Abstract
L'article vise à montrer que l'approche régulationniste peut éclairer l'analyse des dynamiques de transition vers l'usage des ressources renouvelables en mobilisant le concept de patrimoines productifs collectifs. On s'appuie sur l'étude du cas de la chimie doublement verte pour identifier les patrimoines à l'œuvre, et la façon dont ceux-ci sont le support de stratégies d'acteurs qui contribuent à réguler le changement technologique. On peut ainsi enrichir à la fois les analyses des systèmes sectoriels d'innovation et les démarches de management de la transition vers un nouveau système socio-technique soutenable. Or la reconnaissance d'une diversité technologique peut jouer un rôle crucial en management de la transition vers un développement soutenable.

Mots clés : régulation, changement technologique, patrimoines productifs collectifs, chimie doublement verte, développement durable
Collective Productive Patrimonies (patrimoines productifs collectifs) and Sustainability Transitions

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Summary
We use a regulationist approach of sustainability transition in sectoral systems of innovation and production (=SSIP). Following the methodology proposed by Piore (2005), a case study allows us to test the respective capacities of the regulationist approach and of the theory of “SSIP” to explain actors behaviors in sustainable technological change and environmental innovations. This case study describes the construction of a sector dedicated to the transition towards renewable resources in Chemistry that we call “doubly green chemistry”.

The French “théorie de la régulation” is traditionally considered as a macro institutionalist approach; but recent developments (Laurent et Dutertre, 2008) are about sector and territory regulation (= régulation sectorielle et territoriale). We intend to show that such approach can be mobilized for discussing and helping to clarify the Evolutionary economics of SSIP used in sustainability transition research (into the ”MultiLevel Perspective” school of thought, e.g. Geels, Grin, or vari autors - see a presentation of this research school and the 2th symposium of the Sustainability Transition Research Network in Nieddu in Nature science et Société, 4/2013).

Regulationist approach analyses in an “historicism perspective” the dynamics of sectoral systems; So, we use the conceptual framework of collective productive patrimoines (patrimoines productifs collectifs). Collective Productive patrimonies are, first and foremost, non-material resources (e.g. collective visions of the future, or the construction of intermediate objects - in the sense of sociology of science) producing coordination between users and producers and and collective learning. Collectives productive patrimonies are also material resources: dedicated public or private collective laboratories and technological development activities, or pre-industrialisation pilot units. Collective patrimonies can be sectoral institutions and institutional tools for the constitution of communities - such as Europe’s ‘technological platforms’ or competitiveness clusters (poles de compétitivité) in France -.

In the first section we discuss the scenario of spontaneous emergence of a “dominant design” into “innovative niches” - a strong hypothesis of the Multilevel perspective of sustainability transition Studies - by showing the importance of the logic of collective productive patrimonies to understand the emergence and the management of these “niches of innovation”. This scenario of spontaneous emergence of a dominant design into the innovation niches must be discussed considering the strategies of entrenched actors.

In the second section we describe the origine of collective productive patrimonies into biomass refining that contribute to form the new sector. We show that the ideas and the new technologies of transition towards renewable in chemistry are the product of food and fiber industries’s dynamics rather than issues of sustainability transition or environmental innovations.

In the third section, we focus on four collective productive patrimonies. Each one seeks - through innovations- to project into the future its own existence. Into each of these four productive patrimonies, the set of innovation has its own logic of environmental progress. Two ”Majority
search to mimic the division of labor and the supply chains of petrochemicals chemistry. Two "minority reports" search to exploit the macromolecular complexity of biomass into another pathways. Therefore, the assumption of the formation of a dominant design must be rejected; and the explanation that use technological path-dependency must also be discussed. Innovations that are presented as radical innovation appear as enforcing existing productive patrimonies.

Introduction

Economic activities can only exist when a certain number of resources are "lumped together" as collective productive patrimonies (we want to explain why we prefer this polysemic french term to the term assets). "In innovative, fast-changing environments it becomes more and more difficult to pinpoint firms (whether systems integrators or mere assemblers) as the correct unit of analysis. Problems are solved 'socially', and understanding how problem-solving strategies unfold within communities of specialists that cut across firm boundaries is a challenge to both practitioners and scholars." (Brusoni et alii, 2004:20). What we refer to as collective productive patrimonies (patrimonies productifs collectifs) are resources which (1) are sought after for their collective value, (2) have to be shared in order to exist, and (3) justify, through their own characteristics, the effort expended to preserve them, in phases of strong doubt as to their actual ability to produce new objects, at acceptable market conditions (Nieddu, 2007). Productive patrimonies are, first and foremost, non-material resources (e.g. construction of visions to the future, or construction of intermediate objects, as cognitive tools) producing coordination and collective learning between users and producers (Foray, 1994). These immaterial resources are systems which recognise free resources – scientific knowledge, for example – as being ripe for mobilization as resources in a given sector or network (Billaudot, 2004). As material resources, collective productive patrimonies is a matter of 'localized' facilities which allow scientists and economic actors to meet: dedicated public or private collective laboratories and technological development activities, demonstration and pre-industrialisation pilot units. Collective productive patrimonies can also be sectorial dedicated institutions (Barrère, 2007) or institutional tools for the constitution of a community, such as Europe’s ‘technological platforms’ or French competitiveness clusters (pôles de compétitivité).

