and brothers.

[34] In 2001 the EC stopped granting funding for pure sequencing projects and GATC had to find new markets to survive.

[35] Thomas Pohl, personal communication.

principle the platform's members supported the EC's R&D programmes "looking for possible applications of the sequencing knowledge to their own research and development projects" and sought "to contribute to regulatory, educational, and communication issues, in order to achieve a balanced image of the biotechnology industry" (Yeast Industry Platform n.d., p. 2). In practice, the companies paid an annual sum to cover the administrative costs of the consortium and to gain privileged access to the sequencing information produced by the yeast genome project. YIP companies were also facilitated in establishing collaborations with the sequencing laboratories, when the contractors uncovered yeast genes of potential interest (Goujon 2001, pp. 430–434).

Despite the many expectations placed by the EC on YIP, at the end of the sequencing project the overall evaluation that the members gave of the consortium's activity was negative, because YIP had failed its mission to improve significantly the "translation of results into products" (Wolf 1996). Relationships with the academic researchers involved in the project had not developed systematically.[36] However, YIP members lobbied for and became involved in the EUROFAN projects (Aguilar et al. 1998; Goujon 2001, pp. 497–511). These projects were set up to perform a systematic functional analysis of the data produced in the yeast genome project and the YIP companies had privileged access to the information and could evaluate its potential for commercial exploitation (Dujon 1998).

The unsatisfactory outcome in building industrial capabilities was not peculiar to the yeast genome project, but considered a critical aspect in EC's biotechnology strategies. The Community's policymakers constantly flagged this issue (European Commission 1991, p. 15) and the European political establishment shared their concerns. For instance, Gordon Adam, a British MEP and a member of the Energy, Research and Technology Committee of the European Parliament, likened the EC's investments in precompetitive research to building a new dam and wished to "let that water flow out of the dam into our industries" to achieve the

[36] Oral history with Edward Louis (March 2017).

promised economic growth.[37] No one, however, had an effective recipe about how to let the water flow. EC's civil servants and policy advisors working for the Commission constantly stressed that Europe was falling behind United States and Asia in the commercialisation of biotechnology and solutions were needed to reverse the trend (Senker 1998). Several factors were at stake in producing this result: "Europe's capabilities in developing linkages with the private sector", access to finance, patenting and regulation of biotechnology inventions (Senker 1998, p. 157; 162). All these elements had, besides economic value, ethical, social and environmental implications that made them highly debated topics in the European political scenario. EC's civil servants felt that these debates constrained the development of biotechnology policies and the achievement of economic growth in comparison to the attitude adopted by the US and considered more permissive (Garon and Montpetit 2007). They feared that this could significantly hamper the developments of European biotechnology and threaten the capacity building exercise that they had tried to stimulate:

> We seem to be moving towards an international division of labour, in which Europe will have ethical debates, bioethical committees, parliamentary resolutions and technology-specific regulations, and US (and Asia) will have patents, investment, employment and economic growth.[38]

Yet, little could be done to avoid this situation because the economic development of European biotechnology was never dissociated from political and social choices, as discussed by Jasanoff (2005) and Gottweis (1998).

[37] Talk entitled "Technology transfer and the exploitation of European Research and technological development", Gordon Adam Papers, Historical Archives of the European Union, Ref. GA/35.

[38] Gordon Adam Papers, Historical Archives of the European Union, Ref. GA/33/2/i.

Table 2: YIP members in 1990

Name	**Country**	**Sector of activity**
Alko Ltd	Finland	Agrofood
Boehringer Mannheim GmbH	Germany	Pharmaceutical
Champagne Moët & Chandon	France	Agrofood
Guinness Brewing Worldwide Ltd.	United Kingdom	Agrofood
Interbrew N. V.	Belgium	Agrofood
Kabi Pharmacia A.B.	Sweden	Pharmaceutical
Lesaffre & Cie	France	Agrofood
Nestec Ltd	Switzerland	Agrofood
Orsan Eurolysine	France	Agrofood
Pernod Ricard	France	Agrofood
Rhône Poulenc Rorer	France	Pharmaceutical
Royal Gist-brocades	The Netherlands	Pharmaceutical
Smith Kline Beecham Biologicals	Belgium	Pharmaceutical
Tepral BSN	France	Agrofood
Transgène	France	Biotech
Unilever	The Netherlands	Agrofood/chemicals

Data source: Yeast Industry Platform (n.d.).

