9

Genetic Engineering and Moral Responsibility

Bruce Small
AgResearch Ltd
New Zealand

1. Introduction

Over the past 12,000 years humans have gradually developed greater understanding and control over life. Agriculture, including plant and animal husbandry, were early important developments. Medicine also contributed to the control of life by fighting disease and more recently through technologies to control and manipulate fertility. Knowledge and technologies from physics and chemistry provide the tools to investigate biological processes at a molecular and even atomic level. Late 20th century and 21st century genetic science heralds remarkable advances in our understanding of life and our ability to control and manipulate it for our teleological endeavours. Emerging biotechnologies are in the foreground of modern scientific research.

Evolutionary theory, Mendel's laws of inheritance, the discovery of DNA, the mapping of the human genome, genetic engineering (GE) of organisms, gene therapy, synthetic biology, cloning, stem cell therapies, epigenetics, and life extension research are theories and technologies providing powerful new insights into the nature of life and the development of technologies to manipulate all aspects of life. This knowledge is deconstructing and reconstructing our knowledge of what life is and what it means to be human, and where humans sit in the order of nature. Table 1 lists a brief selection of important milestones in humanity's understanding and control of life along with some loosely associated worldviews.

Genetic technology has the potential to change biological and social reality. Its development and application have consequences for humans, other animals and the planetary biosphere. These consequences are open to moral evaluation, questions that may be asked include: what are the likely social and moral impacts? is this progress? are these consequences good or bad? does the potential good outweigh the potential bad? for whom? how fair are the consequences? how easily can they be accessed or avoided? and how do different social and biophysical contexts affect their moral status? Another relevant question is, can the positive consequences obtained by use of genetic technology be obtained using alternative technologies (perhaps with less potential for negative consequences)? These questions demonstrate that the practice of genetic science (and indeed science in general) is inextricably bound to moral reasoning, moral behaviour and technological foresighting.

This chapter will investigate the social and moral issues that surround various aspects of new genetic technologies with a particular focus on genetic engineering. These technologies and moral questions will be considered in relationship to the sustainability imperative. Public moral attitudes to genetic engineering will be touched on and contrasted with those of the science community. Finally, the chapter will conclude with a discussion on the rights and responsibilities of scientists in society.

Biological Milestones	**Approx. date**	**Associated worldview**
Agriculture – plant and animal husbandry	10,000BC -	Animistic/magical/mythological
Ancient medicine (e.g.,Imhotep, Hippocrates, Galen)	2500BC – 180AD	Animistic/magical/mythological /religious/Ptolemaic
Medieval medicine (e.g., Avicenna, Ibn an-Nafis, Paracelsus)	1000-1500AD	Religious/Ptolemaic
Renaissance medicine (e.g., Vesalius to Jenner)	1500-1800	Religious/Copernican/scientific
Darwin's Theory of Evolutionary	1860	
Mendel's Laws of inheritance	1865	
Pasteur invents vaccines	1880	
Morgan' discovery of the chromosomes	1915	
Fleming invents antibiotics	1928	Religious/Copernican/scientific/ modernist
Watson and Crick discover DNA	1953	
Fertility control – oral contraceptive, in vitro fertilisation	1960	Copernican/scientific/modernist
Genetic engineering	1971	
Tissue engineering	1987	Copernican/scientific/post-modernist
Gene therapy	(1970) 1990	
Epigentics	1990	
Animal cloning	1996	
Stem cells therapy	1998	
Life extension	2000	
Synthetic biology	2000	

Table 1. Selected milestones in the understanding and control of life, approximate dates and associated worldviews

2. The rise of genetic science

Darwin's Theory of Evolution completely revised our notions of the nature of life and its origins. Species were no longer created individually by God, nor once 'created', were they fixed and immutable. No longer were we a unique and special creature, made in the image of a miraculous supernatural creator, rather, it became apparent that humans were one of approximately ten millions species inhabiting earth, evolving to fit selection pressures in a similar fashion to the other animals on the planet. Gregor Mendel's laws of inheritance statistically demonstrated that characteristics could be passed on from one generation to the next. The discovery, in the early twentieth century by Thomas Hunt Morgan, of chromosomes and the genetic diversity engendered by sexual reproduction, and the mid century discovery of DNA by Crick and Watson provided a causal mechanism for inheritance and a molecular level mechanism for Darwinian natural selection. Technology has enabled the genomes of organisms to be 'read' and compared, showing that humans share more than 98% of our genes in common with the chimpanzee (Jones, 2006), giving us new insights into our biological and moral position within nature.

The Human Genome Project (HGP) achieved three major goals. First, it sequenced the order of all the 2.9 billion base pairs in the genome. Second, it developed maps locating genes for major section of all our chromosomes. Third, it produced 'linkage maps' enabling inherited traits to be tracked over generations. Francis Collins, the director of the HGP described the results and meaning of the HGP as:

> *It's a history book - a narrative of the journey of our species through time. It's a shop manual, with an incredibly detailed blueprint for building every human cell. And it's a transformative textbook of medicine, with insights that will give health care providers immense new powers to treat, prevent and cure disease.*

(Cited by National Human Genome Research Institute, 2009)

As the relationship between genes and individual health and behaviour becomes more apparent, moral questions arise as to who may have access to an individual's genome, and what will they be able to do with this information. As significant a milestone as it is, sequencing of the genome merely marks a beginning. It will take many decades (and massive computer power) to understand how the approximately 20,000 genes in the human genome interact with one another to produce over two hundred thousand different proteins. A great deal is not currently understood about how the genome works. Long held theories continue to be questioned. For example, contrary to the last hundred years of scientific belief, Mendel's Laws have recently been challenged. Although still believed to be fundamentally correct, it has been claimed that Mendel's Laws are not absolute and exceptions occur (Lolle, Victor, Young, & Pruitt, 2005). Likewise, the idea of inherited acquired characteristics was for a long time considered biological and scientific heresy, but the received scientific dogma has been challenged by the new science of epigenetics (Jablonka & Raz, 2009; Kaati, Bygren, & Edvinsson, 2002; Lumey, 1992). Similarly, a dozen years ago, with perhaps a little scientific arrogance, molecular biologists designated long stretches of organisms' genomes as "junk DNA" claiming that these non-coding segments served no purpose. However, it is logically obvious that human lack of knowledge about the function of elements of nature does not mean they lack function.

Recently, research has shown important roles for junk DNA (Nowacki, et al., 2009), demonstrating the hubris of the junk DNA assumption. Indeed, it now appears that junk DNA plays a vital role in evolution (in particular enabling fast genetic adaptation to changing environmental circumstances) and will be crucial for the refining of GE techniques and for gene therapy (Feng, Naiman, & Cooper, 2009; Vinces, Legendre, Caldara, Hagihara, & Verstrepen, 2009). New evidence also suggests that the rDNA repeats known as "junk DNA" are essential for repairing the DNA damage caused by factors such as UV light (Ide, Miyazaki, Maki, & Kobayashi, 2010). The use of technologies with powerful potential to affect the physical and social worlds, without a good understanding of the science involved, has the potential for unexpected and unforeseen negative social and moral impacts.

3. Developments in genetic science and moral questions

3.1 Genetic engineering

The breeding of promising individuals over generations in order to create desirable phenotypic characteristics in plants and animals has long been practiced in horticulture and animal husbandry. This is a relatively slow process with progressive changes made over many generations, not by nature or natural selection, but by human intervention in the evolutionary progress of the species. Racehorses, domestic cattle, show dogs and the staple grains are prime examples of centuries and even millennia of breeding to slowly bend nature to the aesthetic tastes and teleological desires of humans.

In the past forty years, with the discovery of recombinant DNA, humans have gained the power to make changes to an organism's genome in a single generation. Genetic engineering (GE) involves the chemical addition or deletion of a specific gene from an organism's genome in order to bring about a desired change in the organism's phenotype. With this process organisms can have current characteristics enhanced or removed and even entirely new characteristics, not evident in the organism's species, added. Thus, a gene from one species (or a synthetic analogue of the gene), may be spliced into the genome of the same or a different species, or even an organism from a different biological kingdom, giving the new GE organism phenotypic characteristics from the donor species (Small, 2004a).

In this way GE can create organisms with desired attributes much more quickly than traditional breeding (i.e., in a single generation). This amounts to a speeding up of evolution in a direction decided by humans. This also differs from normal evolution and animal and plant husbandry in that the new organism does not co-evolve, in little steps, over time with the other organisms in its environment. Instead an evolutionary leap is engineered within a single generation. Another difference between GE and selective breeding is that organisms can be created that could not possibly have come about naturally, as organisms generally cannot breed with others from different species or kingdoms. Proponents see great hope for the common good of humanity in GE technology, and often claim that the technology will be necessary to produce enough food to feed the future population (Borlaug, 1997; Fedoroff, et al., 2010; Ortiz, 1998).

While GE offers the potential to further bend nature to our desires, critical commentators express concern about negative extrinsic moral impacts. These include the potential to develop dangerous organisms, the impossibility of reversibility once such organisms are loose in the environment, and the potential for negative impacts on humans, other animals and the environment (Antoniou, 1996; Fox, 1999; Ho, 2000; Rifkin, 1998; Straughan, 1995b). Others criticise the technology from an intrinsic moral perspective; creating life is the province of 'God' or nature – human attempts to usurp the role of God or nature are seen as acts of hubris – against God or disrespectful to nature (Appleby, 1999; Straughan, 1995a).

Currently GE is being used to engineer micro-organisms and bacteria (particularly for the production of medicines such as insulin, factor 9 clotting agent, human growth hormone, etc.), plants and animals for food production, production of medicines, industrial production and phytoremediation. An example of a potential GE food animal is the 'eco-friendly' GE pig, engineered to contain bacteria which help pigs remove phosphate from their food, thus stopping it from passing through into the environment, where it causes harm to life in streams and rivers (Golovan, et al., 2001). Pigs have also been genetically engineered to contain human genes, so that their organs will be less susceptible to immune system rejection when used for xenotransplantation (White, Langford, Cozzi, & Young, 1995); the replacement of failing human organs with those from animals.

Advocates of GE claim that the technology is safe. In 2008 GE crops were grown on 300 million acres worldwide. GE crops have been consumed for over 13 years without any incident, it is claimed. Furthermore, production has increased and so have farmers' profits, while pesticide and herbicide use have been reduced and the use of the no-till method of agriculture (helpful for reducing soil erosion) increased (Fedoroff, et al., 2010). However, so far the principal use of GE in food crops has been to engineer insect resistance (bt crops) or to make the crops resistant to a specific herbicide used to eliminate weeds from fields of growing crops – a major beneficiary being the company selling the proprietary herbicide and seeds (one and the same company – Monsanto). On the positive side, the herbicide for which resistance is engineered (Roundup or glyphosate) is relatively environmentally benign and the whole process eliminates the need for further applications of less environmentally benign herbicides.

