RISKY SUPPLY CHAIN

Dependence on unreliable Chinese sources for critical rare earth magnet materials puts the U.S. military equipment and electronics industry at risk.

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Today, nearly 100% of the world's rare earth metals and over 94% of rare earth oxides come from China. This dominance has become unmistakable during the past decade, and has been accompanied by a steep decline in U.S. production capabilities. It is most notable in the NdFeB (neodymium-iron-boron) market, for which there is currently no domestic production. Chinese dominance is further demonstrated by its production of over 85% of hard ferrite and 65% of Alnico and SmCo (samarium cobalt) magnet materials. These facts are significant because magnet materials are the backbone of manufacturing technologies that support U.S. energy and defense markets.

The loss of production capabilities has also resulted in a brain drain of engineers with permanent magnet materials capabilities. In a recent article entitled "Offshoring Technology Innovation: A Case Study of Rare-Earth Technology," by Fifare, Veloso, and Davidson in the *Journal of Operations Management*, (Vol. 26, 2008), the authors described the current situation. They showed that after the domestic bonded NdFeB magnet industry went to China, innovation by U.S. industry dropped dramatically. The drop was measured by the drop in the number of patents involving bonded NdFeB magnets.

Chinese President Jiang Zemin stated in 1999 that China must "improve the development and applications of rare earths and change the resource advantage into economic superiority." China has accomplished this aim through hard work, improving technologies and manufacturing, and low labor costs and practices.

For example, intellectual property rights abuses in China resulted in a series of lawsuits in 2003 and 2004 by the two key worldwide patent holders who have cross-licensed over 600 patents in NdFeB technologies.

Magnequench, a North American company with Chinese operations; and Sumitomo (now Hitachi metals), a Japanese firm with Japanese operations, fought non-licensed Chinese NdFeB sales by suing magnet users such as Walmart, Dell Computer, and others based on U.S. product sales – a rather upside-down way to enforce IP abuses in China. At the present time, there are nine Chinese licensees

United States Navy ships, such as the USS New York shown here, need rare earth magnets for the proper function of innumerable electronic devices.

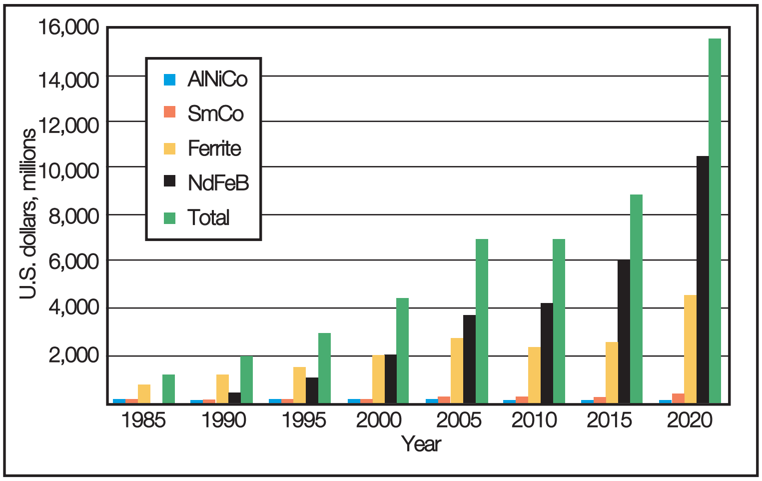

Fig. 1 — Global supply, demand, trends, and forecast of permanent magnet materials. In terms of dollars, demand for NdFeB will continue to grow through the recession. Ferrite demand will slacken because the automotive industry is its primary market. AlNiCo and SmCo are limited to applications in niche markets. Source: WebMagnetics.com

and sublicensees to these master patents, according to the Hitachi Metals website. However, as many as one hundred companies in China could be producing NdFeB magnets. This is in stark contrast to the total lack of NdFeB manufacturing in the United States.

Rising prices

On July 14, 2005, Chinese rare earth oxide producers agreed on production caps, which began a significant trend of reduction in tonnages on the worldwide market. The producers agreed, potentially in violation of the World Trade Organization (WTO), that if producers sold at less than agreed-upon prices, fines could be levied of roughly $100 per metric ton. However, after prices of elements such as neodymium metal rose by a factor of four

