Hitachi’s Involvement in Material Resource Recycling

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OVERVIEW: Innovative new materials have an essential role in achieving energy and resource efficiency in Hitachi’s social innovation businesses that seek to realize a low-carbon society. Establishing technologies and schemes for recycling these materials contributes to reliability of supply, lower production costs, and a reduction in the environmental burden associated with materials. Hitachi is proceeding with actions associated with the recycling of rare earth magnets, copper wire, amorphous core transformers, and FRP from the perspective of material resource sustainability.

INTRODUCTION

HITACHI operates a social innovation business that deals with equipment, systems, home appliances, and other products for the energy, IT (information technology), transportation, public sector, and industrial fields. The business is working toward the realization of a low-carbon society by achieving high levels of energy and resource efficiency through developments and innovations in the materials that underlie these activities (see Fig. 1).

Based on an awareness that the realization of a low-carbon society and sustainable society has an important role in solving environmental problems, Hitachi has proposed an environmental vision comprising “Prevention of Global Warming,” “Conservation of Resources,” and “Preservation of Ecosystem.” As part of the “Conservation of Resources” objective, Hitachi has been actively involved in activities like home appliance recycling.

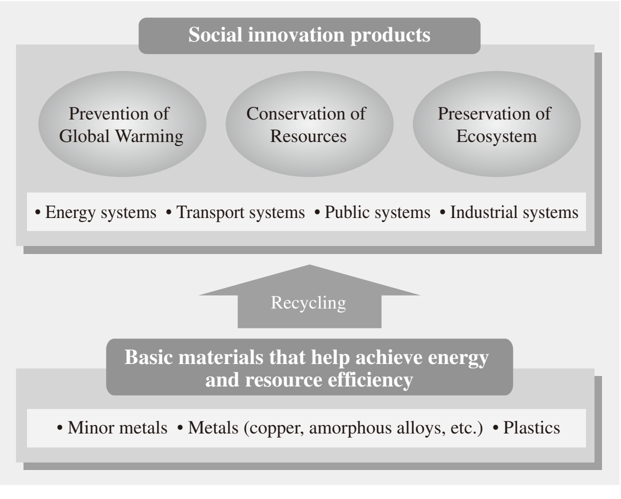


Fig. 1—Basic Materials that Underpin Social Innovation.
Hitachi aims to achieve sustainable use of energy-efficient and resource-efficient materials.

In relation to the problem of resources, recycling of common metals like iron, copper, and aluminum and minor metals such as rare earth magnets (neodymium and dysprosium) and lithium has attracted attention. Because all of these are essential materials for the production of products such as high technology IT equipment, energy-efficient appliances and other equipment, and eco conscious cars, achieving a low-carbon society without them would be difficult. While material resources are not being depleted rapidly, prices are believed to be on a rising trend globally due to the medium-to-long-term expansion in demand associated with economic growth in emerging economies, although price fluctuations due to speculative movements and resource nationalism can also occur.

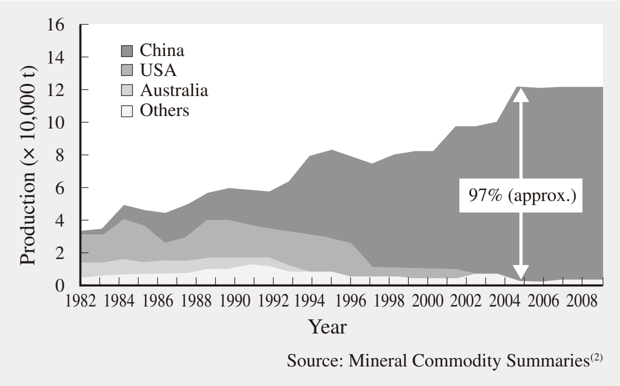
Hitachi is working on these activities associated with resource sustainability through its materials businesses which include metals, plastics, and other materials.

This article describes technologies and schemes for the recycling of rare earth magnets, copper wire, amorphous core transformers, and FRP (fiber-reinforced plastics).