One possibility presented by GE is the enhancement of nutritional qualities of crops, as for example, the much heralded golden rice. Golden rice has been engineered to contain extra beta-carotene which converts to vitamin A when consumed by humans. Many people in developing countries, where rice is the primary staple, suffer from vitamin A deficiency (Tang, Qin, Dolnikowski, Russell, & Grusak, 2009). Foods with genetically enhanced health qualities or with healthy additives are referred to as functional foods and the science of developing them and studying the relationship between food plant genes, health and the individual human genome is called nutrigenomics. Of course, the societal benefits of functional foods will be dependent upon the public's acceptance of GE food.

Genetic engineering for medical purposes is considerably more acceptable to the general public than GE of food crops (Small, Parminter, & Fisher, 2005). Proponents hope that numerous medicines will be able to be grown in GE plants and/or GE animals and produced more cheaply than through current techniques. A biotech company, SemBioSys, has submitted an Investigational New Drug application for safflower-produced recombinant human insulin to the U.S. FDA (SemBioSys, 2008). Edible vaccines (e.g., potatoes, tomatoes, bananas etc) are being developed for a range of diseases (e.g., cholera, measles, malaria, hepatitis B, type 1 diabetes etc) and are proposed as a logistically simpler resolution of the problem of getting vaccines to those in need in developing countries (Chowdhury & Bagasra, 2007; Levi, 2000). However, it remains unclear how vaccine dosages would be controlled and how accepting the public will be of the conflation of food and medicine. Nonetheless, biotech and pharmaceutical companies have high hopes for rich profit streams from genetically enhanced medical foods and functional foods.

GE animals have been used as 'bioreactors' to produce medicines and industrial products. Cows, sheep and goats have been genetically engineered to produce human proteins in their milk for medical purposes (Wells, 2010). Silk worms have been genetically engineered to produce a form of the human protein collagen which scientists hope to harvest for applications such as artificial skin and wound dressings (Tomita, et al., 2003). The industrial sector also contains many potential applications for GE technology in terms of new methods of producing currently available materials, new materials with desirable qualities, and the production of chemicals and biofuels. For example, spider silk is stronger than steel and as resilient as kevlar, but it is very expensive to produce. Scientist have placed artificial versions of silk genes in various plants (potatoes, tobacco) and animals (goats) and, using this technology, hope to be able to mass produce silk protein for the development of new biodegradable 'super-materials' (Scheller, Guhrs, Grosse, & Conrad, 2001). Gene engineered viruses have even been used to manufacture a 'green battery' which the authors claim is capable of powering an iPod three times as long as current iPod batteries (Lee, et al., 2009).

However, some GE animals seem largely for human entertainment, for example, the first GE pet commercially available in the U.S. was a florescent red zebrafish called a GloFish (GloFish.com, 2010). A company called Lifestyle Pets has marketed a genetically engineered hypoallergenic cat. Given the history of animal breeding for traits of interest to humans, further such applications seem highly probable. Indeed, GE pets suggest mythological sized possibilities; anyone for a pet gryphon? Chimeras are indeed possible using genetic technologies, with a number of research projects having already created them (however, a gryphon might be a bit of a stretch). Of particular concern to some is the possibility of human-animal chimeras (Robert & Baylis, 2003). Robert and Baylis imagine a fusion between a chimp and a human. They suggest that there might be confusion over the status of such a creature and that it might lead to social disorder. However, Savulescu (2003) argues that there might be good reasons to create human chimeras. He suggests medical reasons (e.g., to confer resistance to specific diseases such as AIDS), to delay aging, or to enhance human capabilities.

Clearly, a range of ethical questions are opened by the creation of chimeras. Undoubtedly, there will be a range of different responses to these questions. Another question some ethicists have raised regarding GE animals concerns respect for the *telos* of the animal. Telos refers to the "genetically based drives or instincts that, if frustrated, would result in a significant compromise to the welfare of an animal" (Thompson, 2010, p. 817). Some ethicists claim that it may be morally acceptable to alter an animal's telos using GE so long as it enhances wellbeing (Rollin, 1998), while others have argued that it is not (Fiester, 2008).

3.2 Gene therapy

Another possible target for GE is humans. There is the potential to treat human genetic disorders through GE and a related technology, gene therapy. GE is conducted on eggs or embryos whereas gene therapy is a technique that may be used to change the genome (germ-line cells i.e., eggs or sperm) or the somatic cells of particular organs (in vitro or in vivo) of a developing or already developed organism. Changes made to somatic cells using gene therapy are not inherited by the organism's descendants (Gene Therapy Net, 2010). Gene therapy uses a vector (most usually a disabled virus) to 'infect' target cells with the desired gene. Genetic engineering has successfully produced germ-line changes in marmoset monkeys (Sasaki, et al., 2009). Gene therapy modifications, when conducted on germ-line cells, are also inherited by the organism's descendants. Using such techniques hereditary diseases could be cured and eliminated from the germ-line and the disease potentially eliminated from a species (Gene Therapy Net, 2010).

Despite some initial setbacks (Neimark, 2009) gene therapy is beginning to look very promising, with a number of recent successful trials. Gene therapy has succeeded in curing, amongst other things, some cases of 'bubble boy syndrome', a degenerative disease of vision called 'Leber congenital amaurosis', and a cancer of the blood called 'EBV lymphoma'

(Neimark, 2009). The gene therapy drug ProSavin has been found effective for treating a monkey analogue of Parkinson's Disease and is being trialled with human subjects (Jarraya, et al., 2009). Hope is high for the promise of gene therapy or GE to cure a number of deadly hereditary diseases including cystic fibrosis, hemophilia, Tay-Sachs, muscular dystrophy, multiple sclerosis and diabetes. Gene therapy may also be used to activate the immune system against infectious diseases and cancers and to trick the body into growing new tissue to heal wounds, repair injured hearts and rejuvenate arthritic joints (Neimark, 2009).

3.3 Genetic enhancement

Gene therapy has been used to give colour vision to naturally colour blind monkeys (Mancuso, et al., 2009), suggesting similar enhancements to human senses may be possible. Thus, besides therapeutic human GE, there is also the possibility of using GE to enhance humans. Given the money and prestige involved in sports, and given the human and political propensity for aggression, super athletes and super warriors spring to mind. Doubled muscled cattle (e.g., Belgium Blue) have 20% extra muscle mass, this is known to be caused by a mutation on bovine MSTN, the myostatin coding gene (Grobet, et al., 1997). Scientists have been able to create double muscled GE myostatin knockout mice (McPherron, Lawler, & Lee, 1997). These mice have muscles 2-3 times heavier than normal mice. While extremely rare in humans, at least two children are known to have this mutation naturally, exhibiting exceptional strength and speed (Associated Press, 2007; Schuelke, et al., 2004). This suggests a gene target for super-athletes and super soldiers.

Several genes have been discovered in mice which, when manipulated by GE, improve brain performance by stimulating nerve fibre growth, enhancing problem solving and memory (Routtenberg, Cantallops, Zaffuto, Serrano, & Namgung, 2000). Between 40-80% of variation in human intelligence is believed attributable to genetic factors. A genome wide scan, involving 634 sibling pairs, identified two chromosomal regions (on chromosomes 2 and 6) that explain variation in IQ (Posthuma, et al., 2005). These genes offer clues to increasing the intellectual potential of humans or ameliorating the effects of diseases such as Parkinson's, Alzheimer's, autism and dyslexia. While considerable moral debate is associated with therapeutic GE (i.e., curing disease), enhancement gene technologies create even greater moral concern for most people. Approximately 80% of New Zealand public and a similar percentage of New Zealand scientists either strongly disagreed or disagreed that it is acceptable to genetically engineer humans in order to enhance human capabilities (Small, 2006). However, some ethicists argue that, if we can enhance humans, and so long as this promotes human wellbeing, then we have a moral obligation to enhance (Savulescu, 2005).

Savulescu (2005) cites gene therapy experiments that turned lazy monkeys into workaholics and promiscuous rodents into monogamous ones. Clearly, there may be debate about what counts as an enhancement, and the line between therapy and enhancement is easy to blur. Another social and moral concern regarding enhancement is, who gets it? Only those who can afford it? Is it another means to increase the positional advantage of the wealthy over the poor? To what extent will people choose to alter their genomes or the genomes of their descendants? Will the wealthy, with access to enhancement, become a new type of human from the poor, thus enhancing human inequity at the genetic level? Enhancement raises social and moral issues of justice and fairness. A more extreme but less immediate concern is, will humans evolve (through genetic enhancement) into multiple separate species, unable to breed with each other? What tensions might exist between separate species descended from homo sapiens? Enhancement is laden with social and moral questions.

Given the aforementioned hubris regarding junk DNA and our current lack of understanding of how genes interact with one another to form a multitude of proteins, human considerations of the nature of genetic enhancements might also be deluded. Our efforts may well do more damage to our species than good. Time may tell. Of course, future knowledge may eliminate the threat of lack of knowledge. However, completely understanding the human genome may take some time yet – with approximately 2.9 billion 'letters' the possible combinations and interactions within the genome are astronomical.

3.4 Eugenics or conscious evolution?

Another issue that concerns some people regarding genetic therapy and enhancement is the historically sinister shadow of eugenics. Eugenics "requires that natural selection be replaced by intentional human control" (Hansen, Janz, & Sobsey, 2008, p. S105). Somewhat perversely, human medical control is currently unintentionally replacing aspects of natural selection. Advanced medical interventions enable individuals who would have died before procreation to contribute to the human gene pool. Our moral concern for the health and wellbeing of individual members of our species, unfit under conditions of natural selection, unintentionally or incidentally negatively impacts the overall fitness of the human species.

One thing is clear, new medical and genetic technologies gives us the power to consciously, (or unconsciously), manipulate the evolution of our species. Should we do it just because we can? Or is it too much of an intellectual, moral and ontological minefield? What might be the *unintentional effects* of such tinkering with human nature? If we do it, on what basis should it be done? Should individuals be free to design their own offspring and, if so, what degree of freedom should be allowed? Would it, for example, be acceptable for deaf parents to have their children genetically engineered to be deaf? What are the rights of the genetically engineered offspring in this regard? Who makes the decision and by what authority?

Another possibility is that conscious human evolution might be 'centrally controlled' so that a uniformity remains about our species rather than allowing us the freedom to diverge into a range of new and different species which may have quite disparate capabilities and perhaps even needs. How much 'central control' would be acceptable? Will there come a time when specific genetic enhancements are enforced for the good of the species? Designer babies, conscious evolution and eugenics are complex moral topics raised by current scientific and technological development in the field of genetic science.

