Outcomes of the presentations and discussions

Bioeconomy 2020–2050
The challenges facing the French agricultural, food and energy sectors

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The symposium was devoted to the **bioeconomy from the European standpoint**: *….an economy that encompasses the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy. It includes agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries.*

The first day, after a presentation of European and national policies, two issues were addressed: (a) regional opportunities, from the local to the global[1]; and (b) the effects on the biosphere: is bioeconomy a viable option at the environmental level? Will there be enough

[1] This event was followed by a second one *Bioeconomy is a circular economy … in essence !* in Reims, on Campus Sciences Po on July 1st, 2015, with a focus on local development (contact J-M Chauvet).

biomass for everyone? What will be the interactions with climate change? In other words, is the pursuit of the anthropization of the biosphere possible within a context of sustainable development?
The second day was first devoted to the benefits and promises of the biotechnologies and then to societal changes linked to the bioeconomy.

The results of several research projects (Futurol, BioTfuel, Biotechnologies-bioressources, TWB, Scénarios de la biodiversité, etc.) were presented, without claiming to be exhaustive. The presentations of the four main speakers put insights on the bioeconomy into perspective in terms of the different energy, food, climatic and ecological transitions, and proposed several promising new directions.
A total of 227 people, including a wide range of stakeholders (from research to economic spheres) and disciplines (for research), attended the 33 presentations. Regional stakeholders (regional councils, in particular), whose contribution to these reflections is essential for constructing a vision that is both closely linked to the region and coherent at the macro level, were made conspicuous by their absence.

Beyond the explanation of key concepts and a shared vision of the necessity for integrative approaches to the bioeconomy, the symposium made it possible to identify several orientations that are presented below.

1. Contributing to sustainable development via regional enhancement. The role of organizational/systemic innovation.

The bioeconomy is above all a political vision that is by nature contextualized due to the fact that it is based on locally available biological resources (thus the importance of the forest in Scandinavian countries, seafood products in Iceland, more balanced biomass clusters in other countries), consistent with the concept of a regional biorefinery combined with production and transformation. The perimeter of the bioeconomy extends to the biological utilization of CO_2 (e.g., concentrated sources of CO_2 at the outlet of heating systems in order to inject fossil C into the carbon cycle via injections into micro-algae crops where the dissolved CO_2 content can be a limiting factor).

The bioeconomy is also an economic reality to be understood and modeled. The development of biorefineries raises the question of how to set prices for co-products of the food industries in order to establish co-product supply functions and to thus identify hidden links between sectors (e.g., oleochemistry and livestock production).

The **main challenge is to assess sustainability**, which requires a clarification of the importance that we give to **negative externalities.** The first difficulty is to more effectively take account of the diversity of the different scenarios in life cycle analyses (LCA) by considering local conditions (water, pollution, etc.) and the necessity of being able to compare very different human activity systems without making an exception for anteriority. A second difficulty is the need to have a dynamic vision: in fact, characteristic time responses for technological segments of the system cover a wide time range, from the instantaneous act of consumption, the hours and weeks of transformation, up to the years of forest production. Finally, the development of indicators linking agricultural and forestry practices to products resulting from the bioeconomic system assumes that links within the sector or

between different sectors (e.g., between milk and meat) are taken into account by proposing robust distribution criteria.

The bioeconomy **is partially *(but not completely)* inscribed in the circular economy.** It is not intrinsically sustainable and its components must be evaluated independently. Two **new concepts** enrich the landscape:
- cascading uses,
- the closing of C, N, P and K cycles.
These concepts challenge the notion of a null or even negative value of waste in the value chains and, as a consequence, the link between the material specifications of products entering or exiting successive operations. Waste is a resource, including CO_2 (concentrated sources of CO_2 from heating systems, cement works), to close C (passively through respiration-photosynthesis), N, P and K cycles, with substitution possibilities and cascading uses. In this way, the bioeconomy makes it possible to decouple growth from the use of raw materials. A major question still remains about phosphates that are non-renewable since they are mined, requiring a 'recycling' perspective as well. If we are looking for the best way to use waste, shouldn't we combine renewable carbon use and the recovery of phosphates within a global approach rather than having to revise our strategies 20 years from now to deal with a shortage of phosphates? More attention must be given to the notion of recycling, recalling that nature can also produce waste (fossil resources are an example).

