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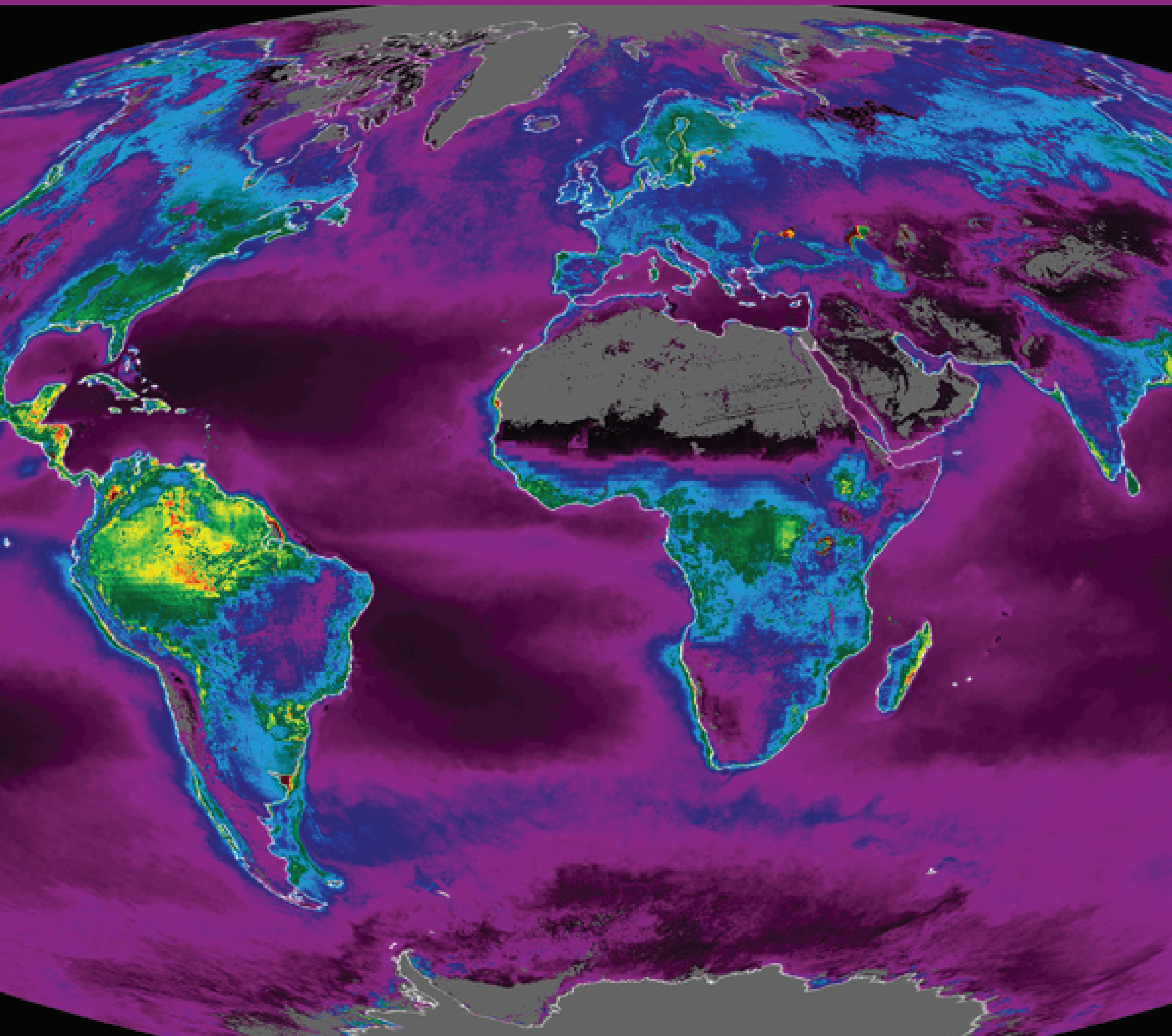
UNU-IAS Report

Innovation in Responding to Climate Change:

Nanotechnology, Ocean Energy and Forestry



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In collaboration with the University of New South Wales, the Yokohama National University, and the Tokyo Institute of Technology

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Foreword

Climate change is high on the global agenda. While the United Nations Climate Change Conference in Poznaǹ, Poland, in December 2008, is an important step towards achieving an international agreement on climate change scheduled for the upcoming Conference of the Parties in Copenhagen at the end of 2009, policy makers and practitioners alike are increasingly looking for practical solutions. This report offers three innovative solutions in responding to climate change, namely nanotechnology, ocean energy and forestry. It goes beyond the technological, biological and procedural aspects of these solutions by critically assessing the opportunities and challenges that each type of innovation presents. This report addresses the question why these innovations—despite their large potential to reduce emissions, ocean energy alone could cover the world's electricity needs—have not yet reached the stage of mass commercialization.

This research is an example of how UNU-IAS, as a strategic think tank of the United Nations, works towards advancing studies on emerging issues of importance to the United Nations and its Member States. UNU-IAS is mandated to find 'workable solutions' to the challenges of sustainable development, and mitigating the adverse effects of climate change is an integral part of this goal. This report aims at offering innovative solutions that combine 'technological advances with environmental protection, human wellbeing with economic development, and sound policy-making with good governance'. UNU-IAS is an active partner in the effort to inform policy makers with relevant information for policy planning, implementation and evaluation, especially during the United Nations Climate Change Conferences. The research presented in this report was made possible through collaboration with the University of New South Wales, the Yokohama National University, and the Tokyo Institute of Technology, demonstrating how partners can join forces to address a topic of global importance.

Last but not least, I would like to take this opportunity to express my appreciation to the authors of this report, Dr. Miguel Esteban, Dr. Christian Webersik, Dr. David Leary and Mr. Dexter Thompson-Pomeroy for bringing to the table a novel perspective on addressing the challenges of global warming. It is our hope that this discourse will trigger a constructive debate on some of the possible ways forward.

A.H. Zakri
Director, UNU-IAS
November 2008

Executive Summary

Much of the debate on and investment in technological solutions to climate change has focussed on a narrow range of technologies such as carbon capture and storage or geo-sequestration, ocean fertilization, the so called new generation of nuclear technologies, and biofuels, to mention but a few. However, as recent experience with the development and production of biofuels and the associated debate on its role in food security has illustrated, unexpected consequences can sometimes arise from these new technological solutions. What is more, the development and implementation of new technologies does not occur in a vacuum. While an existing or novel technology may offer solutions to pressing environmental problems such as climate change, it may also bring with it new environmental, social and economic consequences that had not been foreseen.

In this report we begin by highlighting specific examples of how technological innovation is being implemented, some of the potential advantages of these innovations and the new challenges they in turn raise. The main conclusion is that solutions to the energy problem already exist. They are the result of decades of research and development, and are already at the first stages of commercialization. Furthermore, these solutions are the result of considerable investment in research and development by the private sector. It is therefore possible that, given adequate government leadership, clear market signals and regulatory frameworks, the private sector will continue to play a significant role in developing innovative responses to climate change.

In part two, we examine the role of nanotechnology in responding to climate change. Nanotechnology is best described as a 'platform technology' and refers to the science and engineering innovations resulting from the manipulation of matter's most basic building blocks: atoms and molecules. Nanotechnology by itself will not have a dramatic impact on climate change, but its incorporation into larger systems, such as the hydrogen based economy, solar power technology or next generation batteries, potentially could have a profound impact on energy consumption and hence greenhouse gas emissions. In this report we highlight the role of nanotechnology in innovation in three broad categories, namely the development of efficient hydrogen powered vehicles, enhanced and cheaper photovoltaics or solar power technology, and the development of a new generation of batteries and supercapacitors.

The review of technological innovations presented in this report suggests that nanotechnology may have a major role to play in responding to climate change. However, there is evidence of obstacles to the widespread rollout of technologies developed utilising nanotechnology. One of the major obstacles highlighted is the lack of a robust transparent regulatory regime able to address concerns that have been expressed by some about potential human health and other environmental risks associated with some forms of this technology. It is not clear if these perceived risks are relevant to the advances in nanotechnology used in responding to climate change. Further scientific studies are needed to assess the risks. Such studies should also consider how these compare to risks associated with other proposed technological solutions to climate change. For example, the well documented risks and hazards of nuclear power. We also recommend further detailed analysis of the benefits to be gained from the development of nanotechnology in the context of climate change. Such studies need to consider ways to overcome obstacles to widespread use of this technology such as inadequate infrastructure (as in the case of the hydrogen economy), the reliability of supply of raw materials (such as silicon utilised in photovoltaics) as well as other impediments such as government polices and incentives (or lack thereof) that hinder the wider adoption of these technologies.

In part three we examine the potential of Ocean Energy as an alternative energy source. Ocean Energy defines a wide range of engineering technologies that allow energy to be obtained from the ocean using a variety of conversion mechanisms. It is an emerging industry, with the first commercial units going into production in 2008, although there has already been considerable research and development in this field over the last 30 years. Ocean Energy has the potential to make an important contribution to the supply of energy to countries and communities located close to the sea. Prominent on this list are several of the world's greatest consumers of energy, such as Japan, the UK, Korea, France, Spain, Portugal, Canada and the USA, amongst others. With low visual impact, virtually zero CO_2 emissions, and few foreseeable environmental concerns associated with it, this group of technologies appears to interfere far less with the environment than other established forms of energy production.

The fourth part of this report relates to the increasing importance of forests in reducing greenhouse gas emissions. An estimated 20 percent of total emissions result from deforestation and degradation, thus making deforestation and degradation the second largest source of green house gas emissions after fossil fuels, namely oil, gas and coal. The deforestation rate of tropical forests is proceeding at an alarming rate. The last climate talks in Bali created momentum in dealing with emissions from deforestation and degradation of tropical forests in developing countries. This new mechanism, commonly referred to as REDD (Reducing Emissions from Deforestation and Degradation), could become realty under the post-2012 Kyoto regime. Instead of discussing the biological and technical aspects, this report critically examines ongoing project implementation of REDD, and will discuss the potential benefits and risks involved in this mechanism.

The disadvantages of each of the proposed solutions discussed in this report must be clearly understood in order not to repeat the mistakes that have been associated with other forms of energy. However, although all solutions will always have a downside, the ones proposed in the present report have a more localized impact than other conventional energy production methods. The risk of global warming or nuclear meltdown of a power station affects the planet on a global or continental scale, while, for example, Ocean Energy would have at worst an effect on a localized area of the shoreline. Also, the solutions highlighted in the present report have not been shown, to date, to have any major negative environmental effects. These areas of technological innovation appear to be quite promising and thus warrant further investment.

1. Introduction

Academics and policy makers alike now recognise climate change as the most significant environmental, economic and security threat facing humanity. Much has been written and said about the potential and actual role of various new technologies and other non-technological innovations in helping to respond to the global challenge of climate change. Numerous innovative solutions have been put forward throughout this debate and many of these ideas are the subject of considerable research and development world wide. Some innovative technologies have already gone into commercial production or rollout while many of the non-technological innovations are at the pilot project stage.

The 1992 United Nations Framework Convention on Climate Change (UNFCCC) recognises the important role the development, application and diffusion of new technologies will play in reducing greenhouse gas emissions. More recently the United Nations Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report has highlighted the important role mitigation technologies, especially those associated with increased energy efficiency will play in addressing climate change.[1] For the period beyond 2012 (the initial commitment period under the Kyoto Protocol), there are a number of potential future climate change regimes under discussion both within and outside of formal UNFCCC processes.[2] All of these re-enforce existing views that technology, especially new technologies that offer cleaner and more advanced energy efficiency and lower emissions, will be an essential component of any comprehensive regime to address climate change post 2012.[3] The Bali Action Plan, endorsed at the 13th Conference of Parties of the UNFCCC, mandates enhanced technology development and transfer to support mitigation and adaptation to climate change.[4] This includes inter alia consideration of ways to accelerate deployment, diffusion and transfer of affordable environmentally sound technologies, and cooperation on research relating to current, new and innovative technology.

At the same time it is recognised that technological innovation alone will not provide a comprehensive solution to the challenges presented by climate change. Policy makers recognise that a comprehensive response to climate change will involve innovation in other areas such as land use and forestry, to mention but a few. This is clearly evidenced by the debate in Bali on the possible role of measures to reduce emissions from deforestation and degradation of tropical forests. It is estimated that in 2004 alone, emissions from deforestation were responsible for between 7 to 16 per cent of total green house gas (GHG) emissions, thus making deforestation and degradation the second largest source of GHG emissions.[5]

The deforestation of tropical forests is occurring at an alarming rate. What is more, increasing demand for first generation biofuels could further increase GHG emissions when tropical forests are cleared for palm oil plantations or commercial crops.

Reducing Emissions from Deforestation and Degradation or so called REDD initiatives seek to create financial incentives to reverse this trend and to preserve existing tropical forests. This mechanism might allow developed countries and individual companies to offset carbon credits generated through REDD against their emissions targets. At this moment, carbon credits from REDD projects can only be traded and sold in the voluntary carbon market. However, some propose that REDD credits might enjoy official value in the 2012 post-Kyoto regime. If this is possible then for the first time, preserving tropical forests could become a financially viable alternative to commercial logging. Additional benefits include biodiversity preservation, water and soil conservation, or opportunities for eco-tourism.

1.1 Overview of this report

While there has been considerable debate in both academia and amongst policy makers on the role of innovation in responding to climate change, especially in relation to the post 2012 regime, there is now a need for information on specific examples or case studies illustrating how these innovations can be implemented in the real world. This report purports to do just that by highlighting some specific examples of how innovation is being implemented.

Moreover, this report offers a comprehensive approach by examining innovative ways of reducing as well as avoiding green house gas emissions from fossil fuels and land use. This can help in formulating strategic policies, such as those aimed at substituting coal energy with Ocean Energy, which has the potential to satisfy global electricity consumption.

Much of the debate on and investment in technological solutions to climate change has focussed on a narrow range of technologies such as carbon capture and storage or geo-sequestration, ocean fertilization, the so called new generation of nuclear technologies, and biofuels, to mention but a few. However, as the recent experience of the development and rollout of biofuels and the associated debate on its role in food security has illustrated, quite unexpected consequences can arise from these new technological solutions. What is more, the development and implementation of new technologies does not occur in a vacuum. While an existing or new technology may offer solutions to pressing environmental problems such as climate change, it may also bring with it new environmental, social and economic consequences that had not been foreseen.

In many respects therefore, we find that some of the technological solutions to climate change being currently debated present us with 'hard choices'. They offer solutions to climate change but they may also have unintended environmental, economic and social consequences, or so called negative externalities. But so far much of the debate on these 'hard choices' and management of the risks of these technologies has not kept pace with the debate on the benefits they may bring for mitigating climate change.

In part two and three of this report we examine the 'hard choices' that two emerging technological solutions for climate change mitigation—nanotechnology and ocean energy present to policy makers. For each of these solutions we begin by providing a 'snap shot' of the current state of technology research and development and the potential (or actual) role of this technology in responding to the challenges of climate change. We begin with a brief overview of the technology and the history of research in this field, and provide a number of case studies and examples of ongoing research and development projects in these fields. This 'snap shot' is not intended to be comprehensive, since much of this technology is still in the early stages of development and is rapidly evolving. Where feasible we also highlight examples of actual commercialisation and rollout of this technology.

Beyond technological solutions, in part four we also highlight a number of pilot projects relating to REDD as well as the benefits and 'hard choices' that this solution presents. Initial pilot projects are underway in Bolivia, Indonesia and Australia, which are analysed in the relevant section of the report. In particular, we examine potential risks for the successful implementation of REDD projects including 'governance failure'. Another challenge we examine is the need to engage local forest-dependent communities in a meaningful way to allow for benefit sharing and access in order to promote the alleviation of rural poverty. We also examine a fundamental criticism of the logic underlying REDD projects. REDD rests on the assumption of the "avoided bad" rather than the "committed good" of mitigation activities, e.g. new technologies, such as solar or nanotechnolgy, that could be recognised under the clean development mechanism.