GEOGRAPHICALLY UNEVEN CONCENTRATION AND DEPLETION OF METALS

Risk of Geographic Concentration of Rare Earths in China

The rare earths are a group of 17 elements made up of the 15 lanthanides from lanthanum (La) with atomic number 57 to lutetium (Lu) with atomic number 71, as well as scandium (Sc) with atomic number 21 and yttrium (Y) with atomic number 39. Their characteristic high melting points and high thermal conductivities(1) have led to widespread use in high-technology and



Source: Mineral Commodity Summaries(2)

Fig. 2—Trend in Rare Earths Production by Country.
The source of most rare earths production shifted from Europe and America to China in the mid-1990s.

energy-efficient equipment, and worldwide production in 2009 had grown to approximately 124,000 t or roughly double the level in 1990(2). Neodymium (Nd) and dysprosium (Dy) in particular are key materials because of their use in the permanent magnet motors used in hybrid vehicles. They are also essential for other devices such as personal computer HDDs (hard disk drives), high-efficiency compact motors, and MRI (magnetic resonance imaging) machines and further growth in demand is anticipated as a low-carbon society becomes a reality.

Although Europe and the USA previously accounted for the bulk of rare earth production, the scale of production in China is growing rapidly with French company Rhodia Rare Earths having shifted its raw materials production from Australia to China due to environmental problems and US company Molycorp Minerals, LLC. having closed its large Mt. Pass mine due to its inability to compete with the low cost of production in China in the 1990s (although a restart to mining was announced in August 2009). China's share of production since 2005 has been about 97% (see Fig. 2)(2). The procurement and security of supply of rare earths will become even more important in the future.

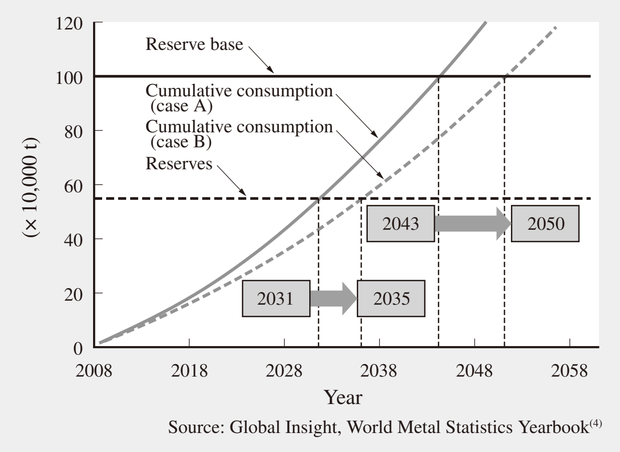
Risk of Depletion of Copper Resources

This section discusses the risk of resource depletion using copper as an example. Copper is a common metal and one that underpins social infrastructure businesses where it is widely used in electrical, mechanical, communications, electric power, and other fields. It is also a mineral ore that has raised concerns about resource depletion of a similar nature to those relating to minor metals.

Although approximately 20% of world production of electrolytic copper derives from recycling which uses as its raw material copper scrap recovered from the production process, used products, and other sources(3), recoverable reserves of copper are typically estimated at about 34 years. This estimation is calculated by dividing the reserves by the annual production for a particular year and takes no account of future changes in production. When consideration is given to the strong consumption of copper by China in recent years (copper consumption in 2008 was approximately ten times its level in 1990)(2), it is anticipated that copper will be consumed at an even more accelerated rate in the future.

To consider this, forecasts were made using a regression formula that relates future copper consumption to real GDP (gross domestic product). Demand was forecasted by estimating the cumulative consumption for 2008 onwards and supply was forecasted for two different cases using the "reserves" (the economically viable part of the reserve base) and the "reserve base" (the part of known mineral ore deposits that it is technically feasible to mine). The forecasts did not consider any increases resulting from new mining developments.

A simulation was performed to determine when copper resources will be depleted for two cases. The first case assumed that the proportion of copper scrap used in electrolytic copper production would remain at its current level of 20% (case A) and the second case assumed an increase to 40% (case B) (see Fig. 3).