7. Conclusion: European biotechnology as a conundrum of science, politics and business

The yeast genome project sponsored by the EC increased sequencing capabilities in academic laboratories and industrial settings and involved private companies in the use of the genomics information collected. Whilst this effort certainly strengthened academic science across the EEC and helped several small and recently founded biotechnology companies to establish themselves

in the sequencing business, it was not so successful in promoting the translation of genomic data into applications that food, pharmaceutical and biotech companies could exploit to improve their processes or commercialise new products. In this sense, the yeast genome project already exposed the problems in the translation of genomic data that became a major and recurrent concern in the life sciences (Sunder Rajan and Leonelli 2013).

By bringing together academic laboratories and private companies, basic science and industrial applications, the yeast genome project fulfilled the expectations of EC's biotechnology policies. Even though ambitions had to be downsized in practice and only partial results were accomplished in industrial development, the political vision of transnational cooperation and economic growth that inspired the project was never refuted and EC's civil servants had a direct and constant involvement in it. The EC even sponsored the publication of the *Yeast Genome Directory* that summarised the project's results ('Yeast Genome Directory' 1997). However, influential sectors of the European biological community criticised the involvement of the EC in science policy, including its strategy for genome research. Lennart Philipson, then director of the European Molecular Biology Laboratory (EMBL), contested the peer review process established by the EC, accused the Commission of distributing "funds on geographical rather than scientific criteria" and of suffering from "an opaque, bureaucratic, time-consuming, costly and laborious administration" (Philipson 1991, p. 92). EMBL, indeed, had a very marginal involvement in the yeast genome project despite its commitment to collaborative research and scientific training (Morange 1997).

Members of the scientific community, like Philipson, failed to realise that the EC's strategy was by no means limited to scientific research, even though it was grounded on it. Promoting transnational research efforts was part of a political design to favour integration within the countries of the EEC and to build skills and industrial know-how in biotechnology, considered a key sector for economic and social development. Geographically distributed collaborations like the yeast genome project contributed to achieving this goal because they gave

an opportunity to join transnational networks to institutions based anywhere in the EEC. Even though these networks were dominated by the European countries that had greater expertise in biotechnology – France, Germany and Belgium for the yeast genome project –, they were nevertheless an opportunity to build capabilities also for the institutions based in the EEC nations where biotechnology research was still in its infancy. These transnational networks complemented the work of research institutions, like EMBL and CERN, that prided themselves on excellence in scientific research, but unavoidably remained multinational rather than transnational institutions and were located at the heart of the European scientific establishment, but could hardly reach its peripheries (Morange 1997; Krige 1996, 2002).

If the foundation of EMBL in the 1970s coincided with a "move to a more complex level of social organization" in molecular biology and the opportunity to "strengthen Europe politically and economically" (Krige 2002, p. 563), even deeper were the changes that accompanied the developments of European biotechnology in the 1980s and 1990s. After the fall of the Berlin Wall, European political geography was constantly changing and the EC had to take this into account while drafting and implementing R&D strategies. Moreover, the management of European biotechnology was never only a scientists' business. Politicians, bureaucrats, citizens, consumers, entrepreneurs, workers were all considered by the EC as relevant stakeholders in biotechnology. Therefore, political designs and industrial strategies, issues raised by citizens' and consumers' movements, concerns of labour forces and requests of professional groups had to be taken into account when biotechnology strategies were at stake.

European biotechnology was a conundrum of science, politics and business because it was part of the active process of building a European shared identity within the countries of the EEC. Similarly to what the history of technology has done for specific artefacts, therefore it should be assessed as a set of "Europe-building practices" (Misa and Schot 2005, p. 9), in which scientific expertise was mobilised and knowledge networks and industrial innovation created as part of the European integration process. The proactive role of the EC was crucial in the yeast

genome project and the capacity building exercise the Commission stimulated can be regarded as an early example of these Europe-building practices. By investing in human resources development rather than in technological improvement and by establishing connections between academic research and industrial applications the EC was able to bring together in the yeast genome project the scientific, economic and political dimensions of its biotechnology policy, satisfying its ambitions as a political entrepreneur. The capabilities developed in the project remained for the EC's civil servants something to be proud of, as evident in the opening quotation taken from Fasella's interview, and a building block of the ambitious agenda that wanted to build European identity from day-to-day policies (Schipper and Schot 2011) rather than political treaties.

