Algae oil on trial

Conflicting views of technology and nature

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Rathenau Instituut

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Preface

This report describes the debate initiated by civil society organisations who have criticised the use of oil from genetically engineered algae as a basic ingredient in consumer cleaning products. It is the result of a study undertaken in the context of a Rathenau project focussing on the role of industrial biotechnology and synthetic biology in the emerging bio-based economy.

Industrial biotechnology positions itself as a key player in a future bio-economy, contributing to smarter and more sustainable uses of plant-based materials as resources for the production of food, medicines, chemicals and energy. However, as we have argued in an earlier Rathenau report, the bio-economy concept is a breeding ground for profound public controversy. A more prominent role for industrial biotechnology in a bio-based economy will evidently put the sector in the full glare of public debate. The critical response triggered by the use of genetically engineered algae oil clearly illustrates the tensions and controversies found in the current bio-economy debate. These responses can be viewed as an early warning, indicating potential public sensitivities about the increasing role of industrial biotechnology as a producer of “natural” or “nature-derived” substances in an emerging bio-economy.

What do these responses tell us about the issues raised, in the move towards a bio-economy, by the potential contributions of industrial biotechnology and synthetic biology? As this report shows, the resulting discussion revolves around the question of whether the use of genetically modified algae contributes to a more sustainable bio-based production of high-value vegetable oils, or whether it is tinkering with nature in a way that will bring about disruptive ecological, economic and social risks. The report argues that different positions in this debate are structured by worldviews which can be described in terms of varying perceptions of nature, corresponding to different perceptions of technology, risk and sustainability. Analysis is based on interviews with several actors involved in the debate. Both academic and popular media were also studied to give further width and depth to the data obtained from interviews.

Given its crucial role in achieving optimal biomass use, industrial biotechnology could be in a favourable position to win broad societal approval in a future bio-economy. But, as this report shows, the sector undoubtedly faces important challenges. Sustainability is not only a core concept in the bio-economy debate, it is also a highly contested issue with disagreement about criteria, supporting evidence, and the values which frame it. Given these disagreements and uncertainties, the development of a bio-economy will require a collective process of learning in which the industrial biotechnology sector cannot rely on its own strength alone. Indeed, extensive stakeholder engagement will be needed as an important condition for meaningful dialogue about sustainable futures for industrial biotechnology.

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Contents

1 Introduction

When Ecover, a Belgian company producing sustainable cleaning products, announced a change to one of the ingredients in its basic cleaning formula, it suddenly found itself under attack from a coalition of environmental organisations whose members used to be among Ecover's most loyal customers, with the international ETC Group (pronounced Etcetera) prominent among them. The new ingredient which invoked all this criticism was oil produced from genetically engineered algae (Thomas, 2014).

As far as Ecover was concerned, this ingredient did not fundamentally differ from anything it had used before. In their detergents Ecover had used enzymes produced by genetically modified bacteria for years, as most companies in this area do, and had hardly received any criticism for it. In the eyes of its critics, however, the oil produced by engineered algae does represent something fundamentally different. To these critics, the engineered algae symbolise a socio-technological system that is inherently unsustainable because it reinforces existing economic inequalities. The controversy led Ecover to stop using the algae-produced oil and to reflect on its strategy as a company seeking to be a front-runner in the field of sustainable innovations as Ecover describes itself.

This report picks up on the question emerging in this debate: what exactly does sustainability amount to in the context of natural feedstocks? In doing so we seek to untangle some of the notions that underlie a fundamental societal transition which is currently taking place: the increased use of natural feedstocks or biomass to replace the use of fossil resources. This results in a myriad of products sourced from natural feedstocks, ranging from biofuels and bioplastics to biomedicines. Algae have long been considered a key technology in this transition.

The debate surrounding the algae-produced oil can function as a searchlight for issues that should be on the public agenda when we consider how to use biomass sustainably. The impact of this debate is potentially wide-ranging, since many actors are on a quest for sustainable, renewable resources. Besides Ecover, companies such as Unilever are using algae-produced oil as a replacement for palm oil (Unilever, 2016). Their decision on whether to continue with this innovation will be informed by developments in this public debate. Key issues revolve around the question of what constitutes a "natural" feedstock; whether advanced modifications of natural resources bring about new ecological, economic and social risks or benefits; and how these might be managed.

To understand the development of the debate, we will first describe the case at hand in more detail in chapter 2. What is the technology under scrutiny, who are the various actors involved in the debate and what are their positions? In chapter 3, we will move on from those various particular positions to discuss the frames that have structured the debate. By frames we mean the various understandings of the world used by actors to make sense of a complex and uncertain reality, and to guide their actions (Kupper et al, 2007). They can, for instance, comprise beliefs about whether nature should be protected against technology, or alternatively, that technology can be used to exploit natural resources more effectively.

2 Mapping the debate

2.1 The bio-economy

The use of biomass for the replacement of fossil resources has been hailed as a sustainable solution that can help combat both climate change and pollution (OECD, 2009). Biomass can be obtained from food and feed crops, non-food crops, woody forest-based sources and various types of waste and residue, including the biodegradable elements of municipal or industrial waste. The bio-economy is an economy where biomass is the main resource for energy, materials and chemicals and this resource is used with the utmost efficiency. It is expected to contribute significantly to global sustainability.

Aside from promising visions of sustainability, new technologies emerging under the banner of the bio-economy also bring with them new uncertainties. Questions arise about the exact environmental impact of new technologies, such as the actual reduction in CO_2 emissions. Questions also arise about whether new regulations are required for the control of any new potential risks. Questions are raised, too, about what sustainability amounts to, and about which innovation trajectories lead to sustainability. Should innovation focus, for instance, on small-scale production that accommodates the interests of smallholders in developing countries? Or should innovations be as technologically efficient as possible, implying large-scale production sites and advanced technologies that intensify the industrialisation of farming practices? (Asveld et al, 2011).

For biomass to be used as a sustainable resource, these questions need to be addressed. The transition to a sustainable bio-economy is a social one that requires the involvement of many different actors. Widespread social support for a sustainable bio-economy will depend, at least in part, on how the above questions are approached and on the answers that are formulated.

2.2 Algae as a resource

For Ecover, as long-term innovation manager Tom Domen emphasizes, sustainability is a key value. The company puts it into operation by trying to limit any negative impact on the natural environment. Based on this value, Ecover sought opportunities to move away from problematic land-based resources such as palm oil. It found an appealing alternative in the products of Solazyme[1], a US based company, that had been experimenting with algae to produce various kinds of oil [interview Domen].

Palm oil is a widely used resource, popular as a sustainable replacement of fossil oil as it has similar properties, but is renewable and less environmentally degrading (Lam et al, 2009). It is used

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1 In this report we refer to the producer of the algae oil as “Solazyme”, the name of the firm during the period in which this study was conducted. The firm recently has changed its name and focus to “TerraVia”: www.terravia.com

in the production of a range of goods including food products, care products, detergents and biofuels.

Its popularity has, however, led to such wide-spread production that new concerns about its sustainability arise. Demand for palm oil causes the clearing of forest for new plantations, which leads to increased CO_2 emissions, loss of biodiversity and sometimes the loss of land used for local food production. In addition, industrial palm oil plantations exacerbate community conflict in many areas across Asia and Africa (Willis et al, 2016, Young et al, 2014).

Algae have featured prominently from the outset in visions of a sustainable bio-economy (Asveld et al, 2011). They are seen as a “third generation” application of biomass because in theory they can produce oil and fuels without any external land-based feedstock; instead, they use sunlight and CO_2. These are the so-called autotrophic algae. Various academic groups and start-up companies work with these algae, such as Photanol in the Netherlands, which is currently scaling up its production (Brinker, 2015, Van Dam, 2015).

