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Interdisciplinary collaborations, promising applications, and basic research within a large regional project on microbial bioenergy
First insights from empirical research.

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Disclaimer

This paper is a preliminary draft. It presents a first account of empirical work in progress that begun in the early spring of 2016, and sketches theoretical arguments and directions for further analysis on this basis. It needs to be completed by a more thorough analysis of the material collected and a more detailed bibliographical and theoretical exploration. Do not cite without author's permission.

Introduction

Context

In this draft, I will present a first account of fieldwork carried out over the year as part of a large interdisciplinary research project focused on emerging bioenergies. This project, entitled MICROBIO-E, is a two-year project that federates a dozen teams spanning a wide array of disciplines within Aix-Marseille University to work on the overarching theme of promising avenues for microbial bioenergies – I will present its content, design and objectives in details in the first section of this paper. It comprises of many smaller projects, usually across two or three teams. Most combine fundamental research concerns with attempts at identifying avenues for technological development or at scaling-up. Some of these sub-projects had started before MICROBIO-E, while others were directly initiated by it – for instance, the attempt to include social sciences within a project dominated by fundamental biology and electrochemistry, which is where I come in. I was hired as a post-doc in sociology in January 2016, about ten months after MICROBIO-E started, and my task is to contribute to this inclusion of social sciences, with the help of one senior sociologist and one economist. Social sciences remain quite exotic for the leaders of the project, so that they have curiosity rather than specific expectations regarding our work as social scientists, leaving us great freedom in designing and carrying out our research.[1] My relationship with the project that serves as the object of this paper is thus both that of a participant and a sociological investigator.

Material and methods

I had easy access to most of the teams involved, and was able to interview a large amount of researchers, post-docs and PhD students, to attend meetings, to visit labs, and in some occasions to observe lab work. I also had access to various documents and archives related to the project (e.g. submitted project, progress report, slides presented in meetings, lists of staff). Fieldwork was carried out between February and June 2016, and will likely be supplemented with additional observations in early 2017. Our objective was to produce a concrete account of research and innovation in-the-making at the scale of an academic research project; we chose to pay particular attention to two dimensions: the place and role of expectations and potential applications in day-to-day research, and the organisation and effects of interdisciplinary, inter-laboratories collaborations.

In mapping the project, I relied on science and technology studies and actor-network theory approaches that emphasise the close intertwinement of the "social", the "natural" and the "technical" in the production of scientific knowledge and technological artefacts (Latour & Woolgar, 1986; Latour, 1987; Akrich, 1992) and direct attention to the diversity of "machineries of knowledge production" (Knorr-Cetina, 1999, p. 3). This is an opportunity to explore what the traditional tools of STS can tell of the current project-based environment for science, technology and innovation. In such a perspective, a research project does not only gather research and institutions who share funding and objectives, and attend meetings together; it also pools together a diversity of research questions, scientific instruments, model organisms, theories, methods used to approach a scientific problem, procedures for validation, etc. Thus, one can expect it to affect simultaneously the organisation and rhetoric of scientific work, and the actual production of knowledge and innovation.

To trace these complex dynamics empirically, I seek to analyse the work of individual researchers and research teams along three dimensions.

[1] In fact, this flexibility is characteristic of the whole project: each work-package is free to organise as they want.

- First, I have gathered information on the characteristics of their everyday scientific work, which turn out to differ substantially across teams: the organisms and objects that they study, the theoretical, technical, material and financial resources that they use to study them, the issues that interest them, the type of results they obtain, the academic communities that they interact with (e.g. by reading papers, attending conference, or exchanging staff), the division of work within the lab…
- Second, I try to identify their role within the project and to map their relative positions in it. This implied tracing their involvement (or not) in the original design of the project, as well as the collaborations within the project and, when relevant, outside of it. I also paid attention to circulations within the project network (e.g. former PhD students now hired in another team, post-docs supervised by two teams, merged teams…).
- Last, I am interested in research strategies and policies, and more specifically how they play out in relation with the MICROBIO-E project. I try to understand how researchers and teams position themselves within the current science, technology and innovation ecosystem: do they consider their work more 'basic' or 'applied' and do they mean by it? How do they navigate the funding environment and adapt to its constraints? I also investigate how they consider the potential applications that their work is supposedly contributing to, and especially bioenergy: to what extent do they view their work as contributing to bioenergy research? And, to the opposite, to what extent does this project and its "bioenergy" direction enable them to pursue their own research interests, and/or influence them?

Objectives

This case study is meant as a contribution to the analysis of tensions and synergies between the actual development of emerging science and technologies and constraints imposed by science, technology and innovation policies. In the next section, I describe how the Microbio-E project is shaped by current trends in research policy, in particular the promotion of academic excellence, the push for interdisciplinary collaborations, and the requirement for so-called societal relevance and applicability. At the same time, it is also shaped by basic research questions that graft on the broad theme of bioenergy. This makes the project an interesting object of enquiry to analyse the relationships between what scientists (have to) promise and what they do, insofar as it does not only organise research, but directs it towards a relatively well-defined, though remote, end in view. In effect, the project enacts the perspective of microbial bioenergy by organising collaborations and framing research questions in its name. It thus provides a setting to observe how techno-scientific promises and expectations materialise (Brown and Kraft, 2006) and the interplays between discourses about visions of future technology (Borup et al., 2006; Joly, 2010; Audétat, 2015) and day-to-day research activities.

The cross-disciplinary collaborations fostered by the project and by its orientation towards bioenergy appear as particularly interesting sites to study the materialisation of promises as well as the potential re-shaping of research by current funding policies. For instance, Hubert and Louvel (2012, p. 23) have wondered whether current modes of funding will lead to a re-organisation of research around fields of applications such as health or energy instead of scientific disciplines, a hypothesis that the study of the Microbio-E project can help discuss: it does indeed organise research around a field of applications, but does this have an impact outside of the frame of the project? Is it really part of a "research area on bioenergy" (Tari, 2015)? Also, how does basic research evolve when set in an applied context, and related to relatively well-defined expectations?

Issues related to the organisation of research and scientific work as affected by project-based funding have been scrutinised in the STS literature. There is work exploring how they affect the temporalities of research (Schultz, 2013), the management and administration of research

institutions (Hubert & Louvel, 2012), the organisation of scientific work (Laudel, 2006; Barrier, 2011; Jouvenet, 2011), or the way scientists set their research agendas (Leysite et al., 2008). The recent trend towards interdisciplinarity, and the way it is organised and practiced have also been analysed (e.g. Weingart & Stehr, 2000; Cummings & Kiesler, 2005). All the same, most of these studies focus on organisational aspects, analysing how scientists choose their topics, combine research work and administrative work, spend time writing and submitting projects, develop collaborations, and manage new types and patterns of funding. The impact of research policy and funding regimes on these aspects of scientific work is thus well-documented.

