# Synthetic Biology

## Church of Scotland

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# Synthetic Biology

## 1. Introduction

1.1 This report has been produced under the auspices of the Society, Religion and Technology (SRT) Project of the Church of Scotland, and sets out to examine some of the ethical, theological, moral and social issues around the field of synthetic biology. This field of research, which has been styled as 'creating life' and 'Life, version 2.0', holds out much promise, but also raises many questions. A glossary of some of the technical terms used is provided at the end of this report; in addition a longer, more technically detailed version of this report is available on the pages of the Church and Society Council of the Church of Scotland website (www.churchofscotland.org.uk).

1.2 Synthetic biology is a new field of scientific endeavour that has strong parallels with the development of the synthetic chemistry revolution of the 19th and 20th century which resulted in many of the great industries of the 20th century[1]. In the 19th century chemists learned how to synthesise compounds that had previously only existed in nature[2]. In 1828 Friedrich Wohler was the first person to synthesise an organic compound – urea – from purely inorganic components. This sent shock waves through the scientific community of the time because it was thought that there was something special and irreducible about living things[3]. This was followed in 1858 by the production of synthetic quinine from benzene leading to the production of a new synthetic purple dye named mauve, and in 1897 the Bayer Company in Germany produced the synthetic drug Aspirin[4]. Synthetic chemistry made possible the development of the pharmaceutical industry as well as much of the food industry, detergents and plastics. It is also important in semi-conductor production which is the basis of all transistors and hence all computers and integrated circuits[5]. Many

[1] Kitney, R.: *An engineer's view of applications.* People and Science, Sept 2009, p. 18. http://www.britishscienceassociation.org/NR/rdonlyres/FC99C5C7-C79A-400D-8C3F-4762954DD981/0/PeopleandScienceSept09.pdf

[2] Johnson, B.: *Scientific community leads on societal response.* People and Science, Sept 2009, p. 22. http://www.britishscienceassociation.org/NR/rdonlyres/FC99C5C7-C79A-400D-8C3F-4762954DD981/0/PeopleandScienceSept09.pdf

[3] Calvert, J.: *Tensions between biology and engineering.* People and Science, Sept 2009, p. 19. http://www.britishscienceassociation.org/NR/rdonlyres/FC99C5C7-C79A-400D-8C3F-4762954DD981/0/PeopleandScienceSept09.pdf

[4] The Royal Academy of Engineering: *Synthetic Biology: scope, applications and implications* (2009). http://www.raeng.org.uk/news/publications/list/reports/Synthetic_biology.pdf

[5] The Royal Academy of Engineering: *ibid*

observers believe that the field of synthetic biology has the potential to create in the 21st century a technological revolution as great as, or even greater than that generated by synthetic chemistry [6].

## 2. Historical Emergence of Synthetic Biology

2.1 Major developments over the last sixty years in the fields of biology, physical sciences and engineering were the precursors to the recent emergence of synthetic biology. Increasing understanding of biological mechanisms and an ability to deploy computing power to analyse large amounts of information have contributed to the development of synthetic biology. Perhaps the most significant relevant breakthrough in biology was the discovery of the structure of DNA by Watson and Crick in 1953 which triggered the molecular biology revolution. The development of DNA sequencing lead to the international effort to sequence the entire human genome, a 10 year project completed in 2001. Work by Claude Shannon in 1948 established the basis for the information and communication technology (ICT) revolution that lead to the high speed telecommunication networks and high performance computers which have been essential to the development of synthetic biology[7].

2.2 A number of reports which include details of the technical development of synthetic biology have been produced; interested readers are particularly referred for further information to the reports of the Royal Academy of Engineering and the Royal Society[8].

## 3. What is Synthetic Biology?

3.1 Synthetic biology, as the term implies, is concerned with artificial or unnatural[9] living organisms or life. Life or living systems is a difficult concept, especially as we tend to think in terms of human or sentient life. However, in the present applications of synthetic biology, life is considered in biochemical terms and is mostly concerned with some of the simplest forms of known life, such as bacteria and viruses. It is

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[6] The Royal Academy of Engineering: *ibid*

[7] The Royal Academy of Engineering: *ibid*

[8] Please see: http://www.raeng.org.uk/news/publications/list/reports/Synthetic_biology.pdf
and http://royalsociety.org/Synthetic-biology-scientific-discussion-meeting-summary/

[9] Cole-Turner, R.: *Synthetic Biology: Theological Questions about Biological Engineering* (p. 136) in *"Without Nature? A New Condition for Theology"* (Albertson, D and King, C (Eds), Cabell. Fordham University Press (2009)

important to grasp that all life forms are composed of molecules (e.g. proteins, sugars, DNA, RNA, lipids), which are in themselves non-living. These molecules are sometimes referred to in synthetic biology as ‘bioparts’. The biochemical definition of life is that of such bioparts assembled within a physical container (i.e. the bacterial cell wall) which are able to continually regenerate, replicate and evolve[10].

3.2 Synthetic biology brings together the two disciplines of biology and engineering and is essentially about the redesigning and reassembly of biological systems, in other words redesigning life[11]. It is about the modifying of present life forms or the creating of new life forms. The biologist wants to understand living systems better, and the engineer wants to create new things[12] . While synthetic biology may be seen as a further development of “genetic engineering” which has given us genetically modified (GM) crops, human growth hormone and human insulin, the key difference is the application to biology of techniques which are used in engineering design and development[13]. The biologist identifies the individual parts or bioparts of the living organism, the engineer then standardises the bioparts (e.g. DNA BioBricks™ as is being undertaken by the BioBricks foundation[14]). The analogy which is sometimes used is that of car manufacture, where the different bioparts are then fitted onto a common ‘chassis’, usually a bacterium such as *E. coli*, where they perform the desired function. The classic engineering cycle of Specification, Design, Modelling, Implementation, Testing and Validation is then adopted in seeking to optimise the performance of these novel systems.

## 4. Why Undertake Synthetic Biology?

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[10] The Royal Academy of Engineering: *ibid*

[11] Royal Society: *Synthetic Biology. Policy Document* 16/08 (2008), p. 2.
http://royalsociety.org/Synthetic-biology-scientific-discussion-meeting-summary/

[12] Calvert, J: *ibid*

[13] The Royal Academy of Engineering: *ibid*

[14] **The BioBricks Foundation (BBF)** (http://bbf.openwetware.org/) is a not-for-profit organization founded by engineers and scientists from MIT (Massachusetts Institute of Technology), Harvard University, and the University of California. BBF encourages the development and responsible use of technologies based on BioBrick™ standard DNA parts that encode basic biological functions. Using BioBrick™ standard biological parts, a synthetic biologist or biological engineer can programme living organisms in the same way a computer scientist can program a computer. The DNA sequence information and other characteristics of BioBrick™ standard biological parts are made available to the public free of charge currently *via* MIT's Registry of Standard Biological Parts. Any individual or organization can design, improve, and contribute BioBrick™ standard biological parts to the Registry. BioBrick™ standard biological parts are used as part of the International Genetically Engineered Machine (iGEM) competition.
The BBF supports an open technical standards setting process that is used to define BioBrick standard biological parts, and other technical matters relevant to synthetic biology research and applications.

