



NanoMarkets

White Paper

Quantifying the disruptive power of nanotechnology

***“How Nanotechnology is Changing
the Energy Equation”***

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How Nanotechnology is Changing the Energy Equation

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NanoMarkets believes that nanotechnology is already affecting all of the most interesting energy technologies and will create dramatic change in the world energy picture. For those currently without access to reliable energy, new nano-engineered solutions will improve their quality of life. For those saddled with inefficient energy storage, generation and transmission options, nanotechnology will provide new power sources that will drive down their effective cost per kilowatt and/or enable improvements in productivity. For investors interested in alternative energy markets, nanotechnology will provide opportunities but with many of the same risks inherent in emerging technology markets. This White Paper reviews the many ways in which the energy industry is being (and will continue to be) impacted by nanotech. The new nano-enabled energy markets will also be the subject of several reports that will appear from NanoMarkets' energy consulting practice in coming months.

Fossil Fuels and Nanocatalysis

Despite all the fuss about alternative energy sources, the truth is that no one sees our reliance on fossil fuels going away any time soon. However, this need not mean that the current level of dependence on OPEC oil will be maintained. There is a lot more natural gas around than oil, and even more coal.

It has been possible to create liquid hydrocarbon fuels from both coal and gas since the 1920s using the Fischer-Tropsch process. As the cost of oil has increased, a clean form of diesel made in this way has become commercially viable. China has recently taken a nanotech-enabled step in this area. The \$2-billion Shenhuan coal liquefaction project, using U.S.-developed nanocatalytic technology, is expected to be an economically competitive way of producing fuel.

The key impact of nanotechnology in this part of the energy sector is to improve reaction efficiencies and control through nanostructuring. Catalysis happens on surfaces, and nanostructuring can open up much more surface for a given volume, increasing reaction rates. It is not that simple, of course—reactants need to make their way to the catalytic site at a rate sufficient to exploit reaction rates, and this can imply structures with mixed scales. But building large and complex structures from the bottom up is very much a discipline that is evolving under the nanotech umbrella.

Enhanced Combustion Systems and Fuel Cells

A lot of development has been seen recently in “mini-turbines,” using the same principles as larger power stations but on a smaller scale. For such established technologies the impact of nanotechnology is not likely to be revolutionary but there are certainly applications of nanocrystalline metallics, ceramics and composites of these that can improve performance parameters, especially lifetimes.

These systems are competing directly with larger fuel cells for small-scale industrial use. And fuel cells in general are also being impacted by nanotechnology in a number of ways. For example, fullerenes are being used to replace large polymers in electrolytic membranes, enabling lower temperature operation. Fullerenes are also being used in proton exchange membranes where they help to move the protons. Nanoporous carbon may also have promise in electrodes—new forms have been created in recent years—and nanoparticulate catalysts can be used for proton/electron dissociation. Meanwhile, “Buckypaper,” has been shown to have great promise as combined electrode material and catalyst support, while nanosensors are finding a role for detecting hydrogen in fuel cells. Indeed, nanotechnology is a major factor behind the recent surge in progress in fuel-cell technology after many years where little changed.

Solar Energy

Fuel cells are very much in vogue these days and so is solar energy, which is also benefiting from nanotechnological innovation. The problem with solar energy to date has been cost. Even if it produced a long-term payback on investment, the initial outlay would be prohibitive for many. Nonetheless, photovoltaic systems have seen a rash of interesting developments over recent years, both improving efficiencies and reducing costs. Efficiencies of around 30 percent have been seen in the lab for a long time (at a cost), but exploiting multiple wavelengths has managed to push this to 50 percent.

Several new approaches using various nanostructures are promising extremely cheap solar panels, although with efficiencies hovering around 5 percent. There has been talk of cheap roll processes and even painting the materials on the walls of office blocks. Some have even predicted materials with better efficiencies than current commercial silicon-based cells at 1/10th to 1/20th of the initial cost. Such an achievement—if it ever happened—would be truly disruptive as economics alone would lead to rapid uptake in much of the world. However, in a true calculation of cost, lifetime has to be taken into account, and this is one of the weaknesses of some of the new materials.

