Chapter 9

Conclusions: On the Road to the Bioeconomy

Obtaining the full benefits of the bioeconomy will require purposive goal-oriented policy. This will require leadership, primarily by governments but also by leading firms, to establish goals for the application of biotechnology to primary production, industry and health; to put in place the structural conditions required to achieve success such as obtaining regional and international agreements; and to develop mechanisms to ensure that policy can flexibly adapt to new opportunities. There are nine main challenges, summarised in this chapter.

A bioeconomy uses advanced biotechnological knowledge and renewable biomass to produce a diverse range of products and processes. The modern bioeconomy has its origins in the first commercial uses of recombinant micro-organisms in the early 1980s. Since then, an increasing number of products and processes in primary production, health, and industry have been produced through an expanding range of biotechnologies.

By 2030, all applications of biotechnology could account for 2.7% of the GDP of the OECD countries and possibly a higher share of the GDP of developing countries. The impact of biotechnology could even be higher within the OECD, since this estimate does not include biofuels. Well before 2030, biotechnology will be used in the development of all new pharmaceuticals and most new varieties of large market crops such as wheat, rice, maize, soybeans, potatoes and cotton.

The bioeconomy will create winners and losers, often within the same sector. The production of feed for farmed fish by GM micro-organisms or algae could replace the use of wild fish as feed, resulting in a fall in fishery production. Other biotechnology applications could negatively affect petroleum-based industries, regenerative medicine and pharmacogenetics could reduce the market for pharmaceuticals, and pulp and paper production in boreal forests could be replaced by fast-growing, disease and drought resistant tree plantations in sub-tropical and tropical regions. The winners will include firms that can take advantage of new business opportunities, consumers from an improvement in food security and health outcomes, and the environment from more sustainable production methods.

The full benefits of the emerging bioeconomy will not, however, develop without purposeful goal-oriented policy. This will require leadership, primarily by governments but also by leading firms, to establish clear goals for the application of biotechnology to primary production, industry and health; to put in place the structural conditions required to achieve success such as obtaining regional and international agreements, and to develop mechanisms to ensure that policy can flexibly adapt to new opportunities.

The following section summarises nine main findings of this report and describes the types of policy actions (in italics) that are needed to support the emerging bioeconomy.

Main findings

1. Reverse the neglect of primary production and industrial applications

In the early 2000s, over 80% of research investments in biotechnology by the private sector, and a similarly high share of public investment, were for health applications. Conversely, approximately 75% of the future economic contribution of biotechnology is likely to be in primary production and industrial applications, where there are also large environmental and social benefits. This suggests that there is a strong mismatch between current investment patterns and future opportunities for maximising the social and economic benefits of biotechnology.

> *A promising strategy for the bioeconomy is to boost research investment in primary production and industrial biotechnologies with environmental and social benefits. Governments should consider giving priority to funding research to support long-term sustainability goals.*

Depending on the application, boosting research can be met by increasing public research investment, encouraging private-public partnerships, or creating and sustaining markets for environmentally sustainable biotechnology products (*e.g.* some biofuels and biopolymers).

The application of biotechnology to primary production is a major success, but the cost of regulation is serious barrier, particularly for small market crops and small firms. Regulations on the use of biotechnology in primary production, especially for GM crops, could have serious impacts on long-term competitiveness and innovation. An open debate on the issue and review of regulations in these terms could be important to maximising the benefits of technology.

Investment in many industrial biotechnologies requires market incentives for bioproducts. Over the short term, these incentives could increase costs for consumers. Higher prices would be difficult to justify without good evidence that such bioproducts meet environmental sustainability goals. Developing performance standards for environmental sustainability, based on robust methodologies for life cycle analysis that include global land use effects, could be essential. Performance standards should ensure that undesirable environmental impacts are not simply shifted from one region to another.

2. Prepare for a costly but beneficial revolution in healthcare

Developments in health biotechnology could substantially improve health, but obtaining the full benefits could require either disruptive or radical changes to existing healthcare systems, including how health products are regulated and health services delivered. Many health technologies that are emerging from the application of biotechnology are likely to increase healthcare and pension costs. These higher costs will be difficult to justify without significant improvements in the effectiveness of health therapies. A key requirement is to better align private incentives for developing health therapies with the public interest in accessible, effective and safe treatments.

Governments should evaluate the implications for innovation and public health of a progressive regulatory system for healthcare products that incorporates pharmacogenetics and medical databases for long term research on adverse effects and other health outcomes.