As a producer of algae oil, Solazyme also started out with autotrophic algae, but then opted to switch to heterotrophic algae, which feed on sugar, as these were more productive. The problem with autotrophic algae is that they require a large surface area to ensure that everything gets enough sunlight, leading to a higher chance of contamination. In addition, they do not generally produce as much oil as heterotrophic strains. This hinders the commercial application of autotrophic algae, but solutions are continuously being sought, applied and improved, according to Dutch professor René Wijffels [interview Wijffels].

The microalgae that Solazyme uses are single cell microorganisms that can live on a wide variety of plant sugars and grow without any light. Unlike microalgae, which rely on sunlight and are commonly cultured in open ponds, Solazyme’s microalgae convert sugars natively, directly into oils, and are kept in containment in fermentation tanks. The oil can have varying fatty acid profiles, depending on which algae are used, which makes it useful for a variety of applications, ranging from home and personal care products to biofuels.

The specific algae-produced oil in which Ecover is interested resembles palm oil, and thus makes a good replacement for it. The oil is produced at the Solazyme Bunge (SB Oils) joint venture facility in São Paolo state in Brazil, where the algae are fed sugar from sugarcane. Through industrial fermentation, the microalgae convert sugars into the desired oil. The company is scaling up its sourcing of sugar with the Bonsucro® certification, a sustainability and social certification standard for the sugarcane sector. Solazyme’s plant is located right next to the sugarcane mill to limit transportation and energy costs. The part of the sugarcane that isn’t processed into sugar – the bagasse – is used to power the mill and heat the plant.

Although the sugar feedstock used at the Brazil facility is sugarcane, Solazyme’s technology platform is extremely feedstock-flexible. According to Jill Kauffman Johnson, sustainability manager at Solazyme, the algae can utilise a variety of renewable plant-based sugars and have been tested successfully with a range of cellulosic material, including switchgrass, miscanthus, green waste, woody biomass and paper pulp. Solazyme believes that sugars made from cellulosics will represent an important alternative feedstock in the long term.

Kaufmann Johnson goes on to say that the initial results of lifecycle analyses (conducted by Solazyme on algal oil produced at the Solazyme joint venture facility in Brazil) indicate that the algal oil has a lower carbon footprint than most other vegetable and animal oils, and much lower than that of petroleum. This is due to the low carbon footprint of the sugarcane feedstock, and the waste sugarcane material (bagasse) which essentially provides all of the energy required to power the facility. In addition, the water consumption footprint for algal oil production in Brazil is low compared with other vegetable and animal oils, largely due to the fact that sugarcane is a rain-fed crop [interview Kauffman Johnson].

The algae that produce the oil which resembles palm oil are genetically engineered to do so. According to Solazyme, they are engineered to produce an oil with the desired properties, including higher stability and a greater level of saturation. To produce the oil, the algae are grown in a fermentation process. This speeds up their natural production pathways, according to the company's website[2]. Then the algae are pressed (as with traditional methods of mechanical oil extraction) to extract the oil for further processing.

2.3 Fuelling debate

When Ecover began to consider algae oil instead of palm oil, it received stern criticism from a coalition of environmental NGOs, the most vocal and prominent of which is ETC Group. This NGO casts a critical eye on emergent technologies such as nanotechnology, biotechnology and the concept of the bio-economy. Another NGO with a strong voice in the debate on synthetic biology, and a close ally of ETC, is Friends of the Earth US. Other Friends of the Earth (FOE) groups take different positions on this debate, such as FOE England, Wales and Northern Ireland, whom we also interviewed.

In an open letter to the Ecologist, Jim Thomas, ETC's spokesperson on this matter, condemned Ecover for using what he considered to be synthetic biology, or in his words, "extreme genetic engineering"*.* In his letter, co-signed by 17 other NGOs, Thomas voiced concerns about the safety risks associated with this technology and about potential socio-economic implications such as the displacement of income for small farmers who depend on coconut oil (Thomas, 2014). Coconut oil could provide a sustainable and far less disruptive alternative to palm oil, according to Thomas and the wider environmental coalition.

This response took Ecover and Solazyme completely by surprise, according to Tom Domen, Ecover's long-term innovation manager. Both companies considered the algae technology to be in line with those already widely used, such as enzymes derived from genetically engineered bacteria, known as "white" or "industrial" biotechnology. Ecover has been using such enzymes in their

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2 http://algawise.com/how-we-innovate/

detergents for a long time. There is hardly any opposition to this white biotechnology because it is kept in containment in industrial plants, minimising the risk of escape and environmental contamination. To Ecover and Solazyme, the algae were just another variation on an existing theme, one that is supposed to solve a pressing sustainability issue, namely the problematic production of palm oil, the demand for which continues to grow [interview Domen].

2.4 Contested Issues

This section will explicate the main points of debate within the controversy over oil produced by algae. It is a spectrum of positions, with ETC Group and its allies at one end, and Solazyme at the other. In between are some environmental NGOs, while academics working with algae are positioned across the whole spectrum.

Is this synthetic biology?

One of the prominent issues in the debate revolves around the question of whether the engineered algae can be defined as synthetic biology or whether they are the product, as Solazyme claims, of traditional genetic engineering. This might appear to be a semantic issue, but for opponents such as ETC, synthetic biology not only reproduces all the ecological and social risks associated with traditional genetic engineering, but it also exacerbates them. The distinction is crucial because of its implications for the regulation of safety. As opponents see it, while regulations meant to guarantee the safety of genetically modified organisms are inadequate, they are at least available. In the case of synthetic biology, regulations are considered to be largely lacking.

“Synthetically modified organisms may create novel features in organisms, beyond those created in genetically modified organisms”, says Jim Thomas of ETC Group. “We cannot use the principle of substantial equivalence to assess these novel features. This is the principle that underpins most safety assessments of GMOs now.[3] Therefore we lack appropriate tools to assess the risks these new technologies pose” [interview Thomas].

What is so novel about synthetic biology when compared with genetic engineering? There is no unequivocal definition of synthetic biology available, which makes it difficult to answer the question of whether the algae are “synthetically” modified. Most definitions hint at the combination of biological and engineering science in the pursuit of more efficient organisms tailored to human needs (Nature Biotechnology, 2009). These engineering sciences include computing and design, and the biological sciences include evolutionary biology and systems biology. The engineering aspect refers to the option of creating DNA from scratch. The vast amount of information that can be processed through computerisation allows engineers to scan a wide range of possible DNA sequences in search of the desired trait. Previously, engineers were dependent on whatever was available in existing organisms, but now they can create traits by themselves. Instead of altering an organism, synthetic biology is more aptly described as “designing an organism”.

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[3] Substantial equivalence embodies the concept that if a new food or food component is found to be substantially equivalent to an existing food or food component, it can be treated in the same manner with respect to safety (FAO/WHO, 1996)

This opens up vast avenues of possibility. Most of these are still explored in the laboratory. Some are in the phase of scaling up and only a few have reached the commercial stage. The oil produced by Solazyme is one of the first products commercially available to consumers. If it can indeed be considered synthetic biology.

Most academics we spoke to in the field of engineered algae thought that the technology Solazyme is using could be termed synthetic biology. “I would think that this is synthetic biology because they tinkered with several of the traits of the algae”, says Klaas Hellingwerf, professor of General Microbiology at the University of Amsterdam. Hellingwerf’s description matches that used by Solazyme to describe their technology, but according to Solazyme it cannot be called “synthetic” engineering [interview Kauffman-Johnson]. Hellingwerf points out that the difference between genetic engineering and synthetic biology is a matter of degree. The basic underlying idea is the same: alter DNA to meet specific needs. Exactly where in this process the relevant technology stops being genetic modification, and starts being synthetic biology, is not clear cut, and in the case at hand, difficult to answer without more detailed information [interview Hellingwerf].

