Pre-print, published in *Philosophica*, 47 (2016), pp. 109-124. ISSN 0872-4784

The End and Rebirth of Nature? From Politics of Nature to Synthetic Biology

Massimiliano SIMONS, KU Leuven[1]

Abstract: In this article, two different claims about nature are discussed. On the one hand, environmental philosophy has forced us to reflect on our position within nature. We are not the masters of nature as was claimed before. On the other hand there are the recent developments within synthetic biology. It claims that, now at last, we can be the masters of nature we have never been before. The question is then raised how these two claims must be related to one another. Rather than stating that they are completely irreconcilable, I will argue for a dialogue aimed to discuss the differences and similarities. The claim is that we should not see it as two successive temporal phases of our relation to nature, but two tendencies that can coexist.

Keywords: Nature, Climate Change, Synthetic Biology, Bruno Latour, Isabelle Stengers

Abstracto: En este artículo, se discuten dos afirmaciones distintas sobre la naturaleza. Por un lado, la filosofía medioambiental nos ha forzado a reflexionar sobre nuestra posición dentro de la naturaleza. Nosotros no somos los maestros de la naturaleza, como se afirmaba antes. Por otro lado, están los desarrollos recientes en la biología sintética. Esto reivindica que, al final, ahora podemos ser los maestros de la naturaleza que nunca hemos sido antes. La cuestión que se plantea ahora es cómo estas dos afirmaciones deben relacionarse la una con la otra. En vez de decir que son completamente irreconciliables, abogaré por un diálogo que apunte a discutir las diferencias y similitudes. La idea es que no deberíamos verlo como dos fases temporales sucesivas de nuestra relación con la naturaleza, sino como dos tendencias que pueden coexistir.

Keywords: Naturaleza, Cambio climático, Biología sintética, Bruno Latour, Isabelle Stengers

1. Introduction

In an article called 'The new philosophies of nature', Dominique Lecourt quotes Merleau-Ponty claiming at the end that we are witnessing a shift in recent philosophy: we are moving from a philosophy centred around history towards a philosophy of nature (Lecourt 1993, 159). Lecourt notices that this prediction has become true and that the question of nature is at the centre of much of contemporary philosophy. There are however different shapes of this philosophy of nature.

In this article, two shapes of this creed concerning a philosophy of nature are discussed. On the one hand, environmental philosophy has forced us to reflect on our position within nature. We are not the masters of nature as was claimed before. On the other hand, there are the recent developments within the life sciences, especially within the recently upcoming synthetic biology. Synthetic biology seems to claim that, now at last, we can be the masters of nature we have never been before.

How should we relate these two points of view? Their simultaneous emergence appears paradoxical. Must these two perspectives on nature be seen as incompatible? Rather than stating that they are completely irreconcilable, I will make a case for a dialogue between the two and hope that the one can learn from the other. Although there are clear differences between both approaches, there are also similarities and possibilities of compatibility. This will be explained first by focussing on the analysis of the crisis of the very concept of nature on the basis of the work of Bruno Latour (second section), then by presenting the claims of synthetic biology (third

[1] PhD Student, Funded by the Research Foundation – Flanders (FWO)

Address: Centre for Metaphysics, Philosophy of Religion and Philosophy of Culture, KU Leuven, Kardinaal Mercierplein 2 - box 3200 3000 Leuven, Belgium.

E-mail: massimiliano.simons@kuleuven.be

section). In the fourth section, lessons will be drawn on how both perspectives can nuance and complement each other.

