Ethical and Societal Issues in Nanobiotechnology

- Setting the Scientific Scene
- Setting the Ethical Scene
- Ethical issues in nanobiotechnologies
- Postscript: Nanobiotechnologies engaging with society

NanoBio-RAISE Co-ordination office:
Julianalaan 67
2628 BC Delft
The Netherlands
t +31 (0)15 278 66 26
f +31 (0)15 278 23 55
info@nanobio-raise.org
www.nanobio-raise.org

This briefing paper reviews ethical and social issues posed by nanobiotechnologies in the climate of greater public accountability of science and technology in Europe. It describes some scientific areas, and identifies gaps between current status and extravagant claims, and between scientific development, ethical assessment, and the awareness of publics. Because many developments remain in the future, the role of different values and world views is important for research goals, priorities and applications. Views about progress, quality of life, justice, the nature of human being affect priorities and ethical limits. We then look at the ethical and social implications of nanobiotechnology applications, including diagnostics and predictive medicine, targeted drug delivery, nano-enhanced food, risk, and human enhancement. The power and risks of intervention at extremely small scales, the convergence of fields and the complex data throw new light on existing ethical issues and pose some new ones. The paper concludes by identifying an important need for appropriate two-way public engagement.

The aim of this briefing paper is to deliver concise, correct and balanced information to advance public debate among consumers, media, policy makers, producers and researchers as part of the European Commission-funded Nanobio-RAISE project.[1] It is intended to provide information and does not represent the views or policy of the European Commission or any other body.

1. Setting the Scientific Scene

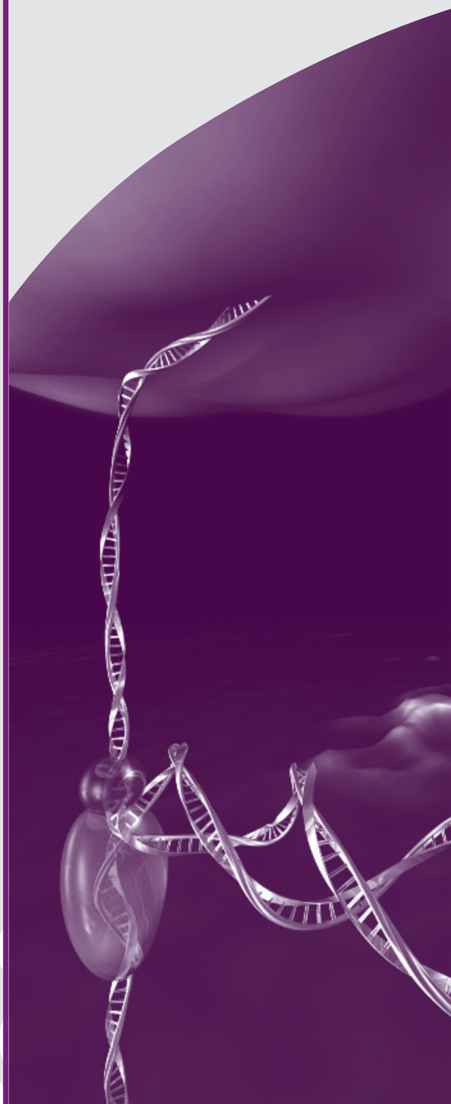
First we look at what nanobiotechnology is and its potential uses, noticing two gaps between exploratory science and grandiose prediction, and also a gap between the technology and ethical and public awareness.

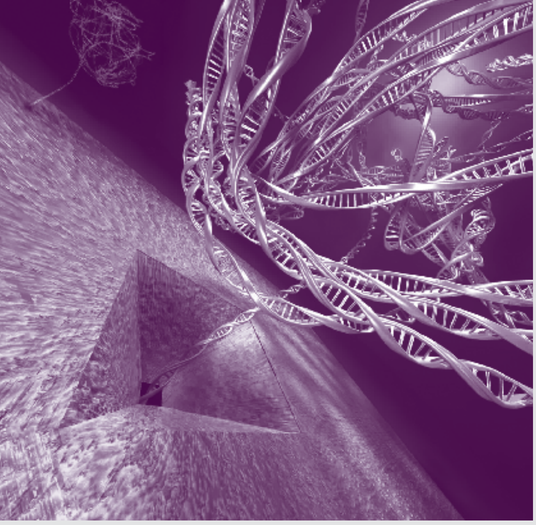
a) What is nanobiotechnology?

