

## SMALL IS BEAUTIFUL – CLEAN ENERGY OPPORTUNITIES FOR NANOTECH

Nanotechnology is the study and control of matter in the dimension of 1 to 100 nanometres. At this scale, materials take on different properties from those they possess at the 'bulk' scale. For instance, metal nanoparticles are often highly catalytic. Properties such as colour, electrical conductivity and magnetism can potentially be tuned by changing the size and shape of nanoparticles. The change in the behaviour of substances comes about for two reasons – nanoparticles have a very much greater surface area than 'bulk' materials and quantum physics begins to come into play, changing the optical, electrical and magnetic behaviour of materials.

Nanotechnology applications to clean energy include insulation, coatings, thin film solar power, lighting (organic LEDs), fuel additives, Li-ion batteries, supercapacitors, fuel cells, hydrogen storage, catalysts and energy-efficient computing. In this research note, we examine the opportunities. First of all some features of the subject:

- Nanotechnology should not be seen as a single, monolithic sector in its own right – it is more of an enabling technology that has a range of applications in many different products and processes ranging from cosmetics to medicine and including a number of clean energy applications.
- There are a number of different nanomaterials, with a range of properties. These include carbon nanotubes, nanoparticles, aerogels, dendrimers, quantum dots, nanowires and fullerenes. For more information on nanomaterials, see Appendix 1.
- As of May 2007, there were almost 475 consumer products using nanotechnology.
- Nanotech companies have underperformed the market over the last few years, in contrast to the clean energy sector, which has surged ahead of benchmark indices.
- Public awareness of nanotechnology is very low and there are a number of potential risks to the performance of companies in the sector. These include risks to health and the environment, a public backlash against the technology and greater regulation.

A nanometre (nm) is a billionth of a meter and nanomaterials have at least one dimension measuring less than 100 nanometres. While nanotechnology remains in its infancy, more so than the clean energy sector, there are many areas where it is already in use, including semiconductors, batteries, car polishes, sunscreens and textiles. The Woodrow Wilson International Center for Scholars' nanotechnology consumer products inventory contained 475 products or product lines in May 2007, up 124% from 212 at its launch in March 2006. Nanotech research group Cientifica says that technologies that are currently available could reduce carbon emissions by more than 1m tons by 2014, chiefly through weight savings and improved fuel efficiency in transportation and through better building insulation.

### 1. Applications

The market for nanotechnology in clean energy falls into four main categories:

- Energy Saving technologies such as better insulation, solid state lighting, making vehicles lighter and improving their fuel efficiency
- Energy Storage, which includes lithium ion batteries for both portable electronics and hybrid electric vehicles, materials that can store hydrogen for use in fuel cells or hydrogen powered vehicles and supercapacitors
- Energy Generation, principally in hydrogen fuel cells and thin film and organic solar photovoltaics.
- Catalytic technology, which could cut the cost of catalysts by 50% and boost their efficiency, as well as improving the viability of biofuels, both first and second-generation.

### ENERGY SAVING

#### Insulation

The built environment is one of the biggest contributors to carbon emissions and one of the main focuses of emissions reductions efforts. Aerogels, with their excellent insulating qualities, have the potential to play a big role. As well as insulation, they can also be used as a substitute for glass, increasing the amount of natural light in buildings and cutting lighting bills. Key players in the aerogels field include Aspen Aerogels, Kalwall and TAASI, all from the US.

Australia's Nanovations makes heat deflecting or insulating paints that can improve building energy ratings, while Nansulate, a US company, claims that its patented nanocomposite insulation, a liquid applied coating that dries to a thin layer "is by far the world's worst conductor of thermal energy and the world's best thermal insulation medium".

The strength and durability of nanomaterials may also improve the operability of clean energy technologies that operate in extreme conditions, including offshore wind turbines, some solar technology and marine energy devices.