Many actors consider the risks associated with synthetic biology to be sufficiently controlled by existing regulations. René Wijffels points out that current risk approaches deal with all the relevant issues. In EU regulation, unknown features are not allowed. They have to be adequately researched, says Wijffels. The chance of escape and the chance of survival outside of containment are both taken into account. The safety of the constructs used is also considered [interview Wijffels]. For these actors, the question of whether this is indeed synthetic biology does not really matter in terms of risk regulation. Klaas Hellingwerf claims, moreover, that synthetic biology is even safer than genetic engineering because it allows for more control over organisms [interview Hellingwerf].

Is it sustainable?

As described above, Solazyme tried hard to live up to current sustainability standards in the production of its algae oil. As Jonathan Wolfson, one of the founders of Solazyme, states on its corporate website, “one of Solazyme’s main goals is to create a better world”. The company tried to find a sugar feedstock with a low environmental impact and worked to have the sugarcane certified on sustainability aspects [interview Kauffman Johnson].

Ecover also aims to live up to the highest sustainability standards, or rather, as Tom Domen has explained, to move beyond legal standards to be a front runner by setting its own standards. In doing so, it endeavours to limit the environmental impacts of its product as much as possible. Ecover sees innovation as key, says Domen, to reaching this goal. The company is open to many new innovations, as long as they limit its environmental impact. One of the few no-go areas for Ecover is the use of genetically modified food crops. Within these targets and limits, oil produced by algae seemed to make perfect sense, since algae are not agricultural crops, but micro-organisms kept in containment [interview Domen].

However, for the critics, the idea of Ecover using such oil is incomprehensible. To begin with, many are highly suspicious of anything produced with advanced genetic technology. They perceive this technology as one that reproduces economic inequalities by concentrating knowledge and control in the hands of the few. Their argument is that large companies with the resources to invest in agricultural knowledge can afford the patents associated with genetic techniques. These patents can be seen as allowing specific actors a substantial measure of control over natural feedstocks, thereby excluding other parties who traditionally make a living off biomass, such as small-scale farmers. Once a plant is patented, those actors will have to pay the company owning that patent to use the plant.

Not all environmental organisations are equally opposed to genetic technology. For ETC Group, the technology itself is undesirable. For other environmental organisations such as Natuur & Milieu (The Dutch Foundation for Nature and the Environment), its acceptability depends on the way in which it is used. If it solves a problem for which there is no better alternative and it is not socially disruptive, then it would be acceptable, says Sijas Akkerman, Head of Food at Natuur & Milieu [interview Akkerman].

Although Natuur & Milieu does not usually categorically condemn a technology, its concerns about genetic engineering are in the same vein as those of ETC Group, namely its potential for social disruption. Natuur & Milieu would also assess any technology in comparison with available alternatives, as would ETC Group, which has blamed Ecover for not thoroughly considering other alternatives to palm oil, such as the use of sustainably sourced coconut oil. According to Thomas, if Ecover had worked with “agro-ecological” producers of coconut oil, that would have been a true sustainable innovation which didn’t disrupt the livelihood of coconut farmers [interview Thomas].

In turn, other actors, which include Ecover and Solazyme, but also Natuur & Milieu, have wondered whether switching to coconut is really a sustainable alternative. In the long run, increasing the demand for coconut would create a similar dynamic as with palm oil, namely the rise of large-scale plantations and the clearing of land. Moreover, the current demand for coconuts will not diminish when Ecover decides to switch to algae, so the livelihoods of coconut farmers are not put at risk by such a decision.

Can this technology be considered a step in the direction of more sustainable solutions?

Ecover would like to adopt algae-derived oil because it wants to move away from problematic land-based resources. Switching to a resource based on sugarcane from large plantations is in this respect not the ideal course, as Tom Domen has explained. Ideally, the company would want to use only local, diversified and inedible feedstocks. In Ecover’s terminology, such feedstocks are future-proof. Indeed, Ecover is conducting an experiment in Mallorca together with the NGO, Forum for the Future, to produce washing detergents solely from local feedstocks. Tom Domen considers algae oil to be a necessary intermediate step towards future-proof feedstocks. Supporting these algae based on sugarcane at the moment can enable a future where plants are spread out across different locations, relying on local, diversified and inedible feedstocks.

Tom Domen sees the idea of an ever-improving roadmap as the basis for all technological progress made in society: “Any new technology needs to be optimised and cannot be compared against a technology that has been optimised already over more than 100 years. When the first solar cells have been made, they were utterly not sustainable, as the material and energy requirements to make them, didn't match the return in renewable energy they were creating. Basically all innovations need to be stopped if we need to assess technologies on the basis of what they are present" [interview Domen].

However, for Jim Thomas, the ideal of a future sustainable use of algae is misguided and should be considered "a green dream". He thinks we should assess technologies on the basis of what they are at present and not on the basis of something they might become. And at present, Jim Thomas does not approve of the engineered algae [interview Thomas].

We will spell out this controversy in the next chapter, using worldviews to place the various perspectives on engineered algae in a broader context. For now, we note that a basic difference in perspective lies in differing assessments of the risks and benefits associated with venturing along an unknown innovation trajectory involving the manipulation of natural resources. For actors such as Ecover and Solazyme, we need to explore such unknown technological pathways because we need to find ways to solve our current ecological predicament. As can be read on Solazyme's website: "We're tackling some of today's biggest issues — like sustainability, resource scarcity and traceability — with microalgae, the world's original oil producer" ("About the 399Company", n.d.).

For actors such as Jim Thomas, however, exploring technologies such as synthetic biology means taking a huge risk with our natural environment. For these actors, synthetic biology (and genetic engineering) present technological risks which we shouldn't even consider bringing upon ourselves. These technologies could evolve into something beyond our control and destroy vulnerable ecosystems.

This concern may relate to a more fundamental worry about the impact humans have on their surroundings. By increasingly manipulating our natural environment, we slowly but steadily enter "the Anthropocene" (Crutzen, 2002). This environment, entirely built by humans, leaves us with no reference to the past to guide individual or collective action. In other words, we can no longer rely on nature to shape our self-understanding as human beings. This may have huge implications for our identity, as we become beings quite distinct from nature, forced to shape our world according to no standards other than our own. As Pauwels puts it, "What is at stake is our ability to understand the long-term variability of the new patterns of socio-ecological and socio-technical systems, which are likely to emerge from 21st century technological developments" (Pauwels, 2013).

A refutation of this argument might be that human beings are not solely natural beings, but also, and utterly, technological beings. We have always manipulated ourselves and our environment. This might ultimately be the very core of being human, so we should not fear losing sight of our humanity as we follow the technological path even further.

2.5 Summarising the debate

Public debate around the use of oil derived from engineered algae by Solazyme focusses on a few prominent issues. Firstly, whether the technologies applied are revolutionary or not and what that implies for the management of possible risks. Secondly, whether algae-based oils are more sustainable than existing alternatives; and thirdly, whether engineered algae can be considered a stepping stone for more sustainable innovations.

With regard to the first issue, Solazyme claims that the algae are not created through synthetic biology but by “classical genetic engineering”. By this they mean that there are no new, unknown risks introduced by using these algae. However, other actors, such as the academics we interviewed and Jim Thomas of ETC, think that the technology can be seen as synthetic biology. According to Jim Thomas, this poses new and unacceptable risks. According to the academics, this does not pose additional risks since existing safety regulations sufficiently cover any alleged risks. Additionally, they claim, synthetic biology may be safer to apply than genetic engineering because it allows more control over biological material.