In contrast, by grounding our analysis in the tradition of laboratory studies, we seek to investigate the relationships between science, technology and innovation policy, and the very practices, objects, devices and results of research and innovation. One aspect of these relationships is whether science, technology and innovation policy also shape the way scientists work with the organisms and objects they study, and the construction, validation and circulation of results. And if they do, how and to what extent? In other words, this case study is an opportunity to look into what happens when scientists relying on different "machineries of knowledge" (Knorr-Cetina, 1999) are brought together to work towards a common end-in-view. Are there transfers, clashes, negotiations, adaptations, compositions? And how do promised applications, however remote and fuzzy, factor in the way scientists design and perform their experiments? Do long-term expectations translate into more concrete, day-to-day expectations about scientific research, or do scientists maintain a firm boundary between the horizons they promise to work towards, and the short-term results they expect their projects to yield?

The fact that the project – and the researchers that take part in it – largely lean towards fundamental research is an opportunity to go even further in this investigation. Indeed, the work carried out within Microbio-E is largely exploratory. Even when there are links with industrial actors or attempts at scaling-up or patenting, there are few industrial or commercial stakes. Microbio-E focuses on objects, mechanisms and technologies that are just beginning to be considered in the light of their potential to produce energy. They are deemed promising but are still very emergent and flexible: there is no telling what actual applications they might turn out to have, if they ever survive out of the labs, and imagination mingles with scientific methods when delineating their potential futures. In such a project, one can thus trace their conditions of emerging and the variety of visions, potentials, possibilities that are gradually enacted at this very early stage in the life of techno-scientific promises.

Outline

The remainder of this draft is divided in two sections. In the first one, I map the contours, objectives and organisation of the Microbio-E project as a whole, explaining in more details how I navigated it during my first ten months as a participant. In the second section, I narrow my focus on two work-packages which are similar in their organisation, but differ in the way they enact the promises that justify them. One consists in the development of pilot bioreactors to produce biohydrogen from waste water, and plans to attempt to use this hydrogen to fuel enzymatic fuel cells also developed in the project; the other one investigates the potential of microalgae as sources of biofuels. For the purpose of this paper, I have mostly relied on interviews and empirical material about these two work packages. I plan to incorporate more material as I take the field analysis further in subsequent iterations of this paper. Given the relatively early stage of my research, I cannot claim to do justice here to all the questions I raised in this introduction; they however inform my enquiry and analysis.

The Microbio-E project as an enactment of the "regime of promising"

Funding and genesis

The Microbio-E project is a large local research project with a total budget of around 1.5 million euros. Its full title is "Biomass valorization by microbes for bioenergy production". It federates a dozen research teams (Table 1) in the Aix-Marseille area so as to foster the emergence of an "internationally recognized task force" (Project proposal, 2014) combining "expertise in microbiology, metabolism, lipidomics, bioinformatics, biophysics, bioprocess, chemical engineering, economy" in order "… to decipher basic biological mechanisms underlying the production of energy-rich compounds from biomass to produce advanced biofuels" (Microbio-E progress report, 2015). Its objectives are thus threefold: to further scientific understanding on a broad range of topics; to foster networking and collaboration among regional laboratories; and to promote and showcase the University's academic impact.

It is funded for two years (2015-2017) by Aix-Marseille University, thanks to a relatively new funding structure called 'AMIDEX' (*Initiative d'excellence Aix-Marseille*). This type of funding is quite specific in its requirements, and Microbio-E was to an extent tailored to meet these requirements. The AMIDEX[2] mechanisms directly originates in the *Investissements d'Avenir* ("Investments for the future") programme, a national research policy scheme initiated by the French government in 2010 to encourage the creation of large regional federations of universities and research organisms in France. Following a national call for proposals, eight academic clusters where selected and labelled as "IDEX", i.e. "Excellence Initiatives". They were then granted several hundred million euros each, that they allocate to research and teaching via an array of internal calls for projects. The IDEXes were assessed in 2016 before their perpetuation was approved (or refused), thereby giving them access to a continuous – and significant – flow of income to supply local research and education.[3]

The assessment took into account the degree to which each IDEX had fulfilled its promises, so it was important for the future of the local academic fabric that the projects funded by AMIDEX fell in line with the initial proposal and ambitions, which themselves reflected both the identified strengths and potential of Aix-Marseille University teams, and more general trends and expectations for research – especially those developed in the report that framed the *Investissements d'Avenir* (Juppé and Rocard, 2009). Among the objectives stated by AMIDEX on its website, two are particularly relevant to understand the framing of the Microbio-E project: though vague in their wording, they are indicative of a specific realm of promises and its associated semantic field. AMIDEX thus aims to "fund top international level research and higher education projects (emergent, interdisciplinary and innovative) in a progressive perimeter of excellence as described in the project" and targets "five priority scientific themes (Energy; Environment; Health and life sciences; Sciences and technologies; Humanities) where Aix-Marseille University and its partners of the site can become leaders at an international level within 10 years" (AMIDEX webpage). Funds

[2] French research policy is characterised by a proliferation of acronyms that makes writing clearly about it a challenging venture; I will try not to overuse them so as not to lose the reader, but they cannot be entirely avoided… which might also help grasp the perspective of a French permanent researcher having to navigate this proliferation!

[3] The perpetuation of AMIDEX was approved in April 2016, and it is now guaranteed to receive 26 million euros a year.