Source: Global Insight, World Metal Statistics Yearbook(4)

Fig. 3—Simulation of How Many Years until Copper Resource Depletion.
When account is taken of future growth in real GDP (gross domestic product), resources will be used up even more quickly than would be indicated by a simple calculation. However, the time until the resource is depleted can be extended by better recycling.

The results indicated that maintaining the current 20% proportion of copper scrap would mean that the 2008 reserves and reserve base would run out by 2031 (24 years of recoverable reserves) and 2043 (36 years of recoverable reserves) respectively. In practice, it is likely that rising mining costs would cause a price increase in the mineral resource. This would mean that raw material costs would make up an increasing proportion of the cost of production in manufacturing. If progress is made on recycling and the proportion of copper scrap raised to 40%, the time would be prolonged by 4 years for reserves and 7 years for the reserve base.

For manufacturing, the strategic utilization of copper scrap as an important source of raw material has an even higher priority when considered in terms of securing a reliable supply of resources.

RARE EARTH MAGNET RECYCLING

Development of technology for recycling neodymium magnets (Nd-Fe-B sintered magnets) is currently underway in a project sponsored by the Ministry of Economy, Trade and Industry (subsidy for encouraging the recycling of new resources).

Hitachi deals with a large number of products that use neodymium magnets including MRI medical systems, HDDs, and compressors used for refrigerant compression and circulation in air conditioners and other refrigeration systems (referred to below as "compressors"). The following sections describe the state of development of recycling equipment (equipment designed to dismantle products to their component parts and materials) intended for use with HDDs and air conditioner compressors, the development of this equipment being one of the measures aimed at coping with future concerns about supply shortages in Japan of rare earths such as neodymium. Magnet remanufacturing technology is also described.

(1) Compressor dismantling machine

Although compressors are made from materials that are comparatively easy to recycle (including iron and copper), because the compressor shell is welded together from steel parts, the main method used to get at the internal components was by fusion cutting using a plasma (gas) cutter. The problem with this method, however, was that oil residue inside the compressor could easily catch fire or give off smoke. In response, a compressor dismantling process that solves this problem and also allows the recovery of the neodymium magnets is currently under development (see Fig. 4).

Fig. 4—Compressor Dismantling Machine.
This is the machine for automatically cutting off the steel shell.

Because compressors come in many different models depending on their manufacturer, year of manufacture, and other factors, and because each model has different characteristics such as its internal structure and where to make cuts, improvements to productivity and safety require the workers to be skilled. Also, the two different types of compressor are the reciprocating compressor and the rotary compressor, and because each of these cuts in a different way, a machine was needed that can handle both types. A feature of the machine is that it solves these problems and the operator simply needs to designate the cutting position for it to perform the cut automatically. Fig. 5 shows the internal structure of a compressor.

Because the magnets are embedded in the rotor, which is the rotating part in the center of the compressor, ultimately an operating function is required that can take this rotor apart and recover the magnets. Fig. 6 shows a cross section of the rotor. Because different rotors have different magnet insertion patterns, investigations are underway into how the magnets can be removed economically. Fig. 7 shows the rotor and magnets before and after removal.

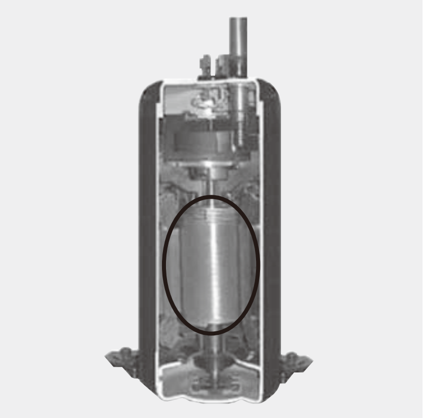


Fig. 5—Internal Structure of Compressor.
The rotor is indicated by the colored line in the center.