4.1 The reasons for doing synthetic biology have much in common with other areas of scientific research, and fall roughly into three classes: utilitarian, curiosity-driven, and wealth-creation.

**4.1.1:** The **utilitarian motivation** imagines that technologies enabling improvements in human functioning and well-being can be brought about by synthetic biology research; for example, better functional materials, food, drugs, diagnostics, detectors or energy sources; environmental remediation (clean-up) and computation[15,16,17,18,19,20].The interest shown in synthetic biology research by some parts of the military-industrial complex also suggests that the utilitarian motivation for some might include a drive to enhanced and novel weapons systems[21].

**4.1.2:** The second kind of motivation is **curiosity-driven** and attempts to answer the question of "what is life?" and to test the evolution paradigm[22, 23]. There is a natural human desire to test the limits of what can be done, perhaps expressed in the proposition "because I can do it, I shall do it". The *de novo* construction of such systems offers "valuable quantitative insight into naturally occurring information processing activities."[24].

4.1.2.1 The exercise of freedom in rational thinking goes one notch deeper in its philosophical motivation. Synthetic biology has been heralded as introducing "Life, version 2.0"[25]. In its ideological extreme, this leads to the philosophical impulse named "transhumanist", or "extropian" in the terminology of the most ardent

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[15] McDaniel, R. and R. Weiss: *Advances in synthetic biology: on the path from prototypes to applications*. Curr. Opin. Biotech. 16: 476–483. (2005) http://dx.doi.org/10.1016/j.copbio.2005.07.002

[16] European Commission NEST Pathfinder: *SYNBIOSAFE: Safety and ethics of synthetic life*. (2007) http://www.synbiosafe.eu/

[17] Kaznessis, Y. N. *Models for synthetic biology*. BMC Systems Biology 1:47. (2007) http://dx.doi.org/10.1186/1752-0509-1-47

[18] van Est, R., H. de Vriend, and B. Walhout: *Constructing Life: The World of Synthetic Biology*. Rathenau Instituut. (2007) http://www.rathenau.nl/

[19] Schmidt, M.: *SYNBIOSAFE e-conference: online community discussion on the societal aspects of synthetic biology*. Syst Synth Biol. 2:7-17 (2008) http://dx.doi.org/10.1007/s11693-008-9019-y

[20] Haseloff, J. and J. Ajioka: *Synthetic biology: history, challenges and prospects*. J. R. Soc. Interface.(2009) http://dx.doi.org/10.1098/rsif.2009.0176.focus

[21] *Synthetic Biology*. The Parliamentary Office of Science and Technology, January 2008 Number 298 http://www.parliament.uk/documents/upload/postpn298.pdf

[22] Benner, S.A., and A. M. Sismour: *Synthetic Biology*. Nature Reviews Genetics 6:533–543. (2005) http://dx.doi.org/10.1038/nrg1637

[23] Harvey, M.: *Synthetic Biology: scientific discussion meeting summary*. Royal Society (London). (2008) http://royalsociety.org/syntheticbiology

[24] McDaniel, R.: *ibid*

[25] Gibbs, W.W.: *Synthetic life*. Scientific American 290: 74-81. (2004)

advocates. This stance may perhaps be summarized such: "We are as gods and might as well get good at it"[26].

**4.1.3:** The third major category of motivation could be defined as **wealth generation**. The fostering of new wealth creating industries and technologies is a stated objective of the UK and other governments [27]. Just as synthetic chemistry lead to the establishment of some of the major industrial companies of the 19th and 20th centuries, synthetic biology is advocated by many (including governments and regulators) as a source of jobs, manufacturing and wealth generation.

## 5. Why is the Church interested in Synthetic Biology?

5.1 What is the right relationship between humanity and nature? Does God give us authority to unpick and reconstruct nature in the fundamental way which seems to be at the core of synthetic biology? While many focus on the call early in Scripture for humanity to 'subdue' creation[28], our relationship with our environment as Scripture unfolds is of course much richer and more complex than simply one of master and servant. As Hodson and Hodson explore in "*Cherishing the Earth*"[29], for example, the spiritual element must be held in concert with the more familiar emotional and physical aspects of a Christian's stewardship of Earth's resources. The spiritual, while perhaps less tangible, is always important to the people of God.

5.2 How far is far enough, and to what extent should our God-given ability to be creative be hemmed in by moral and ethical considerations? In seeking to speak prophetically, the church must always be careful that it actually listens and understands before it speaks. If we wish to discern the mind of God, then we surely have a responsibility to listen to and understand what God says to us.

5.3 A number of important issues are raised by the field of synthetic biology. These include issues such as:

5.3.1: **Reductive approach to life.** In treating biological organisms as little more than sophisticated machines, synthetic biology seems to reinforce a reductive approach to

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[26] Brand, S.: Whole Earth Catalog, Fall 1968. http://wholeearth.com/issue/1010/article/195/we.are.as.gods
[27] The Royal Academy of Engineering: *ibid*
[28] Gen. 1: 28
[29] Hodson, M.J. and M.R. Hodson: "*Cherishing the Earth: How to Care for God's Creation*" Lion (2008)

life and challenges different world-views which do not agree with this particular understanding of life.

5.3.2: **'Playing God'.** In trying to create new life-forms, synthetic biology raises the question of whether humans have elevated themselves to the status of gods, in their ability to create. Some might argue that science has thus transgressed its proper boundaries and acts hubristically against nature and/ or God. These issues are explored more fully in section 11 below.

## 6. Current Activities and Applications of Synthetic Biology

6.1 There has been much research activity in the areas of health, energy, the environment and agriculture. For example, some parts of the production of the anti-malaria drug Artemisinin have already been developed applying synthetic biology techniques in the University of Berkeley. The low cost full scale industrial production of this naturally occurring plant product is presently being funded by the Gates Foundation and it has been claimed that, if successful, it may potentially save 1 million lives each year.

6.2 The development of advanced biosensors for detection of urinary tract infections can also be adapted to detect the hospital superbug MRSA (Methycillin resistant *Staphylococcus aureus*). A similar biosensor can detect arsenic in drinking water – a major problem in Bangladesh. As up to 90% of the biomass from crops such as sugar cane and palm oil is wasted using current processes, more efficient biofuels are being developed which may alleviate problems with land use competition between energy and food crops.

6.3 An example of synthetic biology based biomaterials is a synthetic version of the silk produced by the golden orb spider. Because of its strength and light weight it can be used in a wide range of applications[30].

6.4 Other areas of current research include the use of synthetic biology for nanomotors, biosensors and control systems (e.g. detection of infections, pollutant monitoring) and tissue engineering to refashion/replace damaged tissues (e.g.

[30] The Royal Academy of Engineering: *ibid: Engineering the Salmonella type III secretion system to export spider silk monomers.* Widmaier DM, Tullman-Ercek D, Mirsky EA, Hill R, Govindarajan S, Minshull J, Voigt CA. Mol Syst Biol. 5: 309 (2009)

cartilage architecture). Some other areas where the application of synthetic biology could be of potential benefit are described in the boxes.