Part five of this report then goes on to consider some of the potential consequences of each of these innovations in responding to climate change. This analysis highlights some of the potential 'hard choices' that these innovations present.

We have chosen the two emerging technological solutions of nanotechnology and Ocean Energy as case studies in technological innovation for the very simple reason that so far there has been little detailed examination of the 'hard choices' offered by these technologies either in the literature or in policy discussions. In large part this is simply a reflection of the embryonic state of understanding by policy makers of the potential (and the risks) of these technologies in climate change mitigation and adaptation. In a similar vein, while there is a wealth of literature and studies of REDD, there has so far been very little examination of how REDD might operate in the field. The case studies presented in this report therefore highlight real life experience.

This report therefore serves a dual purpose, first to highlight the potential of innovations in three fields but also to underline that like all solutions, these innovations may also pose new challenges and issues for policy makers to confront. By publishing this report we hope to shed some light, in a clear and concise form, on the nature of the opportunities and 'hard choices' these innovations present.

2. Nanotechnology

2.1 What is nanotechnology?

Nanotechnology is science and engineering resulting from the manipulation of matter's most basic building blocks: atoms and molecules.[6] "Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometres, where unique phenomena enable novel applications. One nanometre is one billionth of a metre and is the width of approximately ten atoms.[7] To put that into perspective, a sheet of paper is about 100,000 nanometres thick."[8]

Scientific research across a range of disciplines including physics, chemistry and biology has advanced to such a stage that it is now possible to engineer matter at this scale, either by making particles or matter uniformly smaller, or by scaling up matter using nano-sized building blocks.[9]

This convergence of scientific disciplines is leading to a multiplication of applications in fields as diverse as materials manufacturing, computer chips, medical diagnosis, biotechnology, energy and national security.[10] By working at the molecular or atomic level it is possible to create materials with properties with a wide range of new applications, including a range of new technologies directly relevant to responding to climate change.

Nanotechnology has been identified by industry and governments globally as a priority area of research.[11] Since 2000, the US Federal Government has invested more than $1 billion a year in nanotechnology research with similar amounts having been invested by industry in that country.[12] Other developed countries have also invested heavily in nanotechnology research and development. For example, in 2004 the Japanese government invested $97.1 billion while the German government invested €290 million in nanotechnology research and development (R&D) in the same year.[13]

It is worth noting though that it is not only developed countries that are investing in nanotechnology R&D. Countries such as China, India, South Korea, Iran and Thailand have also increased R&D across different fields of nanotechnology.[14]

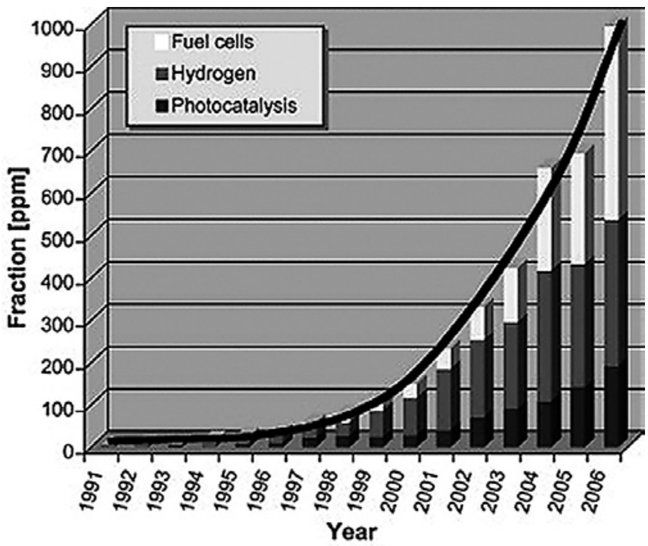
By 2004, venture capitalists had invested in excess of US$1 billion in nanotechnology companies worldwide and by 2014 the Organisation for Economic Co-operation and Development (OECD) estimates that nanotechnology will represent 15% of all global manufacturing output.[15]

2.2 The main fields of nanotechnology R&D and commercialization relevant to climate change mitigation

Nanotechnology is best described as a 'platform technology'.[16] Nanotechnology will not by itself have a dramatic impact on climate change, but its incorporation into larger systems, such as the hydrogen based economy, solar power technology or next generation batteries, potentially could have a profound impact on energy consumption and hence greenhouse gas emissions.[17]

A recent study by Zäch et al. highlights that in the last decade there has been a very rapid escalation in scientific interest in the potential for nanotechnology to provide tools to tackle energy and environment related issues.[18] As Figure 1 below shows, there has been a significant increase in the number of scientific publications dealing with the potential of nanotechnology, especially in the research on fuel cells, hydrogen and photocatalysis.

Figure 1: Growth in scientific publications involving Nanotechnology relating to energy and environment issues



Source: Zäch et al. 2006.[19]

A recent report commissioned for the United Kingdom government recognises nanotechnology has the potential to contribute to efforts to reduce harmful greenhouse gas emissions and therefore assist in responding to climate change in a range of areas including:

- the development of efficient hydrogen powered vehicles;
- enhanced and cheaper photovoltaics or solar power technology;
- the development of a new generation of batteries and super capacitors (i.e. devices that can store and subsequently release electricity) which could make the more widespread use of electric cars a reality;
- improved insulation of buildings;
- fuel additives that could enhance the energy efficiency of motor vehicles.[20]

In a similar vein, a recent study by the United Nations Environment Programme (UNEP) highlights that nanotechnology offers significant new means for transforming energy production, storage and consumption (especially in the fields of solar energy) and better storage for emission-free fuels.[21]

Table 1 provides an overview of some of the main areas of scientific research and development on nanotechnology relevant to climate change.

Table 1: Main areas of nanotechnology applications relevant to climate change mitigation

Broad categories of nanotechnology application	Specific applications / technology areas and examples
The hydrogen economy	Hydrogen as an energy source Hydrogen generation via electrolysis Hydrogen generation from photolysis Hydrogen fuel cells for use in transport (e.g. cars and buses) Hydrogen storage Light metal hydrides Carbon nanotubes storage Molecular sponges
Fuel efficiency	Fuel additives to catalyse fuel efficiency and reduce emissions Cerium oxide powders Cerium salts Improved lubricant additives to minimise corrosion and energy performance Nanodetergents to improve engine performance Nanostructured coatings for turbines Catalytic converters
Photovoltaics/Solar energy	Nanoparticle silicon systems Mimicking photosynthesis Nanoparticle encapsulation in polymers Calcopyrites Molecular organic solar cells Organic polymer photovoltaic systems Single walled nanotubes in conducting polymer solar cells III-V nitride solar cells Flexible film technology Novel nanostructured materials
Energy storage	Energy storage for transport Electric and hybrid cars Supercapacitors Electric trains, trams and trolley buses Batteries for portable consumer information and communication technology (e.g. laptops and mobile phones)
Insulation	Insulation for buildings (to save on heating and cooling) Foam insulation Nanogels Glass fibres Glass Vacuum insulating panels

Source: Collated and adapted from material presented in Oakdene Hollins 2007.

The following discussion concentrates on the role of nanotechnology in innovation in three of these broad categories, namely the development of efficient hydrogen powered vehicles, enhanced and cheaper photovoltaics or solar power technology, and the development of a new generation of batteries and supercapacitors. The reason for this is because in many respects the ongoing R&D and actual commercialisation of these technologies are interlinked. For example, the full scale rollout of hydrogen powered vehicles is dependant on the development of new fuel cell technology; and some (but not all) current R&D on fuel cells draws on advances in photovoltaics. These three areas of nanotechnology are also of significance because they provide numerous examples of nanotechnology R&D that has reached the stage of prototypes and or commercial production.

2.3 Nanotechnology and the hydrogen economy

Nanotechnology plays a crucial role in generation, storage and use of hydrogen as a fuel source. Hydrogen has the potential to replace traditional hydrocarbons as a major source of energy.[22] The most significant role of nanotechnology in the move towards the hydrogen economy is in the development of hydrogen fuel cells. Fuel cells are electrochemical devices that convert a fuel such as hydrogen or methanol directly into electricity.[23] A recent study describes how a fuel cell operates as follows:

> "Fuel cells use catalytic reactions to generate electricity directly from a chemical fuel source. Hydrogen fuel cells operate thus:
>
> > 1) A catalyst splits hydrogen into a proton and an electron.
> > 2) A membrane selectively allows the proton to travel through it whilst preventing the electron from doing so, so that the electron travels through a copper wire to generate an electrical current.
> > 3) A second catalyst on the other side of the membrane combines the proton with the electron and oxygen to form water...
>
> As a general rule, the larger surface areas, the more active the catalyst. The catalytic activity can be maximised by nanosizing the particles of the catalyst...
>
> Nanosizing the catalyst is considered as key to the development of efficient hydrogen fuel cells."[24]

In theory, a fuel cell is similar in structure to a battery, but it does not run down nor need re-charging as long as fuel is supplied. But significantly, conversion of the fuel to energy takes place without combustion and is therefore highly efficient, clean and quiet.[25]

However, it is important to note that hydrogen is a carrier of energy, not a source of energy. As such the use of hydrogen fuel cells is not necessarily carbon neutral. As the hydrogen for fuel cells has to be produced from other sources of energy, this will result in greenhouse gas emissions. The overall impact of hydrogen fuel cells on green house gas emissions will depend very much on the source of energy used to produce the hydrogen. There are examples of R&D utilising nanotechnology, however, that are seeking to get around this limitation. For example, the United Kingdom based company Hydrogen Solar is "developing a solar cell that splits water into hydrogen and oxygen using nanostructured materials" (See Box 1).[26]

BOX 1: TANDEM CELL™ TECHNOLOGY DEVELOPING HYDROGEN FROM THE POWER OF THE SUN

U.K. company Hydrogen Solar Ltd. have developed the Tandem Cell™ technology for the generation of hydrogen fuel using solar energy. As a consequence, this technology can create hydrogen fuel with zero carbon emissions. This technology is one example of so called 'green hydrogen', in contrast to 'black hydrogen' derived from fossil fuels and nuclear energy as illustrated in Figure 2.

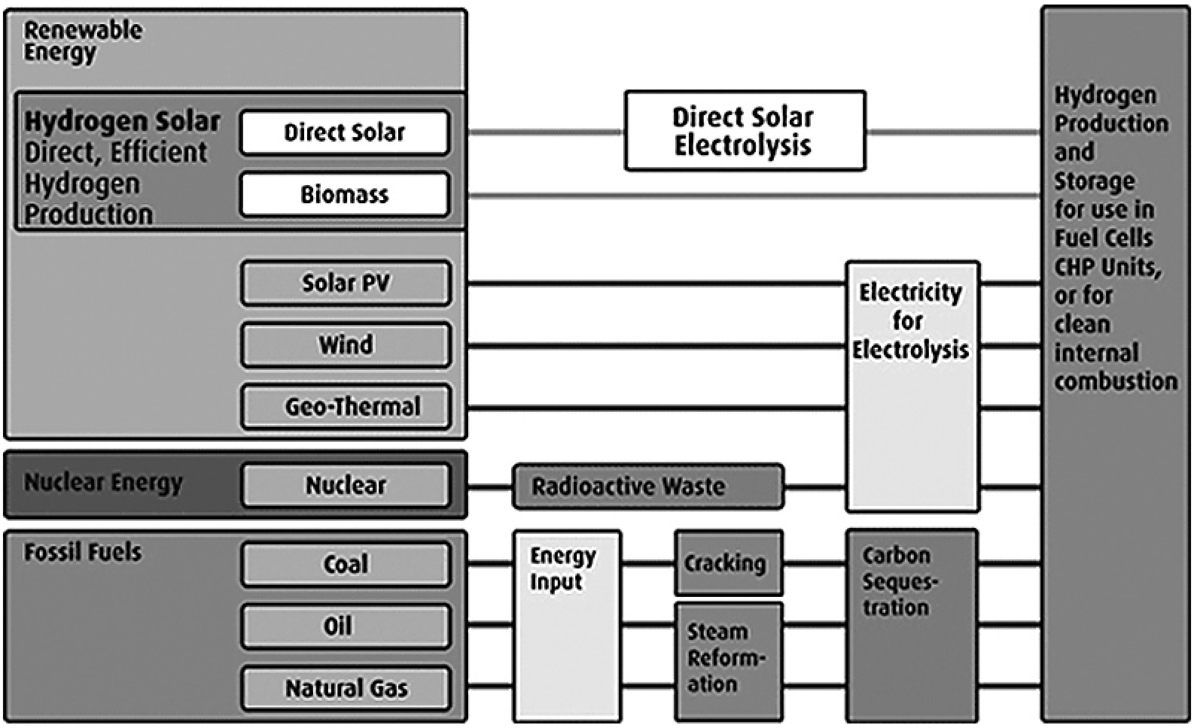
The Tandem Cell™ consists of two photo-catalytic cells in series: the front cell absorbs the high energy ultraviolet and blue light in sunlight, using nano-crystalline metal oxide thin films to generate electron-hole pairs. The longer wavelength light in the green to red region passes through the front cell and is absorbed in a Graetzel Cell producing electrical potential under nearly all light conditions. The two cells are connected electrically and together provide the potential required to split the water molecules in the electrolyte. The Cell is fabricated from widely-available, cheap materials.

The key to the Tandem Cell™ is the performance of the metal oxides in reacting to the photons of the incident light. Hydrogen Solar is currently developing processes to obtain high efficiency films in a usable form. The metal oxides are expected to be the limiting feature of Tandem Cell™ efficiency. Further development of this technology will involve optimising all other aspects, including the counter-electrodes, the electrolytes and the mechanical design to maximise light gathering and hydrogen collection. The most expensive component of the Cells is currently the special glass, on which the nano-crystalline films are deposited. Cheaper alternatives will be required to reduce the cost of the Cell.

Source: Text adapted from the Hydrogen Solar Corporate web page.[27]

While finding a carbon neutral way to generate hydrogen is one of the main challenges for the growth of the hydrogen economy, this limitation has not deterred automobile manufacturers from investing vast sums of money on R&D in relation to the development of hydrogen fuel cells. Table 7 at the end of this report highlights numerous examples of R&D on hydrogen fuel cells for cars by leading manufacturers. It is clear from this data that innovation in hydrogen fuel is a significant area of R&D for many companies. Many of these cars are still in the prototype or design stage. However, there are now signs that this technology has gone beyond this stage with the first such cars appearing on the market. For example, in June 2008 the Honda FCX Clarity went into production and has gone on limited commercial lease in Southern California, USA. Developments in nanotechnology were crucial to the development of the technology embodied in the Honda FCX Clarity (See Box 2 below).

Figure 2: 'Green hydrogen' compared with 'black hydrogen'



Source: Adapted from the Hydrogen Solar Corporate web site.[28]

BOX 2: A HYDROGEN FUEL CELL CAR ON THE MARKET -THE HONDA FCX CLARITY

In June 2008, Honda released the Honda FCX Clarity, one of the first hydrogen fuel cell vehicles in commercial production which has gone on limited commercial lease in the USA. The fuel cell in the Honda FCX Clarity combines hydrogen with oxygen to make electricity.

A key innovation in this vehicle is the Honda-developed Vertical Flow ('V Flow') fuel cell stack. This layout enables a vertical flow of hydrogen and oxygen from the air. The hydrogen fuel cell produces electricity for the vehicle. The fuel cell combines hydrogen, which is stored in a fuel tank on board the vehicle, with oxygen from the air to make electricity. The electricity then powers the electric motor, which in turn drives the front wheels.