The concept of the bioeconomy encourages feedback from experiences and the effects of learning on a large scale. Depending on the local availability of biological resources and/or waste, it is possible to initiate projects that depend on the opportunities provided in a country to develop pilot facilities. Economic actors at the international scale can then use them as learning tools for other countries (the price of natural gas in Switzerland that makes biogas competitive, German policy on biomethane, French tax policy concerning fuel, etc.).

Re-evaluating current sectors in view of a bioeconomic system raises four questions:
- production and transformation processes are not linearly extrapolable and make us question change of scale laws. At this stage, we do not yet know if the bioeconomy will be an exception to the scale economy law. This response will affect the re-evaluation of traditional processes (downsizing, upscaling) using current ecodesign tools.
- usage functions (clothing, bioenergies, hygiene, habitat) can be fulfilled by "bioeconomic" processes and products without necessarily using current synthons (ethylene, propylene) derived from fossil fuels. Two pathways are possible: a progressive evolution through isomolecular substitution or an isofunctional rupture.
- the link to be created with agronomy in view of the rise in agroecology. How can the bioeconomy generate constraints vs. new opportunities for agriculture (economic diversification: evolution of farming systems with land use, cropping systems with the choice of species) and, more generally, the development of ecosystems? Does reflection at a regional scale make it possible to identity new possibilities for designing and optimizing a system that works or does it create more constraints and, overall, a drop in efficiency? A theme of interest and research thus emerges at the intersection of agroecology and biorefinery.
- intra/inter synergies between production areas by exploring space and time scales. Fulfilling several elementary human needs will raise the question of how to ensure supply, resulting in an assessment of the resilience of systems in the face of climate hazards.

The second particularity of the bioeconomy is to respond to global needs and, therefore, to the expectations of consumer markets. Private stakeholders (AVRIL, ENGIE, Procéthol 2G, Roquette) are highly active in this niche, with long-term analyses (AVRIL, ENGIE). In this regard, the instability of regulations in the area of biofuels is the major reason for the lack of industrial development, according to P. Barthelemy (*10 solutions de la Nouvelle France Industrielle*).
The Ademe 2030 proactive scenario provides an original approach based on a significant evolution of life styles, the transition from quantity to quality, new economies built on sharing and collaboration, and the lifespan of products and their ability to be recycled (to be strengthened by cascading uses). Ecodesign/ecoefficiency thus acquires a dimension of sustainability that extends beyond the single object/service being considered.

The *think globally, act locally* approach can lead to the emergence of projects that take advantage of a windfall effect on a local resource. Competition of biomass uses deserves to be approached through integrated visions that have the advantage of emphasizing complementarities as well.

Several **scenario-based foresight** studies are in progress or have already been published. The bioeconomy requires a **long time (2050)** to represent contrasting situations and to simulate scenario-based evolutions that will help us to prioritize research issues. Major efforts are necessary to discern possible evolution pathways of biomass use based on supply or demand from different angles: Agrimonde is focusing on food balance (not including non-foods as such), Agrimonde-Terra is working exclusively on the energy provided by food that is admittedly one of the major variables but that does not include micronutrient aspects nor all of the aspects concerning food quality and diversity. Energy scenarios (ANCRE) focus on the energy demand and translate it into hectares (the most biomass-intensive scenario would correspond to a mobilization of 9% of the metropolitan area for energy, etc.). The "biodiversity scenario" approach makes it possible to propose operational approaches to reconcile economy with ecology with, for example, the idea of a "viability core" (biomass demand compatible with the maintenance of ecosystemic services and functions), etc. Economic actors also presented an advanced reflection on the perspectives of industrial tools and biomass resources, but the risk of silo reasoning persists.