## 7. Potential Social and Ethical issues in Synthetic Biology

7.1 Biosafety is a more difficult area in synthetic biology than in traditional genetic engineering, as systems are created which do not exist in nature. Artificially synthesized organisms could have unpredictable and potentially damaging effects when released into the environment either intentionally or accidentally. Although researchers are trying to come up with "safety locks" which could prevent an environmental hazard (e.g. by making the organisms dependent on artificial nutrients which do not readily occur in nature, or by building in a mechanism which would trigger self-destruction once the population reaches a certain density), it is very difficult to predict the effect of these organisms on nature once they leave the protected environment of a science laboratory or test site. In addition, the build–up of novel biological elements in the food–chain is unpredictable and may have unexpected effects.

**7.2: Bioweaponry and Bioterrorism**. Biosecurity awareness has been studied in a SYNBIOSAFE project[31]. This focused on developments mostly in the US and revealed an overall low level of awareness. The potential for development of bioweapons is real. Synthetic biology could be used to create new biological weapons or to recreate extant viruses, as has already occurred with the Spanish Flu virus or the polio virus[32]. In addition to the risk of a terrorist client obtaining the necessary materials from a DNA synthesis company, however, there is the possibly greater risk of "state bio-warfare" as part of a weapons programme to be considered.

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[31] Kelle A.: *Synthetic Biology & Biosecurity Awareness In Europe*. Bradford Science and Technology Report No. 9 (2007)

[32] Center For Disease Control: *Researchers Reconstruct 1918 Pandemic Influenza Virus* (2005); Cello J, Paul AV, Wimmer E: *Chemical synthesis of poliovirus cDNA: generation of infectious virus in the absence of natural template.* Science 297: 1016–8 (2002).

**Box 2: Complex molecular devices**
**Tissue repair/regeneration:** synthetic biology could aid the development of small assemblies which could sense damage in blood vessels and repair them.
**Vectors for therapy**: the design of viruses to deliver healthy genes to the target tissue in an efficient way, or viruses which may be able to recognize specific cells and target them for destruction.
**Personalized medicine**: Synthesis of personalized drugs, adapted in their mode of action, formulation, dosage, and release kinetics to the specific requirements of the patient.
**Cells with new properties that improve human health**: We may be able to modify human cells to achieve new functions and to introduce them back into the donor - for example, cells could be programmed to target specific viruses in a more efficient way. It may be possible to reprogramme cells in order to regenerate organs.
**Environmentally friendly production of chemicals:** As the world's fossil fuel reserves are coming to an end, chemistry needs a new raw materials base.
**Pharmaceuticals:** more effective discovery of new drugs, through new screening and design strategies for anticancer and antituberculosis compounds. Synthetic biology tools may provide avenues to discover small antimicrobial molecules or design new drugs.
**Improved drug production:** The production process for a number of drugs (for example, artemisinin for malaria and taxol for cancer) has been made significantly more efficient by genetic engineering of yeast and bacterial cells to undertake some of the steps involved in their synthesis

**7.3: International justice.** Synthetic biology holds out the promise of the creation of new drugs and therapeutics. However, the question of fair distribution of resources, availability of new drugs and therapeutics to all people still remain. Furthermore, patenting synthetic biology developments could lead to an increased dependence of poor people and countries on rich countries and companies. For example, the previously mentioned anti- malarial drug Artemisinin was originally derived from a plant native to China. Some have argued that the manufacture of such medicinal and other commercially important chemicals through synthetic biology deprives a poorer country of a potential source of income.

7.4: **Patenting and creation of monopolies.** In order to allow the interchange of parts of an organism which is fundamental to synthetic biology, a certain amount of 'standardisation' of biological molecules is necessary. Much of the oversight of this work, as has been noted, is undertaken by a small number of academic institutions in the United States through the BioBricks Foundation. This has raised concerns for some about the creation of *de facto* monopolies, for example potentially 'locking out' some developing countries from the technology.

7.4.1 Another potential issue of concern is patenting. While much of the work going on in the field of synthetic biology is conducted under 'open source' agreements, and is therefore not currently under patent, the whole rationale for granting a patent is that it provides the inventor with a monopoly of their invention, albeit for a limited period.

7.4.2 If a device is regarded by law as patentable (and is not excluded because of the existence of prior art or some other valid objection), it is no concern of the patenting bodies that this would create a monopoly - on the contrary, the whole *rationale* for granting a patent is that it does provide the inventor with a monopoly of his invention, albeit for a limited period.

7.4.3 The broader questions of whether such a patent may be morally supportable has (in legislative terms) already been answered to the extent provided for by article 6(1) and (2) of Directive 98/44/EC on the legal protection of biotechnological inventions ("the 1998 directive"). Article 6(1) and (2) renders unpatentable inventions which are "contrary to morality" and this does to some extent create an area of responsiveness to changes in what society at any given time may consider to be morally unacceptable. This is more fully discussed at Paragraph 8.5 below.

7.4.4 If it is to be argued that a system of patents for biotechnological inventions is in principle inappropriate or in some way unbalanced, that is an argument which would require to be pursued in the political arena. Such an argument would raise similar arguments to those concerning the appropriateness of granting pharmaceutical patents, with which there is a broad analogy.

**7.5: Unregulated developments:** “Biohacking”, defined as the manipulation of DNA and other biological materials by hobbyists (as opposed to trained and supervised professionals) already appears to exist as a significant phenomenon in the US[33]. The availability of key reagents and components has opened up the possibility of a “garage industry” in synthetic biology – by definition, operating outwith normal regulated research networks such as university and research facilities. Comparisons have been drawn to the explosion in computer usage and capability over the last two decades, and it could be argued that such a development might not be necessarily harmful, leading to community empowerment. In the same vein, there are those who would contend that developments in synthetic biology should not be the preserve of large companies or indeed governments. However, there are still issues around control and misuse, as well as with unexpected or unintended interactions when synthetic biology creations are released into the environment.

## 8. Factors influencing the Progress of Synthetic Biology

8.1 Synthetic biology is a field in its infancy and several technological obstacles remain which may inhibit its potential. There is a need for new technologies which

[33] Schmidt, M. *et al* (2008): *ibid*

are capable of routine, very rapid, DNA synthesis: this may become an increasing obstacle as the ability to design ever larger genetic devices and systems becomes a reality. The final assembly of synthetic DNA constructs and the reliable transfer of such large pieces of DNA into living cells significant technical challenges.

8.2 The design and construction of basic biological tools (Bioparts) and their assembly into small modules has characterised the early years of synthetic biology. Integration of these tools to provide robust, functional systems is not simple as they may arise from very different biological sources and require considerable characterisation and standardisation. Enabling technologies of computational modelling, DNA sequencing and DNA synthesis have given rise to several modules including switches, cascades, pulse generators, time-delayed circuits, oscillators, spatial patterning and logic formulas. Use of these and other modules can regulate a number of biological processes: e.g. gene expression, protein function, metabolism and cell to cell communication.

