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Genomics in Industry: issues of a bio-based economy

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Abstract
What value does genomics hold for industry? Ten years after the White House Press conference where the human genome sequence was first presented, we ask in which ways and to what extent the developments in genomics have been integrated into industry. This enables us to assess whether this integration has been as successful as expected, but also which unexpected developments in genomics advances have triggered additional benefits for industry. Genomics has contributed to the beginning of a global transition to a bio-based economy, but there have been and there still are hurdles to be cleared. The hurdles are not merely of a technological nature, since the objectives are a complex between economic progress, environmental and global climate concerns, and energy security. Therefore, they are at the same time technological, societal and environmental in nature. These categorisations fall short of articulating the many issues that arise, such as economic development (for emerging economies), public opinion formation and scientific and technological progress. We argue that to make this transition happen, industrialists, policy makers and the wider public have to be prepared to be more actively involved in the debate, weighing the pros and cons and taking responsibility in creating the desired sustainable world.

This paper will examine the advances of genomics in the industrial context, the role of these advances in current attempts to find sustainable solutions to a variety of problems, the enthusiasm with which they have been picked up, the implications for industrial innovation and the accompanying discussion about possible consequential social and ethical issues. It will also sketch out the nature of this ongoing establishment of a bio-based economy, the parties that are currently at the negotiation table, and whether the current situation has an impact on the way societal debates emerge.

Introduction
The identification of the structure of the genome provided a glimpse of the complexity and interrelatedness of the components of living matter. Not long after the introduction of the first DNA chips, biotechnology companies started to embrace the technology. They regarded genomics as a new tool for their R&D and increasingly realised that it also provided the basis for a new strategy for research and innovation. Genomics provides a wealth of data that, arguably, creates much more opportunity for applications in innovation than the study of the minute details of a certain metabolic pathway. It also necessitates new interpretation tools.

Genomic innovations yield applications in different types of industry: medical diagnostics and pharmaceuticals; chemical and food fermentation; and seeds and crops. In the medical field, human genome information and the genomics of

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pathogenic organisms promises to increase options for genetic screening and testing, developing diagnostics with higher sensitivity and tailor-made therapeutics, and for exploring 'nutriceuticals'. Further understanding of the workings of the genome, transcriptome, metabolome and proteome (including epigenetics) could provide us with insights into processes such as ageing, disease development (including cancer) and disease protection mechanisms. In the field of industrial biotechnology, genomics promises further understanding of the microorganisms employed for the production of fine chemicals, such as enzymes for use as catalysts in industrial processes as well as household detergents and pharmaceuticals. It could provide better products but also more robust production systems which are better adapted to cheaper feedstock and therefore enable an extension of the product range to bulk chemicals. In the food industry it promises new leads to finding naturally occurring organisms that could produce valuable health or taste components without having to rely on the genetic modification routes less accepted in Europe and developing countries. Genomics was, of course, embraced at an early stage by the plant breeding community as a support tool in the selection of novel varieties.

While the 'new tools' led to more precise, cheaper or better adapted ways to develop new products, they also led to changes in companies' approaches to innovation. This is especially true for the field of industrial genomics, where the technology is used to increase the range of products which use biomass rather than fossil fuels as resources. When these new technologies are deployed for bulk chemistry they lead to novel partnerships in the production chain. The increased need for biomass also necessitates large scale changes to infrastructure, such as trade, transport, biorefineries, etc.[2] This has societal effects, which have not always been projected positively, as demonstrated in the food-fuel debate. Furthermore, given the complexity of such changes and the processes underlying them, many people do not have a clear picture of the scale and nature of these developments.[3] The need for better communication between scientists, producers and users is becoming increasingly urgent. In this respect, it is not sufficient merely to address 'the public' given the wide variety of stakeholders involved, including industry, scientists from a wide variety of disciplines, policy makers, national and international organisations involved in regulation and legislation, smaller and larger companies, domestic farmers and farmers abroad, local communities, etc.

