S. Hrg. 113–759

# RECYCLING ELECTRONICS: A COMMON SENSE SOLUTION FOR ENHANCING GOVERNMENT EFFICIENCY AND PROTECTING OUR ENVIRONMENT

## HEARING

BEFORE THE

## COMMITTEE ON HOMELAND SECURITY AND GOVERNMENTAL AFFAIRS UNITED STATES SENATE

ONE HUNDRED THIRTEENTH CONGRESS

SECOND SESSION

FEBRUARY 27, 2014

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# E–CYCLING—2014

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# RECYCLING ELECTRONICS: A COMMON SENSE SOLUTION FOR ENHANCING GOVERNMENT EFFICIENCY AND PROTECTING OUR ENVIRONMENT

**THURSDAY, FEBRUARY 27, 2014**

COMMITTEE ON HOMELAND SECURITY
AND GOVERNMENTAL AFFAIRS,
*Washington, DC.*

The Committee met, pursuant to notice, at 1:01 p.m., in room 342, Dirksen Senate Office Building, Hon. Thomas R. Carper, Chairman of the Committee, presiding.

Present: Senator Carper.

## OPENING STATEMENT OF CHAIRMAN CARPER

Chairman CARPER. The hearing will come to order.

Good afternoon. I want to thank our witnesses and our staffs for your flexibility. I think originally we were going to have this hearing in the morning, and then we were going to have it later in the afternoon. Now, we are going to have it now.

Unfortunately, they do not let Dr. Coburn and I decide when there are going to be votes on the floor. There are a bunch of votes that start at 2 o'clock, maybe 5 or 6 of them in a row. So that kind of messes things up, the way we originally scheduled it.

So thanks for bearing with us and for being so flexible.

I will ask that my statement be entered into the record.[1] Since there is no one to object, that will happen.

But I would just say very briefly that this is an issue that is very close to my heart. I started recycling because a lieutenant junior grade in the Navy, who was a naval flight officer (NFO) stationed at Moffett Field, California, lived in Palo Alto, when he went overseas, and used to recycle stuff right there in Palo Alto. Took it to an old garage where they took newspapers and bottles and cans and stuff over time.

However, they would not recycle computers. They would not recycle cell phones. They would not recycle BlackBerrys, iPhones, or iPads. And we did not have them. Now we have a lot of them.

And the question is, what do we do when they get old and cannot be used? Or, maybe they just go out of style.

And it is a challenge, but in the words of Albert Einstein, "In adversity, lies opportunity." There is great opportunity here to not just mine, if you will, discarded electronics, but to find value in it.

[1] The prepared statement of Senator Carper appears in the Appendix on page 27.

I will just tell one quick story. When I was Governor of Delaware and in the National Governors Association (NGA), we were always looking at other States to see what we could learn from them and steal their best ideas, and hopefully, they would steal some of ours.

I learned of a good idea they were doing out in the California prison system. They would have some of their inmates that would be trained to take used computers, upgrade them and then do something else with them.

We took their idea, and we used it. We have a lot of banks in Delaware. We asked them, when you have to discard your old computers or laptops, how about donating them to the State of Delaware? We will have trained inmates in our prisons who will upgrade them, and then we will distribute them to our schools.

And, when I stepped down as Governor, we had the best ratio of students to computers of any State in America. And we had people who were inmates who worked in upgrading computers and had a new job skill. Some saved some money because they got paid for doing a little bit of this. So it worked on a lot of different levels.

Who is here from the Postal Service?

Mr. Day, as you know, the Committee has jurisdiction over the Postal Service. Dr. Coburn and I and our colleagues have spent a whole lot of time, trying to make a path forward for the Postal Service, and I will just say this and stop.

I think part of the secret to ensuring that the Postal Service will not just be around, hanging on, but making sure they are relevant and robust, is to find ways to use what is unique about the Postal Service; it goes to every mailbox in America five, usually six, days a week. Nobody else does that.

And, to find ways to use what is unique about the Postal Service, that distribution network, to generate revenues.

And I think we are going to hear today about maybe a good idea, and we are excited about that.

So, having said all of that, some of my other colleagues may join us here. Votes start at 2 o'clock, but we have compressed these two panels into one. You look good.

And I am not even going to give you formal introductions. We will just save the time, if you will, and we will do those for the record.

But, Kevin, we are happy to see you and grateful for your participation today, and we would like for you to lead off, please. Thank you.