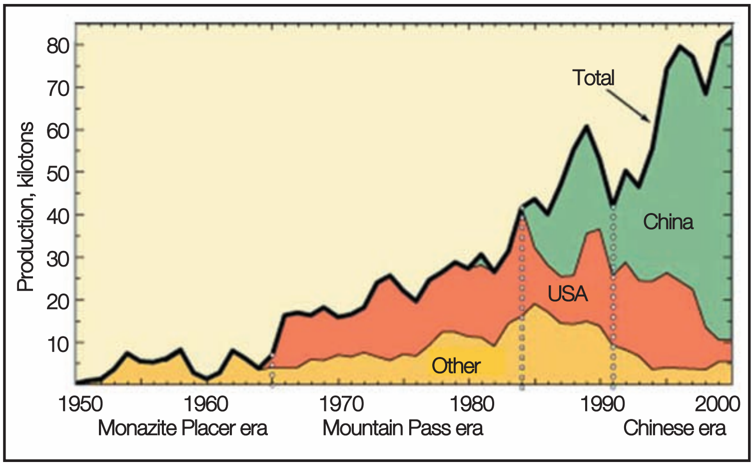

Fig. 2 — This graph shows global production of rare earth oxides from 1950 to 2000. The United States was a major player in the rare earth magnet market until about the year 2000. Source: U.S. Geological Survey

in a period of eighteen months after this meeting date, rare earth metal buybacks from *Chinese* customers were mandated at sub-market levels.

In addition, rare earth export quotas were established. These continue today, along with reports that they are traded or sold among producers. China has not justified its export quotas. On January 1, 2008, China increased its export duties from 10% to 25% on all rare earth metals. Export duties were allowed on some commodities in its protocol of accession to the WTO; however, they did not include rare earth elements used in magnet manufacturing. One Australian report now projects that China may consume all the rare earths it produces by the year 2012.

In addition, recycling of rare earths in China is effectively non-existent. Large Chinese magnet producers do not press parts to near net shape, as is common practice in the rest of the world. Instead, the common practice is to produce large blocks, which require significant amounts of material to be machined away. As a result, much more material is scrapped than in other countries.

These Chinese actions add to export prices for rare earths, and place non-Chinese magnet producers at a structural, competitive disadvantage. These actions also result in significant uncertainty about prices and availability. China views downstream user implications of the rare earth price increases as having positive effects, such as reduced competition among Chinese magnet companies, and higher prices for China's products. This is exactly where the rest of the world's rare earth magnet producers have been moving. It is also conceivable that future access to rare earth materials from China may be dependent on an agreement to move upstream manufacturing processes into China.

On April 21, 2008, the U.S. Department of Commerce announced dumping of flexible ferrite magnets and imposed a duty of 185.3% on Chinese imports.

On June 24, 2009, *The Wall Street Journal* reported that "The U.S. and the European Union filed separate complaints with the World Trade Organization on Tuesday alleging that China is unfairly benefiting domestic industries by restricting exports of certain raw materials."

U.S. Trade Representative Ron Kirk called China's alleged export restraints on raw materials a "giant thumb on the scale" in favor of China's chemicals, steel, and aluminum industries, among others. The U.S. alleges that "by limiting exports on those products through quotas, export duties, licensing, and other restraints, China gives an unfair leg up to its manufacturers that use those materials." The raw materials involved in the dispute include bauxite, coke, magnesium, manganese, silicon metal, and zinc. China is a top producer of these materials. (Rare earths were not addressed in this action.)

U.S. magnetic materials industry

Both SmCo and NdFeB magnet materials were invented in the United States. SmCo was discovered by Dr. Karl Strnat in the late 1960s while conducting research at the U.S. Air Force Research Lab at Wright Patterson AFB. NdFeB was invented in the 1980s. One of the inventors responsible for NdFeB, John Croat, worked for General Motors and was instrumental in the formation of Magnequench, a division of GM.

- **1980s:** The American magnet industry reached its peak in the late 1980s and early 1990s. At the time, roughly 6000 people were employed producing magnets in the United States, with all key types of permanent magnets manufactured. Two or three strong industry trade associations were active. Five manufacturers produced alnico, five produced samarium cobalt, four produced NdFeB, seven produced ferrite, and one produced rare earth mineral and oxide magnets. In 1990, worldwide magnet production was 300,000 metric tons, with sales valued at roughly $2 billion. United States production comprised over 50% of these totals. (Fig. 2)
- **1990s:** Significant changes during this decade caused a dramatic decline in American magnet production. The off-shoring by various U.S. magnet producers commenced and picked up momentum, as manufacturers first moved portions and then full lines of magnet production to China. The Chinese mining operations grew substantially, and their low-cost products displaced other sources of rare earth minerals provided to world markets.

Permanent magnets in automobiles

The number of magnets in automobiles has been on the rise as the number of motors increased from roughly twenty to as many as two hundred over the last twenty five years. These magnets support systems from seat manipulation motors to electric power steering.

Most recently, hybrid electric vehicles have escalated magnet demand with the needs of the motor/generator embedded in the transmission that either recharges the batteries from the mechanical energy of the engine, or draws down the batteries so that the car can operate in electric mode. In alternative energy technologies such as wind power, permanent magnets replace the excitation windings of synchronous machines and eliminate mechanical gear boxes in higher efficiency generators.

Magnequench was sold off from General Motors to a Chinese-led investment group in 1995.

