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Nanotechnology for future

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Abstract

This paper reviews the expected wide and profound impact of nanotechnology for planning future renewable energy policies.

Keywords: Nanotechnology, strategies, future policies, research & development, planning

1. Introduction

This Nanotechnology operates at such a fundamental level that there is very little of a technological nature that it will not impact. Thus its effects on energy generation, transmission, storage and consumption are numerous and diverse. Some will be incremental and some quite possibly revolutionary. As a whole, present technologies are either too limited in terms of resources, too inefficient, or too expensive to deploy on the massive scale that will be necessary in the coming decades. It is in this context that nanoscience and nanotechnology are poised to play a transformative role in providing clean and sustainable energy from secure domestic resources in future. The past decade has shown that the technological challenges of making energy conversion and storage more efficient and more affordable are intimately tied to our understanding and control of nanoscale phenomena. In the next decade, we envision that research in nanoscience and nanotechnology will enable realization of new technologies such as low-cost photovoltaic for solar power generation, new classes of batteries for both transportation and grid-connected energy storage, efficient low-cost methods of converting both solar and electrical energy into chemical fuels, new catalysts and catalyst systems enabling artificial.

2. Advances in last decade

Research in the period from roughly 2000 to 2010 has shown that nanotechnology is a powerful tool for a host of processes in support of efficient, sustainable energy conversion, storage, and conservation, in terms of:

- Tailoring the interaction of light with materials and enabling the processing of low-cost semiconductors into devices such as photovoltaic
- Making more efficient photo catalysts for converting sunlight into chemical fuels
- Developing new materials and membranes for the separations needed in many energy applications
- Converting chemical fuels into electrical energy (and vice versa)
- Improving energy and power density in batteries
- Improving efficiency in areas from displays and solid state lighting to thermoelectric and friction.

There are many promising research areas from the last decade could, with proper support, become transformative technologies in the coming decade. Advances in nonmaterial's synthesis, integration into devices, and characterization, along with modelling and understanding of nanoscale physical phenomena, have all contributed to significant accomplishments in these areas. At the applications level, selected examples of the progress made in the last decade include those discussed in the subsections below.

A. Nanostructured Organic & Inorganic Photovoltaics

In the past decade, low-cost, nanostructured organic solar cells made from polymers like plastics have emerged as one possibility. Organic photovoltaics do not rely on conventional single p-n junctions for their function. Instead, a nano-structured donor/acceptor interface is used to dissociate excitons, while providing co-continuous transport paths for positive holes and negative electrons. The generation of photocurrent comprises four successive steps: generation of excitons by photon absorption, diffusion of excitons to the heterojunction, dissociation of the excitons into free charge carriers, and transport of these carriers to the contacts. Advances in colloidal synthesis have facilitated the use of inorganic nanoparticles as precursors for low-cost, solution-phase deposition of thin-film solar cells. Nanoscale size control offers the ability to tailor optical absorption and energy band alignments, as well as the potential to utilize more exotic phenomena such as carrier multiplication to increase photovoltaic performance.

B. Artificial Photosynthesis

Photosynthesis provides a blueprint for solar energy storage in fuels. Indeed, all of the fossil fuel-based energy consumed today is a product of sunlight harvested by photosynthetic organisms. During the past decade a number of research groups have prepared synthetic analogues of the principal nanoscale photosynthesis components and have developed artificial systems that use sunlight to produce fuel in the laboratory. Fuel production via natural or artificial photosynthesis requires three main nanoscale components: a reaction center complex that absorbs sunlight and converts the excitation energy to electrochemical energy; a water oxidation complex that uses this redox potential to catalyze conversion of water to hydrogen ions, electrons stored as reducing equivalents, and oxygen; and a second catalytic system that uses the reducing equivalents to make fuels such as carbohydrates, lipids, or hydrogen gas. Dramatic improvements in efficiency, durability, and nanosystems integration are needed in the next decade to advance artificial photosynthesis as a practical technology for energy harvesting and conversion.