We want to show that this concept can illuminate a problematic issue in the literature of transition towards uses of renewable resources. This literature borrows from three major theoretical fields (Grin et al, 2010): "Science & Technology Studies", Evolutionary Economy, and Giddens’ theory of structuration, which seek to unify their respective contributions in a general theory of the transition from one socio-technical regime to another. Evolutionary economics relies on a systemic representation of sectorial systems of innovation and production: Its four building blocks are: the scientific and technological knowledgebase, the forms of inter-industrial relations, a specific set of institutions, the nature of the request addressed to the industry (Malerba, 2002). It also suggests the idea that technological change tends to follow a two-stage cycle: the first stage being an exploration of the spectrum of possibilities and the creation of a powerful technological variety; and the second, selection by the markets of a dominant design (Abernathy & Utterback, 1978; Arthur, 1988; Jolivet, 1999).

Hence, recent literature suggests that the competition/selection model of technologies is in need of re-evaluation: "this model is attractive due to its simplicity, but could be too simple to effectively describe change processes" (Sanden & Hillman, 2011:403). Mutations happen "on the edges" of

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1 Also called Multi-Level Perspective (MLP) (Smith, VoB & Grin, 2010).
existing technologies and productive specializations, starting out as "niches" [Grin et al. 2010, op.cit.]. Yet it is important to note that these niches are treated as patrimonies. Given their technological promises, they are protected from competition and from economic calculation in the course of the exploration of their potential.

The notion of the collective productive patrimonies takes these different aspects into account (inter-organisational pooling of resources, path-dependency, and desire to maintain technological variety, or preserve niches). As O. Godard (1993) states, this notion indicates heritage as much as it does the desire for projection into the future: The heritage that you want to see recognised, preserved and developed in the future is a tool to organize a “taking power” on the future and control of this future. Therefore situation of transition must be analysed as competition to control the creation of “visions to the future”, as well as competition of technologies into transition.

A supply chains of chemistry's case study illustrates the theoretical framework and describes an arena of confrontation between productive collective patrimonies.

1- Discussion of the sustainability transition management literature

The literature on the transition towards usage of renewable resources seeks to analyze the transitions from a Multi-Level Perspective (MLP) (Smith, VoB & Grin, 2010) and to offer a "paradigm for sustainable innovation policies" (Nill & Kemp, 2009: 677), using "Science & Technology Studies", Evolutionary Theories of Economic Change, and sociology in a systemic analysis of socio-technical regimes.

1.1. Discussion of a dominant design

Evolutionary economics offers three keys to change: institutional incentives to produce "environmental innovation", conversion of the sector's scientific and technological knowledge-bases to the new 'green chemistry' paradigm, and transformation of the structure of the demand towards less-polluting products (Oltra and Saint Jean, 2009). But it also suggests that technological change tends to adopt a dominant design as the new paradigm. This new paradigm is selected by the market after an initial stage of exploration (of the spectrum of possibilities).

Discussions within this school of thought have already shown that this vision raises two specific problems with regards to transition management. In their reassessment of the MLP model of technological transition, Genus & Coles (2008: 1444) write:"There has been a tendency to focus on ‘winning’ technologies and methodological issues concerning the functionalism of the MLP, and the poor conduct of historical case studies appear to have been undervalued. Moreover, there is a danger that some of the ideas implicit in this treatment of the MLP can seep into the policy making domain so that the ‘reality’ of a neat, mechanistic model of transition could become the dominant interpretation of the MLP." They consider that one of the problems with this model is that of using the startpoint and endpoint for the transition (as exogenous variables) to establish transition strategies. The point of view we want to support here is that it is necessary to empirically document the variety of emerging technological trajectories. Specifically in the context of sustainability issues, the idea of a unique paradigm which would allow determination of which are the "good" environmental innovations presupposes that we will manage to define a priori "green technology" and environmental innovation technologies – a matter which is now hotly disputed.\textsuperscript{2}