3.5 Synthetic biology

"Synthetic biology aims to design and build new biological parts and systems or to modify existing ones to carry out novel tasks" (Parliamentary Office of Science and Technology, 2008, p. 1). Synthetic biology offers prospects for novel methods to produce food, drugs, chemicals or energy, environmental biosensors, and new therapeutic techniques. Engineering principles may be used to build standardised interchangeable segments of DNA for use as biological building blocks to make new, or alter existing, organisms. DNA sequences (potentially even whole genomes) can be designed on computers and manufactured in chemical laboratories. It is possible to construct the genome of a medium-size virus in about three weeks (Parliamentary Office of Science and Technology, 2008).

The potential for the *malevolent* use of synthetic biology is clear. In 2002, researchers from the University of New York constructed the poliovirus by following a recipe downloaded from the Internet using synthetic gene sequences sourced from a mail-order supply firm. Their purpose was to show how easily terrorists could create deadly biological weapons (Cello, Paul, & Wimmer, 2002). It is conceivable, that in the future, entirely new forms of life might be created in the laboratory using the techniques of synthetic biology (Chopra & Kamma, 2006). Synthetic biology attracts the 'do it yourself' brigade', including groups with such exciting names as: OpenWetWare (OpenWetWare, 2009), DIYbio (DIYbio, 2010), Biopunk (Biopunk.org, n.d.), and Biohack (Bishop, 2008). Synthetic biologists in California are about to launch an open source biological production facility called BIOFAB (International Open Facility Advancing Biotechnology). BIOFAB "aims to boost the ease of bioengineering with "biological parts" that are shared resources, standardized and reliable enough that they can be switched in and out of a genome like electronic parts in a radio" (Katsnelson, 2010).

J. Craig Venter, who led the private research project to decipher the human genome in competition with the publically funded project, has been working on creating the world's first synthetic organism since 1995. He envisaged creating organisms that have the ability to manufacture biofuels and other useful compounds. He claims a "new design phase of biology" is about to begin (quoted by Grant, 2008). On May 21, 2010, Venter's team published details of the creation of a synthetic genome that began replicating and producing proteins (Gibson, et al., 2010). Although many useful organisms may be created, the possibility of dangerous ones being created either accidentally or deliberately, is also very real. The Oxford ethicist, Savulescu, reflecting on the achievement of Venter's team said:

> *Venter is creaking open the most profound door in humanity's history, potentially peeking into its destiny. He is going towards the role of a god: creating artificial life that could never have existed naturally. The potential is in the far future, but real and significant: dealing with pollution, new energy sources, new forms of communication. But the risks are unparalleled. (quoted by Henderson, 2010)*

Savulescu continued:

> *We need new standards of safety evaluation for this kind of radical research and protections from military or terrorist misuse and abuse. These could be used in the future to make the most powerful bioweapons imaginable. The challenge is to eat the fruit without the worm. (quoted by BBC News, 2010)*

Biosecurity, biosafety, intellectual property, stakeholder engagement and involvement, unforeseen harmful consequences, human malevolent use of the technology and technological governance are among the serious ethical issues facing synthetic biology.

3.6 Life extension

Impressive work is currently being conducted in the area of life extension (de Grey, 2005; Finkel, 2003). The average life span in the developed countries has been steadily increasing and current projections are that someone born today could potentially live much longer than the current maximum natural full term of around 120 years. It has long been known that calorie restriction (CR) diets can improve the health (in particular reduction of cancers and increased immunity) and extend the life of most mammals by up to 40% (Weindruch, Walford, Fligiel, & Guthrie, 1986). Recently a molecular level epigenetic mechanism for the effects of CR has been proposed (Li, Liu, & Tollefsbol, 2009), glucose restriction produced increased expression of hTERT (human telomerase reverse transcriptase). This provides targets for drugs for life extension.

Telomerase is an enzyme that is responsible for the formation of the telomere DNA sequence. This sequence forms a cap on the ends of chromosomes. Telomeres are responsible for maintaining genomic stability and regulating cellular division. As somatic cells divide the telomere sequences get shorter and shorter, limiting cells to a fixed number of divisions (Harley, Futcher, & Greider, 1990). Cellular senescence and eventually death occur when telomeres reach a critical value. Heritability of telomeres is strong with studies estimating it at 40-80% (Codd, et al., 2010). This is thought to be an important component of aging at a cellular level. Cancer cells preserve their telomeres no matter how many times they divide (i.e., they are immortal). Cancer cells have increased telomerase activity, thus suggesting a possible mechanism for increasing the longevity of normal cells.

A number of genes have been shown to be related to the aging process, the health of individuals throughout their lifespan, and the overall length of lifespan. By manipulating specific genes in various organisms scientist have been able to greatly increase their lifespan. Adding an additional sir-2.1 gene to the genome of *C. elegans* (a nematode worm), led to a 50% increase in lifespan (Tissenbaum & Guarente, 2001). Decreasing the activity of the daf-2 gene led to a doubling of the lifespan of *C. elegans* (Kenyon, Chang, Gensch, Rudner, & Tabtiang, 1993). Single genes which have significant lifespan effects in fruit flies have also been discovered. Mutants fruit flies, with reduced activity (down regulation) of the mth gene (the methuselah gene), have a 35% increase in average lifespan and increased resistance to stressors such as starvation and heat (Lin, Seroude, & Benzer, 1998). Reduced expression of the Indy (I'm not dead yet) gene doubles the fly's lifespan with no noticeable negative side effects (Rogina, Reenan, Nilsen, & Helfand, 2000).

Helfand & Inouye (2003, p. 276) claim that "There is great conservation between different organisms suggesting that what is learned in one model system will be true for others." Research with healthy centenarians (and their very old - 91+ siblings), using genetic linkage analysis, found a region on chromosome 4, that contains between 100 and 500 genes, associated with extra long healthy lives (Puca, et al., 2001). In the past few years a handful of these genes have been identified as important to the aging process (Rucz, 2008). Genetic engineering, gene therapies and stem cell therapies are expected to play a significant role in life extension in terms of rejuvenation of aging or diseased cells and organs and elimination of genetic disorders. Significantly increasing human life spans raises moral problems of justice and fairness in a world still undergoing exponential human population growth and facing depletion of the resources necessary for survival.

3.7 Patenting genes

An important ethical, legal and economic issue with implications for the practice of science, the dissemination of scientific knowledge, and medical practice, is the question of patenting genes and gene sequences (Schacht, 2006). According to an article in Nature Biotech, in the year 2000, over 6000 gene patents had been granted with over 1000 of these specifically related to human genes and more than 20,000 gene patents were pending at that time (Grisham, 2000). While commercial biotech companies are strongly in favour of being able to patent genes, claiming that it is necessary in order to fund research and innovation (Schacht, 2006), many scientists and scientific bodies are opposed to it, claiming that patenting slows the progress of science by restricting open access and use of the genes in further research.

Physicians and patients also claim that patenting of genes restricts patients' access to medical care (Andrews, 2002; Leonard, 2002; Wadman, 2010). Others are strongly opposed to patenting genes on the principle that 'no one should be able to patent life' and that genes are products of nature and are merely discovered by humans and are, therefore, not patentable, as inventions are (Ho, 2000; Wadman, 2010). Some object that the 'patenting of life' "turns organisms, including human parts, into saleable commodities" (Ho, 2000, p. 30).

The topic of gene patenting remains controversial and undecided. It will continue to pose legal, social, moral and economic issues for some time to come.

3.8 Genetic engineering and technological convergence

There are a range of powerful new technologies under development that in convergence will enhance both the power and availability of genetic engineering and other cell based technologies. Two of particular importance are nanotechnology and information technology. Computer processor power has undergone exponential growth since 1965 when Gordon Moore first stated the principle that has become known as Moore's Law; the number of transistors on a chip doubles every two years. This law is still holding true. Also in 1965, I. J. Good proposed a concept that has become known as 'the technological singularity'. This is the point in time when computers become more intelligent than humans, and hence better able than humans to develop their own intellectual capacity, eventually giving rise to super intelligent machines, fostering a near infinite rate of knowledge innovation (Good, 1965). Some futurists consider the technological singularity will occur in the not so distant future. Vinge (1993) predicts 2030 while Kurzweil (2005) predicts 2045. Computers with this level of processing power may enable an understanding and prediction of the interaction of genes leading to a vastly enhanced understanding of genetics and increasing the potential use and power of genetic engineering and related technologies.

Similarly, in the rapidly advancing area of nanotechnology, new tools are being developed that will enhance our understanding and ability to control molecular and cellular behaviour. Nanotechnology will play an important role in the field of tissue engineering and organ regeneration through the generation of biomaterial scaffolding to maintain and regulate cell behaviour such as apoptosis, proliferation and differentiation (Chen, Mrksich, Huang, Whitesides, & Ingber, 1997; McBeath, Pirone, Nelson, Bhadriraju, & Chen, 2004). Small and Jollands (2006) argued that convergence will make these technologies, including genetic engineering, more accessible to an ever widening population. Such accessibility will enhance the ability of the 'do it yourself' brigade to genetically engineer and 'biohack' life. It will also make it increasingly easier for terrorists and others with malevolent intent to use GE technology to cause great harm.

3.9 Genetic engineering and some potential planetary threats

Sustainability has become an ecological, social and moral imperative of our times (Lubchenco, 1998; The World Commission on Environment and Development, 1987). There is currently a range of potential threats to the sustainability of human and other life on earth (Bostrom, 2002; Brown, 2008; Rees, 2003). These threats are related to the increasing number of humans inhabiting Earth and our technological power to effect and impact nature (Small & Jollands, 2006). Main threats include resource depletion, deforestation, land and soil depletion, species extinction, pollution, peak oil, and climate change (Brown, 2008; Rees, 2003). Human behaviour, in particular fossil fuel pollution, is causing climate change, global warming, ice melt, rising sea levels and ocean acidification (Intergovernmental Panel on Climate Change, 2007). These changes will make it increasingly difficult to produce enough food to feed the increasing human population (Fedoroff, et al., 2010; The Royal Society, 2009). Despite the negative impacts of fossil fuel use, without oil it is estimated that the planet can only feed 2-3 billion people (Youngquist, 1999).

The optimistic potential of GE crop production is the development of conventional breeding varieties of crops that are resistant to heat, salinity, drought, disease, pests and toxic heavy metals (The Royal Society, 2009). GE may also be able to increase the effectiveness of plants to extract necessary minerals for growth (such as nitrogen and phosphorus) enabling them to be grown on poorer quality soils using less fertiliser (West, 2010). The Royal Society claimed that the world needs genetically engineered crops to minimise environmental impacts and increase food yields to meet the challenge of feeding another 2.3 billion people by 2050 (The Royal Society, 2009). Another recent paper in the journal *Science* made similar claims (Fedoroff, et al., 2010). Noting that many important crops have sharp declines in production (20-30%) once the temperature exceeds 30 degrees Celsius, they claimed global warming will drastically reduce production in tropical and sub-tropical zones by the mid 21st Century, causing food scarcity.