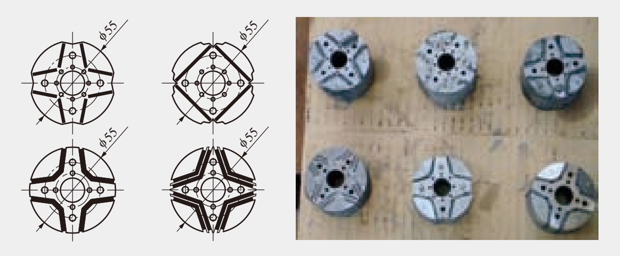


Fig. 6—Rotor Cross Sections.
The thick lines in the diagram on the left indicate where the magnets are inserted. As indicated by the cross sections, the shapes vary widely.

Fig. 7—Recovery of Magnets from Rotor.
The photograph on the left shows the magnets being removed. A proprietary method is used to demagnetize and safely detach the material that has become magnetized.

(2) HDD dismantling machine

Although HDDs are made from materials that are comparatively easy to recycle (including aluminum and iron), not only is disassembly very time-consuming because of the way the parts are connected together by small screws, it also requires special screwdriver bits that have neither a Philips nor flat-head shape. Because the economics of manual dismantling are so poor, a target average disassembly time of one minute or less per HDD was established to improve this. Because the location, number, and other aspects of the screws used to attach HDD components vary depending on the manufacturer, year of manufacture, and other factors, a method was devised that, instead of undoing the screws one by one, subjected the HDD to vibration, mechanical shock, and similar techniques to loosen all of the screws at once and disintegrate (separate into component parts) the HDD. In proof-of-principle tests, this method succeeded in separating an HDD into its main component parts which included the cover, case, disk (platter), magnets, magnetic heads, and printed-circuit board, as shown in Fig. 8. Next, Hitachi intends to improve the ease of operation and practicality of the method.

(3) Magnet remanufacturing technology

In parallel with the development of machines for removing and recovering magnets from compressors, HDDs, and other devices, Hitachi has also been investigating technology for magnet remanufacturing. Because the conventional wet method (solvent extraction method using nitric acid and other solvents) produces waste fluid and other pollutants, reductions in both environmental impact and cost are needed. In response, Hitachi is developing an environmentally conscious process that selectively separates and recovers rare earths such as neodymium and dysprosium with a high level of efficiency. In beaker-level experiments, the process was able to recover approximately 95% of these rare earths from magnet scrap.

Fig. 8—HDD Dismantling (Showing Results of Dismantling).
The method separates an HDD (hard disk drive) into its component parts for recovery. The neodymium magnets are indicated in the center of the image.

It is envisaged that in the future this process will be used in small urban-based plants to recover valuable rare earths from magnets obtained from scrap without requiring a big refinery or other large-scale plant.

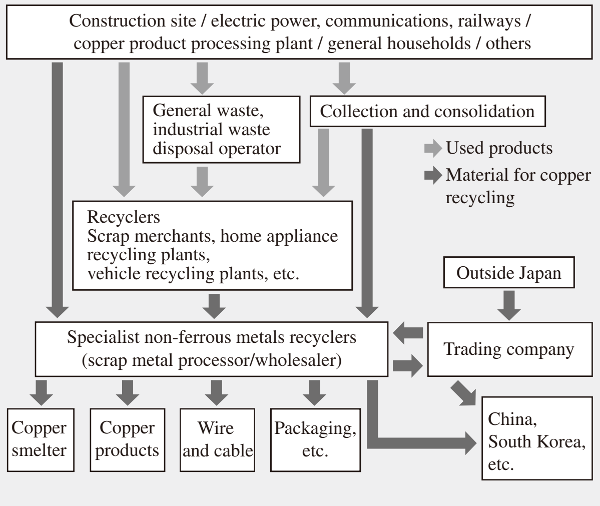
COPPER WIRE RECYCLING

State of Copper Wire Recycling in Japan(5)

Annual worldwide copper consumption in 2007 was approximately 18.17 million t of which Japan was responsible for approximately 1.25 million t. Japan imports the bulk of its copper ore from Chile and other foreign countries and produces approximately 1.5 million t of electrolytic copper. Copper and copper alloy are valuable and their use in remanufacturing is well established. Japan produces approximately 860,000 t of wire and cable, 1.04 million t of copper products (including alloys), 100,000 t of copper castings, and 20,000 t of electro-deposited copper foil using electrolytic copper and copper scrap as raw material. Although pure copper scrap makes up the equivalent of 17% of total raw materials used for wire and cable, the need to satisfy electrical characteristics requirements means this is lower than the proportion in other products. Copper products on the other hand use more than 50% recycled copper.