The fuel cell is made up of a thin electrolyte film wedged between two electrode layers in between two separators. Several hundred layers of these cells are connected in a series. Hydrogen fuel is fed into the anode of the fuel cell. Helped by a catalyst, hydrogen molecules are split into electrons and protons. Electrons are channelled through a circuit to produce electricity. Protons pass through the polymer electrolyte membrane. Oxygen (from the air) enters the cathode and combines with the electrons and protons to form water. Water vapour and heat are released as by-products of this reaction.

The Honda FCX Clarity also incorporates a compact lithium-ion battery that serves as a supplemental power source. Recent developments in lithium-ion batteries are largely attributable to developments in nanotechnology (see discussion below in relation to next generation batteries).

While the safety of hydrogen is one of the major concerns surrounding its earlier uses, Honda has sought to address these concerns through the installation of a number of safety features related directly to the use of hydrogen as a fuel source. Sensors are located throughout the vehicle to provide a warning in the event of a hydrogen leak. These safety systems also include a ventilation system which is activated in the event of a hydrogen leak and an automatic system that closes the main cut-off valves on the hydrogen tank or supply lines as necessary. The high-voltage lines are electrically isolated. Sensors provide a warning in case of grounding. In the event of a collision, high-voltage contactors shut down the source power line.

Honda maintains that repeated flood and fire testing have confirmed a very high level of safety and reliability. This seems to be attested to by the fact that the vehicle has passed relevant safety tests set by US authorities, as the FCX Clarity has been cleared for commercial production and lease in the USA.

Source: Adapted from the Honda FCX Clarity corporate web site.[29]

2.4 Nanotechnology, solar energy and photovoltaics

Generating photovoltaic energy involves converting light into electrical energy, and is achieved through the use of semiconductors or photovoltaic solar cells.[30] These cells are generally encapsulated in water-tight modules for protection from moisture and impact and the resulting assembly is typically referred to as a solar panel or module.[31]

In 2005, annual sales of photovoltaics technology exceeded US$10 billion and the industry is currently undergoing a rapid period of growth unparalleled in its history.[32] This is due in large part to the fact that "photovoltaic technologies offer a potentially unlimited source of emission free, renewable energy by converting sunlight into electricity."[33]

Nanotechnology is widely used in current R&D in photovoltaics. Some of the main areas of research include: nanoparticle silicon systems; mimicking photosynthesis; nanoparticle encapsulation in polymers; use of non-silicon materials such as calcopyrites to develop thin film technology; molecular organic solar cells; organic polymer photovoltaic systems; development of single walled nanotubes in conducting polymer cells; III-V nitride solar cells; flexible film technology; and development of novel nanostructured materials.[34]

While nanotechnology is relevant across a wide range of R&D on photovoltaics, there is now considerable focus on the role of nanotechnology improving the efficiency of existing silicon photovoltaic panels, which are the most common type of photovoltaic panel in use today.[35] There are several different types of photovoltaic panels such as crystalline and non-crystalline or amorphous silicon photovoltaic panels.[36] Each of these photovoltaic panels differs in their efficiency in terms of converting light energy into electrical energy.[37] Crystalline silicon, while more efficient than amorphous silicon, is also more expensive.[38] There are also concerns about the availability of high grade silicon due to increased demand.[39]

Nanotechnology is a central part of on-going R&D aimed at circumventing these problems. One such approach that has attracted considerable attention is the so called Crystalline Silicon on Glass approach. This approach involves depositing a very thin layer of silicon, less than two micrometres thick, directly onto a glass sheet whose surface has been roughened by applying a layer of tiny glass beads. Heat treatment in an oven then transforms the silicon into crystalline form. The resulting layer is then processed using lasers and ink-jet printing techniques to form the electrical contacts needed to get the solar-produced electricity out of the thin silicon film.[40]

Much of this technology was pioneered by the Australian company Pacific Solar. In 2002, Pacific Solar produced a small Crystalline Silicon Glass module (660 cm2) which set the then world record for solar conversion for thin-film crystalline silicon.[41] In 2004, Pacific Solar sold its rights in this technology to the German company CSG Solar AG.[42] CSG Solar AG now manufacturers and markets Crystal Silicon on Glass Modules.[43]

Another area of R&D has focused on improvements to photovoltaic cells using alternate materials such as cadmium telluride. Cadmium telluride is a crystalline compound that can be deposited in a very thin layer on glass as a substitute for silicon.[44] The major advantage of this technology is that it is considerably cheaper than silicon based technologies. However, there have been some concerns expressed about possible environmental health and safety problems, especially at the end of the life cycle of products incorporating cadmium telluride.[45]

Numerous other companies are also involved in R&D relating to photovoltaics and solar technology involving nanotechnology. This includes some of the world's largest companies such as DuPont and General Electric, to mention just two. [46] While much of this nanotechnology R&D is focused on improving the efficiency of solar cells, other innovative solutions are being pioneered by lesser known companies such as Nanosolar, which markets itself as the vanguard of a third generation or third wave of solar power (See Box 3).

BOX 3: NANOSOLAR - THE THIRD WAVE OF SOLAR POWER INNOVATION BUILT ON NANOTECHNOLOGY

Nanosolar claims it is a company at the vanguard of a third wave of new generation solar power technology which has its roots in innovative nanotechnology R&D. Its corporate web site describes this new generation of solar power in the following terms:

"The First Wave started with the introduction of silicon-wafer based solar cells over three decades ago. While ground-breaking, it is visible until today that this technology came out of a market environment with little concern for cost, capital efficiency, and the product cost / performance ratio. Despite continued incremental improvements, silicon-wafer cells have a built-in disadvantage of fundamentally high materials cost and poor capital efficiency. Because silicon does not absorb light very strongly, silicon wafer cells have to be very thick. And because wafers are fragile, their intricate handling complicates processing all the way up to the panel product."

"The Second Wave came about a decade ago with the arrival of the first commercial "thin-film" solar cells. This established that new solar cells based on a stack of layers 100 times thinner than silicon wafers can make a solar cell that is just as good. However, the first thin-film approaches were handicapped by two issues: (1) The cell's semiconductor was deposited using slow and expensive high-vacuum based processes because it was not known how to employ much simpler and higher-yield printing processes (and how to develop the required semiconductor ink); (2) The thin films were deposited directly onto glass as a substrate, eliminating the opportunity of

- using a conductive substrate directly as electrode (and thus avoiding bottom- electrode deposition cost),
- achieving a low-cost top electrode of high performance,
- employing the yield and performance advantages of individual cell matching & sorting,
- employing high-yield continuous roll-to-roll processing, and
- developing high-power high-current panels with lower balance-of-system cost."

"The Third Wave of solar power consists of companies addressing the above shortcomings and opportunities. Most [of] ... the new companies address one or the other of the above aspects."

At the vanguard of this third wave, Nanosolar claims a critical edge over competitors by their use of a durable photovoltaic thin-film semiconductor, called CIGS (for "Copper Indium Gallium Diselenide"), combined with innovations in seven critical areas necessary to reach cost reductions in solar cells, panels, and systems.

One core element of this innovation is a proprietary ink that makes it possible to simply print the semiconductor of a high-performance solar cell. This ink is based on R&D by Nanosolar which has developed various proprietary forms of nanoparticles and associated organic dispersion chemistry and processing techniques suitable for delivering a semiconductor of high electronic quality. This ink displays unique properties because "by design" it consists of four elements which are in specifically designed atomic ratios to each other effectively "locking in" a uniform distribution. The homogeneous mix of nanoparticles in the ink in just the right overall amounts ensures that the atomic ratios of the four elements are correct wherever the ink is printed, even across large areas of deposition. This contrasts to vacuum deposition processes where, due to the four-element nature of CIGS, one effectively has to "atomically" synchronize various materials sources - a challenge with no successful precedent in any industry on a repeatable high-yield production-scale basis.

Source: NanoSolar Corporate web site.[47]

2.5 Nanotechnology and energy storage: the next generation of batteries

The first rechargeable battery was the lead-acid battery which was invented in 1859 by French Physicist Gaston Planté.[48] This was followed shortly thereafter in around 1900 with the invention of nickel-cadmium batteries.[49] These two technologies dominated the re-chargeable battery market for much of the 20th century and are still in use today.[50] More recently, a by-product of the space race in the mid 1960s was the development of the nickel-metal-hydride batteries which, from the mid 1990s, have been widely used in consumer electrical appliances such as laptop computers and mobile phones.[51]

The next generation of batteries, and those most relevant to responding to climate change will be re-chargeable batteries better suited for use in electric cars and other vehicles. Nanotechnology is at the core of mainstream R&D in relation to the next generation of re-chargeable batteries.

Initial work on batteries for use in cars, especially as used in hybrid vehicles, focused on adapting nickel-metal-hydride batteries used in appliances such as laptops and mobile phones. Hybrid vehicles already on the market, such as the Toyota Prius, use nickel metal hydride power cells/batteries.[52]

This R&D continues, but more recently considerable focus has been placed on the potential of lithium-ion batteries. One such example is the R&D of the Japanese car manufacturer Nissan. Nissan has recently developed a new laminated lithium-ion battery for electric vehicles. According to Nissan it is the same size as a conventional car battery, but has double the capacity (140Wh/kg) and 1.5 times the power even after 100,000 kilometres usage over five years. The result is double the driving distance, achieved with no increase in battery load.[53] Utilizing mainstream nanotechnology R&D techniques, higher power and higher battery capacity have been achieved through modification of the negative electrode material. This increases energy density and reduces electrode resistance due to nano-level electrode design.[54] This technology is due to be launched onto the market in 2009.

Nissan is not the only automobile company that has been conducting nanotechnology R&D to develop next generation battery technology for use in electric vehicles. Mitsubishi has developed and has commenced manufacturing advanced lithium ion batteries for electric vehicles for launch in 2009. Mitsubishi and GS Yuasa Corporation have formed a joint venture company to develop and build large format lithium ion batteries for automotive applications. This involves an initial investment of US$30 million to install equipment at Yuasa's main plant to produce up to 200,000 lithium cells annually.[55] The batteries to be produced by the joint venture are based on the "LIM series" of Large Lithium-ion batteries manufactured by GS Yuasa which reportedly have ten times the capacity of those already used in hybrid electric vehicles.[56] Mitsubishi also plans to supply these batteries for use in electric vehicles manufactured by other auto-makers.[57]

In a similar vein, electronics company Sanyo is developing nickel-metal hydride batteries for hybrid electric vehicles. These batteries have been adopted by Ford Motors in the USA and Honda Motors in Japan. Sanyo is also developing next-generation nickel-metal hydride batteries with Volkswagen, Germany.[58]

BOX 4: CASE STUDY OF AN ELECTRIC CAR ALREADY ON THE MARKET—TESLA MOTORS

Tesla Motors is a new automobile company based in San Carlos, in Silicon Valley, California, USA, with production facilities and a subsidiary in the UK. The company is entirely dedicated to Electric Vehicles (EVs), and its debut car is the Tesla Roadster, which came into production in 2008.

The Roadster is powered entirely by electricity, has no exhaust pipe, and therefore is classified as a Zero Emissions Vehicle (ZEV). However, unlike most EVs on the market today, the Tesla Roadster is a luxury sports car. The manufacturer claims it can accelerate from 0 to 96.5 km/hr in 3.9 seconds and has top speeds of 200 km per hour.

While even the Toyota Prius—a Hybrid Electric Vehicle, not an EV—is currently viewed as expensive, the Roadster is more so, currently being sold in the US for US$109,000. It is due to go on sale in Europe in 2009 at €99,000. According to the company website however, Tesla Motors recognizes this disadvantage, and "consciously chose to develop a high-end sports car as our first car in order to develop the "performance DNA" from which we could create other electric vehicles," implying that despite the cost, the Roadster has paved the way for EVs in the future with some important technological advances.

Perhaps the single most important figure regarding the Tesla Roadster is its driving range. While many EVs use Nickel Metal Hydride or Nickel Cadmium batteries, and are restricted to city driving due to their constant need to be charged, the Roadster has a practical range of 255 km per charge due to its lithium ion battery pack. In city conditions this number increases due to the regenerative braking system, which makes use of energy normally lost when braking. Lithium ion batteries also have the additional advantages of a longer shelf-life (the company claims that the battery pack on the Roadster can go for 160,000 km on peak performance).

Tesla Motors also places a heavy emphasis on recycling batteries, which contain valuable material that can be reused, even when they are completely dead. Besides decreased reliance on oil and decreased emissions, another advantage of the Roadster claimed by its manufacturer (and manufacturers of other EVs) is that there is little service needed for the car, because it contains far fewer moving parts.

However it must be noted that the term "ZEV" is in some respects not entirely correct. While the car itself produces zero emissions, generating the electricity used to charge the battery does produce emissions. Although with advances in renewable power, as highlighted in various sections of this report, it is now technically possible to re-charge the vehicles batteries from renewable sources.

Tesla has recently announced that it is planning a new vehicle for release in 2010. The Model S, as it will be called, is expected to have a range of 360 km between charges and cost $60,000 in the US.

Source: Tesla Motors Corporate web site[59] and Associated Press.[60]

2.6 What are the regulatory implications of the use of nanotechnology in new climate change mitigation technologies?

While there are potentially many benefits offered by nanotechnology for responding to climate change, there are also emerging concerns about the potential risks that nanotechnologies present to humans and the environment and the ability of current regulatory regimes to sustainably manage those risks. As nanotechnologies are an emergent field of science and technology, it is not yet clear precisely what risks they pose to humans, animal health and the broader environment.[61] As Kuzma and VerHage have observed

> "the risks could be practically zero or they could be significant, depending on the properties of a particular product and exposure levels. For the most part, no one knows. Few risk assessments have been done that allow one to predict what happens when these very small materials, some designed to be biologically active, enter the human body or are dispersed in the environment."[62]

The most significant issues raised so far relate to the toxicity of manufactured nanoparticles and their ability to enter the human body and reach vital organs via the blood.[63] However, there are still "significant gaps in knowledge about how nanoparticles act, their toxicity and how to measure and monitor nanoparticle exposure."[64]

Clearly many more scientifically rigorous studies and risk assessments still need to be undertaken to confirm or refute these initial concerns, and perhaps more significantly, to clearly delineate the nature and scale of the risks potentially associated with the use of nanotechnology.

What is not clear is whether any of the concerns that have been raised in relation to nanotechnology are at all relevant to the technologies relevant to climate change, including those discussed in this report. This requires further detailed study.

Given the sophisticated and expensive nature of nanotechnology R&D, there are also ethical issues raised concerning the ability of less developed countries to benefit from and sustainably manage such advances in technology. What is unclear is whether less developed countries will be able to readily access this new technology, and perhaps more importantly, whether they have the capacity to properly assess and manage potential risks.

The extent to which the public and, perhaps more importantly, civil society (which has a major role to play in shaping public responses and attitudes to nanotechnology) fully understands both the technology that lies behind nanotechnology and the potential risks and benefits offered by nanotechnology is unclear. In some sections of civil society and in the community more broadly, there appears to be an emerging visceral response to nanotechnology which is both sceptical, and in some cases, outright hostile.

In part this is motivated by very genuine and reasonable concerns about the scientific uncertainty surrounding the potential risks to human health and the environment posed by some forms of nanotechnology; in part there is also a lack of understanding of the new technology. Already we are seeing quite emotional comparisons between asbestos and genetically modified organisms or GMOs. Whether those concerns are well founded remains to be seen, but for public trust and enthusiasm for nanotechnology to be maintained, it is vital that developments in nanotechnology occur against the backdrop of a robust, transparent, and efficient regulatory regime for nanotechnology.