Fedoroff et al. (2010) claimed that a radical rethink of agriculture is required. They argued for the development of crops which are heat, salt and drought tolerant and which do not require the current high levels of chemicals and fertilisers. Genetic engineering is their preferred radical strategy. They stated that GE will be necessary in order to produce crops at current production levels, let alone the production levels required in 2050 (Fedoroff, et al., 2010). Given the likelihood of significant future temperature increases (Anderson & Bows, 2008; J. Hansen, et al., 2008; Intergovernmental Panel on Climate Change, 2007), water shortages (Brown, 2008; Gleick, 2003; Vorosmarty, et al., 2004), salinity and degraded soil conditions in many of the world's major growing regions (Lal, 2007; Pimentel & Sparks, 2000), genetic engineering of crops is certainly an appropriate research strategy.

However, Fedoroff, et al's. (2010) arguments may be queried on several accounts. First, they made their claims about the *necessity* of GE without considering possible viable alternatives. Second, they ignored the impact of fossil fuel depletion on food production (Pimentel & Pimentel, 1996; Pimentel, Pimentel, & Karpenstein-Machan, 1999; Youngquist, 1999). This is a factor which would further add to their pessimism about actually being able to achieve the goal of feeding the planet's population in 2050. Currently available GE crops are heavily dependent on oil products for their success. Third, they omitted to point out that, so far, no commercial GE plant crops have the particular attributes that they claimed will be beneficial (however, research is being conducted to this end and GE crops may well have these attributes in the future). Fourth, they made their case sound more favourable by failing to note that the beneficial attributes they proposed are attributes that increase the fitness of plants and, therefore, increase the probability that horizontal gene transfer to weedy relatives will also make problem weeds fitter.

Further, it is clear that, even if GE technology did contribute to enable production of adequate supplies of food to feed the population of 2050, there is no guarantee that economic and political action would not thwart these good intentions. Indeed, that is the very reason that, despite the currently adequate food supply, over a billion people still suffer from hunger and thousands starve to death each day (May, 1999). Although it is no reason to stop this line of GE research, there is abundant evidence that having a technological solution to a problem is no guarantee that humans will implement it. If people have no land to produce food themselves, or no money to buy it, they will likely starve, irrespective of any biotechnological bounty. No matter how useful the technology potentially is, the crucial issue is how people will choose to use it. Currently, economics trumps morals.

This well known political fact is probably a major reason why approximately 60% of both the New Zealand public and New Zealand scientists are either sceptical or uncertain about the claim posited by some scientists' that 'GE will help solve the world's food problems'. Regarding this statement a survey of the New Zealand public (n=860) found 9% strongly agreed, 29% agreed, 22% neither agreed nor disagreed, 21% disagreed, 11% strongly disagreed and 7% did not know (Small, 2009). This survey was conducted in May 2005 at the same time as a survey of NZ scientists (n=733) which also asked the same question. A very similar level of scepticism was also evident amongst NZ scientists; only 6% strongly agreed, 33% agreed, 24% neither agreed nor disagreed, 21% disagreed, 10% disagreed strongly and 6% did not know (Small & Botha, 2006).

Nonetheless, GE has the potential to help address several of the planetary threats noted above (including food production). Synthetic genetic organisms could be used to produce fuel to help replace petroleum with bioethanol, butanol and other such products (Sticklen, 2008). Genetically engineered plants could also be used for phytoremediation of polluted soils (Cherian & Oliveira, 2005). Some have suggested that genetically engineered trees may be able to help sequester greater amounts of carbon from the atmosphere – helping to reduce a major cause of climate change and global warming (Jansson, Wullschleger, Kalluri, & Tuskan, 2010). While it would clearly be better to not create these problems in the first place, rather than relying on a 'technological fix' being developed in the future, given the current problems and their magnitude and urgency, it would be foolish not to continue with GE research that may help us address these issues.

3.10 Genetic engineering and the potential for harm

Despite having a large range of intentionally positive applications, it is also clear that GE and gene therapy could create harm in the world through *accidental* unforeseen and unintended side effects, *incidental* effects – known side effects associated with positive intentional effects, or from *malevolent* intent (Small & Jollands, 2006). For example, scientists experimenting with the mouse pox virus (a mouse analogue of smallpox in humans) accidentally succeeded in making the virus much more virulent and deadly –killing even mice vaccinated against the disease (Jackson, et al., 2001).

Area of application	Tech/product	Potential benefits	Potential harms
Food	GE crops	Increased production Less pesticides and herbicides Less fertilisers No till Agriculture (soil conservation) Environmentally resilient crops Crops with enhanced nutritional value	**Extrinsic** Resistant pests (evolve) Super weeds (outcrossing and escape) Irreversibility Single generation evolutionary impacts Conflation of food and medicine Lack of knowledge Accidental or incidental negative impacts on humans, animals, and environment **Intrinsic and emotional** Playing God Disrespectful to nature Morally/spiritually wrong Emotional yuk factor
	GE animals	Increased production Healthier meat More resilient animals (less medicines, increased environmental tolerance)	**Extrinsic** Reduced species diversity Single generation evolutionary impacts Conflation of food and medicine Lack of knowledge Accidental or incidental negative impacts on humans, animals, and environment **Intrinsic and emotional** Playing God Disrespectful to nature Disrespectful to animal telos Morally/spiritually wrong Emotional yuk factor
Medicine	Therapy Medicines derived from GE micro-organisms, plants, animals. Gene therapy Stems cells Tissue engineering	New medicines for curing illness, and injury Organ replacement Elimination of some diseases Increased life expectancy	**Extrinsic** Outcrossing (and/or escape) Irreversibility Lack of knowledge Accidental or incidental negative impacts on humans, animals, and environment Zoonotic disease (e.g. from xenotransplantations) Overpopulation Malevolent actions (GE virus developed as weapon) **Intrinsic and emotional** Same as for GE food animals

Table 2. (continues on next page) Some current applications of GE and some potential benefits and harms (note: these are meant to be illustrative rather than exhaustive)

Area of application	Tech/product	Potential benefits	Potential harms
Medicine	Therapy Medicines derived from GE micro-organisms, plants, animals. Gene therapy Stems cells Tissue engineering	New medicines for curing illness, and injury Organ replacement Elimination of some diseases Increased life expectancy	**Extrinsic** Outcrossing (and/or escape) Irreversibility Lack of knowledge Accidental or incidental negative impacts on humans, animals, and environment Zoonotic disease (e.g. from xenotransplantations) Overpopulation Malevolent actions (GE virus developed as weapon) **Intrinsic and emotional** Same as for GE food animals
	Enhancement Somatic and germ-line therapy (enhanced physical, social mental capabilities, life extension) Chimeras	Enhanced human (and non-human) capabilities Increased human resilience Disease elimination Promotion of human wellbeing Much increased life expectancy	**Extrinsic** Super warriors Eugenics Lack of knowledge Accidental or incidental negative impacts on humans, Fairness/justice Autonomy Species divergence Potential enforcement Overpopulation **Intrinsic and emotional** Playing God Disrespect to nature Disrespectful to human telos Morally/spiritually wrong Emotional yuk factor
Industry	GE Pets GE plants, animals, micro-organisms for manufacturing Chemicals and materials Energy and fuels Synthetic biology Bioinformatics Biomimetics	Pets with reduce allergic potential New and existing chemicals and materials with a range of new or enhanced properties Mitigation of peak oil New production methods and processes	**Extrinsic** Outcrossing or escape Dangerous organisms Irreversibility Competition between food and fuel for land and water Lack of knowledge Accidental or incidental negative impacts on humans, animals, and environment Malevolent bioweapons **Intrinsic and emotional** Same as for GE food crops
Area of application	Tech/product	Potential benefits	Potential harms
Ecosystem services	Phytoremediation Trees with enhanced carbon absorption	Remediation of pollution and toxic sites Climate change mitigation	**Extrinsic** Outcrossing or escape Irreversibility Lack of knowledge Unforeseen or incidental negative impacts on humans, animals, and environment Accidental or incidental negative impacts on humans, animals, and environment Malevolent application as bioweapons **Intrinsic and emotional** Playing God Disrespectful to nature Morally/spiritually wrong

Table 2. (continued) Some current applications of GE and some potential benefits and harms (note: these are meant to be illustrative rather than exhaustive)

The potential to alter human smallpox or to combine genes from different diseases to create super diseases for the purpose of warfare or terror is clear and very real (*malevolent* intent). Indeed, it is reported the former Soviet Union succeeded in using recombinant DNA techniques to combine features of smallpox and Ebola (Katz, 2001). As Sir Martin Rees noted regarding biological and chemical weapons "A few adherents of a death-seeking cult, or even a single embittered individual, could unleash an attack" (Rees, 2003, pp. 48-49). The possibility of creating lethal pathogens that target specific groups in society based on gene markers specific to that group also exists (Katz, 2001). Given the current racial and religious fanaticism demonstrated by some groups in society this is an extremely alarming possibility.

Another a worrying trend is 'do it yourself' (DIY) bioengineering. Reportedly, home hobbyists (often without training in the field) are conducting GE and synthetic biology experiments from information and products found on the Internet and equipment constructed in home labs. Such experiments are conducted without regulation or control. These biohackers, as they call themselves, claim that the future Bill Gates of biotech could be developing a vaccine for cancer in their garage (Wohlsen, 2008). A worrying scenario is that synthetic organisms escaping from uncontrolled home GE labs could cause outbreaks of dangerous diseases and serious environmental damage. Table 2 presents some selected applications of GE technologies along with some potential benefits and some potential harms.

3.11 Challenges to the development and use of GE technologies and products

3.11.1 New Zealand public perceptions of GE and GE products

In the preceding sections, I have considered some potential positive applications of genetic engineering, potential problems with some of these applications, and some potential negative applications of the technology. Of course, the examples considered are only a fraction of the potential applications, the potential benefits and the potential harms. However, from these examples, it is clear that GE technology may result in both benefit and harm. Next, I consider the challenges facing the adoption of GE technologies with applications that ostensibly are 'for good'. Even for technologies with no harmful uses or side effects, in order for them to provide benefit there must be significant degrees of acceptance by society. People have to want and use the products that provide benefit. If people do not want the products then their development may be a very expensive waste of time and resources, which could be better spent elsewhere.

A recent study conducted with a random sample the of New Zealand public (N = 1008) showed complex public attitudes to GE. Small (2009) asked respondents whether they had ever consumed GE food products and whether they had ever used GE medicines. The results are presented in Table 3.