The Microbio-E project emerged in this context, and specifically as part of the ambition to assert the "excellence" of Aix-Marseille University's research on energy. As MICROBIO-E project leader explained when she first presented the project to me, meetings within the University and the region had suggested that bioenergy was the area of research for which it would be easier to federate and showcase energy-related research within Aix-Marseille University (Interview 1, January 2016). The leader of Microbio-E is the head of a large and renowned biology laboratory in Marseille, and she is involved in the university's internal cross-disciplinary network on energy; the University thus encouraged her to submit a proposal on bioenergy once AMIDEX was created. There were several iterations and an inflation in scope before the project was accepted – one key modification for that apparently having been the inclusion of engineering and social sciences (Interview 1, project leader, January 2016). The need for a flagship project on energy to stay in line with AMIDEX's stated objectives was probably instrumental in the eventual validation of the project, and the steering committee of Aix-Marseille University wanted it to be as broad as possible. The project leader explains:

> "So, that's how the project was set up, and I think there really was, at some point, a political, strategic will of the University to say, we have to show that we are doing something in this field, so we will fund it. And so that's why this project – when I wrote this project, in comparison with other AMIDEX or ANR projects, it seems very broad: but that's because we needed to bring everyone together" (Interview 1, January 2016, my translation).[4]

Table 1: list of laboratories involved in MICROBIO-E

Teams	Disciplines and expertise	Location	Approximate number of researchers actively involved in Microbio-E	Microbio-E funded PhD students or post-docs
BIP	Biology, electrochemistry, biophysics	Marseille	15-20	4 (incl. 1 with LCB, 1 with IUSTI)
LCB	Biology	Marseille	~7	3 (incl. 1 with BIP)
IGS	Bioinformatics	Marseille	2	1
BBF	Biology, enzymology, bioprocess	Marseille	5	2 (with AFMB)
AFMB	Biology, enzymology	Marseille	4	2 (with AFMB)
M2P2	Process engineering	Aix-en-Provence	3	1
IUSTI	Heat transfers, study of porous media	Marseille	2	1 (with BIP)
LB3M	Biology (algae, lipids)	Cadarache	6	1
LEMIRE	Microbial ecology, microbial fuel cells	Cadarache	4-5	1
LBC	Biology, enzymology, cristallography	Cadarache	1-2	0
Cité des Energies	Bioprocess	Cadarache	2	1
LAMES	Sociology	Aix-en-Provence	2	1
GREQAM	Economics	Marseille	1	0

Promises and their enactment in the design of the project

Both in its wording and in its design, the project relates to promises associated with AMIDEX objectives as well as with extra-academic socio-political objectives (European and French policies on the reduction of greenhouse gas emissions, production of renewable energies and waste recycling, for instance, are cited in the project). The presentation of the project frames it in terms of interdisciplinary, emergent and innovative strategies to develop "advanced biofuels", and stresses the assets of the teams involved to work on such strategies. Basic biological research is presented as relevant – even necessary – to address energy issues. This translates clearly in wording: project documents weave together grandiloquent promises (on the relevance of "environment friendly biological processes" to meet "one of the greatest challenges for human society in the 21st century", namely the need to phase out fossil fuels, on the current lack of economic maturity of promising technologies, and on the potential of biotechnology to "revolutionize" the energy industry like it did the health- and agro-industries) and specific, detailed scientific objectives that remain largely grounded in basic research. This is not particularly original: most of the senior scientists I interviewed said that they were used to this kind of rhetorical exercises, as it is now necessary to position research in relations to wider, socially-relevant themes when answering calls for proposals.

But this interweaving of techno-scientific promises and more modest scientific interests also translates in the very organisation of the project, which relies on interdisciplinarity as a way to test the applicability and potential of the organisms, mechanisms and processes investigated. In other words, interdisciplinary collaborations are presented as a way to start bridging the gap between basic research and promised applications.

> "Our ambition is to set up and promote innovative and original scientific projects involving disciplinary approaches from biology to process engineering that push back the frontier of knowledge relative to the great world challenges and that will eventually allow the emergence of new biotechnological processes and economy" (Microbio-E project proposal, 2014)

> "The innovative aspect of the proposal is the association between fundamental research and engineering approaches ie cultivation systems, modeling, scale-up with the aim to optimize biofuel production." (Microbio-E project proposal, 2014)

> "We ambition to describe and subsequently control biological processes, based on multi-disciplinary and multi-level approaches, including advanced genomics, proteomics and metabolomics coupled with the exploration of biodiversity and functional genomics. The proposed integrated approach constitutes a key link for removing the constraints on production of advanced biofuels." (Microbio-E progress report, 2015)

To enact such interdisciplinary collaborations, Microbio-E is organised as a collection of sub-projects centred around a shared object, organism or energy vector, most involving at least two teams. In many cases, collaborations materialise in the co-supervision of a PhD student or a post-doc. As a matter of fact, most of the budget of Microbio-E serves to fund short-term contracts: it enabled involved teams to hire 11 post-docs and 3 PhD students, seven of which officially work at the interface between two teams (Table 2). As the eleventh post-doc, I have been circulating across teams for interviews, visits and observations, asking questions and transferring information about the project as whole, and thereby I probably contributed in bringing Microbio-E as a collective entity into existence.

Table 2: Microbio-E-funded post-docs and PhD students

Post-doc 1	Enzymatic hydrogen fuel cells	Electrochemistry (BIP), process engineering and modelling (IUSTI)
Post-doc 2	Microbial fuel cells	Microbial ecology (LEMIRE)
Post-doc 3	Biohydrogen production from waste water	Process engineering (M2P2), relations with work in microbiology (BIP)
Post-docs 4 and 5	Enzymes for lignocellulosic degradation	Biology and enzymology (BBF and AFMB)
Post-doc 6	Enzymes reducing CO_2	Biology (LCB) and physics (BIP)
Post-doc 7	? (not interviewed yet)	Biology (LCB)
Post-doc 8	Cyanobacteria	Biology (LCB)
Post-doc 9	Cultivation of micro-algae (*Asterionella formosa*)	Biology (BIP), in relation with process engineering (Cité des Energies)
Post-docs 10	Cultivation of micro-algae (*Asterionella formosa*)	Process engineering/biology (Cité des Energies), in relation with basic biology (BIP)
Post-doc 11	Social study of the project	Sociology (LAMES), circulation across teams for field work
PhD student 1	Genetic analysis of micro-algae (*Asterionella formosa*)	Bioinformatics (IGS), experimental biology (BIP)
PhD student 2	Biohydrogen production	Microbiology (BIP), process engineering (M2P2)
PhD student 3	Lipid production by micro-algae (*Chlamydomonas rheinarditi*)	Vegetal biology (LB3M)

Overall, there is indeed little to remind participants of their involvement in this broad and ambitious initiative. Only one general meeting was organised in April 2016, roughly one year after the first post-docs were hired, and several of the researchers I interviewed only had a fuzzy notion of the perimeter and content of the project as a whole. The project is structured in three thematic axes within which researchers have more or less tight interactions; bioenergy provides a unifying perspective but is never the sole, or even the main, motivation of projects.