Which scenarios integrate these different components in order to verify the comparative interest of certain options and their compatibility, in particular, and to shed light on the choice of future investments?
The major problem is the lack of integration between the different activities, whether it be the species-variety-cropping system shift or the integration of crop production and initial transformation. A generic tool to develop scenarios and to model systems at the regional scale, to create scenarios for the development/destruction of activities (because it will occur) and to reflect on training and education is also lacking.

In these scenarios, it would be necessary to summarize the underlying hypotheses, whether they be explicit or not, and to undertake a survey of the scenarios and models that are currently used or proposed (or, if this is not possible, to propose a "bioeconomy" framework within which the models and scenarios could be analyzed). This would make it possible to identify convergences, contradictions, overlapping of scales and possible links within a bioeconomic perspective ranging from the impact of humans on ecosystems to public

policies, and including the biotechnologies, processes, **organizations, jobs, environmental externalities, etc.**

2. Providing technological innovation

In addition to the contribution of a systemic vision, the contribution of new technologies is essential to the bioeconomy. Green and white biotechnologies have already clearly revealed the contributions of incremental innovation and the disruption of production and processing systems, and remain the major hope for new technological innovations, with, in perspective, synthetic biology coupled with systems biology.

Cognitive hurdles are varied:
- the availability of the **plant biodiversity** of the biomass (new species including micro-algae), its deconstruction and its modifications. The greatest expectations at this time concern the two biochemical fractions, lignocellulose and proteins. The lignocellulose inherent in all plants is a source of synthons and fibers, and is not in direct competition with food uses. Plant proteins are also of great interest because of their vital contribution to animal feed and changes in human consumption, requiring research into their sensory and nutritional qualities (essential amino acid content) in order to reduce the dependence on meat. Studies on the plants of the future should include environmental and economic aspects (in particular, the competition for the earth, i.e., the comparative advantages for producers to produce miscanthus or legumes as opposed to other plants).
- Microbial consortia, i.e., as much the microorganisms as the communications within **microbial ecosystems** that are at the core of the process in humans and in animals, as well as legumes and processes. In particular, the interactions between microorganisms are an extremely fundamental issue and can help to regulate the profiles of bacterial consortia. The same is true for interactions between plants and their general biotic environment (positive or negative) that could help to improve nitrogen fixation. The final objective is to be capable of "designing" these interactions in relation to a given functionality and to be able to control them.
- the informational content of the biomass. Its production and transformation throughout the processes generates data, hence a link with *big data,* even if *low data* is not to be overlooked. Its structure and composition linked to the context create different situations (in contrast to gasoline that is more homogeneous) that must be taken into account in order to corroborate sustainability and to enrich *in silico* experiments to test a diversity of possible situations in terms of biomass and processes or combinations of processes.

At this stage of development, **micro-algae** are a niche market for high value-added products: additional research is necessary to increase technological maturity. Micro-algae constitute the emergence of new biological systems that have little dependence on ecosystems, modifying the determination of sustainability. In contrast, the transformation of the wood sector has been the subject of a specifically French policy debate for several decades now where the development potential has failed to translate into jobs and wealth.

On this subject, a wide range of **research** is to be considered:
- developments based on predictive approaches in modern biology (-omics) and engineering to take advantage of genetic diversity, including synthetic biology to generate new resources. The breeding of annual and perennial plants is the first stage of the bioeconomy,

making the supply of the agro-industrial sub-system sustainable (sobriety, resilience, margin/ha and the reduction of GHG/ha). The optimization of photosynthesis is also included in a more long-term perspective.
- quantitative structure-property relationships for anatomical fractions of interest, in order to encourage the production of plants adapted to their use at the expense of undifferentiated production, leading to extensive fractioning followed by separation and, therefore, the occurrence of sub-products.
- quantitative structure-property relationships for molecules and biosourced materials in order to catch up with the level of knowledge about petrosourced products. Iso-functional substitutions will then be possible without overlooking ecotoxicology that undermines established markets.

These prospects for innovation require the availability of infrastructures to ensure advances in technological maturity. The advancement of any project would necessitate the mobilization and synchronization of the engineering disciplines, the humanities and microeconomics. The link between bioeconomy and agroecology raises the question of systemic experiments. The link between varietal innovation and the optimization of cropping systems is an element of rupture to be integrated into experimental setups to corroborate synergies between crops and the associated ecosystemic services. A consequence of this is to design long-term projects that include Go/NoGo steps.