2. The End of Nature

Within the context of the ecological crisis, Bruno Latour claims that we are witnessing the 'end of nature': there is no clearly defined nature independent of human beings (Latour 2004, 25). In a certain sense, this claim is not exceptional, and very common within environmental philosophy and sociology. It exists in two shapes: either one claims that the end of nature is near, because humans are destroying nature, which is finally starting to come forward as a political problem (McKibben 1990). Or else one claims that the end of nature means the end of an independent nature: there is no independent nature from human intervention (anymore), but it has become a social or even artificial product (Cronon 1996). Anthony Giddens, for instance, claims: "Natural disasters obviously still happen, but the socialization of nature in the present day means that a diversity of erstwhile natural systems are now products of human decision-making." (Giddens 1994, 78) His claim is very similar to social constructivist claims about nature: nature is not something given, but is always represented or produced by humans. The end of nature from a social constructivist perspective means the recognition of the discursive and social nature of nature: nature is nothing but "a product of discursive practices situated in a network of power relations" (Dingler 2005, 223).

Although Latour's claim seems similar, it presents some crucial differences that make it more challenging. For instance, he fiercely distances himself from all of the above positions. Rather, he celebrates this end of nature as the possibility for a real political ecology: "nature is the chief obstacle that has always hampered the development of public discourse." (Latour 2004, 9) To understand where he is heading at, however, we first have to go back to his earlier sociology of science that serves as a crucial background for this claim.

2.1. Latour's Philosophy of Science

Latour started as an 'anthropologist of science', studying the way scientists produce knowledge within their laboratories. One of his crucial findings is that science has a double face: on the one hand there is *ready-made science* and on the other *science in the making* (Latour 1987). Science presents itself to the outside world, once the scientific controversies are over, as a pure, rational representation of an independent nature. During the controversies, however, when scientific facts are still disputed, science is a messy and hybrid activity which involves numerous associations to social, political and technical aspects (Latour and Woolgar 1986, 64, 128). In scientific practice, nature is not given beforehand: "Nature is not outside the fighting camps." (Latour 1987, 96) Nature is rather the object of the debate itself: both parties involved aim to make as many strong alliances as possible, *both with humans and nonhumans*, to substantiate their scientific claims. If you have no strong network supporting your claims, an adversary can argue that your claim is nothing but a construction invented by yourself.

The question is of course: How are these alliances made? Phenomena do not just agree with you no matter what. They always have their own interests, own behaviours and own tendencies. In this, Latour is inspired by the metaphysics of Michel Serres: everything in the world always emit some kind of noise, both humans (speech) and nonhumans (DNA code, heat waves, light, etc) (Serres 1972, 110).

Isabelle Stengers, influenced by Latour, states that the crucial aspect of science is the reshaping of this noise into reliable *witnesses*: the phenomena must be steered to the extent that they will affirm the theory of the scientist and his theory alone. Noise must be shaped and purified into relevant information so that it can affirm the theory. The scientist

> has to succeed in making one admit that the reality he has fabricated is capable of supporting a faithful witness, that is to say, that his fabrication can claim the title of a simple purification, an elimination of parasites, a practical staging of the categories with which it is legitimate to interrogate the object. The artifact must be recognized as being irreducible to an artifact. (Stengers 2000, 167)

He or she has to

> produce a testimony that cannot be disqualified by being attributed to his or her own 'subjectivity,' to his biased reading, a testimony that others must accept, a testimony for which he or she will be recognized as a faithful representative and that will not betray him or her to the first colleague who comes along. (Stengers 1997, 88)

Take as an example from biology the polymerase chain reaction (PCR) technology, used for genetic identification (in forensic science or DNA paternity testing). Although forensic science can present it as if it merely 'reads' the DNA of a suspect in the same way we read any other text, this is only because the whole technical mediation is made invisible. The functioning of PCR depends on a forgotten network. It presupposes for example thermal cycling, which implies the repeated heating of DNA to almost 100°C, or the use of *Taq* polymerase, which is DNA polymerase of a specific thermophilic bacterium *Thermus aquaticus,* thus from a 'foreign' organism, which is able to resist the necessary temperatures. These elements could all be seen as possible distorting processes, but are constructed in such a way that the following statement is impossible to deny: The DNA which is read after the multiplication through PCR is the same as the original sample. "The set of statements considered too costly to modify constitute what is referred to as reality. Scientific activity is not 'about nature,' it is a fierce fight to *construct* reality. […] The cost of challenging the reified statements is impossibly high. Reality is secreted." (Latour and Woolgar 1986, 243)