8.3 Some observers believe that we are now entering a "second wave" of synthetic biology where modules may be integrated to create systems level circuitry[34]. The design and control elements may increase in complexity and may involve incorporation of adaptive, intelligent processes potentially leading to systems which may impinge on multiple pathways, systems or targets. Effects on multiple cell populations or organs could result in innovative environmental and therapeutic applications. However, the level of uncertainty and variability in biology may present significant challenges in modelling systems behaviour as biological systems tend to behave less predictably than conventionally engineered systems.

**8.4: Additional tools.** Selection of the "chassis" or host organism for the synthetic system may influence the functionality of the designed process. Cell viability and interference from host cellular processes may influence host selection and construction of a minimal genome. Cell free systems may offer greater control and flexibility but still present significant technical challenges such as energy provision and avoiding process-related toxicity. It is also possible to manipulate the genetic code by introducing new codons in tandem with modified translation machinery resulting in the incorporation of novel amino acids and consequently novel proteins.

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[34] Purnick, P.E. and R. Weiss: *The second wave of synthetic biology: from modules to systems.* Nat Rev Mol Cell Biol. 10: 410-22. (2009)

**8.5: Standards.** There is a drive to adopt universal standards covering tools and components ranging from complex systems to genes. The BioBricks Foundation is currently a leading facilitator promoting the setting and adoption of standards.

**8.6: Research Networks**. Support from various Research Councils seeks to foster research networks within the UK. In addition, the EU has established several initiatives designed to stimulate inter-disciplinary and international research. Academic and commercial organisations in the USA are major players while interest in Asia is also evident.

## 9. Responsibility and Synthetic Biology

9.1 Responsibility can be defined as a state of being accountable and answerable for something or for someone. In other words, it means that one could eventually be called to give an account for an action, an object or subject with which one is seen to have a special relationship. Responsibility also means that one may be accountable before society, the law or God when the actions, things or people for which one is responsible may negatively impact upon other people, the environment or society.

Several concepts important in considering responsibility are explored:

9.1.1 **Principles of responsibility.** All involved have a responsibility to guard against negative effects resulting from new synthetic biology products. This is a resonance of the traditional understanding of the creator's responsibility towards his or her creatures. This manifests itself in the realisation that the creator has **responsibility for** his/her creation, and a **responsibility to** the creature.

9.1.1.1 While it must be remembered that, at present, synthetic biology will result in simple organisms rather than sentient beings, this bond between the creator and the creature has often been explored in fiction. Among the most well known is Pinocchio. The character of Pinocchio, created as a wooden puppet carved from a piece of pine, but who dreamed of becoming a real boy, first appeared in a book by Carlo Collodi in 1883. A number of other, more contemporary, works of fiction explore very similar themes – for example, Isaac Asimov's "*I, Robot*", and Philip K. Dick's "*Do androids dream of electric sheep?*" (popularised in the film "*Bladerunner*")

### 9.2 Responsibility for

9.2.1 It is necessary to take into account the possible risks of any negative outcome which may be occasioned by synthetic biology. These may include using synthetic biology as a source of destruction, or the possibility of bringing about unacceptable suffering and distress through the use of synthetic biology. Experimentation on animals which causes unnecessary suffering has often invoked revulsion among the general public. The scientific community must take seriously the responsibility for life-forms brought about through synthetic biology, or affected by it.

**9.3 Responsibility to: the concept of *telos***

9.3.1 While bearing in mind that synthetic biology is currently dealing with non-sentient organisms such as bacteria, another issue which should be addressed by scientists and society is the concept of *telos*, sometimes also termed the 'intrinsic value' or 'integrity' of a being. It has been revived recently by Rollin and others[35,36,37]. It has been aptly described as 'the pigness of a pig', the sum total of an organism's potentialities (whether realised or not)[38]. By interfering with a living being's inherent characteristics, one may be changing what this being 'is', its 'natural' form of life, its purposes and ends.

9.3.2 *Telos* can be applied to any living organism, whether sentient or not. Modifying *telos* is not necessarily the same as violating *telos* and one must also ask if all genetic manipulations must necessarily compromise *telos*. It may conceivably be possible for a genetically modified animal to live a fully normal life, giving free rein to its intrinsic nature and preferences. Despite its lack of conceptual clarity, however, the question of *telos* deserves serious attention. In most cases it is obvious that violations of an animal's *telos* may also result in some disadvantage to its welfare[39].

9.3.3 In Sweden, legislation has been introduced which stipulates that farm animals must be allowed to live their lives in accordance with their *telos*[40]. In addition, under

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[35] Rollin, B.E. (1986). *On* telos *and genetic manipulation*. Between the Species 2, 88-89.
[36] Verhoog, H. (1992). *The concept of intrinsic value and transgenic animals*. Journal of Agricultural and Environmental Ethics 5, 147-160.
[37] Vorstenbosch, J. (1993). *The concept of integrity: its significance for the ethical discussion on biotechnology and animals*. Livestock Production Science 36, 109-112.
[38] de Pomerai, D.: *Are there Limits to Animal Transgenesis?*, Human Reproduction and Genetic Ethics: 3 (1997). http://geneticethics.org/
[39] de Pomerai, D.: *ibid*
[40] Straughan, R.: *Ethics, Morality and Animal Biotechnology*, p. 21 (1999) Biotechnology and Biological Sciences Research Council. http://www.bbsrc.ac.uk/

Dutch law, *telos* is an important issue in deciding whether or not transgenic animal research should be allowed to go ahead[41, 42].

**9.4 The precautionary principle**

9.4.1 The precautionary principle is enshrined in EU law. This principle exists in several forms, one of which is set out in the EU Communication on the precautionary principle in 2000. This indicated that:

"*the precautionary principle forms part of a structured approach to the analysis of risk, as well as being relevant to risk management. It covers cases where scientific evidence is insufficient, inconclusive or uncertain and preliminary scientific evaluation indicates that there are reasonable grounds for concern that the potentially dangerous effects on the environment, human, animal or plant health may be inconsistent with the high level of protection chosen by the EU.*"[43, 44]

In other words, the precautionary principle states that if a new action or policy may cause severe or irreversible harm to an individual, a community or the general public, in the absence of full scientific certainty that harm would not ensue, the burden of proof falls on those who would advocate taking the action.

9.4.2 The precautionary principle is often applied to biological procedures because changes cannot easily be contained and may affect everyone. In the case of technological innovation, it may be all the more difficult to contain the impact because of the possibility that the technology can self-replicate. Application of the principle modifies the status of innovation and risk assessment: it is not the risk which must be avoided or amended, but a **potential** risk which must be prevented. However, it should be remembered that no activity or process can ever be guaranteed to present no risk whatever and to be completely safe.

