THE COMMERCIAL POTENTIAL OF HIGH-T_c SUPERCONDUCTORS

John J. Gilman

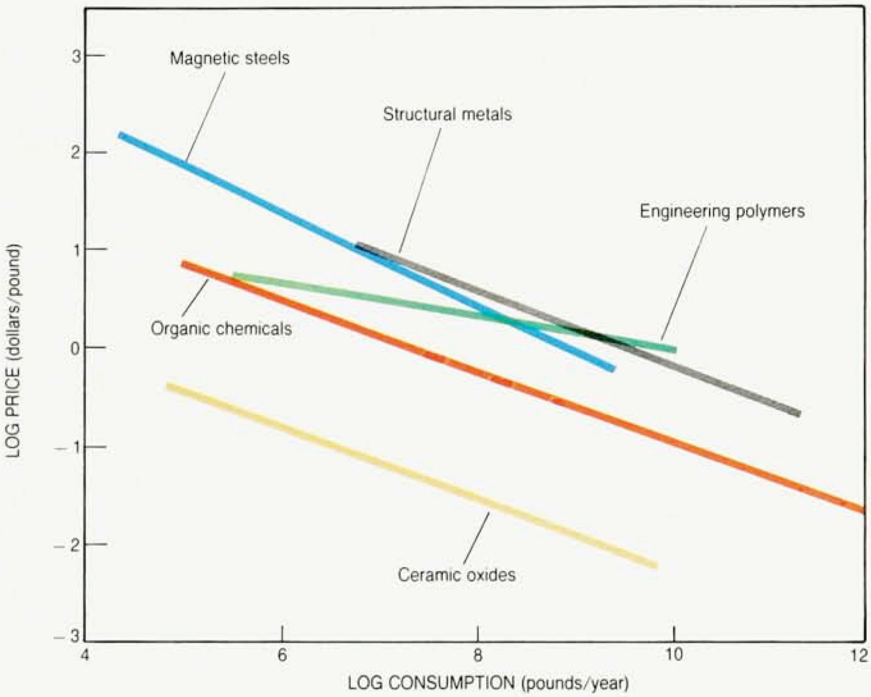
Commercial success does not necessarily follow from technical success. Successful commercial application requires that the economic utility provided by an advance exceed the total cost of production. Furthermore, the excess utility must be substantial. Otherwise, the rate of introduction of the advance will be too slow. Thus the commercial significance of the new superconductors depends on quantitative factors that enthusiasm alone cannot overcome.

Although it is far too early to be concerned about manufacturing costs in detail, it is not too early to be guided by estimates of cost in planning R&D directions.

There are two general classes of applications for these materials: first, as integrated parts of devices—small-scale items such as computer elements and sensors—and second, as differentiated components of subsystems—large-scale magnets, levitators and so forth. My discussion here refers mainly to the latter applications, where materials costs are more critical.

Markets for differentiated materials are sensitive to prices. Demand charts (which plot price vs volume) describe this sensitivity.[1] The data points on such charts often have high correlation coefficients (up to 0.98), and so it is perilous to ignore them. A summary chart for a variety of materials is shown in the figure at right. The data are for raw or semi-finished materials, not for materials integrated into devices.

The lines on the chart are regression lines. They are exclusionary: To the right and above one of these lines no market exists for the given type of material. This means that consumption is associated only with points below and to the left of the line. Commercial significance is determined by annual revenues, that is, by the product of price and consumption at a given point. Revenues in turn determine how much can rationally be spent on research, prototype development and manufacturing development to supply the market. This reasoning assumes, of course, that subsidies do not create an artificial market.



Demand lines show the trade-off between price and consumption for various groups of differentiated materials; above and to the right of the line no market exists for a material.

One can estimate the potential price of differentiated superconducting materials in two ways. Raw materials costs dominate in the first estimate, and fabrication costs dominate in the second. For both, only the lower limit is of interest.

The new superconductors are oxides. Their prices are determined mainly by three factors: concentrations in the ores from which the cations are extracted, purity and particle size. In the $YBa_2Cu_3O_{7-y}$ superconductors the most expensive cation is yttrium, but it is the smallest fraction and its contribution to the total retail cost is not very different from that of the barium cation. Both cations are only about twice as costly as the copper. Catalog prices yield total costs for medium-purity oxides of about \$100 per pound and for high-purity oxides of about \$500 per pound. High incentive might reduce these costs, perhaps by a factor of two or three.

Purity is a critical factor. For example, consider the costs of aluminum oxide for various commercially available levels of purity. (See the table on page 87.) These costs vary by a factor of 5000 depending on the purity.

For a given purity, small particles are much more expensive than larger ones. This fabrication cost is highly sensitive to processing method, but to keep the discussion focused on the lower limit of cost I shall not further

John J. Gilman is a senior scientist at Lawrence Berkeley Laboratory in Berkeley, California.