Regenerative medicine and personalised and preventive medicine could change how healthcare is delivered, alter the relationship between doctors and patients, increase life spans and the quality of life, and open up new business models for biotechnology based on closer links between the provision of healthcare services and the development of treatments. One concern is that new business models to take advantage of these developments might be simpler to implement in countries with private healthcare systems, but the majority of OECD member countries have publicly funded healthcare systems that are strongly supported by their citizens.

Governments need to analyse the long-term structural effects of regenerative and personalised medicine on healthcare, including data confidentiality, new models for healthcare delivery such as home healthcare, new relationships between patients and doctors, robotic administration of drugs, etc. New developments in medicine could also increase life spans, with implications for pensions, employment, and the quality of life for elderly citizens. Governments need to fund research into the social, ethical and physical consequences of longer life spans.

3. Manage the globalisation of the bioeconomy

The bioeconomy of 2030 will be a global endeavour. Growing populations and wealth will shift the main markets for primary production and for many industrial biotechnologies from developed to developing countries. Countries will need to collaborate to effectively use biotechnology to manage global resources such as ocean fisheries and forests, control the risks of infectious diseases in animals, plants and humans and achieve economically competitive and sustainable biotechnologies for low carbon energy and for environmentally sustainable primary production.

International agreements to promote collaborative research, regulatory systems, and market incentives for the use of biotechnology will likely be essential to addressing many global problems.

Drawing developing countries into global collaborative research networks for biotechnology will increase the benefits of the emerging bioeconomy by increasing the number of researchers working on scientific challenges and by applying biotechnology to the specific problems of the developing world. International collaboration is likely to focus on products with large social benefits, such as new antibiotics, other necessary drugs,[1] and improved crop varieties.

Regulatory requirements to establish the efficacy and/or safety of primary production, health and industrial biotechnology products vary by country. These variations increase costs to firms, particularly when research in one country is not accepted in another. Regulatory agencies in both developed and developing countries are collaborating in some areas, such as on the safety and efficacy requirements for health products. Conversely, there is a need for better international agreement on data sharing and the types of data that are acceptable for establishing the safety of primary production and industrial products produced through biotechnology. Regulations should not be unduly burdensome, but they must also protect the public interest in safety and/or efficacy. In addition, effective international regulation and enforcement is required to protect global resources, such as fishing stocks and forests, and to control infectious diseases.

International agreements to create and sustain markets for biotechnology products would increase investment in biotechnological research. In addition to support for free trade in biotechnological products, agreements could include performance standards to support environmental sustainability, possibly supported through carbon trading systems or environmental taxes.

Of note, international collaboration does not require the agreement of all countries.[2] In many cases, consensus among a few regions or several important actors could be sufficient to launch the bioeconomy's potential, such as for sustainable industrial production.

4. Turn the economically disruptive power of biotechnology to advantage

Biotechnological research is generating innovations that will disrupt current business models and economic structures. Nevertheless, there is a policy interest in supporting these technologies when they offer substantial social and economic benefits. For example, disruptive and radical innovations such as regenerative medicine and personalised, preventive medicine could help reverse the declining rate of health innovation, providing effective prevention and treatment for chronic illnesses such as cancer, diabetes, arthritis and coronary heart disease. Metabolic pathway engineering and synthetic biology could revolutionise industrial processing and provide environmentally sustainable and low-cost methods of producing a wide variety of chemicals and biofuels.

Although a difficult challenge, policy makers will need to implement flexible policies that can adapt to and support socially and economically beneficial disruptive and radical biotechnologies.

This will require foresight research to identify disruptive biotechnologies, incentives (market and other) for investment in necessary infrastructure, education and training needs to create a pool of skilled workers that can use disruptive technologies, long-term support requirements for research, and regulations and standards that support emerging business models.

5. Prepare for multiple futures

Some of the commercial possibilities of biotechnology are impossible to predict – there are multiple futures that will vary depending on regional resource endowments or investment in existing technological systems. For example, industrial biotechnology could draw energy and carbon from biomass or from sunlight and the atmosphere, two methods that may or may not be mutually exclusive. Past investment in healthcare services could make it difficult to introduce new business models or methods of providing healthcare.

Identifying and preparing for multiple futures in order to prevent "lock-in" to inferior technological solutions may provide countries with a competitive advantage.

Some of the policy options are similar to those for disruptive and radical biotechnologies: invest in foresight research to identify future opportunities and bottlenecks, support investment in multi-purpose infrastructure rather than in single use infrastructure, provide training to smooth transitions, and fund basic and applied research into alternative technologies to keep options open.

6. Maximise the benefits of integration

Greater integration between the different research disciplines and commercial applications of biotechnology will create knowledge spillovers that can maximise the social and economic benefits of the bioeconomy. The greatest potential for integration is between primary production and industrial applications, where close integration could pave the way for environmentally sustainable production of many products. Integration can be supported by policy, but this requires coordinated government actions that draw on the expertise of government ministries responsible for industry, agriculture, natural resources, and research. There is little current evidence of a lasting coordination structure for the bioeconomy in governments.

