This process creates materials comprised predominantly of single-walled carbon nanotubes.

**Carbon Nanotube Microarrays Grown on Nanoflake Substrates**

*Lyndon B. Johnson Space Center, Houston, Texas*

This innovation consists of a new composition of matter where single-walled carbon nanotubes (SWNTs) are grown in aligned arrays from nanostructured flakes that are coated in Fe catalyst. This method of growth of aligned SWNTs, which can yield well over 400 percent SWNT mass per unit substrate mass, exceeds current yields for entangled SWNT growth. In addition, processing can be performed with minimal wet etching treatments, leaving aligned SWNTs with superior properties over those that exist in entangled mats.

The alignment of the nanotubes is similar to that achieved in vertically aligned nanotubes, which are called "carpets." Because these flakes are grown in a state where they are airborne in a reactor, these flakes, after growing SWNTs, are termed "flying carpets."

These flakes are created in a roll-to-roll evaporator system, where three subsequent evaporations are performed on a 100-ft (=30-m) roll of Mylar. The first layer is composed of a water-soluble "release layer," which can be a material such as NaCl. After depositing NaCl, the second layer involves 40 nm of supporting layer material — either Al2O3 or MgO. The thickness of the layer can be tuned to synthesize flakes that are larger or smaller than those obtained with a 40-nm deposition.

Finally, the third layer consists of a thin Fe catalyst layer with a thickness of 0.5 nm. The thickness of this layer ultimately determines the diameter of SWNT growth, and a layer that is too thick will result in the growth of multiwalled carbon nanotubes instead of single-wall nanotubes. However, between a thickness of 0.5 nm to 1 nm, single-walled carbon nanotubes are known to be the primary constituent. After this three-layer deposition process, the Mylar is rolled through a bath of water, which allows catalyst-coated flakes to detach from the Mylar. The flakes are then collected and dried. The method described here for making such flakes is analogous to that which is used to make birefringent ink that is coated on U.S. currency.
Muon tomography has been used to seek hidden chambers in Egyptian pyramids and image subsurface features in volcanoes. It seemed likely that it could be used to image injected, supercritical carbon dioxide as it is emplaced in porous geological structures being used for carbon sequestration, and also to check on subsequent leakage. This allows growth gases and atomic hydrogen to reach the flakes, but does not allow the flakes, which rapidly nucleate SWNTs, to escape from the cage.

In order to retain the flakes, a cage is constructed by spot welding stainless steel or copper mesh to form an enclosed area, in which the flakes are placed prior to growth. This allows growth gases and atomic hydrogen to reach the flakes, but does not allow the flakes, which rapidly nucleate SWNTs, to escape from the cage.

This innovation enables tracking of carbon storage or enhanced oil recovery in subsurface reservoir projects.

NASA’s Jet Propulsion Laboratory, Pasadena, California

Muons are generated by high-energy cosmic rays resulting from supernova explosions, and interact with gas molecules in the atmosphere. This innovation has produced a theoretical model of muon attenuation in the thickness of rock above and within a typical sandstone reservoir at a depth of between 1.00 and 1.25 km. Because this first simulation was focused on carbon sequestration, the innovators chose depths sufficient for the pressure there to ensure that the carbon dioxide would be supercritical.

This innovation demonstrates for the first time the feasibility of using the natural cosmic-ray muon flux to generate continuous tomographic images of carbon dioxide in a storage site. The muon flux is attenuated to an extent dependent on, amongst other things, the density of the materials through which it passes. The density of supercritical carbon dioxide is only three quarters that of the brine in the reservoir that it displaces. The first realistic simulations indicate

A contour plot of the Muon Intensity Change due to CO₂ injection into the reservoir over a period of one year, expressed as standard deviations from the initial value.