To be able to discuss the societal issues involved in the introduction of genomics to industry it is important to distinguish between the different processes and uses of genomics, in view of the fact that they involve different stakeholders and give rise to different issues.[4] Each industrial field shows its own characteristics in integrating genomics platforms. These characteristics determine the feasibility of the applications of the genomic data, their economic viability in the business environment and the societal acceptance of the evolving products. As we have seen in earlier debates on the implementation of new technologies, issues of concern to the public are more closely linked to the field of application than to the industrial use of the technique.[5] There are many non-governmental organisations that have entered the debates on single issues, leaving the other topics (eg medicines) untouched in their crusade for or against certain uses of the new technologies.

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This paper will focus on developments in the fermentation industry, later called ‘industrial’ or ‘white’ biotechnology. ‘White’ in this respect has come to refer to the environmental advantages of these production methods even though it was originally used to distinguish it from ‘green’ (environmental and agricultural uses) and ‘red’ (used for humans and animals) biotechnology. It is the area that focuses mainly on developing new production processes for pharmaceutical ingredients, chemical compounds and biomaterials. The industry has suffered some negative characterisations recently because of a perception that its production of biofuels from food crops comes at the expense of producing food. These public controversies potentially slow down the innovation process as well as its implementation in society. This is problematic because the potential of these processes for sustainability is expected to be high, and the impact of the developments involved cannot be simply sketched out as a simple and inevitable trade-off between food and fuel: by engineering organisms to convert a basic feedstock into a higher value product, industrial biotechnology allows a more sustainable chemistry to be developed, both reducing the chemical industry’s dependence on petrochemical products and allowing smaller scale, more local production to take place. By concentrating on using byproducts as feedstock rather than using a primary (food) product, the technology has the potential to create high-value fine and bulk chemicals and pharmaceuticals from what may otherwise be waste materials. This potential also furthers several agendas of society as it has the potential to decrease emissions of greenhouse gases and decreases the (political) dependency on fossil fuels. These societal drivers can, if the communication process is organised in an effective fashion, increase societal acceptance of the technology.

Industry will not be able to accommodate all societal issues involved in a self-evident manner. In fact the transition from a fossil-based economy to a biobased economy requires the active involvement and change of many parties. A one-directional communication process would therefore not be sufficient, as this would not engage people as participants in such a transition to a biobased economy. It is in the interest of all parties including industry to be involved in an early dialogue on these societal issues. This would help shape the innovation agenda and strengthen societal awareness, both of which are necessary in order to change present unsustainable practices while maintaining economic viability. This means that a more democratic structuring of both the communication process and the innovation process would be in the interests of both industry and society. Awareness of these advantages needs to increase. We will explore the societal dimension of this growing industry where novel technologies and societal drivers have arguably paved the way to what has recently been claimed to be the largest transition since the industrial revolution.[6]

Microbial Genomics for Industrial Production

Microorganisms are used to produce valuable chemicals and materials from renewable sources such as sugar. Genomics provides a strong possibility of adapting these microorganisms so that they can use other renewable biomass, such as wood sugars and celluloses, which are much cheaper than sugar and which do not necessarily compete with food usage. Due to its complexity and large infrastructural demands, innovation in white biotechnology is currently embedded in specific

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organisational structures. When the potential of genomics became evident, the fermentation industry was interested in sequencing its own already established 'specially selected' production microorganisms. The industry soon recognised that collaboration with academia and other genomics expertise would increase the success rate and industrial potential of novel, but very expensive, techniques. Various collaborations were established in different countries, such as: the Energy Bioscience Institute in the USA, set up with $500 million from BP; the UK Centre for Sustainable Bioenergy, supported by the UK Biotechnology and Biological Sciences Research Council (BBSRC); the Porter Alliance, including the University of Cambridge and Imperial College London; the Kluyver Centre for Genomics of Industrial Fermentation and the Centre for Biobased Ecologically Balanced Sustainable Industrial Chemistry (BE-Basic) in The Netherlands; a number of German centres supported by Länder government funding; the Portuguese MIT initiative; and a series of projects supported by the Knowledge and Bio-based Economy (KBBE) Programme of the European Commission.

