OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

ReactWell™

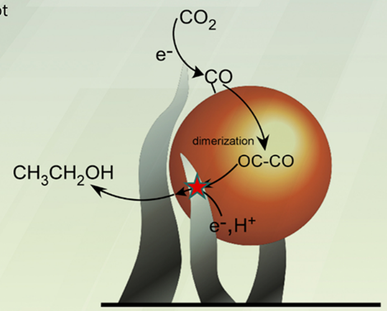
FLC 2020 Impact Award, A Catalyst to Produce Ethanol and Reduce Reliance on Fossil Fuels

Technology

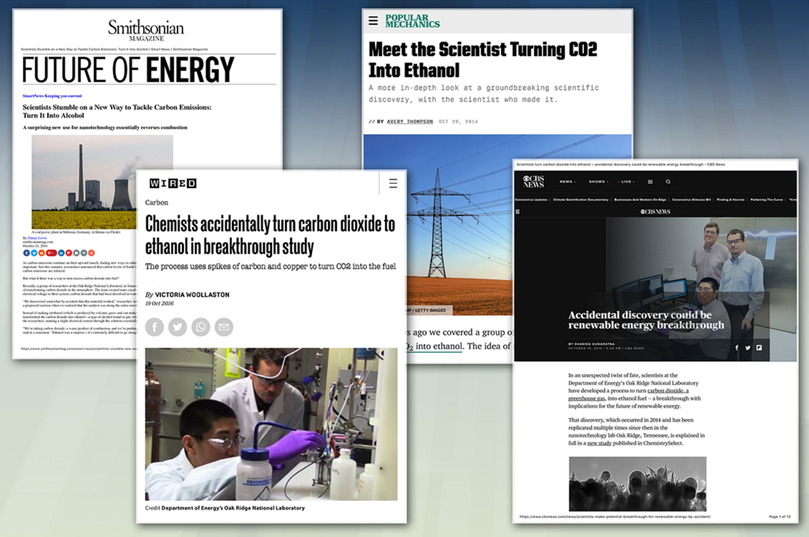
- Addressing carbon emissions and limiting the impact of carbon dioxide (CO_2) on Earth's climate and environment are among the most urgent challenges of modern society.
- Of the many proposed CO_2 mitigation strategies, recycling is a compelling option. To make CO_2 recycling a viable, scalable option, a process that can use surplus electricity to produce useful products from CO_2 is needed. Researchers at Oak Ridge National Laboratory (ORNL) have developed an electrochemical process that combines CO_2 with water and electricity to produce ethanol. The process can be operated as a dispatchable load that can supplement intermittent renewable energy sources, such as wind and solar. It is also a useful alternative to batteries for long-term or portable storage of renewable electricity.
- "This is the kind of technology industry must pursue if we're going to reduce our use of fossil fuels." – Dr. Adam Rondinone

Key advantages of ORNL's technology include:

- **Simplicity:** Converts CO_2 to ethanol in a single-pot reaction at room temperature and pressure
- **Broad applicability:** Benefits any operation that produces a CO_2 by-product
- **Efficient:** Boasts total energy efficiency of ~22% with a ~$1.98 electrical cost for synthesizing 1 gallon of ethanol
- **Cost-competitive:** Competes with the costs of converting corn into ethanol, even before attempting to scale up the process, which may lead to further cost-saving efficiencies
- **Streamlined:** Uses no rare earth elements, which are expensive and difficult to acquire
- **Robust:** Offers a solution to many sites that off-gas CO_2 at high purity (e.g., geothermal applications) yet fail to convert the CO_2 into a useful product



This conceptual illustration of ORNL's reaction mechanism shows the nanotechnology-based sequential catalyst with unprecedented selectivity for ethanol.



Publicity issued by ORNL resulted in hundreds of media mentions of the laboratory's discovery, including articles in leading publications such as Wired, Smithsonian Magazine, Discovery Magazine, Popular Mechanics *and more, as well as mainstream news outlets such as CBS News. The widespread media attention surrounding this innovation may further aid ReactWell's commercialization efforts by encouraging industry adoption of fossil fuel-mitigating technologies.*

Key Mechanisms and Resources

- **Strategic Development and Impactful Marketing with TIP**
  ORNL's technology was incubated using the lab's unique Technology Innovation Program (TIP), which supports technology development using royalties from existing licenses to accelerate market readiness of high-potential technologies. TIP also provided a framework for diligent and proactive marketing efforts, which included generation of publications, press releases, and direct mailings to targeted parties as well as a showcase for potential licensees. These diligent efforts by ORNL's Technology Transfer Office (TTO) resulted in global interest, including more than 400 media mentions and multiple potential licensees.
- **Proactive Interest, Initiation, and Ongoing Discussions**
  In October 2016, ReactWell discovered the media covering the ORNL catalyst discovery and proactively reached out to the inventor, while ORNL's TTO followed up with ReactWell to arrange discussions and site visits, enabling ReactWell to preview the technology. During this time, ReactWell also hired a staff scientist who had been part of the original technical team working on the catalyst. The strategic hire enabled the company to have an in-house expert on the technology for further development and collaboration with the ORNL team of scientists.
- **Diligent Licensee Selection**
  ORNL's TTO vetted multiple interested companies using a researched ranking system, considering myriad factors, including ability to commercialize at industrial-fuel scale, background and expertise, and facilities that would enable production at scale. The objective scoring system enabled ORNL to select ReactWell as the licensing candidate best poised for a successful commercialization effort to increase the chances for the innovation having the greatest impact.
- **Strategic Funding and CRADA for Further Development**
  ORNL and ReactWell are currently working on a Collaborative Research and Development Agreement (CRADA) to deploy a large prototype for producing ethanol using ORNL's catalyst at ReactWell's site, with plans to eventually deploy it at a refinery. The company is also contributing in-kind funds, and the Department of Energy awarded a Technology Commercialization Fund grant for these efforts. These resources will enable demonstration of large-quantity ethanol production, improving ReactWell's chances of a successful industrial-scale rollout, which the company has planned within the next decade.

