Australian Government
Department of Defence
Defence Science and
Technology Organisation

DSTO

Overview of Biotechnology Futures: Possible Applications to Land Force Development

Margaret Egudo

DSTO-GD-0419

Australian Government
Department of Defence
Defence Science and
Technology Organisation

Overview of Biotechnology Futures: Possible Applications to Land Force Development

Margaret Egudo

Land Operations Division
Systems Sciences Laboratory

DSTO-GD-0419

ABSTRACT

This review of selected scientific and technological advances occurring in the field of biotechnology discusses their possible impact for Land Force capability development in the next decade or two. Some studies suggest that the socio-technical impact of biotechnology may surpass that of the Information Revolution, and it could become a major force in the 21st Century. Its synergy with nanotechnology, materials and information technology has led to the development of new and revolutionary applications that are likely to be adopted in agriculture, health, environmental applications, manufacturing industries, and by the military. The implication of this technological impact has raised complex social, political and legal issues all of which will impact to some degree on the future Land Forces and their operational environment. This report discusses these issues both in relation to how they may affect society and hence future contexts, and their pertinence to the future military in terms of direct application of these technologies.

RELEASE LIMITATION

Approved for public release

Published by

DSTO Systems Sciences Laboratory
PO Box 1500
Edinburgh South Australia 5111 Australia

Telephone: (08) 8259 5555
Fax: (08) 8259 6567

AR 013-254

Submitted: January 2004
Published: November 2004

APPROVED FOR PUBLIC RELEASE

Overview of Biotechnology Futures: Possible Applications to Land Force Development

Executive Summary

The report presents a review of selected scientific and technological developments in biotechnology, and discusses their potential impact for Land Force capability development in the next decade or two. It discusses these issues in relation to how they may affect society and future military contexts. Given the rapid rate of development in the field, this report is intended to be a working document to be updated regularly to incorporate new developments.

The Convention on Biological Diversity defines biotechnology as "any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use". While biotechnology applications date back to 6000 BC, developments since the 1970s in genomics, genetics, cell and tissue engineering have identified a range of possible novel applications and given the field new impetus. Its facilitation through nanotechnology, materials and information technology has fuelled research and development of new technologies with broad applications in health care, agriculture, environment, and industrial production.

New and promising technologies include:

- Recombinant deoxyribonucleic acid (rDNA) technology, which involves artificially joining pieces of DNA from different organisms. The technology is relatively immature, and its future benefits are still to be realised, and in many cases recognised. It has wide ranging applications such as agriculture (e.g. boosting yields, plant-based pharmaceuticals); human health (e.g. DNA vaccines, xenotrans-plantation); environmental health (e.g. GM organisms for remediation); and industrial production (e.g. manufacture of stronger materials).

- Cell and tissue engineering technology promises new skin and tissues for repair, regeneration, and restoration of human function. Stem cell tissue production is still in early stages of development, and remains a controversial (and potentially limiting) issue.

- Biochip technology promises applications such as: gene and protein chips for rapid screening and disease diagnoses; biochips for in-time detection and identification of threat molecules in food, air, and water; and multifunctional lab-on-a-chip systems to deliver disease targeting drugs *in vivo* or *in vitro*. Currently in the clinical trial stage, these miniaturised devices could be commercially available in the next five to ten years.

- Biocomputing is expected to provide miniaturised, more powerful, highly energy efficient and potentially cheaper computers than current silicon-based ones. Commercially viable applications are expected to appear within the next ten to twenty years.

Alternative energy sources could be derived from biofuels (e.g. ethanol, biodiesel, methane). These have both environmental and cost benefit advantages.

From the military point of view, biotechnology presents opportunities for radical changes to a broad range of applications. The potential exploitation of these technologies for the enhancement of outcomes and capabilities of future Land Forces include:

- Sensor technologies: to monitor health and assist in biowarfare defence by providing added battlefield intelligence of chemical and biological threat agents in the environment.
- Biocomputing: features such as portability, high capacity data storage, lightweight, high energy efficiency, massive parallelism, cheap production costs, and the potential to protect C4ISR systems against some levels of radiation.
- Cell and tissue engineering: self-replicating systems for wound healing, such as biosealants, could help injured soldiers while further treatment is being sought.
- Bioengineered materials: to provide lightweight and durable clothing, and non-illuminating paints for concealment and radiation protection.
- GM foods: to provide soldiers with extra nutrients, food vaccines, and biomarkers for soldier identification. Long shelf life foods could reduce refrigeration and supply requirements.
- Gene therapy and brain implants: to enhance mental and physical capabilities. This may raise the prospect of soldier screening and selection for suitable tasks based on physiological and psychological data.
- Recombinant DNA technology has increased the scope for hostile exploitation of biotechnology. The technology can develop new or modified pathogens and toxins with enhanced lethality capable of avoiding detection and current control measures.

In addition to the direct social and military applications, there are a number of broader social and cultural issues that may impact on how biotechnology develops and is applied. Issues concerning cloning, gene patents, GMOs, stem cells, and gene databases have raised philosophical, ethical, moral and legal issues. These issues are expected to dominate future debate, and could determine maturation or the extent of adoption of new technologies in various countries. As such, they are likely to have some direct and indirect impacts on future warfighting and combatants.

Author

Margaret Egudo
Land Operations Division

Margaret Egudo has a BA (Hons) in Political Science and Public Administration (Makerere, Uganda), a Graduate Diploma in Education (Monash) and MBA (Central Queensland). She worked as Lecturer at Monash University and was a Senior Analyst at the Centre for Army Lessons (Puckapunyal) before joining DSTO in 2002, where she is currently working on Future Warfighting Studies tasks.

Contents

1. Introduction

Biotechnology has been broadly defined as "any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use" [1]. Its applications date back to 6000 BC when yeast was first used by the Sumerians and Babylonians for fermentation to make bread, cheese and beer [2]. The current interest in biotechnology has been fuelled by technological developments, especially in the area of information technology, which have opened up opportunities to realise the enormous potential that genomic technologies (particularly structural and functional genomics), advanced molecular and cellular engineering, and the emerging fields of proteomics and bioinformatics may provide. It has been suggested that biotechnology (especially genomics) might constitute the third great technology driven revolution, after the Industrial and Information Technology Revolutions [3]. In the next decade or two, it is expected to revolutionise health care, agriculture, environmental management and national security.

We have undertaken a review of some selected developments in biotechnology to highlight the range of technologies particularly: sensors, materials, biocomputing, health and energy applications, and the implications they may have in influencing shaping of the future context of Army capability development. This report aims to summarise current developments in biotechnology and highlight some of its socio-technical implications. As such, it provides possible future contexts for society and the military environment.

First, this report discusses the range of applications for biotechnology. In doing so it gives a brief overview of the science behind biotechnology. However, it is not our intent to give detailed technical information. This may be found within the references.

This report includes a brief overview of the driving forces behind biotechnology development and application (section 2). We have divided biotechnologies into health (section 3) and non-health applications (section 4). However, these are not exclusive and there is some overlap. In such cases we have discussed applications in only one section to minimise redundant discussion. Having detailed applications, we briefly discuss social impacts (section 5), selected possible military applications (section 6), and conclude (section 7) with implications of biotechnology.

Of course biotechnology is a large field, constantly expanding as new discoveries are made and applications are realised. Therefore this is intended to be a working document to be updated regularly to incorporate new developments.

2. Trends and Driving Forces

Taken alone, biotechnology will only have a limited capacity to deliver on its potential. Rather, it is a combination of factors such as the integration with other technologies especially nanotechnology and IT, market support, continued scientific discovery, and cultural changes that will dictate biotechnology impacts and outcomes. These trends and driving forces include:

- **Technological synergy.** Parallel technological developments in biotechnology, nanotechnology, materials technology, and cross facilitation with information technology are enabling the development of new concepts and applications in medicine, agriculture, mining, food processing, and materials design [4]. For pharmaceutical companies, the convergence of biotechnology and information technology has revolutionized drug discovery and design, and reduced costs. Before the genomics revolution, drug development took approximately 15 years, and cost approximately US$880 million. With genomic technologies, companies expect to save approximately US$300 million and two years on drug development. The convergence of biotechnology and information technology has assisted in the development of biomedical applications for technologies such as imaging, sensors, and robotics [5].