The availability of genomic techniques was certainly not the only driver for the success of industrial biotechnology. Much stronger political drivers were the desire to mitigate climate change, to increase sustainability, to provide energy security, and to prepare industry for the inevitably depleting stock and increasing costs of fossil oils.[7] Mitigation of climate change can be achieved by the reduction of CO_2 and other greenhouse gases and this can be achieved by using biomass as a renewable source for manufacturing. Most bulk products such as plastics and chemicals are usually produced from fossil oils, but their use rapidly releases enormous amounts of CO_2. Replacing these fossil sources by plants, whether as the primary crop or as waste from other crops, avoids the additional release of CO_2 as plants bind CO_2 from the air in their growth process, which is then released when they are used as sources for production (figure 1).

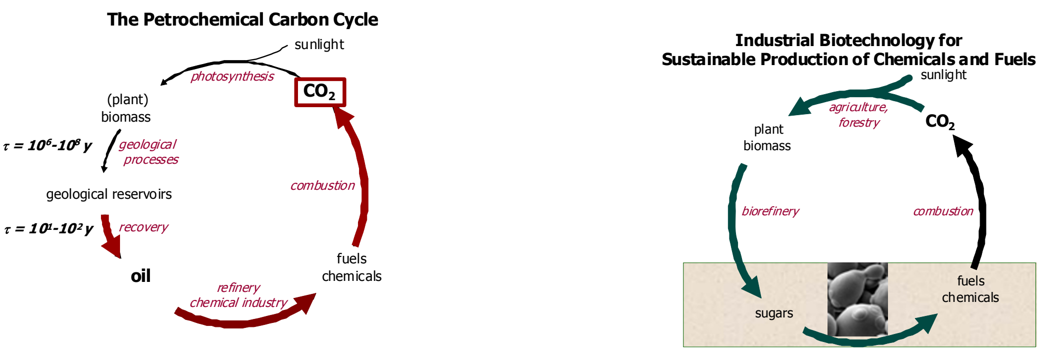

Figure 1. The petrochemical and industrial biotechnology cycles showing the CO_2 storage times. When plants are immediately used for fermentation, CO_2 is bound and released in the same time frame. When fossil oils are used, CO_2 is released which was bound many years ago.[8]

Biomass can be grown at many locations throughout the world, so that when biomass is used for energy or chemical production, it decreases political dependency on oil-producing countries. Furthermore, biomass provides a continuously renewable source, while fossil sources are rapidly depleting. Thus, apart from the potential offered by genomics to increase profit for industry, it also contributes to goals that are supported widely in society and in the political arena.

An example of these initiatives is the new genomics research programme launched by the Dutch government in 2002. A number of international Netherlands-based fermentation companies specifically requested certain university research groups in microbiology and bioprocess technology to jointly establish a centre of excellence in genomics research. The Kluyver Centre for Genomics of Industrial Fermentation started in 2002 as a collaboration between 11 companies and eight universities and research institutes, with a budget of more than €50 million over five years. Of that budget, €17 million was contributed by the government's Netherlands Genomics Initiative. A total of 25 per cent (€13 million) came from industry, while the remaining budget was provided by the participating universities and research institutes and by the projects they brought in. Together, the participating companies at that time represented a joint turnover of €10 billion per year, which made the Kluyver Centre an important economic feature for The Netherlands. The Centre's mission[9] as stated in its Business Plan was: "To provide scientific excellence in microbial genomics for quantum-leap innovations in industrial biotechnology aimed at improving sustainability and quality of life." Genomics would be used to improve microorganisms so that more products from renewable sources could be made economically viable. This would be the foundation for a bio-based economy. Here, we examine to what extent these promises have been realised and whether they have succeeded in addressing the societal dimension of the developments in question.

In the mid-term review carried out in 2006 it became clear that the Kluyver Centre had delivered on a number of its promises.[10] The government invited the Centre to present a new research plan which was prepared in close collaboration with the industrial partners. Boosted with a new grant of €21 million for the 2008-2012 period and an overall budget of €55 million, the Centre's focus has now extended to study specific industrial conditions and to develop genomics techniques for mixed cultures of microorganisms which are often used, for example in the dairy industry, rather than cultures of single organisms. Understanding the complex relations between these organisms will increase opportunities for tailoring and optimising their use for specific applications. The Centre increasingly collaborates with other international centres such as the Chinese Academy of Sciences and the number of international partners has grown steadily and now represents an annual turnover of around €120 billion. As of 2010 the Centre has produced 42 patents, for which 61 licences are provided, more than 500 publications, and employs more than 100 young researchers.[11]

In the autumn of 2009 the participating companies were asked to quantify the benefits of the partnership for a submission to the Netherlands Genomics Initiative Valorisation Award.[12] One small company calculated that its link to the Centre contributed to 60 per cent of its financial turn-over in one way or another. Those members with limited availability for staff networking activities also valued the

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international exposure highly. Larger companies cited early access to interesting leads providing the opportunity to be ahead of competitors, education and networking opportunities, access to expensive infrastructures and to a knowledge base for handling social issues.