Internationally there is increasing recognition of the need for closer examination of the regulatory implications of nanotechnology. As one recent author has noted

> "There are two key issues at the heart of regulation of nanotechnology applications and products. Does the nanotechnology create something new and currently unknown to the applicable regulatory regime? Does the unprecedented small scale of the nanotechnology application or product make a currently known material, process or product significantly different, from the perspective of regulatory goals? If the answer to one or both of these questions is yes for a given nanotechnology application, then regulatory changes are likely to be required. If neither of those two conditions exist for a given nanotechnology application, then the existing regulatory framework can effectively handle the application."[65]

As noted above, more detailed research is required on the nature of potential risks associated with nanotechnology before regulators can determine what might be an appropriate regulatory response. So far no country has yet formulated regulations that apply specifically to nanotechnology, although many countries are currently examining proposals for such regulation. One of the few countries that has considered the regulatory implications of nanotechnology in any significant detail is the USA. Thus in early 2007, the US Environmental Protection Agency (EPA) issued a White Paper on Nanotechnology which considers the future role of the EPA in environmental issues that may emerge from current and future developments in nanotechnology.[66] But so far there is no wide ranging proposal in the USA for nanotechnology regulation at the national level, while a number of proposals are in various stages of development at the state level. Similar developments at the national and state and or provincial level are also underway in other developed countries such as Australia and in Europe.

At the international level, the consideration of the regulatory implications of nanotechnology by intergovernmental organisations (especially within the United Nations System) has been at best rudimentary and fragmented, and has so far failed to comprehensively grasp the full range of regulatory challenges posed by nanotechnology across all sectors.

Despite having a wide mandate on a range of environmental issues, the main United Nations organisation dealing with environmental issues, the United Nations Environment Programme, does not yet have a dedicated program or project related to nanotechnology. In 2007, UNEP's fourth annual report on the changing global environment (GEO Yearbook 2007) highlighted the urgent need to adopt appropriate assessment and legislative processes to address the unique challenges presented by nanomaterials and their life cycles.[67]

As well as stressing both the potential risks and benefits offered by nanotechnology, the GEO report also highlighted a number of policy recommendations for future actions by nations and international organizations including, inter alia, the need to: standardise nomenclature and test protocols for assessing risks associated with nanotechnology; evaluate the potential environmental and human health impacts of nanotechnology, giving priority to nanotechnology already being mass produced and potentially released into the environment; identify, evaluate and share private sector risk management methods and best practices relating to worker safety and materials handling procedures; and study what lessons can be learnt from the existing knowledge and experience related to environmental health issues.[68]

Significantly, this cursory UNEP study also recognised that a high priority must be attached to sensitizing national regulatory and environmental agencies to the potential opportunities and risks of nanotechnology. It similarly endorses the need for action to educate the public about the benefits and risks of nanotechnology, raise awareness, and provide access to information about the health and environmental impacts.[69]

Apart from this cursory analysis, there has been little substantive examination of the regulatory implications of nanotechnology within the UN system. In fact, by far the most advanced developments with respect to the consideration of the regulatory implications of nanotechnology are occurring outside of formal UN processes and national government legislative systems. The most significant developments so far have occurred under the auspices of the International Organization for Standardization or ISO, which is the world's largest developer and publisher of International Standards. The ISO is a non-governmental organization which is essentially a network of national standards institutes of 157 countries with a central Secretariat in Geneva, Switzerland.[70] In 2005 the ISO established a new technical committee "ISO/TC 229 Nanotechnologies" hosted by the United Kingdom to develop International Standards for Nanotechnologies.[71] The mandate of this committee is to examine standardization in the field of nanotechnologies that includes either or both of the following:

> "(1) Understanding and control of matter and processes at the nanoscale, typically, but not exclusively, below 100 nanometres in one or more dimensions where the onset of size-dependent phenomena usually enables novel applications; [and] (2) Utilizing the properties of nanoscale materials that differ from the properties of individual atoms, molecules, and bulk matter, to create improved materials, devices, and systems that exploit these new properties."[72]

The current and future work of this committee include "developing standards for: terminology and nomenclature; metrology and instrumentation, including specifications for reference materials; test methodologies; modelling and simulations; and science-based health, safety, and environmental practices."[73]

Similarly, in 2005, the OECD established a process to facilitate exchange of information on the development of nanotechnology regulations and to assist OECD member countries in developing regulatory frameworks. This process is ongoing. In March 2007, the OECD's Committee on Scientific and Technological Policy established a Working Party on Nanotechnology. The objective of this Working Party is to promote international co-operation that facilitates research, development, and responsible commercialisation of nanotechnology in member countries and in non-member economies.[74]

A work programme is under development to address some of the main policy challenges and will include work on statistics and indicators of nanotechnology; examination of the business environment for nanotechnology; fostering international collaboration in nanotechnology research; work on public perceptions towards nanotechnology and the engagement of stakeholder communities in the debate on nanotechnology; as well as a dialogue on policy strategies to spread good policy practices towards the responsible development of nanotechnology.[75] In 2006, the OECD also established a Working Party on Manufactured Nanoparticles which is currently looking at international co-operation in health and environmental safety related aspects of manufactured nanomaterials.

Finally, it is worth noting that outside of all of these processes pending the development of regulatory regimes there are also a number of initiatives underway to develop interim voluntary standards for the safe production, use and disposal of nanotechnology.[76] These include the Voluntary Reporting Scheme for engineering nanoscale materials sponsored by the government of the United Kingdom and joint industry and civil society initiatives such as the Environmental Defense-DuPont Nano Partnership Nano Risk Framework.[77]

Amongst academics there is also an emerging debate on "whether and how governments should regulate nanotechnology."[78] Reynolds for example highlights how regulatory responses to nanotechnology "could fall along a broad spectrum, ranging from complete relinquishment or prohibition, to permissible use only in military programs, to more moderate regulation, to laissez-faire."[79] Several other scholarly publications have canvassed aspects of the wide ranging implications of the rapid up-take of these new developments in technology in industry.[80]

Clearly a number of existing principles of environmental law such as the precautionary principle and the polluter pays principle have a role to play in shaping regulatory responses to nanotechnologies. There is a considerable body of legislative practice and academic literature on the application of these principles to other emergent technologies such as GMOs. Lessons learned from these earlier technological innovations clearly show the "need for finding a balance between industry innovation, risk reduction and public discussion concerning the future regulatory framework governing the technology."[81]

2.7 Further research required on the role of nanotechnology in responding to climate change

In summary, we recommend further detailed research on how nanotechnology can contribute to addressing climate change. The cursory review of some fields presented in this report suggests it may have a major role to play. However, there is evidence of obstacles to the widespread rollout of technologies developed utilising nanotechnology. Clearly, further detailed analysis of the benefits to be gained from the development of nanotechnology in the context of climate change is warranted. Such studies need to consider ways to overcome obstacles to widespread rollout of this technology such as inadequate infrastructure (as in the case of the hydrogen economy), the reliability of supply of raw materials (such as silicon utilised in photovoltaics) as well as other impediments such as government polices and incentives (or lack thereof) that hinder the wider adoption of these technologies.

Questions also remain on the potential risks to human health and the environment from nanotechnology. Further scientific studies are needed on these risks. Such studies should also consider how these compare with risks associated with other proposed technological solutions to climate change. For example, the well documented risks and hazards of nuclear power.

This in turn will lead to better understanding of the extent to which gaps and uncertainties exist in the current international and domestic legal and regulatory frameworks with respect to nanotechnology. Are these gaps and uncertainties relevant to nanotechnology relevant to climate change? If so in what way? Further detailed studies on these issues are clearly warranted.

3. Ocean Energy

3.1 What is Ocean Energy and how is it relevant to climate change mitigation?

Ocean Energy (OE) defines a wide range of engineering technologies that are able to obtain energy from the ocean using a variety of conversion mechanisms. It is an emerging industry, with the first commercial units coming online in 2008. It has the potential to make an important contribution to the supply of energy to countries and communities located close to the sea. This in itself is an important possible limitation of OE, as contrary to an extended belief, over 60% of the world's population lives over 120km away from the coastline.[82] Consequently, although it has been reported that the theoretical global potential for the various types of OE is between 20,000 and 92,000 TWh/year, compared to the world consumption of electricity of around 16,000 TWh/year, it is unlikely that this technology alone will be able to solve the energy needs of the planet.[83] Nevertheless, it is likely that certain countries well endowed with this type of energy could eventually rely on it to produce a significant percentage of their energy needs.

The first patents for wave-power devices were issued in the 19th century, and by 1966 the French had built a tidal barrage power station at La Rance River, with an annual production of 600 GWh, which is still operating today. However, the idea that OE could supply a large amount of the world's electricity did not really catch on until the oil crisis in the 1970s.[84] During this time, research on a number of ideas and prototypes began, and although the decrease in the price of oil in the 1980s dramatically slowed down the development of the industry, a number of these technologies have recently reached the commercial stage.

Although there is a range of ways to convert the various types of OE to electricity, this report will mainly concern itself with the two types that have recently produced commercial plants, namely:

- Wave energy, where the energy of the surface wind waves is used to produce energy by a variety of devices installed on the surface of the sea.

- Hydrokinetic energy, where the energy of ocean (or fluvial) currents and tides is captured by devices which are installed under the surface of the water.

Other possible types of OE include ocean thermal energy, being developed mainly by Japanese researchers, and osmotic energy, which is still very far from commercialisation.[85]

The OE industry has recently received an increased amount of attention, with utility companies beginning to take the sector seriously, and venture-capitalists starting to invest considerable sums of money.[86] The majority of research and development is currently being undertaken by developed countries, mostly in the EU, USA, Japan and Australia. However, other countries such as Korea and China have recently started to show an interest in OE. For example, the Chinese government signed an agreement in 2004 to cooperate in the development of a 300 MW tidal lagoon next to the mouth of the Yalu River.[87] The Korean government has installed a 1MW Gorlov turbine on the Uldolmok Strait.[88]

The key concept behind OE is that, like wind power, it is completely renewable, and that it produces no greenhouse gases beyond those involved in the production of the machinery necessary for it. However, unlike wind power, it is a lot more predictable and as such potentially more compatible with large grid power systems.

3.2 State of the Ocean Energy Industry

Although tidal barrages were built as early as 1966, a number of problems associated with these designs (which are similar to large scale hydro-electric installations) hindered their wide-scale application. Other tidal barrages, such as the one proposed for the Severn in the South West of the U.K. are currently being re-appraised, although opposition from the Environment Agency and other groups appear to make it unlikely that the project will ever reach construction.[89] To date, around 260MW of tidal barrages are installed world-wide, though it looks unlikely that many more of these will be built in the future.

In contrast, the modern OE industry is currently moving from the prototype stage to installation of the first showcase commercial farms (See Table 3). The first of these have just recently come into operation, with the Pelamis (See Box 5) and SeaGen (See Box 7) having just completed installation at the end of the summer of 2008. A number of other devices have completed prototype testing and are awaiting planning permission, such as the WaveDragon (See Box 6), or waiting for support installations to be constructed (such as the WaveHub).

BOX 5: THE PELAMIS

The Pelamis units installed off the coast of Portugal 100km north of the Pilot Maritime Zone (PMZ) created by the Portuguese government constitute the world's first multi-unit commercial wave farm. The Pelamis Wave Energy Converter devices are made of articulated semi-submerged cylindrical sections, which are linked by hinged joints. The motion of these joints due to waves is resisted by hydraulic rams, which are able to produce electricity. The power produced by the units is transmitted to the grid using a single seabed cable, which regroups all the energy produced by all the devices that make up the farm.

Each of the three machines used at this location are 140m long and 3.5m in diameter, with a total installed capacity of 2.25MW (750kW each). However, the energy actually produced by the machines depends on the wave conditions, with the machines typically producing 25-40% of the full rated output over the course of a year. Thus, the three machines can produce enough power to meet the demand of approximately 1,500 households.

The Portuguese government has put in place a feed-in tariff (a legislative price incentive which encourages the adoption of renewable energy) currently equivalent to approximately €0.23/kWh in order to support the project. The PMZ has a total area of 320km2 and can eventually support over 200MW of capacity. There are plans to thus expand the site with a further 20MW of Pelamis units, with work on this phase already under way.

Photo: Courtesy of Pelamis Wave Power Ltd.

Source: Adapted from the Pelamis Wave Power Ltd. Website.[90]

The present capacity of OE installed worldwide is relatively insignificant compared to other sources of power. For example, Sizewell B nuclear power station in the UK produces by itself 1,188MW, with each MW of electric energy (or power consumption) being equivalent to that typically used by a 1,000 homes. But the potential for growth in the industry is considerable, as it has a potential capacity of over 20,000 TWh/year.[91] Thus, it appears likely that the actual amount of electricity produced by 2015 could be much greater than that suggested by Table 2.

The distribution of OE research and development throughout the world is very unequal, with a small number of countries (such as the USA, Portugal, UK, Korea and Japan) conducting most of the research. Portugal and the UK in particular are providing a lot of encouragement to the industry, in the form of the creation of a Pilot Maritime Zone in Portugal and the WaveHub in the UK.

BOX 6: THE WAVE DRAGON

The Wave Dragon is a floating device that is able to transform the power of waves that pass over it into energy. It can be deployed as single units or in arrays, and thus be scaled up to a capacity comparable to conventional power plants. Although the device floats on top of the water, its low height ensures that it is practically invisible from the shoreline. The first prototype connected to the grid has been located at Nissum Bredning in Denmark since 2003. The device was developed with funding support from the European Union, the Welsh Development Agency, the Danish Energy Authority and the Danish Utilities PSO Programme.

The company responsible for it is currently ready to construct and deploy a full-scale commercial demonstration unit in Pembrokeshire, Wales. This unit would have a capacity of 7MW, which should produce enough green electricity each year to meet the annual demand of 2000-3000 homes, and offset the release of approximately 10,000 tonnes of CO2.

Photo: Courtesy of Wave Dragon ApS

Source: Adapted from the Wave Dragon Website.[92]

It could be concluded that for the case of OE, the “First Generation Technology” is currently at the stage where the first commercial devices are starting to be connected to the grid (or “showcase commercial product stage”, see Figure 3).[93] At this stage it is expected to yield tried and tested products that can be deployed in different ways to supply energy to a power grid. It is forecast that, like other new power generation technologies, it will eventually be followed in 2-3 years by a “Second Generation Technology”, which would further improve the current designs using the benefit of experience.

