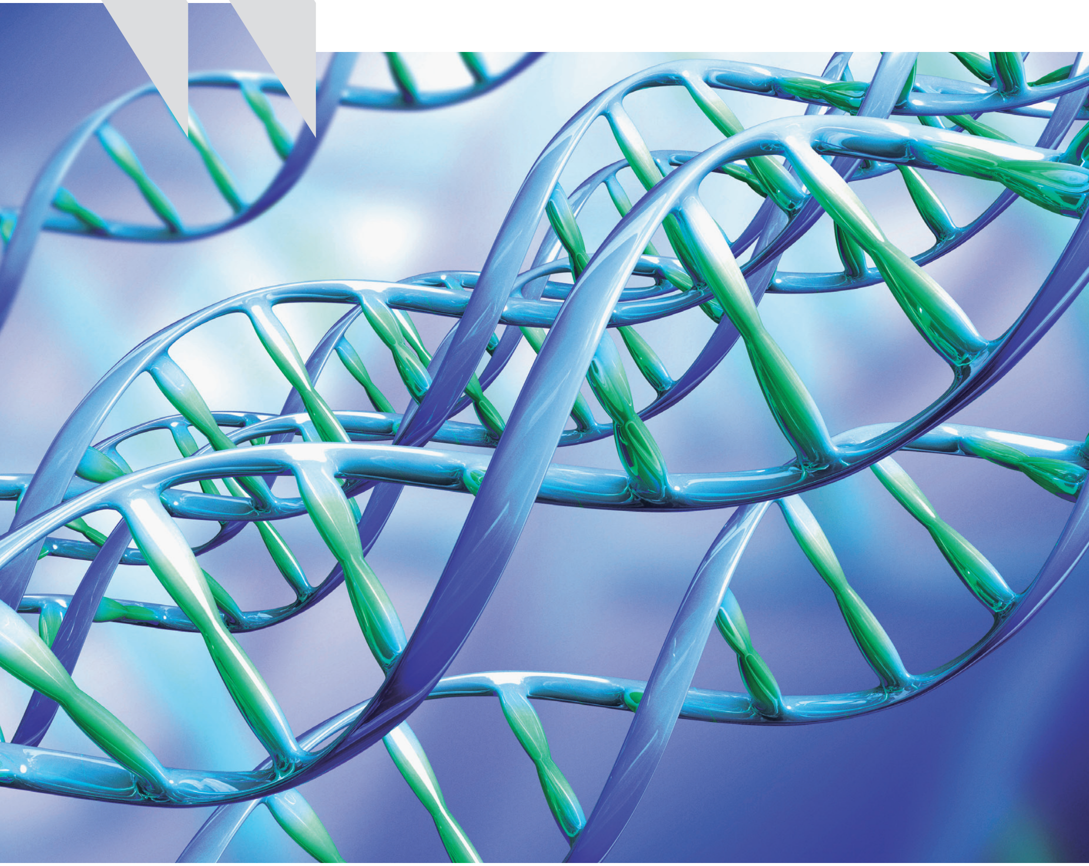
The Bioeconomy to 2030

DESIGNING A POLICY AGENDA

Main Findings and Policy Conclusions



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Main findings and policy conclusions

OECD International Futures Project

Foreword

Over the past two decades, biotechnology has provided a motor for environmentally sustainable production and for the development of a diverse range of innovative products. The continued commercial application of biotechnology could lead to the development of a bioeconomy, where a substantial share of economic output is partly dependent on the development and use of biological materials. The potential economic and environmental benefits of biotechnology have created a growing strategic interest in the bioeconomy in both OECD and non-OECD countries. But for the bioeconomy to succeed, considerable uncertainties and global challenges will need to be addressed. Innovative policy frameworks, strategic thinking by both governments and firms, and citizen support will be required to meet these challenges.

The report, *The Bioeconomy to 2030: Designing a Policy Agenda*[1], is the outcome of an interdisciplinary foresight project by the OECD on the bioeconomy. It provides a broad-based analysis of future developments in the three sectors where biotechnology has the greatest potential impact: agriculture, health and industry. It also explores the implications of developments in these sectors for the economy and society over the next two decades and develops a policy agenda.

The bioeconomy project was carried out by an OECD Secretariat team in the International Futures Programme (IFP). The IFP, which reports directly to the OECD Secretary-General, was created in 1990 to examine long term futures. Past work has covered, among other themes, long-term prospects for the world economy, the future of international air transport, emerging risk in the 21st century, and infrastructure investment needs in the 21st century.