- **Market forces.** Global economics is driving international competition among biotechnology companies to develop new products and applications. The growing recognition of biotechnology as an economic and social growth factor has prompted governments in many countries to provide financial support to their local biotechnology companies to encourage research, development and commercialisation of ideas and products [6]. For example, in the 2000-2001 Budget, the Australian Government allocated $30.5 million over the 2001-2004 year period to support its biotechnology industry initiatives under the National Biotechnology Strategy [7].

- **Biomedical research and development.** A considerable amount of basic research is being undertaken within the field of biotechnology. Progress in human genome sequencing, and scientific advances in molecular and cell engineering research are producing new discoveries that are leading to new fields within biotechnology (e.g. proteomics) whose full potential is yet to be recognised. Therefore, the fundamental quest to enhance knowledge provides a significant driver for the ongoing expansion of the field and discovery of new areas of application.

- **Cultural expectations.** The drive to 'beat nature' is often considered as a driver for biotechnology. Expectations of an aging population, untreated diseases, and unresolved environmental problems have provided incentives for biotechnology companies to innovate and provide quality products and services [8]. In addition, changing public perceptions will determine when and how (if at all) current and emerging biotechnology applications become palatable and hence established within society.

3. Health Related Biotechnologies and Applications

3.1 Introduction

In the next 10 to 20 years, health care is expected to shift towards molecular and preventive medicine, and the use of recombinant DNA (rDNA) and monoclonal technologies. Genetic testing, gene therapy, and personalised medicine may become common practice [9]. New surgical tools and techniques such as antioplasty, laser surgery, and hybrid imaging techniques promise to be largely non-invasive. They will not only improve survivability, but could reduce patient costs related to lengthy hospital stays. Advances in cell and tissue regeneration promise to develop organic and artificial tissues for repair and replacement functions [4].

3.2 Diagnostics

Automation in genomics has made genetic testing possible, with nanotechnology enabling the development of chip based diagnostic tools that can simultaneously screen and analyse entire genomes on a chip with speed and accuracy. These genomic tools include:

- DNA chips for rapid, efficient and simultaneous analysis of large numbers of genes including mutations in each of these genes to identify genetic diseases [10, 11].

- Biochips to act as biosensors to monitor bacteria, viruses, and other microorganisms in the environment, and perform biological and chemical analysis on people.

- Lab-on-a-chip systems to perform laboratory functions and provide fast and accurate diagnostic information in real time [12]. The system has the potential to deliver multiple drugs in timed and measured doses, and may become an alternative method in drug delivery. Society could benefit from the availability of multiple drug regimes in the treatment of various diseases [13].

- Protein-encrusted chips to perform various functions quickly and cheaply. They could monitor specific microbes, disease cells, and harmful chemicals in the environment. Soldiers could use these chips to detect chemical and biological agents and improve battlefield data collection [14]. Tests are currently being conducted to use protein chips to detect disease biomarkers and assess levels of toxicity of protein-based drugs [15].

It is expected these new technologies will result in significant performance improvements [16], and health outcomes because of their emphasis on point-of-care and personalised treatment [17].

3.3 Treatment and Prevention

3.3.1 Recombinant DNA technology

Recombinant deoxyribonucleic acid (rDNA) is a genetic engineering technique used to artificially join pieces of deoxyribonucleic acid (DNA) from different organisms [18]. In a study by the University of Toronto's Joint Centre for Bioethics, it was ranked among the

most promising biotechnologies with potential to benefit global health within 5-10 years [19, 20]. However, the field of rDNA technology continues to rapidly expand, so many of its future benefits are still to be realised, and in many cases recognised. There are many potential medical applications of this technology, although these can be categorised in two areas:

- New forms of drugs: development of molecular based drugs such as new antibiotics that may solve current problems associated with antibiotic resistance to treatment, and drugs to treat complex medical conditions such as Alzheimer's disease, diabetes and obesity.

- New forms of administration: design and development of safer and more effective vaccines to control infectious diseases such as HIV/AIDS, malaria and tuberculosis. This technology could be used to improve the effectiveness of current vaccines. The possibility of inhalable drugs, powdered vaccines, and plant based vaccines as an alternative to drug injection could make drug delivery cheaper and safer.

Creating improved ways of delivering medicine has a number of substantial and immediate uses. Compared to traditional vaccines, these new vaccines offer the following advantages [21]:

- New means of delivery;
- Economical to mass produce and transport;
- Heat stable, eliminating the need for refrigeration;
- Subunit vaccines (not attenuated) for increased safety.[1] These vaccines cannot replicate in the host and are less likely to induce adverse immune reactions;
- Enhanced compliance especially in children (e.g. edible vaccines); and
- Can be integrated with other vaccine approaches.

For instance, from the military viewpoint, edible vaccines could solve problems associated with production, distribution, and delivery of health care in operational environments.

3.3.2 Transgenic animals and fish

There are many examples of animals being genetically altered to produce non-naturally occurring products. Cows and goats have been engineered to secrete human proteins in their milk. Pigs could become donors of xenografts for human transplants and relieve organ shortages [22]. Tilapia, a fish of the cichlid family, has been engineered with a human gene to produce Factor VII, a substance vital for blood clotting [23].

[1] Attenuated vaccines: A disease-causing micro-organism is isolated and then attenuated (made less virulent) by ageing it or altering its growth conditions (such as by depriving it of an essential nutrient). Because this vaccine is actually a living microbe, it multiplies within the body and therefore causes a strong stimulation of the immune system. Vaccines for measles, mumps, and rubella are prepared in this way. See: Glossary, Australian Academy of Science. http://www.science.org.au/nova/012/012glo.htm

3.3.3 Pharmacogenomics

New technological advances in high throughput DNA and messenger RNA (mRNA) analysis, and efficient processing of this data is enabling rapid generation of patient information. This development has created 'pharmacogenomics', a new field that combines pharmacology and genetics to study how individual genetic profiles determine drug response. Pharmacogenomics will enable physicians to deliver tailored treatment to their patients, and promises safe drugs with fewer side effects, thereby eliminating prescription related medical errors [24, 25].

3.3.4 Cell culture technology

Cell culture technologies involve growing of stem cells outside living organisms to produce transplantable tissues for therapeutic purposes. Stem cells have the ability to develop into more than one form of human tissue. They may be sourced from embryos or adult stem cells, with the former having greater scope for types of cells produced [26]. For example, adult stem cells have developed into bone and blood cells. It has been reported that stem cells from bone marrow can also develop into brain cells. This discovery has improved the prospects of using adult stem cells to repair damaged or diseased brains of patients suffering neurological diseases and stroke [27].

Tests on mice using embryonic stem cells have shown promising results with potential clinical applications in the treatment of human neurodegenerative diseases such as Alzheimer's and Parkinson's disease, diabetes (type 1 Juvenile diabetes), spinal cord injury, and haemophilia [28]; bone and cartilage diseases such as osteoarthritis, heart conditions, cancer and immune diseases, multiple sclerosis and lupus [26]. However, the current controversy surrounding embryonic stem cell therapy has restricted its application. In Australia, only harvested stem cells from surplus IVF embryos can be used for research [29], causing some constraints on the development of this field.

3.3.5 Gene therapy

Gene therapy is based on the premise that those diseases that are caused by faulty genes can be treated when the faulty gene is replaced with a normal version. Gene therapies could control, prevent or even cure particular diseases [30]. There are broadly, two types of gene therapy.