If nature is constructed in this sense, what is it a construction of? What are its materials? Social representations? Power relations? If this was true, it would only be a social construction that would in fact keep nature alive. The claim that all our ideas about nature are mere social representations of nature still implies that these are all representations of one independent nature (Latour 2004, 20). Or even that there is no reality, but only power relations. But this is not what Latour claims. Rather, his claim is that nature and society are both constructed from this eternal noise of things. In this sense Latour recognises a reality existing independent of us:

> Yes, there is indeed an objective external reality, but this particular externality is not definitive: it simply indicates that new nonhumans, entities that have never before been included in the work of the collective, find themselves mobilized, recruited, socialized, domesticated. […] There is indeed an external reality, but there is really no need to make a big fuss about it. (2004, 38)

As he states, there is a new type of externality, and it differs from the classic idea by not presupposing a unity, but a multiplicity. Every unity of nature is a construction, namely the composition of the chaos of nonhumans emitting noise into one consistent and passive whole. And they do not necessarily agree with whatever we say about them, but have to be persuaded and purified. In this case there is always a reduction of complexity: some parts of the noise are preserved, other aspects are dropped as irrelevant.

So we are faced with a double practice: on the one hand the creation of hybrid networks of humans and nonhumans, based on these externalities, and on the other hand the discursive separation of these networks in the realms of society (with active subjects) and nature (with passive objects). In his later work Latour will describe this as *our modern condition*: the combination of the process of *translation* (of these active, noisy things into passive objects

emitting only the relevant information) and *purification* (of these networks of alliances of humans and nonhumans into a realm of nature and a realm of society) (Latour 1993).

2.2. Politics of Nature

If this double process of translation and purification is the core of the scientific practice, and nature and society as categorical products of it, then why is Latour celebrating the 'end of nature'? The end of nature does not imply that the era of science is completely over. Rather, it implies that it is not successful for all cases, and that we are recently faced with a multiplicity of cases that are shown to be problematic. As Stengers also points out, we have to see the experimental practice as an exception, not as the rule: it is not evident that these externalities can be translated into reliable passive objects (Stengers and Schlanger 1989, 34). However, starting from this idea of a unified nature, we tend to see all nonhumans as passive objects, and even if they went through a (successful) process of translation, we see them as passive parts of nature *forever*, without the possibility that there will be some unforeseen consequences (noise) that will redefine these objects. This has become problematic:

> We are not witnessing the emergence of questions about nature in political debates, but the progressive transformation of all matters of facts into disputed states of affair [or matters of concern], which nothing can limit any longer to the natural world alone—which nothing, precisely, can *naturalize* any longer. […] Political ecology does not shift attention from the human pole to the pole of nature; it shifts from *certainty* about the production of risk-free objects (with their clear separation between things and people) to *uncertainty* about the relations whose unintended consequences threaten to disrupt all orderings, all plans, all impacts. (Latour 2004, 24-25)

Climate change, for instance, shows that there are parts of nature that refuse to be nature: they are not passive objects, but active networks with all kind of new unforeseen consequences. The end of nature implies a "crisis of objectivity" (Ibid., 20): We are faced with an unpredictable multiplicity of noise out of which nature was constructed, but a construction that is seemingly falling apart. To get rid of nature is then to finally see the real problem: we are faced with "*generalized revolts of the means*: no entity—whale, river, climate, earthworm, tree, calf, cow, pig, brood—agrees any longer to be treated 'simply as a means' but insists on being treated 'always also as an end.'" (Ibid., 155-156)

Or to give another example from the context of biology, the debate about genetic modified organisms (GMO's) can be seen in this light (Ibid., 256n22). Although it was expected that these GMO's would behave as passive matters of fact, instead they revealed themselves as unpredictable matters of concern with unforeseen and potential harmful consequences, both in their interaction with nature as well as in public opinion (see Stengers 2015, 35-43).