The eighteen month project on the bioeconomy was completed at the end of 2008. The project was funded by voluntary contributions from governments, government agencies, academia, and corporations who were represented on the Steering Group (see Annex). The participants of the Steering Group were drawn from 18 OECD countries.

This short summary presents the main findings of the project. As with the final report, this summary is published under the responsibility of the Secretary General and does not reflect an official consensus of OECD Member governments. It is conceived as a forward looking, evidence-based think piece to stimulate reflection about a policy agenda to ensure that the biosciences are able to make a significant contribution to tomorrow's world through productivity gains, welfare gains and environmental sustainability.

Michael Oborne
Director, OECD International Futures Programme
Paris, May 2009

For further information: Please see our website www.oecd.org/futures/bioeconomy/2030 or contact David Sawaya (david.sawaya@oecd.org) or Pierre-Alain Schieb (pierre-alain.schieb@oecd.org) at the OECD International Futures Programme.

Summary of the Report's Principle Policy Conclusions

The study considers the role biotechnology could play in addressing what are considered the most serious challenges to world economies and societies over the next decades. These challenges include providing food, water, energy, healthcare and other resources and services to a world that will see its population increase by a third in the face of mounting environmental stresses over the next 20 years. The bioeconomy can have a major impact in many of these areas to ensure long term economic and environmental sustainability. Below are the study's principle policy conclusions.

1. Prepare the foundation for the long-term development of the bioeconomy
Getting the most out of the bioeconomy will require identifying and preparing for a range of possible futures to prevent locking-in inferior technological solutions. To achieve this, broad approaches, such as creating and maintaining markets for environmentally sustainable products, funding basic and applied research, and investing in multi-purpose infrastructure and education, will need to be combined with shorter term policies, over the next five years, to establish a foundation for future applications. These foundational policies include:

1. In *agriculture*, encourage the application of biotechnology to improve plant and animal varieties through improving access to technologies for use in a wider range of plants, expanding the number of firms and research institutes that can use biotechnology (particularly in developing countries), and fostering public dialogue.
2. In *health*, develop regulatory, research, and health record systems which can link prescribing histories, genetic and other information, to support long-term follow-up research into health outcomes.
3. In *industry*, increase support for the adoption and use of internationally accepted standards for life cycle analysis, along with other incentives to reward environmentally sustainable technologies (*e.g.* boosting research into high energy density biofuels).

2. Reverse the neglect of agriculture and industrial biotechnologies
The bioeconomy will be global, with heavy involvement from both OECD and non-OECD countries, especially in agricultural and industrial applications. Approximately 75 percent of the future economic contribution of biotechnology and large environmental benefits are likely to come from these two areas. Yet, over 80 percent of research investments in biotechnology by the private and public sectors go to health applications.

1. Boost research in agricultural and industrial biotechnologies by increasing public research investment, reducing regulatory burdens and encouraging private-public partnerships.
2. Encourage the use of biotechnology to address global environmental issues (*e.g.* climate change and fishery depletion) by supporting international agreements to create and sustain markets for environmentally sustainable biotechnology products.

3. Prepare for a costly but beneficial revolution in healthcare
As countries grapple with soaring health expenditures, the high cost of many health biotechnologies will be difficult to justify without commensurate health improvements in health outcomes. Furthermore, some emerging technologies, such as regenerative medicine and personalised and preventive medicine, could require far-reaching changes in healthcare delivery.

1. Ensure that private incentives for developing health therapies are better aligned with the public interest in accessible, effective and safe treatments.
2. Continue actively developing regulatory systems for healthcare products that incorporate pharmacogenetics.
3. Support long term research, using population-based medical databases, into health outcomes.
4. Analyse the long-term impacts of regenerative and personalised medicine on healthcare, including data confidentiality, new models for healthcare delivery, and new relationships between doctors and patients.
5. Examine the social, ethical and physical consequences of longer life spans.

4. Turn the potentially disruptive power of biotechnology to economic advantage
Several biotechnologies that promise productivity improvements, better health, or environmental sustainability could disrupt current business models and economic structures. Many of these technologies will not reach their potential unless they can overcome economic and social barriers to their development.

1. Implement flexible policies that can adapt to and support socially and economically beneficial disruptive biotechnologies.
2. Fund foresight research to identify beneficial disruptive biotechnologies and the types of incentives, infrastructure, regulation, education, and business models that would support their development.

5. Reduce barriers to biotechnology innovation
High research costs, regulatory barriers, and market concentration can prevent new entrants, hindering biotechnological innovation, especially for small market applications.

1. Identify factors that can prevent the development of competitive and innovative markets for specific biotechnology applications.
2. Evaluate possible policy actions that could free up markets and access to knowledge, including encouraging public research institutions to adopt intellectual property guidelines that support rapid innovation and collaborative mechanisms for sharing knowledge.