Concerning the sustainability of the oil, for many actors, the Life Cycle Assessment (LCA) of the oil (including the feedstock) determines its sustainability. But for ETC Group and the coalition of environmental NGOs it represents, the socio-economic implications of the technology determine its sustainability. In this case they deem synthetic biology to be a technology that reinforces existing power imbalances and inequalities at the expense of vulnerable small-scale farmers.

The third point for debate is whether a technology that can be judged as suboptimal by some standards can nonetheless be considered valuable because it offers an intermediate step towards a more sustainable technology. To Ecover, the algae can be seen as having just such a role. To the critics of this technology, such a prospect is a green illusion that does not justify the risks associated with the algae’s current design.

3 Conflicting understandings of the world

3.1 Worldviews as frames of meaning

As we saw in chapter 2, the debate about the sustainability of algae-based oil involves widely diverging perspectives. In this chapter we will focus on the frames of meaning which structure the debate. As argued by Kupper and others, actors differ in the way they handle factual uncertainties, depending on their respective views and understandings of the world (Kupper et al. 2007, Brom et al., 2011). In other words, conflicting positions in debates on technologies, risks and implications do not only result from disagreements over the facts, but also from clashes in values and worldviews (Hedlund-de Witt, 2014).

Worldviews are culturally dominant frames of meaning made up of coherent structures of values, beliefs and attitudes shared by a wide range of people in society. Individuals' perspectives will never completely coincide with these worldviews, but in making sense of an issue and articulating their ideas, individuals will rely on one worldview more than another (Kupper et al. 2007).

A wide body of literature exists with regard to worldviews, which are usually broken down into four distinct types. Defining characteristics often include issues such as the local or the global, the role of the government, and the vulnerability of the natural environment (Douglas & Wildavsky, 1982, Dobson, 1998, Dryzek, 2005, Aalbers, 2006, De Vries & Petersen, 2009, Hedlund-de Witt, 2014). In this chapter we will describe four worldviews in versions relevant to this debate. These versions will be derived from existing descriptions of worldviews, but tailored to this case.

In the existing literature, worldviews are usually depicted in a quadrant. The quadrant in figure 1 is an example of such a representation. This quadrant summarises much of what has been argued about worldviews in the general body of literature. As the quadrant shows, prominent defining characteristics can be portrayed as points on a spectrum between two extremes, whereby each worldview takes a specific position as most desirable on this spectrum, such as between the opposing values of globalisation and regionalisation.

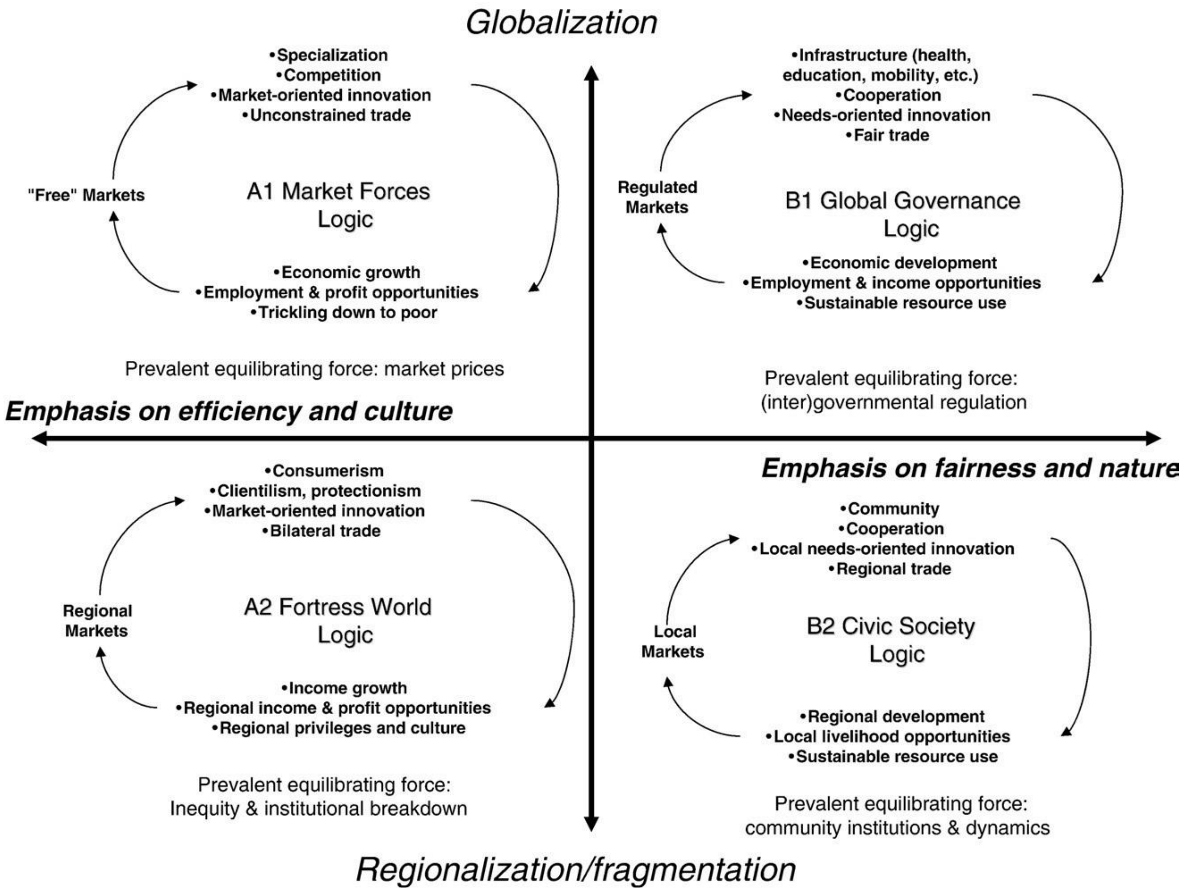

Figure 1: from De Vries & Petersen (2009), based on IPCC-SRES scenarios (2000)

We will use these defining characteristics to better understand different ways in which participants frame the issues in the debate. Combined with insights from Douglas and Wildavsky (1983), Thompson et al (1990) and other literature discussing perceptions of nature and worldviews, the quadrant in figure 1 can be transformed into a second, more case-specific quadrant (figure 2). We used this quadrant in an earlier publication to explain diverging perceptions of sustainability in the bio-economy in general (Asveld et al, 2014).

3.2 Conflicting views of technology and nature

The second quadrant depicts the worldviews most applicable to the case at hand, informed by the first quadrant. The axes depict defining characteristics. One axis represents the opposition between globalisation and regionalisation. Actors favouring local economies and short chains of supply will flock to the regionalisation part of this axis, whereas actors favouring global, open markets can be found on the globalisation end.

A second prevalent opposition is that between individualism and solidarity, portrayed in the first quadrant as efficiency versus fairness. Individualism is a guiding ideal for someone who supports a high performance society with lots of individual competition, and a free, global market (Aalbers, 2006). The collectivism ideal points to a strong concern for community and a willingness to accept regulation and bureaucracy as a means to safeguard a certain degree of equality within that community (Dryzek, 2005).