Involvement in Wire and Cable Recycling

According to a survey by the Japan Electric Cable Technology Center, Inc. (JECTEC), the volume of waste wire and cable handled by wire and cable recyclers in Japan during 2007 was approximately 130,000 t and is reducing year by year(7). The reason is believed to be the increasing volume of waste wire and cable that is exported as scrap. Conductive copper has for some time been one of the recycled materials of which 100% is reused. The proportion of polymer insulation that is reused has also been growing annually due to the rapid rise in the price of the material over recent years. Fig. 9 shows a flow chart for the recycling of copper, including copper wire. Used copper and copper alloy collected by industrial waste disposal operators or other businesses is passed on to recyclers for sorting. When the metal type is obvious and the quantity large, the proportion that is reused as a raw material for wire and cable or other copper products is high.



Source: Survey of Advanced Copper Non-ferrous Metal Scrap Separation and Sorting Technology
The Mechanical Social Systems Foundation (March 2009)(6)

Fig. 9—Flow of Reuse of Copper Recycling Material.
The figure shows the flow from the collection of copper scrap through to the reuse of the recycled copper, with the copper scrap including waste material such as waste wire and cable, copper tube, and other copper reclaimed from buildings, wire and cable from electric power, communications, and railway facilities, shavings produced as factory waste, and used machinery and other equipment from households and commercial operators.

The Hitachi Cable group was one of the first businesses to proceed with recycling of waste wire and cable which it has undertaken using a flow like that shown in the figure. Close to 100% of recovered conductors are recycled.

In the case of polymer insulation, on the other hand, although large quantities of crosslinked polyethylene is used as an insulator, it is generally considered that material recycling of this plastic is difficult because it is not amenable to melt forming. Instead, Hitachi Cable has developed its own technology that uses a solvolytic reaction with supercritical alcohol at high temperature and pressure to produce thermoplastic polyethylene and has succeeded in recycling this material as polymer insulation for wire and cable(8).

RECYCLING OF AMORPHOUS CORE TRANSFORMERS

Fig. 10 shows the structure of an amorphous core transformer. The core material is an amorphous alloy formed by melting down and then rapidly cooling an alloy consisting mainly of iron, boron, and silicon steel. "Amorphous" means that the material has been frozen into a random non-crystalline state instead of forming a crystalline structure with atoms arranged in a regular pattern that is characteristic of metals (see Fig. 11).

The amorphous alloy (with a sheet thickness of approximately 25 μm) has excellent properties for use as a soft magnetic material. In particular, it has become

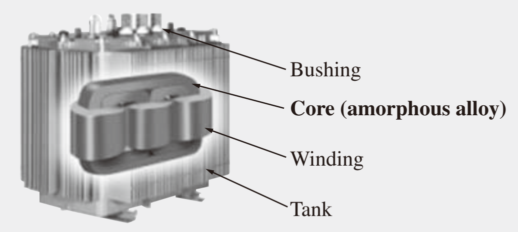


Fig. 10—Structure of Amorphous Core Transformer.
An amorphous alloy is used as the transformer core material.

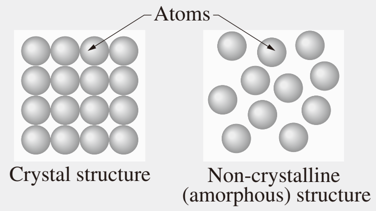


Fig. 11—Conceptual Diagram of Amorphous Alloy.
Amorphous alloys have a non-crystalline structure in which the atoms are arranged randomly.

widely used as the core material in passive inductors because of its high magnetic permeability and low iron loss. With the aim of improving the efficiency of power distribution transformers, Hitachi was one of the first companies to recognize the potential of amorphous core transformers for reducing no-load losses that occur continuously regardless of the load by using amorphous alloy in the transformer. Hitachi embarked on the development of the underlying technology in the early 1980s and has since supplied the transformers to customers.