6. Promote the integration of biotechnology research across commercial applications
Knowledge spillovers across research disciplines and commercial applications can maximize the economic and social of the bioeconomy. Support for integration requires coordinated actions that draw on the expertise of numerous government ministries, including those responsible for agriculture, education, environment, health, industry, natural resources, and research.

1. Although coordinating policies across government ministries has always been a challenge, the benefits from promoting the integration of biotechnology and research should be worth the effort.

7. Create an ongoing dialogue among governments, citizens and firms
Many of the policies to support the bioeconomy will require the active participation of citizens and firms. Governments need to address some of the misconceptions around biotechnology and describe the different alternatives for managing sustainability.

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

The Bioeconomy to 2030: Designing a Policy Agenda

Overview of the Main Findings and Policy Conclusions

OECD and non-OECD countries face a range of environmental, social, and economic challenges over the next two decades. By 2030, the global population is expected to increase by 28%, from 6.5 billion in 2005 to 8.3 billion, and average global per capita income by 57%, from USD 5 900 in 2005 to USD 8 600. A larger and a more affluent population will increase world demand for health services that improve the quality and length of life and demand for essential natural resources: food, animal feed, fibre for clothing and housing, clean water, and energy. At the same time, many of the world's ecosystems that support human societies are already overexploited and unsustainable. Climate change could exacerbate these environmental problems by adversely affecting water supplies and agricultural productivity.

Biotechnology offers technological solutions for many of the health and resource-based challenges facing the world. It can increase the supply and environmental sustainability of food, feed and fibre production, improve water quality, provide renewable energy, improve the health of animals and people, and help maintain biodiversity by detecting invasive species. Yet biotechnology is unlikely to fulfil its potential without appropriate regional, national and, in some cases, global policies to support its development and application.

The bioeconomy offers technological solutions for many challenges facing the world…but achieving its potential will require appropriate national, regional, and in some cases, global policies.

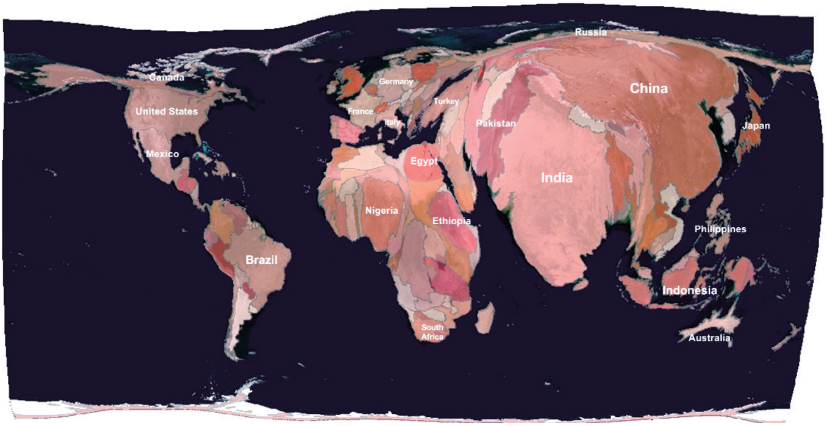
A bioeconomy can be thought of as a world where biotechnology contributes to a significant share of economic output. The emerging bioeconomy is likely to involve three elements: the use of advanced knowledge of genes and complex cell processes to develop new processes and products, the use of renewable biomass and efficient bioprocesses to support sustainable production, and the integration of biotechnology knowledge and applications across sectors.

There are three main sectors where biotechnology can be applied: agriculture, health, and industry. While primary production includes all living natural resources, such as forests, plant crops, livestock animals, insects, fish and other marine resources, the main current uses of biotechnology are for plant and animal breeding and diagnostics. Human health applications include therapeutics, diagnostics, pharmacogenetics to improve prescribing practices, functional foods and nutraceuticals, and some medical devices. Industrial applications include the use of biotechnological processes to produce chemicals, plastics, and enzymes, environmental applications such as bioremediation to clean up polluted soils, biosensors, methods to reduce the environmental effects or costs of resource extraction, and the production of biofuels. Several applications, such as biopharmaceuticals, *in vitro* diagnostics, some types of genetically modified crops, and enzymes are comparatively "mature" technologies. Many other applications have limited commercial viability without supportive policies (*e.g.* biofuels and bioplastics) or are still in the experimental stage, such as regenerative medicine and health therapies based on RNA interference.