These examples are there to show that this uncertainty about the objects we are faced with has become our permanent condition. This is the ground for Latour's call for a 'parliament of things' (1993, 144), inspired by Serres' claim that we need a 'natural contract' to replace our social contract (1995, 38). We cannot assume anymore that nature will be there as a passive instrument to our will. From now on, we are living in an amodern world. This is why we need to discuss, rather than impose our definitions once and for all on the nonhumans (and the humans) we are faced with. In this sense, we can never assume to be the master of nature anymore, but need "a democracy extended to things themselves" (Latour 1993, 142).

3. The Rebirth of Nature

At the same time that Latour proclaimed the end of nature as a passive object, a new biological discipline came into being that announces the exact opposite: synthetic biology. An essential part of synthetic biology is the idea that one can apply *engineering* and *design* to nature. It, thus,

intends to create artificially biological systems without necessarily accepting the existing biological and natural constraints. Or as Jane Calvert describes it: "Scientific biology is a new scientific field which literally aspires to construct nature, by building living things 'from scratch'. Because of this approach, it challenges our ideas about what we should think of as 'natural'." Synthetic biology thus leads "towards a reconstruction of nature which is instrumentalizable and utilizable for our purposes." (2010, 95) In this sense the notion of 'synthetic' can be understood in two ways: either as the *construction* of artificial life or as the construction of *artificial* life. The underlying premise in synthetic biology seems to be that the only way to get real knowledge about biological systems is by creating them: "If you understand it, then you can make it; if you can make it, then you can say that you understand it." (Sismour and Benner 2005, 1410)

The ambitions and dreams of synthetic biology are huge: it aims to uncover the secrets of life and biological cells, but also to develop industrial applications such as cheaper medicines or even a solution for climate change. Transporting the industrial production processes of chemical products into biological cells would be more efficient, since biological reactions can happen at room temperature or can even produce energy itself. Craig Venter, one of the foremost synthetic biologists, even dreams of reaching the moment where all the information behind living cells is extracted, and using 3D printing one could simply e-mail nature to be printed on demand: "Borne upon those waves of information, life will move at the speed of light." (2014, 249)

3.1. DIFFERENT WAYS TO CREATE LIFE

In the case of synthetic biology, we are however still faced with a science in the phase of discipline-building. It draws its inspiration from other disciplines, such as synthetic chemistry, engineering and computer sciences (Bensaude-Vincent 2013b). Because of these different inspirations, there are several tensions within the field, and numerous ways to divide its subdisciplines. In general, it is possible to distinguish four different varieties: bioengineering, synthetic genomics, protocell synthesis and unnatural biology.

Bioengineering refers to projects that are mainly inspired by engineering sciences: these synthetic biologists claim that the road to certain biological knowledge is to first apply engineering foundations to biological systems: one has to standardize biological systems in their different modules or BioBricks (functional entities with well-defined and context-independent functions) and store them in a central database for everyone to use, such as the Registry of Standard Biological Parts. Once all these modules are described, they can be used to assemble new natural entities in a similar fashion as one does with Lego bricks (Endy 2005).