#### Thin film solar

Thin film photo-voltaic panels offer the opportunity to transform the economics of solar power by allowing the industry to move away from its reliance on silicon. Such a move would allow solar cell production to move from its current production process, which is akin to semiconductor manufacture – a high-tech, high-cost endeavour, to something more like newspaper production, which uses basic, proven technology and is much cheaper. The market is predicted to grow from \$1bn to \$7.2bn by 2015, when it will account for 35% of the solar market.

A number of nanotechnologies contribute to thin film technology, including nanowires, nanoparticles and carbon nanotubes (CNTs). Companies in this space include US groups Spire, Konarka, Nanosolar, Heliolt, Eikos, Nanergy, Cyrium Technologies, and Israel's Orionsolar. Capacity is expanding fast, with a number of 100MW-plus plants being built by manufacturers such as First Solar, Fuji Electric, Nanosolar, Sanyo, Uni-Solar and G24i. German group Centrotec Sustainable makes nano-coated antireflective glass to improve the efficiency of PV systems through subsidiary CentroSolar, while Energy Conversion Devices is another major player.

Concentrated PV manufacturer Solfocus is working on a nanocoating to keep the glass in its components clean. Large companies involved include BP, GE, Eni, Bosch and BASF, while Shell and Honda are now focusing their solar efforts exclusively on thin-film. Activity is stepping up in emerging markets, too, with Mexico's Lamba Energia planning to open a plant in Eastern Germany and China's Jiangsu Sunshine also working on nanostructured PV cells.

#### OLEDs (Organic Light Emitting Diodes)

The OLED market will be worth \$5.9bn by 2014, according to research firm Nanomarkets, and will transform the possibilities for lighting, allowing lighted ceiling tiles or curtains, for example, although their initial applications will be in backlights for consumer electronics devices such as mobile phones and MP3 players. Displays using CNTs can be used to create transparent signage, allowing signs and adverts on windows. OLEDs offer a greater range of colours, brightness and viewing angle and they use far less power than other lighting, because they do not require a backlight to function and can therefore extend battery life or reduce energy use in electronic goods. Because they can be printed on to any suitable substrate, they are likely to cut manufacturing costs as well.

The lighting market is one where established players are likely to remain dominant, with large companies such as Motorola, Eastman Kodak, DuPont, GE and Philips involved. The latter recently bought LED manufacturer and NEX constituent Color Kinetics, while fellow NEX constituent Cree uses nano-materials in semiconductor drivers for LED applications that improve efficiency.

#### Fuel additives

Adding nanoparticulate cerium oxide to diesel fuel improves fuel economy by up to 10% and cuts soot emissions by up to 15%. The UK's Oxonica is one of the clear leaders in this sector.

#### ENERGY STORAGE

Nanomaterials improve the performance of a range of energy storage devices, including supercapacitors, fuel cells and batteries. American Superconductor uses nanotechnology to improve the electric current carrying capability of their superconductive wires.

#### Batteries

In traditional Lithium-ion batteries, nanomaterials allow the production of electrodes with substantially more power output, higher discharge rates, faster recharging times and extended battery life, improving the viability of hybrid electric cars. Currently 50% of lithium batteries incorporate carbon nanofibres that double their energy capacity and this figure is expected to reach 85% by 2010. NanoEner and NanoeXa are among the companies involved in this field, but the leaders appear to be A123, which is co-developing a battery with GM and Altair Nanotechnologies, which is working with giants such as AES and Alcoa. Meanwhile, Chinese group Advanced Battery Technologies, which makes Li-ion batteries using nano-materials, has secured a deal to supply US electric carmaker ZAP.

**Supercapacitors & ultracapacitors**

Supercapacitors can store a high density of energy in a short amount of time because of the large surface area that nanomaterials provide. They are used in everything from portable electronics to hybrid vehicles and also for energy storage in many renewable energy applications. Significant companies in this technology include Maxwell Technologies of the US, South Korea's NessCap, Elit from Russia and Cap-XX from Australia.

