Diamond catalyst shows promise in breaching age-old barrier

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In the world, there are a lot of small molecules people would like to get rid of, or at least convert to something useful, according to University of Wisconsin-Madison chemist Robert J. Hamers.

Think carbon dioxide, the greenhouse gas most responsible for far-reaching effects on global climate. Nitrogen is another ubiquitous small-molecule gas that can be transformed into the valuable agricultural fertilizer ammonia. Plants perform the chemical reduction of atmospheric nitrogen to ammonia as a matter of course, but for humans to do that in an industrial setting, a necessity for modern agriculture, requires subjecting nitrogen to massive amounts of energy under high pressure.

"The current process for reducing nitrogen to ammonia is done under extreme conditions," explains Hamers, a UW-Madison professor of chemistry. "There is an enormous barrier you have to overcome to get your final product."

Breaching that barrier more efficiently and reducing the huge amounts of energy used to convert nitrogen to ammonia—by some estimates 10 percent of the world's electrical output—has been a grail for the agricultural chemical industry. Now, that goal may be on the horizon, thanks to a technique devised by Hamers and his colleagues and published today (June 30, 2013) in the journal *Nature Methods*.

Like many chemical reactions, reducing nitrogen to ammonia is a product of catalysis, where the catalytic agent used in the traditional energy-intensive reduction process is iron. The iron, combined with high temperature and high pressure, accelerates the reaction rate for converting nitrogen to ammonia by lowering the activation barrier that otherwise keeps nitrogen, one of the most ubiquitous gases on the planet, intact.

"The nitrogen molecule is one of the happiest molecules around," notes Hamers. "It is incredibly stable. It doesn't do anything."

One of the big obstacles, according to Hamers, is that nitrogen binds poorly to catalytic materials like iron.

Hamers and his team, including Di Zhu, Linghong Zhang and Rose E. Ruther, all of UW-Madison, turned to synthetic industrial diamond—a cheap, gritty, versatile material—as a potential new catalyst for the reduction process. Diamond, the Wisconsin team found, can facilitate the reduction of nitrogen to ammonia under ambient temperatures and pressures.

Like all chemical reactions, the reduction of nitrogen to ammonia involves moving electrons from one molecule to another. Using hydrogen-coated diamond illuminated by deep ultraviolet light, the Wisconsin team was able to induce a ready stream of electrons into water, which served as a reactant liquid that reduced nitrogen to ammonia under temperature and pressure conditions far more efficient than those required by traditional industrial methods.

"From a chemist's standpoint, nothing is more efficient than electrons in water," says Hamers, whose work is funded by the National Science Foundation. With the diamond catalyst, "the electrons are unconfined. They flow like lemmings to the sea."

While the method was demonstrated in the context of reducing nitrogen to a valuable agricultural product, the new diamond-centric approach is exciting, Hamers argues, because it can potentially fit a wide range of processes that require catalysis. "This is truly a different way of thinking about inducing reactions that may have more efficiency and applicability. We're doing this with diamond grit. It is infinitely reusable."

The technique devised by Hamers and his colleagues, he notes, still has kinks that need to be worked out to make it a viable alternative to traditional methods. The use of deep ultraviolet light, for example, is a limiting factor. Inducing reactions with visible light is a goal that would enhance the promise of the new technique for applications such as antipollution technology.

Provided by University of Wisconsin-Madison

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