Germ line gene therapy involves transfer of sperm cells and egg cells of the reproductive system. Since the creation in 1996 of Dolly the sheep from an adult stem cell, cows, goats, pigs and mice have all been cloned [31]. However, animal cloning has yet to overcome a number of hurdles. Many of the cloned sheep, cattle, goats and mice are reported to have died before birth or were born with severe abnormalities. Dolly died prematurely in February 2003 aged six years from arthritis and lung disease [32, 33]. In humans, this form of therapy could eliminate inherited genetic diseases before birth and save subsequent generations. However, the prospect of engineering identical human beings has raised moral, ethical, religious, and scientific issues. Many countries have legislated to prohibit its human application.

Somatic cell gene transfer involves transfer of adult cells and could treat various types of cancers, cystic fibrosis, diabetes, and acquired infectious diseases such as HIV/AIDS and tuberculosis. Its application in human tissue transplantation could reduce organ

rejection, as the recipient is also the cell donor. Compared to adult stem cells, embryonic stem cells offer the greatest potential. However, due to various legal and ethical concerns, the extent of use is currently limited.

3.3.6 Xenotransplantation

Animals such as baboons or pigs could be genetically modified and cloned to grow organs or tissues for human transplantation. This technique could alleviate supply shortages of human organs, save and prolong the lives of recipients. However, organ rejection and ethical concerns of using animals to grow human organs constitute a barrier to xenotransplantation [4].

3.3.7 Bioinformatics

Bioinformatics is a new field that has emerged to provide analytical and computational tools for biological research. It draws elements from computer science, mathematics, physics, medicine, and biology. These tools will store, search and analyse genomic and other biological data [34], and provide valuable information that may lead to new drug development, more rapid diagnosis and better health outcomes [35].

3.3.8 Genetically modified food

Genetic engineering involves a technique of altering the genetic makeup of cells or organisms by deliberately inserting, removing, or altering individual genes [6]. In modern agriculture, this technique is producing food crops with enhanced nutritional and health benefit. For instance, the 'Golden' rice variety has been enriched with beta-carotene and iron to overcome vitamin A deficiency and prevent blindness [36].

4. Selected Non-Health Biotechnologies and Applications

4.1 Introduction

While there is considerable research being undertaken in the fields of health-related biotechnology applications, it is in the field of non-health biotechnology that much of the immediate impact will be felt. In many cases, the changes wrought by biotechnologies are evolutionary in nature. The production of genetically modified (GM) crops has focussed on crop improvements (through disease resistance or greater productivity). Significantly, this area is quite mature in some areas and has a number of commercialised products. However, in addition to this, there are a number of emerging possible applications for biotechnology, ranging from novel approaches to computing to the development of materials with unique and desirable properties.

4.2 Molecular computation

There is a possibility for biologically based molecular computers to replace some of the functions currently performed by silicon-based computers in the next decade. These

computers are expected to possess beneficial features that include: extremely dense information storage, enormous parallelism, extraordinary energy efficiency, and multiple switching. They will be miniaturised, more powerful and potentially cheaper than silicon-based computers [37].

These computers could provide high-speed signal processing and communication, large data storage, linear and non-linear memories [38]. Compared to electronic computers that can analyse only one potential problem at a time, enormous parallelism in DNA computers could enable simultaneous processing of possible answers. The tools of molecular biology may be useful in solving complex problems [39, 40]. Exploiting the chemical properties of bacteria such as bacteriorhodopsin may reduce increasing dependence on semiconductor electronics and assist in protecting C4ISR systems against radiation and electromagnetic pulses.[2] Biocomputing focuses on the hybrid field of computer science and biology, including the computational properties of cells (e.g. genetic regulatory circuits); DNA computations; DNA self-assembly; cellular and DNA logic gates; computer immune systems for combating computer viruses; artificial life; artificial neural nets; and genetic evolutionary algorithms [40].

Biocomputing could become an alternative to semiconductor-based electronic computing. The unique photo physical properties as well as thermal and photochemical stability of the bacteriorhodopsin protein could address some of the limitations of semiconductor electronic computers such as: vulnerability to electromagnetic radiation, potential limitations in memory capacity, weight, and high energy consumption problems which could pose problems for future battlefield environments. Biological computers could circumvent some of the problems anticipated by Moore's law in the next few years [40].[3] It may offer significant advantages in terms of low cost, compact size, three-dimensional (3-D) optical memories, parallel processing capacity, and high tolerance to electromagnetic radiation.

4.3 Biomaterials engineering

Dragline spider silk is estimated to be stronger than nylon, and is elastic, waterproof, stretchable and biodegradable. There is potential for large-scale production of spider silk, which could be used to manufacture protective clothing, ropes and nets [41]. Nexia Biotechnologies in Canada is reported to have successfully produced man-made spider silk using recombinant silk proteins from the dragline spider. Nexia is also planning to engineer goats to secrete these proteins in milk [42]. Dragline spider silk proteins have also been engineered into tobacco and potato plants to be harvested, spun and mass-produced [43].

Advances in cell and tissue regeneration promise biomaterials with superior advantages to synthetic materials due to their compatibility to the human body. This technique has already produced skin products for wound treatment, and clinical tests are being conducted on new cartilage and functional tissue to treat heart disease. It will also enable using stem cells to replace dead or damaged tissue, which could assist in the treatment of wounds and accelerate healing. Artificial tissues have included bioactive

[2] Bacteriorhodopsin is said to maintain its structure and function in temperatures as high as 140°C, a temperature at which most proteins can no longer function.

[3] Moore's law is named for the founder of Intel. This law predicts that the density of components possible on a computer chip will approximately double every 18 months.

polymers to act as meshes, sponges, or hydrogels to stimulate tissue growth, and ceramics for bone regeneration [4].

4.4 DNA Forensics analysis

The discriminating power of DNA fingerprinting technology has contributed significantly to law enforcement, particularly in solving serious crimes such as rape and murder. New DNA technologies can match minute biological samples to their sources. Aided by computer technology, DNA databanks have assisted in criminal investigations that led to prosecution in unsolved cases [44].

DNA testing has been instrumental in correcting miscarriages of justice for innocent individuals accused of crimes. This was highlighted in the U.S. Department of Justice Report on 28 cases reviewed where DNA tests later exonerated individuals convicted on the basis of eyewitness testimonies. Had DNA tests been conducted on physical evidence, their innocence would have been proven much earlier [45].

DNA testing is said to have 99 percent accuracy and has been instrumental in cases involving disputed paternity. Fathers have used it to deny or reduce child support payments. It has also enabled children to prove their biological heritage [46].

DNA has assisted in the identification of aircraft and war victims using personal items containing tiny amounts of human genetic material (e.g. skin or hair). For instance, DNA testing identified most of the victims of the World Trade Center disaster in New York in September 2001. The US Defense Department used DNA to identify remains of missing soldiers who died during the Vietnam War, Korean War, and World War II [47]. It was also used to identify victims who died during the Bali bombing in October 2002 [48].

4.5 Genetic engineering

Genetic modification of natural biological systems for non-medical applications has a large number of diverse applications, which are already in the marketplace. Indeed, from a commercial sense, this is probably the most mature area. Some examples include:

- **Food production.** This technology promises crops with higher yield and quality; improved resistance to pests and diseases; better tolerance of environmental extremes (e.g. drought and salinity); new food stuffs; modified plants to control water and soil pollution; and crops that can grow faster, and in competitive production systems [49]. Corn and potato engineered with proteins from the soil bacterium *Bacillus thuringiensis* enables them to develop pesticide resistance [50]. One tomato variety (Flavr-Savr) has been modified to extend its shelf life [4]. Recombinant technology is also expected to produce healthier, more productive and disease resistant farm animals.

- **Biosensors.** Using recombinant techniques, plants and bacteria are being modified to act as biosensors to detect and monitor hazardous materials in the environment [4]. Indeed, bacteria have been modified to be sensitive to substances such as TNT, creating opportunities for land mine detection. Environmentally, there are significant potential benefits to engineering fish to detect pollutants like dioxin or polychlorobiphenyl (PCB) [23].