Some commentators suggest that there are two forms of the principle, which they call the "strict form" and the "active form". The former requires inaction when a new

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[41] Brom, F.W.A. and E. Schroten: *Ethical questions around animal biotechnology: the Dutch approach*. Livestock Production Science 36, 99-107 (1993)

[42] de Pomerai, D.: *ibid*

[43] Commission adopts Communication on Precautionary Principle
Brussels, 2 February 2000, http://ec.europa.eu/dgs/health_consumer/library/press/press38_en.html

[44] COMMISSION OF THE EUROPEAN COMMUNITIES, 2.2.2000, COMMUNICATION FROM THE COMMISSION on the precautionary principle, http://eur-lex.europa.eu/LexUriServ/site/en/com/2000/com2000_0001en01.pdf

action might pose a risk, while the latter means choosing less risky alternatives when they are available, and taking responsibility for potential risks.

### 9.5 The proportionality principle

9.5.1 The proportionality principle states that the scientific benefits or advantages expected from a procedure being considered should be weighed against the perceived resulting disadvantages or risks. Thus, according to the proportional principle, an act can be justified if the overall good involved in doing the action compares favourably with the overall disadvantages which it would bring about. Alternatively, an action is not undertaken if the overall disadvantages compare unfavourably to the overall benefits which it is considered to bring about.

9.5.2 In other words, it is a tool assisting in moral decision–making according to which an agent ought to choose – through a preliminary assessment – that alternative course of action which promises the greater proportion of good over disadvantages[45].

### 9.6 The concept of '*ordre public*'

9.6.1 Although there is no universally accepted notion of '*ordre public*', the concept is useful to consider since it includes the protection of animal and plant life in addition to health and may be applied to any subject matter which may lead to serious prejudice to the environment.

9.6.2 This concept is already established on the international stage with, for example, the European Patent Office Guidelines for Examination***, Part C, Chapter II, 7. Prohibited matter, 7.2 Matter contrary to*** **ordre public** ***or morality*** which state that a patent cannot be accepted if a subject matter may undermine '*ordre public*'. Examples of the kind of subject matter coming within this category include: incitement to riot or to acts of disorder; incitement to criminal acts; racial, religious or similar discriminatory propaganda; and grossly obscene matter[46].

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[45] Lawler, R., Boyle, J. and W. May: *Making good moral choices: Two approaches*, Rev. Ronald Lawler, Joseph Boyle and William May, http://www.ewtn.com/library/DOCTRINE/PROPORT.TXT (1994) http://www.ewtn.com/library/DOCTRINE/PROPORT.TXT

[46] European Patent Office Guidelines for Examination, Part C, Chapter II, *7. Prohibited matter, 7.2 Matter contrary to ordre public or morality*, http://www.european-patent-office.org/legal/gui_lines/e/c_ii_7_2.htm

Traditionally, “*ordre public”* in US legislation was referred to the subject matter which was “frivolous or injurious to the well-being, good, or sound morals of a society”[47].

**9.7 Public policy**

9.7.1 Patent legislation has long contained provision allowing patents to be refused on public policy grounds. For example, in the United Kingdom, section 1(3) of the Patents Act 1977 as originally enacted provided that a patent should not be granted for an invention which At the root of these exclusions is "likely to encourage offensive, immoral or antisocial behaviour"; and, in the United States, there has traditionally been a similar exclusion for inventions which are “frivolous or injurious to the well-being, good policy, or sound morals of a society”[48].

At root of these exclusions in the common law concept of *public policy,* by which is meant not government policy, but, rather what is offensive to the sense of morality of society. Where there are public policy considerations, a court will refuse to recognise an otherwise legal act - the paradigm example is a contract between two highwaymen concerning the division of their spoils.

Napoleonic systems have a close analogue of the common law concept of public policy in the notion of ‘*ordre public’* which, however, is rooted in a philosophy which is not precisely the same: putting emphasis on the good order of society rather than morality as such.

These strands were bought together within the European Union in Directive 98/44/EC on the legal protection of biotechnological inventions, which applies in all of the EU Member States. Article 6 provides:

> "1. Inventions shall be considered unpatentable where their commercial exploitation would be contrary to *ordre public* or morality; however, exploitation shall not be deemed to be so contrary merely because it is prohibited by law or regulation.
>
> 2. On the basis of paragraph 1, the following, in particular, shall be considered unpatentable:
>
> (a) processes for cloning human beings;

[47] Lowell v. Lewis, 15 (a. 1018 No. 8568) (C.D. mass. 1817)
[48] Lowell v. Lewis, 15 (a. 1018 No. 8568) (C.D. mass. 1817)

(b) processes for modifying the germ line genetic identity of human beings;

(c) uses of human embryos for industrial or commercial purposes;

(d) processes for modifying the genetic identity of animals which are likely to cause them suffering without any substantial medical benefit to man or animal, and also animals resulting from such processes."

Article 6(1) is reflected in the wording of section 1(3) and (4) of the Patents Act 1977, as now amended:

"(3) A patent shall not be granted for an invention the commercial exploitation of which would be contrary to public policy or morality.

(4) For the purposes of subsection (3) above exploitation shall not be regarded as contrary to public policy or morality only because it is prohibited by any law in force in the United Kingdom or any part of it."

9.7.2 The concepts of public policy and of *ordre public* are constantly changing in tune with the *mores* of society. *Ordre public* and public policy are, in reality, not shapers, but lagging indicators of public morality.

Article 6(1) is deliberately left open in its terms as the concepts of public policy and of *ordre public* are constantly changing in tune with the *mores* of society. A flavour of what is meant by Article 6(1) can be had from *The European Patent Office Guidelines for Examination***,** *Part C, Chapter II, 7. Prohibited matter, 7.2 Matter contrary to ordre public or morality*, which states that a patent cannot be accepted if a subject matter may undermine '*ordre public*' and cites as examples: "incitement to riot or to acts of disorder; incitement to criminal acts; racial, religious or similar discriminatory propaganda; and grossly obscene matter"[49].

Against that background, it is politically significant that a decision was made in article 6(2) to provide an "irreducible minimum" definition of what is included in the *ordre public* exception (the list, of course, is not exclusive) every item of which deals with matters of genetic engineering.

[49] European Patent Office Guidelines for Examination, Part C, Chapter II, 7. Prohibited matter, 7.2 Matter contrary to ordre public or morality, http://www.european-patent-office.org/legal/gui_lines/e/c_ii_7_2.htm

This begs the question of whether there ought to be such a provision. On the one hand, if the *mores* of society were, at a given time, to be opposed to certain other forms of biotechnology, then that raises the possibility of a Patent Office applying the *ordre public/* public policy exception to declare a particular invention unpatentable, although it is likely that a public policy objection would be upheld only if the vast majority of the members of society found it truly offensive. *Ordre public* and Public Policy is, in reality, not a shaper, but a lagging indicator of public morality. For example, in the 1930's a successful objection on the ground of public policy was made to a patent application in respect of a contraceptive device[50] though, as public attitudes changed no such objection has ever subsequently been upheld, even though a vocal minority of society finds the use of contraception as immoral.

On the other hand, if the *mores* society were to alter so that any of the items listed in article 6(2*)* were to be regarded as acceptable, that would require legislative change.

Thus, one is drawn into a debate on the claims to primacy of, respectively, absolute and relative morality, a debate addressed elsewhere in this paper.