Figure 3: Flow diagram of Ocean Energy Development

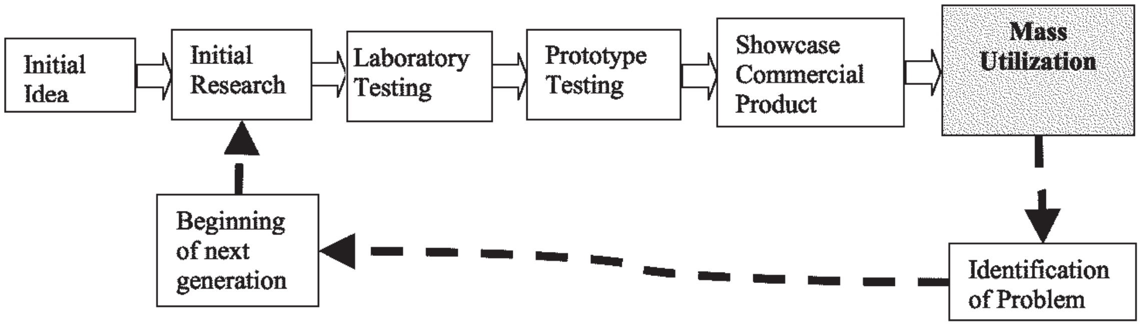


Table 2: Tidal Barrage project matrix

Name	Location	Company	Type of Ocean Energy	Design Type	Technology Stage	Installed Capacity	Expected Capacity
La Rance, France	France		Tidal	Tidal Barrage	Operating since 1966	240Mw, connected to grid	N/A
Annapolis pilot tidal power plant (TPP)	Annapolis Royal, Nova Scotia, Canada		Tidal	Tidal Barrage	Operating since 1984	20MW, connected to grid	N/A
Kislaya Guba tidal power station	Kislaya Guba, Russia		Tidal	Tidal Barrage	Under Construction	N/A	400kW
The Philippine Dalupiri 2.2 GW Blue Energy Project	San Bernardino Straight, Philippines	Blue Energy Company	Tidal	Tidal Fence	Project on Hold. It appears that concept and technology was not further developed after 1985.	N/A	N/A
Severn Tidal Barrage	Severn Estuary, UK	N/A	Tidal	Tidal Barrage	Has been at concept stage for decades	N/A	N/A
Mersey Tidal Barrage	Mersey Estuary, UK	N/A	Tidal	Tidal Barrage	Has been at concept stage for decades	N/A	N/A

Table 3: Ocean Energy project matrix

Name	Location	Company	Type of Ocean Energy	Design Type	Technology Stage	Installed Capacity	Expected Capacity
Open Centre Turbine	Orkney, Scotland, UK	OpenHydro Tidal Technology	Tidal	Current Turbine	Operating since 2008	250 kW, connected to grid	N/A
Roosevelt Island Tidal Energy (RITE)	NYC East River, USA	Verdant Power	Tidal	Current Turbine	Operating since 2007	70kW	Potential 10MW installed capacity at site
SeaFlow	Lynmouth, Devon, U.K.	Marine Current Turbines Ltd's	Tidal	Current Turbine	Operating since 2003	300kW	N/A

Name	Location	Company	Type of Ocean Energy	Design Type	Technology Stage	Installed Capacity	Expected Capacity
SeaGen	Strangford Narrows, Northern Ireland	Marine Current Turbines Ltd's	Tidal	Current Turbine	Operating since 2008	1.2MW connected to grid	N/A
SeaGen	Anglesey, North Wales, U.K.	Marine Current Turbines Ltd's	Tidal	Current Turbine	-	N/A	10.5 MW to be commissioned by 2010-2011
Open Centre Turbine	Bay of Fundy (Canada) and Alderney (Channel Islands, UK)	OpenHydro Tidal Technology	Tidal	Current Turbine	Turbine under construction	N/A	1 MW Turbine under Construction
Pelamis	Portugal	Pelamis Wave Power	Wave	Pitching Device	Operating since 2008	2.25MW, connected to grid	Letter of intent for 20MW more issued, site potential is over 200MW
Blue Concept	Kvalsundet, south of Hammerfest, Norway	Hammerfest STRÿM AS	Tidal	Current Turbine	Operating prototype since 2003	300 kW, connected to grid	N/A
Venturi	European Marine Energy Centre (EMEC)	Lunar Energy	Tidal	Current Turbine	Half-scale prototype to be installed in 2008	N/A	.About 8MW by 2010/2011, 300MW project in Korea by 2015
Oyster	EMEC, Orkney, U.K.	Aquamarine Power	Wave	Oscillating Wave Surge	Full scale prototype about to be installed	N/A	300-600kW
Wave Dragon	Pembrokshire in Wales, UK	Wave Dragon Group	Wave	Overtopping Device	Construction to start in 2008	N/A	7MW by 2009, 50 MW project in the demonstration Zone Portugal by 2011 and a 70 MW project in Wales in the Celtic Sea by 2012
Pelamis	Orkney, Scotland, UK	Pelamis Wave Power	Wave	Pitching Device	Commercial Farm. Licenses, consents and funding granted	N/A	3MW
Pelamis	Cornwall, UK	Pelamis Wave Power	Wave	Pitching Device	Commercial Farm, Funding and consent for Wave Hub granted. Wave hub is currently scheduled for 2010	N/A	Up to 5MW
DHV Turbine	Gold Coast, Queensland in 2002, first prototype	Tidal Energy Pty Ltd	Current (Tidal or fluvial)	Current Turbine	Two production prototypes being beta tested, expected commercial production to start by around Q1 2009	N/A	Unknown
Underwater Electric Kite	Unknown	Underwater Electric Kite Corporation	River Current	Current Turbine	First commercial sale	100 kW	N/A
Gorlov Helical Rotor	Uldol-muk Strait, Korea	GCK Technology	Tidal	Tidal Helical Rotor	1 kW Experimental Plant operational from 2007	N/A	N/A

Name	Location	Company	Type of Ocean Energy	Design Type	Technology Stage	Installed Capacity	Expected Capacity
Stingray	Scottish Coast, UK	Engineering Business (EB)	Tidal	Current hydroplane	150kW prototype tested. Currently project is on hold.	N/A	N/A
LIMPET	Island of Islay, U.K.	Wavegen	Wave	Oscillating water column	Operating since 2000	100kW	Submitted for planning approval for 4MW plant
Sea Snail	Eynhallow Sound off of Orkney, UK	Aberdeen's Robert Gordon University	Tidal	Tidal Turbine	Prototype installed	150 kW	N/A
	Swansea, UK and Liaoning, China	Tidal Electric	Tidal	Tidal Lagoon	Feasibility Stage	N/A	N/A

BOX 7: THE SEAGEN TURBINE

SeaGen is the first commercial scale tidal turbine to have been connected to the grid. Developed by the renewable energy company Marine Current Turbines Ltd. after years of testing of similar prototypes such as the Seaflow, it is situated approximately 400m from the shoreline in Strangford Narrows, Northern Ireland. The company was established in 2000 and its principal corporate shareholders include BankInvest, ESB International, EDF Energy, Guernsey Electricity, Triodos Bank, Guernsey Electricity and Carrs Milling.

The structure has four times the rated power of any other tidal stream project built so far, with a double set of turbines mounted on a monopile structure that supports itself via four pins drilled into the seabed to a depth of about 9m. The monopole also emerges from the water so that the turbines can be easily raised above the surface of the sea for maintenance, which can be carried out by a small boat. Its rotors operate for up to 18-20 hours per day, producing energy equivalent to that used by 1000 homes.

A £2 million programme to evaluate the environmental impact of the project has also been put in place, involving the Queen's University Belfast (QUB) and the Sea Mammal Research Unit at St. Andrew's University (SMRU). The objective of the program is to observe how the marine life (which includes sea lions and some species of sharks amongst others) interacts with the structure.

In February 2008, the company announced a joint initiative that would see the installation of a further 10.5MW of power using SeaGen devices off the coast of Anglesey, in north Wales. This project could eventually be commissioned around 2011/2012.

Source: Adapted from the Sea Generation Ltd. website.[94]

3.3 What are the challenges for Ocean Energy?

As with all renewable energies, the main challenge is to bring the cost of producing electricity down to something that approaches the rates produced by other generating sources. Currently, coal power is one of the cheapest ways of producing energy, at around US$0.05 per kWh, although a study by the Massachusetts Institute of Technology (MIT) puts the cost at US$0.08 if the CO_2 from coal-fired power stations had to be captured and stored underground, or if a carbon tax of $30 per tonne was to be imposed on coal power generation.[95] Thus, in order to be competitive, OE should have to produce energy at somewhere in the US$0.05-0.08 range, as otherwise it is unlikely that it would be used widely due to it being uneconomic.

It is quite difficult to ascertain the current cost of OE, as this information is naturally not readily released by the leading companies in the industry. However, it is currently believed that the cost of generation on a life-cycle cost basis would be around US$0.15-0.20 per kWh for small projects, and that these would fall into the US$0.05-0.08 range as the technology develops. At present, various governments around the world are promoting minimum quotas for renewable energy (for example, the Portuguese have introduced a feed-in tariff currently equivalent to approximately €0.23/kWh for the Pilot Maritime Zone, or PMZ). OE can initially provide electricity as part of these quotas until the technology reaches the mass production stage which theoretically would bring the prices down.

Currently the world uses over 19,000 TWh/year of electricity, of which around 2,800 Twh/year are produced by nuclear fuel.[96] The challenge for OE is thus to attempt to continue to develop quickly enough to be able to significantly contribute to the decline of fossil fuels. There are currently about 4MW of modern OE devices installed, which could realistically expand to over 65MW within the next 2-3 years from various projects currently under development.

3.4 What are the possible environmental implications related to Ocean Energy?

It is characteristic of all new technologies to be greeted initially with a degree of euphoria that does not consider the potential problems that can arise due to large-scale utilisation. Nothing in nature comes without a price, and taking energy from one system inevitably will have a consequence. Thus, it is imperative to determine what are the possible implications of Ocean Energy and evaluate if these effects are more acceptable than those of other power generating methods. As at present there are no large-scale OE installations, a lot of the potential problems associated with it are speculative, as shown on Table 4.

As the first commercial Ocean Energy installations are only just coming online, there is a lack of knowledge regarding the real effects. Nevertheless, a number of Environmental Impact Assessments have been undertaken, and these have all so far provided findings indicating no significant environmental impacts.[97]

Table 4: Possible problems of Ocean Energy

Potential Environmental implications	Rationale	Analysis
Disruption to sea currents or long-shore sediment transport	The reduction of the amount of incident wave energy on a shoreline is a well-known cause of disruption in the long-shore sediment transport. This results in an increase in the amount of sediment deposition in the area where the wave energy is reduced, which in turn results in an increase in erosion in adjacent areas which are not protected. Also, a reduction in the incident wave energy can modify the sea currents in the neighbouring area, and both of these effects can lead to changes in the local bathymetry.	It is probable that the wave and current climate around the site of a potential OE site would not be seriously disrupted. For instance, a recent study of the impact of energy absorption by a possible wave farm on the nearshore wave climate of the Maritime Pilot Zone of the coast of Portugal showed that the energy extraction does not exceed the values of 9.1% (for the most extreme month, January) and 21.1% (for the calmest month, July). [98] These correspond to a decrease in wave height of 20 and 16cm respectively, meaning there is a difference of less than 12% with respect to the original values. This study was based on the assumption of a 202.5MW Pelamis wave farm. The study thus appears to indicate that the longshore sediment transport will probably not be significantly affected. Also, if the installation of such a farm is compared with the hypothetical construction of a port —which normally completely blocks sediment transport—then it can be clearly seen that a wave farm probably is a rather "light" case of human intervention upon the coastline.
Hazard to shipping	Many of the OE proto-types currently in development are held in place using mooring lines. If these lines are broken, due to storms or colliding ships, the units can drift away and become a hazard to shipping. Contrary to what might appear logical, typically OE installations produce most of the energy during periods of low or medium wave intensity, and need to be shut down during periods of high wave intensity to prevent damage from storms. The areas where OE installations will be located should be clearly delimited and human activities in these areas, such as fishing or shipping, might be restricted. This could have an effect also on the local economy of some areas.	Also, although these areas could represent a hazard to shipping, the delimitation of certain areas of the sea is not at all difficult, and this is done for many other reasons, such as for example to warn of the presence of sea wrecks. The delimitation of some sea areas is often seen as beneficial to the preservation of fishing stocks, and hence this could actually constitute a long-term benefit to local fishing communities.

Potential Environmental implications	Rationale	Analysis
Risks to biodiversity	It is not inconceivable that the noise associated with some of the types of OE, or the rotary movement of tidal turbines, could have an effect on certain species of mammals or fish. Tidal turbines are much slower than wind turbines but could nevertheless have an effect on some species. Also, some of these devices could have an effect of diving birds, or some species of fish. There is a clear need to investigate how a certain type of OE might affect the biodiversity of the area as well as other potential environmental impacts.	Regarding marine biodiversity it also does not appear likely that OE will have a significant impact. For instance, the UK government has allowed the installation of the first commercial Seagen device in Strangford Narrows, In Northern Ireland, which has a nearby seal colony and occasionally basking sharks. With a speed of rotation of 12rpm, and a maximum rotor blade tip velocity of around 12m/s, it is unlikely that animals that can hunt down fish in fast moving turbulent water will be more likely to collide with the tidal turbine rotor blades than with a rock.[99]
Fluid spillages or leakage.	Many of these structures use hydraulic fluids, and poor designs could lead to these substances being released into the environment.	Can be managed through careful design. The amount of fluid that could hypothetically be released is insignificant compared to, for example, the common practice of washing of petrol tanks on the high seas.

Thus, at present there is no evidence that OE has a significant environmental impact, and it appears likely that even if it does have an effect on the environment, this would not be any more serious than other human activities which already affect the coastline. In this view, and due to the ease of installing small amounts of units and then scaling up to larger farms, it appears that it should be possible to proceed fairly quickly with the installation of trial farms in order to ascertain if these hypothetical problems exist or not.

3.5 Socio-economic impact of Ocean Energy

The shift from traditional ways of generating energy to newer methods could have significant socio-economic effects. For example, it is estimated that the creation of an OE energy industry could have a positive effect on the economy of coastal regions, which could be in the range of 10-20 jobs/MW.[100] However, a certain number of jobs in other traditional ways of transporting energy could be potentially lost. For example, at present in remote islands, electricity is often produced by using low-scale diesel power stations, and the advent of OE could remove the need to transport the fuel by tankers and thus reduce these types of jobs. Consequently, the location and types of jobs present in the energy industry would be altered. However, the advantage of large scale utilization of OE is that medium and high skill jobs would be created in areas that traditionally did not offer these jobs, which could lead to a certain revitalization of isolated costal communities.

A possible positive impact of restricting access to certain areas of the coastline could be a medium-term increase in catches for local fisherman. There has been recent evidence that five years without fishing around Lundy Island off the coast of Devon have brought a significant revival in sea life.[101] In many cases, the implementation of these restricted areas is difficult, due to opposition from local groups. However, the creation of medium and high skilled jobs in certain coastal areas could offset the short-term losses in the fishing industry, and thus pave the way for a medium-term revitalization of fisheries.

In contrast to wind turbines, OE devices do not visually pollute the environment, as they are either located underneath the water or close enough to the surface so that they are not visible from a distance. The one exception are tidal barrages which, although they are generally classified as OE, have a visual impact comparable to a dam of the same dimensions. Not only that, but they also create other problems such as silting and loss of habitat, which explains why no significant new ones have been built since the 1970s.

3.6 Industry promotion

Currently, OE suffers from a number of problems that hinder its development. Amongst these the main problem is a lack of connection between the coastal areas and the national electricity grids of various countries, which make the development of OE conditional on these being constructed as well. Also, the regulatory framework that governs the development of offshore farms is complicated and often takes a long time. As OE is a new industry it often cannot provide any hard data of the possible impacts as most projects at the moment are pioneering their respective technologies.

Nevertheless, some countries are trying to actively promote the development of OE. For example, the Portuguese government recently created a 320 Km2 Maritime Pilot Zone of the West coast of Pedro de Muel in an area of low environmental sensitivity. Currently 3 Pelamis devices have been installed just north of this area (See Box 5), with the possibility of more being installed in the future if the initial project is successful. Portuguese authorities are taking the view that by slowly going ahead with a project of these characteristics it will be possible to study its consequences as the project proceeds. As each unit is installed in a piece-meal fashion, and due to the low environmental sensitivity of the area concerned, any long-term effects can be studied while allowing electricity to actually be generated.

In the UK, the South West Regional Development Agency (RDA) is planning to build by 2010 a Wave Hub, which would connect up to 20MW of offshore devices to the grid. This is expected to generate £76 million over 25 years for the regional economy, by creating at least 170 jobs and generating enough electricity for 7,500 homes, saving 24,300 tonnes of carbon dioxide every year. This would support South West England's target for generating 15 per cent of the region's power from renewable sources by 2010.