This will not come easily…other forces are driving the bioeconomy globally…

The future bioeconomy will be global. Rapid income and population growth will ensure that the main markets for biotechnology in agriculture and industry will be in developing countries (see Figure 1). Rising levels of educational achievement across the developing world, particularly at the tertiary level, will create centres of biotechnology research that can address some of the problems that are likely to develop in these countries, including a growing need for low carbon energy, clean water, and high-yield agricultural crops that can tolerate drought, heat and other stresses.

Figure 1. **World land mass by expected population in 2030**



Source: Figure produced by Salim Sawaya, data from the UN's 2006 medium variant estimate of population growth.

Some interesting developments are already evident over the short and medium term…

What will the future bioeconomy look like? Two characteristics of biotechnology that are not shared by many other technologies improve our ability to predict the future applications of biotechnology. The first consists of regulatory requirements for some agricultural and health biotechnologies. These leave a data trail that can be used to predict what will possibly reach the market over the next five to seven years. The second characteristic is that biotechnology is frequently used as a process technology to make existing products such as fuels, plastics, and crop varieties. It can also be used to produce entirely new products such as medicines to treat cancer. For all of these examples, the problems that need to be solved are known in advance. These include the problem diseases, the types of crop traits that would improve agricultural output, and the types of industrial products that can be produced using biomass. In addition, the size of the potential market for products such as biofuels or anti-cancer drugs can be estimated with a reasonable degree of accuracy. Nevertheless, there are many unknowns, including the rate of technological advance and the ability of biotechnologies to compete with alternative technologies.

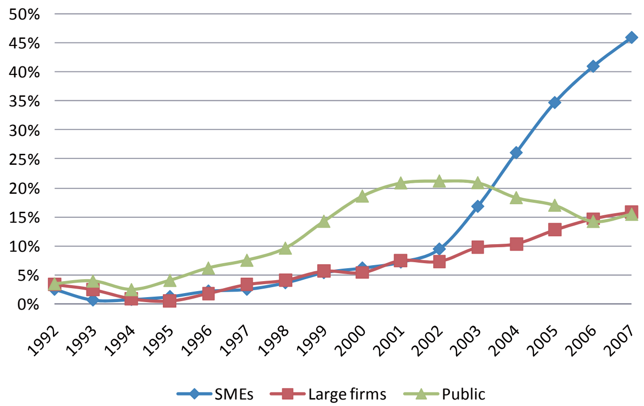
The Bioeconomy of 2015

For instance, the pervasiveness of biotechnologies is set to increase by 2015… virtually all new drugs, about half of major crops around the world, and an increasing number of everyday products will be produced using biotechnology.

The use of biotechnology in agriculture is an evolving success story. By 2015, approximately half of global production of the major food, feed and industrial feedstock crops could come from plant varieties developed using one or more types of biotechnology. These biotechnologies include not only genetic modification (GM) but also intragenics, gene shuffling and marker assisted selection. Research into agronomic traits to improve yields and resistance to stresses such as drought, salinity and high temperatures has increased rapidly since the early 1990s, as shown by the increase in the number of GM field trials of agronomic traits by small and large firms and by public research institutions (see Figure 2). A detailed analysis of this field trial data indicates that research will lead to improved crop varieties with agronomic traits reaching the market between 2010 and 2015, particularly for major food and feed crops such as maize and soybeans. Some of the agronomic traits will also be available for alfalfa, cotton, potato, rice, tomato and wheat varieties. Biotechnologies, other than GM, will be widely used to improve the quality and health of livestock for dairy and meat.

In health, biotechnological knowledge will play a role in the development of all therapies by 2015, including both small molecule pharmaceuticals and large molecule biopharmaceuticals. Pharmacogenetics will develop rapidly, influencing the design of clinical trials and prescribing practices. In industry, the value of biochemicals (other than pharmaceuticals) could increase from 1.8% of all chemical production in 2005 to between 12% and 20% by 2015. Biofuel production could partly shift from starch-based bioethanol to higher energy density fuels manufactured from sugar cane or to bioethanol from lignocellulosic feedstock such as grasses and wood.

Figure 2. **Agronomic field trials as a percent of all field trials by type of performer (three-year moving average)**



Note: The figure shows the percentage of all trials by each type of organisation that were for agronomic traits. For example, 46% of all trials conducted by small and medium sized firms (SMEs) in 2007 while 15% of all trials conducted by large firms in 2007 were for agronomic traits.
Source: Authors, based on UNU-MERIT (2008), *GM Field Trial Database*, Maastricht.

Challenges and Opportunities to 2030

In the longer term, the emerging bioeconomy will be significantly influenced by technological developments, regulatory conditions, intellectual property, human resources, social acceptance, market structure, and business models…addressing these needs to start today.