Nanotechnology is a broad term covering many types of technical application which rely on scientific phenomena that happen on a very small scale, measured in nanometres, a millionth of a millimetre, typically the size of a few atoms and molecules. Nano*bio*technology refers to applications which bring together – physics, chemistry, materials and engineering at this scale in applications in biological systems, especially in medicine, but also in food science, agriculture and environmental protection and remediation.

The cells of our body operate on this scale, for instance. In medical diagnosis, nanobiotechnology is already enabling us to design instruments to image parts of the body to new levels of detail and precision, down to chemicals inside a cell. Research with nano-sized particles is underway, which aims to enable us to follow what happens in cells, or other parts of the body, to see what may go wrong, and signal if there seems to be a problem. Combining these nano-scale particles with finely-tuned biological detector molecules may enable us to intervene in cells much more precisely than many of our present drugs can, say in chemotherapy, by recognising and destroying cancerous cells while leaving their healthy neighbours unharmed. This concept of 'targeted drug delivery' has potential applications for many diseases, and could greatly reduce adverse reactions and side-effects of pharmaceuticals.

The continuing precision engineering of materials down to the nanoscale opens up many possibilities for performing tiny scale chemical analyses, combined with miniscule computer chips. This could enable us to take a drop of blood and make a rapid analysis of a patient's whole DNA, or quickly find the water-borne virus content from sampling a local stream in Africa. Tiny mechanical devices like pumps and motors can be made, mimicking or even using natural biological systems. Nanoscale processes can build up special coatings to protect sensitive surfaces or make surgical implants more compatible with the body. Again on this scale, computer chips





can make an interface with nerve cells with many potential applications. Not downloading our brains, as some exaggeratedly have claimed, but perhaps one day it may enable severed nerves to be regrown, allow thought control of a prosthetic limb, or restore at least some degree of lost sight.

Sometimes materials have unusual properties at the nano-scale. Fish oil droplets might be added to a soft drink, to fortify it in omega fatty acids. Ordinarily, the drink would go cloudy and smell of fish, but at a nanoscale the droplets are invisible and odourless. Nanoscale particles can pass barriers across cells, which may have both good and bad aspects.[2&3]

b) Science and Future Predictions: Mind the gap![4]

With such prospects, there is great interest and research investment by the EU and its Member States, in North America and Asia. But nanotechnologies have been especially prone to the current *zeitgeist* of exaggeration. Futurologists have made grandiose claims for their potential to transform our lives, that all will be inevitable and wonderful, asserting certainty about outcomes which the writers cannot know. Yet much of the research, as pioneer Don Eigler observed, remains in its discovery and exploratory stage, where scientists are still exploring basic ways of doing things.[5]

Various groups have stepped into this uncertainty space, to make nanotechnology a vehicle for their particular views. On the one hand, the campaign group “Erosion, Technology and Concentration” (ETC) already called for a moratorium in 2003 before there was much to assess,[6] and some activist groups portray nanotechnology as the latest risky technology for the global domination of companies or nation-states, following nuclear power or GM food.
On the other hand, a group known as transhumanists sees in the convergence of nano-bio-info-technologies and cognitive sciences, an inevitable trajectory of human enhancement through which humanity (or at least those people fortunate to have money and access) will take hold of evolution and direct our very human nature according to their own designs.[7]

c) Science, Ethics and Public Awareness: Another Gap

Polarised views like these highlight another gap between those developing nanotechnologies, their public discussion and the assessment of their ethical and social implications.[8,9&10] A study of UK public engagement initiatives[11] confirmed EC Eurobarometer surveys that public awareness of nanotechnologies is low and the concepts difficult to grasp.[12] For people to engage requires focusing on applications affecting people’s lives. The relatively few people contacted in these initiatives were impressed by the potential to do good, but had misgivings about how little is known about risks from nanoparticles, and wished to have more say in how research priorities are being decided.