- **Pollution control.** Genetically engineered bacteria that feed exclusively on oil could control oil slicks. Other microorganisms could also break down pesticides, herbicides and chemical waste, and assist in environmental pollution control. Researchers at The Institute for Genomic Research (TIGR) and the University of Massachusetts, Amherst, have decoded and analysed the genome of the bacterium *Geobacter sulfurreducens* and found that it has potential for bioremediation of radioactive metals and electricity generation. It could assist in the clean-up of ground water contaminated with radionuclides and metals, and in industrial sites [51].

4.6 Power and energy

Genome sequencing of the *G. sulfurreducens* bacterium indicated evidence of aerobic metabolic, one-carbon and complex carbon chemotactic behaviour. It also possessed many two component sensors and c-type cytochromes. These characteristics provide the bacterium with the capability to reduce metal ions or create electricity as part of its energy-generating metabolism [52].

4.7 Fuel cells

Scientists have developed an efficient bacterial microbial cell using the unique characteristics of the *Rhodoferax ferrireducens* bacterium. The bacterium was shown to be capable of generating electricity while feeding on simple sugars such as glucose, fructose, sucrose, and xylose. Tests carried out reported efficiency in energy conversion in these sugars was over 80% [53, 54].

5. Social Impacts of Biotechnological Advances

5.1 Introduction

While there may be benefits to be derived from prospective biotechnological applications, society may be confronted with social, economic, political and legal challenges arising from their implementation. Although these may not have direct implications for the military, indirectly they do, as biotechnology may fundamentally change the environment within which the future Army recruits, trains and operates.

Some of the issues that could dominate future debate include [4]:

- Disparity in access to biotechnology products;
- Cloning (especially of humans);
- Gene patents;
- Genetically modified organisms and transgenic crops;
- Use of embryonic stem cells for tissue engineering;
- Xenotransplantation;
- Privacy of genetic databases; and
- Increased risk of engineered biological weapons.

5.2 Disparities in research and access to products

Bio-medical advances and interventions are expected to enhance health and prolong survival rates of the global population, allowing people to enjoy more active lives than ever before. While some of these new genomic interventions may become available, there is concern that a new type of inequality may emerge where access to health care will be determined by existing social and economic structures. The capacity to pay will determine who gets quality medical care from the costly and specialised medical techniques [55].

There is a possibility of increasing marginalisation of the health problems affecting the developing world because the research agenda will largely be determined by the priorities of the developed world and its market potential. As drug development requires high capital investment, is time consuming (8-12 years) and involves high risk taking, there are fears that this could widen the current gap in global health research spending between developed and developing countries [56]. Already, more than 90% is spent on the health needs of richest 10% of the world's population. The concentration of research funding in developed countries, and largely in the private sector, may widen this gap because research priorities will be influenced by market considerations such as individual purchasing power in the global competitive economic environment [57].

Because of profit potential, drug companies may direct their investment to those diseases and patients with a high rather than low profit margin. Many developing countries in Africa, Asia and South America where infectious diseases kill more than 14 million people a year may miss out on new and effective medicines that are critical for the survival of their populations. For life-saving drugs that are already in the market such as for HIV/AIDS, access is limited because poor people cannot afford them. Research and development costs, government regulations and patents have contributed to raise prices [56]. It has been estimated that of the 1233 new drugs marketed from 1975 and 1999, only 13 were approved specifically for tropical diseases. Of these, six were developed by the World Health Organisation (WHO), United Nations Development Program (UNDP) and UNDP/World Bank/WHO-supported Special program for Research and Training in Tropical Diseases (TDR). The challenge will be how to direct global resources into research and development to address health needs of developing countries, and make drugs and vaccines more affordable [57].

5.3 Genetic databases and privacy issues

It is expected that bioinformatics will result in integrated databases of DNA and other health related information including that relating to genetic predisposition to disease, intelligence, sexuality and behavioural traits. Although genes are not the only contributing factors for these conditions, the potential exists for excessive surveillance and inappropriate use of this information by employers, insurance companies or government bodies. Particular individuals, their families or ethnic groups could be targeted and subjected to various forms of discrimination. There is concern that this may result in the creation of a genetic underclass of undesirables in society and further widen the current societal divide. This possibility has raised complex ethical and legal questions. How to balance freedom of access by government bodies, private companies and researchers for the purposes of scientific research, while maintaining confidentiality, will require legislative protections to safeguard the rights of vulnerable populations and ensure fairness [58]. The Iceland government has developed a national gene database of

its entire population. Use of the database has been opposed by professional groups such as the Iceland Medical Association and the World Medical Association, on the basis of potential breaches of medical ethics and patient confidentiality [59].

5.4 Gene patents

As policies are not uniform across the globe, questions of ownership and control of genetic information will have to deal with the yet unsolved issue of clarity of patents [4]. The potential for commercial monopoly of patents has raised questions among researchers and medical professionals who are concerned that patents on disease causing genes may restrict innovative medical research and harm public health [60, 61]. They argue that patent monopolies place data restrictions on upstream product discoveries. This may jeopardise downstream product development where data from upstream products could have provided useful information to enable refinement of tests for diseases. Patent restrictions also impose high licensing fees and raised medical costs that are passed on to patients. This may result in those patients on lower incomes being denied access to effective treatment [62].

5.5 Human cloning

The prospect of cloned human beings challenges traditionally accepted norms of what societies consider to be human and culturally appropriate [63]. New genetic knowledge and reproductive technologies raise the possibility of human beings with identical DNA and genes. Fears of designer babies and genetic enhancement have raised ethical and moral questions with regard to the identity and dignity of cloned children in society. Genetic enhancement could create categories of superior or inferior human species. The fight for survival of the fittest may ultimately result in elimination of specific genes. Cloning humans is said to constitute an 'unnatural science' and undermines human dignity and liberty. It could promote genism, racism, and eugenics [64]. Many countries have legislated to ban human cloning.

5.6 Xenotransplantation

While xenografts may solve the shortage of human organs and tissue, and improve health and life expectancy of patients, there are theological and ethical questions on what constitutes a human being, when transgenic animals are used to produce human organs [4]. There may be risks of animals transmitting diseases that currently only affect them to human recipients and the wider society. Indeed, the recent appearance of HIV has been attributed to such a transfer. Genetic engineering of animals could also jeopardise animal welfare and their relationship with humans.

5.7 Transgenic Crops

While there is considerable optimism regarding GM crops, questions are being asked with regards to possible harm to human health, damage to the environment and the unease about the 'unnatural' nature of genetic modification.

These concerns have sparked protests particularly in the United Kingdom and Europe where environmentalists, consumers, and religious groups have pressured their

governments to prevent GM crop production until potential impacts have been evaluated [65]. Concerns include:

- The perception that powerful multinational companies will have a significant influence on agriculture and food production, and this could undermine traditional farming practices (e.g. farmer-saved seed). This could force subsistence farmers to become dependent on multinationals for plant seed.

- Religious groups argue that this technology 'tinkers with nature and breaches the species barrier', and would prefer conventional breeding methods [66].

- Consumers are concerned that gene technology could transfer compounds with known allergens into new plants. This may adversely affect individuals sensitive to these allergens. The reported case of allergenic reaction to proteins from the Brazil nut in transgenic soybeans highlights this possibility. This allergen affected some people during human trials, resulting in withdrawal of the particular soy product [67].

- Environmentalists worry that GM crops may spread rare transgenes into natural plant populations and destroy the genetic pool of local species. This could disrupt the natural balance of the ecosystem in the long term. In addition, soil ecology could be affected if GM crops destroy naturally occurring bacteria, which play important roles in the ecosystem.

Given the range of these concerns, and in the absence of clear scientific consensus on possible risks associated with GMOs, there are calls for governments to adopt precautionary measures such as mandatory regulations on food labelling and risk monitoring [65, 66].

6. Selected Possible Military Applications and Implications

6.1 Introduction

The application of biotechnology to the military sphere is likely to provide opportunities not available through other approaches. Indeed, a report by the Committee on Opportunities in Biotechnology for Future Army Applications has highlighted that new advances in biotechnology could in particular prove useful in enhancing health and survival of troops in the battlefield. As indicated in the previous sections, this could be in the form of novel vaccines and GM products. However, they could also alleviate transport and logistical problems, provide efficient communications infrastructure, and alternative energy sources [38].