The development of the bioeconomy requires successful innovation. Biotechnology R&D must be performed, paid for, and result in commercially viable products and products. This process is influenced by many factors, including regulatory conditions, intellectual property, human resources, social acceptance, market structure, and business models.

Regulations to ensure the safety and efficacy of biotechnology products influence research costs and the types of research that are commercially viable. As shown in Table 1, pure regulatory costs are highest for genetically modified plant varieties (ranging from USD 0.4 million to USD 13.5 million per variety) and for the open release of genetically modified micro-organisms (approximately USD 3 million per release), such as for bioremediation to clean up polluted soils. In health, the future of regulation is not clear, with economic pressures and technical opportunities pushing the system in different directions. Increasing development costs could result in regulatory changes that increase the market for individual pharmaceuticals by extending the effective life of patents. Alternatively, technological developments could add to regulatory requirements and reduce the size of these markets.

Table 1. **Indicative regulatory costs to commercialise a biotechnology product** (USD thousands)

Agriculture	
Plant	
GM crop[2]	435–13 460
MAS crop[3]	5–11
Animal	
Vaccine[4]	242-469
Therapeutic[5]	176–329
Diagnostic[4]	9-189
Health	
Therapeutics[6]	1 300
In vitro diagnostics[7]	150–600
Industry	
GM open release[8]	1 200–3 000
GM in closed loop	Unknown

Sources: See page 16 for sources and explanatory notes.

Intellectual property rights could be increasingly used by both firms and universities to encourage knowledge sharing through collaborative mechanisms such as patent pools or research consortia. Social attitudes to biotechnology will continue to influence market opportunities, but public opinion can change, for instance when biotechnology products provide significant benefits for consumers or the environment.

Social, economic and technological factors will create new business opportunities for biotechnology, requiring new types of business models. The main business models to date have been the small, dedicated biotechnology firm (DBF) that specialises in research and sells knowledge to large firms, and the large integrated firm that performs R&D and manufactures and distributes products. This structure characterises the health sector, where there are six times as many DBFs than in agriculture and ten times as many as in industry. In agriculture, gene modification technology has created economies of scope and scale that have driven rapid corporate concentration. Only a few DBFs have been active in industrial biotechnology, as profitability depends on the ability to scale up production. This requires specialised engineering knowledge and large capital investment. Both DBFs and large integrated firms will continue to play a role in 2030.

Two business models could become increasingly important in the future: collaborative models for sharing knowledge between entities and reducing research costs, and integrator models that coordinate various disperate actors to create and maintain markets. Collaborative models are relevant to all application areas. Their adoption, combined with new business opportunities for non-food biomass crops, could revitalise DBFs in agriculture and in industry. Integrator models could develop in health biotechnology to manage the complexity of predictive and preventive medicine, based on biomarkers, pharmacogenetics, shrinking markets for individual drugs, and the analysis of complex health databases.

The application of biotechnology to improve and manage food, feed and fibre crops is likely to increase substantially to 2030, driven by rising demand and increased agronomic stresses from climate change. In addition, the expectation of a long-term increase in the cost of fossil fuels from a decline in the supply of low-cost sources of petroleum; an increase in demand for energy; and restrictions on the production of greenhouse gases (GHGs) could create a growing market for biomass, including non-food crops such as grasses and trees, as a feedstock for biofuels, chemicals and plastics. Other potential biotechnology markets include the use of plants to produce valuable chemicals such as biopharmaceuticals and the production of nutraceuticals from plant and animal sources. All of these trends are likely to increase investment in agricultural technologies.

Some of the main challenges for agriculture are social and institutional factors, including public opposition to biotechnology, a lack of supportive regulation, and barriers to the use of biotechnology in developing countries. First, public opposition to GM food crops or GM or cloned animals is unlikely to halt the use of biotechnology, but it may drive firms to alter the *type* of biotechnology that they use. Second, the potential market for biomass is likely to be strongly dependent over the future on regulatory policies to shift economies towards zero- or low-carbon energy sources. Third, much of the future growth of agriculture will be in developing countries. These countries will need to increase their capacity to use biotechnology in order to develop improved food, feed and fibre crops that are adapted to local growing conditions.

Technological developments are creating both new opportunities and major challenges for existing business models in health. Regenerative medicine, pharmacogenetics, and predictive and preventive medicine will shrink markets for individual drugs, but pharmacogenetics could also reduce the share of new molecules that fail in clinical trials, reducing drug development costs. On the other hand, predictive and preventive medicine could be hugely expensive to develop, due to the cost of long-term trials to validate thousands of potential biomarkers.