Indeed, in their research goals and laboratory prototypes, scientists may already be embodying assumptions about moral and ethical categories without realising it, which then direct the trajectory of development without publics being aware.[13] European concerns about legitimation and public accountability have therefore led to the present NanoBio-RAISE programme on ethical and communication initiatives with stakeholders, policy makers and publics.[14] They also stimulated the creation of an ethical, legal and social board of the Nano2Life European Network of Excellence on nanobiotechnology in parallel to its scientific programme. The European Commission’s advisory European Group on Ethics called for interdisciplinary research and public engagement on nanomedicine to ensure developments take into account the explicit or implicit diversity of values in the European societies.[15]

2. Setting the Ethical Scene

Because so much nanobiotechnology remains in the future, the more important are the goals of research and who or what sets them. We therefore consider first how values and world views influence research into particular directions, before turning to more detailed issues.

a) How do values drive nanobiotechnology?

It is a common mistake in the scientific world to say that a technology is neutral or objective. Philosophers and social scientists have long pointed out that the artefacts and systems of technologies are already a product of the values of the society within which they are produced. As a new technology becomes embedded in a society, take cars, computers, refrigerators or vaccination for example, it alters, in turn, people’s values, practices and expectations. This synergic relationship could act like an invisible social contract, in which society sets implied conditions it would expect the developers of any new technologies to meet.[16]

A technology would be welcomed if certain conditions are fulfilled - if the values and goals of the inventor are close to those within the society, and the invention correctly anticipates what society wishes. On the other hand, if the inventor is remote, or the aims do not correlate with the values and goals of the society, or if the invention is unfamiliar or risky, there can be a disjunction. The importing of unlabelled GM soya and maize products into the EU generally failed the conditions, and their rejection by consumers was predictable.[17] The mobile phone, for example, broadly fulfilled the conditions.

Conditions for Public Acceptance of Novel Technologies

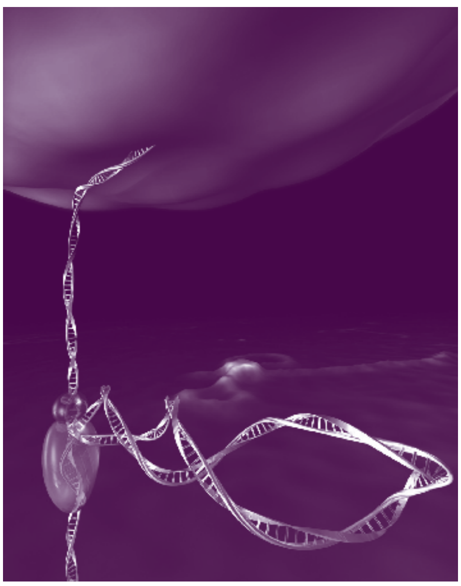
- Does it uphold or challenge widely held **Values**
- Is it something **Familiar**?
- What can we **Compare** it with? Did it work or not?
- How much do we **Feel In Control** of it?
- How far do we **Trust** those in control?
- Do we **Share** their motives, vision and goals?
- Are there uncertainties about potential **Risks**?
- Do we have any **Choice** - voluntary or imposed risk?
- Are there tangible **Benefits** to people?
- How is it **Portrayed** in the mass media?

Similarly, with developments as novel, technical and remote from the person in the street as nanobiotechnology, are its values widely shared with society as a whole, or are only the values of an elite with far-reaching powers, by default, imposed on the rest? Do people want the claimed benefits and goals? Would the downsides lead people to avoid them?