- One axis aims to "provide better biocatalyst for biomass formation (including CO_2 reduction) and degradation" (Microbio-E progress report, 2015). It focuses on enzymes and enzymatic reactions at a molecular scale. It is the most diverse in terms of topics and potential applications considered, and the most loosely structured – no meeting of its participants was organised. I will not consider it much for the purpose of this paper.
- The second axis is devoted to building "an integrated vision of micro-organisms involved in bioenergy production to provide more predictive, generic and translatable knowledge" (Microbio-E progress report, 2015). In more concrete terms, it explores the potential of micro-algae for the production of biofuels and high value compounds, focusing on three categories of model organisms: *Asterionella formosa* (a freshwater diatom), *Chlamydomonas rheinarditi* (a classic model organism in plant biology) and cyanobacteria. Regular meetings and informal interactions take place among most of the teams involved in the project, and I was able to attend some of them.
- The objective of the third axis is to "develop controlled bioreactor for biogas production, biofuel cells to produce electricity from biogas or waste" (Microbio-E progress report, 2015). It focuses on the production of hydrogen by micro-organisms and on its use in fuel cells. It combines work studying hydrogen-producing microbial consortium, attempts at scaling-up the identified process using waste water, and work related to enzymatic and

microbial fuel cells. One meeting of all participants took place in October 2015, and interactions are closest on the topic of hydrogen production.

Microbio-E is thus a patchwork of smaller collaborations and projects largely driven by basic research interests put together because they were identified as potentially relevant to future applications in the field of bioenergy. It provides human resources, operating funds, and an opportunity for networking within the Aix-Marseille area. But the framework it provides is rather loose: participants are free to develop their projects and to organise their collaborations as they wish. As a result, distinct research teams may relate differently to the project according to their strategy and interests, to the resources they allocate to it, and to what they expect from it. From a first analysis of part of the interviews conducted, I have identified several examples of (sometimes overlapping) expectations and motivations, ranging from the development of new, potentially decisive collaborations to the opportunity to obtain funding for ongoing research and insert it in a network without substantially modifying it. For instance:

- Creating or sustaining interdisciplinary collaborations that may generate their own objects

  "The 'bio' idea added something in terms of research, an opening, and other issues and ways of thinking that seemed interesting, and… so that's how we got into the project." (Interview 22, engineer, April 2016, my translation)

  "Really, each of us keeps doing what they did before while trying to federate, to stimulate interactions, too." (Interview 4, biochemist, February 2016, my translation)

  "We'll see what it leads to, if there's a follow-up, Microbio-E, but… it's true that it forces us – well, forces us, it encourages us to collaborate, that's not a bad thing." (Interview 28, plant biologist, April 2016, my translation).

  "Aside of the scientific objectives, which are real, yes, I think it's mostly a structuring project around the topic of bioenergy. It works more or less, I think it will – it's bound to work very well between some partners, not so well with others, but that's normal. That's how it is with collaborative projects. I think that, for us, it's the start of a strong collaboration." (Interview 9, process engineer, March 2016, my translation)
- Developing a diverse regional academic network on bioenergy (with varying goals)

  "Well, we hope that, yes, it will boost us at the regional level if those topics are recognised within university policies, regional policies… I think there's a great scientific potential in the region, both in Marseille and here. I think we have the capacity to be leaders on these topics, at least nationally. […] Yeah, that's also why we're in the project, it's important for us that it gets displayed" (Interview 25, lab director, Cadarache, April 2016, my translation)
- Obtaining means to pursue ongoing research (and that's it)

  "For me, the idea is that I have scientific interests that fit in this issue. But that is not going to guide what I do on a daily basis, you see. Now, I'm very happy, because it enables me to get means to take my projects forwards; of course, I hope that it will be useful, too, to produce artificial compounds with the data we bring […], but…" (Interview 14, physicist, April 2016)
- Getting identified by other teams and benefitting from their expertise, fostering future interactions

  "[The institute in Marseille] they're people I never had interactions with. Now, poof!, I'm in, now we all know each other, you see. While I used to be an UFO, nobody knew what I was doing. So that changed the relations between me and the others completely." (Interview 17, bioinformatician, April 2016, my translation).

  "For us, as we're starting, we're small, we need to be visible, recognised, and in a way, leaning on a big centre like the CNRS in Marseille, you see, and the Microbiology Institutes, it makes sense." (Interview 24, Cadarache, April 2016, my translation)
- Linking bench research and process optimization, working towards pilots or proofs of concept

  "So we're working at our small scale, and they [at the Cité des Energies] move to the pilot phase." (Interview 4, biochemist, April 2016, my translation).

  "In concrete terms, if you like, what we do here is process development, transfer, scaling up. So in a way, we can lean on biology labs that will work on the clarification [mise au point] of what we will breed in our systems." (Interview 24, Cadarache, April 2016, my translation).

The very organisation of the project makes its perimeter hard to delineate. Though there is a coherent narrative behind it, it is very diverse in many respects: it incorporates a wide range of disciplines, techniques and areas of expertise; it proposes to address highly specialised scientific topics and issues that have little to do with each other, save for a more or less direct relevance to the development of novel forms of bioenergy; it accommodates different degrees of involvement, to the extent that it is sometimes difficult to know who is in and who is not[5]; the degree of integration and collaboration varies across work packages; some topics are very exploratory while others have matured for a long time; awareness of the global scope of the project is not evenly spread, and expectations as to its outcomes vary.

The broad scope of the project is a challenge for observation, both in terms of scientific understanding and of field logistics. The regional character of the project means that involved teams are relatively concentrated in one area, but field work still involved a lot of travelling across the region, and the number of laboratories to visit automatically limits the time spent in each of them. Most importantly, the variety of disciplines and topics involved translates into a proliferation of technical terms, specialist languages, biological, chemical and technological entities, theories and lab equipment that can be hard to navigate. Each lab is a world unto itself, so that each visit to a new team implies a form of training and adaptation on the observer's part. In the remainder of this paper, I consider in more details two tasks within the project, and describe how they unfold in relations with the techno-scientific promises that they are supposed to help fulfil.