Many social and institutional challenges will also arise in health applications. The ability to create and analyse large databases of genetic, phenotypic, prescribing, and health outcome information will be essential to predictive and preventive medicine. The construction of these databases will require solutions to confidentiality issues and the question of whether patients will be required to release information on risk factors to insurers. The increasing ability to discover adverse drug reactions or outcomes from analysing large longitudinal databases will increase risks for pharmaceutical firms and make it difficult to predict future sales. At the same time, these approaches could identify unknown health benefits, creating new markets.

In industry, the concept of a biorefinery that can use different types of biomass inputs to flexibly produce different products has elements of a new business model. The main challenges in the near term for biorefineries are logistical. Biorefineries need to be located close to sources of biomass because of high transport costs. In the longer term, the biorefinery business model will be challenged by technological developments in metabolic pathway engineering and synthetic biology. These two technologies have the potential to develop micro-organisms capable of producing a number of products, including carbon-based fuels and chemicals, with very little biomass feedstock. These production systems would draw energy from the sun and carbon from the atmosphere. If successful, the economic future of biorefineries could be limited to the production of high-weight and low-value products, such as biofuels, in regions with ample supplies of low-cost biomass.

Scenarios of the bioeconomy in 2030

The report develops three scenarios to examine the bioeconomy in 2030. The first scenario estimates the economic impact of the "probable" bioeconomy in 2030, assuming steady technological progress and a "business as usual" policy environment. The second two scenarios are fictional and examine how different drivers and events might shape the future bioeconomy, both within the OECD countries and worldwide.

Success could produce great gains…biotechnology could contribute up to 2.7% of 2030 GDP in OECD countries … and even more in non-OECD countries.

The probable bioeconomy: Several biotechnologies with a high probability of reaching the market by 2030 are summarised in Table 2. The use of these biotechnologies in 2030 is estimated to contribute to 35% of the output of chemicals and other industrial products that can be manufactured using biotechnology, to 80% of pharmaceuticals and diagnostic production, and to approximately 50% of agricultural output. Given these figures, a "business as usual" estimate is that biotechnology could contribute up to approximately 2.7% of GDP in the OECD by 2030. Biotechnology could account for an even higher share of GDP in non-OECD countries, due to the greater importance to GDP of primary and industrial production compared to OECD countries.

These figures underestimate the potential for biotechnology in 2030, as they exclude biofuels, new applications that are not currently imaginable, and impacts that are difficult to measure in monetary terms. Such impacts include the effect of health biotechnology on the length and quality of life and the environmental benefits of agricultural and industrial biotechnologies. Furthermore, they do not take into account increases in the output of each application, such as an increase in agricultural output in response to increasing demand for biomass as an industrial feedstock.

Table 2. **Biotechnologies with a high probability of reaching the market by 2030**

Agriculture	Health	Industry
Widespread use of marker assisted selection (MAS) in plant, livestock, fish and shellfish breeding.	Many new pharmaceuticals and vaccines, based in part on biotechnological knowledge, receiving marketing approval each year.	Improved enzymes for a growing range of applications in the chemical sector.
Genetically modified (GM) varieties of major crops and trees with improved starch, oil, and lignin content to improve industrial processing and conversion yields.	Greater use of pharmacogenetics in clinical trials and in prescribing practice, with a fall in the percentage of patients eligible for treatment with a given therapeutic.	Improved micro-organisms that can produce an increasing number of chemical products in one step, some of which build on genes identified through bioprospecting.
GM plants and animals for producing pharmaceuticals and other valuable compounds.	Improved safety and efficacy of therapeutic treatments due to linking pharmacogenetic data, prescribing data, and long-term health outcomes.	Biosensors for real-time monitoring of environmental pollutants and biometrics for identifying people.
Improved varieties of major food and feed crops with higher yield, pest resistance and stress tolerance developed through GM, MAS, intragenics or cisgenesis.	Extensive screening for multiple genetic risk factors for common diseases such as arthritis where genetics is a contributing cause.	High energy-density biofuels produced from sugar cane and cellulosic sources of biomass.
More diagnostics for genetic traits and diseases of livestock, fish and shellfish.	Improved drug delivery systems from convergence between biotechnology and nanotechnology.	Greater market share for biomaterials such as bioplastics, especially in niche areas where they provide some advantage.
Cloning of high-value animal breeding stock.	New nutraceuticals, some of which will be produced by GM micro-organisms and others from plant or marine extracts.	
Major staple crops of developing countries enhanced with vitamins or trace nutrients, using GM technology.	Low-cost genetic testing of risk factors for chronic diseases such as arthritis, Type II diabetes, heart disease, and some cancers.	
	Regenerative medicine providing better management of diabetes and replacement or repair of some types of damaged tissue.	