Revolutions in technology are often linked with streams of thought and culture. When in 1517, the monk, Martin Luther, nailed 95 bullet points to the church door in a small German town of Wittenberg, this was a standard way of publishing one's ideas for debate - a local 16th century blog. But the invention of the printing press fifty years before meant that his ideas spread across Germany within a month, and Europe in three months. The combination of moveable type and a recovery of personal faith in God rather than church rituals created one of history's most important revolutions. Similarly the industrial revolution arose in the era of the Enlightenment notion of human autonomy and mastery over nature. The somewhat anarchic bottom-up style of the Internet resonates with the condition of post/late-modernity in which it emerged. In our very plural European cultures, what values and views of the world will influence or challenge the uptake of a potential nanobiotechnology revolution?

b) Values and world views and 'progress'

An important value is an implicit belief in 'Progress' through technology to improve the human condition in its widest sense, confident of human skill and ingenuity to overcome problems, but it is less clear if we agree what it means. For example, government strategies frame nanotechnologies in terms of their capacity for wealth generation and jobs. In the dominant economic model, progress means an (unsustainable) promise of sustainable economic growth, within which the free market will determine what is developed.



For many people, however, progress is more about 'quality of life'. Technology is less the engine for economic ambitions as a tool in the service of humanity. Its advances must be balanced by care for our fellow humans and a fragile environment, and to redress stark global inequities, to look out for the losers from a technology as well as its winners. Others see progress more personally, what will make life better on my own terms.

Curiosity and innovation are driving forces of science, but so also are academic reputation, company policy, research funding, publications and patents. Powerful value drivers for nanobiotechnologies include redressing suffering in medicine; providing sustainable food supplies, clean water and renewable energy; or military and security applications.

The values of religious belief systems remain important in European society, that interventions should respect God-given limits for the human condition, human societies especially the poor and disadvantaged, and the environment. Transhumanism, on the other hand, throws down a challenge to traditional views in its radical, some would say quasi-religious, future vision to evolve a new human race beyond current biological limits.

c) How values and world views influence nanobiotechnology

Two examples illustrate the effect of world views and values on research priorities and directions in nanotechnologies. The ability to manipulate and construct at the molecular level opens up the potential to construct materials, surfaces and biological systems layer by layer, so-called 'bottom-up construction'. To realise such potential requires much investment, but with what applications should the priorities lie? We could aim for sophisticated enhancements for soldiers, water purifying membranes, colourless sunscreens for tourists, or to harness cell regeneration to reconstruct optic nerves? Our value judgements decide our priorities. For example, at an equivalent stage, GM crops were promoted 'to feed the world', while research was primarily focused on Western supermarket products. 'Orphan' developments which are unprofitable to finance cannot simply be left to the market.

A second example is our view of the nature of the human being. Depending on our view of human nature, what limits apply to future nanotechnological interventions in the body? Should we now monitor every possible physiological function to be considered 'healthy', or is health something more? Should we develop brain-chips that can interface with external or internal controls? Suppose a future device could recover memory in a stroke victim, should it be used to 'enhance' normal memory? How far should we develop expensive techniques in nanobiotechnology from which only the rich would benefit? Is there more to us than mere bodily function, and if so, would the relational, aesthetic, and creative parts of our nature be promoted or compromised by potential new interventions?

