



Carbon Nanomaterials: Opening a Path to a Sustainable Future

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Opinion

As described by Dr. Richard E. Smalley in 2002, energy (it tops the list) and environment would be two of the top ten problems facing humanity over the next 50 years. Nowadays climate change, as one of the world's most pressing problems, is mainly exacerbated by inefficient energy and environmental technologies and thus affecting our security, health and quality of life. Luckily, the potential of nanotechnology has been demonstrated to be a key technology on the path to a sustainable future of energy and environment. Despite nanotechnology is not tied exclusively to sustainable technologies of energy and environment, it could help us to develop techniques (such as nanocoatings, nanostructured catalysts, nanomembranes and so on) to access and use energy sources much more efficiently, effectively and environment-friendly.

Carbon is one vital element as important for nanotechnology as silicon is for electronics. And certainly carbon nanomaterials can be engineered with a wide range of properties and in a variety of forms (such as zero-dimensional fullerene, one-dimensional carbon nanotubes, two-dimensional graphene, and three-dimensional graphite or diamond) that make them important materials for current and emerging energy and environmental technologies. Specially, as to the importance and potential of carbon nanomaterials, it can be recognized by some famous awards in recent decades including the 1996 Nobel Prize in Chemistry (for the discovery of fullerenes), the 2008 Kavli Prize in Nanoscience (carbon nanotubes), and the 2010 Nobel Prize in Physics (graphene).

Carbon nanomaterials constitute an important branch in the burgeoning field of nanoscience owing to their exceptional thermal, electrical, chemical and mechanical properties. They have been applied in many areas including energy storage and conversion, gas storage and separation, catalyst support and catalyst, super capacitor electrodes, reagents for water purification, smart sensors, targeted drug delivery, field-emission devices, paints, quantum wires, composite materials, nanoelectronics, soil additive, and so on. Looking at the broad spectrum of possible applications, it seems to be that we find ourselves in the carbon age. Here let's take the application of carbon nanomaterials in catalysis as an example.

In the foreseeable future, as known, fossil fuels will continue to be the major energy source. Therefore, the most feasible and

practical strategies used for a sustainable energy and environment can be described as follows:

- a. To gradually reduce the consumption of fossil fuels and to effectively improve the efficiency
- b. To efficiently control the negative environmental impacts caused by the consumption of fossil fuels
- c. To energetically develop renewable energy sources and technologies [1,2].

For all the cases, catalysis will play a vital role because there are many potential advantages by using carbon nanomaterials as catalyst supports or catalysts in comparison to other materials (e.g., metal oxides), shown as follows [3]:

- a. Better pore structure
- b. More uniform characteristics
- c. Reduced number of defects and impurities
- d. Enhanced oxidative resistance for chemical reactions
- e. Better electron and heat transport
- f. Better mobility of surface species and electronic coupling between active sites
- g. Different mechanisms of adsorption
- h. Specific surface reactivity associated to bond strains due to curvature
- i. From isolating to metallic properties through semi-conducting behavior
- j. Specific active sites
- k. Nano-engineering of catalytic sites

Although some of these aspects maybe need to be further investigated, there are many motivations for the utilization of carbon nanomaterials for advanced catalysis.

The catalytic application of carbon materials can be traced back to the utilization of activated carbons in waste water and/or

gas treatment. Nowadays, applications of carbon nanomaterials for catalysis are extremely varied, reflecting a number of different energy, environmental and economic markets along their value chain. Besides carbon nanomaterials could lead to energy savings through weight reduction or through optimized function, for example, they could improve energy generation and energy efficiencies.

Most of the reactions catalyzed by carbon-based catalysts can be classified into the following five groups [3,4]:

- a. Oxidation-reduction
- b. Hydrogenation-dehydrogenation
- c. Combination with halogens
- d. Decomposition
- e. Dehydration, isomerisation and polymerization

In addition, there are also some emerging catalytic applications [3] such as carbon molecular sieves for shape selectivity reactions, some advanced photo and electro-catalysis, gasification of organics and biomass, methylamines synthesis, bio-electrodes (made by supporting enzymes over nanocarbon based electrodes) as one frontier research for exploring new sustainable catalytic routes for using renewable resources, some catalytic membranes (e.g., nanodiamond immobilized membranes for enhanced desalination via membrane distillation), and so on.

The examples mentioned above do not certainly cover all the application field of carbon materials to develop novel or advanced catalysts for a sustainable development, but they give us the feeling of the broad range of possible applications. Especially, it should be emphasized that carbon nanomaterials are increasingly investigated and deployed in advanced technologies and devices for sustainable energy conversion and storage such as solar cells, supercapacitors, water splitting, lithium ion batteries, biomass conversion, and fuel cells [3-6]. In the past decades, research on carbon nanomaterials had been largely focused on the synthesis procedures [6], and it is important and necessary for a further effort in this direction. But a more rational analysis of the characteristics will be conducive to developing next-generation advanced catalysts based on the ability of a better control at the nano-scale and at the macro-shape levels the composition, active centers, over structure and architecture [3].

Clearly, more fundamental knowledge is needed in enhanced characteristics as a support for catalytic functionalities, stabilization of small catalytic particles with enhanced catalytic behavior, direct catalytic role of nanocarbon functional groups, nanoconfinement and electron-transfer induced changes in the properties of supported nanoparticles, defect-related catalytic reactivity, and catalysis by two-dimensional carbon nanomaterials [4]. Despite significant progresses have been made in preparation and applications of carbon-based catalysts, however, there are still some important issues that have yet to be addressed. For example, nanocarbon catalysts with high performance are highly desired and remain a great challenge, and affordable methods for synthesis, industrial scalability, and economic viability are needed as well [2].

It can be worth to continuously advance carbon nanomaterials because they will play a key role in many critical and enabling routes for a resource and energy-efficient future. The purpose of this essay is not a systematic analysis or discussion, but to give a glimpse on the future directions of carbon nanomaterials, as an introduction of the specific issue of "Research & Development in Material Science". It is expected to inspire scientists, engineers and researchers to devote efforts in the research and development of carbon nanomaterial technologies that enable a sustainable future. High quality of research and the breadth of topics in material science will be warmly welcomed by this journal.

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