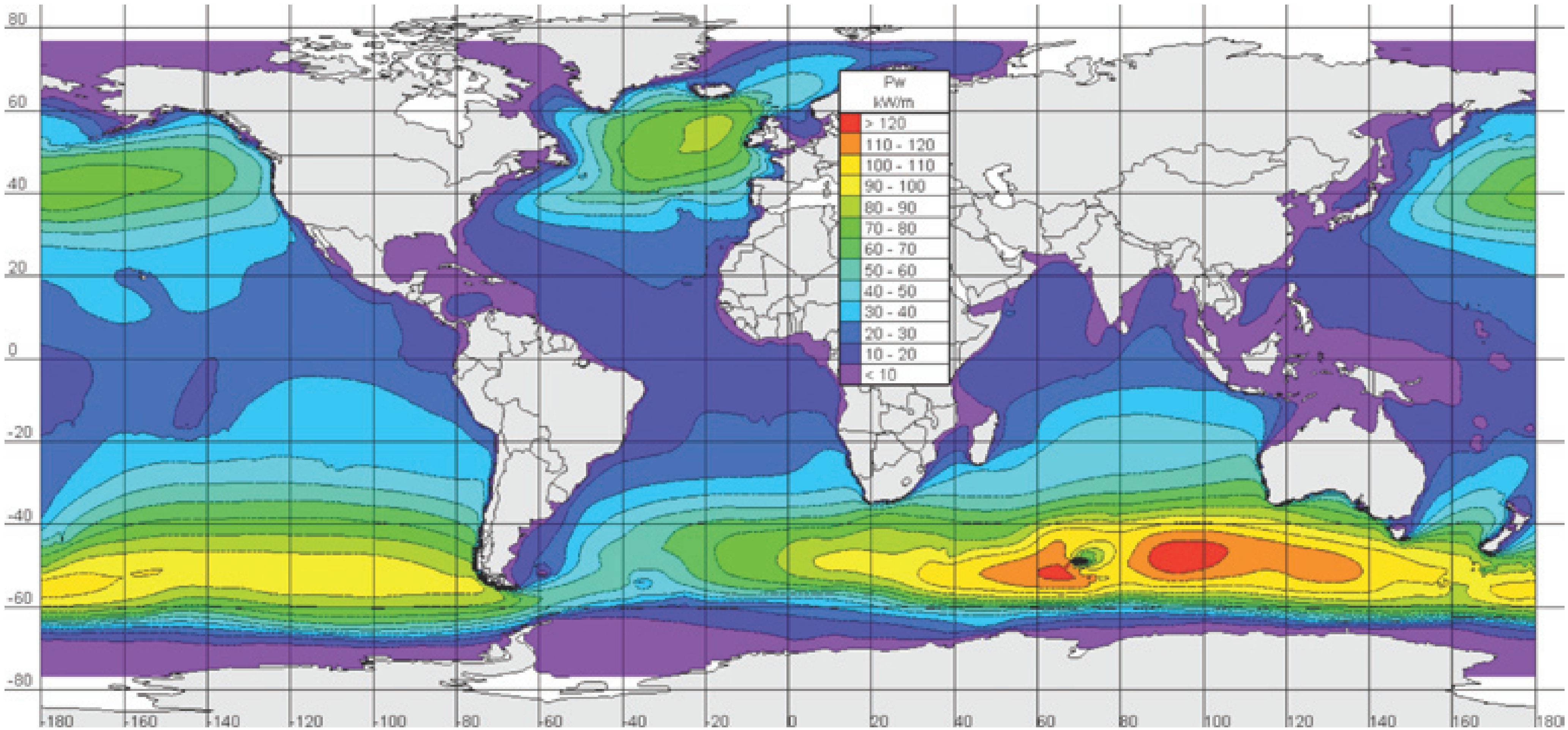
For the industry to succeed, it is vital that other initiatives such as these allow the various leading companies to start generating electricity on a commercial scale, in order to show possible investors that the technology is viable and to allow further innovation in the sector.

3.7 Conclusions

Although the sector is currently only at the early stages of commercialization of the first generation of devices, it is estimated that OE could provide a significant proportion of the electricity of countries well endowed with OE (marine currents could provide 5-10% of the UK's electricity, wave possibly up to 25%). Prominent on this list are several of the world's greatest consumers of energy, such as Japan, the UK, Korea, France, Spain, Portugal, Canada and the USA, amongst others.

Although it appears unlikely that OE will be able to satisfy the electricity needs of the entire planet, as a great deal of the world's population is located in areas where it appears unlikely they could benefit from it (See Figure 4), it can form one of the elements of the solution to future energy needs. With low visual impact, virtually zero CO_2 emissions, and low foreseeable environmental problems associated with it, this group of technologies appears to interfere far less with the environment than other established forms of energy production.

Figure 4: Ocean Energy potential[102]



4. Reducing Emissions from Deforestation and Degradation in Developing countries: Marketing Forest Offsets?

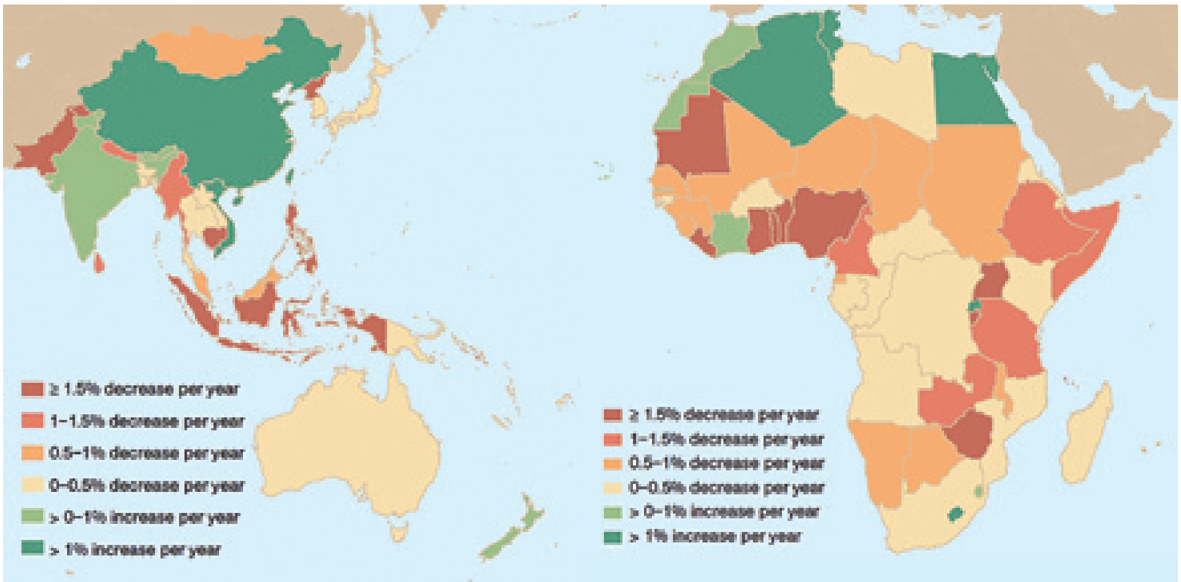
4.1 The background

At the United Nations Climate Change convention in Bali, Indonesia in December 2007 (UNFCCC COP13), a new mechanism was discussed to deal with emissions from deforestation and degradation of tropical forests in developing countries, commonly referred to as REDD (Reducing Emissions from Deforestation and Degradation).

It is estimated that in 2004 alone, emissions from deforestation were responsible for 7-16 per cent of total green house gas (GHG) emissions, thus making deforestation and degradation the second largest source of GHG emissions after fossil fuels, namely oil, gas and coal.[103]

The deforestation rate of tropical forests is proceeding at an alarming rate. For instance, research shows that between 1950 and 2005, Borneo, an island shared by Malaysia, Indonesia and Brunei, lost large expanses of tropical lowland and highland forests, including vast areas of rainforests.[104] On a regional level, most of the tropical countries in Africa and South East Asia lost forest cover between 2000 and 2005 with high rates in Indonesia, Nigeria and Brazil, just to name a few (See Figure 5).

Figure 5: Forest Change in Asia and Africa, 2000-2005



Source: State of the World's Forests 2007, FAO 2007.

What is more, increasing demand for first generation biofuels could further increase green house gas emissions when tropical forests are cleared for palm oil plantations, agriculture and other land uses. The purpose of REDD is to reverse this trend, by helping countries preserve tropical forests and generate forest carbon offsets, which may have the potential to be included in global carbon markets.

BOX 8: REDD DEFINITIONS

Deforestation: According to the UNFCCC, deforestation is the conversion of forested land to other types of land use.

Forest degradation: There is no widely accepted definition for degradation. From a climate change point of view and as defined by the IPCC, it means the reduction of biomass that can store carbon. Others define it as tree crown cover loss or the reduction of benefits from forests (including carbon, wood and biodiversity). As degradation is a process of gradual loss of biomass below the canopy, particularly if it is human-induced, it is more difficult to monitor with remote sensing and other radar technologies.

Forest: According to the UNFCCC, forest must have a canopy cover of above 10 to 30 percent with an average tree height at maturity of at least 2 to 5 meters.

REDD: Reducing Emissions from Deforestation and Degradation is a policy under consideration by parties to the United Nations Framework Convention on Climate Change (UNFCCC). At the Conference of the Parties (COP 13) in Bali, member states adopted decision 2/CP.13 calling for "meaningful action to reduce emissions from deforestation and forest degradation in developing countries."

4.2 How REDD works

In addition to managing national green house gas inventories, REDD mechanisms could allow countries and individual companies to offset carbon credits against their emissions targets. There are other additional environmental benefits, such as prevention of biodiversity loss, new opportunities for sustainable forest management and eco-tourism. In addition, rather than clearing forests for palm oil plantations, forest waste could be used to produce second-generation biofuels that rely on organic waste.

Until recently, forest carbon trading was only possible through Clean Development Mechanism projects that only allowed afforestation and reforestation projects. Following proposals by Papua New Guinea and Costa Rica, the debate on forest carbon trading has shifted towards including reducing emissions from deforestation and degradation.[105] Today, carbon credits from REDD projects can only be traded and sold in the voluntary carbon market. However, one suggestion under discussion is that REDD credits could enjoy official value in the 2012 post-Kyoto regime.

Ongoing REDD projects have shown that technological solutions, such as remote sensing and geographic information system technologies are readily available to meet the challenges of establishing baselines or to ensure monitoring. As this report demonstrates, the major obstacles to conservation of tropical forests are social and governance failure rather than the lack of technological solutions.

However, before REDD becomes an approach to preserve forests and generate carbon offsets, the following issues must be tackled and solved in the current negotiation process:

Establishing baselines: In order to understand the level of deforestation and forest degradation, baselines or reference scenarios must be established. They may be based on past rates of forest change derived from remote sensing imagery. Baselines will be essential for two purposes: to monitor the status of each project site in order to avoid deforestation and forest degradation elsewhere; and secondly, to claim carbon credits for avoided deforestation and forest degradation.[106]

Verification of carbon credits: Today, there are only a few independent certification agencies, the major players being TÜV SÜD and SGS, which verify carbon credits. Given the potentially large areas of forests to be certified in tropical countries, agencies will have to rely on sampling techniques using a combination of high and medium resolution satellite data in combination with ground surveys.

Acknowledging the rights of indigenous people and forest-dependent communities: Successful REDD project implementation depends on the inclusion of indigenous and local communities who depend on forests for their livelihoods. Although the latest Conference of the Parties decision recognizes that "the needs of indigenous and local communities should be addressed", it is not clear how this will done in practice.

Traded or not traded?

One of the contested issues is the question whether emission reduction certificates from REDD projects should be tradable, and if so, whether they should be traded in a separate market.[107] Some argue REDD should be fund-based, others that it should be market-based. However, it is beyond the scope of this report to go into all the details of this debate. One project mentioned in this report uses a combination of funds and tradable permits to finance REDD validation and monitoring.

There are several other issues that need clarification, for instance whether REDD will be implemented on a national or a project-based level and whether parties to the UNFCCC should advocate avoided deforestation, both deforestation and degradation, or compensated conservation. Bearing in mind the many methodological and political pitfalls and open questions of REDD implementation, successful REDD projects—three will be outlined in this section—could achieve two important objectives: increasing the present stock of biomass as well as avoiding the loss of carbon (See Figure 6).

4.3 The potential benefits of REDD projects for climate change mitigation

There are three potential benefits of REDD worth mentioning: First, REDD can make a significant impact on reducing greenhouse gas emissions as deforestation is the second largest source of CO_2 emissions following fossil fuels. Second, REDD is a relatively low cost option as it does not involve cost-intensive technologies. And third, the carbon mitigation benefits of REDD exceed in the long-term the benefits from afforestation and reforestation.[108]

4.4 Understanding deforestation and degradation

One of the factors that need to be understood in the implementation of REDD projects are the drivers of deforestation and degradation. So far, most international workshops have focused on the technological and methodological challenges of REDD with little emphasis on the role of governance, land tenure and livelihoods creation. There are six underlying causes of deforestation. These include:

(1) The failure of markets to reflect the true value of forest functions, such as water and soil conservation, biodiversity, and climatic controls;

(2) National policies to exploit forests to foster rural development and industrialisation with poor environmental standards;

(3) Business, political and military elites exploiting forest in an unsustainable manner;

(4) Poverty and high fertility rates;

(5) Poor governance structures, corruption and sudden political change; and

(6) Insecure and inequitable land tenure.[109]

Deforestation and degradation is often an outcome of social and governance failure rather than caused by a lack of understanding how to manage a forest in a sustainable way. Successful REDD projects can therefore only be implemented in countries that make explicit commitment towards avoiding deforestation and degradation.

One example is Indonesia. According to a presentation at a recent UNFCCC workshop, the Government of Indonesia committed to stop illegal logging and to suspend permits for palm oil plantations on peatland.[110]

The fact is that 90 percent of forests in South East Asia are owned by the government or the public giving the state a major role in assigning forest rights to stakeholders.[111]

According to the International Tropical Timber Organisation (ITTO), 71 percent of forests in the Asia-Pacific region are under concessions but it is estimated that only 15 percent of the concessions are managed in a sustainable manner.[112] Unsustainable management of forests are often the result of the lack of resources to monitor and to evaluate forestry operations. Here, REDD projects are believed to be able to provide the necessary financial means to enforce forest policies and to control illegal logging.

Illegal logging is a serious problem in most countries endowed with large tropical forests. In Indonesia, the Ministry of Forestry stated that illegal logging occurred in 37 of 41 national parks.[113] In one case, more than half of the entire park has been heavily logged.[114] One of the main drivers for illegal logging in Indonesia and Malaysia is the establishment of palm oil plantations. Corruption—Indonesia ranks 143 out of 179 countries of Transparency International's corruption perception index in 2007—lack of equipment and training, insecure land tenure are all challenges for successful REDD project implementation.[115]

Concessionaires often cut above quotas, or outside the concession boundaries, or fell undersized trees. Another reason for failing forestry governance is the economic and political exclusion of local and indigenous people who heavily depend on forest resources for their livelihoods.

4.5 The role of local and forest communities

The success of REDD implementation at both the project and national-level heavily depends on how and in what way local and forest communities are involved. For too long, local and forest communities have been considered by forest departments and governments as agents of deforestation rather than recognising their role in forest management. Gradually, this view has shifted towards an understanding that community-based forest management is more likely to achieve forest conservation than the models of excluding local communities from forest management.[116] Local communities are needed to monitor and to evaluate REDD projects, and often, they cost less than professionals. Moreover, proceeds from REDD trading schemes could finance forest community development projects, such as schools and health services.