**Fuel cells**

Nanotechnology is likely to play a major role in the advent of the hydrogen economy. Nano-engineered membranes and nanoparticles of catalyst materials allow more intense catalytic processes by increasing the surface area of material that can be acted upon. This should lead to smaller, more efficient fuel cells. Cientifica, the nanotech information company, says multiwalled nanotubes can improve the performance of fuel cells tenfold. Companies using nanomaterials in fuel cells include Japan's Nano Fusion Technologies, Nanosys, Plug Power and Italy's Acta. The field has also attracted the attention of some of the largest companies in the world, including 3M, which is working with nano-structured materials for hydrogen & fuel cells.

**Hydrogen Storage**

Hydrogen storage is another vital component of the move away from fossil fuels, but it is one of the most problematic elements of the hydrogen economy, particularly in relation to hydrogen-powered vehicles. Hydrogen has a low energy rating by volume, so you either need a massive tank to store, or you have to compress it or liquefy it, reducing its efficiency. Carbon nanotubes, because of their huge surface area, show great promise for hydrogen storage. Nanergy, HCE and Nanomix are among the companies involved in this area.

**CATALYTIC TECHNOLOGY**

**Catalysts**

Nanocatalysts play a key role in fuel cells, with nanotubes cutting the cost of catalysts by 50%. They can also make usage of other resources more efficient. Headwaters, the largest provider of technologies to produce coal-based solid synthetic fuels, is developing and commercializing proprietary nanocatalyst technology to convert or upgrade fossil fuels into higher-value products, to convert gas to liquid fuels and for use in direct coal liquefaction.

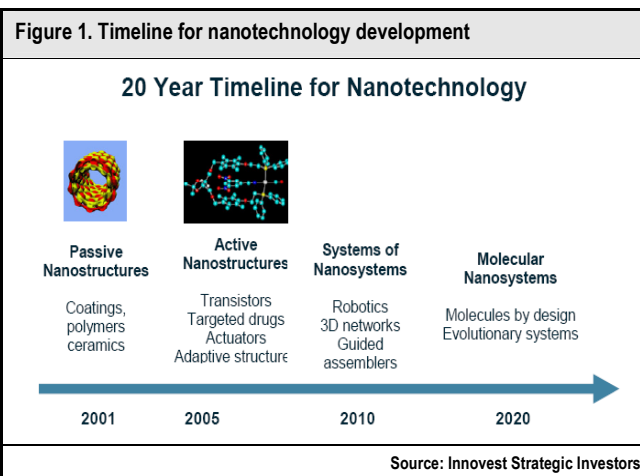
**Biofuels**

Nanotechnology is set to play a key role in improving the viability of biofuels, both in the first generation and cellulosic applications. BP has launched a \$500m research project into biofuels technology with the University of Berkeley and the University of Illinois looking at, among other things, the creation of microbial 'factories' from bacteria. Tata Chemicals has an innovation centre focusing on nanotech, biofuels and fermentation, while US company Nanodynamics has licensed its process intensification technology to Australian group Global Technex, which is introducing new technologies to the Australian biofuels industry.

**2. Time to market**

According to Innovest Strategic Investors, there are approximately 200 public companies involved in nanotechnology research and development, about 77 of which are large corporations, and 700 private firms, most of which are concentrating on the science and are not close to having a viable product in the near future.

A report for Defra looked at various environmentally beneficial nano-technologies and provided a timescale for implementation (Figure 2). Fuel additives are available now from companies such as Oxonica, although there are some concerns about the health impact of free nanoparticles in diesel exhaust gases. PV applications are likely to be implemented in about five years time, the report says, although Lux Research puts the timeframe for widespread market penetration at nearer to 10 years. The major barrier to this technology is the incorporation of the nanotechnology into the solar cell, not the nanotechnology itself, the report says.



Within three to eight years, insulation applications will be fully available, which will play a major role in retro-fitting non-cavity walled buildings, which make up more than one third of the UK housing stock. Aerogel companies, meanwhile, already have commercially available 'daylighting' technologies.

