Scientists build 'nanobowls' to protect catalysts needed for better biofuel production

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It may sound like a post-season football game for very tiny players, but the "nanobowl" has nothing to do with sports and everything to do with improving the way biofuels are produced. That's the hope of a team of scientists from the Institute for Atom Efficient Chemical Transformations (IACT), an Energy Frontier Research Center led by Argonne National Laboratory (ANL), and including Northwestern University, the University of Wisconsin and Purdue University. The team is using a layering technique developed for microchip manufacturing to build nanoscale (billionth of a meter) "bowls" that protect miniature metal catalysts from the harsh conditions of biofuel refining. Furthermore, the size, shape, and composition of the nanobowls can easily be tailored to enhance their functionality and specificity.

The team, led by Jeffrey Elam, principal chemist in ANL's Energy Systems Division, will present its research during the AVS 59th International Symposium and Exhibition, held Oct. 28-Nov. 2, 2012, in Tampa, Fla.

In recent years, nanoparticles of metals such as platinum, iridium and palladium supported on metal oxide surfaces have been considered as catalysts to convert biomass – organic matter from plants such as corn, sugarcane and sorghum – into alternative fuels as efficiently as possible. Unfortunately, under typical biorefining conditions where liquid water may reach temperatures of 200 degrees Celsius (392 degrees Fahrenheit) and pressures of 4,100 kilopascals (600 pounds per square inch), the tiny metal nanoparticles can agglomerate into much larger particles which are not catalytically active. Additionally, these extreme conditions can dissolve the support.

"We needed a method to protect the catalysts without reducing their ability to function as desired during biorefining," Elam says. "Our solution was to use atomic layer deposition [ALD], a process commonly employed by the semiconductor industry to lay down single-atom thick layers of material, to build a 'nanobowl' around the metal particle."

To create a matrix of nanobowls containing active catalysts, the researchers first use ALD to deposit millions of metal nanoparticles (the eventual nanocatalysts) onto a support surface. The next step is to add an organic species that will only bind to the metal nanoparticles and not to the support. This organic "protecting group" serves as the mold around which the nanobowls are shaped.

"Again using ALD, we deposit layer upon layer of an inorganic material known as niobia [niobium pentoxide] around the protecting group to define the shape of the nanobowls in our matrix," Elam says. "Once the desired niobia thickness is reached, we remove the protecting groups and leave our metal nanoparticles sheltered in nanobowls that prevent them from agglomerating. In addition, the niobia coating protects the substrate from the extreme conditions encountered during biorefining."

Elam says that the nanobowls themselves can be made to enhance the overall functionality of the catalyst matrix being produced. "At a specific height, we can put down ALD layers of catalytically active material into the nanobowl walls and create a co-catalyst that will work in tandem with the nanocatalysts. Also, by carefully selecting the organic protecting group, we can tune the size and shape of the nanobowl cavities to target specific molecules in the biomass mixture."

Elam and his colleagues have shown in the laboratory that the nanobowl/nanoparticle combination can survive the high-pressure, high-temperature aqueous environment of biomass refining. They also have demonstrated size and shape selectivity for the nanobowl catalysts. The next goal, he says, is to precisely measure how well the catalysts perform in an actual biomass refining process.

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