# Carbon-Based Materials for Cost-Effective Solar Energy Conversion

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## Abstract

More energy from sunlight strikes Earth in 1 hour than all of the energy consumed by humans in an entire year. In fact, the solar energy resource dwarfs all other renewable and fossil-based energy resources combined. With increasing attention toward carbon-neutral energy production, solar electricity or photovoltaic (PV) technology is receiving heightened attention as a potentially widespread approach to sustainable energy production. The global solar electricity market is currently more than $10 billion/year, and the industry is growing at more than 30% per annum. However low-cost, base-loadable, fossil based electricity has always served as a formidable cost competitor for electrical power generation. To provide a truly widespread primary energy source, solar energy must be captured, converted, and stored in a cost-effective fashion. Even a solar electricity device that operated at near the theoretical limit of 70 % efficiency would not provide the needed technology if it were expensive and if there were no cost-effective mechanism to store and dispatch the converted upon demand. Hence, a complete solar-based energy system will not only require cost reduction in existing PV manufacturing methods, but will also require science and technology breakthroughs to enable, in a convenient, scalable manufacturable form, the ultra low cost capture, conversion, and storage of sunlight.

In thin film based solar cells, currently transparent conductive oxides in industry are dominated by indium tin oxide (ITO). Thin films of ITO in industry are used as the principal transparent electrode because of ITO's high electrical conductivity coupled with high optical transmittance. ITO is capable of delivering a thin film with optoelectronic properties of 10 Ω/sq coupled with 85 % optical transmittance at a wavelength of 550 nm. ITOs' remarkable optoelectronic properties are necessary to provide acceptable resistive capacitive delays for flat panel displays. However, ITO is inherently brittle, strains as low as 1.5 % result in severe deterioration of electronic properties, is not chemically stable, has poor transmittance in the blue-green visible regime, and a mismatch of ITO's work function with hole transport layers in organic light emitting diodes (OLEDs) typically creates significant barriers for hole injection. Furthermore, the principal material in ITO, indium, is expensive with a cost of $565 per kilogram in 2010, is expected to climb to $1000 per kilogram, and prices as high as $3000 per kilogram are suggested by the Chinese press.

To that end, optically transparent carbon-based nanomaterials including graphene and carbon nanotubes (CNTs) are promising candidates as transparent conductive electrodes due to their high electrical conductivity coupled with high optical transparency, are robust materials that can be flexed several times with minimal deterioration in their electronic properties, and they do not require costly high vacuum processing conditions. Therefore, carbon based nanomaterials transparent electrodes are investigated in this work.