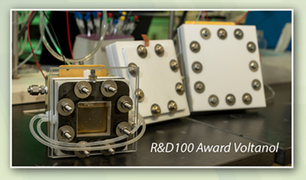
Partner

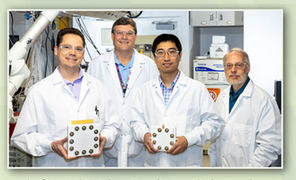
- The invention was matured at laboratory and small-pilot scale through ORNL's unique Technology Innovation Program, leading to worldwide media and licensing interest. ORNL selected innovative startup ReactWell as the exclusive licensee, given its demonstrated qualifications and expertise. The company has contributed additional in-kind funding and is a cost-share partner on a Department of Energy Technology Commercialization Fund grant awarded to ORNL for this effort.
- ReactWell's commercialization plans start with introducing this waste-to-fuel technology to niche markets and eventually scaling up to the ethanol fuel industry within the next decade. If successful, this transfer effort will be highly impactful, helping to improve energy conversion methods for cleaner, more efficient oil and gas, chemical, and bioenergy production. This effort has the potential to introduce to industries worldwide a simple and cost-effective way to recycle CO2 that would otherwise be released into the atmosphere and to reduce society's reliance on fossil fuels.

Outcomes

- **Introducing Energy-Efficient Technologies to the Marketplace**
  ORNL's fundamental scientific research for this effort has resulted in innovation that advances the Department of Energy's goal of addressing the nation's need for more energy-efficient technologies and increasing US energy security overall.
- **Providing Public Benefit and Environmental Impact**
  ORNL's technology offers a simple electrochemical approach to producing ethanol. The value of this approach is also simple: the surplus CO_2 used in the process, which would otherwise be emitted into the atmosphere, becomes a feedstock through which useful products can be produced—specifically, ethanol for fuel, solvents, and beverages/spirits.
- **Creating New and Renewable Sources of Energy**
  ORNL's catalyst lowers ethanol production costs and is carbon-neutral, enabling operation by variable renewable electricity sources, such as wind power. In fact, one of the use cases for this technology is as a modular, add-on feature to wind farms and solar energy sites for intermittent operation during times when supplementation is needed. Specifically, the process would allow renewable energy plants to take advantage of extra electricity when available by making and storing ethanol for later use. This would then help to balance a grid with intermittent renewable sources.

  In addition, successful commercialization could impact the efficiency of cars and long-distance transportation vehicles by increasing the capacity to synthesize more ethanol. This would allow the adoption of higher ethanol blends, such as E-30. By enabling widespread availability of high-ethanol blends, this technology transfer effort could encourage automobile companies to design engines optimized for high- ethanol blends that would achieve much higher efficiencies than today's engines.
- **Keeping Surplus Carbon Dioxide Out of the Environment**
  ORNL's technology enables reducing emissions per unit of fuel. The process is completely carbon-neutral, channeling surplus CO_2 into a fuel source rather than releasing it into the atmosphere. Depending on the application and the reactor used, the process could also be carbon-negative, if no additional processes result in CO_2 emissions during production.
- **Adding Value to Current Ethanol Industry Infrastructure**
  Although ORNL's catalyst does not require corn fermentation, that does not mean that the catalyst would supplant corn. In fact, currently operating fuel ethanol companies see this technology as adding value to existing fermenter operations. The average fuel ethanol fermentation plant annually produces 100 million gallons of ethanol but produces even more CO_2 in the process. If that CO_2 could be captured and converted back to ethanol, then the ethanol could be purified and distributed through existing infrastructure.
- **Improving the US Economy and Energy Security**
  This technology transfer success is expected to boost the economic competitiveness of the United States by providing additional ethanol fuel without additional farming. In addition to potentially lowering fossil fuel import requirements, the effort may also boost economic competitiveness by creating jobs and improving overall efficiencies in various markets. These markets include existing ethanol manufacturing sites, where new modular add-on units can be colocated; wind farms for energy storage; and geothermal fields or other CO_2 generators with the ability to sell liquid ethanol in lieu of compressed CO_2.





(Left to right) Adam Rondinone, Dale Hensley, Yang Song and Peter Bonnesen