However, some structural conditions may require modification … such as a mismatch between current R&D investment and the potential economic contribution of biotechnology…

A striking implication of these estimates is that the economic contribution of biotechnology is potentially greatest in industrial applications, with 39% of the total output of biotechnology in this sector, followed by agriculture with 36% of the total and health applications at 25% of the total. These results are in marked contrast to an OECD estimate of the distribution of R&D expenditures by businesses in 2003, as shown in Table 3. The lion's share of private sector R&D investment, 87%, went to health applications in 2003, with only 2% of biotechnology R&D expenditures spent on industrial applications.

The mismatch between recent R&D investment and the potential economic contribution of biotechnology could partly reflect higher R&D productivity in agricultural and industrial biotechnology compared to health biotechnology. A lack of policy incentives, supporting regulations, skilled researchers, or complementary investment in public sector R&D could also play a role.

Table 3. **Current R&D expenditures versus future markets for biotechnology**

Application	Share of total OECD business expenditures on biotech R&D in 2003	Estimated potential share of total biotechnology gross value added (GVA)[1] in the OECD area[2] for 2030
Health	87%	25%
Agriculture	4%	36%
Industry	2%	39%
Other	7%	-
	100%	100%

1. Detailed methodology for determining potential share of GVA is included in the publication.

2. Most OECD member countries plus several EU-25 countries that are not members of the OECD.

Source: For the distribution of biotech R&D expenditures, OECD (2006), Biotechnology Statistics, OECD, Paris.

Fictional scenarios: The probable scenario describes a future bioeconomy with evolutionary advances from the use of biotechnology in agriculture, health, and industry, but the full potential of biotechnology is not realised. How biotechnology could result (or not) in more revolutionary changes are explored in the two fictional scenarios.

Up to 2030, the potential revolutionary effects of biotechnology will derive from both the *extent* to which specific biotechnologies are used and solutions to technical problems. The challenges are greatest in health and industry. In health, regenerative medicine and preventive and predictive medicine have the potential to revolutionize health care services and to significantly improve the quality of life. Some developments in both of these areas are possible by 2030, but both face major barriers that could limit both technical advances and the extent of use. In industry, biotechnology offers the means to manufacture a wide range of chemicals and high energy density biofuels, but this will require major technical breakthroughs and policies to ensure that these production systems are environmentally sustainable.

The two fictional scenarios extend technology trends to 2015 up to 2030, assume a multi-polar world, and include plausible natural and political events that could influence the bioeconomy. An analysis of the scenarios showed that two factors will be key in shaping the future bioeconomy: the quality of governance (defined as the system of regulations and policies that influence the development of the bioeconomy) and the economic competitiveness of biotechnological innovations.

The fictional scenarios describe how a change in the funding system for health therapies could encourage rapid innovation in regenerative medicine. In another fictional scenario, public attitudes result in some biotechnologies not reaching their potential. An example is predictive and preventive medicine, where the advance of this technology is limited by public resistance to poorly planned and intrusive healthcare systems. The fictional scenarios also explore different technological outcomes such as growing competition between biofuels derived from biomass, algal biofuels, and electrical transport systems. Problems with the competitiveness of environmentally sustainable technologies are exacerbated by insufficient long-term, credible support for promising technologies.

One lesson from the scenarios is that the future development of the bioeconomy will be shaped by how governments react to future crises (*e.g.* those caused by finance, food scarcity or pandemics). The future will also be influenced by international co-operation, especially with developing countries, and incentive structures for research and markets. Incentives influence the types of biotechnologies that are commercially viable and the distribution of its benefits. The structure of incentives can also support environmentally sustainable technologies over less benign alternatives – or the opposite.

Designing a Policy Agenda

Achieving the full promise of the bioeconomy by 2030 requires a policy framework that can address technological, economic and institutional challenges. Some biotechnology applications are only likely to require minor adjustments to current policies. Other areas of biotechnology will not develop their full potential without major policy interventions and new policy mechanisms.

The required mix of policies is linked to the potential economic impacts of biotechnological innovations on the wider economy. Each type of innovation can have incremental, disruptive or radical effects. In many (but not all) cases incremental innovations fit well within existing economic and regulatory structures. Disruptive and radical technologies generally have a longer time horizon than incremental technologies and can lead to the demise of firms and industrial structures, creating greater policy challenges, but they can also result in large improvements in productivity. The challenge is to develop a policy framework that can flexibly support the economic and social benefits of each type of technology.