Co-ordinating policies across government ministries has always been a challenge, but the economic benefits from promoting the integration of biotechnology research and applications might be well worth the effort.

7. Reduce barriers to biotechnology innovation

High costs for acquiring or sharing knowledge or corporate concentration that blocks new entrants can hinder innovation. In the former case, knowledge markets or greater collaboration can reduce transaction costs for accessing knowledge and free up knowledge that is hidden within firms and organisations. Corporate concentration, by creating economies of scale and scope, can support innovation, but it can also block the entry of new firms, in part by limiting access to enabling biotechnologies.

Governments should identify factors that might prevent the development of highly competitive and innovative markets for biotechnology and examine possible policy actions that could free up markets and access to knowledge. The latter could include support for knowledge markets and collaborative mechanisms for sharing knowledge, plus encouraging public research institutions to adopt intellectual property guidelines that support rapid innovation.

8. Create a dynamic dialogue between governments, citizens and firms

Economic sustainability will require bold policy actions. Examples include carbon taxes to mitigate climate change or a reduction in water allowances for farmers in increasingly drought sensitive areas. Biotechnology can help ease the transition to such policies by offering technological solutions, such as biofuels that meet environmental performance standards or GM crop varieties that are drought tolerant. Furthermore, some of the health benefits of personalised and preventive medicine will require citizens to take responsibility for nutrition and other lifestyle changes, while other developments could increase healthcare costs. None of these potential applications of biotechnology will be possible without public support.

Governments need to address the misconceptions that surround biotechnology and describe the different alternatives for managing sustainability and costs. Governments also need to conduct a dialogue with firms on the types of regulations, standards and other policies that provide a commercially and politically viable framework for new business models for biotechnological innovations.

Governments should create an active and sustained dialogue with society and industry on the socio-economic and ethical implications, benefits, and requirements of biotechnologies.

9. Prepare the foundation for the long-term development of the bioeconomy

The long-term development of the bioeconomy will require foresight research and policies that can last for several decades, such as to create and maintain markets for environmentally sustainable products. Other policies need to be implemented over the next five years in order to establish a foundation for future biotechnology applications. Some of these short-term policy challenges are summarised below.

In **primary production**, the application of biotechnologies to developing improved plant and animal varieties is constrained by public opposition in some regions, a lack of low cost access to enabling technologies, and the concentration of expertise in a few major firms. These barriers to the full application of biotechnology need to be overcome, particularly in developing countries which are the largest future market for primary production biotechnologies. Over the long term, the main challenge will be to maintain international agreements that support sustainability and manage food and feedstocks.

In **health applications**, the technologies to create and analyse integrated "cradle to grave" health records are already available and promise significant improvements in healthcare treatments. However, it may be difficult to fully implement these technologies without modifications to regulatory structures that could include requiring post-marketing trials and public funding for long-term follow-up studies. Once a supporting regulatory, research funding, and health record system are in place, the cost of developing personalised and preventive medicine may fall to a level conducive to rapid improvements in healthcare.

In **industrial applications**, the main short term tasks are to increase support for research into high-energy density biofuels and to ensure that biotechnology supports environmental sustainability. The latter requires international agreement on life cycle analysis methodologies so that the environmental effects of competing technologies can be accurately compared. The results of life cycle analysis must also be linked to instruments such as mandates or environmental taxes to ensure that economic incentives preferentially reward the most environmentally sustainable technologies. In the long term, the main challenge is to implement and maintain international agreements to sustain markets for environmentally sustainable products and processes.

Concluding comments

The full potential of the bioeconomy in 2030 will not develop automatically. Success will require intelligent and flexible government policy and leadership to support research, markets, and create incentives for private firms to invest in biotechnology.

The financial crisis that began to impact the global economy in late 2008 creates an opportunity for governments to invest domestically, and in a targeted fashion, internationally in areas which will provide short and long term stimuli to the economy. If suitable policies are implemented, the bioeconomy could meet many of the requirements for such ambitious investment: it offers improvements to economic productivity which are also linked to environmental sustainability. Possible areas for immediate investment include the funding of comparative clinical trials of pharmaceuticals, research into new antibiotics, biosensors, and real-time diagnostics for animal and plant diseases; support for universities and agricultural colleges to create freely accessible marker libraries for small market crops such as barley, oats, orchard fruits, and vegetables; and increased support for research and prototype plants to produce high-energy density biofuels from cellulosic crops or algae.

