earths in pure elemental form. Subsequent discoveries of each element's unique electrical, optical, magnetic, and fluorescent properties, to name a few, and their associated behavioral characteristics, led to a virtual explosion of new and advanced applications.

Rare earths, when combined with certain other elements, form metal alloys having unusual magnetic properties. The resulting products pervade modern society. The red elements of color television pictures, for example, emanate as colored light from rare earth phosphors. Compact starter motors in automobiles make use of powerful rare earth magnets. Such magnets also make possible the miniaturization of magnetic tape readers, popularized in the so-called "walkman" audio cassette players. Some rare earth lasers are used to cut steel. Others surgically repair tissues of damaged or diseased eyes. Rare earth materials are used as well in advanced defense warning systems to detect submarines at great distances.

Today, 17,000 tons of rare earths are used annually in the United States to manufacture such products. Global consumption is far greater. Producers worldwide use separation methods, or extensions thereof, of the basic technologies originally developed by Basic Energy Sciences researchers.

Rare earth elements, such as ytterbium, praseodymium, dysprosium, and gadolinium, represent a class of metals, numbered 57 through 71 in the Periodic Table of Elements. They were once so obscure that for a hundred years after their discovery they were little more than laboratory curiosities. Although originally named "rare," the scarcest of their kind is now known to be considerably more abundant than silver and gold combined.

When first confronted by the needs of the nuclear research community, Basic Energy Sciences researchers attacked the problems of separation and purification by seeking improvements in existing processes. These processes had proven successful in separating small quantities of rare earths.

One process in particular called for a column of "absorbent" material to be packed inside a vertical tube. A liquid solution containing dissolved rare earths was poured in at the top of the column and "soaked up" by the absorbent material. Once full, a second "washing" solution was then introduced at the top of the column. It was allowed to flow continuously down through the tube, slowly passing through the absorbent material.

Because of its special properties and varying chemical affinities for the different rare earth elements, the washing solution tended to attract some rare earth elements slightly more strongly than others. Hence, different rare earths moved down the column and out the bottom of the tube at different rates. Those that moved more easily came out first, and so on. This resulted in enhanced concentrations of certain rare earth elements at different stages in the process.

Although this process worked, it was slow and tedious. The process had poor selectivity, in that there was only partial separation of the rare earths with each pass down the tube. This required repeated processing of the output in successive stages. Recovering minute quantities at high levels of purity took months.

Basic Energy Sciences researchers hypothesized that the key to improving this process was to increase the selectivity of the washing solution. This might be accomplished by adding a chemical called a "complexing agent."

The researchers were familiar with a large class of such agents as a result of their work on other separations having to do with fuel for nuclear reactors. They knew, for example, that each molecule of a complexing agent is shaped in such a way that it forms a "pocket." This pocket, depending upon its particulars, can attract and physically "hold" certain types of atoms.

With this knowledge, the researchers selected several agents, each with a pocket believed to be well matched to the physical attributes of certain groups of rare earth atoms. The results were dramatic. The affinity between the washing solution and the targeted rare earth atoms rose significantly, leading to faster trips down the tube, higher selectivity, and more concentrated separations.

Building on this advance, the researchers further improved the process by becoming adept at optimizing the conditions, such as the acidity and temperature of the washing fluid, under which the complexing agents performed. In this way, they produced practical processes for separating commercial amounts of all of the rare earth elements in reasonable time periods. Purity levels of 99.9999