6.2 Less vulnerable biomolecular electronics and computing

Biocomputing could provide a viable alternative to semiconductor based electronics and computing. The unique photo physical properties as well as thermal and photochemical

stability of the bacteriorhodopsin protein could address some of the limitations of semiconductor electronic computers such as: vulnerability to electromagnetic radiation, potential limitations in memory capacity, weight and high energy consumption, which could pose problems for future battlefield environments. It may offer significant advantages in terms of low cost, compact size, 3-D optical memories, parallel processing capacity, and high tolerance to electromagnetic radiation and cosmic arrays.[4] Three dimensional data storage can store roughly three times more information in the same size enclosure than a two-dimensional optical disk. The computers are insensitive to external moisture, and can be submerged under water for months without compromising reliability of the data.

Biomolecular electronics may take many years or decades to develop. However, the possibility of the new biological and hybrid devices being lighter, faster, and possibly cheaper than the current computer-engineered devices used by the Army provides opportunities for Army to harness this potential to enhance capability where necessary.

6.3 Biomaterials

The potential to exploit chemical properties of bacterial proteins may yield materials for clothing and concealment, and increase soldier protection. The technology could be used to make non-illuminating paints and coatings capable of absorbing radiation, to be sprayed on tanks and aircraft and protect soldiers from enemy radar detection. It could develop combat uniforms that change colour and blend with the environment.

There is the possibility to develop lightweight, flexible and much more durable protective armour for soldiers, thereby reducing the load that soldiers have to carry with them. Material from the Dragline spider is claimed to be much stronger than Kevlar synthetic fibres and could be utilised in ballistic protection.

Approximately 55% of battlefield deaths are caused by excessive bleeding. Biosealants could provide immediate care in the battlefield by preventing bleeding and haemorrhaging of injured soldiers while permanent treatment or transportation is being sought. Individual soldiers could also carry biosealants in their backpacks. Self-replicating systems for wound healing would improve treatment of soldiers in the battlefield and save lives.

6.4 Biosensors

Lab-on-a-chip systems could be implanted to monitor soldiers' health for exposure to harmful agents, and carry out fast, ultra sensitive, and low cost analysis in real time. A lab-on-a-chip system could trigger the release of an antidote or activate a protective mask of the combat soldier. A network of biosensors could also provide added battlefield intelligence to commanders. They could provide early warning signals to enable the adoption of protective measures when necessary. This technology has the potential to produce compact devices the size of a postage stamp that could be worn like

4 Biocomputing focuses on the hybrid field of computer science and biology, including the computational properties of cells (e.g. genetic regulatory circuits), DNA computation, DNA self-assembly, cellular and DNA logic gates, computer immune systems for combating computer viruses, artificial life, artificial neural nets, and genetic and evolutionary algorithms.

wristwatches. These unobtrusive biosensors could perform a variety of functions in the combat environment.

6.5 Functional foods

GM foods may assist in improving combat effectiveness, reducing logistic support requirement needs and improving readiness. GM technology could provide foods with extra nutrients, that require less refrigeration or storage, and foods with enhanced digestible enzymes. A food dye or biomarker incorporated into food could assist in distinguishing friendly soldiers from enemy forces, and enable commanders to monitor troop movements during combat or peacekeeping operations.

Highly digestible food would reduce the amount transported to troop locations. Vaccines incorporated into common foods such as potatoes could protect soldiers from common ailments such as diarrhoea and other infectious diseases encountered in exotic locations. This could simplify the need to carry vaccines that require refrigeration and would save on energy consumption. The technology would also provide crops that can be grown to maturity in days rather than weeks, and ensure a continuous supply of fresh fruits or vegetables for combat soldiers.

6.6 Performance enhancement

The convergence of nanotechnology, biotechnology, information technology and cognitive science could enhance the cognitive, behavioural and physical attributes of soldiers. Mental and physical enhancements would have direct war zone applications. Sensory implants to measure brain chemistry, antidote implants, and gene-based drugs may assist soldiers during periods of critical stress. They also provide the possibility to screen and select individuals for specific tasks based on physiological and psychological characteristics [68].

6.7 Bioweapons

Studies on genome sequencing, molecular biology and genetic engineering have produced large quantities of information and knowledge of the biology of plants, animals, insects and humans. This has increased people's understanding of genetics, particularly that of biological function in pathogens and target hosts. There is concern that, while this knowledge may benefit humankind by improving health, it also provides opportunity for terrorists groups and foreign governments to use the new biomedical methods for the development of biological weapons for military purposes. The capability could develop enhanced biological agents to circumvent current or planned countermeasures [4].

An official American study in 1977 reported the possibility of developing the following novel agents [69].

- benign organisms, genetically altered to produce a toxin, venom or bioregulator;
- microorganisms resistant to antibiotics, standard vaccines and therapies;
- microorganisms with enhanced aerosol and environmental stability;
- immunologically altered microorganisms able to defeat standard identification; detection and diagnostic methods; and
- combinations of the above four types with improved delivery systems.

GM technology provides the capability to increase the pathogenicity of known viruses and bacteria. For instance, while attempting to produce an effective contraceptive for mice, Australian researchers inserted two new genes into the mouse pox virus and created a new but lethal version of this virus that ended up killing all the mice that were infected with it. This virus would normally cause only mild illness [70].

It is possible to synthesise simple viruses from scratch. US researchers were able to synthesise a viable poliovirus from commercially available chemicals and the genome sequence for polio obtained by mail order supply. The recipe was downloaded from the Internet. This proved that these viruses could be reconstructed from blueprints [71].

Future biological agents could be engineered at the molecular level to target specific human biological systems such as cardiovascular, immunological, neurological, and gastrointestinal systems. They could also be used covertly to target a specific civilian population based on genetic or cultural traits. The emerging biotechnologies pose a threat to civilian and military populations and present challenges to biological defence strategies [72].

Anticipated advances in microbiology, molecular biology and genetic engineering may play a dual role. While contributing to improve the quality of human life, easy access to the readily available information provides unlimited opportunities for individuals with a motive to develop sophisticated biological weapons. A biological weapon attack could result in death and economic losses to society [73].

This may mean that international conventions such as the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and their destruction (BTWC), may need to be modified in view of the evolving threats posed by advances in biotechnology. Recently some in the biomedical community have suggested strengthening of the BTWC with a legally binding protocol to prevent potential abuse of biological warfare programs [74, 75, 76, 77].

6.8 Recruitment and retention

There is a possibility that new discoveries, techniques and tools of modern biotechnology may increase human life span beyond the current average. In 2000, the average life expectancy for an Australian male was 77; for females it was 83 years [78]. Longevity is expected to surpass the theoretical age limit previously set at 120 years [79]. As people become healthier and live for much longer, particularly in developed countries, this expectation could serve to influence perceptions of working lives and retirement plans [80]. This expectation could also alter the generally accepted concept in the ADF of retiring at 55 years of age. There is possibility for delayed retirement for those soldiers wishing to continue their employment in the ADF.

Given that populations in most OECD countries including Australia are aging, the traditional pool (18 – 24 age group) of potential ADF recruits may shrink [81]. A stronger economy and short supply of skilled young applicants could result in tough competition for talent with other government and private industry sectors for potential candidates. This raises the possibility of lateral recruitment of older people to the ADF, not just those in the late teens and early twenties.

7. Conclusion

Rapid developments in biotechnology promise significant health improvements including: molecular based drugs and vaccines to control variety of infectious and genetic diseases; advanced diagnostic tools for accurate genetic testing and risk prevention; non-invasive surgical techniques to minimise pain; gene therapy to treat immune and age related diseases, and enhance non-disease traits; tissue and cell based therapies to replace damaged skin, muscle, and other body functions [9, 4]; and implantable biochips for *in vivo* health monitoring and controlled drug release [15]. Genomic-based applications could eradicate many common and untreatable diseases [20], improve the quality of human health and extend life expectancy [4], and enhance human physical and cognitive capabilities [68].