\textsuperscript{2} This question was the subject of an R. Kemp keynote: "Sustainable technologies do not exist!" at the DIME Conference on "Innovation, Sustainability and Policy", Bordeaux, 11-13, September 2008, and an article of Debre (2012).
Furthermore, the idea of a transition pathway via selection of the "winning technology" from among the various niches, because it would be the most efficient solution for the transition, allows neither the dynamics of the constitution of the scientific and technological corpus to be taken into account, nor correct documentation of the stylized facts on which collective deliberation can draw. The difficulty lies in the fact that the cumulative effects related to growing yields cannot stand in for explanation, since they are largely unknown ex ante. The selection of technologies therefore leads back to the logic of actors, and to their representations of the future at the moment of making their decisions. It is necessary to “...consider them not just in the context of the current regime, but also in competition with unsustainable practices in niches more closely aligned with the interests of the regime (...). Others have also argued that sustainability analysis must include the counter-veiling effects of unsustainable transitions in the making (...). There is a contest between various niches, each positioned differently in relation to regimes (...).” (Smith & al, 2010:443).

Moreover, technologies can be both complementary and in competition. Innovations are therefore only worthwhile if they allow the organization of interactions with existing collective productive assets (collectives patrimonies). Therefore, certain technologies "catalyse development and open the way up towards others" (idem): They can then be qualified as "bridging" or "two-world" technologies. (Kemp and Rootmans, 2005: 335).

1.2. Technological trajectories and collective productive patrimonies

The evolutionary theory sequence “exploration of a variety / exploitation of a dominant design” has its own explanation within the argument of benefit from the cumulative effects of rising yields. But it functions like a "black box" which raises a set of questions (Jolivet, 1999). In particular, it supposes: (1) that new knowledge is generated about the emerging family of technologies, and (2) that the related learning is translated into a collective capitalization of knowledge, so as to result in technological convergence. Since the actors (laboratories or companies) hold heterogeneous knowledges that are partially contradictory, they have the obligation of produce collective theorizing about technology, in order to stabilize technologies, so as to knit together the fragmented and piecemeal knowledge they carry.

A further reason leads us to be attentive to the dynamics of “collective productive patrimonies”. The literature on transitions towards new socio-technical regimes, and on path dependence, invites us to consider that mutations happen "on the edges" of existing technologies and productive specializations, starting out as "niches" [Grin et al. 2010, op.cit.]. Yet it is important to note that these are treated as patrimonies. They are protected from both competition and economic calculation in the course of the exploration of their potential, because of the technological hopes associated with them. This orients the work of scientists, who are called upon to transform in reality "an eagerly-awaited novelty" whithin a niche ; or to explore a range of possibilities, depending on whether the actors want to move forward along a particular path or whether they prefer to keep real options open [Avadikyan & Llerena, (2009)].

As O. Godard states “le patrimoine est non seulement un heritage transmis, mais une tentative de prise de pouvoir sur le futur en créant de l’irrévocable “ : “... la logique patrimoniale, écrit Godard [1990:232], a finalement autant, sinon plus, à voir avec la création de l’irrévocable qu'avec la lutte contre l’irréversible. ». The concept of “patrimoine” indicates that inheritance is more than transmission of the past, but also a strategy to “confiscate the future”, (organize and control the future). The notion of the “collective productive patrimonies” takes these different aspects into account (inter-organisational pooling of resources, path-dependency, desire to maintain technological variety, or preserve niches, desire to control the future). This concept has
to be accompanied by a concept of techno-scientific promises (Joly, 2010). “Technological hopes” will be tested into cycles of development of new products [Rosenberg (1976)]. "Expectations and visions about the future are increasingly acknowledged as a central aspect of science and technology development processes and as key elements in analysing and understanding scientific and technological change". [Borup et alii, (2006)].

1.3. Our case study: biorefinery and collective productive patrimonies

We analysed sustainability transition using the case study of biorefineries. This is an example of strategies that have worked to provoke the emergence of a dominant design. Biorefineries are presented as the new paradigm for using renewable resources to produce energy and chemicals. We will discuss this by considering that biorefinery concept must be recognized more as productive heritage of agro-industrials systems than an entirely new paradigm. The biorefinery concept has been worked on in USDA "technological roadmap" exercises (1999, 200'), as well as in such European projects as the Biorefineries Joint co-ordination and Support Action Call (2008). This project was be financed to produce scientific progress, but to elaborate and render explicit the new paradigm's “vision for the future”.

We were able to follow the evolution of these representations via scientific projects conducted in the field of agrimaterials since 1995 [Nieddu & alii (1999)]. These projects were part of strategies of instrumentalisation of the oil shocks. Actually, they were designed to support the agendas of agribusiness development, in the hope of finding a quick route to a "plant-based refinery" by transferring know-how from petrochemicals. This has made us aware of a long history of non-food usage strategies for plant-based products, centered on agribusiness know-how, rather than petrochemicals. The actors themselves probably under-estimated this history, since they were led to propose a representation of the future, using as their starting point a recent birth of biorefinery, as suggested by the scientific literature.