C. Nanostructures for Electrical Energy Storage

Along with energy production, renewable energy systems such as solar or wind require the ability to store energy for reuse on many different scales. Electrical energy, which offers the greatest potential for meeting future energy demands as a clean and efficient energy source, can be stored by electrically pumping water into reservoirs, transforming it to potential energy and back. However, this is only possible for very large-scale localized storage. As recently outlined in a workshop report from the U.S. Department of Energy (2005), the use of electricity generated from renewable sources, such as water, wind, or sunlight, requires efficient distributed electrical energy storage on scales ranging from public utilities to miniaturized portable electronic devices. This can be accomplished with chemical storage (i.e., batteries) or capacitive storage (i.e. electrical capacitors). Nanostructuring can increase the efficiency of both storage, release of electrical energy, and the stability of electrode materials against swelling-induced damage from ion uptake.

D. Nanotechnology for Thermal Insulation

Based on recent DOE Annual Energy Outlook reports, residential and commercial buildings account for 36% of the total primary energy use in the United States and 30% of the total U.S. greenhouse gas emissions. About 65% of the energy consumed in the residential and commercial sectors is for heating (46%), cooling (9%), and refrigeration (10%). In addition to developing new renewable sources of energy for heating and cooling, nanotechnology can play an important role in energy conservation. Nanoscale titania low-emissivity coatings made by sputtering or chemical vapor deposition are now commonplace on commercial and residential insulating glass units (IGU). Porous and particulate nanoscale materials are also crucial to advanced thermal insulation. Silica aerogels are exceptional thermal insulators because they minimize the three methods of heat transfer (conduction, convection, and radiation).

E. Nanotechnology for Hydrogen Storage

Overall during the last decade, significant improvements in nanoparticle purity and characterization techniques have allowed the field to arrive at a consensus that it is no longer worth investigating hydrogen uptake in pure CNTs for on-board storage applications. It is anticipated that the next decade will see new types of ultrahigh-surface-area nanoscale materials, like metal organic frameworks (MOFs) designed and developed for more efficient hydrogen storage. Continued improvements in battery technology are likely to place increasing pressure on hydrogen as an energy storage medium.

3. Planning for future

There are three different levels at which the nanotechnology R&D infrastructure needs to be considered: basic research, “directed” or applied research, and development.

A. Basic Research

It is assumed that most of the nanoscience basic research will be done in universities and in national laboratories, because the time-line for output is too long for industry. Funding for basic research needs to be enhanced both for single investigators or small groups of faculty members, and for centres or institutes that may be located at a single campus or laboratory or involve multiple universities and national laboratories.

B. Directed Research

The challenges of directed or applied research in the area of nanostructures are more difficult for the single investigator model; the model of centre activity is recommended as the more effective approach. Research fundamental to the integration of nanosystems is appropriate for this category. Collaboration between scientists and engineers in academe, private sector, and government laboratories needs to be integrated in the directed research programs.

C. Development

The development cycle for many “nanoproducts” is expected to be too long at this time for large companies and for venture capital to be able to support this research. Resources must therefore come from the Government, and the work must be carried out in university and national labs and in incubators. However, to optimize the eventual commercialization of ideas generated through this research, it is essential that relationships between universities, national labs, and relevant industries be strengthened. Nanotechnology partnership programs should be formed, small high-tech companies can fill this role. Early success is apt to be in sensor and instrument areas. Grants can help promote the programs. Incubator programs should be developed at universities that support large efforts in the field of nanostructure science and technology. The university or national lab makes infrastructure available to a small company for a start-up, often with a faculty member or members taking the lead in the formation of the company. The "incubator" is a temporary intermediate stage in the formation of these start-up companies.

4. Investment and implementation strategies

Nanotechnology research and development requires a balanced, predictable, strong, but flexible infrastructure to stimulate the further rapid growth of the field. Ideas, concepts, and techniques are moving at such an exceedingly rapid pace that the field needs coordination and focus from a national perspective. Demands are high, and the potential is great for universities and government to continue to evolve and transition this science and technology to bring forth the technological changes that will enable industry to commercialize many new products in all sectors of the economy. Even greater demands are on industry to attract new ideas, protect intellectual property, and develop appropriate products.