It might be asked why one would think that a breakthrough in solar energy is near after years of relative stagnation. The answer is in the variety of technological developments that have an impact in the area, akin to the surge that has kick-started fuel-cell developments. The key developments are in semiconductor nanostructures and more efficient electron transport materials, including fullerene-based materials. These play a similar role here to that in fuel cells, i.e. carrying electrons away from where they are generated before they can spontaneously, and wastefully, recombine with the holes created alongside them.

Wind, Biomass and Geothermal Energy

Several other alternative energy sources seem as if they will also be rendered more practical as a result of nanotechnology. These include wind, biomass and geothermal energy.

Although one of the most ancient forms of generating energy, wind farms are suddenly sprouting up in many countries as their economics are improving considerably. However, the proportion of a nation's energy needs that they can produce is limited and for nations without extensive coastlines and the option of offshore farms they can take up considerable amounts of real estate.

You might wonder how nanotechnology would impact something as ancient as wind power and the answer is in materials. The power of a wind turbine increases with the square of the blade length. Already these blades use the most advanced carbon fiber composites but carbon nanotube composites promise many times the strength-to-weight ratio.

Biomass is also attracting increasing interest and nanotechnology bears on it in much the same way as it does on fossil fuels—improved catalysis and gas separation. There are also a lot of touch points here with fuel-cell technology.

Geothermal energy gets little attention, being seen as something available only in certain parts of the world, such as Iceland. In fact it is an almost limitless supply of energy just beneath your feet wherever you are. “Just” in geological terms, that is. To reach the depths required to make good use of the heat in the interior of our planet, drilling technology would have to improve or our ability to make use of lower-grade heat would have to improve.

Nanocrystalline metals and ceramics are producing a variety of new materials that have potential in drilling technology. But a more interesting development here is the use of thermoelectric tunnelling to generate electricity from low-grade heat. Companies have already been created to exploit this technology, which relies on electrically insulating nanolayers with very precisely-controlled dimensions, and the target markets are much more mundane than large-scale geothermal energy. Exploiting waste heat from car engines to run the electrics (and increase efficiency) is one target and the same technology could be used for exploiting waste heat in traditional generating environments.

Consumption

There are a number of ways in which nanotechnology can reduce energy consumption in major applications. However, this won't automatically lead to less total consumption. In fact there is every reason to believe that if costs can be cut then demand will increase at least proportionately and maybe even more.

Air travel is the area where nanocomposites promise the greatest impact in terms of global economics. Most of the internal structures of passenger aircraft are already made of

carbon fiber composites and carbon nanotube composites promise substantial weight reductions for the same performance—materials at least five times stronger for the same weight have been made in the lab. Weight savings of only 3 percent are generally enough to justify the investment required to incorporate new materials in commercial passenger aircraft.

Advanced nanocomposites will also lead to reduced energy consumption in cars (they are already doing so, in fact, with nanoclay composites now widely used), although the impact will be less dramatic than in aerospace. Here, though, real energy savings will be seen since car use does not increase substantially when energy costs come down. Weight reductions can also be made in car engines with stronger nanocrystalline metals. Ceramics may overcome earlier disappointments as the result of less brittle nanocrystallines—nanocrystallinity having a quite different effect in ceramics than in metals. Carbon nanotube composite ceramics have also been made with markedly improved strength. Fuel efficiency in cars can also be improved through the incorporation of catalytic nanoparticles, and this technology is already commercialized with cerium oxide nanoparticles that offer up to 10 percent reduction in diesel consumption and improved emissions.