In fact, this takes root in the history of agricultural production excess cycles and the resulting saturation of the agribusiness markets. In the United States, the "chemurgy" movement, and the 1935 creation of the National Farm Chemurgic Council (Finlay, 2003) bear witness to this investment. Productive patrimonies presented in section 3 have thus long since been documented. The technological foresight exercises of the late 1970s, following the first oil shock, did no more than pick up the technological ideas and hopes of chemurgy. And it is striking to note, in consulting documents of the time (Chesnais, 1981: 226) that it could be reproduced today without any modification.

2- The past of collective productive patrimonies into biomass refining

The scientific journal literature gave rise to the concept of biorefinery at the start of the 1980s [in reference to an article of Levy et al. (1981)]. It describes a three-phase history (Kamm et alii, 2006, Clark & Deswarte, 2008). The first biorefinery would have been dedicated to the production of biodiesel and ethanol, on the basis of “a single raw material, a single major product”. Yet, within this logic, waste remains – and therefore, questions about the management of these co-products. In the case of biodiesel, for example, developing the production mechanically generates a “fatal” product - glycerol.

The second generation is still based on the process of a single raw material. Yet it

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suggests using all the biorefinery co-products\(^4\) and thereby extracting a whole range of products for energy, chemistry and the materials. This generation is expected to exceed that of 1990. The experts consider that they are now emerging from the pilot stage.

The third generation may be in a phase of emergence, set to reach maturity as a process around 2020. Sharing the same multi-product approach as the previous one, it diverges in two ways. Firstly, it would be capable of using different types of raw materials and transformation technologies. Secondly, it would be capable, depending on price developments, of modifying the technical itineraries to reverse the hierarchies between key-products and sub-products. This possibility - of instantaneously selecting the most profitable combination of raw materials and process -relies on a vision of the ideal production tool that would be fully adaptable to market fluctuations.

Derived from chemical literature, this linear, three-phase representation must be considered as a proposal for logical classification – more of an educational tool than a historical reality. It is centred on liquid fuels, and the “inflection point” of the oil shocks of the 1970s. Yet, although those oil shocks of 1973 and 1979 did lead (especially in the first European framework programme of 1984) to the launch of ‘Energy from biomass’ themes, separated from chemistry, it seems to us that a re-evaluation of the role of agriculture and agribusiness actors is necessary, particularly given the fact that the productive assets shaped by their know-how and units of transformation were likely to be redeployed in other projects.

Indeed, the "cracking" of agricultural resources is a generic process. In the 1960-1970 period, the emergence of industrial engineering in food industrialization was dominated by an agribusiness fracturation (cracking) and refining model: "the IFP [Intermediate Food Products] phenomenon became important mainly through the development of raw materials fractionation, which entails the extraction and purification of proteins, fats and carbohydrates, with compositions studied at the request of customers: soy proteins, caseinates, glutens, as well as diverse milk- or plant-sourced glucose formulae, have multiplied to become part of the composition [of industrial products]." [Nicolas and Hy, (2000),p.35 ].

Therefore, the collective patrimonies contributing to a "plant refinery" are not, historically organised around fuels – even though, with installation in a world of structural agribusiness excesses (which arrived in Europe via the Mansholt plan of the late 1960s) the idea of regulatory constraints aimed to incorporate a minimum amount of “biofuel” in petrol. This seems all the more natural because of the fact that the agricultural profession has merely reactivated solutions that are already deeply engraved in its memory\(^5\).

How is this important to what we have to say about the emergence of collective productive patrimonies? Actors of industrial agriculture and agribusiness (e.g. the Champagne Céréales co-operative in France, the industrial player Roquette, Novamont, in Italy, linked to

\(^4\) Production of biodiesel-sourced glycerol has exploded, completely replacing fossil-sourced glycerol and also partially replacing that issuing from soap production. The problematic thus moves from the problem of undesirable co-products towards the idea that these become, in a biofuel economy, a stable, abundant and cheap source of potentially profitable substrata, on the condition that the research finds these solutions adequate: this one will find itself much in demand around the issue of the formation of a "glycerol community".

\(^5\) The first French law concerning the incorporation of alcohol in petrol dates back to 1923; the vineyards of Southern France sought to protect themselves from competition from sugar beet and cereal-based alcohols, pushing the farmers of Northern France into industrial usages, particularly “ternary superfuel” (supercarburant ternaire), which was in use right up to the end of the 1950s.
major agriculture on the Po Plain, Cargill, etc.) have come a long way from the discovery of “cracking” or “refinery” technologies. They are very familiar with the variety of potential non-food outlets that are not only agrifuels. Over time, they have positioned themselves as suppliers to industry: their job is to be producers of intermediate agricultural products. They adjust the functionalities of these intermediate products in order to satisfy agribusiness customers (additives) or other sectors (stationery and cosmetics, for example).