• **2000s:** In 2002, the rare earth mine in Mountain Pass, California, which contains some of the world's richest deposits of these key minerals, suspended operations because it could not compete with Chinese producers. The Chinese moved the Magnequench operations to China in 2003, then moved the R&D Center from North Carolina to Singapore in 2003. In that same year, Vacuumschmelze closed its operations in Elizabethtown, Kentucky, and consolidated production in Germany and Slovakia. Hitachi Metals procured Sumitomo's magnet business.

In 2005, the China National Offshore Oil Corporation attempted to purchase Unocal, the owners of Molycorp. However, this bid was rejected in Washington due to the concern of Chinese ownership of such a substantial U.S. energy interest, which didn't even recognize the danger in selling off these rare earth mines. In 2005 Hitachi closed its production facility in Edmore, Michigan, which was formerly part of General Electric, effectively ending all NdFeB production in the USA.

As the U.S. industry shrank, the U.S. industry associations first consolidated, then finally dissolved in 2007. In 2009, the Mount Weld Australia rare earth mine ceased operations, and the Lynas Corporation sold a 25% stake in the company to a Chinese firm.

• **Today**: The U.S. magnet industry now employs roughly 400 people. There are now three Alnico producers, one independent hard ferrite producer, one SmCo producer, and no NdFeB producers, even though NdFeB is now the largest seller

What are rare earths?

Rare earths comprise a group of fourteen elements that were largely undiscovered when the periodic table of elements was developed. However, they are not rare; they are abundant within the earth's crust. The deposits are generally not deep, and are easy to access through open pit surface mining. Figure 3 shows the strengths of the various types of magnet materials.

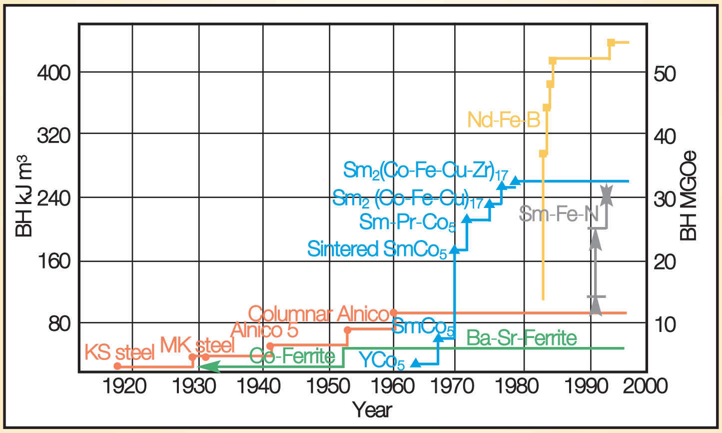

Fig. 3 — This graph clearly shows that neodymium-iron-boron magnets have the highest energy product of all magnet materials. B = magnetic induction; H = magnetizing force; BH = Energy product.

High-performance magnets

High performance metal magnets consist of aluminum-nickel-cobalt (Alnico), samarium cobalt (SmCo) and neodymium iron boron (NdFeB). These magnets exhibit the highest temperature stability and maximum energy product (a measurement of a magnet's ability to retain and provide magnetic flux).

Thses magnets are produced by two methods:

- **Casting**: The pure molten alloyed metals are cast into molds, heat treated, then machined to size and magnetized.
- **Powder metallurgy:** The pure metals are melted, cast, crushed, and then milled to the 2 to 5 micron range, single crystals with a single magnetic domain. They are then pressed in a magnetic field for magnetic alignment, sintered, and heat treated. They are machined to size by grinding techniques, then inspected and magnetized. These rare earth-transition metal compounds have the highest magneto-crystalline anisotropy and dramatically higher magnetic properties than all other magnet materials.

and most recent type of permanent magnet material. Worldwide magnet sales topped $9 billion before the recession, with U.S. manufacturing capacity a tiny portion of the total.

Molycorp has initiated steps to re-commence mining in California, and today the company is drawing out materials set aside before suspending operations in 2002. There is no independent industry association, although the permanent magnet group did become a division under the Small Motors Manufacturing Association (SMMA), and plans to reintroduce a statistics program. Most of the participants were once American magnet producers, but are now predominantly importers from sources in Europe and (mostly) Asia.

The future of the U.S. industry

As recently as June 2009, Congress took small but significant steps to counter this trend in the magnet and specialty metals industries.

First, the House Armed Services Committee included important provisions in its bill expressing concern at the trends in domestic specialty metals prosecution. The bill specifically mentioned high performance magnets and the dependence of defense systems on foreign sources of NdFeB.

Additionally, the House of Representatives commissioned a study by the Government Accountability Office on the effects of such dependence on defense systems.

These congressional actions are the first in a series of steps that would be required to reverse the trends of U.S. supply chain vulnerabilities. The tiny band of remaining high performance magnet producers and raw material suppliers is committed to advancing the state of the art in magnet technology and enhancing the U.S. manufacturing presence in spite of tremendous challenges.

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