One example is Tanzania where the establishment of village forest reserves has shown a significant increase in forested land. Although only 11 percent of the forests are currently under community management, the Tanzanian government has been fairly successful in reducing the rates of forest loss.[117] In general, forests are considered 'open access' lands, not just in Tanzania but in most developing countries. Accordingly, they are used for fire wood collection or charcoal production. Moreover, forests are threatened by infrastructure development and land-use change, such as agriculture or livestock grazing, in order to provide employment for an impoverished rural population.

In sum, forest communities can play an instrumental role in monitoring forest degradation. For instance, remote sensing can detect deforestation but it is more difficult to measure degradation, a process that largely occurs below the canopy. Trained community members can provide the data needed to establish baselines for REDD projects and assist in monitoring exercises.[118]

4.6 Where REDD has been implemented

REDD projects are already underway in Bolivia, Indonesia, and Australia (See Table 5). An Indonesian project covers a 770,000-hectare area of the Ulu Masen forest in Sumatra's Aceh province, home to endangered species, such as orang-utans, tigers and elephants. In order to implement projects successfully, local communities need to benefit from the preservation projects. Table 5 highlights various key aspects of three pilot REDD projects, and evaluates their scope and stakeholder involvement.

Table 5: Examining REDD projects in Bolivia, Indonesia and Australia

Project Name	Noel Kempff Climate Action Project	Ulu Masen Ecoystem Project	Minding the Carbon Store
Project Location	Bolivia Department of Santa Cruz	Indonesia Nanggröe Aceh Darussalam (hereafter Aceh) special territory	Queensland , Australia
Project Size (ha)	Protects 832,000 ha of tropical forest Claims to be largest REDD project world-wide	750,000 ha of forest in the Ulu Masen ecosystem	12,000 ha of native Australian vegetation
Project Duration	At least 30 years	Baseline estimates only take into account the next 30 years but project proposes to operate for 100 years	Not Specified
Project Initiation Date	1997	2007	Not Specified
Tons of CO_2 emissions avoided Carbon offsets yes/no	Projected to avoid a total 25-36 million tons of CO_2 About 500,000 carbon offsets assigned to private investors, and about 500,000 offsets assigned to the Bolivian government Bolivian government can sell offsets at the Chicago Climate Exchange market	3.37 million tons of CO_2 can be avoided each year	1.25 million tons of CO_2 were avoided each year Credits sold to Rio Tinto Aluminium to offset the company's carbon emissions
Baseline Scenario Deforestation Rate Project rationale	Park was under "imminent and demonstrable threat" of deforestation and degradation from logging and conversion to agriculture	There are an estimated 188 tons of carbon per ha stored in the Ulu Masen ecosystem Forests of Aceh continue to disappear at a rate of 21,000 ha per year Estimates range up to 266,000 ha in 2005-2006 Estimates suggest an average annual deforestation rate of 1.283% per year - "very conservative" estimate	The native Australian vegetation would have been cleared and burnt by owners if not for the financial incentives offered by the project
Ownership of Land	Government owned	Government owned	Privately owned by farmers
Government Policy	Approved by Bolivian and United States governments, funded in part by Bolivian government	To be endorsed by the Government of Indonesia Supported, funded and managed in part by the Provincial Government of Nanggroe Aceh Darussalam Governor Irwandi of Aceh Province has put in place already a temporary logging moratorium until project is confirmed BUT: Government lacks resources to prevent illegal logging	Endorsed and funded in part by the Australian government
Private Sector involvement NGO involvement	Funded by The Nature Conservancy, American Electric Power (AEP), British Petroleum, Pacificorporation Cooperation with Canopy Botanicals—a private sector company dedicated to the sustainable development of Bolivia's resources Enjoys support by the Friends of Nature Foundation	Merrill Lynch has agreed in February 2008 to invest US$ 9 million over four years in the project Supported by Fauna and Flora International (FFI) and Carbon Conservation Ltd. Pty. Currently three logging companies are active within Ulu Masen ecosystem (Over half of Ulu Masen ecosystem can be legally logged) Fauna and Flora International (FFI) and national focal point for REDD of the Ministry of Forestry have facilitated an initial provincial REDD consultation workshop	The project is run by Carbon Conservation Pty Ltd and its wholly owned subsidiary The Carbon Pool

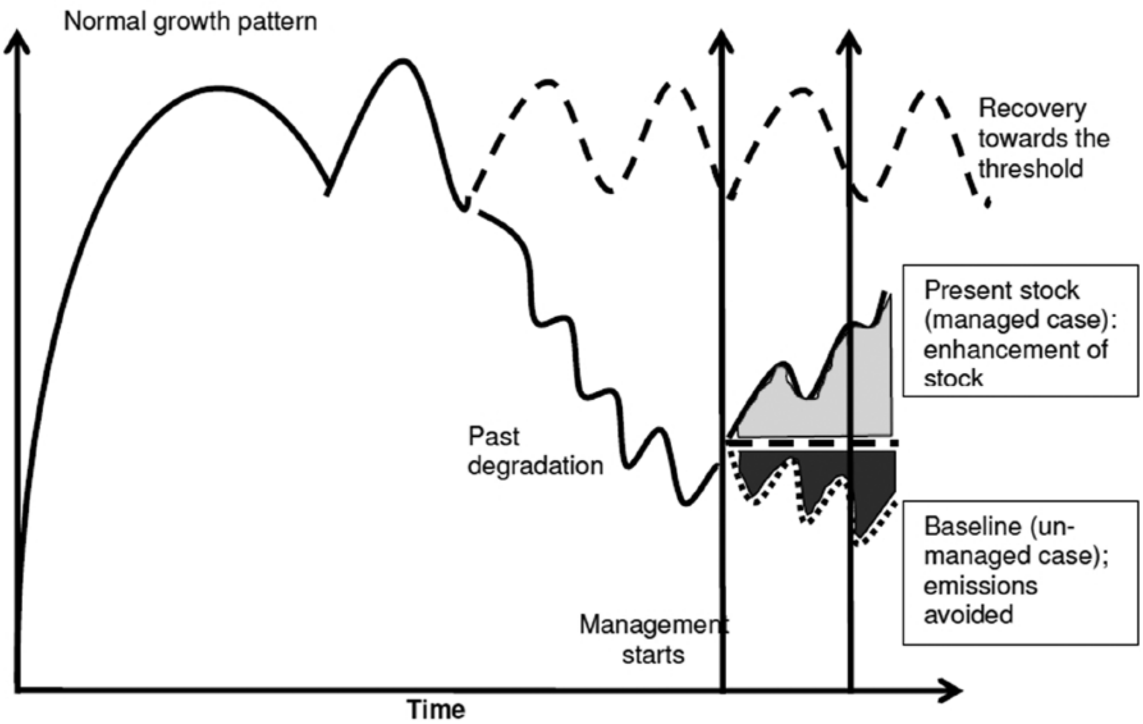
Project Name	Noel Kempff Climate Action Project	Ulu Masen Ecoystem Project	Minding the Carbon Store
Local Community Involvement, who benefits?	Project has provided funding to improve health care in local communities, improve sanitation, improve schools, repair roads and bridges Project also provides technical and legal assistance to local indigenous peoples to obtain rights to land More than half of the park rangers were hired from local communities A local NGO, Friends of Nature Foundation (FAN—FundaciÛn Amigos de la Naturaleza), is in charge of managing the park	Benefits will be equally shared among stakeholders, including forest dependent communities and those with customary rights to land Especially focused on consulting traditional democratically elected Mukim leaders who have a role in management of land and natural resources in Aceh's rural communities Mukim leaders are now formally recognized by Aceh's Special Autonomy Law Approximately 130,000 people live in communities adjacent to forest areas in Ulu Masen. Within these communities 2,000-3,000 villagers participate in illegal logging	The farmers receive financial incentives
Project Design Document yes/no	Exists	Exists	Unknown
Certification yes/no By whom? Costs?	Carbon offsets measured and reported by a Technical Advisory Panel, certified by the government of Bolivia. "An independent external verification process will be developed in the future..."	Passed the Climate, Community and Biodiversity Standards (CCBA) validation	Emissions reductions were verified and approved under the Australian Government's Greenhouse Friendly Initiative
Monitoring yes/no By whom? Type? Costs?	Carbon monitoring and verification program developed with assistance of Winrock International and using aerial monitoring technology developed by University of Massachusetts	The project will establish, equip and train provincial GIS (Geographic Information System) units based at provincial forest service offices. There is also a Joint Community-Ranger Forest Monitoring Program	Not Specified
Additional Environmental Pros/Cons Potential 'knock-on' effects Conflict of interest	Park is home to more than 130 species of mammals, 620 species of birds, 70 species of reptiles, and 110 species of orchids. The Noel Kempff Project also operates two lodges for ecotourism. The park has created jobs for the local community - more than half the park rangers were hired locally. The project has established microloan systems for agroforestry projects, animal husbandry, small bakeries, etc. The project has also provided funds for local health care, sanitation, and education. The project provides technical and legal assistance for local indigenous people trying to obtain titles for land.	Project estimates that proposed activities will reduce deforestation by 85%. Aceh is home to many endangered species including Sumatran rhinoceros, tiger, orang-utan, and elephant. Existence of Sumatran Rhinoceros inside project area but unconfirmed. Biodiversity monitoring projects are currently underway. Forests of Aceh are rich in hardwood trees—logging is very lucrative and poverty rates are high. The 2004 tsunami devastated region, with over 150,000 dead or missing and 500,000 left homeless, and damage to over 37,500 ha of land. As a consequence, the demand for timber for reconstruction has increased.	Farmers can continue sustainable grazing. Populations of the eucalypt poplar box tree which provides lodging and nesting sites for a wide variety of birds, mammals and reptiles have been conserved, among other species.
Comments		Aceh has suffered 30 years of civil conflict between Government of Indonesia and Gerakan Aceh Merdeka (Free Aceh Movement), which ended in 2005 with a peace deal. One complicating factor is that the armed conflict has effectively prevented logging in certain areas, which makes estimates difficult.	The Carbon pool is also involved in a project involving biodiverse reforestation (not conservation) on the coast in the Australian state of New South Wales.

4.7 What are the risks?

One potential risk for the successful implementation of REDD projects could be governance failure to ensure that forests are conserved. Another challenge is the engagement of local forest-dependent communities in a meaningful way to allow for benefit sharing and access while promoting the alleviation of rural poverty.

There is another fundamental criticism often voiced about the logic of REDD projects. REDD rests on the assumption of the "avoided bad" rather than the "committed good" of mitigation activities, such as new technologies, for instance solar or hydrogen fuel that could be recognised under the Clean Development Mechanism. Besides REDD, many other activities could claim emissions avoidance, even measures that aim at reducing population growth in developing countries.[119] Despite this weakness, it cannot be ignored that land-use change is a major contributor to GHG emissions.

Figure 6: Forest management can lead to enhanced stock by avoiding emissions



Source: Think Global, Act Local, In REDD, the second D is for Degradation.[120]

Another risk of REDD implementation is what is commonly referred to as 'leakage'. If forests are protected under REDD, deforestation and forest degradation may appear elsewhere. Also, it is not clear how long carbon will be stored in biomass. There is the likelihood that carbon stored in trees is released at a later stage, a phenomenon that experts refer to as 'permanence'.[121]

Despite the technological challenges which appear now to have been addressed, and the operational and policy challenges discussed in this report, REDD presents a unique opportunity to address climate change, biodiversity loss, as well as water and soil conservation.

4.8 Making REDD work: Evidence from Bolivia, Indonesia and Australia

The above listed REDD projects, one in Bolivia, one in Indonesia, and one in Australia, need some critical evaluation (See Table 5). Each project's potential for success or failure depends on government policy, financial feasibility, community involvement, and overall mitigation effects. In addition, it is important to consider in what way the individual project addresses the above mentioned risks of REDD implementation.

All three projects have been endorsed by the respective governments, which partly fund them. All three governments are committed to forest conservation but in the case of Indonesia, the government lacks the capacity to enforce regulation that would prevent illegal logging in the project area.

There are further obstacles on the path to REDD implementation in Indonesia. The special territory of Aceh is rich in oil, natural gas, timber, minerals—the province provides 15-20 percent of Indonesia's oil and gas output. Oil and gas account for 43% of the Regional Gross Domestic Product (RGDP) while agriculture accounts for one third of the RGDP—these are both activities which provide incentives for deforestation. In addition, logging provides employment, infrastructure, and additional economic and social benefits. It is estimated that deforestation generates US$ 200 to 250 per ha.[122] Deforestation as a "business as usual" scenario would generate hundreds or thousands of jobs for an impoverished region. Aceh is one of Indonesia's poorest regions. Approximately 50% of the population lives below the poverty line with 48% of the population is without access to clean water. Because of the 2004 tsunami, approximately 861,000 metric tons of timber is required to rebuild. Accordingly, the region has experienced an increase in illegal logging in the post-tsunami period. Further, rapidly developing new markets for palm oil provide incentives to clear land for cultivation.

Another important aspect of successful REDD project implementation is the involvement of local communities. In all three projects, local communities are involved and are likely to benefit from the proceeds of projected carbon credits. In one of the three cases, the Bolivian project, the government will receive 50 percent of the carbon credits. The project has provided funds for infrastructure development and helped to improve health and educational services. The Bolivian project involves local communities in monitoring the carbon stock. In Indonesia, special attention is paid to customary land tenure and community leader involvement. While thousands of people depend on the forest, it is often only a small fraction of people who engage in illegal logging activities as the Indonesian case demonstrates. In the forests adjacent to the Ulu Masen ecosystem, approximately two to three percent of the local communities engage in illegal logging (See Table 5).

Another crucial element is the role of the private sector. The Bolivian and the Australian projects have entered into collaborative relationships with the corporate sector. In both cases, companies contribute to financing the project while receiving carbon credits to offset against their emission targets. Especially energy intensive industries and energy providers show interest in collaborative work, as the Bolivian and Australian cases demonstrate. This is an important step towards making forest conservation a lucrative option.

Overall, especially the Bolivian and Australian projects look promising in becoming a role-model for REDD project implementation. The Indonesian project faces serious governance challenges. Tropical countries in particular, though they sometimes have large REDD potential, are often prone to governance failure, poverty and insecure land tenure arrangements. As a consequence, it may be important to focus more on forest governance and regulation rather than emphasizing methodological and technical issues.

As the individual projects show, the technological and methodological issues are solvable whereas the socio-political obstacles pose a greater challenge to successful REDD implementation.

5. Potential Consequences of Innovation in Responding to Climate Change

Recent developments in renewable sources of energy - for example the increased use of biofuels have been partially responsible for an increase in the price of food - have highlighted how there is no easy answer to the energy question. It is very clear at this point that in the near future some hard choices will have to be made about how energy is produced and distributed. Business as usual is no longer an option, both from the economic and environmental point of view.

The need for targets in cutting carbon emissions is a debate the present report does not address, but regardless of what targets are agreed new strategies are needed to tackle the question of how to meet the growing demand for energy in a sustainable manner. These strategies have to address all aspects of the carbon emissions problem, namely how to prevent more carbon dioxide from being released into the atmosphere (carbon emission prevention), how to generate electricity from alternative sources of energy, and how to convert this generated electricity into something that can be easily transported (a new energy carrier). The present report highlights possible strategies to deal with all three aspects of the carbon emission problem, with Table 6 showing the main advantages and disadvantages of each of the proposed solutions.

The disadvantages of each of the proposed solutions must be clearly understood in order not to repeat the mistakes that have been associated with other forms of energy. However, although all solutions will always have a downside, the ones proposed in the present report have a more localized impact than other conventional energy production methods. The risk of global warming or nuclear meltdown of a power station affects the planet on a global or continental scale, while for example Ocean Energy would have at worst an effect on a localized area of the shoreline. The solutions highlighted in the present report have not been shown, to date, to have any major environmental effects. Although of course this could change in the future, these areas appear to be quite promising and thus warrant further investment.