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Appendix A: Institutions participating in the European Yeast Genome Network*

Nation	Institution(s)
Belgium (Founding member)	1. Université Libre de Bruxelles 2. Vrije Universiteit Brussel 3. CERIA-COOVI (Brussels) 4. Université de Liège (Gembloux) 5. Universiteit Gent 6. Katholieke Universiteit Leuven 7. Université Catholique de Louvain 8. **Innogenetics** (Gent)
Denmark (joined CEC in 1973)	1. Technical University of Denmark (Lyngby) 2. **Carlsberg Laboratory** (Copenhagen)
Finland (joined CEC in 1995)	University of Helsinki
France (Founding member)	1. Institut de Biochimie et Génétique Cellulaires CNRS (Bordeaux) 2. Université de Bordeaux II 3. Institut Curie (Orsay) 4. Université de Paris-Sud (Orsay) 5. Institut National Agronomique Paris-Grignon (Thiverval-Grignon) 6. CNRS Recombinaisons Génétiques (Rennes) 7. Institut Pasteur (Paris) 8. École Normale Supérieure (ENS) (Paris) 9. CNRS Institut de Botanique (Strasbourg) 10. CNRS Centre de Génétique Moléculaire (Gif-sur-Yvette) 11. Service de Biochimie CEN (Saclay) 12. **Pharmacia Biotech** (Orsay)
Germany (Founding member)	1. Technische Universität Darmstadt 2. Justus-Liebig-Universität Giessen 3. Georg-August- Universität Göttingen 4. Technische Universität München 5. Ludwig-Maximilians-Universität München 6. Max-Planck-Institut für Biochemie (Martinsried) 7. MIPS (Martinsried Institute for Protein Sequences) 8. Universität Konstanz 9. Johann-Wolfgang-Goethe-Universität (Frankfurt am Main) 10. RWTH Aachen 11. EMBL (European Molecular Biology Laboratory) (Heidelberg) 12. DKFZ (Deutsches Krebsforschungszentrum) (Heidelberg) 13. Universität Bielefeld 14. Johannes Gutenberg-Universität Mainz 15. Hans Knöll Institute (Jena) 16. Heinrich-Heine-Universität (Düsseldorf) 17. **GB-Genome Analysis** (Braunschweig)

	18. **AGON GmbH** (Berlin) 19. **MediGene GmbH** (Martinsried) 20. **TIB MolBiol** (Berlin) 21. **GATC (Gesellschaft für Analyse Technik und Consulting)** (Konstanz) 22. **QUIAGEN GmbH** (Hilden) 23. **Genotype GmbH** (Wilhelmsfeld) 24. **Labor für DNA-Analytik** (Freiburg)
Greece (joined CEC in 1981)	Foundation for Research and Technology-Hellas (Heraklion)
Ireland (joined CEC in 1973)	Trinity College (Dublin)
Italy (Founding member)	1. Università di Milano 2. Università di Padova 3. Università di Roma La Sapienza 4. Università di Roma Tor Vergata 5. Università della Tuscia (Viterbo) 6. ICGEB (Trieste) 7. INCIB (Trieste)
The Netherlands (Founding member)	1. Universiteit Leiden 2. Universiteit van Amsterdam 3. Vrije Universiteit Amsterdam 4. TU Delft
Portugal (joined CEC in 1986)	Instituto Gulbenkian de Ciência (Oeiras Codex)
Spain (joined CEC in 1986)	1. Universidad Complutense de Madrid 2. Universidad Autónoma de Madrid 3. Consejo Superior de Investigaciones Científicas 4. Universitat de València (Burjasot) 5. Universidad de Salamanca 6. Universidade da Coruña (A Coruña) 7. Universitat de Lleida 8. Universitat Autònoma de Barcelona 9. **La Cruz del Campo S.A.** (Sevilla)
United Kingdom (joined CEC in 1973)	1. Manchester Biotechnology Centre (UMIST) 2. AFRC Institute of Food Research (Norwich) 3. Radcliffe Hospital (Oxford) 4. University of Durham 5. University of Aberdeen 6. The Queens University of Belfast
Sweden	Royal Institute of Technology (KTH) (Stockholm)

(joined CEC in 1995)	
Switzerland (EFTA member)	1. Universität Basel 2. **Microsynth GmbH** (Balgach)
Norway (EFTA member)	The Biotechnology Centre of Oslo
Czech Republic (joined EU in 2004)	Academy of Sciences (Prague)
Poland (joined EU in 2004)	Wroclaw University

*The table was generated using the institutional affiliations listed in official publications of the yeast genome project (see 'Yeast Genome Directory' 1997, p. 9). Only universities or research institutions are listed, not the individual laboratories that took part in the Yeast Genome Sequencing Network. Companies are listed in bold type.