3. Contributing to sustainable development through changes in consumer behavior. The role of training and education.

Within the overall bioeconomic system, the evolution of the consumption of meat and milk products is an adjustment lever of the biological resource system. The **worldwide generalization of the Western food model is not possible** without endangering the ecosystems themselves. The determinism of contrasted evolutions of diets observed worldwide requires dedicated research that combines nutritional and cultural components, as well as an analysis of generational evolutions (the impact of long-term flexitarian/vegetarian behavior). This "consumption of animal products" variable must be combined with demographic evolutions, along with the major uncertainties concerning their quantitative predictions. Qualitatively, trends in aging and urbanization are significant and will have a strong influence on consumption patterns and the consumption of space.

More generally, **the issue concerning food can be extended to other consumer goods**.
Several methods and tools could be implemented within this framework.
- Experiments where the behavior of citizen-consumers is a variable in interaction with other variables (type and availability of consumer goods, organization of space, etc.) require living labs that will also make it possible to observe *in vivo* the coherence of technological and organizational innovations.
- The availability of datasets concerning environmental, economic and social impacts in order to eliminate ambiguities about new solutions and to adopt cost-benefit approaches, systematically taking the *business as usual* option into consideration.

Impediments to using these new tools arise from both companies that are not ready to share and citizen stakeholders who sometimes hesitate to make choices.

An overall consequence of this aspect is the need to **develop training programs**, both in terms of their content and their methods for managers capable of mastering data, modeling and making decisions based on multicriteria. Training "to and by a systemic vision" is indispensable and must include systemic research projects that are, above all, platforms for co-construction between training and research, in order to go beyond the call for interdisciplinarity alone. This results in the need to develop a community/network/Labex (and to mobilize platforms) for multiscale and transdisciplinary systemic modeling and design.

4. Creating synergies between public policies

The bioeconomy is initially a European **political strategy,** subsequently included in recognized national strategies in a large number of European countries as well as on other continents. These strategies point out the need and the objective to **more effectively develop the resources inherent** (natural and regional, human, scientific) to each country or region). The bioeconomy therefore constitutes a very strong focal point of economic development in Finland, which is founded on a vision promoted by the government that is based on the country's assets (the forest, etc.) and on a broad consensus of the stakeholders involved.
It should be stressed that the African continent, with the exception of South Africa, is absent from this vision, whereas it is Africa that should experience the greatest demographic growth between now and 2050 as well as land use changes critical to environmental and social plans and a strong impact of climate change on agricultural production.

The context of the COP21 is favorable to the development of reflections concerning the bioeconomy that also respond to food, chemical and ecotoxicological challenges in addition to that of the climate.

In France, the convergence of the concerns of the MENESR (SNR), the MAAF and, to a lesser degree, the MEDDE and MEIN, has led to the bioeconomy being put on the agenda. A working version of the national strategy in terms of bioeconomy, currently being drawn up within the different ministries, should be available in September 2015.

The origin of the term "bioeconomy", initially associated with concepts of negative growth, and its current link with the notion of growth, played a major role in the 2000s for the Knowledge Based Bio-Economy Network (European expert group), and today for economic investment (jobs and wealth) and research, and perhaps tomorrow for labels that will orient consumer choices. In substance, the notion of bioeconomy helps us to go beyond an additive vision of the different fields of activity concerned by the biomass and biology (with the exception of health), to develop a systemic and operational vision of relationships between human societies and ecosystems. In this perspective, human nutrition is considered as a priority with diets undergoing a major evolution and in which meat and milk products certainly constitute one of the adjustment variables at the world scale (but little explored until now: what are the scenarios for an eventual decrease in Europe of milk and meat products from 10 to 20% over 30 years, and what would be the impacts on the availability of biomasses and farmland?).