It can however be questioned whether biological systems can really be divided in these different modules. So other projects use different approaches, but to reach similar goals. *Synthetic genomics* aims to create an artificial or minimal genome in a top-down process: start from a living organism and remove all nonessential parts to get to the minimal genome which then can be used as a foundation to create nature. In this context synthetic biologists often use the analogy of computers, such as the software/hardware dichotomy: "Synthetic biology and synthetic genomics, the large-scale remaking of a genome, [a]re attempts to capitalize on the facts that biological organisms are programmable manufacturing systems, and that by making small changes in their genetic software a bioengineer can effect big changes in their output." (Church and Regis 2012, 4)

Another way is bottom-up, which is the essence of the *protocell synthesis*, which aims to create synthetic protocells (systems with functions similar to living cells) out of non-living matter. A final path is *unnatural biology*, which aim to bypass all complexities of existing life

by create alternative forms of it, such as a lifeforms based on other than the four nucleic acids (C, G, A, T) or Unnatural Base Pairing (UBP).

All these different approaches imply a whole range of attitudes towards nature, although often related: improving nature, challenging nature, emancipating from nature, etc. (Bensaude-Vincent 2013a, 25) Another common factor is their agreement on the fact that synthetic biology is somehow distinct from traditional genetic engineering. Genetic engineering might remain a part of synthetic biology, but synthetic biology is more ambitious: a complete engineering of biological nature. In the case of synthetic biology, biotechnology goes beyond being a mere application of biology, but becomes the core of the life sciences itself (Bensaude-Vincent and Benoit-Browaeys 2011, 9-10). Or as Joachim Boldt & Oliver Müller describe it:

> if we look at nature through the glasses of genetic engineering, we see a world filled with entities that are already useful to us in many respects and that just need some reshaping here and there to perfectly match our interests. […] Seen from the perspective of synthetic biology, nature is a blank space to be filled with whatever we wish. (2008, 388)

However, it can be nuanced that this radical design is an ideal, not a reality. The claim that 'we can finally create artificial nature while all those before us…' is a common claim in the history of biology (Campos 2009, 16). So, a more accurate description might be that of a continuum between complete lack to full control of the construction process, with synthetic biology aiming to be a more extreme form of control (Lewens 2013, 643). Or as one of the early lab manuals describes it, it is a matter of scale: rather than merely changing one or two genes, you change the whole parts of the cell or the genome (Kuldell, et al. 2015, 4).

4. Two Tendencies of Nature

4.1. Synthetic Biology as a Modern Project?

There are however many critiques formulated on this project of synthetic biology, mainly by ethicists, but also by biologists themselves. The question is raised whether this engineering paradigm of nature is feasible and even desirable. Oron Cats and Ionat Zurr, for example, argue that synthetic biology forms a threat in the sense that life gets colonized by the engineering paradigm by excluding all other perspectives (Cats and Zurr 2014). A similar critique is formulated by Paul Rabinow. He warns that it implies imposing the engineering ideal of American culture on nature itself. Echoing the earlier mentioned social constructivist claims: "Nature will be known and remade through technique and will finally become artificial." (Rabinow 1999, 411)

However, also biologists have serious doubts about the possibility of the reduction of life to modules that can be reconfigured at will (Delgado and Porcar 2013). Antoine Danchin, for instance, criticises synthetic biology for only focussing on the software, the genome, but not on the 'chassis' or the hardware (Danchin 2012). Some projects within synthetic biology seem to presuppose that the genetic code controls the whole functioning of the cell and all its aspects. In reality, however, there are numerous influences from the environment, gene expression or cell cycle variations, or interdependencies between different parts of the cell.

So, faced with these problems, the real accomplishments of synthetic biologists are often far away from rational design and more akin to a form of kludging of nature (O'Malley 2009). Even if they succeeded in reducing all the complexity and reach a point where they are faced with a cell as a perfectly passive object, this might come at a great cost: the deletion of all relevant parts that made the cell so interesting to work with in the first place. "Must we not, therefore, say that the plausibility of an engineering approach decreases in line with the increasing expectations placed in the capabilities of biotechnological artefacts?" (Kogge and Richter 2013, 186)

So in this sense, one could ask whether synthetic biology is not exactly one of the modernist projects that the framework of Latour tries to problematize and one that recreates a form of nature that had to die according to Latour: a unified, passive nature. Does synthetic biology really hold a promise of scientific knowledge, or is it not a mere instrumentalist epistemology aimed to impose the model of a passive modular object on a living and dynamic cell that refuses to play along? If this is the case, synthetic biology will soon die or only keep going on due to the interests of the knowledge economy aimed at industrial applications rather than of biological knowledge.