Batteries, specifically for transport applications, have the potential to significantly reduce GHG emissions, and any new technologies should be relatively easy to roll out, according to Defra. Indeed, A123 Systems is supplying nano-enabled Li-ion batteries to General Motors, while nano-enabled supercapacitors are finding their way into regenerative braking systems. However, these technologies are currently uneconomic and need encouragement from fiscal measures to be competitive. Other aspects of energy storage will take between 10 and 40 years to be implemented.

"Nanotechnology is likely to be an enabling technology in the development of a hydrogen economy, with hydrogen fuel cells most likely to be utilised in transport applications," the Defra report says. However, "even the most optimistic projections suggest that it is unlikely that hydrogen will make any significant impact on private sector transport before 2030," the report adds. Furthermore, the success of the hydrogen economy is dependent on hydrogen storage, hydrogen generation and hydrogen fuel cells all coming to fruition.

Integrating LEDs into domestic and commercial lighting should be quite easy, but the overall benefit of using these devices over competing technologies is relatively modest, Defra says.

### 3. Investors

Clean energy indices, including the NEX, have substantially outperformed the mainstream stock markets in the last four years, but nanotech investors have not been so fortunate. The Merrill Lynch Nanotech index has consistently lagged the Nasdaq and the S&P500 since its launch last year.

Although there are a number of products on the market that incorporate nanotech, the sector is even more in its infancy than clean energy, with a number of issues to address before it can become mainstream. These include production costs, health and safety concerns, possible regulatory constraints and public perception. Jaideep Raje at Lux Research says that in 2006, investment in clean technology totalled \$24.5bn, while nanotechnology attracted just \$1.1bn. However, he says: "There is a loading up of applications at the back end of the R&D cycle that is creating a wave of innovation set to hit the markets in the next two to three years."

Given the enthusiasm for clean energy and the advantages that nanotech is likely to bring to a range of clean energy applications, there are many investment opportunities. Indeed, NEX constituent Harris & Harris is a dedicated nanotech investor. "We tend to look at how nanotechnology can add value to a finished product, rather than investing in particular nano-materials," says the company's CEO Charles Harris. In the UK, Foresight Venture Partners is also looking closely at nanotech investments, having invested in nano-materials company Nanotecture and fuel additives group Oxonica. The opportunities in nanotech are often at a stage that the firm would normally consider too undeveloped, according to Jamie Richards, a partner at Forsyth, but the potential they offer is so great that the company has relaxed some of its usual investment criteria in order to take stakes. Most companies in the sector have been recently spun out of, or are still within universities,

**Figure 2. Timescale for nanotechnology implementation**

Application	Impact of Nanotech in area	Infrastructural Changes	Benefit (Mte CO2 per annum)	Timescale for implementation (yrs)
Fuel Efficiency	Critical	Low	<3	<5
Insulation	Moderate	Low	<3	3 to 8
Photovoltaics	High	Moderate	<6	>5
Electricity Storage	High	High	10 to 42	10 to 40
Hydrogen Economy	Critical	Very High	29 to 120	20 to 40

Notes: 1. Impact describes the effect nanotechnology is likely to have in the area compared to other technologies.  
2. Infrastructure changes reflect the effort needed to bring to market.

Source: Environmentally Beneficial Nanotechnologies: Defra UK

**Table 1. Case Study: Harris & Harris**

Harris & Harris is a publicly traded venture capital firm exclusively focused on investing in 'tiny technology'. It says that because it is a publicly held company that invests only its own, permanent capital, it can be an unusually patient investor. It has a portfolio of 25 companies involved in nanotechnology, microsystems and microelectromechanical systems (MEMS).

