Transforming THE CHEMICAL INDUSTRY

There are huge reservoirs of oil in the deep waters of the Gulf of Mexico. Retrieving that oil safely presents very substantial challenges. Yet today a major oil company is poised to lower a string of pipe 7,000 feet down to the bottom of the Gulf to start pumping that oil, which comes out of the seabed at very high temperatures. The steel pipe is coated with a unique insulating layer, a type of plastic with remarkable properties: it can safely cope with oil at temperatures as high as 390°F while surrounded by water at temperatures close to freezing. The insulating plastic also protects the outside of the pipe from the corrosive effects of the seawater.

The special plastic or polymer is made from chains of organic (carbon-based) molecules that do not occur in nature. Rather they are synthesized by a powerful chemical process, which in addition to specialized plastics has also found application in the food industry, in the pharmaceutical industry, in agricultural chemicals, and even in novel biorefineries that transform natural products such as palm oil into chemicals and fuels. The result is a much more powerful toolkit for synthesizing new organic molecules, especially those known as *olefins* that contain double bonds between carbon atoms. This widespread industrial impact would not have occurred without long-term support for the underlying science from DOE's Basic Energy Sciences (BES) office and other federal agencies.

Drilling rig used for oil exploration and recovery. It lowers drill strings and specialized oil recovery pipe as much as 7 miles down to the seabed in the Gulf of Mexico. *(iStock.com /Mikeuk)*

The chemical process—catalysis—involves a substance that makes a chemical reaction possible without being itself consumed in the reaction. An example is the catalytic converter in your car that changes dangerous pollutants into less damaging carbon dioxide and water using tiny amounts of platinum as a catalyst. In producing the oil pipe material above, the catalytic reaction involves breaking double chemical bonds between carbon atoms in small molecules, and then, with the aid of a temporary intermediate partner (the catalyst), linking them together to form larger molecules with new properties.

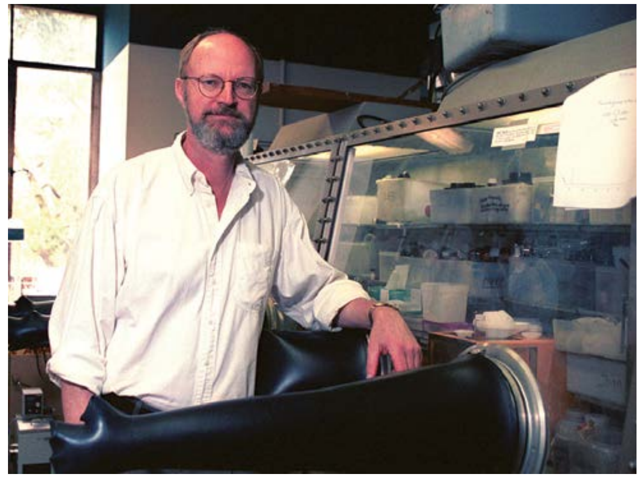
Yet after the mechanism for this reaction was understood in principle, in 1971, it took two decades of persistent research—mostly in university laboratories, supported by BES and other federal agencies—to devise the first practical catalysts, and another two decades to refine those catalysts for use in commercially important applications.

Unlike the catalytic converter in your car, which is made of platinum particles in a solid matrix, the catalysts described here are organic molecules that include a metal atom and are dissolved in solution with the molecules that will form the end product. The challenge was to find a catalyst that was selective—reacting only with double bonds—and whose activity could be adjusted depending on the desired final reaction product. Richard Schrock at MIT began work in this area in the late 1970s, focusing on catalysts based on tungsten and molybdenum. After much trial and error, he found a successful solution in 1990. Robert Grubbs at Caltech started work even earlier, in the early 1970s, and focused his efforts on catalysts based on ruthenium. He published successful results in 1992. Both scientists shared a Nobel Prize for these discoveries.

The research effort to develop specific catalysts for different applications has continued since then right up to the present, gradually producing a wide range of commercially significant results. These include:

> The high-temperature plastic protecting the oil recovery pipe mentioned above that is being deployed by Shell in the Gulf of Mexico, and a wide variety of other specialized plastics.

> An effective treatment for hepatitis B developed by Johnson and Johnson—a two-drug cocktail, one of which is produced using a ruthenium catalyst—as well as other pharmaceutical products.



BES-supported research for individual university-based investigators, including Robert Grubbs at Caltech, played a significant role in the development of powerful catalysts that have transformed the chemical industry. *(Caltech)*

> A photoresist material—produced with tungsten or molybdenum catalysts—that helps create nanometer-sized patterns with light and is widely used in the manufacture of semiconductor chips.

> A biorefinery in Indonesia that uses ruthenium catalysts to convert palm oil into chemicals and fuels, one of a number of applications that use natural products as feedstocks.

> A wide range of pest control chemicals used in agriculture, as well as synthesis of an organic chemical that is a primary ingredient in many perfumes.

More broadly, the discovery and development of these powerful metal-based catalysts have transformed the chemical industry: they have enabled more efficient synthesis of organic compounds, cleaner and more environmentally friendly production processes, and the ability to create novel materials. None of this could have been foreseen back in the 1970s, when BES support for individual investigators in this area of science—including, at various times, both Schrock and Grubbs—began. Both scientists say that an important driver of these results has been the consistency of research support—for example, BES has been supporting work on the synthesis of polymers for more than three decades, since the mid-1980s—as well as the availability of collaborative support from multiple federal agencies.