Comparison of two application-oriented work packages in the project

In this section, I focus on two out of the many tasks included in Microbio-E: the study of hydrogen (H_2) production by micro-organisms both at the cellular level and at the process level; and the exploration of issues related to the cultivation and exploitation of a freshwater microalga, *Asterionella formosa*. The reason for this choice is threefold. First, from a practical perspective, these are the tasks about which I have collected the most field material so far. Second, both are in-depth interdisciplinary collaborations centred around a shared object. As such, they showcase different ways of engaging scientifically with an issue/object and provide an opportunity to observe not only how scientists interact, but also how their interests may evolve to the contact of other perspectives. At the same time, all the teams involved had previous experience related to their task in Microbio-E, even when they are new to the interdisciplinary approach, so the contours and objectives of the work-packages are relatively clear compared to those in Microbio-E that are more exploratory. Last, on paper at least, both work packages are directed towards a well-identified application relevant to bioenergy, however far from development it may be: in both cases, there is a clear interplay between so-called "basic" and "applied" perspectives that is not necessarily as marked in other Microbio-E tasks.

Biohydrogen production

The work package on biohydrogen production involves two teams with very different backgrounds: one in microbiology and one in process engineering applied to waste water treatment. So far, three permanent researchers (among which the scientific leader of Microbio-E), two PhD

[5] For instance, one research team is listed as involved in the project in its entirety because it mutualises funding; nonetheless only a few of its members are actually working on scientific issues directly related to Microbio-E and can be considered as actively involved in the project.

students, one post-doc, and one intern have taken part in it. It is the continuation of previous work undertaken in collaboration between the two teams, and is emblematic of the approach adopted in the whole Microbio-E project: the interaction of fundamental biology with process engineering served as a model to design other work packages in the project. Its horizon in terms of potential applications is presented as follows in the 2014 project proposal:

> "Some microorganisms (fermentative bacteria, photosynthetic micro-organisms, nitrogen-fixing bacteria) produce H_2 naturally (biohydrogen); the development of biotechnologies based on these microbial systems could lead to clean, renewable sources of H_2. However, the development of a sustainable energetic alternative based on bioH_2 still awaits a major breakthrough in the yield of H_2 production and needs research on the development of microbial consortia, genetic modification of micro-organisms and metabolic engineering, enzyme engineering…" (p. 9)

In the same document, its objective is synthesised as such:

> "To increase the stability and the efficiency of dark fermentative processes, it is now necessary to acquire a better understanding of the metabolic interaction networks existing between producing and consuming micro-organisms in order to improve the H_2 production using biomass waste as energy source. We will develop an innovative and multidisciplinary approach to ecological engineering, which consists of the design, construction and study of synthetic microbial consortia to establish the metabolic networks existing between micro-organisms for further optimization of bioH_2 production" (p. 21)

None of the two teams involved work primarily on energy, but hydrogen production relates to the research interests of both. The microbiologists have long been specialised in the metabolism of hydrogen in bacteria; in other words, they work with micro-organisms that use and/or produce hydrogen. The process engineers work on waste water treatment, and producing hydrogen from waste water to then use it as an energy vector falls within their scope, as it is a means to improve the energy efficiency of the process (Interview 9, March 2016).[6]

Figure 1: The bioreactor designed for biohydrogen production (photo by Cristian Barca)

Their common project within Microbio-E is at the interface of these two areas of interests. From a microbiological perspective, the interest lies in the study of the metabolic interactions among bacterial species that intervene in waste degradation. Microbiologists most often work with single species cultures under sterile, highly controlled conditions, so the project constitutes an interesting shift to the less investigated area of mixed cultures, which is a little closer to real-world conditions – though still very, very idealised: we are talking of two, then three species together. In some previous research, they have shown that, under certain conditions, the two species get in contact and communicate by producing a molecule that acts as a signal; this increases the hydrogen yield. This phenomenon is interesting to investigate in itself and raises basic biological questions, but it can also be of interest to develop biohydrogen production processes: the idea is that the molecule identified as a signal could be used as a controller to track hydrogen production at larger-scale, and help optimize the process:

> "If we manage to catch this small molecule, then, in process engineering, it will be quite easy to track: 'there it [the molecule] is, it's working', or, 'I don't want it here anymore, I am going to put this in to block it'. So the idea is to move towards a process in which, according to what we will decipher at the molecular level, processes can be applied at another scale to produce energy" (microbiologist, project meeting, 2015, my translation).

From a process engineering perspective, the project is an opportunity to design, test and optimize a new system that is quite different from those they usually work with. Because they start from the system studied by their microbiologist colleagues, and not from waste water residues as they usually do, they have to design a system that works under sterile (to avoid contamination) and anaerobic (the studied bacteria only produce hydrogen in the absence of oxygen) conditions. But the point of this venture is not just to test the potential for scaling up a phenomenon observed in vitro, and the study is also designed to investigate more traditional process engineering issues: design and optimisation of a specific type of bioreactors[7] than can also be used with waste residues (Figure 1), study and modelling of heat, matter and energy transfers in the reactor…

All the same, his sub-project appears to be structured around a collaboration more than around a shared scientific problem. The two teams met because they were both involved in the University's network of researchers working on topics related to energy. Their interaction started a few years before Microbio-E, with an interdisciplinary project which initiated the attempts at scaling-up the production of hydrogen by micro-organisms. Their perspectives, techniques and questions have been brought together because of their common relevance to study biohydrogen production at different scales and under different conditions. Yet, the point is more to see how the two approaches may influence each other and where the collaboration might take both teams than to work together towards a specific, well-defined objective.

During the course of this first project, one researcher in process engineering obtained a grant to spend two years as a visiting researcher in the microbiology lab, taking the collaboration to the next level. Process engineering methods and devices developed in the context of research on waste water treatment were translated into the sterile, highly controlled setting of a microbiology laboratory. The bacterial consortia studied in vitro in small 10-milliliter batches were translated into two-litre glass reactors that run continuously for several weeks. Daily interactions between the two approaches – embodied by the collaboration of the visiting researcher with one PhD student in microbiology – required mutual adjustments and enabled a cross-fertilization of research interests, which now shape the work carried out as part of Microbio-E.

[7] A bioreactor is a system in which a biological reaction takes place.

Interestingly, instead of moving towards technological and potentially industrial developments – as might have been expected given the applied horizons that the project referred to – the collaboration mainly yielded new basic questions (so far and to my knowledge, at least). By basic questions, I mean specific research questions that aim to enhance the understanding of a phenomenon, process or entity, but could potentially be relevant to a wide range of applications. The microbiologists decided to study the effects of adding a third bacteria to their two-bacteria consortium, while the visiting process engineer plans to develop smaller-scale reactors to get a finer grasp of their functioning. In other words, in this case, in adapting their research to the requirements of an interdisciplinary project with an applied perspective, researchers have found new inspirations to work on their specialities, and to refine their understanding of their own topics at a basic level.