During the 1970s, research into the fractionation of the main agricultural substrata (cereals, milk and sugars) dreamed of recomposing any type of food using any raw material. Agricultural substrata “can be woven like nylons and result in a texture that is identical to that of lean meat.” ... "Texturized vegetable proteins" have been successfully promoted, and seem likely to have a growing impact on food markets" (Hudson, 1976, p.579). The rapid biotechnological progress made in the 1980s seemed capable of turning these hopes to reality (our 2009 interview with Hervé Bichat, Director General of INRA (French National Institute for Agronomic Research), 1990-1992).

How is this technological fractionation model set to transform itself? On the one hand, an impasse emerges as soon as food ceases to be thought of solely in terms of unitary nutritional values in undifferentiated carbons: organoleptic dimensions or social acceptability start to be taken into account. On the other hand, in the course of the 1980s, although oil-related prices fell significantly, the widespread incidence of excess food led actors from the agricultural world, and researchers at INRA, to continue their efforts by theorizing an overall value development strategy for biomass aimed at compensating for the low level of added value in agribusiness, via “VANA” (non-food uses). This was the context in which the concept of biorefinery emerged.

It is therefore necessary to track the progress of biorefinery along two pathways, each of which saw the emergence of research and production communities: the first being related to problems of substitution for liquid fossil fuels (the main purpose of cracking being for energy), and the second being the broadening of the range of products supplying materials and basic products for a specialty chemistry founded on sugars or oils. The paper industry has been experiencing the same market saturation with the emergence of excess production capacity, which is leading it to draw the same conclusions (Stuart, 2006).

Following major foresight exercises conducted in the late 1970s, the notion of biorefinery could only be constructed gradually. VANA actors, in parallel to the pick-up of plant-based fuels, sought to transfer competences from the field of biomedical technologies and so-called ‘white’ (or ‘industrial’) biotechnologies, so as to produce ‘biopolymer’ materials. This is when, for the first time, the ‘sustainable development’ qualities of agricultural substrata made progress, in the form of a functional advantage in terms of biodegradability (Nieddu et alii, 1999).

In the 1999-2005 period, the actors developed their overall vision through ‘technological roadmaps’ and forecasting exercises. These exercises were to give rise to a joint Europe-USA working group in 2004, and the work was extended by two European projects (Biorefinery Euroview and Biopol, 2007-2009), carried out the 6th PCRD and explicitly dedicated to the construction of a long-term ‘vision’ of the biorefinery. They brought together

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scientists and private decision-makers with collective status (international chemical industrial federations and agricultural co-operatives).

3- The future of the use of renewables : four productive patrimonies

Using a survey of the literature, we have documented the sources of variety presented in European projects. The important point is that the scientists agree on the fact that there is no key to getting a priori a definitive advantages of one type over another, as Hayes has shown in a review for Catalysis Today. The fact that there is a variety of processes, each of which must be seen as “having its strengths and weaknesses” (Hayes, 2009:148) is attested to by several other general overviews (e.g.: Gallezot (2007) in Green Chemistry, Octave and Thomas (2009) in Biochimie). In the Catalysis Today, article, Hayes stresses the fact that assessments of technological hopes will be different, depending on the location of biorefineries and the timescales used.7

The documents resulting from the Biorefinery Euroview and Biopol project submission days in March 2009, and the debates with the scientific leaders of research communities, suggest that the "vision of the future" that emerges from the institutional documents is a compromise between the actors of the thermochemical and biochemical pathways. This compromise masks the diversity in the conceptions of the priority to produce biofuels or other intermediate products. Bennett (2009) who conducted a series of interviews, stresses the tensions that are perceptible between actors having a preference for bioethanol or biodiesel technologies (coupled with the transformation of co-products to chemical products with high added value), and other actors from agribusiness and specialty chemistry, reticent to follow the same path. These others were seeking to discuss both the definition of initial fractionation and the dominant destination of production.

3.1. In the core of differences : supply chains and philosophies of chemistry

These oppositions must be understood within the context of a strong interrogation within the agribusiness industry about the recomposition of sectors and value chains for which it must prepare. American foresight exercises (1999-2004) suggested defining the intermediate products on the basis of a strategy of substitution, term by term, of existing intermediates of petrochemical-origin. Yet come the question of "how should it be fractionated, and which intermediate agribusiness products should be delivered?". These discussions on review literature with scientists working in the field,8 and with our collaborating team of chemists from Reims provide a comparative perspective for the institutional forecasting exercises. We have therefore produced a stylized representation of four main pathways towards intermediate products. These four pathways were based on biomass most widely-used biomass fractionalition patrimonies, arising from philosophies and organisation of various value chains rather than from the

7 For example, the acid hydrolysis pathways on a sugar platform are better controlled today, whereas the enzymatic hydrolysis routes provide technological hopes that are higher, but more distant. Hayes highlights the fact that the Biofine process is immediately operational, can be adapted to several raw materials (including solid municipal waste), and the idea that it is highly unlikely that we will one day enter a “winner takes all” scenario. Indeed, according to him there are “numerous examples of cases in which the competitive advantage between technologies varies in line with the specificity of conditions and raw materials; whence it becomes necessary to conduct a holistic examination to determine the most appropriate biorefinery regime for the place it must be processed” (Hayes, 2009:149).