Technology	Yes (%)	No (%)	Don't know (%)
Consumed GE food	20.2	12.1	67.7
Used GE medicine	6.4	23.8	69.8

Table 3. Percent of respondents consuming GE food and using GE medicine (N = 1008)

Most notable is that nearly 70% of respondents did not know whether they had consumed GE food or used GE medicines. Respondents were next asked their level of support for GE food and GE medicine. Results are presented in Table 4.

Level of support	GE food (%)	GE medicine %
Totally support it	7.3	26.2
Support it in some circumstance	61.2	55.0
Totally oppose it	20.8	9.4
Don't know	10.6	9.4

Table 4. Percent of respondents supporting GE food and GE medicine (*N* = 1008)

GE medicine is supported more strongly than GE food, with more respondents finding it acceptable than unacceptable. However, more respondents found GE food unacceptable than acceptable. Of note is the high percent of respondents who are prepared to support both GE food and GE medicine "under some circumstances" This indicates that although they have concerns about GE food and medicine they perceive that under some circumstances it may be justified. Also supporting this contention, 60% of the sample agreed that GE applications need to be considered on a case-by-case basis rather than totally supporting or totally opposing all applications of the technology. For 67% of the respondents their primary concern about GE was potential negative consequences for humans, animals, and the environment, only 6.5% considered their primary concern was that GE is in principle unethical, disrespects nature or is against God, while 26.1% did not have any major concerns about GE technology. Small (2009) also reported that respondents were neutral regarding "GE helping to cure disease" but sceptical about other proposed benefits such as "helping to feed the world", being "environmentally friendly" and being "of more benefit than harm".

3.11.2 The practice of genetic science

The technoethicist Mario Bunge held the position that although pure science "is intrinsically valuable, technology can be valuable, worthless, or evil, according to the ends it is made to serve. Consequently technology must be subjected to moral and social controls" (Bunge, 1977, p. 106). This is a teleological ethical argument. People may reject new technologies, including genetic engineering, for two main ethical reasons (Appleby, 1999; Small, et al., 2005; Straughan, 1995a, 1995b). They may reject it for deontological (intrinsic) reasons (i.e., they consider the technology bad in itself, or an affront to God or nature) or for teleological (extrinsic) reasons (i.e., they believe the consequences of the use of the technology will be bad e.g., negative impacts on humans, animals or the environment). However, generally people tend to use both deontological and teleological reasoning when considering moral issues. When these two ethical perspectives are at odds with one another the individual may weigh the degree of perceived good and bad to reach a 'balanced' conclusion. Understanding public attitudes and moral perspectives may have important social consequences for the development and promulgation of powerful new technologies. The theoretical assumption of post-normal science (Funtowicz & Ravetz, 1993) and the methods of empirical ethics (Borry, Schotsmans, & Dierickx, 2007) may help provide understandings of public perceptions appropriate to policy development regarding genetic engineering.

However, even applications of GE that are developed for good purposes may produce harm. Small and Jollands (2006) identified two primary ways in which technologies developed for good purposes may lead to harm. The first is through *accidental* causes, that is, unforeseen and unintended consequences, that are premised by a lack of knowledge or a lack of precaution regarding the use and potential consequences of the technology. The second is through *incidental* causes or coincidental effects of the technology. In this case there is awareness that the technology has potential harmful side effects, but nonetheless, we choose to use it for the perceived benefits (e.g., for many years leaded petrol was one such technological product). This highlights the importance of two related approaches to harm reduction associated with the development of powerful modern technologies. The first is foresight and the second is the precautionary principle.

Jonas (1985) argued forcefully that, in order to respond to the techno-crises threatening nature and humans, a new ethic of scientific responsibility was necessary. Jonas' (1985) insight, and a contention of the current work, is that modern technology changes the landscape of ethics. In the past, without modern technologies, the effects of human actions were proximally located in time and space and limited by their degree of control of energy and matter, as were their consequent impacts on human life and other conscious beings. Under such circumstances our moral responsibility need extend only as far as the effects of our actions. Now that humans possess sufficient power over nature as to affect the global conditions for human and non-human life, the far-off future and even the physical destiny of the planet, the framework of former ethics is no longer valid.

Jonas (1985, p. x) claimed that to discharge this new moral responsibility "we must lengthen our *foresight* with *a scientific futurology*", by which he meant using scientific knowledge about cause and effect relationships to extrapolate and attempt to predict future states associated with technological development. Bradshaw and Bekoff (2001) and Small and Jollands (2006) made the further claim that any such endeavour must take account of the psychology of human nature, as technological impacts on nature and humans arise from the application of technology *by humans*. Jonas acknowledged that, due to insufficiency of our predictive knowledge, foresight will always be uncertain and incomplete. Therefore, given the magnitude of what is at stake, he proposed that we should adopt a "pragmatic rule to give the prophesy of doom priority over the prophesy of bliss" (p. x). Foresight is a logical prerequisite for teleological ethical reasoning. Both Bunge and Jonas, like more recent technoethicists (e.g., Luppicini, 2008; Moor, 2005), claimed that, because of their role in developing technology, scientists have an extra responsibility (and perhaps accountability) regarding the social and moral impacts of technology.

The precautionary principle is another proposed response to the risks and potential negative impacts of technology on nature and humans. It may be the only possible effective response to existential risk (Bostrom, 2002). One widely accepted formulation of the precautionary principle states: "when an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically" (Raffensperger and Tickner, 1999, cited in Kriebal, et al., 2001, p. 872). The precautionary principle is proposed as a guideline for decision-making. It has four main components: "taking preventative action in the face of uncertainty; shifting the burden of proof to the proponents of an activity; exploring a wide range of alternatives to possible harmful actions; and increasing public participation in decision making" (Kriebal, et al., 2001, p. 872). The term 'precautionary principle' is an English translation of the German word *Vorsorgeprinzip* which might also be translated as 'foresight principle', a translation which focuses on anticipatory action rather than the slightly more negative reactive focus of the English word 'precaution'.

The precautionary principle is, therefore, a teleological ethical approach. As noted earlier, genetic knowledge is still undergoing rapid discovery and revision. Suzuki (2001) pointed out that, considered today, the leading ideas of genetics in 1961 seem naïve and absurd. He made the further plausible claim that many of our current scientific ideas will ultimately be wrong, irrelevant or unimportant. From this, he concluded that the wise approach to technological development is to take a precautionary approach rather than rush to apply the latest ideas. However, such an approach does not necessarily come easily to scientists engaged in leading edge research. Scientists tend to have their focus on the good that could be accomplished from their discoveries (Small, 2011) Indeed, top experts tend to be overly optimistic about the technologies they are developing, often underestimating the risk associated with their field of work and underestimating realisation and diffusion problems (National Science Board, 1977; Rollin, 1996; Ticky, 2004). Less specialised experts were found to be less optimistic than top experts (Ticky, 2004).

Small and Jollands (2006) also identified a third way in which technology may cause harm to nature and humans. This cause of technological harm they called *malevolent.* In this case, the technology is developed specifically to cause harm to humans or the environment. Thus, the 'telos' of such technologies is evil. Nuclear weapons and other weapons of mass destruction are examples of technologies whose telos is evil. Although gene technologies hold fantastic potential for public good and the benefit of humanity, they also hold fantastic potential for harm. In a worst case scenario, through accidental, incidental or malevolent causes, the result could be the demise of life on Earth (Bostrom, 2002; Joy, 2000; Rees, 2003). Much depends upon how and what humans choose to use powerful technologies for. As these technologies become increasingly accessible and available for use by all echelons of society, what humans choose to use these technologies for will be determined by the full range and extent of human nature and human behaviour, from the altruistic to the malevolent. In keeping with the advice of Jonas (1985) to give priority to the prophesy of doom over the prophesy of bliss, a problem that will have to be solved, sooner rather than later, is how to stop the potential malevolent applications of genetic technologies (some of which pose existential threats).

4. Rights and responsibilities of science in society

In the case of genetic engineering it is reasonably clear that some applications of the technology are almost universally acceptable to society (i.e., production of GE insulin raises almost no resistance), and medical applications are generally viewed with reasonable favour. Others, such as GE food raise greater deontological and teleological moral concern for society, but may not be rejected outright and are likely to be considered acceptable under some circumstances (Small, 2005; Small, et al., 2005). Human technology and actions are changing the ecological balance of the planet with some potential catastrophic outcomes (Lubchenco, 1998). Perhaps, if as suggested by Federoff (2010) and The Royal Society (2009), GE technology will be able to help us address these issues, society will consider the circumstances appropriate. However, there are other GE technologies or potential products which society has greater moral trepidation about. The genetic engineering of animals is less acceptable than the genetic engineering of plants or crops, while the use of genetic engineering to enhance human potential is currently very unacceptable to society. Although, to my knowledge, there is no empirical data regarding the public acceptability of genetically engineered weapons of mass destruction, I would suggest that such use of the technology would be considered morally reprehensible by any right thinking person.

A question that the analytical and empirical considerations discussed in this chapter raise is: What are the rights and responsibilities of science and scientists with respect to the wider society in regard to the development of controversial science and technologies such as genetic engineering? A common argument made by scientists working in the field of GE, when considering public criticism of the technology, is that the public are arguing from an emotional rather than a rational perspective and, therefore, their arguments should be dismissed. (As an aside, scientists too might have an emotional stake in the issue – attachment to years of education, passion for their field of science, justification of their own research endeavour and life path, and the social status and financial security provided by their career, etc.).

However, Small (2004b) argued that emotions are just as relevant to humans as rationality. Individuals grow up within a particular culture and are trained to adopt the culture's explicit moral values and assimilate its tacit ones from an early age. These deeply embedded values comprise the core of an individual's self identity and provide a lens through which they examine and evaluate the world and construct personal meaning. People have strong emotional attachments to their core values. To be human is to be both rational and emotional. To deny either of these components is to be less than human. Without our emotions our moral sensibilities would be severely diminish. If we do not respect people's emotional experience then we are not respecting them. When it comes to understanding public acceptance of a technology and respecting people's core values, it is essential that science consider how the technology will impact on people's emotional, moral, cultural and spiritual sensibilities, as well as their rational reasoning (again emphasising the need to foresight the societal implications of new technologies from an understanding of human nature and behaviour). Responsible science is obligated to acknowledge, respect and appropriately incorporate the cultural, spiritual, and moral values of society. This may be an essential requirement for science to gain and maintain the trust and co-operation of society.