Its clean energy investments include **BridgeLux**, which develops high-power indium gallium nitride light emitting diodes used in various solid state lighting applications; **Cambrion Technologies** – the company uses genetic approaches to evolve rapidly biomolecules that can produce an extremely large variety of inorganic or commercially useful material, including semiconductors, metals, ceramics, and magnetic materials; **Innovolight** develops low-cost, high-performance renewable energy products based on silicon nanotechnology; **Kovio** develops semi-conductor products using thin film technologies, printed electronics and nanoparticle inks; **NanoGram**, which owns a portfolio of approximately 75 patents and a complementary family of trademarks in fields including nanomaterials-based films, new nanomaterials compositions, and rapid synthesis of nanopowders and films; **Nanomix** is developing nanoelectronic sensors that add value across a broad range of applications including: low power consumption, small size, high specificity, reproducibility and wireless integration; **Nanosys** is developing nanotechnology-enabled systems incorporating novel and patent-protected zero and one-dimensional nanometer-scale materials such as nanowires, nanotubes and nanodots (quantum dots). **Nextreme Thermal Solutions** is developing thermoelectrics for applications that require extreme thermal management solutions. **Solazyme** is harnessing the power of the sun through the evolution of selected photosynthetic microbes to provide efficient bioproduction solutions to the energy, pharmaceutical, chemical and nutraceutical industries.

Source: New Energy Finance, Harris & Harris

Richards adds. "It is significant that both of our nano investments are clean energy plays."

Nanotechnology analysis firm Lux says that governments across the world invested \$1.1bn in 2006 on nano-enabled clean technology, up 16% on the 2005 figure, but just 5% of clean tech funding overall. It adds that last year saw 983 US patents issued and 7,132 scientific papers published on nano-enabled clean technologies, while venture capitalists invested \$292m into nano-enabled clean tech companies. This was a 91% increase on the amount invested in 2005, and it accounted for 15% of all clean tech VC. However, in an illustration of the sector's lack of maturity, nano-enabled cleantech companies made up just 2% of clean tech M&A activity and IPO values. Of the roughly 1,500 start-ups focused on clean tech operating across the globe in 2006, 19% of these companies are developing nanotech approaches, with a large majority (80%) working in energy.

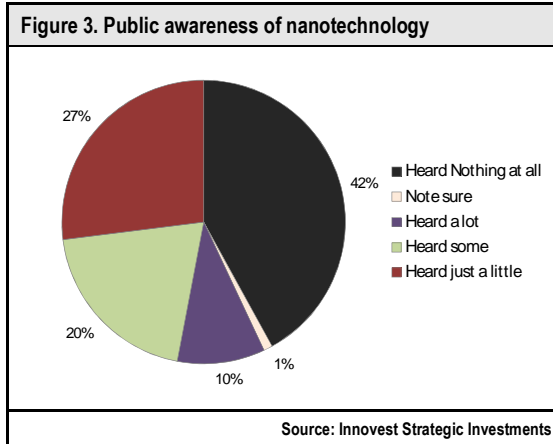
Nanoscience will be applied across multiple disciplines and enable advances across a range of potential applications according to Innovest. As such, the investment focus is on products and not nanotechnology itself. At the moment, most nano profits remain in commodity type applications such as automotive coatings. The vast majority of companies who claim to be involved in nanoscience or nanotechnology development are still engaged in basic research. "The universe of companies will eventually narrow to a few who claim to have product ready for the market. These will be bought by large cap firms or their technology will be licensed. Fewer still will remain who can survive as viable nano pure play companies," says Innovest. To date the ratio of venture capital to government R&D spending is very low and the number of licensing agreements, IPOs and acquisitions is also low.

Lux Research predicted that 2007 would see more IPOs and consolidation between pure plays. However, there has been limited activity – Nanodynamics recently cancelled its IPO due to the market turmoil while in April, Carbon Nanotechnologies, a Texas-based CNT manufacturer and Unidym, a developer of nanotube-based electronics in Silicon Valley, announced a merger.

**Risks - nanosafety**

Nanoscale materials present unique challenges because of their novelty and their size. It is still unknown what effects nanomaterials may have on the environment or health – some nanomaterials are likely to be highly toxic – and because nanomaterials offer few applications directly for consumers, public knowledge about nanotechnology is not high and public support for it is neutral, at best. Some analysts, such as Innovest, compare the potential risks with those that affected the asbestos industry, where the risks did not become obvious until long after the substance was in widespread use or GM foods, where companies such as Monsanto failed to demonstrate to the public that GM benefited them, rather than just allowing Monsanto to manipulate agriculture for its own profit.