A third defining characteristic relevant to the debate in question is the relation between technology and nature. Conflicting views of this relationship cannot be placed along an axis, but correspond to various positions on the aforementioned axes. For this characteristic we rely on the work of Douglas & Wildavsky (1982) and Thompson et al (1990) in which they distinguish four prevalent views of nature as depicted in figure 2:

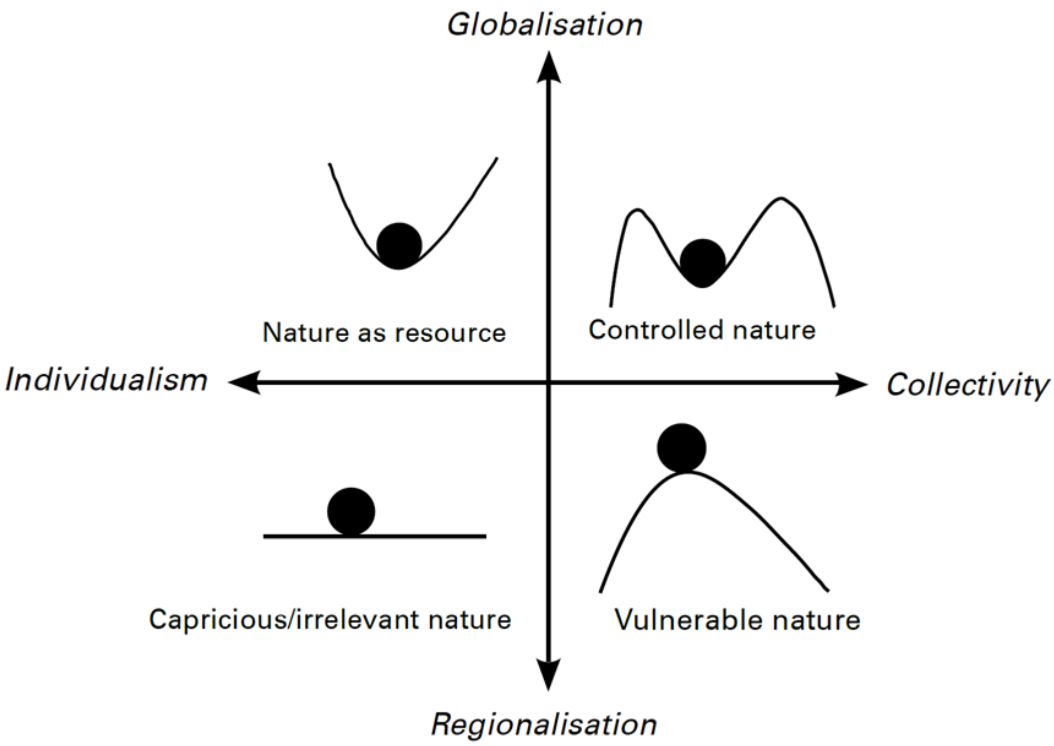

Figure 2: from Asveld *et al.* (2014)

These different perceptions of nature correspond to different perceptions of risk and sustainability associated with new technologies. How these perceptions relate to the ideals of collectivism versus individualism, and regionalisation versus globalisation is described for each worldview below.

Nature as resource/Market forces logic

In this worldview, nature is perceived as basically resilient – not easily "pushed over the edge". Nature can therefore be exploited ("nature as resource") without too many problems. Additionally, market forces are generally expected to produce beneficial (sustainable) effects for everyone. This worldview is found among multinationals (such as the Dutch Sustainable Growth Coalition, 2014), but often also among pioneers of new technology, such as small start-ups and venture capitalists. Actors who share this worldview see no need for strong regulation, in line with an attitude of individualism and an aversion to collectivism. Adherents of this worldview might state the following in relation to the algae case:

> We need to move away from our old production mechanisms for environmental and marketing reasons. Tinkering with existing natural production mechanisms opens up vast and increasingly efficient production avenues for beautiful, renewable and sustainable resources that might lead us out of our current environmental predicament.
>
> Innovation is key to progress. Not all innovation will be perfect immediately, but we will learn and develop as we go along. We need innovation to increase the efficiency of our existing economic infrastructure. Risks associated with engineered biological entities are controllable because we can engineer organisms more precisely due to new engineering technologies and containment.

A sentence from the Solazyme website can be understood as fitting within this worldview: “By unlocking the power of microalgae, Solazyme is building the foundation for the products of the future” (“Solazyme”, n.d.).

Vulnerable nature/Civic society logic

In this worldview, nature finds itself in precarious balance - a push in any direction could be fatal (“vulnerable nature”). Therefore, technologies may pose great, potentially uncontrollable and irreversible risks and can only be beneficial when bound by solid social and legal frameworks. Those who sympathise with this worldview have a strong preference for local economies, in which buyers and producers know one another and in which large companies are either absent or have only limited influence. Open markets are considered detrimental because they preserve or increase existing inequalities between economic players. So, one needs to be constantly wary of imbalances in power and strive for a collective decision-making process in which everyone has their say. This worldview is found among some NGOs and “dark-green” consumers and citizens. Adherents of this worldview might state the following in relation to the algae case:

> We should fear the sugar economy in which everything is turned into a monoculture. In such an economy, feedstock becomes irrelevant, and with that, natural diversity, local identities and local needs become irrelevant. It will lead to the ultimate destruction of ecological, economic and social ecosystems. Also, the patenting of natural resources by large-scale companies is inherently wrong. We should invest only in small-scale, diverse solutions that prevent knowledge monopolies and the concentration of power over resources. With many so-called sustainable innovations, the economic benefits often accrue to a single actor, while the promised ecological and health benefits remain unproven.
>
> We need innovations, but only those which are truly sustainable and do not reinforce current inequalities and unsustainable practices. We need to consider the direction a particular innovation is taking: which other pathways are we neglecting by investing resources into a particular innovation? We should reject disastrous innovations such as synthetic biology and focus instead on promising innovations such as solar cells. New tools for engineering biological entities are risky because whole new organisms are created, the ecological effects of which we cannot predict. To think that these organisms can be controlled is a dangerous illusion. We cannot control nature.

A quote from a Friends of the Earth report on synthetic biofuels echoes this worldview: "It is short-sighted to create new and unpredictable life forms that fit with our current infrastructure instead of investing in a new, clean and sustainable infrastructure" (FOE 2010, p. 20).

Controlled nature/Global Governance logic

The "controlled nature" worldview combines particular characteristics of the two worldviews described above – emphasising opportunities for exploiting nature but also recognising that there are limits that must not be exceeded. Those who share this worldview usually recognise the benefits of new technology, but are also concerned about possible risks, and therefore desire regulation. Market forces are generally considered to be beneficial as long as they are properly regulated to assure fair and open trading conditions. In this worldview it is possible to arrive at global agreement on the values underlying regulatory frameworks for either technology or markets. Actors relying on this worldview include NGOs, some companies and government actors. In the context of this case, adherents of this worldview might state the following:

> Whatever solution we can think of to support sustainability is worth considering. We should not condemn any innovations upfront and should try to steer innovations in the right direction. With any new innovation, risks are inevitable. As long as we take the right measures, we will be able to minimise risk to an acceptable level.
>
> The main criterion for judging an innovation should be whether something is sustainable or not. Efficient use of resources can be expected to contribute to sustainability, be it large-scale or small-scale. We can (and we have) developed indicators to define sustainability. We can already rely to a great extent on LCAs to determine the sustainability of various feedstocks. Once we agree on all the indicators, such as sustainability criteria, we will know how to proceed. Therefore everyone has to join in the conversation for establishing these indicators.

Ecover's position can be seen as fitting mostly into this worldview, since the company critically assesses new technologies to increase sustainability on the basis of measurable indicators, while inviting a wide range of actors to give their input.

Capricious nature/Fortress World Logic

Finally, in the "capricious nature" worldview, nature is seen as beyond our control. There is no point in seeking regulation and no interest in new technology, unless it produces obvious benefits in the local region for the community or for individual day-to-day lives. Those who share this worldview include poorly educated people in Western societies and subsistence farmers in developing countries. Noting that these groups and their voices are often marginalised by market-driven and global technological innovations, NGOs in particular often raise concerns about the ways in which the existence, interests and rights of these groups may be threatened by new technologies.