3. Ethical issues in nanobiotechnologies

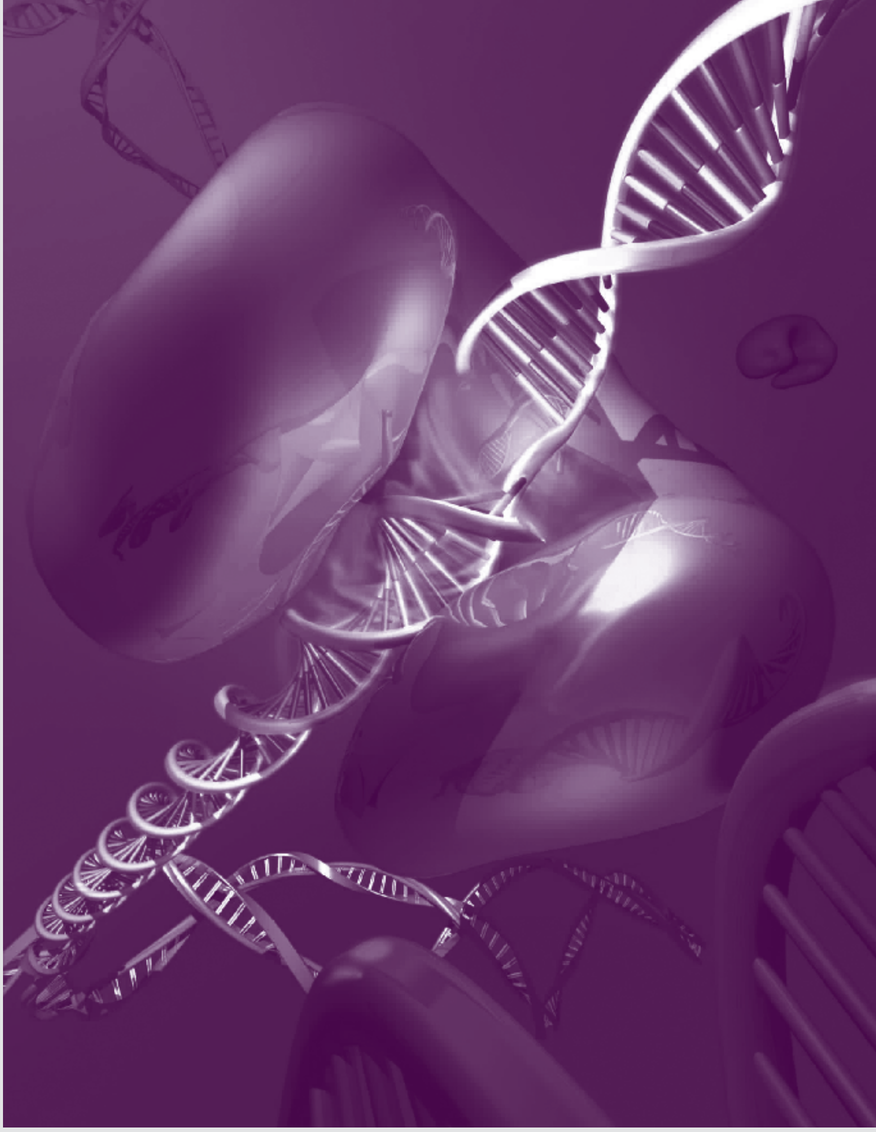
a) General Issues

Many ethical questions about nanobiotechnology are familiar in other technologies, such as medical diagnostics, genetic information, novel foods, and stem cells. Nanotechnologies are often enabling tools which bring potential issues to present reality. But the convergence of different fields, or specific features of operating at a very reduced scale, may present existing issues in a new light, or in some cases raise genuinely new issues.

The capacities to understand and intervene at this smallest, most reduced, level raise perceptual issues well known in genetics, but with a new focus. Thus we may be tempted to think that at this level we find the real nature of things, but many philosophers and theologians point out that scientific descriptions do not 'explain away' higher meanings. Each may provide complementary accounts, in different terms. Humans are more than just genes, for example. The power to define functions and examine processes at a highly reduced level may not adequately represent complex holistic systems, such as human disease or an eco-system, just as the 'same' gene may not function precisely the same way in different organisms. The ability to analyse and manipulate may presume the right to reconstruct as we wish, without necessarily knowing how the new pieces fit together. Mistakes with some early animal genetic modification in the 1980s might have been predicted had the genetic researchers talked with the relevant scientists in other fields.[18] Many GM animals have since been successfully created, but the basic lesson remains that precision interventions at a reduced scale also need to take account of wider connections.

Nanomedical biotechnology thus brings together two very different disciplines. Whilst welcoming many remarkable new possibilities to treat disease and alleviate suffering, medicine should not be reduced to engineering solutions. It is important not to lose sight of the wider values of medicine and health care that see the patient as more than mal-operating functions.

Having set the scientific and ethical scene, we now turn to specific issues in nanobiotechnologies in targeted drug delivery, remote monitoring of patients, diagnostics and predictive medicine, nano-food, risk and ethics, and, lastly, human enhancement.



b) Targeted drug delivery

One of the most attractive goals of medical nanobiotechnology under current investigation is to deliver therapeutics to specifically targeted cells or group of cells. Nano-scale monitors could identify cancerous cells; nano-sized particles would then deliver therapeutic molecules through the bloodstream and across cell membranes to repair or destroy these cells selectively. The potential for precision guidance could revolutionise cancer treatment, and help gene- and stem cell-based therapies.