Nanoparticles may have greater reactivity and toxicity than larger sized particles. Because of their size, nanoparticles may also evade some of the body's natural defence systems and accumulate in some tissues. But currently there is little information on the impact of engineered nanoparticles, and what there is can be contradictory. As a result, one of the earliest investment opportunities is likely to be detection technologies, but although there are products such as New Zealand company Nano Cluster Devices' hydrogen sensor and Nanomix's gas detection products, there are few products that can detect nanoparticles themselves.



## Appendix 1

### Nanomaterials and their properties

There are three types of nanomaterials – those that are nanoscale in one dimension create layers, such as thin films or surface coatings. Those that have two dimensions in the nanoscale include nanowires and nanotubes, while three-dimensional nanomaterials include precipitates, colloids and quantum dots.

There is a range of different nanomaterials, each with different attributes and applications.

1) **Carbon nanotubes.** There are two types of nanotube – single-walled and multi-walled. Single-walled carbon nanotubes (SWNTs) can be thought of as one atom thick sheets of graphite (which is brittle and very soft, hence its use in pencils) rolled into a cylinder. They are very strong – 100 times the strength of steel and only one sixth of the weight, flexible and conductive of both heat and electricity. Multi-walled nanotubes (MWNTs) are multiple layers of graphite, resembling either a rolled up piece of paper or a Russian doll, depending on whether they are cylindrical or spherical.

2) **Nanoparticles** exhibit different properties to their bulk counterparts. For example, copper becomes a superhard material at the nanoscale, while titanium dioxide becomes transparent, allowing sunscreens that do not leave a white residue but also having implications for optoelectronics. It can also be used as a photocatalytic agent in coatings that can be applied to stay-clean windows, causing the dirt to be oxidized and easily washed away by rain. Specially designed nanoparticles are presently used as fuel additives to increase the fuel efficiency of commercial vehicles by up to 10% and cut their soot emissions by up to 15%.

Nanoparticles have a very high surface area to volume ratio and a lower melting temperature, allowing them to be formed into coatings or bulk materials at lower cost and also improving the performance of catalysts by increasing the surface area the catalyst can work on.

3) **Aerogels** are a type of nanofoam - nanostructured, porous materials derived from gels where the liquid component has been replaced by gas. This produces a low-density, semi-transparent material, sometimes called Frozen Smoke, which is very strong but light, although it is brittle.

Aerogels can be used for sound and heat insulation, offering 2-8 times the insulation of traditional insulation materials and also being lighter, more environmentally friendly and water and fire-resistant. They will play a large part in reducing the 30% of CO<sub>2</sub> emissions that come from households and in cutting the amount of energy used to cool liquefied natural gas.

4) **Dendrimers.** Large spherical molecules formed by self assembly at a nanolevel that can act as carrier molecules and trap metal ions. The inside of dendrimers is very high density and attempts have been made to produce dendrimers that absorb light. The structures can act as carrier molecules, useful not just for drug delivery but also environmental remediation. They can form films, coatings and membranes with hydrophilic or hydrophobic properties and can also be used in printed circuit boards, sensors and catalysts.

5) **Quantum dots.** Semiconductor nanostructures that confine the movement of electrons in all directions. The optical properties (eg the colour) of the structures can be finely tuned depending on their size. Quantum dots have the ability to improve the efficiency of silicon PV cells and their use in light-emitting diodes will drastically cut the costs and energy used in lighting and display screens, eg TVs and computer monitors.

6) **Nanowires** allow electrons to travel in one dimension only. They can be made from a wide range of materials and have interesting optical, magnetic and electronic characteristics. Nanowires are more conductive and lighter than traditional wires, helping to reduce weight in the space shuttle, for example, while they will also herald cheaper, lighter and more powerful consumer electronics products.