The bioeconomy in France has not yet given rise to **a collective policy construction involving**

all of the actors of society: imagine the future and the new foundations of the "good life" (Paul Ricoeur[2]). Such a construction should be based on a line of thought targeted at the young generations who will be the actors in 2030-2050, by focusing on "environment-diet-health-life" relationships. It assumes a re-assessment of the organization between the different stakeholders in the agricultural community, including industries and managers of end-of-life products within a shared systemic framework, with emphasis on desired use functions to determine degrees of freedom, consequently revealing links and material savings between sectors.

The contribution of new technologies must be supplemented with an adaptation to standards and regulations in relation to those that exist concerning the use of fossil fuels. The appropriation by the consumer will depend on an enhanced use (service and sustainability) due to biosourced products and job creation. In addition, the convergence and stabilization of the different public policies must be ensured over long periods of time to allow for the investment and, therefore, the commitment of private stakeholders.

Committing to the transition (and accelerating it) requires clear, coherent, consistent and persistent signals:

- Changing the system of relative prices for products by creating value through the internalization of the cost of damage to the environment (water, biodiversity, climate, health) or of the value of ecosystemic services rendered, via incentive (taxes or permit markets) or normative systems.
- Including the entire life cycle in the price (e.g., problem of wind and photovoltaic sustainability)
- Redistributing this value creation at the core of loops that are virtuous because of their incentive potential, thus encouraging the convergence towards new standards of production and consumption.

This raises three research questions in relation to:

- permit markets or taxation (depending on local conditions and type of product), all along the value chain, by integrating new values (water, GHG, etc.) as well. The political sciences should be involved in the design of societal management processes (= public policies) that govern the bioeconomy.

- the understanding of dynamic equilibriums through the legal sciences, compared to static objects that are easier to understand.

- the ethics of action. How or where to bring ethics philosophers on board? The issues to be debated are multiple: evaluation of benefits and risks, societal impact, "from mending man to enhancing man", the relationship to living organisms and the ethics of biotechnological innovations and their development in relation to the general public.

The bioeconomy must therefore rely on a real **research strategy**. Even if this notion of the bioeconomy is already present in several sections of the national research strategy, it nevertheless consists of an identification of societal challenges and areas of science that do not extend to research questions.
The Investments for the Future program (PIA) has already proven itself to be an excellent

[2] Paul Ricoeur. *Oneself as Another*, trans. Kathleen Blamey, Chicago: University of Chicago Press, 1992

vector for integrated research in bioeconomy, with a **public-private partnership that places France in a good position in Europe.** In contrast, other European countries have a national policy, but have not yet been able to define the necessary original program supports.
New impetus could be given by strengthening the dialogue with companies and with a more explicit driving force for regional funds (FEDER, FEADER). These regional funds would facilitate the adaptation to local opportunities/strengths/weaknesses. In any event, the diversity of program supports requires an effort to clarify the links between these tools and the identification of synergies between H2020 and regional smart specialization strategies. The regions are responsible for allotting regional funds and FEDER funds whose end-purpose is linked to economic development. At the strategic level, it would be important to take another look at regional S3 strategies in order to imagine the bioeconomy information network that could take form at the end of the CPER (French State-Regional Plan Contracts). Local communities could nevertheless be interested by a general reflection that they could use to bring together the actors of a value chain capable of supporting ambitious and wide-reaching projects (e.g., Futurol).
Concerning innovation, a particular hurdle thus exists in the transition from the recognition of the strategic axes of the bioeconomy to the establishment of scientific and technological roadmaps that include the evolution of dedicated infrastructures to ensure the increase in technological maturity.

The stacking of public policies that oppose or ignore food and non-food end-purposes, or production vs. transformation, constitutes a final difficulty. This segmented approach overlooks activities that already exist (agri-food, for example, where food, chemical and energy uses of the biomass are considered together in economic and technological models), impeding the revision of their economic model and neglecting the role of small and medium-sized companies in the establishment of an industrial sector. Agricultural cooperatives, some of which combine production and initial processing, play an important role by occupying the first level of the biorefinery. However, the identification of specific research dedicated to the bioeconomy is still to be done, with the danger of exclusively relying on disconnected sector policies of the necessary systemic vision.

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