In spite of the benefits that genomics can bring to industrial biotechnology, large-scale implementation of biorenewable production may also result in adverse societal responses. The public is concerned about the effects of industry on the environment and public health and, without proper communication strategies, such concern may hinder public and political support for the aforementioned innovation trajectories. Furthermore, the technology-internal language used in science and industry does not fit well with the vocabularies used in politics and public debate,[13] creating a fertile ground for further public concern. Early identification of 'hot' issues and early communication with the public on intended innovation paths may help adjust industrial agendas as well as pre-empting potential resistance.

First steps to integrate societal issues in industrial innovation agendas

The Kluyver Centre carried out a series of workshops in 2004, 2005 and 2006 to identify ethical, legal and societal issues in industrial biotechnology. Experts in industrial genomics, business innovation, environmental sciences, ethics, communication, governance, and policy studies came together for three three-day meetings to analyse likely future issues and to discuss challenges and best strategies for communication with stakeholders, politicians and the public at large.[14] After consulting a number of case studies and reports and considering media patterns and NGO priorities, they identified five issues which they considered likely to feature in any coming public debate (Table 1).

Issue	Considerations
Safety	Plants producing pharma ingredients: issue of co-existence
Land-use	Food-energy conflicts: food prices, rain forest degradation
Energetics	Eco-efficiency: uncertainty in scientific reports
Environmental pressure	Biodiversity, soil quality, water usage, mono-cultures
Economic feasibility	Oil price versus sugar price, uncertainty for investment

Table 1. Possible future issues on industrial biotechnology identified by experts in Kluyver Centre workshops 2004, 2005 and 2006.[15]

The political and public demand for sustainability was recognised as a most important driver of the development of industrial biotechnology. Yet this obscures a number of relevant considerations. For example, there exists no common understanding of the complex concept of "sustainability" and the challenges inherent in achieving a single definition are substantial. Beyond this, there are enduring concerns about the nature of public engagement regarding emerging technologies.

The substantial need for biomass which is used as feedstock to develop such sustainable products was seen as a major issue. Also, it was recognised that the debate tends to focus on biofuels, yet for most chemical products the use of bio-renewable

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sources is the only option to replace fossil-based sources and that would necessitate the use of only a limited area of agricultural land. For example, the annual global demand for plastic, which is currently around 100,000 tons, could be produced using 100 km^2 agricultural land while it is estimated that 5000 million km^2 is available for production worldwide. So the total world plastic demand could be produced on a tiny percentage (0,000002 %) of the total arable area.[16]

Indeed, the biomass needs for the production of bioenergy for both electricity and transport fuels would be much larger than for transport fuels alone. This is a result of the quantities used for transport and the growing global demand for energy.[17] The experts considered the use of other sources for renewable energy which are regarded as sustainable, such as wind and hydroelectric generation. Although these are often seen as a preferred option, long-distance road and air transport will probably depend on diesel and kerosene fuels respectively for a considerable period of time. The experts therefore concluded that the development of biofuels especially was expected to be of considerable political and public interest. At the time when these workshops were held, biofuels were only produced from food and feed sources such as corn (maize), sugar cane and soya. While there is great variability in the efficiency of converting these crops into fuels, these first-generation' biofuels can create competition with food and feed production. However, recent innovations appear to alleviate this problem.[18]

Public debates about novel technologies often aim at reaching some type of consensus to be able to come up with a generally agreed opinion for policy makers. When such debates depart from statements that are already accepted by the majority, they do not manage to go much beyond stating the obvious, or affirming long-established policy lines, based on already deeply entrenched interests and opinions. When dealing with much more complex issues, as described above, it would be preferable to have a deeper analysis and a clearer view on the issues that are at stake. Starting from *dissensus* may then be much more fruitful. To that end, it is important to invite as many different stakeholders as possible to the negotiation table, and also to explore different issues such as vested interests, and views on economic development and moral values. The problem with current debates over sustainability issues is that marginalised voices are often not taken into consideration. At the Kluyver Centre workshops it was recognised as a core issue to encourage a wide variety of stakeholders to collaborate and to manage the inevitable opposing opinions to reach some outcome that may yield positive effects.