## TESTIMONY OF KEVIN KAMPSCHROER,[1] DIRECTOR, OFFICE OF FEDERAL HIGH-PERFORMANCE GREEN BUILDINGS, OFFICE OF GOVERNMENTWIDE POLICY, U.S. GENERAL SERVICES ADMINISTRATION

Mr. KAMPSCHROER. Good afternoon, Chairman Carper and Members of the Committee when they arrive. My name is Kevin Kampschroer, and I am the Deputy Senior Sustainability Official at the U.S. General Services Administration (GSA). Thank you for inviting me to testify about electronics recycling and the opportunities that this area provides for increased environmental stewardship by the Federal Government.

E-waste is the largest growing waste stream in the country. According to the most recent estimates, more than 5 million tons of electronics were in storage, nearly half was ready for end-of-life management, and yet, only 25 percent were collected for recycling.

The Administration is committed to reducing e-waste and realizing efficiency by standardizing procedures across the government. As the world's largest consumer of electronics, e-waste is a significant opportunity for the Federal Government. Acting under the President's Executive Order (EO) 13514, 3 agencies led an Interagency Task Force on Electronics Stewardship. They are the General Services Administration, the Environmental Protection Agency (EPA) and the White House Council on Environmental Quality (CEQ). The President charged the task force with developing a national strategy for electronic stewardship, which the task force released on July 20, 2011.

Today, I look forward to discussing the development of the strategy, its important tenets, and our work to help address this critical challenge.

The General Services Administration has always had programs for the disposal of equipment, including electronics, but these programs were not designed with the specific challenges of e-waste in mind.

The 16 agencies on the task force hosted several listening sessions with electronics manufacturers and recyclers, with nongovernmental organizations, with State and local governments, and with Federal agencies. We solicited public comments and addressed all of these in the strategy issued on July 20. The strategy details the management of electronics throughout the products' life cycle, from design to eventual reuse or recycling.

Several items are being addressed over the coming years—issuance of governmentwide policy and guidance on the reuse and disposal of electronics, including acquisition of electronics that are more sustainable, can be easily reused and are designed to have minimal end-of-life environmental impact, and transparency of newly collected Federal data about this.

On February 29, 2012, we published a bulletin in the Federal Management Regulations, presenting a specific list of options to consider when electronics are identified as no longer meeting their original use. First, offer them to other Federal agencies for reuse through GSAXcess, a program that we run, or transfer them to schools and other educational organizations through the Computers

[1] The prepared statement of Mr. Kampschroer appears in the Appendix on page 30.

for Learning program. Second, donate them to State and local governments and nonprofit organizations. Third, sell or return the electronics to the original vendor. We are incorporating these take-back provisions into many of our contracts, and we are also developing governmentwide guidance about doing that for other agencies. Fourth, direct nonfunctional electronics to a third-party certified electronics recycler and not landfills or incinerators. All electronics recyclers listed on schedules today are third-party certified.

Another goal of the strategy is to promote the purchase of green electronics to reduce their life cycle environmental impact. We will continue to improve our contract vehicles in order to simplify Federal agencies' acquisition of green electronics.

Currently, there are over 120,000 Energy Star products offered across several schedules. Used and refurbished electronics are also offered on schedules.

We have developed two online tools to help agencies find products that meet the goals. GSA Advantage uses icons such as the Energy Star, and the Green Procurement Compilation tool which consolidates all sustainable products designated for Federal procurement preference—Energy Star, bio-preferred and so on—and they show where to buy the product and how to find vendors.

We have been deploying Energy Star servers and work stations since 2001 in the General Services Administration. Servers and personal computers have been Electronic Product Environmental Assessment Tool (EPEAT)-compliant since 2005 and EPEAT-Gold since 2009.

A crucial part of this strategy is the collection and use of consistent, reliable data about electronics. Although many e-waste recycling programs exist, there are no guidelines across the Federal Government to measure their use governmentwide.

We will publish a proposed rule for public comment next week, which already includes a requirement for agencies to submit data for all disposed electronics. This data, which could be publicly available on data.gov, would provide greater transparency into Federal Agencies' performance against the goals of the strategy and provide access to business opportunities to multiple parties.

The Federal Government, as the largest purchaser of information technology (IT) in the world, has a unique responsibility to be a leader in the management and disposal of electronics. We play an important role in helping agencies meet the goals set forth in the National Strategy for Electronics Stewardship and through policy guidance and responsible acquisition, donation and disposal of electronics.

We have a lot more work ahead of us and hope to continue to make progress on this important issue.

I am pleased to be here with you today, and I am happy to answer any questions you may have. Thank you.

Chairman CARPER. Thank you so much.