## 10. Regulation and Synthetic Biology

### 10.1 Public awareness and the need for regulation.

10.1.1 Developments in synthetic biology are bringing new horizons into view, but with them come new problems. There has always been an ambivalence in the eyes of the public around medical or scientific advances. In Greek the word '*pharmakon*' translates both as 'remedy' and as 'poison'. In medicine, heightened public awareness of the possible side effects of therapies together with some therapeutic disasters (e.g. thalidomide) have led to a suspicion of new initiatives. Synthetic biology would appear, however, to have created less concern in the media than, for example, genetic modification. One public consultation found that 67% of those sampled had not heard of synthetic biology[51].

10.1.2 Public perception of a new technique or development can be critical, especially if there is suspicion that there is a potential for harm. With a field as complex as synthetic biology there is real difficulty in raising awareness. Ordinary citizens,

[50]*Re Riddlesbarger's Application* (1935) 53 RPC 57
[51] *Ethical Aspects of Synthetic Biology*. European Group on Ethics. (2009) See Pauwels, E.: p41 http://ec.europa.eu/european_group_ethics/publications/docs/round_table_ethical_aspects_of_synthetic_biology.pdf

however, must be aware of both the potential risks and benefits of synthetic biology and need assurance that controls are in place to avoid harm. Undoubtedly openness and transparency are prerequisites in achieving public acceptance of new technology, and there is a need for researchers to address this issue.

**10.2 Regulatory models.**

**10.2.1 Regulatory models.**

There has often been a perception in the scientific community that any kind of control other than self-regulation as a disincentive to progress. The situation is akin to the artist's views on censorship. Self-regulation is obviously fraught with difficulty, not least the inevitable temptation to take "short-cuts" to avoid delays imposed by external controls.

10.2.2 Some control can be imposed by patents or property rights. There is concern that research can be hindered by patenting of basic tools. One of the leading proponents of synthetic biology, for example, has already established patents on an artificial microbe.

10.2.3 The European Commission (EC) has established a model which recommends a:

> *"code of conduct for responsible nanosciences and nanotechnologies research"*[52].

10.2.4 The EC European Group on Ethics (EGE) has produced a paper specifically on synthetic biology; recommendation 3 of this report takes the view that a Code of Conduct would seem more appropriate than legislation, national or international, which is viewed as difficult to impose[53]. This report also specifically recommends 'philosophical and religious input' into debate on these issues.

10.2.5 Any successful model should have a participatory approach, involving lay as well as scientific stakeholders. Transparency is critical to the process. The complexity of the science involved in synthetic biology may, however, present a challenge to scientists in presenting the issues involved in an understandable form.

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[52] European Commission Recommendation of 07/02/2008 on a code of conduct for responsible nanosciences and nanotechnologies research. ftp://ftp.cordis.europa.eu/pub/fp7/docs/nanocode-recommendation.pdf

[53] Opinion of the European Group on Ethics in science and new technologies to the European Commission. No 25. 17/11/2009. *Ethics of synthetic biology*. http://ec.europa.eu/european_group_ethics/docs/opinion25_en.pdf

## 11. Synthetic Biology and Theology

### 11.1 Reductive approach to life

11.1.1 Scientists can now create new life-forms which could never occur naturally. Does this mean that science has finally managed to answer the millennia-old question 'What is life?'. If a synthetic virus can now be created in a scientific laboratory, does this mean that synthetic biology has proved that life is nothing more than a series of chemical reactions?

11.1.2 Reduction is the process by which an object, property, concept or theory is shown to be explicable in terms of another, lower level object, concept or theory. Such a method is very popular in science because it promotes conceptual and theoretical economy. Some scientists appear to believe that synthetic biology proves the superiority of reductionism over other life-theories and has unravelled the fundamental nature of life. However, others in the scientific community have pointed out that:

> *"scientific definitions of life are working hypotheses – tools – used in the process of research that do not necessarily cover what counts as life from the everyday-life experience, or other perspectives."*[54]

### 11.2 Holistic approach to life

11.2.1 Christian theology supports a completely different ontological theory which is based on the doctrine of creation, the Trinitarian doctrine and Christology. According to the Christian tradition, God created everything which exists *ex nihilo*, out of nothing. The *ex nihilo* creation affirms that God created everything out of divine sovereignty and freedom and not out of necessity. God did not create the world and then abandon it. The incarnation of Christ demonstrates that God remains in an intimate and loving relationship with creation. Creation is seen more like a project and less like a static work of art. The whole cosmos, being the work of God, was created good[55]; nature followed humanity in the fall but will also be redeemed at the end of time[56].

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[54]Boldt, J. and O. Müller: *Newton of the leaves of grass*, Nature Biotechnology, 26: 337-339 (2008)

[55] Gen. 1: 31

[56] Rom. 8: 19- 22

11.2.2 The Christian doctrine of creation offers a holistic understanding of the cosmos. Holism affirms the goodness of the created world and therefore gives a particular normative ethical meaning to all creation. Nature should not be abused, exploited or destroyed; on the contrary it should be approached with respect and love, and nurtured in stewardship. Boldt and Müller argue that if we start creating lower forms of life and thinking about them as 'artefacts' then there is the fear that in the long run we might lose respect for higher forms of life too[57]. Christian theology, by affirming the inherent goodness of creation, offers a normative reason for why life should always be respected.

11.2.3 Yet, is 'artificial' life of the same moral calibre as 'natural' life? Is artificial life also worthy of protection in the same way that we believe that 'natural' life is (or should be)? These questions have engaged theologians as well as wider society. They have also been repeatedly explored in fiction, as noted previously[58]

11.2.4 Synthetic biology seeks to treat biological systems as analogous to mechanical and electronic ones, so that individual components can be removed and replaced at will. Technological advances have allowed the addition of a small number of genes to a biological system. Synthetic biology seeks to take this a step further, by developing the ability to add or subtract whole biological pathways in a single unit.

11.2.5 Perhaps one of the fundamental areas of disquiet over synthetic biology is the deliberate blurring of the border between the natural and artificial: as Cole-Turner puts it, in synthetic biology:

> *"…nature may still be the matrix….but it is hardly the norm"*[59].

11.2.6 Just as the church would hold that wealth is more than money, religion more than ritual, and relationships more than sex, it views life as being more than simply the interactions of chemicals.

**11.3 'Playing God'**

11.3.1 Markus Schmidt and colleagues identify 'playing God' as a central theme within synthetic biology:

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[57] Boldt, J. and O. Müller (2008): *ibid*

[58] See, for example, "*I, Robot*": I. Asimov; *"Do Androids Dream Of Electric Sheep?":* P.K. Dick

[59] Cole-Turner, R.: *ibid*

*"the idea of 'creating life' from scratch, in a way only nature has done so far ('playing God') as well as the often powerful yet difficult to pin-point feeling of uneasiness which surrounds the emergence of such a technology, a feeling which may either reflect our prejudices or be an indicator of deeper ethical problems."*[60].