4.2. NOT ALL MODERNS HAVE TO DIE!

However, we must be weary of an easy-going *a priori* critique of synthetic biology. If we would simply state that synthetic biology is doomed to fail because it contradicts Latour's framework, we could also ask the opposite question: is it not a falsification of our amodern condition? If Latour was right about his claim about the end of nature, why does synthetic biology still exist?

I claim that both conclusions are premature and that a more nuanced view is necessary. Of course there is a lot of criticism and scepticism towards the synthetic biology project, but this is not necessarily a bad sign. As Bensaude-Vincent and Benoit-Browaeys point out, stressing the commodification of life and science is an element of the scientific climate we are living in, but not by definition of synthetic biology itself. Even a justified criticism is not necessarily a problem, since it is of the essence of the scientific practices that such controversies and a reduction of complexity exist (2011, 9-14).

Let us have another look at the criticisms of synthetic biology. They mainly follow the scheme: 'synthetic biology claims that such and such is a natural property of cells, but in fact it is not.' However, this is an interesting claim in the case of synthetic biology, for it does not simply aim to follow a given nature to which its models will either correspond or not. Rather the countermove would be: if it does not exist in nature, then let us construct it by ourselves. This is what is actually happening within the field of synthetic biology, for instance under the banner of 'a second wave in synthetic biology' (Purnick and Weiss 2009). Synthetic biologists recognise these problems, but see them as a challenge to construct themselves those parts of nature that are missing. Take for instance the following quote from a review study of Delgado and Porcar:

> Another possible argument here, a kind of an "engineering argument" this time, is that even when biological systems do not display natural orthogonality [context independence], and even if modular and standard parts cannot be found as such in nature, by manipulating biology *as if* it was modular, it will eventually become so. (2013, 43)

Or as Calvert summarizes, based on several discussions with synthetic biologists: "if biology is not modular, perhaps synthetic biologists can make it so." (2010, 100) So, what is happening is that one is seeing the cell itself as a laboratory environment for constructing the reliable witnesses, in a very similar way as in *science in the making* as described by Latour and Stengers. Starting from the engineering perspective, synthetic biology ends up by being an interesting blurring of the line between *science in the making* and *ready-made science*: it presents itself in its ready-made form as a science that constructs its own reliable witnesses. So possible solutions to make cells into passive objects are openly discussed: one can incorporate the context of the BioBricks into their standardization, or insert the evolutionary processes in the digital models describing the cell resulting in a programmed evolution (Delgado and Porcar 2013, 43). Or one could synthetically reshape its environment or even completely create one *de novo* (Purnick and Weiss 2009, 420).

Again, there is no certainty that these ambitions would succeed either, but this cannot be excluded beforehand. Even the critique by such authors such as O'Malley or Lewens, stating

that the rational design of synthetic biology is not so rational, but rather a form of kludging might in fact not be that fatal, since this is an essential part of the *science in the making.* The real sin rather would be that synthetic biologists copied the ready-made science of engineering a bit too literally, rather than drawing inspiration from the science in the making of engineering.