However, with 18 years having passed since the introduction of amorphous core transformers for electric power applications in 1991, these devices are now coming due for disposal. In response, Hitachi established a closed-loop recycling process that recycles the amorphous cores of the transformers into ferroboron, its main constituent material, and has been operating this process with a number of power companies since 2009 (see Fig. 12). The process involves checking in-use transformers to determine whether they can be repaired and, if not, dismantling the transformer and either reusing or recycling its core depending on its condition. The recycling route involves collaboration between users, trading companies, dismantlers, intermediate processing companies, and materials manufacturers.

For the future, Hitachi intends to investigate

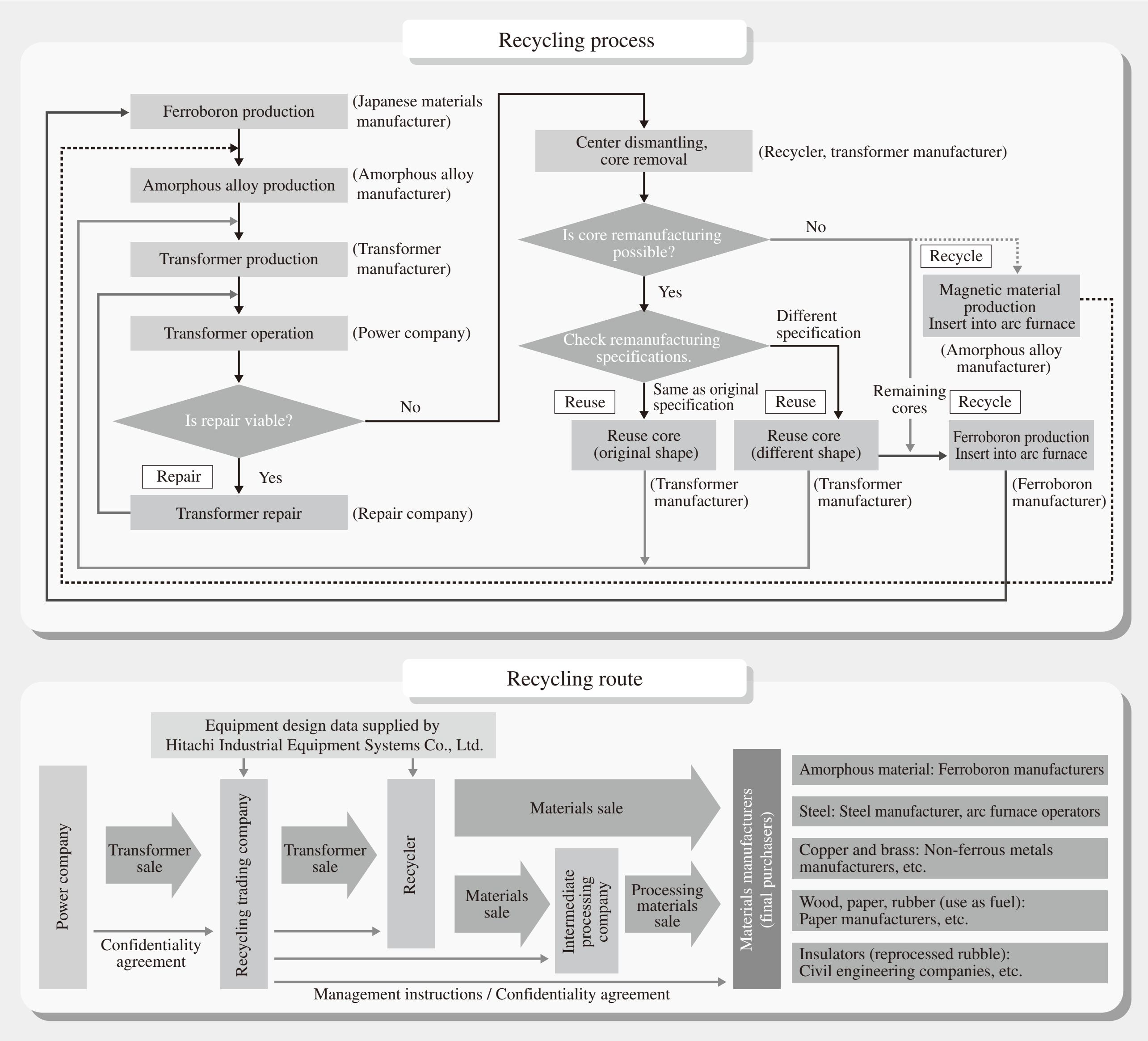


Fig. 12—Recycling System for Amorphous Core Transformers.
The recycling system forms a closed loop in which the amorphous core is recycled as ferroboron which can be reused as a raw material for new cores. Hitachi's has a role in the recycling route with links to all the companies involved.

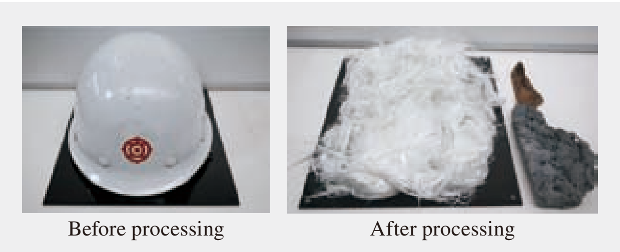
the possibility of recycling the material directly as amorphous alloy and also to make a reality of environmentally conscious transformers that take account of their production, operation, and disposal phases by extending the system to the entire electricity and general industrial market.

FRP RECYCLING

FRP is a durable structural material that is used in many different applications. Hitachi is investigating the use of FRP made from glass fiber and/or carbon fiber in products. The core technology for achieving this is the "depolymerization under ordinary pressure" method which can be used to recycle both GFRP (glass-fiber-reinforced plastic) made using unsaturated polyester resin and CFRP (carbon-fiber-reinforced plastic) made using epoxy resin. The "depolymerization under ordinary pressure" method uses an alkali metal salt catalyst and high-boiling-point solvent to perform depolymerization of the thermosetting resin at about 200°C under ambient pressure conditions to make it soluble, thereby enabling the various components of the composite material to be separated out and recovered. The indications are that the fiber recovered from used composites and fillers will be able to be reused. Fig. 13 shows an example of recycling GFRP helmets.