Nonetheless, when considering the rights of science in society, Small (2004b) argued that moral beliefs about what is acceptable or unacceptable differ between cultures and societies, and between groups within a society. While some moral values enjoy almost unanimous support (e.g., murder is wrong) others may be more controversial (e.g., abortion is wrong). Similarly, cultures change and evolve over time, along with their moral values. Practices that were once commonplace, and consistent with the moral values of the time, are no longer acceptable in modern societies (or are becoming less so). Slavery, child labour, child marriages, drink driving, environmental pollution, and the death penalty are clear examples. Similarly, practices and values once unacceptable to society, have over time, become more morally acceptable, sometimes even enshrined in changed law. Clear examples include religious freedom, freedom of speech, birth control, homosexuality, divorce, and children born outside traditional marriage (Svensson & Wood, 2003).

Science and ethics are irrevocably intertwined. New knowledge, including that discovered by science, may help to change society's moral, spiritual and cultural values and practices. Science has played a major role in the development of modern western culture and modern values. Two prime historical examples are Galileo's proof of the Copernican heliocentric worldview and Darwin's theory of evolution. These examples are particularly useful because they not only show how science has helped shape modern values but they also show that it can be important for scientists to challenge both the received scientific beliefs of the day and the received spiritual, cultural and moral values of the day. Demonstrating that the Earth revolves around the sun, Galileo removed humans from the physical centre of the universe. Darwin's theory of evolution continued this revolution in thought, removing humans from the spiritual centre of the universe. These scientific theories changed our understanding of our place in nature. They have implications for the moral status of humans, non-human life, and the environment (Small, 2004b).

Galileo and Darwin challenged not only the received scientific wisdom of their time but also the cultural, spiritual and moral norms. Both theories caused moral and religious outrage when first introduced. Today they are the received wisdom. With hindsight we can see that Galileo and Darwin's beliefs were ahead of the rest of society. They are great figures in human history precisely because they had the courage to challenge not only contemporary scientific thought, but also the cultural spiritual and moral values of their time. An essential criterion for scientific progress is that the propositions and theories of science are open to challenge and revision in the light of new evidence. I propose that an important criterion for the evolution of cultural, spiritual and moral values is that they too are open to challenge from new knowledge and new ways of thinking about the world, including scientific progress.

5. Conclusions

I have argued that it is important for the science community to acknowledge, respect and incorporate the cultural, spiritual, and moral beliefs and values of society. I have also argued that, since such beliefs are not immutable, but change over time, it is equally important that science has the freedom to challenge the cultural, spiritual and moral values of society. As the examples of Galileo and Darwin illustrate, challenging values and beliefs is an important way in which science and culture change and progress. Indeed, perhaps raising such challenges is an important responsibility of science to society. The issue then becomes one of finding an appropriate balance between these two somewhat opposed objectives. Not every scientific challenge to the mores of society will eventually be accepted. Science and rationality are very powerful ways of knowing about the world, but they do not necessarily know better than culture, religion, emotion and morality in all situations. Rather, the arguments made above support a post-normal science approach to technological development; indicating the need for openness, debate and ongoing dialogue between science and society about the directions of science and society's cultural, spiritual and moral imperatives. By being open and transparent and engaging in public dialogue and debate about controversial or leading edge scientific research, the science community not only demonstrates social responsibility but may also be on the leading edge of cultural, spiritual and moral evolution of society.

As argued by Jonas (1985), an essential component of this dialogue is the scientific foresighting of the potential biophysical, social and moral impacts of new technologies. In this way scientists can help the public understand the implications of new technologies with respect to the values they hold and the worldly objects they value. Bunge (1977) goes further, arguing that scientists should be held responsible and accountable for the uses to which their technological inventions are put and their impacts on society. It is certainly true that scientists are given credit and praise for the benefits that accrue from their technological inventions and this suggests that, conversely, they should be blamed and held accountable for the harms that accrue. However, in this context, there appears to be an asymmetry between credit and blame. This asymmetry is a consequence of two facts. First, scientists cannot control what others choose to do with the technologies that they develop, and second, as Jonas points out, despite the moral requirement for foresighting the implications and impacts of new technologies, foresight will always remain imperfect. Hence, in the development of powerful new technologies, such as genetic engineering, which have the potential to irrevocably alter human and non-human life, and planetary ecosystems forever, it is essential that the scientific community apply the precautionary principle.

However, debate and dialogue between science and society, while being important moral imperatives for both the science community and the public, will not necessarily provide the science community with the most accurate understanding of public attitudes and values nor indicate the directions in which public mores are trending. Debate and dialogue tend to primarily engage individuals who gravitate to extreme positions leaving the majority unengaged and the subtleties of their positions unrecognised. The relatively new discipline of empirical ethics (Borry, Schotsmans, & Dierickx, 1995, 2005; Borry, et al., 2007) combines normative ethics with descriptive ethics. Descriptive ethics has a social science methodological basis, anchored in the disciplines of sociology, anthropology, psychology and epidemiology, and using qualitative and quantitative scientific methods. The aim of empirical ethics is to combine descriptive ethics understandings of various different publics with the analytical insights of normative ethics to produce contextually relevant moral decisions (Borry, et al., 2007). Post-normal science and empirical ethics may provide methodologically sound techniques for increasing transparency about the social and moral implication of genetic engineering.

6. References

Anderson, K., & Bows, A. (2008). Reframing the climate change challenge in light of post-2000 emission trends. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 366*(1882), 3863-3882. doi: 10.1098/rsta.2008.0138

Andrews, L. B. (2002). Genes and patent policy: rethinking intellectual property rights. *Nat Rev Genet, 3*(10), 803-808. doi: 10.1038/nrg909

Antoniou, M. (1996). Genetic pollution. *Nutritional Therapy Today, December 1996. 6,* 8-11.

Appleby, M. C. (1999). Tower of Babel: Variation in ethical approaches, concepts of welfare and attitudes to genetic manipulation. *Animal Welfare, 8*, 381-390.

Associated Press. (2007). Rare condition gives toddler super strength Retrieved 15 March, 2010, from http://www.ctv.ca/servlet/ArticleNews/story/CTVNews/20070530/strong_toddler_070530/20070530

BBC News. (2010, 20 May). 'Artificial life' breakthrough announced by scientists Retrieved 23 May, 2010, from http://news.bbc.co.uk/2/hi/science_and_environment/10134341.stm

Biopunk.org. (n.d.). Biopunk.org Retrieved 26 January, 2010, from http://www.biopunk.org/

Bishop, B. (2008, 28 January). The open biohacking project / Kit Retrieved 26 January, 2010, from http://biohack.sourceforge.net/

Borlaug, N. (1997). Feeding a world of 10 billion people: The miracle ahead. *Plant Tissue Culture and Biotechnology, 3*, 119-127.

Borry, P., Schotsmans, P., & Dierickx, K. (1995). Empirical research in bioethical journals. *Journal of Medical Ethics, 32*, 240-245.

Borry, P., Schotsmans, P., & Dierickx, K. (2005). The birth of the empirical turn in bioethics. *Bioethics, 19*(1), 49-71.

Borry, P., Schotsmans, P., & Dierickx, K. (2007). Bioethics and its methodology: The rise of empirical contributions. In K. D. Chris Gastmans, Herman Nys and Paul Schotsmans (Ed.), *New Pathways for European Bioethics*. Antwerpen: Intersentia.

Bostrom, N. (2002). Existential risks: Analyzing human extinction scenarios and related hazards. *Journal of Evolution and Technology, 9*(1). Retrieved from http://www.jetpress.org/volume9/risks.pdf

Brown, L. R. (2008). *Plan B 3.0: Mobilizing to save civilization*. New York: W. W. Norton & Company.

Bunge, M. (1977). Towards a technoethics. *Monist, 60*(1), 96-107.

Cello, J., Paul, A. V., & Wimmer, E. (2002). Chemical synthesis of poliovirus cDNA: Generation of infectious virus in the absence of natural template. *Science, 297*(5583), 1016-1018. doi: 10.1126/science.1072266

Chen, C. S., Mrksich, M., Huang, S., Whitesides, G. M., & Ingber, D. E. (1997). Geometric control of cell life and death. *Science, 276*(5317), 1425-1428. doi: 10.1126/science.276.5317.1425

Cherian, S., & Oliveira, M. M. (2005). Transgenic plants in phytoremediation: recent advances and new possibilities. *Environmental Science Technology, 39*(24), 9277-9290.

Chopra, P., & Kamma, A. (2006). Engineering life through synthetic biology. *In Silico Biology, 6*(5), 401-410.

Chowdhury, K., & Bagasra, O. (2007). An edible vaccine for malaria using transgenic tomatoes of varying sizes, shapes and colors to carry different antigens. *Medical Hypotheses, 68*(1), 22-30. doi: 10.1016/j.mehy.2006.04.079

Codd, V., Mangino, M., van der Harst, P., Braund, P. S., Kaiser, M., Beveridge, A. J., et al. (2010). Common variants near TERC are associated with mean telomere length. *Nat Genet, advance online publication*. doi: 10.1038/ng.532

de Grey, A. D. N. J. (2005). A strategy for postponing aging indefinitely. *Studies in Health Technology and Informatics 118*, 209-219.

DIYbio. (2010). DIYbio Retrieved January 26, 2010, from http://diybio.org/

Fedoroff, N. V., Battisti, D. S., Beachy, R. N., Cooper, P. J. M., Fischhoff, D. A., Hodges, C. N., et al. (2010). Radically rethinking agriculture for the 21st century. *Science, 327*(5967), 833-834. doi: 10.1126/science.1186834

Feng, J., Naiman, D. Q., & Cooper, B. (2009). Coding DNA repeated throughout intergenic regions of the Arabidopsis thaliana genome: evolutionary footprints of RNA silencing. *Mol. BioSyst., 5*, 1679 - 1687. doi: 10.1039/b903031j

Fiester, A. (2008). Justifying a presumption of restraint in animal biotechnology research. *American Journal of Bioethics, 8*(6), 36-44. doi: 10.1080/15265160802248138

Finkel, T. (2003). Ageing: A toast to long life. *Nature, 425*(6954), 132-133. doi: 10.1038/425132a

Fox, M. W. (1999). *Beyond evolution: The genetically altered future of plants, animals, the earth... and humans*. New York: Lyons Press.

Funtowicz, S. O., & Ravetz, J. R. (1993). Science for the post-normal age. *Futures*(September), 739-755.

Gene Therapy Net. (2010). What is gene therapy? Retrieved 16th March, 2010, from http://www.genetherapynet.com/what-is-gene-therapy.html

Gibson, D. G., Glass, J. I., Lartigue, C., Noskov, V. N., Chuang, R.-Y., Algire, M. A., et al. (2010). Creation of a bacterial cell controlled by a chemically synthesized genome. *Science*, science.1190719. doi: 10.1126/science.1190719

Gleick, P. H. (2003). Global freshwater resources: Soft-path solutions for the 21st century. *Science, 302*(5650), 1524 - 1528. doi: 10.1126/science.1089967

GloFish.com. (2010). GloFish: Experience the glo Retrieved 8 February, 2010, from http://www.glofish.com/

Golovan, S. P., Meidinger, R. G., Ajakaiye, A., Cottrill, M., Wiederkehr, M. Z., Barney, D. J., et al. (2001). Pigs expressing salivary phytase produce low-phosphorus manure. *Nat Biotech, 19*(8), 741-745. doi: 10.1038/90788

Good, I. J. (1965). Speculations concerning the first ultraintelligent machine. *Advances in Computers, 6*, 31-88.

