# Carbon Nanotubes for Human Spaceflight Applications

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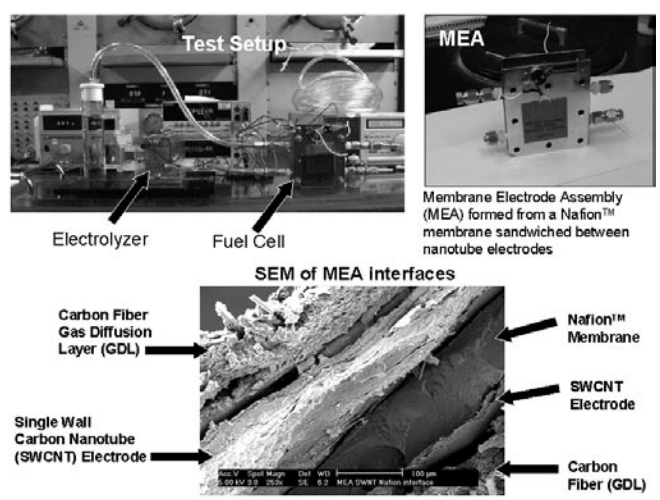
The NASA-Johnson Space Center (JSC) Nanomaterials Team has matured its research and development effort of applying nanomaterials to support NASA's larger goal of developing an exploration system that will be affordable, reliable, versatile, and safe. Given the needs expressed by the exploration community, in particular that of human spaceflight, the team has continued its applications research in power and energy systems, regenerable life support systems, electromagnetic interference and radiation shielding, and multifunctional nanocomposites. This work is a multidisciplinary effort that involves active collaboration with other NASA centers, government agencies, industry, and academia.

In collaboration with both the NASA-JSC Energy Systems Division and the NASA Glenn Research Center, research and development of high-performance proton exchange membrane fuel cells (PEMFCs) has matured. The JSC Nanomaterials Team approach has concentrated on increasing the current density and performance of the fuel cell catalyst supports through the use of high surface area and conductivity single-wall carbon nanotubes (SWCNTs). The team has brought a much-needed knowledgebase in PEMFC materials to the JSC community. Addressing both an industry and a NASA need, the team has developed a thorough materials analysis and testing protocol to characterize properties such as porosity, particle size, surface area, electrical conductivity, purity, and overall PEMFC performance. By using transmission electron microscopy ultramicrotomy and scanning electron microscopy freeze facture, the team has paid special attention to the membrane electrode assembly interfaces on the nanoscale. The JSC Nanomaterials Team also used various characterization methods to develop a relationship between material aspects on the nanoscale and PEMFC performance. Improvements found in fuel cell characterization and performance have been reported in various peer-reviewed journals, including that of the Materials Research Society.

NASA is interested in developing a new regenerable system for the removal of carbon dioxide ($CO_2$) as part of the environmental control and life support systems (ECLSSs) in space applications. To develop a lighter weight, smaller volume, and more efficient system for long-duration space missions to Mars, the JSC Nanomaterials Team, is developing a material that uses SWCNTs combined with $CO_2$ sequestering compounds to remove water and $CO_2$ from cabin atmospheres. Since SWCNT materials have extremely high surface areas and thermal transport characteristics, the resultant material would lead to a system that can be operated for longer times between regenerations. Conversely, one may conceive of constructing smaller adsorption beds, thus resulting in a smaller, lighter scrubber system that could potentially be used in spacesuits and smaller space vehicles as well. In collaboration with the Crew & Thermal Systems Division and researchers at Rice University, the University of Hartford, and Hamilton




*Testing of PEM fuel cell with SWCNT electrodes.*

Sundstrand Inc., the JSC Nanomaterials Team has successfully developed a microscale testing method for carbon-nanotube-based adsorbents, as well as a method for chemically bonding the reactive chemical to the surfaces of carbon nanotubes. Preliminary results show that these materials do adsorb CO2 and have the potential to perform as well as current technologies. JSC's work has also led to the development of new characterization techniques for SWCNTs that combine thermogravimetric analysis and x-ray photoelectron spectroscopy to characterize the surface chemistry of the SWCNT materials as well as its thermal stability. These results have been presented in peer reviews journals, including that of the Materials Research Society.

NASA is interested in developing a new system for purifying potable water as part of the ECLSSs for long-duration space exploration. An effective low-power system for water purification will not only result in cleaner drinking water from the fresh supply, but it will also allow for the conversion of wastewater to potable water. The JSC Nanomaterials Team, in collaboration with the JSC Water Recovery Group, is developing a nanostructured water purification to kill bacteria. Oxygen radicals can be produced by the interaction of high-energy (ultraviolet (UV)) photons with dissolved oxygen in water, which can be produced, by the interaction of UV light with carbon nanostructures called fullerenes. Current efforts have also centered on the design of the disinfection device, and have focused on solving technical problems including design of the light source and the photon emission source. Collaboration with researchers at Rice University has focused on developing a method to deposit thin uniform layers of fullerenes onto substrates such as quartz. First attempts at physical vapor deposition of fullerenes onto quartz have been relatively successful, and have yielded mechanically tough coatings that may be resistant to degradation by water. NASA will soon evaluate these new photon emitters.

Electrochemical double-layer capacitors, or "supercapacitors," have tremendous potential as high-power energy sources for use in low-weight hybrid systems for human space exploration. The high surface area and mesoporosity of SWCNT electrodes offer a compelling alternative to activated carbon, which is the current standard. NASA has collaborated with ReyTech Corporation and Georgia Tech Research Institute to develop electrochemical capacitors based on SWCNT electrodes. This effort has focused on optimizing materials for electrodes, electrolyte, separator membrane, and other components for desired power and energy performance characteristics, as well as on compatibility between chosen materials. Capacitors with SWCNT electrodes have been successfully fabricated that demonstrate capacitive behavior. One approach to enhanced performance has been the direct growth of nanomaterials in a preferential direction onto current collectors. Another approach is to vary the type of electrolyte ions that accumulate on the high surface area electrodes according to porosity characteristics of the nanomaterials. Higher power density and higher current output than produced by commercial supercapacitors has been demonstrated, and performance has been reported in NASA Tech Briefs and Journal of Materials.

Carbon nanotubes offer a convincing possibility to detect in "real time" harmful ionizing radiation during interplanetary space missions. Radiation damages DNA in living cells, leading to health problems such as nausea, cataracts, and cancer. Radiation hazards come in the form of trapped radiation, galactic cosmic rays, and solar particle events. A carbon nanotube dosimeter would detect radiation by monitoring changes in the conductivity of a nanotube sensor. Studies have shown that nanotube conductivity increases with radiation (doses to about 170 kGy) and then decreases after that. A possible reason for the conductivity increase is the addition of free radical electrons to the nanotube network. The conductivity probably decreases above 170 kGy because the radiation causes defects in the nanotube network. The JSC Nanomaterials Team has therefore begun a collaboration with Prairie View A&M University to test at Texas A&M, Brookhaven, Los Alamos, and other high-energy radiation facilities nanomaterials that are found to be suitable as dosimeters.