**Table 2. Case Study: Carbon nanotubes**

If they can be produced cheaply enough, carbon nanotubes (CNTs) will take over from carbon fibre as a filler in composite materials, to be used in any application where materials need to be lighter and stronger. Nanotubes will therefore have a huge impact on the fuel efficiency of any kind of transport by making vehicle bodies much lighter. The bike ridden by 2006 Tour de France winner Floyd Landis used CNTs to make the frame stronger and lighter, for example, but they are likely to be much in demand for all vehicles from bicycles to space rockets.

CNTs allow the creation of conductive plastics, which opens up a whole new range of opportunities for plastic to replace metals in applications where it was previously impossible because of the non-conductive nature of plastics.

Their thermal conductivity also allows them to be used in advanced computing applications and their electron field-emitting properties allow for low-voltage flat-panel screens for TVs or computer monitors.

CNTs also have a big role to play in a range of energy storage applications. Their massive surface area, good electrical conductivity and molecular structure mean they make a big difference to the performance of batteries and supercapacitors, while their surface area and thermal conductivity make them ideal catalyst supports in PEM fuel cells. Other applications include lubricants, coatings, catalysts and electro-optical devices.

Source: Cientifica, Penn State University, Wikipedia, Nanowerk

7) **Fullerenes.** Discovered in 1985, Buckminsterfullerene, or C60, is a carbon molecule in the shape of a football. It is named after Richard Buckminster Fuller, an architect famous for designing geodesic domes, and is sometimes called a Buckyball. Carbon nanotubes are cylindrical fullerenes. They can be heat resistant and superconducting. Uses include lubrication, by using the fullerenes as miniature 'ball bearings', in electronic circuits and to make organic solar cells. They also help fuel cells for personal electronics operate at lower temperatures.

### Appendix 2.

Company	Sector	Date	Investors
<b>Solexant</b>	Solar	August 2007	Trident Capital, Firelake Capital, X/Seed Capital, Medley Capital
<b>Cnano Technology</b>	Nanomaterials	August 2007	CMEA Ventures, Pangaea, WI Harper
<b>Nano Fusion</b>	Fuel cells	July 2007	Yasuda Enterprise Development,
<b>Nanotron Technologies</b>	Computer components	July 2007	Zouk Ventures, Accera Venture Partners, Danfoss Ventures, IBB, Micronas Semiconductor Holding, PolyTechnos Venture Partners
<b>Intematix</b>	Solar/nanomaterials	November 2006	Crosslink Capital, Samsung Ventures Presidio STX, Draper Fisher Jurvetson, East Gate Capital, Pacifica Fund
<b>Nanosolar</b>	Solar	June 2006	Mohr Davidow Ventures, Benchmark Capital, Onpoint, Mitsui, SAC Capital, GLG Partners, Swiss Re, Grazia Equity, Christian Reitberger, Capricorn Management,
<b>Innovalight</b>	Solar	May 2006	Harris & Harris, Apax Partners, ARCH Venture Partners, Sevin Rosen Funds, Triton Ventures
<b>NanoGram</b>		January 2006	Harris & Harris, Technology Partners, ATA Ventures, Nth Power Technologies, Bay Partners, Rockport Capital Partners, Institutional Venture Partners, SBV Venture Partners
<b>Cyrium Technologies</b>	Solar	Dec 2005	Pangaea Ventures Fund, BDC Venture Capital, Chrysalix Energy II US Ltd Partnership
<b>Nanosys</b>	Fuel cells	November 2005	El Dorado Ventures, Masters Capital, Medtronic, Wasatch Advisors, Alexandria Equities, ARCH Venture Partners, CDIB BioScience Ventures, CW Group, Harris & Harris, In-Q-Tel, Intel Capital, HB Fuller Company, Lux Capital, Polaris Venture Partners, Prospect Venture Partners, UOB Hermes Asia Technology Fund, Venrock Associates
<b>Nano Fusion</b>	Fuel cells	Nov 2005	Conduit Ventures, Yasuda Enterprise Development, Nanotech Partners, Orix Capital
<b>Oxonica</b>	Fuel catalysts	July 2005	Richard Farleigh, Foresight 2VCT, Stagecoach Group
<b>Nanosolar</b>	Solar	June 2005	Mohr Davidow Ventures, Benchmark Capital, Onpoint, Mitsui,
<b>Solaris Nanosciences</b>	Solar	May 2005	Slater Technology Fund
<b>Nanotecture</b>	Nanomaterials	May 2005	Foresight Venture Partners, Top Technology, Quester, East Hill, Artemis VCT
<b>Orionsolar</b>	Solar	April 2005	21 Ventures
<b>Nanomix</b>	Solar/ hydrogen storage	March 2005	Harris & Harris, STAR Ventures, Alta Partners, Apax Partners, Sevin Rosen Funds, EnerTech Capital Partners