Grant, B. (2008). Artifical life, a step closer. *TheScientist*. Retrieved from http://www.the-scientist.com/blog/display/54212/

Grisham, J. (2000). New rules for gene patents. *Nat Biotech, 18*(9), 921-921. doi: 10.1038/79381

Grobet, L., Royo Martin, L. J., Poncelet, D., Pirottin, D., Brouwers, B., Riquet, J., et al. (1997). A deletion in the bovine myostatin gene causes the double-muscled phenotype in cattle. *Nat Genet, 17*(1), 71-74. doi: 10.1038/ng0997-71

Hansen, J., Sato, M., Kharecha, P., Beerling, D., Berner, R., Masson-Delmotte, V., et al. (2008). Target atmospheric CO2: Where should humanity aim? *Open Atmos Sci J, 2*, 217-231. doi: 10.2174/1874282300802010217

Hansen, N. E., Janz, H. L., & Sobsey, D. J. (2008). 21st century eugenics? *The Lancet, 372*(Supplement 1), S104-S107. doi: 10.1016/S0140-6736(08)61889-9

Harley, C. B., Futcher, A. B., & Greider, C. W. (1990). Telomeres shorten during ageing of human fibroblasts. *Nature, 345*(6274), 458-460. doi: 10.1038/345458a0

Helfand, S. L., & Inouye, S. K. (2003). Aging, life span, genetics and the fruit fly. *Clinical Neuroscience Research, 2*(5-6), 270-278. doi: 10.1016/S1566-2772(03)00003-3

Henderson, M. (2010, 21 May). Scientists create artificial life in laboratory Retrieved 23 May, 2010, from http://www.timesonline.co.uk/tol/news/science/biology_evolution/article7132299.ece

Ho, M.-W. (2000). *Genetic engineering: Dream or nightmare?: Turning the tide on the brave new world of bad science and big business* (2nd ed.). New York: Continuum.

Ide, S., Miyazaki, T., Maki, H., & Kobayashi, T. (2010). Abundance of ribosomal RNA gene copies maintains genome integrity. *Science, 327*(5966), 693-696. doi: 10.1126/science.1179044

Intergovernmental Panel on Climate Change (Producer). (2007, 24 August 2009). Climate change 2007: Fourth assessment report of the intergovernmental panel on climate change. Retrieved from http://www.ipcc.ch/

Jablonka, E., & Raz, G. (2009). Transgenerational epigenetic inheritance: Prevalence, mechanisms, and implications for the study of heredity and evolution. *Quarterly Review of Biology, 84*(2), 131-176. doi: 10.1086/598822

Jackson, R. J., Ramsay, A. J., Christensen, C. D., Beaton, S., Hall, D. F., & Ramshaw, I. A. (2001). Expression of mouse interleukin-4 by a recombinant ectromelia virus suppresses cytolytic lymphocyte responses and overcomes genetic resistance to mousepox. *J. Virol., 75*(3), 1205-1210. doi: 10.1128/jvi.75.3.1205-1210.2001

Jansson, C., Wullschleger, S. D., Kalluri, U. C., & Tuskan, G. A. (2010). Phytosequestration: Carbon biosequestration by plants and the prospects of genetic engineering. *BioScience, 60*(9), 685-696. doi: 10.1525/bio.2010.60.9.6

Jarraya, B., Boulet, S., Scott Ralph, G., Jan, C., Bonvento, G., Azzouz, M., et al. (2009). Dopamine gene therapy for Parkinson's Disease in a nonhuman primate without associated dyskinesia. *Science Translational Medicine, 1*(2), 2ra4-2ra4. doi: 10.1126/scitranslmed.3000130

Jonas, H. (1985). *The imperative of responsibility: In search of an ethics for the technological age*. Chicago: The University of Chicago.

Jones, S. (2006). Why creationism is wrong and evolution is right. London: The Royal Society.

Kaati, G., Bygren, L. O., & Edvinsson, S. (2002). Cardiovascular and diabetes mortality determined by nutrition during parents' and grandparents' slow growth period. *European Journal of Human Genetics, 10*(11), 682-688. doi:10.1038/sj.ejhg.5200859

Katsnelson, A. (2010). DNA factory launches. *The Scientist*. Retrieved from http://www.the-scientist.com/blog/display/57090/

Katz, R. (2001). Biological weapons: A national security problem that requires a public health response. Princeton: Office of Population Research Princeton University.

Kenyon, C., Chang, J., Gensch, E., Rudner, A., & Tabtiang, R. (1993). A C. elegans mutant that lives twice as long as wild type. *Nature, 366*(6454), 461-464. doi: 10.1038/366461a0

Kurzweil, R. (2005). *The singularity is near*. New York: Viking.

Lal, R. (2007). World soils and global issues. *Soil and Tillage Research, 97*(1), 1-4. doi: 10.1016/j.still.2007.04.002

Lee, Y. J., Yi, H., Kim, W.-J., Kang, K., Yun, D. S., Strano, M. S., et al. (2009). Fabricating genetically engineered high-power lithium-ion batteries using multiple virus genes. *Science, 324*(5930), 1051-1055. doi: 10.1126/science.1171541

Leonard, D. G. B. (2002). Medical practice and gene patents: A personal perspective. *Academic Medicine, 77*(12, Part 2), 1388-1391.

Levi, G. (2000). Vaccine cornucopia: Transgenic vaccines in plants: new hope for global vaccination? *EMBO reports 1*(5), 378-380. doi: doi:10.1093/embo-reports/kvd103

Li, Y., Liu, L., & Tollefsbol, T. O. (2009). Glucose restriction can extend normal cell lifespan and impair precancerous cell growth through epigenetic control of hTERT and p16 expression. *FASEB J.*, Published online. doi: 10.1096/fj.09-149328

Lin, Y.-J., Seroude, L., & Benzer, S. (1998). Extended life-span and stress resistance in the drosophila mutant methuselah. *Science, 282*(5390), 943-946. doi: 10.1126/science.282.5390.943

Lolle, S. J., Victor, J. L., Young, J. M., & Pruitt, R. E. (2005). Genome-wide non-mendelian inheritance of extra-genomic information in Arabidopsis. *Nature, 434*(7032), 505-509. doi: 10.1038/nature03380

Lubchenco, J. (1998). Entering the century of the environment: A new social contract for science. *Science, 279*(5350), 491-497. doi: 10.1126/science.279.5350.491

Lumey, L. H. (1992). Decreased birthweights in infants after maternal in utero exposure to the Dutch famine of 1944-1945. *Paediatric and Perinatal Epidemiology, 6*(2), 240-253. doi: 10.1111/j.1365-3016.1992.tb00764.x

Luppicini, R. (2008). The emerging field of technoethics. In R. Luppicini & R. Adell (Eds.), *Handbook of research on technoethics* (pp. 1-18). Hersey: Idea Group Publishing.

Mancuso, K., Hauswirth, W. W., Li, Q., Connor, T. B., Kuchenbecker, J. A., Mauck, M. C., et al. (2009). Gene therapy for red - green colour blindness in adult primates. *Nature, 461*(7265), 784-787. doi: 10.1038/nature08401

May, R. (1999). Melding heart and head Retrieved 10 March, 2010, from http://www.unep.org/OurPlanet/imgversn/111/may.html

McBeath, R., Pirone, D. M., Nelson, C. M., Bhadriraju, K., & Chen, C. S. (2004). Cell shape, cytoskeletal tension, and RhoA regulate stem cell lineage commitment. *Developmental Cell, 6*(4), 483-495.

McPherron, A. C., Lawler, A. M., & Lee, S.-J. (1997). Regulation of skeletal muscle mass in mice by a new TGF-p superfamily member. *Nature, 387*(6628), 83-90. doi: 10.1038/387083a0

Moor, J. (2005). Why we need better ethics for emerging technologies. *Ethics and Information Technology, 7*(3), 111-119. doi: 10.1007/s10676-006-0008-0

National Human Genome Research Institute. (2009, 27 October). What was the human genome project? Retrieved 15 December, 2009, from http://www.genome.gov/12011238

National Science Board. (1977). Science at the bicentennial. A report from the research community (pp. 154). Washington, DC: National Science Foundation.

Neimark, J. (2009). The second coming of gene therapy. *Discovery,* (September). Retrieved from http://discovermagazine.com/2009/sep/02-second-coming-of-gene-therapy/article_view?b_start:int=0&-C=

Nowacki, M., Higgins, B. P., Maquilan, G. M., Swart, E. C., Doak, T. G., & Landweber, L. F. (2009). A functional role for transposases in a large eukaryotic genome. *Science, 324*(5929), 935-938. doi: 10.1126/science.1170023

OpenWetWare. (2009, 3 March 2009). OpenWetWare Retrieved 26 January, 2010, from http://openwetware.org/wiki/Main_Page

Ortiz, R. (1998). Critical role of plant biotechnology for the genetic improvement of food crops: Perspectives for the next millenium. *Electronic Journal of Biotechnology, 1*(3). Retrieved from http://www.ejb.org/content/vol1/issue3/full/7/

Parliamentary Office of Science and Technology. (2008, January). Synthetic biology. *Postnote, 298*.

Pimentel, D., & Pimentel, M. (Eds.). (1996). *Food, energy and society* (Revised ed.). Niwot: University Press of Colorado.

Pimentel, D., Pimentel, M., & Karpenstein-Machan, M. (1999). Energy use in agriculture: An overview. *Agricultural Engineering International: The CIGR EJournal, 1*, Retrieved 21 January, 2010 from http://www.cigrjournal.org/index.php/Ejounral/article/view/1044.

Pimentel, D., & Sparks, D. L. (2000). Soil as an endangered ecosystem. *BioScience, 50*(11), 947-947. doi: 10.1641/0006-3568(2000)050[0947:saaee]2.0.co;2

Posthuma, D., Luciano, M., de Geus, E. J. C., Wright, M. J., Slagboom, P. E., Montgomery, G. W., et al. (2005). A genomewide scan for intelligence identifies quantitative trait loci on 2q and 6p. *Am J Hum Genet. 2005, 77*(2), 318-326.

Puca, A. A., Daly, M. J., Brewster, S. J., Matise, T. C., Barrett, J., Shea-Drinkwater, M., et al. (2001). A genome-wide scan for linkage to human exceptional longevity identifies a locus on chromosome 4. *Proceedings of the National Academy of Sciences of the United States of America, 98*(18), 10505-10508. doi: 10.1073/pnas.181337598

Rees, M. (2003). *Our final century?* London: William Heineman.