This was taken on board in the fourth workshop, which focused on biofuel development and was held in October 2008. International stakeholders on scientific development, industry, trade and financing issues were invited together with ethicists, politicians, NGO representatives and specialised consultants. The objective was to analyse the contribution of novel genomic techniques to biofuel development and to make policy recommendations for the sustainable development of biofuels. With new genomic techniques it was by then possible to make microorganisms such as yeast that could convert agricultural waste products into ethanol as a biofuel. Oil-producing plants could be improved to produce biodiesel while a great deal of attention was

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focused on algae as efficient cell factories for biodiesel production, especially as they can grow in saline water, obviating direct competition for land used for food production. These so-called 'second generation' biofuels could help resolve the issue of using crops which would otherwise be used for food for energy production. The workshop was preceded by an analysis of issues in biofuel reports published by various stakeholders (eg the Food and Agricultural Organization, The World Bank, Worldwatch, the International Energy Agency, Greenpeace, Friends of the Earth),[19] which revealed uncertainty among scientific experts and other stakeholder clusters, as different reports presented different facts and figures, and highlighted different societal, legal and ethical issues.[20] The Centre also organised two public debates held in The Netherlands during September 2008 to identify issues of concern to the public.[21] The first debate, organised in Amsterdam, was aimed at defining sustainability criteria. This event was attended by a few invited stakeholders, but did not attract large audiences, which presumably indicates low public interest in this subject at the time. The second debate, organised in Rotterdam, looked at the practical implementation of such criteria and focused on its impact for local business and the Rotterdam Harbour. It drew an audience of about 60 people. Although the practical implementation of sustainability criteria is an important factor in the establishment of a bio-based economy, the definition of such criteria is crucial. It has become increasingly apparent that this issue deserves greater attention and greater public awareness, despite the widely recognised difficulty of achieving a common understanding of this concept. However, greater awareness could facilitate the development of a common understanding and definition through shared language and reference points.

Further presentations in the workshop focused on the importance of market development, financial investments and trade issues. The issues identified in the previous workshops were revisited and amended to include the latest developments (Table 2).

Issue	**Considerations**
Safety	*Plants producing pharma ingredients: issue of co-existence**
Land-use	Food-energy conflicts: food prices, rain forest degradation
Energetics	Eco-efficiency: uncertainty in scientific reports
Environmental pressure	Biodiversity, soil quality, water usage, mono-cultures
Economic feasibility	Oil price versus sugar price, uncertainty for investment
Issues added in 2008	**(focus on biofuel development)**
IP and multinationals	Open source versus patent protection
North-South distribution	Ownership of development, neo-colonialism
Cultural values of nature	Western values for sustainability pressed upon developing nations

Table 2. Possible future issues on industrial biotechnology identified by experts in Kluyver Centre workshops 2004, 2005 and 2006 amended with focus on biofuel development in 2008.
* Safety was not regarded as a relevant issue for biofuel development.

To prepare the workshop debate on policy recommendations and to increase depth of analysis, participants were interviewed before the event about their viewpoints on

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sustainability and economic development and about their own vested interests. This revealed that different participants have different opinions on sustainable choices for society, but a clear link between interest and opinion could not be established. During the workshop participants were asked to make 'value trees' at different points in time. Several participants changed their opinions on values for sustainable development and implementation as a result of new information received during the presentations and discussions.[22]

After three days, the meeting produced a generally agreed statement with recommendations[23] to policy makers which was presented and discussed with European Parliamentarians in a debate co-organised with the Science and Technology Options assessment of the European Parliament (STOA). It took place at the European Parliament[24] in November 2008. The meeting also published a formal report to provide input into the global initiative Lausanne Round Table on Sustainable Biofuels (RSB) which aims to produce a global vision on sustainable biofuel production.[25] The most important conclusions presented in the recommendation were:[26]