But the very power of such precision carries its own hazards. One obvious risk would be if the intended therapeutic molecule hits the wrong target, or has side effects that the researchers did not look for. The presumption that a few molecules or small but detectable functional changes are sufficient to indicate abnormalities or deliver therapies carries risks. If a degree of automation is involved which embodies the medical advice (that some function is dangerously high or low, for instance), there must be a very high resilience to misleading data. If there is significant dependence on time of sampling or on external factors, a snapshot of current levels of a protein, say, may mislead. These are not entirely new issues, but nanotechnology gives them a fresh perspective.

c) Remote or personal monitoring of health status

In future, implants or particles may be inserted in patients to monitor key functions in their bodies, so that they could go home but the hospital could still keep an eye on their condition remotely. This could revolutionise health care systems. Is this a great idea for reducing time in hospital and bed occupancy, or is it too much 'big brother' surveillance? Should nano-scale implants and devices be developed for all of us to have in our bodies, to monitor the state of important body or brain functions regularly, say, for the onset of a cancer? Would this impact too much on our autonomy and freedom? What will doctor-patient relationships look like if nano-biomarkers mean we can monitor our body functions ourselves but do not have the training to be able to interpret the data properly? Can any one medical professional, let alone a lay person, handle so much diagnostic information correctly? If nanotechnology eventually offered measurements to represent almost any body function, what is a well person then when we would have so much previously unsuspected data?

d) Diagnostics and predictive medicine

Much is made of the potential of nano-enabled 'lab-on-a-chip' devices that could perform a rapid genome analysis in one's family doctor's surgery. To prescribe an antibiotic suited to one's own genetics is clearly an advantage, but how useful is any pre-symptomatic knowledge this might also provide? This can present problems for doctor and patient alike. If the genomic analysis on the computer screen also reveals a susceptibility to a serious potential condition, at what point does the physician tell her patient, when he only came about his sore throat? For the patient, it may be of little value, or worse, to have advanced knowledge of a serious genetic disease before symptoms exist if, at present little or no action could prevent or help reduce the disease.

The knowledge is usually also probabilistic. To discover that one carries a gene which increases one's chance of a particular disease, but not knowing if it will happen, can merely add to stress. Diagnostic technology itself is insensitive to such questions. The presumption of predictive medicine - that prior knowledge of a medical condition is a good thing - is not always true. The religions and literature of many cultures suggest that in a person's life there may be a proper time for ignorance and a proper time for knowing about a future event like a terminal disease.

e) Nano-enhanced food

Nano-scale fish oil droplets or droplets encapsulated in nanoparticles can be added to soft drinks to 'fortify' the drink with beneficial omega-3 fatty acids. The nano-scale makes this possible without the drink becoming cloudy and tasting of fish. Other encapsulations are proposed which delay metabolic uptake to downstream parts of the digestive system where there would be additional benefits. Low fat potato crisps could be made by using hollow fat globules.

Would these be publicly acceptable? Some food companies have become reluctant to use the word 'nano' for fear of a stigma being created like 'GM'. These are novel foods, but they are not genetically modified. Ethical questions about crossing species barriers do not apply, but if changes are made in the food itself, concerns about tampering with nature may still surface. There are clearer tangible benefits to the consumer, unlike most first generation GM products, but these have to weighed against possible risks of nanoscale particles. And are foods with lowered fat levels or enhanced beneficial chemicals the best way to address questions that might be answered better by an improved diet?