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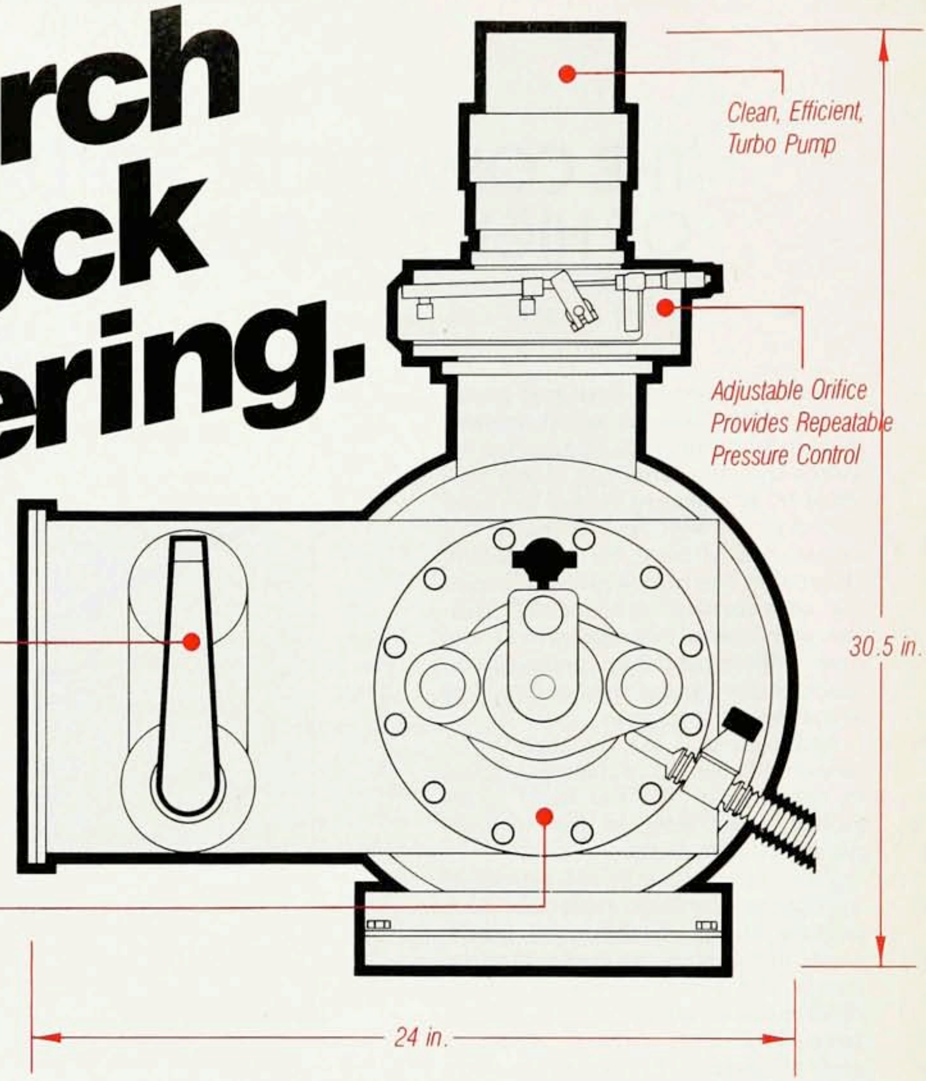

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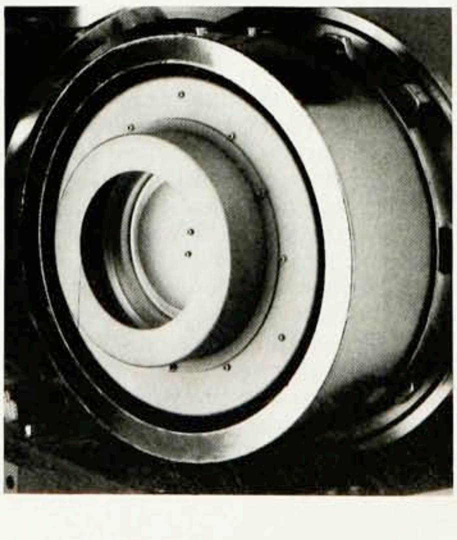

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Prices of some differentiated forms of aluminum oxide

Form	Price (dollars/pound)
Powders	
Bauxite (65% Al_2O_3)	0.11
Calcined Bayer process	0.25
Reagent grade	4.20
Medium purity (99.9%)	22.00
High purity (99.999%)	494.00
Sintered parts (medium purity)	
Electronic substrates (10 mil)	120.00
Electronic substrates (60 mil)	30.00

consider the effects of processing.

To estimate a floor for fabrication costs, consider technical-ceramic items that are mass-produced. Such items are used as substrates in microelectronics. The common ones, made from aluminum oxide, cost from $30 to $120 per pound (see the table). From the above data an optimistic price level for ceramic superconducting materials is $30 per pound, whereas a pessimistic, but quite possible, price might be $300 per pound. From the figure, which is a distillation of long experience, the corresponding rates of consumption are 630 000 pounds a year (at $30 a pound) and 5600 pounds a year (at $300 a pound). These rates convert into annual revenues of about $20 million and $200 000, respectively. Such potential revenues do not justify research programs of more than a few million dollars a year for differentiated ceramic superconductors.

Even if one abandons caution and expects to make these materials for $10 per pound, the corresponding revenues one can rationally expect are only about $90 million per year. This expectation might justify an R&D program of about $10 million per year, with a very high risk.

The case for integrated materials is quite different. For them, the materials costs are a small fraction of the value of the device. The research style, however, should also be quite different. Simply stated, the materials research and the device research cannot be independent. By materials research I mean the physics, chemistry, microstructure, geometry and fabricational aspects of the device. Working with specific devices rather than generic specimens is undoubtedly difficult. For the new superconductors, however, there is evidence that integrated materials and device research will be necessary for an effective R&D program.

Reference

1. J. J. Gilman, Res. Management **30** (4), 32 (1987). ■