- Development of sustainable and secure alternatives for energy need governance
- More emphasis should be given in policy making to the need for a secure and reliable supply of sustainable energy
- The public debate should be improved to include issues of security supply and energy savings
- Future fuel, fibre, feed and food production will be intimately linked to agriculture and forestry which necessitates a comprehensive agro-industrial policy
- Development of alternative energy sources requires a level playing field for all agricultural and forestry products
- Policy measures should stimulate efficiency improvements in agriculture
- Priority should be given to the development of global standards for monitoring and certification systems
- Policy measures need to recognise investment options
- Biofuel development needs priority in the short-term while the development of alternative infrastructures with alternative energy sources is stimulated for the long-term
- Attention should be given to addressing the growing world population

Since this series of workshops, the issues of direct and indirect land use changes and of eco-efficiency and sustainability have received considerable public and media attention. Many newspaper articles and TV documentaries have argued that land used for biofuel or bioenergy production undermines food security. Others, including *An Inconvneient Truth,* a documentary about former US Vice-President Al Gore's climate change campaign,[27] claimed that biofuel production should be employed to make our world more sustainable. They spread conflicting messages while referring to individual reports produced by a variety of organisations including those from reputable organisations such as the United Nations, the World Health Organization, the Food and Agricultural Organization and the World Wildlife Fund.[28] Currently, there are many conflicting reports with lists and shortlists of sustainability criteria, produced by a multitude of NGOs, charities, companies and governmental bodies. There is, however, no clear view on how these different lists of criteria are or may be picked up either by policy makers or by industry. To gain more clarity, the Kluyver Centre's societal programme conducted the aforementioned meta-analysis of 32 reports on biofuel development published by NGOs, industry, governmental organisations, etc.[29] This analysis mapped how various issues, from fair trade to eco-efficiency and from economic development in developing countries to protection of local ecosystems, were brought to the foreground by different stakeholders, how these different reports relate to each other, and whether there is a similarity in approaches detectable per stakeholder category. The initial findings indicate uncertainty among scientific experts and other stakeholder clusters. From this analysis, it appears that there is still a great need for better communication between different stakeholder groups.

Pros and cons of a bio-based society

Current debates provide no clarity in the argument regarding transition to a bio-based society, and show considerable disagreement among experts about the merits of such a transition. For example, biofuels are blamed by some for the deforestation of rain forests in Brazil and Asia. This is rejected by others who claim that only 0.4 per cent of the agricultural land in Brazil is used for biofuel production while 25 per cent is used for pasture and the raising of beef cattle.[30] Strict government regulation in Malaysia restricts the land area covered by palm oil plantations to no more than 5 million hectares (50,000 km^2)[31]. In fact only 3 per cent of global palm oil production is used for biofuels. The majority is used by the cosmetics and food industries.

Issues of food security are even more complex.[32] The European Commission's Group on Ethics published its Opinion on sustainable agriculture in December 2008.[33] It reported that Europe has shifted its focus from food security to food safety. The Opinion declares that availability of, access to and quality of food is a human right. It also states that we should protect the disadvantaged and that we should govern and protect a sustainable supply of food, ensuring a food supply for future generations:

> Production, processing, storage and distribution of food and agricultural products are generally accepted as routine parts of everyday life all around the world. Therefore, these activities have rarely been addressed within the realm of ethics. But food and agriculture, and the economic benefits derived from taking part in the associated system, are means to an inherently ethical end: feeding the world's population and preserving the Earth's food-producing capacity and natural ecosystems for future generations. (page 48)

Biofuel development is seen as beneficial and potentially able to help to open markets that would create access to food for more people. The Group points out that factors other than biofuel development are much more important for food security such as warfare, political leadership, lack of markets, mis-managed food aid programmes, protection of European and US farmers, increase of meat intake, etc.