Do you pronounce your last name, Kampsure?

Mr. KAMPSCHROER. I do. Thank you.

Chairman CARPER. Why?

Mr. KAMPSCHROER. It is——

Chairman CARPER. I look at it, and it looks like Kampshrower.

Mr. KAMPSCHROER. Well, it is a German-Dutch name, and when——

Chairman CARPER. They just mispronounced it, right?

Mr. KAMPSCHROER. Yes, my grandfather moved to this country, and it seemed simpler to just slur over a lot of letters. So it is Kampsure like New Hampshire. Oh, that is good.

Mr. KAMPSCHROER. Thank you.

Chairman CARPER. Well, maybe we will have a Senator here, and she will know how to pronounce your name—Senator Ayotte.

OK, Mr. Day. Your first name is Thomas. I got that one down. Day is a pretty good one, too.

We are excited that you are here.

Mr. DAY. Thank you.

Chairman CARPER. Happy to learn about the Postal Service and what the Postal Service might do here to make a few extra bucks and do a good public deed. Thank you.

## TESTIMONY OF THOMAS G. DAY,[1] CHIEF SUSTAINABILITY OFFICER, U.S. POSTAL SERVICE

Mr. DAY. Thank you. Good afternoon, Chairman Carper, and thank you for calling this important hearing on recycling electronics.

My name is Thomas Day, and I am the Chief Sustainability Officer for the United States Postal Service (USPS).

Working closely with departments throughout the Postal Service, our vendors and the mailing industry, my team sets policies and assists in areas of environmental compliance, sustainability and energy initiatives.

I am pleased to be here today to provide an overview of the USPS BlueEarth Federal Recycling Program. This new program offers participating Federal agencies and their employees a free and easy solution to securely and efficiently recycle unwanted lightweight electronic devices in an environmentally friendly way.

Chairman CARPER. When you say lightweight, what are we talking about, if you can tell me what would be lightweight and what would not?

Mr. DAY. Under 20 pounds.

Chairman CARPER. Thank you.

Mr. DAY. Improper disposal of electronic waste is an acknowledged worldwide environmental problem, and this program aims to increase the percentage of used electronics that are recycled.

Federal agencies can enroll in the BlueEarth Recycling Program to recycle unwanted electronics, free of charge, throughout the mail. Examples of items eligible for recycling include cell phones and their accessories, laptops, tablets, and cameras and, as I already indicated, up to the weight of 20 pounds. This program is designed to supplement an agency's existing recycling program. Currently, there are 11 participating Federal agencies in the program. There is no cost to the agencies to implement this program, and it is a very simple process for them to launch it on a national level. The program has two components. Agencies can recycle govern-

[1] The prepared statement of Mr. Day appears in the Appendix on page 35.

ment-owned electronics, and employees of participating agencies can dispose of their own personal electronics.

The BlueEarth Recycling Program is web-based. An employee from a participating agency selects their agency name and their device information on a website. The individual then packages the device and prints a shipping label, free of charge, from the website. The shipping includes free package tracking. In the course of normal delivery, a postal letter carrier picks up the package while completing his or her route, a certified recycler receives the item, wipes the data as appropriate and ensures it is either securely recycled or prepared for resale opportunities. The recycler receives the residual value of the recycled product, which funds the transportation costs via the U.S. Mail to the recycler's destination.

The recycler is responsible for removing the data associated with electronic devices, wiping the data in accordance with the data sanitization standards of the National Association of Information Destruction (NAID) as well as the Department of Defense (DOD) standards. A certificate is issued confirming such an action takes place.

Through the BlueEarth Recycling Program, Federal agencies receive recycling activity. They get the reports with data to assist them in meeting the documentation requirements of Executive Order 13514.

USPS BlueEarth is a branded suite of customer services and product initiatives from the Postal Service, designed to provide sustainability solutions and innovations to our customers. The Postal Service is perfectly positioned for this program because we are using existing processing, transportation and delivery networks, making it a financially, as well as an environmentally, efficient way to recycle.

The BlueEarth Recycling Program was launched in April 2013, and while we are encouraged by the number of agency agreements that we have signed thus far, the participation in the program has been low. Rather than continuing to pursue additional participating agencies, our focus is on developing promotional materials to expand the use of the program at the existing agencies.

So far, in fiscal year (FY) 2014, the BlueEarth Recycling Program collected and recycled approximately 15,000 items. The most popular items being recycled have been printer and toner cartridges, smartphones, and laptops. The most active agencies have been the Postal Service followed by the Department of Energy (DOE) and the Department of the Interior.