> [talking about whether the themes of calls for proposals impact the content of research] "Well, I understood it more as: is everything you develop when you are part of an energy thing necessarily going to be about energy? It's not. However, being part of an energy thing […] directly impacted my orientations. What I feel like doing, at any rate. What I feel like developing scientifically. Even though I remain within the frame of my discipline and within the frame of bioprocess, but… I don't see things in the same way. So yes, it does impact, but, well, it is a bit subtle, because… it does impact, yet in the end, the next project I submit is on health. Not energy. So… It's quite a peculiar thing."[8] (Interview 9, March 2016, my translation)

In this case, research thus remains confined in the labs. Objects, organisms, techniques, methods and perspectives are displaced from one lab setting to another – and this is already a significant displacement, considering the huge differences between the environments of microbiology and of process engineering applied to waste water treatment. But they are not taken out of the controlled, artificial, isolated context of the lab. Applications as well are envisaged within the laboratory; the teams plan to use the small quantities of biohydrogen produce in the biofuel cells that are developed by other participants in the project, which also are pure laboratory creatures. This demonstrates some form of applicability, but within the lab. Much like the model organisms that biologists work with, those technologies and innovations are "models, laboratory systems that die as soon as they're put outside" (microbiologist, project meeting, 2015). Besides, on this sub-task, there does not appear to be any established contact with industrial actors, or with anyone aware of the current prospects of the hydrogen industry, and the visions of hydrogen as a promising technology seems to be directly (and solely?) shaped by the recent proliferation of academic calls for proposals on the topic. The potentials of these innovations to thrive in other socio-technical environments than the laboratories, and the many elements that would define these potentials, are barely envisioned – not so much, it seems, because of a lack of interest, but rather because at this point the scientists find it hard to imagine them in other settings.

> "It seems to me that we are on technologies that we would qualify – or, I, at any rate, I think that we are in the initial stages, even in the very first stages, because we still have many questions before we can move towards an application, I think… And we are rather, I think, saying that *this* can be done, could be done, without really having an application in mind – well, I'm talking about the great biological questions, it might be less so for process engineering […]. What we're getting in hydrogen production, we are very well aware that, for now, we are either on such low power, or such small quantities of hydrogen, that we think that it can only be local, punctual, or a really small thing to monitor a controlled temperature […]. But without having, in fact, to be honest, thoroughly thought about... Even when we did the experiment […], in truth, we never wondered how it would be used for real. We thought: we're happy, look, what we made has worked for a week!" (microbiologist, project meeting, 2015, my translation)

"The uncertainty as I see it is more on the application, let's say, or the interest of what we do for society as a whole. We say it, because we know that we have to, that probably, we are not wrong – still and all. We think that what we're doing contributes, but we sort of have this notion that the scale at which we work, at any rate, is disconnected for the direct applications and issue. But on the other hand, we have to go through this scale, because if nobody does it, we'll never be able to scale-up!" (microbiologist, project meeting, 2015, my translation)

Asterionella formosa

The second sub-project analysed in this paper is part of the Microbio-E axis on "microalgae as factories for the production of biofuels and high-value compounds" (Microbio-E progress report, 2015). This axis explores two strategies for improving the productivity of algal strains in order to reach economically viable production of biofuel: strain engineering (i.e. genetic modification of microalgae to make them produce more lipids) and consortium management (i.e. identifying species in association with which microalgae produce more lipids). Here, I focus on the work package on consortium management. Three teams are involved in it: one team of biologists/biochemists in Marseille, one team of bioinformaticians also in Marseille, and one team devoted to process engineering, scaling-up, and transfer of emergent renewable energy technologies from laboratories to industrial settings based in Cadarache.[9] In total, four permanent researchers (2 biologists, 1 bioinformatician, 1 chemist), one research engineer (in biology), two post-docs (both biologists, one in Marseille and one in Cadarache) and one PhD student in bioinformatics take part in this task. Renewable energy – and, in fact, algae valorisation – is the central interest of the team in Cadarache, which is named the "Cité des Energies". However, the other two teams do not usually work on energy-related topics – though the biologists had previously worked on the production of lipids by microalgae. The three teams had not worked together before Microbio-E. Their collaboration was set up for the purpose of the project, and it is organised as a federation of interests about one shared object, that they aim to understand better by approaching it from their distinct perspectives. The project also benefits from additional collaborations with teams not in Microbio-E, but working in parallel on related issues.

The central character in this collaboration is named *Asterionella formosa*. It is a fresh water diatom that originates from the Lake District in England but has "relatives" living in rivers in the region of Marseille, and "that can produce quite big amounts of lipids" (Interview 6, post-doc, February 2016). It is stick-shaped, about 50 micrometers-long, lives in star-shaped colonies, and, like all diatoms, it has a silica shell. Though currently stored in freezers in the lab, it is a natural strain, and not a laboratory specimen. One of its peculiarities and interests is that it grows with a community of bacteria that it apparently cannot survive without (Figure 2).

"So, *Asterionella,* roughly, is an organism – [sketching on paper] you see, if I do it like this, it kind of has a stick shape, like this. And this stick, it is about 50 micrometers long […]. And it's about three micrometers wide. So it's – it's quite small. Well, it's the size of one of our cells, actually. And it's going to structure as stars, in fact. That is to say, the stick is not going to stay alone, but to associate in starlike structure, like this. […] And all around, you're going to see small bacteria swimming. And some are clinging to *Asterionella*, too." (Interview 10, biologist, March 2016, my translation).