8 These discussions were into various researchers schools eg. Summer Schools of biorefinery chemists (Eurobioref, Biocore), and école chercheurs CNRS
competition of the two previously mentioned processes. Our representation is better understood by giving a brief overview of the chemistry paradigm which serves as the sectorial knowledge-base.

The modern chemistry paradigm is based on the idea of the breakthrough and recomposition of links between chemical elements: the stages go from the fractionation of products into elementary units (with significant energy costs), their purification (within processes and using solvents which can be harmful to the environment) so as to isolate and control elementary reactions – this is the first transformation in the above diagram. Next we come to key-intermediates, and then reforming operations are conducted on complex products, via a cascade of multi-stage chemical reactions (which are also costly in terms of energy, and mobilize catalysts, the safety of which is hotly debated).

The constant dilemma of chemists using renewable resources, as A. Lattes, honorary chairman of the Fédération Française pour les sciences de la Chimie has already stated⁹, is to choose between two strategies: (1) the perfecting of the "destructuring" fractionation pathways that are typical of the oil industry, conceptually well-mastered by the chemists, (2) a "weak-destructuring" pathways (i.e.: which preserve the functional properties or active principles contained in the complexity of living organisms). This leads some of them to identify the fractionation-modification pathways in order to obtain functionalities without having to go through the full destructuring phases: "Rather than following current industrial practice, where macromolecules present in the biomass are broken into C1 building blocks first, which are next reassembled into the desired functional molecules, the synthesis power of nature should be used to the maximum possible extent. For this purpose, the rich molecular structure in the biomass has to be accessed without significant degradation" (Marquardt et alii, 2010, p.2229).

In the same manner of thought, the biomass conversion strategy passing via biochemical pathways has been under discussion recently in major scientific "critical reviews" (Sheldon, 2010, Gallezot, 2012, yet to be published). At this point, chemists in search of alternatives refer to a heritage from the agribusiness and oleochemistry sector, which will lead us to characterize each of these pathways on the basis of the productive heritage which carry them:

"In the future the platform molecule value chain could become more and more successful to produce high tonnages of bioproducts, but in the meantime most of the high tonnage industrial bioproducts are produced by a different strategy which does not aim at producing pure isolated chemicals competing with those derived from petroleum. This strategy consists of converting biomass in minimum steps to functional products such as surfactants, lubricants, plasticisers, polymers, ..., paints, food additives, and cosmetics. Many examples illustrating this approach are given in Sections 4 and 5 of this review. As practised in the food industry, it is not always needed to isolate pure chemicals to make marketable products. This value chain is more likely to be cost competitive because it reduces drastically the number of conversion, extraction and purification steps.” (Gallezot Chem. Soc. Rev., 2012, 41, 1538-1558, p.1551)

3.2. Two “majority” pathways, but a single biomass conversion strategy?

The American forecasting exercises carried out an inventory of substitution pathways for products which were from agricultural origin before the era of cheap oil. They conclude that proposed to scientific research efforts should be directed towards these searches of substitution. E.g. an emblematic product at the end of the 1990s being lactic polyacid (=PLA), has been

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⁹ in response to a presentation of the various fractionation-modification pathways we have covered at the CNRS researchers Summer School; "Which chemistry for a sustainable society?" (October 2009)
known since the early 20th century. It was synthesised by petrochemical means for medical purposes during the 1980s. Biotechnological advances have led to the perfecting of fermenting processes, by breaking down of renewable resources such as starch into building blocks\(^\text{10}\). These monomers were identical to petrochemicals; then by polycondensation (i.e. a chemical reaction), we reach this “biopolymer” – which is in fact chemio-synthetic – that is PLA.

This pathway sets out a strategy which comes back to "mimicking" the traditional organisation of petrochemicals, the basic chemistry of which is founded on five major oil intermediates (ethylene, propylene, butadiene, benzene and toluene) that were precursors to specialty chemistry. The “technological roadmap” exercises will determine around thirty major intermediates produced from biomass - which is quite a few, if you consider the cost of learning and the relatively high number of itineraries which will have to be explored. These exercises offer to reduce this number by inviting both public and private actors to concentrate their learning efforts on a “Top 12” platform molecules. This top12 was earmarked by experts as the most promising. The industrial and research issues thus travel through this limited list of precursors, which builds, very largely, on perspectives foreseen in the late 1970s.

