Environmentally Beneficial Nanotechnologies: Barriers and Opportunities

Executive summary

The purpose of this Defra commissioned study is to provide an overview of the areas where nanotechnology could have a beneficial environmental impact above current technology and the barriers preventing its adoption. Green House Gas (GHG) reduction was taken as the major factor in targeting environmentally beneficial nanotechnologies. Five nanotechnological applications were subject to detailed investigation: fuel additives, solar cells, the hydrogen economy, batteries and insulation.

Summary of nanotechnologies

1) Fuel additives: Nanoparticle additives have been shown to increase the fuel efficiency of diesel engines by approximately 5% which could result in a maximum saving[1] of 2-3 millions of tonnes (Mte) per annum of CO_2 in the UK. This could be implemented immediately across the UK diesel powered fleet. However this must be tempered by concerns about the health impact of free nanoparticles in diesel exhaust gases.
Recommendations include: Comprehensive toxicological testing and subsidised independent performance tests to validate environmental benefit.

2) Solar cells: The high prices of solar cells are inhibiting their installation into distributed power generation, preventing increased energy generation from renewables. Nanotechnology may deliver more benefits in significantly decreasing the cost of production of solar cells. Conservatively, if a distributed solar generation grid met 1% of our electricity demand, approximately 1.5 Mte per annum of CO_2 could be saved. The major barrier to this technology is the incorporation of the nanotechnology into the solar cell, not the nanotechnology itself. The UK is one of the world leaders in understanding the fundamental physics of solar cells, but we lack the skills that allow us to transfer our science base into workable prototypes.
Recommendations include: Develop programmes and facilities for taking fundamental research through to early stage prototypes where established mechanisms can be employed to commercialise new technologies. Develop centre of excellence in photovoltaics (either from

[1] It should be noted that the CO_2 savings quoted throughout this summary are for guidance and represent the absolute maximum saving achieved through full adoption of the technology, it is unlikely that these figures will be met using nanotechnology and should be taken as an order of magnitude to compare relative benefits of the nanotechnologies.

existing centres or completely new) which allows cross fertilisation of ideas from different scientific disciplines.

3) The hydrogen economy: Hydrogen powered vehicles could eliminate all noxious emissions from road transport, which would improve public health. If the hydrogen were generated via renewable means or using carbon capture and storage, all CO_2 emissions from transport could be eliminated (132 Mte per annum). Using current methods of hydrogen generation, significant savings in carbon dioxide (79 Mte per annum) can be made. The hydrogen economy is estimated to be 40 years away from potential universal deployment. Nanotechnology is central to developing efficient hydrogen storage (which is likely to be the largest barrier to wide scale use). Nanotechnology is also a lead candidate in improving the efficiency of the fuel cells and in developing a method for renewable hydrogen production. Although we do not have, in global terms, a substantial automotive R&D base, the international nature of these companies will allow ready integration of UK innovation into transport.
Recommendations include: Consider the use of public procurement to fund hydrogen powered urban public transport to create a market and infrastructure for hydrogen powered transport. Continue to fund large demonstration projects and continue R&D support.

4) Batteries and supercapacitors: Recent advances in battery technology have made the range and power of electric vehicles more practical. Issues still surround the charge time. Nanotechnology may provide a remedy to this problem by allowing electric vehicles to be recharged in much more quickly. If low carbon electricity generation techniques are used, CO_2 from private transport could be eliminated (resulting in a maximum potential saving of 64 Mte per annum) or, using the current energy mix, maximum savings of 42 Mte per annum of carbon dioxide could be made. Without nanotechnology, electric vehicles are likely to remain a niche market due to the issues of charge time. Significant infrastructural investment will be required to develop recharging stations throughout the UK.
Recommendations include: Fiscal incentives to purchasers such as the congestion charge scheme, fast track schemes for commercialisation and cultivation of links with automotive multinationals.

5) Insulation. Cavity and loft insulation are cheap and effective, however, there are no easy methods for insulating solid walled buildings, which currently make up approximately one third of the UK's housing stock. Nanotechnology may provide a solution which, if an effective insulation could be found with similar properties to standard cavity insulation, could result in emission reductions equivalent to a maxim potential of 3 Mte per year. Ultra thin films on windows to reduce heat loss already exist on the market. There are claims that nano-enabled windows are up to twice as efficient as required by current building standards. However, industry believes that significant further insulative savings in glass maybe made instead using aerogels, which themselves are nanostructures.
Recommendations include: Fund a DTI Technology Programme call on novel insulation material for solid walled buildings and include in government estate procurement specifications highly insulating nanotechnology based windows.

Nanotechnology is likely to have a significant positive effect on the UK's green house gas emissions. Initially, these effects are likely to be the result of large numbers of small innovations. An R&D infrastructure that allows the development of good science into a commercial product is important. Public procurement and policy can be used (with caution) to act as a market pull for environmentally beneficial nanotechnologies. From the areas we have studied, nanotechnology could reduce our green house gas emissions by up to 2 % in the near term and up to 20 % by 2050 with a similar saving being realised in air pollution. These savings are based on the wide scale adoption of nanotechnology and the assumption that predicted breakthroughs within the field will occur when expected. Some of the findings and recommendations made within this report echo those made in the Stern report in 2006.

Table 1: Summary of environmentally beneficial nanotechnologies

Application	**Impact of nanotech in area** [1]	**Infra-structural changes** [2]	**Benefit (Mte CO_2 per annum)** [3]	**Timescale for implementation (yrs)** [4]
Fuel efficiency	Critical	Low	<3	<5
Insulation	Moderate	Low	<3	3-8
Photovoltaics	High	Moderate	c.6	>5
Electricity storage	High	High	10-42	10-40
Hydrogen Economy	Critical	Very high	29-120	20-40

1 Impact of nanotechnology describes the effect nanotechnology is likely to have in the area compared to other technologies.
2 Infrastructural changes indicates the effort bring the nanotechnology to market.
3 Benefit is the estimate of the maximum potential CO_2 saving by implementing the technology.
4 Timescale for implementation is the projected distance (in years) before the technology will be fully implemented.

Table 2: Summary of the recommendations for the five nanotechnologies reviewed

	Regulation	**Research Funding**	**Demonstration and Diffusion**	**Procurement**	**Economic Instruments**	**Standards / Mkt Transformation**	**Awareness and Communication**
Hydrogen Economy		Develop high level links with the automotive sector and research into hydrogen storage techniques	Expand the hydrogen bus demonstration projects				
Electricity Storage	Engage on issues of end of life vehicles	Enable long term research projects		Encourage large fleet procurement of battery powered vehicles	Fiscal incentives for vehicle ownership (such as congestion charges)		Engage with stakeholders for electric vehicles infrastructure
Photovoltaics		Develop centre of excellence for PV Develop funding for pre-commercialisation		Use energy efficient stand alone products	Revise taxation regime to level micro generation playing field	Ensure that new-builds obtain certain percent of power from renewables	
Insulation		Research novel insulants call through the DTI-TP		Advanced window procurement for governmental offices		Increase insulation requirement for Part L – windows on new builds	
Engine Efficiency	Research into toxicity of airborne nanomaterials	Use DTI/EPSRC funding for catalytic converters	Trial of fuel additives				