Genetic modification could produce transgenic crops with enhanced nutritional value, pesticide and herbicide resistance, and extended shelf storage, and crops that can grow faster and tolerate harsh environments. Other possibilities include plant-derived vaccines, modified plants and bacteria to monitor the environment for pollutants, and farm animals that have been genetically engineered to resist disease, enhance production, and produce human proteins to treat diseases. There are indications that these new applications could be in the market by the year 2015 [4].

Some of these applications might help soldiers survive and perform better in the 21st Century battlefield. There is potential to benefit from the possibility of a reduction in the logistics burden, added battlefield intelligence, improved communication and decision-making, and survivability [38].

The realisation of these applications will depend on a variety of factors such as social and cultural acceptance of technological change, levels of technology and infrastructure investment in respective countries, market drivers and other structural determinants. Technological impacts may also vary between the developed and developing countries [4, 82].

Developments in biotechnology are also raising significant social and cultural issues and challenges. There are concerns that some of these developments may lead to new forms of ideology, and could threaten established social structures. Indeed, some of these perceptions have contributed to limit the extent of certain aspects of biotechnology research and development.

From the military viewpoint, biotechnology presents an opportunity for radical changes to a broad range of capabilities, especially enhancement of individual soldiers' readiness, protection of information infrastructures, and warfare defence. It could provide the Army with significant advantages in the next decade or two. An emerging threat from biotechnology is the potential for bioweapons development and proliferation, which may change conventional war patterns and threaten regional security. There is a danger for bioweapons to be incorporated into the weaponry of terrorist organisations and states experiencing regional instability where they could be used for social and political purposes.

8. Acknowledgements

We would like to thank Neville Curtis and Peter Dortmans for providing some insightful comments and advice in the framing of this report.

9. References

1. The Convention on Biological Diversity, Article 2, 1992.

2. Biotechnology Australia, Biotechnology Food Timeline, Commonwealth of Australia.

3. Prime Minister's Science, Engineering and Innovation Council, Molecular medicine, paper prepared by an independent working group, sixth meeting, 30 November 2000, pp. 3, 7 & 8.

4. Antón, P.S., Silberglitt, R., Schneider, J., The global technology revolution: Bio/nano/materials trends and their synergies with information technology by 2015, RAND's National Defense Research Institute, Santa Monica, 2001, pp. 1–2.

5. Houghton, J., Information technology and the revolution in healthcare, Pharmacy Industry Project – Equity, sustainability and industry development, Centre for strategic economic studies, Victoria University of Technology, Melbourne, Australia, Working paper no. 4, June 2002, pp. 1 & 35.

6. Australian Bureau of Statistics, Science and technology statistics update, Commonwealth of Australia, Bulletin no. 7, December 2002.

7. The Institution of Engineers, Australia, Submission to the National Research Priorities Taskforce, August 2002.

8. Economic and Social Research Council Genomics Scenarios Project, Key drivers of genomics: Forecasts for 2015, Scenario Workshop, Centre for Research on Innovation and competition, University of Manchester, U.K., January 16 –17, 2002, p. 7.

9. Nakamura, R.M., Technology that will initiate future revolutionary changes in healthcare and the clinical laboratory, Clinical Laboratory Analysis, vol. 13, no. 2, 1999, pp. 49-52.

10. Meldrum, D., Automation for Genomics, Part One: Preparation for sequencing, Genome research, vol. 10, no. 8, August 2000, p. 1090. Review.

11. Brown, P.O., and Botstein, D., Exploring the new world of the genome with DNA micro arrays, Nature Genetics Supplement, vol. 21, 1999, pp. 33-37.

12. Meldrum, D., Automation for genomics: Part two: Sequencers, micro arrays, and future trends, vol. 10, no. 9, September 2000, pp. 1294-1295, 1298. Review.

13. The Economist, Microchips in the blood, vol. 364, no. 8291, 21 September 2002, p.7.

14. Science Daily News, First protein 'biochips' may deliver improved detection, diagnosis, 3 July 2000.

15. The Economist, London, The quest for the protein chip, vol. 366, no. 8315, 15 March 2003, p.15.

16. Chakravarti, A., Population genetics—making sense out of sequence, Nature Genetics Supplement, vol. 21, January 1999, p. 56.

17. Jain, K.K., From molecular diagnostics to personalised medicine, Meeting Report, The IBC workshop, London, UK, 1 May 2002. p. 299.

18. Access Excellence Glossary, National Health Museum, Washington, DC.

19. Daar, A.S., Thorsteinsdóttir, H., Martin D.K., Smith, A.C., Shauna Nast, S., and Singer, P.A., Top 10 Biotechnologies for improving health in developing countries, University of Toronto Joint Centre for Bioethics, 3 October 2002, p. 7.

20. Daar, A.S., Thorsteinsdóttir, H., Martin D.K., Smith, A.C., Shauna Nast, S., and Singer, P.A., Top ten biotechnologies for improving health in developing countries, Nature genetics, vol. 32, 3 October 2002, p. 229– 230. Commentary.

21. Webster, D.E, Thomas, M.C, Strugnell, R.A., Dry, I.B., and Wesslingh, S.L., Appetising solutions: An edible vaccine for measles, Medical Journal of Australia, vol. 176, 6 May 2002, p. 435.

22. Van Reenen, C.G., Meuwissen., T.H.E., Hopster, H., Oldenbroek, K., Kruip, T.A.M., and Blokhuis, H.J., Transgenesis may affect farm animal welfare: A case for systematic risk assessment, Animal Science, vol. 79, 2001, p. 1764.

23. Pew Initiative on Food and biotechnology, Future fish: Issues in science and regulation of transgenic fish, Overview of report, Washington DC, January 2003, p. 2.

24. Morley, K., Pharmacogenetics and pharmacogenomics, Fact sheet 6, Office of Public Policy and ethics, Institute for Molecular Bioscience, The University of Queensland, Australia, September 2002.

25. Gurwitz, D., Pharmacogenomics will reduce prescription-related medical errors, British Medical Journal, 31 December 1999.

26. UNESCO, The use of embryonic stem cells in therapeutic research, Paris, 6 April 2001, p.1.

27. New Scientist, Stem cells migrate from bone to brain, 20 January 2003.

28. GeneInformation.org., Stem cells and their possible uses, September 2001. http://www.geneinformation.org/author-whatarestemcells.htm

Accessed 11 Feb 2004.

29. New Scientist, Australia OKs human embryo research, 5 December 2002.

30. Fry, J.W., and Wood, K.J., Gene therapy: potential applications in clinical transplantation, Expert reviews in molecular medicine, Cambridge University Press, UK, 8 June 1999, pp.2-3.

31. Committee on Science, Engineering, and Public Policy (CLOSEP), Board on Life Sciences (BLS). Scientific and medical aspects of human reproductive cloning, National Academy Of Sciences National Academies Press, 2002, p.24.

32. BBC News, Animal cloning: What is the future?, Friday, 4 January, 2002.

33. New Scientist, Dolly the sheep dies young, 14 Feb 2003.

34. Ardeshir, B., Science, medicine, and the future: Bioinformatics, British Medical Journal, vol. 324, 27 April 2002, p.1018. Clinical review.

35. The Economist, Bioinformatics: The race to computerise biology, December 12, 2002.

36. Woodhouse, D., Rice genome falls to science, BBC News online, Friday, 26 January, 2001.

37. Australian Broadcasting Corporation, Molecular computers move closer, News in Science, 28 August, 2000.

38. National Academy of Science (US), Opportunities in biotechnology for future army applications, Report of the Board on Army Science and Technology (BAST), Washington, D.C. 2001.
Online: <http://books.nap.edu/books/0309075556/html/pagetop>

39. Kiernan, V., DNA-based computers could race past supercomputers, researchers predict, Chronicle of Higher Education, November 28, 1997.