Attaining the greatest socioeconomic benefits from the bioeconomy will require a multi-layered policy framework that encourages knowledge spillovers between sectors and that addresses application-specific technological, economic and institutional challenges.

Policy will need to be able to address challenges for the use of biotechnology in each of the three main application fields (agriculture, health and industry), manage cross-cutting issues for intellectual property and integration across applications, and tackle global challenges.

Agriculture provides a diverse range of policy challenges. Examples include the need to simplify regulation, encourage the use of biotechnology to improve the nutritional content of staple crops in developing countries, ensure unhindered trade in agricultural commodities, and manage a decline in the economic viability of some sectors when faced with competition from more efficient producers. The main challenges for health applications are to better align private incentives for developing health therapies with public health goals and to manage a transition to regenerative medicine and predictive and preventive medicine, both of which could disrupt current healthcare systems. Industrial biotechnology faces multiple futures due to competitive alternatives from both outside and within biotechnology. Efficient policies to support many industrial biotechnologies will need to be linked to life cycle analysis standards to identify the most environmentally sustainable alternatives.

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 agriculture, 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.

Endnote

1. The findings and policy recommendations provided in the final report benefited from substantive contributions provided by members of the Steering Group throughout the project, from expert papers written by external academics and consultants (see www.oecd.org/futures/bioeconomy), and from the comments of colleagues in other OECD Directorates, including the Directorates for Science, Technology and Industry; Trade and Agriculture; Employment, Labour and Social Affairs; and the Environment Directorate. The report was written by Anthony Arundel and David Sawaya.

Table 1 Notes

2. Authors, based on Just *et al.,* 2006. Lower estimates exclude all costs that could be associated with proving environmental or human safety, while higher estimates include such costs. All estimates exclude "facility & management overhead costs".

3. Figures from the German Bundessortenamt and converted from Euros to USD using the average of monthly exchange rates from June 2005 to September 2008 (1 EUR = USD 1.34).

4. Provided by the USDA Center for Veterinary Biologics. Estimates assume that the applicant already possesses an establishment license.

5. Fiscal year 2008 fees for the FDA from US Federal Register, 2007a.

6. Based on a new drug application requiring clinical data, product fees, and a rough estimate of the costs of production establishment inspections per drug, from US Federal Register 2007b.

7. Fiscal year 2008 fees, based on FDA, 2008.IVDs are classified as medical devices. Lower figure is for businesses with less than USD 100 million in sales.

8. Total costs to industry in first year, in 1995 USD, from EPA, 1997.

Annex: The Bioeconomy to 2030 Project Steering Group

The Steering Group was established to provide advice to the OECD Project Team. It included high-ranking experts and decision makers from public agencies and private firms that were responsible for or active in biotechnology and which contributed financially to the project. The organisations represented at meetings of the Steering Group are listed below.

Agriculture and Agri-Food, Canada

Australian Commonwealth Scientific and Research Organisation (CSIRO), Australia

Bundesministerium für Bildung und Forschung (BMBF), Germany

Canadian Biotechnology Secretariat, Government of Canada, Canada

Centre for European Economics Research, Germany

Ciba, Switzerland

CONACYT, Mexico

Danish Agency for Science, Technology and Innovation, Denmark

Département de l'Économie, Belgium

Department for Environment, Food and Rural Affairs (DEFRA), United Kingdom

Department of Trade & Industry, United Kingdom

Evonik Degussa GmbH, Germany

Finnish National Fund for Research and Development (Sitra), Finland

Fraunhofer Institute for Industrial Engineering (IAO), Germany

Institut National de la Recherche Agronomique (INRA), France

Ministère de l’économie/DGE, France

Ministère de la Recherche/DGRI, France

Ministère du Développement économique Gouvernement du Québec, Canada

Ministère du Développement économique, de l’Innovation et de l’Exportation, Gouvernement du Québec, Canada

Ministry for Science, Technology and Higher Education, Portugal

Ministry of Agriculture, Iceland

Ministry of Health, Welfare and Sport, The Netherlands

Ministry of Research Science and Technology, New Zealand

Montreal in Vivo, Canada

Munich Re Group, Germany

National Institute of Advanced Industrial Science and Technology (AIST), Japan

Novo Nordisk A/S, Denmark

Novozymes, Denmark

Organon BioSciences, The Netherlands

Research Council of Norway, Norway

Secrétariat d’Etat à l’économie (seco), Switzerland

State Secretariat for Education and Research, Switzerland

Swedish Governmental Agency for Innovation Systems (VINNOVA), Sweden

US Department of Agriculture, United States

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