Rifkin, J. (1998). *The biotech century*. London: Victor Gollanz.

Robert, J. S., & Baylis, F. (2003). Crossing species boundaries. *The American Journal of Bioethics, 3*(3), 1-13.

Rogina, B., Reenan, R. A., Nilsen, S. P., & Helfand, S. L. (2000). Extended life-span conferred by cotransporter gene mutations in drosophila. *Science, 290*(5499), 2137-2140. doi: 10.1126/science.290.5499.2137

Rollin, B. E. (1996). Bad ethics, good ethics and the genetic engineering of animals in agriculture. *J. Anim. Sci., 74*(3), 535-541.

Rollin, B. E. (1998). On telos and genetic engineering. In A. Hollands & A. Johnson (Eds.), *Animal biotechnology and ethics* (pp. 156-187). London: Chapman and Hall.

Routtenberg, A., Cantallops, I., Zaffuto, S., Serrano, P., & Namgung, U. (2000). Enhanced learning after genetic overexpression of a brain growth protein. *Proceedings of the National Academy of Sciences of the United States of America, 97*(13), 7657-7662.

Rucz, K. (2008). Longevity genes. *Hungarian Medical Journal, 2*(4), 499-507. doi: 10.1556/HMJ.2.2008.28335

Sasaki, E., Suemizu, H., Shimada, A., Hanazawa, K., Oiwa, R., Kamioka, M., et al. (2009). Generation of transgenic non-human primates with germline transmission. *Nature, 459*(7246), 523-527. doi: 10.1038/nature08090

Savulescu, J. (2003). Human-animal transgenesis and chimeras might be an expression of our humanity. *The American Journal of Bioethics, 3*(3), 22-25.

Savulescu, J. (2005). New breeds of humans: the moral obligation to enhance. *Reproductive BioMedicine Online, 10*(Supp 1), 36-39. Retrieved from www.rbmonline.com.article/1643

Schacht, W. H. (2006). Gene patents: A brief overview of intellectual property issues. Washington: Congressional Research Service - Report for Congress.

Scheller, J., Guhrs, K.-H., Grosse, F., & Conrad, U. (2001). Production of spider silk proteins in tobacco and potato. *Nat Biotech, 19*(6), 573-577. doi: 10.1038/89335

Schuelke, M., Wagner, K. R., Stolz, L. E., Hubner, C., Riebel, T., Komen, W., et al. (2004). Myostatin mutation associated with gross muscle hypertrophy in a child. *N Engl J Med, 350*(26), 2682-2688. doi: 10.1056/NEJMoa040933

SemBioSys. (2008). Insulin Retrieved 4 August, 2008, from http://www.sembiosys.com/pdf/SBS-1723-Product-FS(Insulin).pdf

Small, B. (2004a). Emotion and evolution in science and ethics. *Reflections on the use of human genes in other organisms: Ethical, spiritual, and cultural dimensions*. Wellington: Toi te Taiao - the Bioethics Council.

Small, B. (2004b). *Responsibilities and rights of science in society: the case of placing human genes in other organisms.* Paper presented at the Technologies, Publics and Power: The Terrain of the 6th Framework in New Zealand and Beyond Conference, Akaroa, New Zealand,1-5 February 2004.

Small, B. (2005). *Genetic engineering: New Zealand public attitudes 2001, 2003 and 2005.* Paper presented at the Talking Biotechnology: Reflecting on science in society, Wellington, New Zealand.

Small, B. (2006, 10-12 January). *GE and medicine: A comparison of NZ public and scientists' attitudes.* Paper presented at the New Zealand Bioethics Conference, University of Otago, Dunedin.

Small, B. (2009). Interim Report: New Zealander's Perceptions of Genetic Engineering Including a Comparison with Surveys Conducted in 2001, 2003, and 2005. Hamilton: AgResearch Ltd.

Small, B., & Botha, N. (2006, 23-29 July). *Scientists' moral attitudes and beliefs about genetic engineering* Paper presented at the XVI International Sociology Association Congress, Durbin, South Africa.

Small, B., & Jollands, N. (2006). Technology and ecological economics: Promethean technology, Pandorian potential. *Ecological Economics, 56*(3), 343-358.

Small, B., Parminter, T. G., & Fisher, M. W. (2005). Understanding public responses to genetic engineering through exploring intentions to purchase a hypothetical functional food derived from genetically modified dairy cattle. *New Zealand Journal of Agricultural Research, 48*, 391-400.

Sticklen, M. B. (2008). Plant genetic engineering for biofuel production: towards affordable cellulosic ethanol. *Nature Reviews Genetics, 9*(6), 433-443.

Straughan, R. (1995a). Ethics, morality and crop biotechnology. 1. Intrinsic concerns. *Outlook on Agriculture, 24*(3), 187-192.

Straughan, R. (1995b). Ethics, morality and crop biotechnology. 2. Extrinsic concerns about consequences. *Outlook on Agriculture, 24*(4), 233-240.

Suzuki, D. (2001). Introduction: A geneticist's reflections on the new genetics. In R. Hindmarsh & G. Lawrence (Eds.), *Altered genes II: The Future*. Carlton North, Victoria Australia: Scribe Publications Pty Ltd.

Svensson, G., & Wood, G. (2003). The dynamics of business ethics: a function of time and culture - cases and models. *Management Decision, 41*(4), 350-361.

Tang, G., Qin, J., Dolnikowski, G. G., Russell, R. M., & Grusak, M. A. (2009). Golden rice is an effective source of vitamin A. *Am J Clin Nutr, 89*(6), 1776-1783. doi: 10.3945/ajcn.2008.27119

The Royal Society. (2009). Reaping the benefits: Science and the sustainable intensification of global agriculture. London: The Royal Society.

The World Commission on Environment and Development. (1987). *Our Common Future (The Brundtland Report)*. Oxford: Oxford University Press.

Thompson, P. B. (2010). Why using genetics to address welfare may not be a good idea. *Poultry Science, 89*, 814-821. doi: 10.3382/ps.2009-00307

Ticky, G. (2004). The over-optimism among experts in assessment and foresight. *Technological Forecasting & Social Change, 71*, 341-363.

Tissenbaum, H. A., & Guarente, L. (2001). Increased dosage of a sir-2 gene extends lifespan in Caenorhabditis elegans. *Nature, 410*(6825), 227-230. doi: 10.1038/35065638

Tomita, M., Munetsuna, H., Sato, T., Adachi, T., Hino, R., Hayashi, M., et al. (2003). Transgenic silkworms produce recombinant human type III procollagen in cocoons. *Nat Biotech, 21*(1), 52-56. doi: 10.1038/nbt771

Vinces, M. D., Legendre, M., Caldara, M., Hagihara, M., & Verstrepen, K. J. (2009). Unstable tandem repeats in promoters confer transcriptional evolvability. *Science, 324*(5931), 1213-1216. doi: 10.1126/science.1170097

Vinge, V. (1993). The coming technological singularity: How to survive in the post-human era. *Vision-21: Interdisciplinary Science & Engineering in the Era of CyberSpace Symposium*. Retrieved from http://www-rohan.sdsu.edu/faculty/vinge/misc/singularity.html

Vorosmarty, C., Lettenmaier, D., Leveque, C., Meybeck, M., Pahl-Wostl, C., Alcano, J., et al. (2004). Human transformation of the global water system. *EOS, 85*(48), 509-513.

Wadman, M. (2010). Breast cancer gene patents judged invalid: Court ruling may spell bad news for biotech industry. *Nature, 30 March, doi:10.1038/news.2010.160*.

Weindruch, R., Walford, R. L., Fligiel, S., & Guthrie, D. (1986). The retardation of aging in mice by dietary restriction: Longevity, cancer, immunity and lifetime energy intake. *J. Nutr., 116*(4), 641-654.

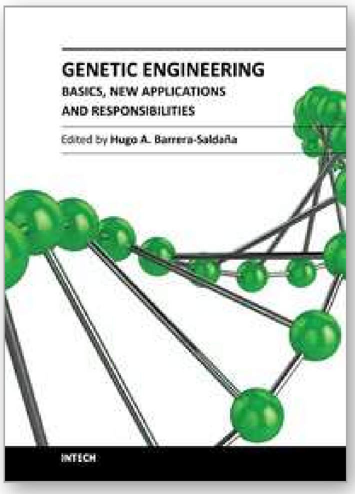
Wells, D. J. (2010). Genetically modified aninals and pharmacological research. In F. Cunningham, J. Elliot & P. Lees (Eds.), *Comparative and veterinary pharmacology* (Vol. 199, pp. 213-226): Springer.

West, A. (2010). *Approaching the limits: Feeding 9+ billion humans whilst sustaining civilisation*. Paper presented at the West Oxford Farming Conference, Oxford. http://gw/noticeboard/Pages/Speeches-2010.aspx

White, D. J. G., Langford, G. A., Cozzi, E., & Young, V. K. (1995). Production of pigs transgenic for human DAF: A strategy for xenotransplantation. *Xenotransplantation, 2*(3), 213-217. doi: 10.1111/j.1399-3089.1995.tb00097.x

Wohlsen, M. (2008, 26 Dec). Hobbyists try genetic engineering at home: Critics worry that amateurs could unleash an environmental or medical disaster Retrieved 21 Jan, 2010, from http://www.msnbc.msn.com/id/28390773

Youngquist, W. (1999). The post-petroleum paradigm -- and population. *Population and Environment: A Journal of Interdisciplinary Studies 20*(4).



Genetic Engineering - Basics, New Applications and Responsibilities
Edited by Prof. Hugo A. Barrera-Saldaña

ISBN 978-953-307-790-1
Hard cover, 256 pages
Publisher InTech
Published online 18, January, 2012
Published in print edition January, 2012

Leading scientists from different countries around the world contributed valuable essays on the basic applications and safety, as well as the ethical and moral considerations, of the powerful genetic engineering tools now available for modifying the molecules, pathways, and phenotypes of species of agricultural, industrial and even medical importance. After three decades of perfecting such tools, we now see a refined technology, surprisingly unexpected applications, and matured guidelines to avoid unintentional damage to our and other species, as well as the environment, while trying to contribute to solve the biological, medical and technical challenges of society and industry. Chapters on thermo-stabilization of luciferase, engineering of the phenylpropanoid pathway in a species of high demand for the paper industry, more efficient regeneration of transgenic soybean, viral resistant plants, and a novel approach for rapidly screening properties of newly discovered animal growth hormones, illustrate the state-of-the-art science and technology of genetic engineering, but also serve to raise public awareness of the pros and cons that this young scientific discipline has to offer to mankind.

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821