Source: New Energy Finance

### Appendix 3: Nanotechnology Research

Institution	Location
The Richard E. Smalley Institute for Nanoscale Science and Technology at Rice University, Houston	AMER
Mcgill University, Montreal	AMER
Interdisciplinary Nanoscience Centre, Denmark	EMEA
Centre for nano-device modelling, Leeds, UK	EMEA
Center for Nanotechnology, University of Washington, Seattle	AMER
Centre for Molecular and Nanoscale Electronics, Durham, UK	EMEA
The Center for Near-Field Atom-Photon Technology, South Korea	ASOC
Institute of Biophysics and Center Interdepartmental on Biophysical-chemical and Biomedical Technologies (IBF & CITBB), University of Genoa	EMEA
Institute of Physical and Chemical Research, Riken, Japan	ASOC
Nanoscale Physics Research Laboratory, Birmingham, UK	EMEA
Nanocentre, Newcastle University, UK	EMEA
Nano Science and Technology Centre, Chinese Academy of Sciences	ASOC
PNNL (Pacific Northwest National Laboratory), Nanoscience, Nanoengineering and Nanotechnology	AMER

Source: New Energy Finance

Investments in nanotechnology R&D grew to \$12.4bn worldwide in 2006, while over \$50bn worth of nano-based products were sold, according to Lux Research. Government spending on nanotechnology grew to \$6.4bn in 2006, up 10% from \$5.9bn in 2005. The US has the lead, with \$1.78bn from federal and state governments, followed by Japan with \$975m and Germany with \$563m. Corporations spent \$5.3bn on nanotech R&D in 2006, a 19% increase over 2005, with the US out in front at \$1.93bn, followed by Japan with \$1.70bn.

**Table 5. Selected Companies Mentioned in this Report**

Company	Ticker (if applicable)	Ownership	Relevant Sub-activities
Advanced Battery Technology	ABAT	Quoted	Nano-Lithium Ion batteries
Altair Nanotechnologies	ALTI	Quoted	Electrodes for Nano-lithium Ion batteries
American Superconductor	AMSC	Quoted	Nano-enabled superconductive wires
Aspen Aerogels		VC/PE funded	Aerogels
Centrotec Sustainable AG	CEV.DE	Quoted	Nano-coated glass for PV systems
Cree	CREE	Quoted	LEDs
Energy Conversion Devices	ENER	Quoted	Thin film solar
First Solar	FSLR	Quoted	Thin film solar
Harris & Harris	TINY	Quoted	Nanotechnology investment
Kalwall		Private company	Aerogels
Konarka		VC/PE funded	Thin film solar
Maxwell Technologies	MXWL	Quoted	Supercapacitors
Nanosolar		VC/PE funded	Thin film solar
Nanovations		Private company	Insulation
Nansulate	INTK	Quoted	Insulation
Oxonica	OXN	Quoted	Fuel Catalysts
Spire	SPIR	Quoted	Thin film solar
TAASI		Private Company	Aerogels

Source: New Energy Finance

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