f) Risk and ethics

The exquisite sensitivity or specificity of small-scale interventions may have remarkable benefits but also important risks. Micro-electrode stimulation of the brain can dramatically reduce tremor in severe Parkinson's disease patients, but may also affect mood, and the operation is hazardous. The toxicological effects of nanoparticles on biological systems and human health lie beyond the scope of this paper, but the uncertainty of current knowledge is an area of scientific and governmental as well as emerging public concern. In both food and medical applications, nanoscale particles may transport to unintended parts of the body or have uncertain effects on metabolism. Such risks have to be duly evaluated and weighed against the perceived benefits.
Once the scientific data are available, against what criteria should we weigh these risks against benefits to medicine and food, to judge what constitute acceptable or unacceptable risks? How do we balance the potential of nanobiotechnology for environmental clean up and any ecological risks? To address some of these questions will require good research, ethical judgements, and also careful engagement with different publics. Where uncertainties remain intractable, or would take a very long time to assess, how precautionary should we be today? As the 21st century unfolds, creating a culture of reasonable safety is under threat from one of minimising liability, but it raises the question of what level of safety should we require of others, and especially technologists, in an inherently and unavoidably risky universe?

g) Human enhancement

One of the most profound ethical issues so far identified with nanobiotechnologies is the potential for the convergence of info-, bio- and cognitive technologies to improve upon human performance and abilities. Should we only use it to make humans better, or to make 'better' humans, by manipulating our capacities beyond medical conditions? Traditional presuppositions hold that there are moral or societal bounds which should act as a restraint on what may otherwise be feasible technically in intervening in the human condition.
These limits are drawn from the insights of religious and cultural values and traditions, philosophy and theology, the arts and humanities, and the social sciences.
These are challenged by the transhumanist belief that humans are destined to go beyond our current biological limitations.
A European expert group urged submitting enhancement goals to wider social scrutiny, if our humanity is not to be redefined by a techno-logic driven primarily by technical and economic feasibility.[19]
This suggests we may need to draw lines to limit some technological possibilities but promote others.

Many conceptual models of the human being exist. Depending on the context, we might be a bag of genes, a conscious mind, a spiritual and bodily being, a set of capacities restrained by natural form, and so on. A secular dream of human enhancement sees the human condition as something which we can manipulate to our own design, if we think we can do better. This assumes a functional understanding of the human being, which may conflict with more holistic understandings. Here are some critical observations on radical physical enhancement:

Firstly, instead of seeing life as a gift to be handled well, as in traditional morality, if human beings are primarily functions to be enhanced, our humanity becomes something accepted only in so far as it meets with our specification. The notion of performing a technical fix on human characteristics carries the risk of mistaking the worth of human beings with limited notions of functional perfection. It begs two questions. Amid the complexity and interdependences of the human body and social and cultural variations, how do we know *what* is truly an enhancement? *Who* will lay down what is an enhancement and what is 'being left behind'?

Secondly, it is a relatively short conceptual step from this functional understanding of humans to resurrecting eugenic agendas, which accept someone in society only if they are seen as functionally 'fit'. Enhancement is apt to exalt youth and beauty over age and normalcy. It glorifies the winners but has no satisfactory account of, or may discriminate or even penalise, the underclass who do not reach the mark. Notions of human enhancement are seen by some to be inherently socially divisive because an injustice lies at its heart. The prospects it holds out are for those who have the money, potential and access, but are not for those who do not.

Thirdly, some argue that improving isolated individual characteristics misses important things in the account of the whole human being. What is so unsatisfactory about life as we know it, is that we should feel the need for enhancement, and would these manipulations make it better? The major world religions agree that something is wrong with the human condition, but not a lack of strength, longevity, intelligence, beauty, athleticism, art, science or even education as such. Rather, according to these religions, the problem lies in our moral, social and spiritual shortcomings, as the world's ongoing conflicts show. Nanotechnologies may create many, many good things, but however much we sought to 'enhance' ourselves physically, our inherent human failings would remain because they require a change which lies beyond technical fixes.

To focus on humans in terms of functions we should tweak in order to improve, seems an impoverished view of humanity. To be a little bit faster, taller, blonder, smarter, more retentive, more musical, or whatever, would not necessarily result in better humans. The Western cult of celebrity focuses on a few 'perfect' achievers, but presents a very fragile view of human beings as individuals who are acceptable only while their success lasts. For most people, these aspects of life are probably not what they equate with happiness, because in themselves they do not seem ultimately to give satisfaction in life. Beyond a certain basic point of physical survival and necessity, what matters most to humans above basic necessities such as food and shelter are not functional and material things but the relational, the creative and the spiritual.