11.3.2 According to Christian theology, the divine creation of life and its inherent goodness affirms its normative status. There is clear distinction between the created cosmos and the Creator God. God pre-existed everything; the cosmos is created by God, *ex nihilo,* out of nothing. God always existed and thus God pre-existed creation[61], whereas the cosmos came into being through divine action. God and the cosmos do not share the same substance (*ousia*). God is eternal, self-existent/uncreated, self-contained and self-sufficient. Creation, on the other hand, is temporal, created and dependent on God for its existence. If God, in His eternal nature, is 'Being', then creatureliness by contrast is a state of 'non-Being'. This doctrine describes and underlines the origin and the nature of created beings, and sets the basis of the relationship between God and creation. It is not just a juristic or ethical form of relationship, but a more meaningful, causative relationship where finite existence derives directly from, and depends entirely upon, infinite existence.[62]

11.3.3 Does synthetic biology challenge the distinction between Creator and creature? Has synthetic biology turned humans into a 'Creator' too? Pat Mooney of the Erosion Technology and Concentration (ETC) Group, commenting on the work which created the first synthetic bacterium, claimed that

*"For the first time, God has competition"*.[63]

11.3.4 In order for this claim to be true, though, scientists must be able to create something out of nothing. However, as Boldt and Müller note:

*"in contrast to the impression which bold statements in the lay press may give rise to, synthetic biology research is currently a good way off from the point where the creation of life as such will become feasible. After all, the*

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[60] Schmidt, M. *et al* (2008): *ibid*

[61] It is recognised that time (and thus the concept of pre- or post-existence) is itself part of creation

[62] Matsoukas, N.: *Dogmatic and Symbolic Theology B*, Thessaloniki: Pournaras, (1999) p. 144ff.

[63] ETC Group, *Patenting Pandora's Bug: Goodbye Dolly …Hello, Synthia!* 7 June 2007. http://www.etcgroup.org/upload/publication/631/01/etcnr_syn_final2.pdf

*platform organism that synthetic biology relies on when attempting to create new life forms is a modified, stripped-down version of an existing organism, not an organism assembled from separate small molecules in the laboratory."*[64]

11.3.5 Furthermore, the concept of idolatry (of human capability) enters into the debate: we are not gods; and it would be a false premise to assume so. Creating new forms of life in the way described above does not constitute *ex nihilo* creation. Humanity has not managed to transcend the boundaries of creatureliness and become a 'Creator'. Human beings are part of nature. Humanity's creative nature is defined and underlined theologically by the doctrines of creation and redemption. The doctrine of *Imago Dei* (the image of God) gives a special status to humankind over the rest of the creation. As Gunton points out:

*"Genesis makes the human race both the crown of, and uniquely responsible for, the shape that creation takes."*[65]

11.3.6 Humanity's unique position in the cosmos cannot be understood outside Christology.

*"By speaking of Jesus Christ as the true image of God, the New Testament shows that this responsibility takes shape through him."*[66]

11.3.7 As mentioned above, creation is seen in Christian theology more as an evolving project rather than a static work of art. In order for creation to achieve its end, redemption is necessary. Humanity's relationship with the rest of creation must not be confused with a wrongful domination and exploitation. Creation should not be perceived as sacred, as a given which needs to be kept untouched (pantheism). Rather, it needs to be viewed as a gift:

*"to be cherished, perfected and returned."*[67]

### 11.4 A Christian response

11.4.1 Synthetic biology is a new scientific application which, if used correctly, could revolutionise medicine, transform the primary and secondary sector of industry and

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[64] Boldt, J. and O. Müller (2008): *ibid* p. 387.

[65] Gunton, C.E., *"The doctrine of Creation"*. Continuum International Publishing Group - T & T C (2004), p. 144.

[66] Gunton, C.E., *ibid*, p144

[67] Gunton, C.E., *ibid*, p. 155.

offer solutions to energy and environmental problems. If appropriate legislation and effective control could make sure that all potential risks were eliminated, or at least avoided, there is no compelling reason to stop or ban synthetic biology. Everybody, including the Christian world, could welcome this scientific innovation. Eliminating human suffering, protecting the environment, promoting general well-being and advancing scientific knowledge using reason and human ingenuity are goals in harmony with Christian teaching. God has endowed human nature with mental and intellectual capacities. It is our responsibility to use the divine gifts for the benefit of humanity, and of nature as a whole.

11.4.2 Humanity has long sought to tame nature, to bring the wilderness under control. From the domestication of animals and plants in prehistory to current attempts to alleviate drought by 'seeding' clouds to produce rain, or to ameliorate climate change using ocean seeding, ingenuity and innovation have been important to the progress of human society. Could synthetic biology be viewed as just another step along the road of humanity adapting the environment to our own benefit?

11.4.3 We live in – and are thus called to have a prophetic role in – the digital age. In many ways, synthetic biology could be viewed as being the perfect approach to the natural world for the digitally–inspired 'net generation'. In his book "*Grown Up Digital: How the Net Generation is Changing Your World*", Don Tapscott identifies:

> "*eight norms that define Net Geners".*

11.4.4 These include valuing freedom and choice in everything they do, a love of customisation and personalisation, an expectation of constant innovation, and that everything will be achieved quickly[68].

11.4.5 Much of what goes on in nature could be seen as being wasteful in a purely mechanistic sense: biological pathways contain redundancy (often to prevent catastrophic failure of the organism), reproduction results in some offspring which are better adapted to survival (and, as a corollary some which are less well suited, and which consequently perish). What better use of human ingenuity, some may argue, than to circumvent the need for selective breeding, and to start with a clean slate, a basic platform or chassis on which to build the organisms that we need?

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[68] Tapscott, D.: "*Grown Up Digital: How the Net Generation is Changing Your World*" McGraw-Hill (2008)

11.4.6 The practical application of synthetic biology in order to achieve the benefits described above need not constitute a problem for Christian theology. It is the philosophical/anthropological connotations of synthetic biology which may be seen to be 'treading on religious toes'. Christian theology fundamentally disagrees with a reductive understanding of life. Reductive life theories argue that the only thing which exists is matter and that all phenomena, including mental and spiritual phenomena, can be reduced to physical and chemical processes. However, reductive theories are unable to satisfactorily and fully explain events such as beliefs and emotions, and ideas such as free will. Christian holism holds that life is an interrelation of spirit and matter, and is able to account for physical as well as mental and spiritual phenomena.

11.4.7 Reductionism as a methodological approach is very useful for scientific research: it allows scientists to break down a system and focus on the part which most interests them. As an ontological theory, however, it is neither the only one available nor the most comprehensive.[69] As Caplan argues, the fact that scientists can create a virus does not mean that they have found the answer to all questions regarding life[70]. Christian holistic ontological theory has strong philosophical and theological foundations and encompasses all aspects of life, human and non-human. Furthermore, it justifies the normative ethical status of nature. Scientists are making great progress in unravelling and explaining the mechanistic mysteries of life. When attempting to transfer their scientific discoveries into the area of ontology and metaphysics, scientists need to collaborate and engage in open dialogue with philosophers and theologians.