International collaboration will also be essential, both because the major markets for many industrial and primary production biotechnologies will be in developing countries and because collaboration will be necessary to solve global problems such as resource constraints and climate change. With appropriate policy and good leadership, the bioeconomy of 2030 should provide a higher quality of life and a more prosperous and environmentally sustainable future for all of the world's citizens.

Notes

1. For example see the OECD's Noordwijk Medicines Agenda at *www.oecd.org/sti/biotechnology/nma*.
2. The OECD's Innovation Strategy Project is examining how to use innovation policy to address global issues. First results are due in mid-2009 and final results will be published in 2010.

Abbreviations and Acronyms

ADR	adverse drug reaction
AG	agronomic trait
AIDS	acquired immunodeficiency syndrome
ALL	acute lymphoblastic leukaemia
APHIS	Animal and Plant Health Inspection Service
BP	British Petroleum
BRIC	Brazil, Russia, India and China
BSE	bovine spongiform encephalopathy
CDER	Center for Drug Evaluation and Research
CGAP	Cancer Genome Anatomy Project
CGIAR	Consultative Group on International Agricultural Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DBF	dedicated biotechnology firm
DDT	dichlorodiphenyltrichloroethane
DHA	Department of Health and Aging (Australia)
DHHS	Department of Health and Human Services (United States)
DNA	deoxyribonucleic acid
DNDi	Drugs for Neglected Diseases Initiative
DOE	Department of Energy (United States)
EEC	European Economic Community
ELISA	enzyme-linked immunosorbent assay
EMEA	European Medicines Agency
EU KLEMS	European Union Capital (K) Labour (L) Energy (E) Materials (M) Service Inputs (S) Database
FAO	Food and Agriculture Organization of the United Nations
FDA	Food and Drug Administration (United States)
FFN	functional foods and nutraceuticals
GAO	Government Accountability Office (United States)
GBOARD	government budget outlays and appropriations for research and development

GDP	gross domestic product
GHG	greenhouse gas
GM	genetically modified *or* genetic modification
GVA	gross value added
HAS	*Haute Autorité de Santé*
HIV	human immunodeficiency virus
HR	human resources
HT	herbicide tolerance
HT-IR	combined herbicide tolerance and insect resistance
IAVI	International AIDS Vaccine Initiative
IB	industrial biotechnology
ICH	International Conference on Harmonisation
ICT	information and communication technology
IEA	International Energy Agency
IMSR	improvement of medical service rendered
IPCC	Intergovernmental Panel on Climate Change
IPO	initial public offering
ISAAA	International Service for the Acquisition of Agri-biotech Applications
ISO	International Organization for Standardization
IT	information technology
IVD	*in vitro* diagnostic
IVF	*in vitro* fertilisation
LCA	life cycle analysis
M&A	mergers and acquisitions
mAb	monoclonal antibody
MAS	market-assisted selection
MEOR	microbial enhanced oil recovery
MSR	medical service rendered
Mtoe	million tons of oil equivalent
NAFTA	North American Free Trade Agreement
NCE	new chemical entity
NGO	non-governmental organisation
NICE	National Institute for Clinical Excellence
NIH	National Institutes of Health (United States)
NMA	*Noordwijk* Medicines Agenda
NME	new molecular entity
OECD	Organisation for Economic Co-operation and Development
OIE	World Organisation for Animal Health
PCR	polymerase chain reaction
PCT	Patent Cooperation Treaty
PDO	polydioxanone

PGD	preimplementation genetic diagnosis
PHA	polyhydroxyalkanoates
PHB	polyhydroxybutyrate
PPP	purchasing power parity
PQ	product quality
PVC	polyvinyl chloride
QALY	quality adjusted life years
R&D	research and development
RFA	Renewable Fuels Association
RNA	ribonucleic acid
RNAi	RNA interference
SARS	severe acute respiratory syndrome
SM	small molecule
SME	small- and medium-sized enterprise
SNP	single nucleotide polymorphisms
Synbio	synthetic biology
TB	tuberculosis
TRIPS	Trade-Related Aspects of Intellectual Property Rights (WTO)
UN	United Nations
UNU-MERIT	United Nations University Maastricht Economic and Social Research and Training Centre on Innovation and Technology
USDA	United States Department of Agriculture
USITC	United States International Trade Commission
USPTO	United States Patent and Trademark Office
VC	venture capital
WHO	World Health Organization
WTO	World Trade Organization

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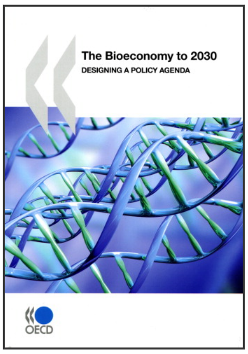

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