Evaluations of the environmental impact and economics of these separation and recovery methods have obtained favorable results indicating that commercialization is practical. Hitachi is currently undertaking prototyping of rolling stock parts, automotive parts, bathtubs, fishing boats, building materials, and other potential uses for recovered inorganic material.

Investigation into techniques for resynthesizing is also in progress for recovered resin. It has been confirmed that the recovered resin consists of monomers and oligomers and it is believed that these will be able to be used as raw materials in the production of resins suitable for use in composites.



Before processing After processing

Fig. 13—Recycling of GFRP Helmets.
Glass fiber with its original fiber length was recovered from GFRP (glass-fiber-reinforced plastic) helmets by depolymerizing unsaturated polyester resin at 180°C for 10 hours under ambient pressure conditions without breaking up or pulverizing the material.

CONCLUSIONS

This article has described technologies and schemes for the recycling of rare earth magnets, copper wire, amorphous core transformers, and FRP.

Although resource recycling is achieved by making recovery, remanufacture, and reuse economically viable, in addition to these short-term benefits it can also, in the medium and long term, extend the life of non-renewable resources. Also, by minimizing the need to mine new resources out of the ground, it also reduces the environmental burden imposed by mining and saves on the energy consumed [and CO_2 (carbon dioxide) emitted] in transport and refining. As an organization whose activities encompass the materials business, Hitachi intends to continue working actively to promote materials and resource sustainability.

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