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In addition to the lack of clarity in the sustainability arguments, there is scientific uncertainty, especially related to the lack of validated measuring tools. Modelling, the art of predicting future land use, specifically poses issues of uncertainty.[34] Sustainability criteria have been developed in abundance.[35] More than 70 sets are suggested by different organisations such as the Lausanne Round Table on Sustainable Biofuels[36] and the Netherlands initiative under the name of "Cramer Committee"[37]. The problem is that some criteria relate to ideologies or values which are immeasurable, while others are difficult to measure, such as indirect land-use changes or soil fertility.[38] Table 3 provides a summary of drivers and ethical arguments and concerns.

Mapping, predicting or quantifying issues of sustainable development is problematic due to issues of scientific uncertainty and of scientific and social complexity. The uncertainties do not only concern the 'state of the art' of novel technologies and what uses are technically possible, but also include the socio-economic context, societal evaluation and environmental impact of different applications.[39] In principle, genomics should be an important contributor to sustainable development, but because of these issues one cannot expect industry to come up with a clear-cut solution to the problems of the production of sustainable energy sources and sustainable materials. Particularly in this important area of research and development, it is necessary to align the technologies involved to societal infrastructures during the process of innovation.

Drivers	**Applications**	**Ethical arguments**	**Social Concerns**	**Scientific uncertainty**	**Clarity in argument**
Mitigate climate change (sustainability)	Use bio-renewable materials in-stead of fossil oil	Distributive justice (food security)	Eco-efficiency of 1st generation biofuels	Yes, in reliability measuring tools	No, debate focuses on urgency climate change
Energy security	Use waste materials from agriculture, pulp and paper industry and households	Governance, ownership of land and IP	Land use	Yes in lack of measuring tools	No, debate focuses on policy models
Replace depleting fossils	Use dedicated energy crops	Interfere with nature	Power to multinational seed and herbicide industry	Limited, in ecological models and in figures for remaining fossils	No, ideologies are maintained on landscapes

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Developing agricultural markets	Use of overproduction of biomass for new bioenergy market	Economy models	Environmental pressure	Yes, lack of economic models for regional development	No, debate on single issues

Table 3. Drivers, application, ethical arguments and social concerns for the development of a bio-based economy considered for clarity in argumentation and scientific uncertainty. Sources: Media releases and stakeholder reports.

Conclusions

As society confronts the challenges of finding suitable alternative energy sources, it becomes clear that genomics will provide an important contribution to the development of economically viable and sustainable production of food, materials and energy. However, the development of a sustainable society can not occur based on scientific developments alone. Active engagement and involvement by the public and other stakeholders is essential. Yet, this engagement must occur in a way that optimises informed input. We also need to acknowledge the potential of dissensus as a starting point for in-depth analysis of the issues involved, rather than 'taming the tiger' by framing debates in such a way that consensus is both the point of departure and arrival. Such approaches only serve to illustrate the obvious. A transdisciplinary approach involving different stakeholders could help to clarify the different values of different groups and then to evaluate the options for resolution. These stakeholders should ideally agree on the institutions who will take the initiative in public dialogue, keeping in mind that trust and leadership are crucial elements in governance for communal objectives.

Currently, the debate suffers from scientific uncertainty, lack of clarity in arguments for policy direction, strongly opposed views and a lack of robust involvement of a larger public. Additionally, the food versus fuel controversy persists, as does a lack of agreement on key terms, such as 'sustainability'. A number of international initiatives have started to address these issues. The Global Biorenewable Research Society (GBR) was established in 2009 with the aim of providing trustworthy, peer-reviewed sources of information similar to the IPCC.[40] The Global Sustainable Bioenergy project (GSB) initiated by Professor Lee Lynd aims to answer the questions of whether we need to or can actually produce enough biomass to deliver a substantial contribution to our global energy needs.[41] These initiatives hope to provide clarity and reduce scientific uncertainty. The outcomes will need to inform the stakeholder

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discussions and public dialogue. This will not be simple, given the complexity of the issue of the development of a sustainable society strongly related to individual values.

What is clear is that we need to find ways to involve people in sustainability issues so they can make informed and considered choices. The forum for these discussions must be accessible and inclusive. The usefulness of advances in genomics and the substantial role that this technology could play in furthering societal environmental, economic, and political agendas are in large part dependent on societal understanding, acceptance and uptake of applications of this technology. It is therefore crucial that greater attention be given to the nature, process, and substance of the debate about a bio-based economy and our sustainable futures.

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