40. Adleman, L.M., Molecular computation of solutions to combinatorial problems, Science, vol. 266, November 1994, pp. 1021-1024.

41. The San Diego Biotech Journal, Spider silk technology, Jan/Feb, 2002, p.14.

42. Chang, K., In experiment, mammal cells produce silk like a spider's, The New York Times, January 18, 2002, Friday, p. 15.

43. Jürgen, S., Karl-Heinz, G., Frank, G., and Udo, C., Production of spider silk proteins in tobacco and potato, Nature Biotechnology, vol. 19, no. 6, June 2001, p.573.

44. U.S. Department of Justice, National Institute of Justice, Special Report: Using DNA to solve cold cases, July 2002, p. 5.

45. Connors, E., Lundregan, T., Miller, N., and McEwan T., Convicted by juries, exonerated by science: Case studies in the use of DNA evidence to establish innocence after trial, U.S. Department of Justice, June 1996.

46. Ben Selinger and Ben Magnusson, The Scientific Basis of DNA Technology, Proceedings of a Conference on DNA and Criminal Justice, held at the Australian Institute of Criminology, Canberra, 30-31 October 1989, p. 2-3.

47. Kakesako, G.K., Search for answers on Korea unknowns begins at Punchbowl, Honolulu Star-Bulletin, 15 September 1999.

48. Davies, J. A., Identifying victims may take months, The Age, October 18 2002.

49. Biotechnology Australia, Fact Sheet 12: Implications of biotechnology for the rural sector, Commonwealth of Australia, Canberra, 2002.

50. IFT Expert report on biotechnology and foods, Benefits and concerns associated with recombitant DNA biotechnology-derived foods, section reprinted from Food Technology, vol. 54, no. 10, October 2000, pp. 45, 49.

51. Genomes to Life Program, U.S Department of Energy, Energy Department-Funded scientists decode DNA of Bacterium that cleans up uranium contamination and generates electricity, Thursday, 11 December 2003. DOE R-03-285.

52. B. A. Methé et. al. Genome of *Geobacter sulfurreducens:* Metal Reduction in Subsurface Environments, Science, 12 December 2003, 302: 1967-1969. (in Reports).

53. Chaudhuri S.K., & Lovley, D.R., Electricity generation by direct oxidation of glucose in mediatorless microbial fuel cells, nature biotechnology, October 2003, Volume 21, Number 10, pp 1229 – 1232.

54. Scholz F. & Schroder U., Bacterial batteries, Nature Biotechnology, vol. 21, no. 10, October 2003, pp. 1151 –1152.

55. Zadoroznyj, M., The 'New genetics', Health and social inequalities: Whose decisions, Whose responsibilities? Invited paper at the Academy of the Social Sciences Workshop on the Ethical, Social and Legal Implications of the Human Genome Project, Dec. 2000.

56. Patrice Trouiller, Els Torreele, Nick White, Susan Foster, Dyann Wirth, and Bernard Pecoul, Drugs for neglected diseases: A failure of the market and a public health failure?, pp.945 – 946.

57. World Health Organisation, Genomics and World Health, Report of the Advisory Committee on Health Research, Summary, Geneva, 2002, pp. 17-18.

58. Jeffords, J.M., and Daschle, T., Policy issues: Political issues in the genome era, Science Magazine, vol. 291, no. 5507, 2001, pp. 1249-1251.

59. Duncan, N., World Medical Association opposes Iceland gene database, British Medical Journal, vol. 318, p. 1096, April 24, 1999.

60. Bbobrow, M., and Sandy, T., Patents in a genetic age, Nature, vol. 409, 15 February 2001, pp. 763-764.

61. Heller, M. A., Eisenberg, R. S., Can patents deter innovation? The anticommons in biomedical research, Science, vol. 280, no.5364, 1998, pp. 698-701.

62. Foubister, V., Gene patents raise concerns for researchers, clinicians, American Medical News, Feb. 21, 2000.

63. Appleyeard, B., The gene gene, The Sunday Times Magazine, Feb 14, 1999.

64. Annas G. J. Genism, Racism, and the prospect of genetic genocide, Paper presented at the World Conference Against Racism, Durban, South Africa, September 3, 2001, pp. 1-7.

65. Dale, P.J., Public concerns over transgenic crops, Genome Research, vol. 9, no. 12, Dec 1999, pp. 1159-1162.

66. Eike, M.C., GM Food: Controversy and uncertainty, Paper for the 3rd POSTI International conference, London, U.K., 1-3 December 2000, p. 7-8.

67. Swan, N., Genetically modified food products, Health Report, ABC Radio National, Monday 22 February 1999.

68. Roco, M.C., Bainbridge, W.S., Converging technologies for improving human performance: Nanotechnology, biotechnology, information technology and cognitive science, National Science Foundation, Arlington, Virginia, June 2002.

69. Wheels, M., & Dando, M., New technology and future developments in biological warfare, United Nations Disarmament Forum – Biological weapons: from the BWC to Biotech, 2000, p.45.

70. Finkel, E., Australia. Engineered mouse virus spurs bioweapon fears, Science, 2001, Jan 26; 291(5504):585.

71. Whitehouse, D., First synthetic virus created, BBC News, 11 July 2002.

72. James B. Petro, Theodore R. Plasse, Jack A. Mcnulty, Biotechnology: Impact on Biological Warfare and Biodefense, Biosecurity & Bioterrorism, vol. 1, no. 3, pp. 161-168, 2003.

73. Alibeck, K., Biological weapons: Past, present and future, In Layne S. P; Beugesdijk T J., and Patel C.K.N., Firepower in the lab: Automation in the fight against infectious diseases and bioterrorism. Joseph Henry press, Washington D. C., 2001, pp. 81, 185.

74. Whitby, S., & Dando, M., The biomedical community and the biological and toxin weapons convention, BMC News and Views 15 August 2001, 2:6. Editorial.

75. Littlewood, J., Preparing for a successful outcome to the BTWC sixth review conference in 2006. Strengthening the Biological Weapons Convention Briefing

Paper no.11 (Second Series), Department of Peace Studies, University of Bradford, United Kingdom, December 2003.

76. Parliamentary Office of Science and Technology, Infectious disease European Molecular Biology Laboratory (EMBL) Conference, Heidelberg, Germany, 8-9 November 2002, p.4. Report.

77. Dando, M., Bio-weapons convention fails to keep up with evolving threats, Jane's Intelligence Review, 1 February 2002.

78. Australian Bureau of Statistics, Year Book 2003, Population Deaths, Catalogue 1301.0 – 2003.

79. BBC News, No limit to human life span, 28 September 2000.

80. Coleman, T., Beyond Uncertainty - Turning Risk into Value, Presidential address presented to the Instititute of Actuaries of Australia, Melbourne, 11 December, 2002.

81. Discussions from the New South Wales Syndicate "D", Are there lessons in personnel retention and recruiting that Defence can learn from industry?, Defence and Industry Study Course.

82. Sager, B., Scenarios on the future of biotechnoogy, Technological Forecasting and Social Change, no. 68, 2001, pp. 109- 129.

10. Glossary

Antibody
A protein found in the blood serum which is formed in response to the presence of an antigen.

Antigen
Foreign macromolecule which does not belong in the host body and which can be bound by antibody or by T-cell receptor.

DNA [deoxyribonucleic acid]
A double-stranded, helical nucleic acid molecule that is the carrier of genetic information.

Functional food
Food that has properties beyond the traditional nutrients it contains, and has been enhanced with specific nutrients or chemicals.

Functional genomics
The study of genes, their resulting proteins, and the role played by the proteins the body's biochemical processes.

Gene
A discrete unit of hereditary information that consists of DNA and is located on the chromosomes.

Genomics
The study of genes and their function.

Genotype
The genetic constitution of an organism, as distinguished from its physical appearance (its phenotype).

Messenger RNA [mRNA]
A type of RNA that relays the genetic information from the DNA in the nucleus to ribosomes in the cytoplasm.