A study commissioned by the Postal Service showed a large potential market for electronics recycling by mail. There are some hurdles that stand in the way of full potential. Current law restricts the work the Postal Service can do with commercial entities and State and local governments. Pending Senate postal reform legislation would allow potential expansion of the program to the State, local and tribal government level.

Mr. Chairman, we look forward to working with you and the rest of the Committee to expand recycling efforts and especially take advantage of the Postal Service's existing processing, transportation and delivery network.

This concludes my remarks, and I would be pleased to answer any questions.

Chairman CARPER. Thank you so much.

Brenda Pulley, welcome. How are you?

Ms. PULLEY. Thank you. Delighted to be here, sir.

Chairman CARPER. Very nice to see you.

## TESTIMONY OF BRENDA PULLEY,[1] SENIOR VICE PRESIDENT OF RECYCLING, KEEP AMERICA BEAUTIFUL

Ms. PULLEY. So thank you. Thank you for your interest in recycling and for holding the hearing today.

In a society where each of us generate 4.4 pounds of trash each day, there is a critical need to raise awareness and, ultimately, provide the motivation to change behaviors to position recycling as a daily social norm.

So, obviously, I am Brenda Pulley, Vice President of Recycling at Keep America Beautiful (KAB), and on behalf of KAB we appreciate the opportunity to reignite the dialogue on recycling and share information on how to increase recycling participation.

We are a leading national nonprofit that has been around for 60 years. We take public spaces and work to transform them to beautiful places. Recycling is one of those issues. We were founded over 60 years ago, and our work is based on executing actionable strategies in environmental education and behavior change.

So a challenge that spurs our work is the fact that the national recycling rate hovers at 34 percent. We have estimates here on electronics recycling. Whatever the exact number is we believe the recycling rates could and should be much higher.

While recycling is considered one of the easiest environmental behaviors to perform and one on which survey after survey individuals indicate it is something they want to do, it does have complexities.

Recycling electronics, like other materials, always relies on an individual taking an action, and so we ask ourselves, what can we do to make recycling easier and to make it second nature?

Behavioral psychologists indicate that recycling behavior can be positively influenced, and further, there is research that has been done to date on how to identify factors that most effectively encourage recycling behavior.

So summarizing the research, surveys, and on-the-ground work done to date, we at KAB categorized the following three areas as the greatest opportunities for improvement—convenience, communication and cause.

And, by cause, I mean, what can we do to make recycling matter?

So, clearly, addressing the convenience factor has the greatest opportunities to increase participation. It is helpful to offer recycling opportunities that are proximate to the behavior—where that material is generated. Briefly a used beverage can—for example, consumption occurs at places like a sports fields and offices, so set the recycling bin near where the recyclable is generated.

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[1] The prepared statement of Ms. Pulley appears in the Appendix on page 39.

But, for electronics, the challenge is greater. You are now trying to capture material that may have been purchased 7 years, 7 months, but not 7 minutes, ago. So the creation of easy access to recycling, such as retail locations and the Postal Service, where consumers go to replace their obsolete electronics, is an excellent example of overcoming that convenience barrier. Special collection events have also proven successful for electronics. You have a specific date, a specific time, and there is usually good promotion around it.

Another key factor is communication. So consumers need to know what is recycled in their community. They want easily accessible information on where, when and what to recycle.

But, while information can make it easier to recycle, there is evidence that increasing knowledge does not mean individuals are motivated to engage in that behavior. So behavioral psychologists recommend that information and knowledge is also combined with a cause, and by that, we mean striking that emotional chord with consumers.

So, at Keep America Beautiful, that is the approach we have taken and particularly in our most recent efforts. In partnership with the Advertising Council, we recently released a national advertising campaign to motivate Americans to recycle more. Based on the research, we learned that when people understood that their garbage can become something else, something new, they are more likely to take the extra step to recycle.

So I invite you to take a look at the campaign. The theme is all about "I want to be recycled" and gives examples of what materials can become.

In addition to convenience, communication and cause, there are other known strategies. I will not go into all those except mention one—social modeling or norming. For example, in a study conducted among 600 households on curbside recycling, when residents were provided with what we call descriptive normative feedback—so, in other words, they were told about the number of residents that participated in recycling and the quantity of material that was recycled—there was a 19 percent increase in recycling among the residents.

For Members of this Committee—and I know you live and breathe this—Mr. Chairman as a public official you have a powerful role to lead by example and to be seen recycling and to be talking about recycling in a very positive way with your colleagues and constituents. I know you do, and I thank you.