"...while technology shapes the future, it is people who shape technology, and decide what it can and should be used for…" (Kofi Annan)

4. Postscript : Nanobiotechnologies engaging with society

This briefing paper has given an overview of some ethical and social issues which emerging nanobiotechnologies are posing. There is much that is ethically positive, especially in nanomedicine, but concerns can also be seen. Wider publics need now to engage with these questions, especially with the priorities and future trajectories for research itself, in the public and, perhaps especially, private sectors. NanoBio-RAISE is one of many initiatives which are seeking to take forward this growing discussion. The science of nanobiotechnology is unfamiliar, but the life issues to which it applies are not. One lesson from GM food is that we need to provide people the time and resources to explore the issues for themselves, to become familiar and develop their own judgements, and be able to play a role in decision-making as these technologies emerge and mature.

References

1 Nanobiotechnology: Responsible Action on Issues in Society and Ethics: http://nanobio-raise.org/
2 The Royal Society & Royal Academy of Engineering (2004): *Nanoscience and nanotechnologies: opportunities and uncertainties*, Royal Society, London.
3 European Science Foundation (2005), *ESF Forward Look on Nanomedicine, ESF, Strasbourg.*
4 Nanotechnology 14 (2003) R9–R13 PII: S0957-4484(03)57090-8 *'Mind the gap': science and ethics in nanotechnologies* Anisa Mnyusiwalla, Abdallah S Daar and Peter A Singer1,2,3
5 Eigler, D. (2004), *Nanotechnology and Converging Technologies*, Images of Science: New Interactions beteen Science and Society, Conference for the Dutch Presidency of the EU, 6-7 December 2004, Amsterdam http://www.imagesofscience.nl
6 ETC Group (2003), *The Big Down – Atomtech: Technologies Converging at the Nano-scale*
7 See for example, World Transhumanist Association (2002), *The Transhumanist Declaration,* http://www.transhumanism.org/index.php/WTA/declaration/
8 Mnyusiwalla, A., Daar, A.S. and Singer, P.A. (2003), *Mind the Gap: Science and Ethics in Nanotechnology*, Nanotechnology, vol.14, pp. R9–R13.
9 Bruce, D. M. (2006), *Ethical Issues in Nanobiotechnology*, EMBO Reports, vol.7, pp.754-758.
10 Nordmann, A. (ed.) (2004), *Converging Technologies and the Natural, Social and Cultural World*, report of a European Commission expert group.
11 Gavelin, K. and Wilson, R. (2007), *Democratic Technologies? The Final Report of the Nanotechnology Engagement Group*, Involve, London
12 Gaskell, G. et al. (2006) Eurobarometer 64.3: Europeans and Biotechnology in 2005, report to the European Commission's Directorate-General for Research http://www.ec.europa.eu/research/press/2006/pdf/pr1906_eb_64_3_final_report-may2006_en.pdf
13 Nano2Life, European Network of Excellence in Nanobiotechnology. http://www.nano2life.org/
14 Nanobio-RAISE; Responsible Action on Issues in Science and Ethics http://nanobio-raise.org/
15 EC (2007) Opinion 21: *on the Ethical Aspects of Nanomedicine of the European Group on Ethics in Sciences and New Technologies*, EC Luxembourg.
16 Bruce, D. M. (2002), *A Social Contract for Biotechnology - Shared Visions for Risky Technologies?*, J. Agricultural and Environmental Ethics, vol.15, pp.279-289.
17 Bruce, D. M. (2002), *op cit*
18 Bruce, D. and Bruce, A. (1999), Engineering Genesis, pp.113-114, Earthscan, London
19 Nordmann, A. (ed.) (2004), *Converging Technologies and the Natural, Social and Cultural World*, report of a European Commission expert group.

Design: Gerritsma Vormgeving bno, Leiden, e vormg@planet.nl, w www.1enof2.nl
The Images: Courtesy of the Molecular Biophysics Group at Delft University of Technology