This “top 12” was to be specified by some actors as going in a very particular direction: towards strict complementarity with existing petrochemistry. This is an installation strategy for biorefineries of major chemical industrial strongholds -such as the ports of Gand, Rotterdam, or Singapore. The challenge lies in making the transition towards renewables resources sustainable for these currently petrochemical industrial areas (by mobilizing an agricultural resource delivered to world markets). The article which best describes this is a Dutch exercise listing the main intermediates produced and consumed by the chemical complex at the port of Rotterdam to envisage, term by term, their supply by biomass: for example, the conversion of "bio" ethanol into ethylene and propylene or glycerol, in a 1,3-propanediol to produce the same propylene glycols as petro chemistry [Van Haveren et alii, (2008)].

The chemical industry could thus remain essentially identical, even as the "biosourced" revolution happens. The processing of plants aims to return towards known chemical intermediates, modifying neither their structure, nor their intrinsic properties. "Biosourcing" thus requires no evolution in production processes for plastics manufacturing, with only the early stages of the chain having to adapt to the change of resources; and the applicative scope remains similar to that of existing markets.

This, then, comes back to a very particular way of selecting research programs and learning pathways on the transformation of the intermediates "Top 12". For example, whilst we know it to be possible in the laboratory, those colleagues questioned in 2005-2006 dismissed the transformation of agricultural ethanol into ethylene as not making much sense because of the energy cost of the reaction; and yet this "complementarity pathway" has imposed itself on observers, as is proven by the construction of production units by oil group Braskem in Brazil, so as to be able to rapidly “greenify” the carbon footprint of industries with an extensive use of plastic bottles.

3.3. "Minority reports”?

Fractionation into small molecules (syngas or platform molecules entering into this fundamental chemistry) has emerged from the foresight exercises as the logical course of action, and yet, other biomass conversion strategies, which are part of the agribusiness competences

\(^{10}\) Building blocks are chemical molecules having low molecular mass as well as at least one reactive chemical function. These molecules constitute, in the language of the chemist, ‘molecular bricks’ as in a set of LEGO.
heritage can also be documented. Here, too, it is important to accept a momentary excursion into the language of chemists.

One feeds on the tradition of agribusiness or oleochemistry processes which isolate natural metabolite molecules or polymers, then, using their specific structure, modifies them in limited ways, without intensive deconstruction: in their own language, chemists thus contradict fractionation into C1, C2, and C4 for thermochemistry or C5 and C6 for the biochemistry of platform molecules. In “minority reports” one prefers “weak fractionation” into long, complex chains. If we take the example of starches, we are not seeking to attain the monomer stage, through fractionation operations, but to achieve a limited transformation of "native" starches so as to “functionalise” them - that is, to endow them with specific functions that are of interest to a particular market; these treatders mobilize the families of know-how which can be physicochemical (through the extruder with the addition of a reagent for thermoplastic starches) or photochemical (grafting of additives to the starch via treatment radiation or triggering of self-organisational reactions on the basis of the properties of its structure to obtain PVC substitutes, for example)\textsuperscript{11}.

Another alternative pathway (alternative to strong deconstruction in biorefinery) relies on agribusiness which, during the traditional separation of the plant’s major components, has conserved their structure so as to conduct the exploration of potentially useful qualities, by means of physical or physico-chemical treatment which is respectful of their complexity. Good illustrations of this are hemp-based concrete, and wool insulation, (in the automobile industry which makes uses of compounds that integrate natural fibres to reduce the use of fibreglass as a resin matrix), or products issuing from the sunflower-oilseed crushing industry (such as those of the Vegemat\textregistered brand, which aim to produce limited-lifespan plastics).[(Garnier \textit{et alii}, 2007)] In contrast to the fractionation into "platform molecules" strategy, this compound is described as drawing its properties from the simultaneous presence of fibres (playing a reinforcement role which improve mechanical properties), starch and proteins (thermoplastic properties), fats (lubrifying action that is useful to the process) [Evon, 2008]. Programmes such as Lignostarch (2007) seek to combine the plant’s major components to obtain materials directly, in the same way, and as indicated by the program name, Lignin + starch.

Conclusion: What is changing and What does not change?

“everything needs to change, so everything can stay the same”

Prince Salinas in The Leopard

Evolutionary economics emphasize the importance of two dimensions of the schumpeteran inheritance: disruptive or radical innovation as origin of change, and pressure of selection to identify a winning technology. Using Evolutionary economics in the context of sustainability transitions, the Multi Level Perspective theory of the Sustainability Transition Management Network is faced with the need to link two levels: the level of niches where relevant environmental innovations are supposed to emerge as winning technologies (considered in MLP as the startpoint of change), and the level of a new sustainable socio-technical regime as target of desired change (considered as endpoint). This Socio-Technical Regime is structured via relationships and coevolution between the winning technology and institutions or organizations that allow it to be successfully deployed.