Tools must be provided to investigators in nanotechnology for them to carry out state-of-the-art research to achieve this potential and remain competitive. Centres with multiple grantees or laboratories where these tools would be available for this support should be established at a funding level of several million dollars annually. In addition to university- and government-led centres and networks, co-funding should be made available to industry-led consortia that will provide a degree of technology focus and different areas of relevance that are not always present in academic-led consortia. These centres should also have diverse research teams that will be effective in different scientific disciplines. Funding is needed for supporting staff to service outside users at existing and new centres. We should also investigate means to achieve the remote use of these facilities.

Funding mechanisms that encourage centres and university-national laboratory-industrial collaboration should be emphasized, as well as single investigators who are tied into these networks. Support to single investigators should provide a corresponding level of personnel and equipment support. University grants should encourage work among research groups to make maximum use of concepts and ideas being developed in other disciplines. The infrastructure must include building links between researchers, developers, and users of nanotechnology innovations. The focus must be on developing critical enabling technologies that will have significant value added in many industries.

It will also be necessary to fund training of students and support of post docs under fellowships that will attract some of the best students available. Students should receive multidisciplinary training in various nanotechnology fields. Both organizational attention and funding should also be devoted to ensuring the open exchange of information in multidisciplinary meetings and rapid publication of results through, for example, workshops and widely disseminated summaries of research.

In terms of investment and implementation strategies, broadly speaking, the funding of energy-related research at both the basic sciences and applied/translational levels needs to be commensurate with the scale of this challenge over a stable, long-term period, reflecting the long-term nature of the problem. Specific recommendations for improving the effectiveness of research dollars spent on energy include:

- *Continue expansion of both student and postdoctoral fellowship programs*. Nanoscience and nanotechnology fellowships in energy will train the next generation of scientific leaders, while enabling the best students to choose the most innovative projects and to explore creative research with more freedom than would be possible if the student/postdoc was funded through an individual principle-investigator (PI) or centre grant.
- *Create a precompetitive "Energy Research Corporation."*

Borrowing ideas and "best practices" from the Semiconductor

Research Corporation model used by the semiconductor industry could create a framework for exploring ways to strengthen precompetitive research in energy science and technology while also building closer ties between academia and industry to accelerate the movement of ideas from the lab to real-world implementation.

- *Realize improved synergy, cooperation, and integration between agencies.* Due to the crosscutting nature of these problems, energy research will require less-exclusive

"ownership" of ideas and programs than the historical norm from Federal sponsors. Leveraging support from multiple sources to achieve major programmatic goals should be encouraged.

- *Increase both average award sizes and overall success rates*. Many recent "special programs" for energy research have had success rates approaching 1%. On the positive side, this reflects the large number of ideas and untapped potential for addressing the energy challenge at all levels of science; however, the 1-10% success rates typical of many new programs result in significant wasted effort by proposers and reviewers and make it difficult for program administrators to pick the best proposals in an environment with a low-signal/noise ratio. Within Federal agencies, subunits that fund disproportionate amounts of energy research should be targeted for appropriate shares of any increases in Federal research dollars.
- *Sustain support for national energy research centers and hubs*. Many large energy initiatives have recently been funded by DOE and other Federal agencies. These centres have the potential to achieve transformative breakthroughs, but they will need stable/predictable support over periods longer than a single funding cycle to achieve their ambitious long-term goals.
- *Fund more small team awards over longer periods*. The energy challenge is interdisciplinary, and building collaborations takes time. Small team awards can

promote collaboration to tackle new ideas in a nimble fashion. Awards that encourage real connections and convergence between computation and experiment have good potential for high impact.

5. Conclusion

During the last five years understanding and knowledge about the risks of nanoscale particles and nanotechnologies have increased substantially. Our approach needs to be careful and responsible. Instead of concentrating only on the conventional sources of energy, we can also think about the use of nanotechnologies in a positive way. We can set the targets and objectives of the research so that they can help us to solve the environmental challenges that we will have in front of us during the coming decades. We should develop new electronics materials that are easier to recycle and/or decomposable in biological processes, and optimize and minimize the energy consumption in the manufacturing of future materials and products. Let us set the targets right – focus in the right set of technologies and introduce nanotechnologies into the public arena in a responsible way. Nanotechnologies can be one key solution towards sustainable future.

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