The main conclusion of the present report is that solutions to the energy problem already exist. The solutions described are the result of decades of R&D, and are already at the first stages of commercialization. Furthermore, these solutions are the result of considerable investment in research and development by the private sector. It is therefore possible that given adequate government leadership, clear market signals and regulatory frameworks, the private sector will continue to play a significant role in innovation in responding to climate change.

Table 6: Advantages and disadvantages of nanotechnology, ocean energy and REDD

Solution	Type of Solution	Opportunities	Challenges	Current Impediments to Mass Commercialization
Nanotechnology	Electricity Generation, Energy Carrier	-Hydrogen fuel cars produce no CO_2 carbon emissions. If Hydrogen is generated by a renewable source (green Hydrogen) then CO_2 is not produced at all	-Uncertainty as to whether nanotechnology relevant to climate change poses risks to the environment and human health . Further research is needed to determine the scale of these risks (if any) and the regulatory implications if such risks exist.	-Lack of widely available infrastructure for the hydrogen economy
		-Increased performance of solar power panels	-concerns about secure supplies of high grade silicon for use in manufacture of photovoltaic cells	-Relative high cost of manufacture in some cases, though costs are rapidly decreasing
Ocean Energy	Electricity Generation	-Predictable and reliable compared to other types of renewables	-Not all countries endowed with it	-Lack of adequate connections to national grids
		-Theoretical capacity to meet the energy requirements of the whole planet	-Areas of great potential are often far from population, poor connection to national grids	-Relatively unknown compared to other renewables
		-Likely to have only minimal environmental impact		-Industry is still at the beginning of commercialization of first generation devices. Costs are thus relatively high and the industry needs help to get off the ground.
REDD	CO_2 emission avoidance	-Low amount of technology required	-Policing the schemes can be quite difficult	-Uncertainty about the standing of these schemes in the post-Kyoto Regime
		- Improved satellite imaginary can monitor deforestation and degradation	-Governance- lack of the political will or resources to ensure forest conservation	-Uncertainty of tradable permits
		-Can contribute to alleviate rural poverty and empower local indigenous groups	-Project failure if indigenous and forest communities are not involved	

Table 7: Hydrogen fuel cell vehicles in development

Automaker	Vehicle Name	Engine Type	Range (mi/km)	Max Speed (mph/kmh)	Fuel Type	Commercial Introduction/ Notes	Website
Audi	A2H2	Fuel Cell/Battery Hybrid	137/220	109/175	Gaseous Hydrogen		
AvtoVAZ	Lada Antel-1	Fuel Cell/Battery Hybrid	155/250	50/80	Compress Hydrogen 3674 psi		
AvtoVAZ	Lada Antel-2	Fuel Cell/Battery Hybrid	219/350	N.A.	Compress Hydrogen 5802 psi	Debuted at the 2003 Moscow Auto Show	http://www.vaz.ru/g02001eng/12-01.htm
BMW	Series 7 Sedan (Hydrogen 7)	ICE (Fuel Cell APU)	180/300	87/140	Gasoline/Liquid Hydrogen	Limited introduction in 2000 (Munich Airport Hydrogen Vehicle Project)	http://www.bmw.com/com/en/insights/technology/efficient_dynamics/phase_2/clean_energy/bmw_hydrogen_7.html
Daihatsu	MOVE FCV KII	Fuel Cell/Battery Hybrid	75/120	65/105	Compressed Hydrogen 3600 psi	Japan road testing started in early 2003	http://www.daihatsu.com/brand/craftsmanship/tech_dev/environment/fcv.html
Daimler-Chrysler	NECAR 1	12 Fuel Cell Stacks	81/130	65/105	Compressed Hydrogen 4300 psi		
Daimler-Chrysler	NECAR 2	Fuel Cell	155/250	68/110	Compress Hydrogen 3600 psi		
Daimler-Chrysler	NECAR 4 (A-Class)	Fuel Cell	280/450	90/145	Liquid Hydrogen		
Daimler-Chrysler	NECAR 4 (California NECAR)	Fuel Cell	124/200	90/145	Compressed Hydrogen 5000 psi		
Daimler-Chrysler	Sprinter (Van)	Fuel Cell	93/150	75/120	Compressed Hydrogen 5000 psi	Delivered to Hermes, also used by UPS	
Daimler-Chrysler	Natrium (Minivan)	Fuel Cell/Battery Hybrid	300/483	80/129	Catalyzed Sodium Borohydride	Uses Millennium Cell's "Hydrogen on Demand" system	
Daimler-Chrysler	F-Cell	Fuel Cell/Battery Hybrid	90/145	87/140	Compressed Hydrogen 5000 psi	60 fleet vehicles in US, Japan, Singapore and Europe, small fleet in Michigan operated by UPS	
Daimler-Chrysler	F600 HYGENIUS	Fuel Cell/Battery Hybrid	250/400	105/169	Hydrogen		http://wwwsg.daimlerchrysler.com/SD7DEV/GMS/TEMPLATES/GMS_PRESS_RELEASE/0,2941,0-1-73635-1-1-text-1-0-0-0-0-0-0-0-0-0,00.html
Daimler-Chrysler	EcoVoyager	Fuel Cell/Battery Hybrid	300/483	115/185	Compressed Hydrogen 10,000 psi		http://www.chrysler.com/en/autoshow/concept_vehicles/ecovoyager/
ESORO	Hycar	Fuel Cell/Battery Hybrid	224/360	75/120	Compressed Hydrogen	Switzerland's first Fuel Cell Vehicle (FCV)	http://www.esoro.ch/english/content/kernk/nhanst/hycar/hycar.htm
Fiat	Seicento Elettra H2 (2001)	Fuel Cell/Battery Hybrid	100/140	60/100	Compressed Hydrogen		
Fiat	Seicento Elettra H2 (2003)	Fuel Cell/Battery Hybrid	N.A.	62/100	Compressed Hydrogen	Being investigated for use in Milan, Italy	

Automaker	Vehicle Name	Engine Type	Range (mi/km)	Max Speed (mph/kmh)	Fuel Type	Commercial Introduction/ Notes	Website
Fiat	Panda Hydrogen	Fuel Cell	125/200	81/130	Compressed Hydrogen	3 delivered to municipality of Mantova, Italy	
Ford Motor Co.	P2000 HFC (sedan)	Fuel Cell	100/160	N.A.	Compressed Hydrogen	First Fuel Cell Vehicle (FCV) by Ford	http://media.ford.com/newsroom/release_display.cfm?release=1907
Ford Motor Co.	Focus FCV	Fuel Cell	100/160	80/128	Compressed Hydrogen 3600 psi		http://www.ford.com/innovation/environmentally-friendly/hydrogen/focus-fcv/focus-fuel-cell-vehicle-338p
Ford Motor Co.	Advanced Focus FCV	Fuel Cell/Battery Hybrid	180/290	N.A.	Compressed Hydrogen 5000 psi	3 year demonstration in Vancouver, Canada beginning 2004. 30 fleet vehicles in Sacramento, Orlando and Detroit, USA.	
Ford Motor Co.	Explorer	Fuel Cell/Battery Hybrid	350/563	N.A.	Compressed Hydrogen 10,000 psi		http://www.ford.com/innovation/environmentally-friendly/hydrogen/gasoline-free-suv/fuel-cell-explorer-362p
Hydrogenics/ GM	Precept FCEV Concept Only	Fuel Cell/Battery Hybrid	500/800	120/193	Hydrogen in Metal Hydride	Figures are concept projections only	http://media.gm.com/news/releases/g000111f.html
Hydrogenics/ GM	HydroGen1 (Zafira van)	Fuel Cell/Battery Hybrid	250/400	90/140	Liquid Hydrogen		
Hydrogenics/ GM	HydroGen3 (Zafira van)	Fuel Cell	250/400	100/160	Liquid Hydrogen	Being used by FedEx Corp. in Tokyo, Japan from 2003~2004	
Hydrogenics/ GM	Hy-Wire Proof of Concept	Fuel Cell	80/129	97/160	Compressed Hydrogen 5000 psi		
Hydrogenics/ GM	Advanced HydroGen3	Fuel Cell	170/270	100/160	Compressed Hydrogen 10,000 psi	1st Fuel Cell Vehicle (FCV) to incorporate 10,000 psi tanks. 6 placed in Washington D.C.	
Hydrogenics/ GM	Sequel	Fuel Cell/Battery Hybrid	300/483	N.A.	Compressed Hydrogen 10,000 psi		http://www.gm.com/explore/technology/news/2006/sequel_091206.jsp
Hydrogenics/ GM	Provoq	Fuel Cell/Battery Hybrid	300/483	100/160	Compressed Hydrogen 10,000 psi		
GM Shanghai PATAC	Phoenix (Minivan)	Fuel Cell/Battery Hybrid	125/200	70/113	Compressed Hydrogen	Seventh Fuel Cell Vehicle (FCV) out of China	
Honda	FCX—V1	Fuel Cell/Battery Hybrid	110/177	78/130	Hydrogen in Metal Hydride		
Honda	FCX—V3	Fuel Cell/ Ultracapacitors	108/173	78/130	Compressed Hydrogen 3600 psi		
Honda	FCX—V4	Fuel Cell/ Ultracapacitors	185/300	84/140	Compressed Hydrogen 5000 psi	Completed Japanese Road Testing	

Automaker	Vehicle Name	Engine Type	Range (mi/km)	Max Speed (mph/kmh)	Fuel Type	Commercial Introduction/ Notes	Website
Honda	FCX	Fuel Cell/ Ultracapacitors	220/355	93/150	Compressed Hydrogen 5000 psi	4 in Japan, 5 in Los Angeles, 3 in San Francisco	
Honda	Kiwami Concept	Fuel Cell	N.A.	N.A.	Hydrogen	Unveiled at Tokyo Motor Show	
Honda	FCX Concept Vehicle	Fuel Cell	270/434	100/160	Compressed Hydrogen		
Honda	FCX Clarity	Fuel Cell	354/570	100/160	Compressed Hydrogen	Lease Program in Southern California	http://automobiles.honda.com/ fcx-clarity/
Hyundai	Santa Fe SUV (2000)	Ambient Pressure Fuel Cell	100/160	77/124	Compressed Hydrogen		
Hyundai	Santa Fe SUV (2001)	Ambient Pressure Fuel Cell	250/402	N.A.	Compressed Hydrogen		
Hyundai	Tucson	Fuel Cell	185/300	93/150	Compressed Hydrogen		http://worldwide.hyundai-motor.com/common/html/ about/news_event/press_ read_2005_02.html
Hyundai	i-Blue Concept	Fuel Cell	373/600	102/165	Compressed Hydrogen	Shown at Frankfurt Motor Show	
Kia	Sportage	Fuel Cell	185/300	93/150	Compressed Hydrogen		
Mazda	Demio	Fuel Cell/ Ultracapacitors	106/170	60/90	Hydrogen in Metal Hydride		
Microcab Industries	Microcab	Fuel Cell	100/160	30/45	Compressed Hydrogen	An urban, ultra light, city speed, "short hop" taxi system	http://www.microcab.co.uk/
Mitsubishi	Grandis FCV Minivan	Fuel Cell/Battery Hybrid	92/150	87/140	Compressed Hydrogen		http://www.mitsubishi-motors. com/corporate/about_us/ technology/environment/e/fcv. html
Nissan	Xterra (SUV)	Fuel Cell/Battery Hybrid	100/161	75/120	Compressed Hydrogen	Will begin driving trials in US states of California and Arizona	
Nissan	X-Trail (SUV)	Fuel Cell/Battery Hybrid	N.A.	78/125	Compressed Hydrogen 5000 psi	Approved for Japanese public road testing, 3 leased to Japanese Government	http://www.nissan-global. com/EN/TECHNOLOGY/ INTRODUCTION/XTRAILFCV/ index.html
PSA Peugeot Citroen	Peugeot Hydro-Gen	Fuel Cell/Battery Hybrid	186/300	60/95	Compressed Hydrogen		
PSA Peugeot Citroen	Taxi PAC	Fuel Cell/Battery Hybrid	188/300	60/95	Compressed Hydrogen 4300 psi		http://www.psa-peugeot-citroen.com/modules/PAC_ en.pdf
PSA Peugeot Citroen	H2o Fire-Fighting Concept	Fuel Cell/Battery APU	N.A.	N.A.	Catalyzed Sodium Borohydride	Uses Millennium Cell's "Hydrogen on Demand" system	
PSA Peugeot Citroen	H2Origin Delivery Van	Fuel Cell/Battery Hybrid	186/300	N.A.	Compressed Hydrogen		
Renault	EU Fever Project	Fuel Cell/Battery Hybrid	250/400	75/120	Liquid Hydrogen		http://ec.europa.eu/research/ rtdinf21/en/clean-car.html

Automaker	Vehicle Name	Engine Type	Range (mi/km)	Max Speed (mph/kmh)	Fuel Type	Commercial Introduction/ Notes	Website
Shanghai Automotive Industry Corp.	Chao Yue I	Fuel Cell	N.A.	68/110	Low Pressure Hydrogen	Developed in conjunction with Tongju University	
Shanghai Automotive Industry Corp.	Chao Yue II	Fuel Cell	122/197	73/118	Low Pressure Hydrogen		
Shanghai Automotive Industry Corp.	Chao Yue III	Fuel Cell	144/230	76/122	Low Pressure Hydrogen 2901 psi	Two 2.2 kg fuel storage tanks	
Shanghai Automotive Industry Corp.	Shanghai	Fuel Cell	N.A.	N.A.	Low Pressure Hydrogen		
Suzuki	Mobile Terrace	Fuel Cell	N.A.	N.A.	Hydrogen	Unveiled at Tokyo Motor Show	
Suzuki	Wagon R FCV	Fuel Cell	N.A.	N.A.	Compressed Hydrogen 5076 psi		
Suzuki	MR Wagon FCV	Fuel Cell	N.A.	N.A.	Compressed Hydrogen 10,153 psi		
Suzuki	SX4-FCV	Fuel Cell	155/250	93/150	Compressed Hydrogen at 10,153 psi		
Tecnalia	H2CAR	Fuel Cell/Battery Hybrid	N.A.	N.A.	Low Pressure Hydrogen 2901 psi		http://www.tecnalia.info/intranet/uploads/noticias/adjuntos/325_NPcocheh2-270608.pdf
Toyota	RAV 4 FCEV (SUV)	Fuel Cell/Battery Hybrid	155/250	62/100	Hydrogen in Metal Hydride		
Toyota	FCHV—3	Fuel Cell/Battery Hybrid	186/300	93/150	Hydrogen in Metal Hydride		
Toyota	FCHV—4	Fuel Cell/Battery Hybrid	155/250	95/152	Compressed Hydrogen 3600 psi	Completed Japanese Road Testing	
Toyota	FCHV	Fuel Cell/Battery Hybrid	180/290	96/155	Compressed Hydrogen 5000 psi	Total of 18 leased in California and Japan	http://www.toyota.co.jp/en/tech/environment/fchv/index.html
Toyota	FINE-S Concept Only	Fuel Cell/Battery Hybrid	N.A.	N.A.	Compressed Hydrogen		
Toyota	FINE-N Concept Only	Fuel Cell/Battery Hybrid	194/311	N.A.	Compressed Hydrogen 10,153 psi	Features by-wire braking, steering and throttle controls	
Volkswagen	HyMotion	Fuel Cell	220/350	86/140	Liquid Hydrogen		
Volkswagen	HyPower	Fuel Cell/ Ultracapacitors	94/150	N.A.	Compressed Hydrogen		
Volkswagen	Tiguan HyMotion	Fuel Cell/Battery Hybrid	N.A.	93/150	Compressed Hydrogen 10,153 psi	Uses regenerative braking	

Source: Adapted from www.fuelcells.org

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