3.3 Reconsidering the debate: how individual positions are framed by worldviews

We now return to the main themes and issues raised in the debate about engineered algae oil. How are the different positions in this debate framed by worldviews? As we have argued, individuals' perspectives will never fully coincide with the culturally dominant worldviews discussed above. But these worldviews can help us to better understand the differences and clashes between these perspectives. As more comprehensive and culturally entrenched frames of meaning, these worldviews provide coherence and depth to relevant individual statements, as shown below.

How will bio-based innovations affect sustainability?

In considering the use of bio-based resources, all actors agree that there are sustainability issues which need to be addressed. The first main dividing issue is whether genetically engineered algae point to a solution, or should be considered a problem. Actors such as Solazyme and Ecover think that the engineered algae could offer a solution, while ETC Group and their associates think that this technology will only exacerbate sustainability problems by creating serious ecological and socio-economic risks. This latter position can be linked to the “vulnerable nature” frame which is critical towards any approach that does not take diversified, local environmental and social interests as a starting point. For the critical environmental coalition, these local interests should be at the forefront of any endeavour to make production sustainable.

Indeed, all actors appear to agree that local, decentralised sourcing of feedstocks is preferable to a system of centralised, global sourcing. However, most actors think that such a goal is compatible with complex, sophisticated technology that requires considerable economic resources. For instance, “In the long run, Solazyme envisions plants all over the world, on different continents where we can use various, local feedstocks” [interview Kauffman Johnson]. And as Klaas Hellingwerf (UvA) says, “Basically smallholders might actually profit from this kind of technology as they can directly deliver the feedstock. Algae enable decentralised production par excellence, because algae can be cultivated anywhere” [interview Hellingwerf].

But Jim Thomas (ETC Group) strongly disagrees: “This technology might lead to decentralised, eco-friendly use, but that is not what it is now. Solazyme is using a centralised production facility and they are not sharing their knowledge. They are investor led, not a co-operatively owned organisation. This technology undermines sustainable livelihoods and concentrates power over the supply chain in the hands of a few. It is a green illusion to think otherwise” [interview Thomas].

Sijas Akkerman (Natuur & Milieu) takes the position that both centralised and decentralised production methods should be explored, because we cannot know beforehand which is superior: “Concerning the algae, I think that both large scale, centralised production relying on sugar cane and small scale production relying on local resources is useful. It all depends on the LCA. It is wise to try out different technological pathways and then optimize them” [interview Akkerman].

The main dividing issue here is whether we should see Solazyme’s engineered algae technology as reinforcing local, small-scale production, or reinforcing a global “sugar economy”. In line with the “vulnerable nature” view of ETC Group and Friends of the Earth US, any process in which a company uses (“extreme”) genetic engineering, based on commercially owned, patented DNA-techniques, is inherently unsustainable. Hence, Solazyme’s production technology is unacceptable. For most other actors, however, engineered algae are not inherently good or bad. Whether they are desirable or not depends on how they are used. This is compatible with the “controlled nature” view, according to which the acceptability of risks and benefits depends on the way in which they are managed.

How to assess the macro-economic effects of this technology?

All actors agree that the production of engineered algae should not threaten the livelihood of small-scale coconut farmers. Additionally, no actor disputes that the production of algae from sugarcane should also benefit the livelihoods of people living close to the algae production plant. What they do disagree about is whether these values can be attained through market forces, or will at least remain unthreatened by them. As became clear in chapter 2 of this report, ETC's Jim Thomas fears that people living close to the production plant will not benefit from Solazyme's activities.

Indeed, fitting the "vulnerable nature" view, ETC Group and its allies proclaim that Solazyme will disrupt the market in its own favour and to the detriment of vulnerable producers like small-scale coconut farmers. As Jim Thomas points out: "If Ecover is switching to algae produced oil, that will have an impact on the livelihoods of coconut farmers. We are talking here about palm kernel oil (PKO) which is comparable to coconut oil. If an alternative for PKO and coconut oil becomes available, the prices will go down. For PKO this is not necessarily a problem, because most of the palm tree is used for palm oil. And the companies in this field are large multinationals with large financial reservoirs. But the coconut farmers do not have such alternatives or reserves" [interview Thomas]

Others do not expect many detrimental effects on smallholders, and if they were to occur, there are options for managing them. This is in line with the "nature controlled/global governance" logic. Sijas Akkerman says, for instance, "If oil from engineered algae would threaten the livelihoods of small-scale coconut farmers, we would consider that to be a problem. (…) But such a threat would only materialize if those farmers have no other market for their oil and that seems unlikely. If a problem would occur, Solazyme could always act on that by adapting their production" [interview Akkerman].

In Solazyme's view, market dynamics determine events, and that gives no reason for concern. It does not consider the economic robustness and potential of other producers to be a significant factor, as it does not envisage a situation in which it dominates the market for vegetable oils to such an extent that other producers might suffer from it: "The concerns voiced by the ETC group about the displacement of coconut farmers surprised us. The market demand for coconut oil, and related coconut products, is growing at a rapid pace. It is also well-documented that demand is generally not the driving threat to the livelihoods of small scale coconut farmers. The main issues impacting them, as acknowledged by the Philippine government, are low productivity, impacts from climate change and thick layers of intermediaries in the supply chain resulting in reduced incomes for farmers" (NEDA, 2014).

Can we reliably predict the risks of this technology and adequately manage them?

Differing visions of man's relation to nature and of human beings' control over technology lead to diverging perceptions of risk. If nature is considered to be something that can easily be kept under control ("nature as resource"), then technology is perceived as a lot less risky than it would be if nature is fragile and quickly disturbed ("vulnerable nature").

For Friends of the Earth US and ETC Group, the risks of synthetic biology are both undeniable and substantial: "While other types of pollution such as synthetic chemicals break down over time and do not breed, synthetic biological creations are designed to self-replicate and once released into the environment they would be impossible to stop and could wipe out entire species. This type of pollution, known as genetic pollution, can be devastating since it cannot be cleaned up" (FOE, 2010, p. 9).

On the other hand, Jill Kauffman Johnson of Solazyme notes that the genetic engineering of microorganisms (e.g. yeasts and bacteria) has been happening for a long time already, to produce pharmaceuticals, enzymes for cheese, and other products. Moreover, this type of production takes place in contained fermentation vessels: "We consider what we do as traditional genetic engineering – we do not create new organisms or DNA de novo – and we use technology and processes that have been in use for decades. Also, we use heterotrophic microalgae that are grown in fermentation tanks, our algae do not live in open ponds. But it seems we are being targeted with arguments that are usually directed at agricultural biotech" [with engineered crops that are uncontained, LA] [interview Kauffman Johnson].

This reply, however, will be unconvincing to those adhering to a "vulnerable nature" worldview, as they believe that nature cannot be safely controlled by humans. Indeed, according to Friends of the Earth, containment will probably fail: "Experts in the field agree that there is no way to contain synthetic or genetically engineered organisms – particularly algae. According to Lissa Morganthaler-Jones, CEO and co-founder of Liverfuels, Inc., a small number of genetically engineered algae have already leaked from the lab into the environment. They have been carried out on skin, on hair and all sorts of other ways, like being blown on a breeze out the air conditioning system, she said" (FoE, 2010, p. 9).