"And, actually, we realised, taking a closer look at the culture, that… well, *Asterionella* was surrounded with bacteria. When we tried to take them out, that was not very easy, actually we still don't really manage to. Hence the idea to think that, in the end, these bacteria may be essential to *Asterionella*'s survival […]. So, you see, a slight change in philosophy: we no longer consider *Asterionella* as an isolated organism, but as an organism living in a community, and so it's not *Asterionella* that's going to serve as a factory to produce lipids that can be used for biofuels, but rather this community that we're going to

[9] Cadarache is a branch of the French *Commissariat à l'Energie Atomique et aux Energies Alternative* (CEA), a research institute mainly focused on nuclear and energy research. It is located in Saint-Paul-lez-Durance, about 70 km north of Marseille.

try to handle in our way to make them produce compounds." (Interview 10, biologist, March 2016, my translation)

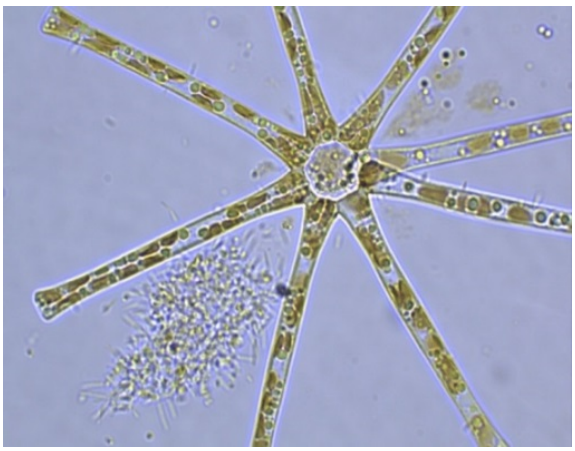

Figure 2: Microscope view of a colony of Asterionella formosa (the star) surrounded by bacteria (source : Powerpoint presentation by L. Prioretti)

The attention of the researchers in the project converges on the consortium formed by *Asterionella formosa* and the bacteria, but each team has its own reasons, motivations and methods for studying it. This case thus provides an opportunity to follow an organism (or rather, a group of organisms) as it is displaced not only from the natural environment to the lab, but also for laboratory to laboratory, and from the lab to a proto-industrial setting, and subjected to various forms of scrutiny and manipulation.

Asterionella formosa was one of the microalgae studied by the team of biologists. They had acquired it from a British colleague who supplies them with lake water samples (Interview 4, biochemist, February 2016). The biologists then provided the team in Cadarache with small flasks containing cultures of *Asterionella*; there, *Asterionella* is cultivated in larger quantities and at higher concentrations: flasks, 5 and 10 litres Schott bottles, 30 litres photobioreactors (Figure 3). The biologists also extracted DNA from the consortium of algae and bacteria, that they sent to a genetic platform in Toulouse for sequencing. The sequences – long series of As, Ts, Gs and Cs – were sent as computer files to the bioinformaticians who analyse them. From the beginning of the collaboration, *Asterionella* thus underwent several transformations just to be adapted to the different research settings of the teams involved.

Figure 3: One of the system for growing large quantities of Asterionella formosa in Cadarache (source: Powerpoint presentation by S. Fon Sing)

Each team has its motivation for working with this alga. The biologists team's senior researcher, who initiated the project, has a long experience of working on both freshwater and seawater diatoms, which she finds "absolutely fascinating, from a metabolic point of view" (interview 4, biochemist, February 2016, my translation). But aside from its fundamental interest as a diatom, *Asterionella formosa* appears well adapted to the variety of interests and perspectives that the project seeks to bring together – or, to put it another way, the participants in the project managed to present it as an obligatory passage point common to their strands of research.

• First, it comes directly from natural waters and was not bred in a laboratory (as opposed to another species of microalgae studied in Microbio-E, *Chlamydomonas rheinarditi*). It means it does not live in pure cultures but in interactions with other organisms. The study of the interactions between diatoms and bacteria has not been studied much so far and it is interesting in itself from a fundamental biology point of view, as the project proposal states:

> "Diatoms and bacteria have co-occurred in common habitats for more than 200 million years, fostering interactions between these two groups over evolutionary time scales. Indeed transferred genes from bacteria to diatoms confirm the paradigm that diatoms and bacteria have developed specific interactions over hundreds of millions of years. […] Understanding interactions between diatoms and bacteria is, thus, of prime importance. Deciphering the crosstalk between these species will strengthen our understanding of these groups." (Project proposal, 2014, p. 8).

But it also appears relevant when considering the domestication of microalgae in an industrial/biofuel production perspective: not only is it difficult to avoid "contamination" in microalgae cultures – especially in open ponds, which are a cheaper option –, the understanding, management and optimisation of associations between microalgae and bacteria is envisioned a possible strategy to improve yields in valuable compounds:

> "Interactions between microalgae and bacteria remain poorly studied, either in the natural environment or in laboratory culture and even less on industrial scale. These associations have long been considered as unwanted contaminations in microalgae culture and the idea of the existence of beneficial functional association is relatively recent. Two major types of functional associations are currently proposed in the literature: (i) the use by bacteria of various organic compounds produced by algae during photosynthesis, (ii) production by bacteria of factors which activate the algae growth (ie vitamins, phytohormones). For instance, it has been shown that phytohormones stimulate both the growth and lipid production of *A. formosa*. In addition, it appears that the interactions between algae and bacteria could be controlled by different processes." (project proposal, 2014, p. 8)

The results of the study of *Asterionella formosa,* as a naturally occurring species, may also apply to local generis of *Asterionella* that can be found in great quantities in river water, and are good candidates for large-scale cultivation (as they would be adapted to local climatic conditions).

• Second, *Asterionella formosa* is a freshwater diatom. This makes it easier to breed in photobioreactors: salty water, though available in larger quantities, is corrosive and makes the maintenance of reactors complicated; so looking into the properties of a fresh water algae is interesting in the perspective of large-scale, potential industrial developments. In addition, no freshwater diatoms have had their genomes sequenced before. Not having the genome available is a disadvantage in certain respects, but the perspective of being the first team to do it is attractive in terms of research impact but also in terms of staying ahead of the curve (Interview 24, April 2016).

• Last, diatoms are interesting organisms with regards to potential industrial developments. Asterionella is presented as "having the potential to produce high amounts of lipids" (Project proposal, 2014, p. 18), so is a candidate for biofuel production – though, as it seems to turn out, it is probably not so well-suited to large-scale biofuel production (Interviews 23, 24, April 2016). But

they produce other compounds that are potentially more readily valuable on the market, and can attract interest from firms in the cosmetic industry or in food-processing.

> "It's an alga with a story, too. […] The microalgae industry, nowadays, is in cosmetics. And when you're in cosmetics, what you sell is a story, an image. […] And *Asterionella* is not bad for that, because it's a delicate alga, it is beautiful, it makes small stars, you see, all that, it's golden, it's really nice, actually, in terms of image. So, when I saw it, I thought there's a potential for high-added value applications; and besides, it is an interesting model for biofuels, because it produces lipids, and because it's a diatom containing silica. And we know that many oil deposits originate from the fossilisation of diatoms. So… all this silica, it plays a role in the conversion." (Interview 24, March 2016, my translation)

This work package of the project is designed so as to gather as thorough as possible an understanding of *Asterionella* and the bacterial community it grows with by combining an array of strategies to work with it and extract valuable products from it – valuable in academic and/or commercial terms. Issues of interests for fundamental biology and genomics, and considerations about the potential values to be extracted from the algae are interwoven throughout the project, all the more so that interactions between teams are rather frequent (small meetings, email exchanges, exchange of material for experiments or of cultures, occasional visits).