Our case study shows that this scenario must be discussed; if one accepts the analytical framework in terms of collective patrimonies, one cannot the niches as the starting point nor socio-technical regime as the end-point can be accepted. The first issue is that the observed niches do not exist _ex nihilo_. They are embedded in collective patrimonies that organize the trajectories of learning from chemio-synthetic knowledge to innovation. Therefore, the explanation using the evolutionary concept of technological path-dependency does not be sufficient, because the exploration of niches to maintain the context and the competitiveness of a specific collective patrimony needs radical innovations (for example dramatic progress in catalysis or enzymatic catalysts as disruptive innovation)\(^{12}\).

The second issue is that the (desired) socio-technical regime is itself a stake in the competition; The dynamics of “entrenched actors” do not consist into a realization of forecasting analysis and exploration into the niches to _discover_ the future. But the collective operations of US Agriculture department or European Commission mentioned in this text are especially exercises of _backcasting_ from a _dominant vision of the future_ to organize the technological and economic choices _today_. Regulationists economists and politists ([Jullien and Smith, 2011](#)) theorize this as political problematization of the sector\(^{13}\); It's true, but this problematization consists in a “patrimonialization” of specific collective patrimonies: Technological roadmaps are designed to focus the efforts of scientists, in order to remove the technological barriers and bottlenecks on roads leading to the vision.

In this backcasting, the development of renewable resources in energy and chemistry is considered as a model mimicking the supply chains and the division of labor into petrochemistry. And the technological change is oriented to maintain these supply chains. This strategy consists of a term-to-term substitution of oil-sourced molecules with a biosourced molecule (for example, the biosourced _polyethylene_ of the firm Braskem is produced from brazilian ethanol). So renewables are integrated into a process of greening that preserve the traditional chemistry supply chains, and the business models of agri-foods firms (founded on the production of intermediates).

The third point we wish to emphasize is that the problem of using incremental and radical innovation categories in a context of sustainability transition and of environmental innovation. The technological trajectories described in our case study show that innovations considered as radical\(^{14}\) from one point of view are actually innovations to maintain a technological trajectory and reproduce a given productive patrimony (eg: biofuels were considered as a radical innovation in the late 1990s by evolutionary economists of environment, such as Faucheux and Nicolai, 1998, despite its role in maintaining the liquid fuel and intensive agriculture trajectories).

Therefore, an innovation that is considered as radical in regards to scientific or technological dimensions, may not be so radical within the socio-technical regime. We have seen the

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\(^{12}\)A specific study of the business models in our ANR - a part published in Biofutur (Nieddu et al. 2013)- identify a model of joint venture between petrochemicals supply chains mimetics firms, and firms that control property rights on biotech processes; The second offer strong techno-scientific promises to to nourish the trajectories of the first one.


\(^{14}\)For example, white biotech (use of biotech in industrial processes, eg the designing of an organism to produce a useful chemical or the using of enzymes as industrial catalysts to produce valuable chemicals). The hope is that white biotechnology tends to consume less in resources than traditional processes used to produce industrial goods.
opposition between the "minority pathways" and the term-to-term substitution strategies. Term- to-term substitution strategy corresponds to building a "biobased chemistry" which does not entail any profound reorganisation of the next stages in the value chain, and so of the current socio-technical chemistry regime. Minority pathways are looking for a paradigmatic breakthrough, in terms of "how green chemistry principles are applied". And they use old know-how and incremental innovations as well as radical ones.

As a result, each productive patrimony seeks to develop its own progress in the use of "green chemistry principles", combining, from a systemic perspective, small steps and disruptive knowledges and innovations. Similarly, it is difficult for us to characterize the emerging innovations in this sector as environmental innovation per se, because of the rebound effects.

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15 Companies seeking to reduce the carbon footprint of products (within their patrimony trajectories) try to mobilize progresses in chemistry mastering the one-to-one substitution of each of these products. For example ethanol that has been massively produced from oil refinery ethylene becomes a source for substituting fossil carbon. But these selected substitutions resulting from narrow minded logics –such as reducing sustainability to CO2 emissions- generate other questions related to product identities. These questions lead to exploring other one-to-one substitutions such as the replacement of PET by partially biosourced PEF (as proposed by the Dutch firm Avantium). In this case the substitution begins with the use of ethanol to produce green ethylene, but the coherence imposes to keep on substituting the other comonomers, by using the available building blocks produced in PH1 such as 2,5 FDCA.
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