11.4.8 Too often the church comes across as simply wanting to say 'no' to anything new- thus the impression is given to those outside the church that our main purpose is to stand in the way of progress. Progress which, if it fulfils its promise, could have a profound effect on many aspects of our lives - and on the environment in which we live.

[69] Ontology is the philosophical study of the nature of being, existence or reality in general, as well as of the basic categories of being and their relations. Traditionally listed as a part of the major branch of philosophy known as metaphysics, ontology deals with questions concerning what entities exist or can be said to exist.

[70] Wilson Centre, *Synthetic Biology: Is Ethics a Showstopper?* Video available at: http://www.wilsoncenter.org/ondemand/index.cfm?fuseaction=home.play&mediaid=D1679245-99F8-2253-E3E356E66B1798F5

11.4.9 Synthetic biology need not be opposed to Christian theology as long as it aims at preventing unintended and unexpected consequences and promoting the common good. However, close collaboration of scientists and ethicists – religious and non-religious – and regular ethical checks are necessary to ensure that synthetic biology is used for the best. As has previously been noted, the report on synthetic biology of the European Group on Ethics, in its final recommendation, specifically recommends 'philosophical and religious input' into debate on these issues[71].

## 12. General Conclusion

12.1 Although still a relatively novel area of scientific exploration, the field of synthetic biology potentially holds great promise in a wide variety of applications. From novel forms of biofuels to improved medical interventions, the manipulation of microorganisms in the ways envisaged by synthetic biology has the potential to revolutionise much of our lives.

12.2 And yet, for many, some nagging disquiet remains: in treating organisms as Lego-like constructs to be disassembled and reassembled at will, are we as humans pushing the boundaries of manipulation of our environment too far? Do we fully appreciate the potential consequences of our actions in this area? Is the unregulated nature inherent in much of what is possible through synthetic biology an opportunity or a problem?

12.3 Humanity is charged not only with the stewardship of the world around us but also the care and concern for other people. For many, to deny the technological breakthroughs and consequent benefits promised by synthetic biology would be irresponsible. The Biblical story of the Tower of Babel could be seen as a salutary illustration of the wrong use of advances in technology – humans seeking to utilise the (then-novel?) tools of man–made bricks and bitumen to

> *"make a name for themselves"*[72]

rather than acting in a humble and responsible manner toward God, their fellow creatures and the environment.

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[71] Opinion of the European Group on Ethics in science and new technologies to the European Commission. No 25. 17/11/2009. *Ethics of synthetic biology.* http://ec.europa.eu/european_group_ethics/docs/opinion25_en.pdf

[72] Gen 11: 4

12.4 This report has sought to explore the relationship between synthetic biology and theology. Despite some protestations to the contrary, synthetic biology does not put humanity on a par with God: our creatureliness remains, our undoubted creativity in such areas notwithstanding. Much of what is highlighted illustrates afresh the need for all aspects of human endeavour to be carried out in an appropriate ethical framework, and the responsibility of the church to engage constructively with those seeking to utilise science and technology in a responsible manner. The participatory 'Deliberative Meetings Of Citizens' (DEMOCS) card game developed by the Genomics Network in collaboration with the New Economics Foundation on the subject is to be highly recommended. This allows a small group to find out about an issue, discuss it, seek common ground, and give their views[73].

12.5 There are potential benefits to be gained from synthetic biology, and the church has a responsibility to be in discussion with those carrying out such research. It is to be hoped that this paper might act as a starting point for such discussion with the scientific community.


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[73] Available to download at http://www.genomicsnetwork.ac.uk/esrcgenomicsnetwork/news/title,22223,en.html

## Glossary

**Amino acid:** The building blocks from which proteins are constructed. There are 20 different amino acids found in nature; just as the letters of the alphabet can be combined to form an almost endless variety of words, amino acids can be linked together in varying sequences to form a vast variety of proteins.

**Biomass:** The amount of living matter that can be converted to fuel and is therefore regarded as a potential energy source.

**Biosensor:** A detection device that combines biological and mechanical components.

**Codon:** A triplet of nucleotides in the messenger RNA chain that codes for a specific amino acid in the synthesis of a protein molecule

**DNA:** Deoxyribonucleic acid (DNA) contains the genetic instructions used in the development and functioning of most known living organisms. The main role of DNA molecules is the long-term storage of information.

**Extropianism:** An evolving framework of values and standards for continuously improving the human condition. Extropians believe that advances in science and technology will some day let people live indefinitely.

**Gene:** The basic physical unit of heredity; a linear sequence of nucleotides along a segment of DNA that provides the coded instructions which, when translated into protein, leads to the expression of hereditary characteristic. Genes hold the information to build and maintain an organism's cells and pass genetic traits to offspring.

**Genome:** The entirety of an organism's hereditary information. The genome includes both the genes and the non-coding sequences of the DNA. The genome of many organisms is made up of a number of chromosomes.

**Inorganic:** Inorganic compounds are considered to be of a mineral, not biological, origin. By contrast, most organic compounds are traditionally viewed as being of biological origin.

**Lipid:** Lipids are a group of naturally-occurring molecules which includes fats and waxes. The main biological functions of lipids include energy storage and as structural components of cell membranes.

**Metabolism:** The set of chemical reactions that happen in living organisms to maintain life. These processes allow organisms to grow and reproduce, maintain their structures, and respond to their environments.

**Molecule:** A group of at least two atoms in a definite arrangement held together by strong chemical bonds**.**

**Nanomotor:** A device capable of converting energy into movement.

**Nucleotide:** Any of a group of molecules that, when linked together, form the building blocks of DNA or RNA. Four different nucleotides are found in DNA: adenine, cytosine, guanine, and thymine (often abbreviated as A, C, G and T).

**Ontology:** Ontology is the philosophical study of the nature of being, existence or reality in general, as well as of the basic categories of being and their relations. Traditionally listed as a part of the major branch of philosophy known as metaphysics, ontology deals with questions concerning what entities exist or can be said to exist.

**Organic:** Organic compounds are considered to be of biological origin. By contrast, most inorganic compounds are traditionally viewed as being of a mineral origin.

**Protein:** Highly varied organic molecules constituting a large portion of the mass of every life form. Composed of amino acids linked in a genetically controlled linear sequence into long chains, proteins include such specialized forms as collagen for supportive tissue, haemoglobin for transport, antibodies for immune defence, and enzymes for metabolism.

**Replication:** The process by which double-stranded DNA makes copies of itself: each strand, as it separates, synthesizing a complementary strand.

**RNA:** Ribonucleic acid: any of a class of single-stranded molecules transcribed from DNA in the cell, containing along the strand a linear sequence of nucleotide bases that is complementary to the DNA strand from which it is transcribed.

**Transcription:** The process by which genetic information on a strand of DNA is used to synthesize a strand of complementary RNA.

**Transhumanism:** An international intellectual and cultural movement supporting the use of science and technology to improve human mental and physical characteristics and capacities. The movement regards aspects of the human condition, such as disability, suffering, disease, aging, and involuntary death as unnecessary and undesirable.

**Translation:** The process by which a messenger RNA molecule specifies the linear sequence of amino acids on a ribosome for protein synthesis.