Monoclonal antibody
An antibody that is mass produced in the laboratory from a single clone and that recognises only one antigen.

RNA (Ribonucleic acid)
A single-stranded nucleic acid molecule involved in protein synthesis. The structure of RNA is determined by DNA.

Subunit vaccines
Are vaccines that use only a defined subunit of the bacterium or virus to stimulate a strong immune response.

Structural genomics
The effort to determine the 3D structures of large numbers of proteins using both experimental techniques and computer simulation.

DNA computing
Uses biochemical processes based on DNA.

Bioinspired computing
Applies biological laws to computer design.

DISTRIBUTION LIST

Overview of Biotechnology Futures: Possible Applications to Land Force Development

Margaret Egudo

AUSTRALIA

DEFENCE ORGANISATION

		No. of copies
Task Sponsor	**DG FLW**	**1**
S&T Program		
Chief Defence Scientist		shared copy
FAS Science Policy		
AS Science Corporate Management		
Director General Science Policy Development		
Counsellor Defence Science, London		Doc Data Sheet
Counsellor Defence Science, Washington		Doc Data Sheet
Scientific Adviser Joint		1
Navy Scientific Adviser		Doc Data Sht & Dist List
Scientific Adviser - Army		1
Air Force Scientific Adviser		Doc Data Sht & Dist List
Scientific Adviser to the DMO		Doc Data Sht & Dist List
Systems Sciences Laboratory		
Chief of Land Operations Division		Doc Data Sht & Dist List
Research Leader Human Systems Integration		1
Research Leader Operations Research		1
Head: Land Future Studies (Joanne Nicholson)		1
Author: Margaret Egudo		1
Information Sciences Laboratory		
Mr Kevin Dean (DSAD)		1
DSTO Library and Archives		
Library Edinburgh		1 & Doc Data Sheet
Defence Archives		1
Capability Systems Division		
Director General Maritime Development		Doc Data Sheet
Director General Land Development		1
Director General Capability and Plans		Doc Data Sheet
Assistant Secretary Investment Analysis		Doc Data Sheet
Director Capability Plans and Programming		Doc Data Sheet
Director Trials		Doc Data Sheet

Office of the Chief Information Officer

Deputy CIO	Doc Data Sheet
Director General Information Policy and Plans	Doc Data Sheet
AS Information Strategies and Futures	Doc Data Sheet
AS Information Architecture and Management	Doc Data Sheet
Director General Australian Defence Simulation Office	Doc Data Sheet
Director General Information Services	Doc Data Sheet

Strategy Group

Director General Military Strategy	Doc Data Sheet
Director General Preparedness	Doc Data Sheet
Assistant Secretary Strategic Policy	Doc Data Sheet
Assistant Secretary Governance and Counter-Proliferation	Doc Data Sheet

Navy

Director General Navy Capability, Performance and Plans, Navy Headquarters
Doc Data Sheet

Director General Navy Strategic Policy and Futures, Navy Headquarters
Doc Data Sheet

Maritime Operational Analysis Centre, Building 89/90 Garden Island Sydney NSW
Doc Data Sht & Dist List

Army

ABCA National Standardisation Officer, Land Warfare Development Sector, Puckapunyal
e-mailed Doc Data Sheet

SO (Science), LHQ, Victoria Barracks, Paddington NSW 2021
Doc Data Sheet & Exec Summ

SO (Science), Deployable Joint Force Headquarters (DJFHQ) (L), MILPO Gallipoli Barracks, Enoggera QLD 4052
Doc Data Sheet & Exec Summ

SO (Science), 3 Bde, Lavarack Barracks, MILPO Townsville QLD 4813
Doc Data Sheet & Exec Summ

SO (Science), 1 Bde, Robertson Barracks, Palmerston NT 0830
Doc Data Sheet & Exec Summ

SO (Science), Training Command – Army, HQ TC-A, Suakin Drive, Georges Heights NSW 2088
Doc Data Sheet & Exec Summ

SO (Science), Special Forces, Maritime Headquarters, Garden Island, NSW
Doc Data Sheet & Exec Summ

Joint Operations Command

Director General Joint Operations	Doc Data Sheet
Chief of Staff Headquarters Joint Operations Command	Doc Data Sheet
Commandant ADF Warfare Centre	Doc Data Sheet
Director General Strategic Logistics	Doc Data Sheet

Intelligence Program

DGSTA Defence Intelligence Organisation	1
Manager, Information Centre, Defence Intelligence Organisation	email pdf

Assistant Secretary Corporate, Defence Imagery and Geospatial Organisation
Doc Data Sheet

Defence Materiel Organisation

Deputy CEO	Doc Data Sheet
Head Aerospace Systems Division	Doc Data Sheet
Head Maritime Systems Division	Doc Data Sheet
Chief Joint Logistics Command	Doc Data Sheet
Head Materiel Finance	Doc Data Sheet

Defence Libraries

Library Manager, DLS-Canberra	Doc Data Sheet
Library Manager, DLS - Sydney West	Doc Data Sheet

OTHER ORGANISATIONS

National Library of Australia	1
NASA (Canberra)	1

UNIVERSITIES AND COLLEGES

Australian Defence Force Academy	
Library	1
Head of Aerospace and Mechanical Engineering	1
Hargrave Library, Monash University	Doc Data Sheet
Librarian, Flinders University	1

OUTSIDE AUSTRALIA

INTERNATIONAL DEFENCE INFORMATION CENTRES

US Defense Technical Information Center	2
United Kingdom - Dstl Knowledge Services	2
Canada - Defence Research Directorate R&D Knowledge & Information Management (DRDKIM)	1
NZ Defence Information Centre	1

ABSTRACTING AND INFORMATION ORGANISATIONS

Library, Chemical Abstracts Reference Service	1
Engineering Societies Library, US	1
Materials Information, Cambridge Scientific Abstracts, US	1
Documents Librarian, The Center for Research Libraries, US	1

SPARES	5
Total number of copies: Printed	**33**
PDF	**1**

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
DOCUMENT CONTROL DATA

1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)

2. TITLE

Overview of Biotechnology Futures: Possible Applications to Land Force Development

3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION)

Document	(U)
Title	(U)
Abstract	(U)

4. AUTHOR(S)

Margaret Egudo

5. CORPORATE AUTHOR

Systems Sciences Laboratory
PO Box 1500
Edinburgh South Australia 5111 Australia

6a. DSTO NUMBER	6b. AR NUMBER	6c. TYPE OF REPORT	7. DOCUMENT DATE
DSTO-GD-0419	AR 013-254	General Document	November 2004

8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR	11. NO. OF PAGES	12. NO. OF REFERENCES
E9505-25-171	ARM 02/066	DGFLW	30	70

13. URL on the World Wide Web

http://www.dsto.defence.gov.au/corporate/reports/DSTO-GD-0419.pdf

14. RELEASE AUTHORITY

Chief, Land Operations Division

15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

Approved for public release

OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DOCUMENT EXCHANGE, PO BOX 1500, EDINBURGH, SA 5111

16. DELIBERATE ANNOUNCEMENT

No Limitations

17. CITATION IN OTHER DOCUMENTS Yes

18. DEFTEST DESCRIPTORS

Biotechnology
Technology forecasting
Military applications

19. ABSTRACT

This review of selected scientific and technological advances occurring in the field of biotechnology discusses their possible impact for Land Force capability development in the next decade or two. Some studies suggest that the socio-technical impact of biotechnology may surpass that of the Information Revolution, and it could become a major force in the 21st Century. Its synergy with nanotechnology, materials and information technology has led to the development of new and revolutionary applications that are likely to be adopted in agriculture, health, environmental applications, manufacturing industries, and by the military. The implication of this technological impact has raised complex social, political and legal issues all of which will impact to some degree on the future Land Forces and their operational environment. This report discusses these issues both in relation to how they may affect society and hence future contexts, and their pertinence to the future military in terms of direct application of these technologies.