Kauffman Johnson, however, states that regulatory oversight in the US and Brazil specifically addresses concerns about accidental escape of microorganisms and that Solazyme has met, or even exceeded, all of the regulatory requirements. She notes that Brazil's regulations, enforced by CTNBio, are consistent with the "precautionary principle" and the *Cartagena Protocol on Biosafety to the Convention on Biological Diversity*. Solazyme did extensive tests as part of the CTNBio approval, testing the native base strain as well as the engineered microalgae in environmental studies. What the study results indicated, according to Kauffman Johnson, is that the microalgae do not reproduce or persist in the environment, that there is no negative impact on soil microbiota or water quality, and that there are no adverse effects on water microorganisms and earthworms [interview Kauffman Johnson].

But again, such studies will not reassure those who favour a "vulnerable nature" worldview, because a study will always have limitations, and unexpected effects can always turn up. When there are more sustainable alternatives available, as the environmental coalition believes, then why even take such chances?

Looking at this from other perspectives in which nature is believed to be relatively controllable, there are several promising options for managing possible risks, including options for engineering safety into the organism ("safety by design"). As Klaas Hellingwerf explains, "Our knowledge on the genetic make-up of organisms is increasing. Therefore I think that synthetic biology can be applied in a safer way than genetic modification. Synthetic biology enables you to assure that organisms can survive only under conditions of containment and not in the outer world" [interview Hellingwerf].

Others, like Sijas Akkerman, are less optimistic about this approach: "I doubt whether synthetic biology is safer than other technologies. Control over natural processes is an illusion. Unexpected effects keep emerging, as we saw in relation to research into human DNA" [interview Akkerman].

Jim Thomas is also doubtful about the lasting effects of engineered safety: “Synthetic biology doesn’t make the organisms safer: you have more control over the DNA but not over the organism. What DNA does within an organism is still difficult to predict. If the algae escape they will quickly adapt to their environment so they will be able to survive, even if they have been engineered to devote most of their energy to producing some product that humans need” [interview Thomas].

These doubts are not completely beyond Hellingwerf either; he notes that “Acquiring the right qualities remains a process of trial and error. We can insert DNA of which we know for what qualities it codes, but the eventual effect on the organism, remains unpredictable. There are a lot of interactions in biology that we do not completely understand. We do know that we can severely limit the range of conditions in which an organism can survive and thereby we can limit ‘escape’ and ‘contamination’ risks. But any kind of large-scale mono-culturing inherently introduces the risk of generating ‘weeds’” [interview Hellingwerf].

Mike Childs of Friends of the Earth England, Wales & Northern Ireland (EWNI) likewise believes that risks associated with engineered algae are an inevitable part of life and technological progress. For him, the main issue is how such risks can be managed: “There are risks around all kind of technology. Society has to deal with all kind of risks. In this case of synthetic biology it is probably true that there is a risk of the engineered algae escaping. Then you also need to ask, what is the risk of them replicating once escaped? We need to do a proper assessment of that” [interview Childs]. This perception fits well with the “nature controlled” worldview, where risks are accepted as an inalienable feature of dealing with technologies, and where proper management is the main issue.

Is this technology a lock-in or a step up?

If nature is seen as controllable, so are the resources which form the basis for bio-based innovations, such as engineered algae. If the relevant resources are considered predictable, bio-based innovation trajectories will, likewise, be perceived as more predictable. If nature, on the other hand, is perceived as difficult to manage and unpredictable, so are future bio-based innovation trajectories.

Various beliefs about the controllability of nature, fitting with a “controlled nature” worldview, can be recognised in expectations around future trajectories of innovation for engineered algae. They can be seen as a step in the direction of more sustainable solutions, as Tom Domen, long-term innovation manager at Ecover, describes them. Domen is most vocal about framing the sugarcane-fed algae as a necessary transitory step towards truly sustainable solutions in which algae do not rely on a bio-based feedstock at all [interview Domen]. More modestly, Solazyme envisions an innovation trajectory which moves towards the growing of algae on inedible fractions of (waste) biomass as a potential feedstock.

Mike Childs is cautiously open to the possibility of such a trajectory: “If you can move on to something more sustainable than current practice then a suboptimal solution can be an acceptable step as long as it doesn’t preclude other more sustainable pathways (…) The basic question should always be: is this application made to address the main challenges and are there alternatives available?” [interview Childs].

Other actors are more sceptical. Sijas Akkerman has his doubts about this envisaged innovation trajectory, considering the development of biofuels in general: “Sometimes investments in suboptimal solutions might lead to optimal solutions. But, with biofuels for example that is not the case. Producers of first generation biofuels claim that their investments will lead to second generation biofuels, but that is a completely different technology, so I doubt that claim” [interview Akkerman].

As we noted in chapter 2, for Jim Thomas, such future ideals are no more than illusions. We should assess the technology as it is now, not what it might be in the future.

Can sustainability adequately be measured with current instruments?

Another potential source of conflict in this debate is the applicability of instruments for assessing the sustainability of bio-based innovations. Currently, these instruments consist of LCAs and sustainability criteria. LCAs measure and add up the overall “sustainability costs” of a given product over its life cycle, including production, use and recycling or destruction. LCAs take into account sustainability effects such as CO_2 emissions, water use and energy use (Wesselink et al, 2016). Sustainability criteria are not a measuring instrument, but provide a range of yardsticks that bio-based products have to live up to in order to be considered sustainable, such as reduced CO_2 emissions in comparison with fossil-based counterparts.

These instruments fit very well with the “controlled nature” worldview. They provide a chart on which to weigh potential benefits against potential drawbacks. LCAs and sustainability criteria provide a way to assess and thereby guide bio-based innovations to the optimal solution. As Sijas Akkerman says, “If the LCA of sugarcane trumps that of palm oil, large scale application of sugarcane seems the preferable route to me” [interview Akkerman].These instruments are also very useful for adherents of the “nature as resource” worldview, as they serve to indicate the sustainability of an innovation to prospective buyers (Flipse, 2014).

However, what LCAs and sustainability criteria fail to address is the possible future evolution of trajectories of innovation, and how particular innovations may reinforce or undermine existing socio-economic structures (Flipse, 2014). For those favouring a “vulnerable nature” worldview, these are exactly the issues that should be prominent in determining the sustainability of an innovation. Socio-economic structures can reinforce economic inequalities and power imbalances, and innovations which support or enhance such inequalities should not be considered sustainable. However, as local complexities differ in every context, such considerations are difficult to capture in LCAs or in general sustainability criteria (Wesselink et al, 2016, see also Pauwels, 2013 and Commission Corbey, 2013). Therefore LCAs and sustainability criteria are not sufficient measures of the sustainability of innovations for those who favour a “vulnerable nature” worldview.

Moreover, a key concern for many NGOs is that sustainability criteria and related assessment schemes are not strict enough, and not sufficiently monitored (Biofuelwatch, 2012). According to Jim Thomas, “Ecover was part of a roundtable on sustainable palm oil and they said they ran into trouble with the certification there. Now they are moving on to another problematic certification scheme, thereby exchanging one problem for another. Bon Sucro also has problems with monitoring and compliance” [interview Thomas].

4 Conclusion

In this report we have identified salient issues emerging from controversy over the use of engineered algae, including the question of whether decentralised production is preferable to centralised production, the effect of market dynamics on vulnerable small-scale farmers, the nature and management of the risks posed by engineering organisms, the future prospects for more sustainable innovations, and the role of LCAs and other assessment schemes.

We have also highlighted three worldviews which are especially relevant to this controversy: “nature as resource/market forces logic”, “vulnerable nature/civil society logic” and “nature controlled/global governance logic”. These worldviews can be positioned at the ends of two axes: individualism vs. collectivism and global vs. local. A third defining element is the perspective on nature as either a robust resource that can be freely exploited with technological means, a resource that can be controlled but not without risks as an issue of concern, or a fragile resource that first of all needs to be protected.