If moving people around is a major consumer of energy, so is making them comfortable when they aren't moving. Heating and cooling our environments use vast amounts of energy. Much energy expenditure in the home and in the office is considered essential. Commercial premises and offices rarely compromise on the level of desired cooling or heating because of cost, though they would welcome savings. Interestingly, a potential energy-saving nanotechnology-based cooling system is simply the reverse of one of the energy-generating systems already mentioned, that of using thermoelectric tunneling. Devices based on this effect promise to be around 20 percent more efficient than the compressors used in refrigerators, and, incidentally, a lot smaller and completely lacking in CFCs or other chemical pollutants.

Preventing heat from going where it isn't wanted, i.e. out on cold days and in on warm ones, is one of the ways of achieving some of the greatest energy savings. Nanostructured aerogels made using sol-gel techniques are already being investigated as insulating layers in double glazing and recent dramatic improvements in the physical strength of aerogels offers prospects of applications for which aerogels were previously too fragile.

Nanoparticulate coatings can selectively prevent warming infrared rays from coming in through windows, and electrochromic surfaces (nanoparticles again) can be used to darken windows at the flick of a switch. High-end cars are seeing some of the greatest interest in both these technologies. One of the biggest energy savings, though, will come in the form of nano-engineered LED lighting, which is sometimes described as being to fluorescent lighting what fluorescent is to incandescent, except that it's also appealing to interior designers. Lighting is responsible for around 20 percent of energy consumption in Western countries and LED lighting promises major savings, once the price comes down enough. The LED lighting sector is rapidly evolving at the moment and nanotechnology can interact in a number of ways, but quantum dots are a particularly promising technology. The reason is that light emission is normally restricted to frequencies based around chemical characteristics—sodium street lighting is orange for this region. Quantum dots

emit light based upon physical rather than chemical properties, namely their size, and as such can be tuned to create light of any desired wavelength.

Apart from traveling and maintaining our environment, there is one other major area of energy consumption—manufacturing. A brief and generalized analysis of the impact of nanotechnology here is impossible as the field is far too diverse and involves a multitude of chemical and physical processes. Nanotechnology, however, goes hand-in-hand with an approach to manufacturing that is intrinsically low in waste and energy-efficient, namely bottom-up manufacturing, especially self-assembly. To date, though, the immediate promise of bottom-up manufacturing is more in making novel materials and devices on a small scale than improving the energy-efficiency of large-scale manufacturing. But we are novices in this area and though growing a toaster, let alone a computer, is not something that we are anywhere near achieving, the philosophies and paradigms of bottom-up manufacturing will become increasingly prevalent over the coming years.

Renewable Fuels

What is really needed is a compact fuel, just like the liquid hydrocarbons we use now, that is produced from renewables. As yet there is little promise of such a system but this is exactly where nanotechnology, as we continue to master it, will yield its greatest power, in molecular engineering. And the work has begun—natural photosynthetic systems are being constantly tinkered with in labs and are becoming better understood all the time. Spinach has even been leveraged to produce photovoltaic systems with an efficiency of 12 percent—more than double that of natural photosynthesis. One day the most sophisticated nanotechnology will deliver the ideal fuel, the perfect replacement for oil.

In the meantime, we look set to see a diversification of energy production sources, with a wide array of nanotechnology already in play or waiting to come into play to help ensure this. The rising cost of oil and falling cost of alternatives will encourage a variety of novel generation options and mixes appropriate for a particular environment—dependent on whether the sun shines a lot, whether there is a water source nearby, or whether grid infrastructure is in place. And until the arrival of that perfect fuel the future of energy looks anything but boring.

About NanoMarkets:

NanoMarkets analyzes the impact of nanotechnology on both established and emerging markets with a focus on the realms of communications, IT, semiconductors, biomedicine and energy. The firm provides market research reports, customized industry analyses and general market commentary for companies looking to capitalize on nanotechnology-based opportunities. For additional information about NanoMarkets' upcoming reports on energy market opportunities, please contact Robert Nolan at (571) 434-7520 or rob@nanomarkets.net.