If such a 'second wave of synthetic biology' were successful, would this then mean that Latour's claims are wrong? No, and that this might seem so is only due to a possible confusion in the argument of Latour. What he is claiming is that not all parts of nature can be seen as unproblematic, since the success of science is the exception and the result of hard constructive work. However, this does not entail that all parts of nature must be seen as problematic. Latour seems to imply this in some of his work, for instance in a fragment quoted earlier:

> We are not witnessing the emergence of questions about nature in political debates, but the progressive transformation of all matters of facts into disputed states of affair, which nothing can limit any longer to the natural world alone—which nothing, precisely, can *naturalize* any longer. (2004, 24-25)

This seems to imply that all modern matters of fact are doomed to become amodern matters of concern. Nature is doomed to end everywhere. But this is in sharp contrast to some of Latour's other work, including later passages from *Politiques de la nature*, in which he claims that not all matters of facts have to be disputed and politicized. Faced with the science wars, climate skeptics, and the confusion between constructivism and debunking, Latour claims that not everything must always be turned in a matter of concern. In an earlier article, the first guarantee for a common world according to Latour is that

> once there, and no matter how it came about, discussion about [an established scientific fact] should stop for good. This is an essential assurance against endless controversies, heckling, superfluous doubts, excessive deconstruction. Such is one of the two meanings of the word 'facts' : once in place, reality should not be allowed to be disputed and should be used as the indisputable premise of other reasonings. (2003, 38)

Or in a later text, discussing the different meaning of politics, he makes a typology of different stages of a political problem. Although all parts of nature presuppose political work, they do not all have to be politicized. Certain parts of society (and nature) can be excluded from such disputes:

> The silent working of the sewage systems in Paris has stopped being political, as have vaccinations against smallpox or TB. It is now in the hands of vast and silent bureaucracies that rarely make the headlines. (2007, 817)

So when we evaluate the case of synthetic biology, one cannot simply state that its perspective on nature is false since we are living in an amodern world. It might still be able to construct a suitable reliable witness, and thus a passive nature. This, however, on two conditions: (a) that the theory's scope is limited, while it would not claim that the totality of nature is a passive object and (b) that there is always the possibility to reopen the discussion about every existence claim and that also this part of nature might disappear and become problematic.

All this depends on the question: will the approach of synthetic biology result in reliable witnesses of nature? You cannot exclude this possibility *a priori*. Question: Can one say without due process, that the era of the passive object is over? Answer: No! So perhaps a better perspective than seeing the modern and amodern condition as a succession of two temporal states, one could use a spatial metaphor: We are faced with *two tendencies*: some areas must be characterized by the end of nature, while others must be seen as places where nature is still well-constructed, or even reborn again.

5. Bibliography

Bensaude-Vincent, Bernadette (2013a), "Between the possible and the actual: Philosophical perspectives on the design of synthetic organisms", *Futures* 48, 23-31.

— (2013b), "Discipline-building in synthetic biology", *Studies in history and philosophy of biological and biomedical sciences* 44(2), 122-129.

Bensaude-Vincent, Bernadette, and Dorothée Benoit-Browaeys (2011), *Fabriquer la vie: Où va la biologie de synthèse?,* Paris: Seuil.

Boldt, Joachim, and Oliver Müller (2008), "Newtons of the leaves of grass", *Nature Biotechnology* 26 (4), 387-389.

Calvert, Jane (2010), "Synthetic biology: constructing nature? ", *The Sociological Review* 58, 95-112.

Campos, Luis (2009), "That was the synthetic biology that was." In *Synthetic biology: The technoscience and its consequences*, by Markus Schmidt, Alexander Kelle, Agomoni Ganguli-Mitra and Huib de Vriend, 5-21. Dordrecht: Springer.

Cats, Oron, and Ionat Zurr (2014), "Countering the engineering mindset: The conflict of art and synthetic biology." In *Synthetic Aesthetics: Investigating Synthetic Biology's Designs on Nature*, by Alexandra Daisy Ginsberg, Jane Calvert, Pablo Schyfter, Alistair Elfick and Drew Endy, 27-37. Cambridge: MIT press.

Church, George, and Ed Regis (2012), *Regenesis: How synthetic biology will reinvent nature and ourselves,* New York: Basic Books.

Cronon, William, (ed.) (1996), *Uncommon ground: rethinking the human place in nature,* New York: Norton.