The different positions of individual actors in this debate, as mapped out in chapter 2 of this report, can be understood as being structured by the particular worldviews that we distinguished in chapter 3. These worldviews provide for a better understanding of diverging perspectives by pointing to a wider body of concerns and background beliefs that inform the particular positions of the relevant actors. As such, these worldviews can provide valuable input to an agenda for public debate.

One important issue to be discussed in such a debate is how the sustainability of existing biomass chains might be evaluated. In debating this issue, it is important not to define the meaning of sustainability in advance, but instead to enable a meaningful dialogue in which different interpretations can be articulated. This deliberation might start with an examination of “formal” assessments like LCAs, followed by an exploration of how these assessments relate to broader, more “informal” ways of evaluating sustainability, and an articulation of the values and frames which inform these differing views of sustainability. An important question in this context is how formal and informal assessments might be linked to each other.

In such a debate, we might also evaluate a range of possible industrial biotechnology biomass chains, in order to generate more comprehensive visions of a future bio-economy. Taking this “big picture” approach, we can also focus the discussion more specifically on particular product development cases, and on the role of technology, i.e. synthetic biology. Again, we might start with formally established road-mapping exercises to examine whether the technical and commercial opportunities envisaged can be seen as viable steps towards a more sustainable future, and to identify alternative, more desirable, innovation trajectories, and the values and worldviews which they embody. On the basis of such a dialogue, we would hope to identify important conditions and challenges for a collective process of learning about sustainable futures for industrial biotechnology.

Bibliography

Aalbers, T.G. (Ed.) (2006) Waardenorientaties, wereldbeelden en maatschappelijke vraagstukken: Verantwoording van het opinieonderzoek voor de Duurzaamheidsverkenning 'Kwaliteit en Toekomst Report 550031002, Bilthoven: Netherlands Environmental Agency

About the Company. (n.d.). Retrieved from www.solazyme.com/company

Asveld, L., J. Ganzevles, P. Osseweijer & L. Landeweerd (2014) *Naturally Sustainable? Societal issues in the transition to a sustainable bio-economy* Delft: Delft University of Technology

Asveld, L., Q v. Est & D. Stemerding, (2011). Getting to the core of the bio-economy: A perspective on the sustainable promise of biomass. Rathenau Instituut, The Hague, The Netherlands: Rathenau Instituut

Biofuelwatch (2012) Sustainable Biomass: a modern myth

Brinker, G. den (2015) Brandstof uit bacteriën: groen, gewild, maar nog niet goedkoop, Financieel Dagblad, 8 mei 2015

Brom, F., A., G. Thijssen, G. Dorren & D. Verhue (red.) (2011): Beleving van technologie en wetenschap - Een segmentatieonderzoek. Den Haag: Rathenau Instituut.

Commission Corbey (2013). Sociale Verantwoordelijkheid. The Hague: Commission Corbey.

Crutzen, P. J. (2002). Geology of mankind. Nature, 415(6867), 23-23.

Dam, L. van (2015) Status of micro-algae application in food, feed and aquaculture – recommendations to accelerate development and commercial implementation Internship Report Master of Science. Wageningen: Wageningen University

Dobson, A. (1998). Justice and the environment : onceptions of environmental sustainability and theories of distributive justice. Oxford ; New York: Oxford University Press.

Dutch Sustainable Growth Coalition 2014. Sustainable Innovation. Game changing solutions for the world's grand challenges, www.vno-ncw/DSGC

Dryzek, J. S. (2005) The Politics of the Earth. Environmental Discourses. Oxford: Oxford University Press

Douglas, M., & A.B Wildavsky, (1982). Risk and Culture: An essay on the selection of technical and environmental dangers. Berkeley: University of California Press.

FAO/WHO (1996) Expert consultation on Biotechnology and Food Safety, Rome: FAO/WHO

Flipse, S. M. (2014). Environmental Life Cycle Assessments as Decision Support Systems within Research and Development Processes: Solutions or Confusions for Responsible Innovation? . International Journal of Business and Management, 9(12), 210-220.

Friends of the Earth (2010) Synthetic solutions to the Climate Crisis.

Hedlund-de Witt, A. (2013) Worldviews and the transformation to sustainable societies. An exploration of the cultural and psychological dimensions of our global environmental challenges. Amsterdam: IVM.

Kupper, F., Krijgsman, L., Bout, H., & de Cock Buning, T. (2007). The value lab: Exploring moral frameworks in the deliberation of values in the animal biotechnology debate. Science and Public Policy, 34(9), 657-670. doi: 10.3152/030234207x264944

Lam, M. K., Tan, K. T., Lee, K. T., & Mohamed, A. R. (2009). Malaysian palm oil: Surviving the food versus fuel dispute for a sustainable future. Renewable and Sustainable Energy Reviews, 13(6–7), 1456-1464. doi: http://dx.doi.org/10.1016/j.rser.2008.09.009

NEDA (2014). Republic of the Philippines, National Economic and Development Authority, NEDA calls for greater support and opportunities for small farmers, http://www.neda.gov.ph/?p=4226

OECD. (2009). The Bioeconomy to 2030: designing a policy agenda International Futures: OECD.

Pauwels, E. (2013). Who let the "Social Scientists" into the Lab? In M. E. G. Nora Savage, Anita Street (Ed.), Emerging Technologies: Socio-Behavioral Life Cycle Approaches. Baco Raton: Taylor & Francis Group.

Solazyme. (n.d.). Retrieved from www.solazyme.com

Thomas, J. (2014) Ecover pioneers 'synthetic biology' in consumer products Ecologist, retrieved online 10-11-2014

Thompson, M., Ellis, R. & Wildavsky, A. (1990) Cultural theory. Political cultures. Boulder, CO, US: Westview Press Cultural theory.

Unilever (2016) Unilever extends agreement on sustainable algal oil https://www.unilever.com/news/news-and-features/2016/unilever-extends-agreement-on-sustainable-algal-oil.html

Vries, B.J.M. de & A. Petersen (2009) Conceptualizing sustainable development. An assessment methodology connecting values, knowledge, worldviews and scenarios Ecological Economics, pp. 1006 – 1019.

Wesselink, L.G., Westra, J. & van der Vlugt, C. (2016). Tools for assessing the sustainability of oils and proteins from genetically engineered algae. Bilthoven: RIVM.

What's in a name? (2009). Nat Biotech, 27(12), 1071-1073.

Willis, J. M. Venant & O. Noel (2016) The rights of BAKA Communities in the REDD+ Ngoyla-mintom project in Cameroon Moreton-in-Marsh: Forest Peoples Programme and Association Okani

Young, C., SACCESS & JKOASM (2014), A national overview and two sub-regional case studies, Moreton-in-Marsh: Forest Peoples Programme

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Who was Rathenau?

The Rathenau Instituut is named after Professor G.W. Rathenau (1911-1989), who was successively professor of experimental physics at the University of Amsterdam, director of the Philips Physics Laboratory in Eindhoven, and a member of the Scientific Advisory Council on Government Policy. He achieved national fame as chairman of the commission formed in 1978 to investigate the societal implications of micro-electronics. One of the commission's recommendations was that there should be ongoing and systematic monitoring of the societal significance of all technological advances. Rathenau's activities led to the foundation of the Netherlands Organization for Technology Assessment (NOTA) in 1986. In 1994 this organization was renamed 'the Rathenau Instituut'.

The Rathenau Instituut promotes the formation of political and public opinion on science and technology. To this end, the institute studies the organization and development of science systems, publishes about social impact of new technologies, and organizes debates on issues and dilemmas in science and technology.

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