The biologists seek to refine their understanding of the algae-bacteria association and of the metabolic pathways involved in lipid production by *Asterionella.* They observe the cultures with microscopes, seek to quantify their growth rate and lipid production, and try to isolate bacterial strains in Petri boxes so as to identify them. They rely on genome sequencing for more detailed biochemistry studies at the molecular level. As the team's post-doc explains,

> "Here, we are mainly biochemists. So, we produce microalgae, we grow microalgae, but other than producing them, we're also trying to study some things really in the metabolism. So, ok, I can induce lipid production from microalgae, but I want also to understand how it happens, so what happens inside the cells to produce lipids. For example, at CEA, they're probably more involved in the big volumes and big production, but maybe from a biochemistry point of view, they are a bit outside of it. […] I mean, these are two faces of the same coin, of course. This doesn't mean that we work better than them or the contrary. It's just a different way of affronting our project." (Interview 6, February 2016)

The team in Cadarache, on the other hand, is interested in optimising conditions for breeding *Asterionella*, in maximising cell density in cultures, and in trying to move to the largest production scale possible. They are not equipped to consider the molecular level, but are in a position to develop contacts and collaborations with industries. Their focus is on whether *Asterionella* can thrive, both concretely in Schott bottles or photobioreactors, and more figuratively in an industrial setting. They also work with quantities of algae that the biologists had never even seen, even after years of working on the organism: the senior biologists gazed in wonder at the 30-litres tubes filled with algal culture when she visited the lab in Cadarache (field notes, March 2016).

> "I cannot go further than characterizing [bacteria] visually. I can say, oh, here, I see many bacteria on the alga, they are round, or stick-shaped, etc. But I stop here." And later: "As you may have noticed, [one of the biologists] told me she diluted the culture to 1/100; and you see almost nothing, it could be water. Whereas here, it's much denser, and it's coloured. But, still, we are still too low in terms of cell density to make it viable for commercialisation one day." (Interview 23, post-doc, Cadarache, April 2016)

Last, the bioinformaticians work with computerised sequences, that they analyse with dedicated software and statistical tools. They can propose hypotheses as to, for instance, the identification of the bacterial species that live with *Asterionella*, or make predictions on characteristics and possibilities of the sequenced microalga, and then confront them with experimental findings. Their work on genome sequencing will also lead to the inclusion of new sequences in global database, and thus add to the data available for researching issues investigated with bioinformatics.

> "There, you know everything the alga's genetic programme, for instance, is able to implement, and so you can predict, well, whether this alga will be able to make a certain type of compounds, react or stress in a certain way, involving a certain metabolic pathway, a certain chain of genes, that kind of things. That's for the part that will interest experimental biologists, who are really interested in how the cell functions. Then, as for me, in that, I find something that I find much more interesting, which is evolution. That is to say that with sequences, you can interpret evolutions, how organisms were in the past and how they became what they are, how they adapted to their new environment, that kind of things. And that's also processed on computer." (Interview 17, bioinformatician, April 2016, my translation).

In this task centred around a specific organism that is subjected to a variety of treatments, trials and transformation, and grown in very different material and scientific settings, issues related to the basic understanding of biological processes and issues related to expectations and promises are tightly and continuously interwoven. The collaboration functions because *Asterionella* appears to be adapted to the diverse interests and expectations of the participants: it is unclear whether it will thrive outside the labs – though the intention to test this is clearly asserted in this case, as opposed to the previous one – but so far it seems able to thrive as a scientific model in very different settings, and under different shapes.

Concluding remarks

These first observations point to the multiple and somewhat ambiguous way promises and expectations influence the organisation of research and materialise in Microbio-E. They are presented as its justification and constitute the guiding principle around which to nurture an academic network and to foster interdisciplinary collaborations. All the same, for many researchers, they appear very remote, not only because there remains much work to do if they are ever to materialise as technological options, but also (and mainly?) because to an extent they seem to belong to a different world. There are exceptions of course: for instance, the Cité des Energies in Cadarache, and to a lesser degree the team working on microalgae in Cadarache (of which I have not said much here), are clearly organised to address issues related to bioenergy. But other teams have hardly ever worked on bioenergy production, though their research may happen to be relevant to the issue. Actual expectations for the project in terms of innovation and technology development are thus rather modest.

That is not to say that the perspective of bioenergy has no effect, but these effects are clearly not straightforward. Bioenergy as a broadly defined area of application serves as a unifying perspective, as an argument for federating diverse teams, for exchanging ideas, methods and staff, and for testing collaborations. It seems to take shape in ways that may be unexpected for an outsider looking for emergent developments for the next generation of biofuels: not so much as pilots, but via the cross-fertilisation of scientific topics, the circulation of staff from one lab to another, the direction of the scientific gaze on specific characteristics of model organisms, the inclusion of extra-disciplinary or extra-scientific considerations (for instance the price of oil) in the design of research strategies…

As the main objective of the project lies in the creation and reinforcement of interactions among labs in the region, one challenge for this study would be to find ways to trace and map these interactions, and understand how they were affected by the project, in finer details. The two

examples detailed in this paper show that they can unfold in quite different manners. In their description, I attempted to consider equally the strategies of researchers, the material and conceptual devices that they rely on in their respective disciplines, the organisational frame of the project, and the object under scrutiny while studying how collaboration unfolds and to what extent promises (including the promise of interdisciplinarity) materialise.

This strategy may help tackling a project such as Microbio-E: the broad scope of the project and the multiplicity of more or less well-defined expectations for it make its perimeter hard to delineate, especially as the modalities of research and the definition of concrete scientific objectives are largely left to participants. Following some of the tasks included in Microbio-E and analysing how they unfold and what they gain from being included in the project, as I have attempted to do here, may be a way to navigate this complex environment.

Another issue has to do with the status of the sociological investigation embedded in the project, especially as there are no predefined expectations as to its precise outcome. Should sociologists act as mere external observers, as allies for project coordinators, as advisers in the design of future projects…? How to account for the effect of having a sociologist circulating between and drawing a picture of the project as it unfolds? What can social studies of science and innovation gain from being included in the very initial stages of potentially applied research?

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