Danchin, Antoine (2012), "Scaling up synthetic biology: Do not forget the chassis", *FEBS Letters* 586(15), 2129-2137.

Delgado, Ana, and Manuel Porcar (2013), "Designing de novo: interdisciplinary debates in synthetic biology", *Systems and Synthetic Biology* 7(1-2), 41-50.

Dingler, Johannes (2005), "The discursive nature of nature: Towards a post-modern concept of nature", *Journal of Environmental Policy and Planning* 7(3), 209-225.

Endy, Drew (2005), "Foundations for engineering biology", *Nature* 438(7067), 449-453.

Giddens, Anthony (1994), "Living in a post-traditional society. " In *Reflexive modernization: Politics, tradition and aesthetics in the modern social order*, by Ulrich Beck, Anthony Giddens et Scott Lash, 56-109. Cambridge: Polity Press.

Kogge, Werner, and Michael Richter (2013), "Synthetic biology and its alternatives. Descartes, Kant and the idea of engineering biological machines", *Studies in History and Philosophy of Biological & Biomedical Sciences* 44(2), 181-189.

Kuldell, Natalie, Rachel Bernstein, Karen Ingram, and Kathryn M. Hart (2015), *BioBuilder: Synthetic biology in the lab,* Sebastopol, CA: O'Reilly.

Latour, Bruno (1987), *Science in action : how to follow scientists and engineers through society.* Cambridge: Harvard university press.

— (1993), *We have never been modern.* London: Prentice Hall.

— (2003), "The promises of constructivism." In *Chasing Technology: Matrix of Materiality*, edited by Don Idhe and Evan Selinger, 27-46. Bloomington: Indiana University Press.

— (2004), *Politics of nature: how to bring the sciences into democracy*, Cambridge: Harvard university press.

— (2007), "Turning around politics: A note on Gerard de Vries' paper." *Social Studies of Science* 37(5), 811-820.

Latour, Bruno, and Steve Woolgar (1986), *Laboratory life: the construction of scientific facts*, Princeton: Princeton university press.

Lecourt, Dominique (1993), «Les nouvelles philosophies de la nature », *Philosophiques* 20(1), 159-176.

Lewens, Tim (2013), "From bricolage to BioBricks™: Synthetic biology and rational design", *Studies in History and Philosophy of Biological and Biomedical Sciences* 44(4), 641-648.

McKibben, Bill (1990), *The end of nature*, London: Viking.

O'Malley, Maureen (2009), "Making knowledge in synthetic biology: Design meets kludge", *Biological Theory* 4, n° 4 (2009): 378-389.

Purnick, Priscilla E. M., and Ron Weiss (2009), "The second wave of synthetic biology: from modules to systems", *Nature Reviews Molecular Cell Biology* 10(6), 410-422.

Rabinow, Paul (1999), "Artificiality and Enlightenment: From sociobiology to biosociality.» In *The Science Studies Reader*, edited by Mario Biagioli, 407-416. New York: Routledge.

Serres, Michel (1972), *Hermès II, L'interférence.* Paris: Éditions de Minuit.

— (1995), *The natural contract.* Translated by Elizabeth MacArthur and William Paulson. Paris: Bourin.

Sismour, Michael, and Steven A. Benner (2005), "Synthetic biology", *Expert Opinion on Biological Therapy* 5, 1409-1414.

Stengers, Isabelle (1997), *Power and invention: situating science.* Minneapolis: University of Minnesota press.

— (2000), *The invention of modern science.* Minneapolis: University of Minnesota press.

— (2015), *In catastrophic times: Resisting the coming barbarism.* Translated by Andrew Goffey. Open Humanities Press.

Stengers, Isabelle, and Judith Schlanger (1989), *Les concepts scientifiques: invention et pouvoir*, Paris: La Découverte.

Venter, J. Craig (2014), *Life at the speed of light: From the double helix to the dawn of digital life*, Abacus.