Electronics recycling has one additional unique aspect that I want to talk about that influences recycling, and that is electronics have a perceived value. That perceived value causes people to want to store their old electronics—their television, their computer, their printer—in basements and garages rather than readily recycle them.

So we do need to identify ways to overcome this barrier, and prompting about recycling when purchasing a new laptop or printer, or putting prompts on packaging or new product instructions, or having that salesperson prompt the new purchaser on the recycling of obsolete products are all important steps in that.

I take the example of the Dell and Goodwill partnership. They partnered in an attempt to address both convenience and the perceived value. Not only is it more convenient for donators to bring along their used electronics for donation, as they are dropping off their household items also they know they are going to be put to good use.

So, look, recycling is a simple action, but there are complexities around it.

Thank you for holding the hearing. We look forward to working with you and your staff on ways that we can overcome these barriers and increase recycling. Thank you, Senator.

Chairman CARPER. Thank you so much and thanks for your leadership and for those who preceded you 60 years ago.

Mr. DAY. Thank you.

Chairman CARPER. Walter Alcorn, it is very nice to see you. Thanks so much.

You have a tough act to follow, the three of these, but you are the warm-up act for Stephen here.

All right, please proceed.

## TESTIMONY OF WALTER L. ALCORN,[1] VICE PRESIDENT, ENVIRONMENTAL AFFAIRS AND INDUSTRY SUSTAINABILITY, CONSUMER ELECTRONICS ASSOCIATION

Mr. ALCORN. Thank you very much, Senator Carper.

My name is Walter Alcorn. I am the Vice President at the Consumer Electronics Association (CEA).

CEA represents more than 2,000 companies who make, sell and install consumer electronics (CE)—so televisions, computers, tablets, the range of consumer electronics. Many of our members are also deeply involved in the recycling of those products, and I appreciate very much the opportunity to testify today on behalf of the industry.

Most consumer electronics products contain valuable materials such as metals, plastics and other things that can be resold in the commodity markets by recyclers, like the one on my left.

Consumer electronics manufacturers and retailers recognize the importance of recycling and support electronics recycling efforts like never before. In April 2011, a dozen leading consumer electronics companies announced the eCycling Leadership Initiative.

And we also issued an unprecedented national challenge to recycle responsibly 1 billion pounds of electronics annually by 2016—something we are calling the billion-pound challenge. This represents a threefold increase over recycling amounts in 2010.

In 2013, last year, we reported 580 million pounds of consumer electronics recycled responsibly by our industry in third-party certified facilities, and that is an increase of 25 percent over the previous year. In order to get this, it requires collection locations, and our industry has sponsored more than 8,000 ongoing public collection locations around the country, all of which can be found in an online zip code locator that CEA sponsors, called GreenerGadgets.org.

[1] The prepared statement of Mr. Alcorn appears in the Appendix on page 44.

We also have done public service announcements for television and radio, reached out to consumers through traditional and social media on numerous occasions, and incorporated implementation of a national recycling system into our organizational goals at CEA.

But there are challenges.

Challenge No. 1 I will mention is collection. According to our own research at CEA, the average household contains 28 distinct electronic devices, and reaggregating those devices whenever they are ready to be recycled is a tremendous challenge. It is a very big issue.

But there are two other challenges I would like to note today that are more recent.

First of all is the patchwork of diverging state electronics recycling programs and laws. Exactly half of the U.S. States have enacted some form of electronics recycling mandate, and unsurprisingly, no two States have the same program. For consumer electronics manufacturers, there are now 21 separate registration forms to fill out, 19 different annual State registration fees to pay, 15 State-specific annual recycling reports to file and all with different calendars and deadlines, and lots of wasted energy on administrative requirements.

The second challenge I will mention is the market for Cathode Ray Tube glass (CRTs). Until about a decade ago, this was the most common technology used for displays like televisions and computer monitors. However, CRT sales have plummeted with new products entering the market with better technologies.

And it used to be that as many old CRTs you could collect for recycle you could recycle into new CRT products, but obviously, since new CRT sales have waned, so has the demand for old CRTs to recycle.

So CEA—and this is in our written testimony—has embarked upon several projects in order to help facilitate the development of demand and markets for CRT glass, but there is a lot more that needs to be done.

And, in terms of recommendations, CEA recommends the creation of a national harmonized industry-driven framework for recycling consumer electronics to facilitate more efficient electronics recycling. A national framework should be structured to maximize the use of market forces and ensure a level playing field that is implemented fairly across consumer electronics manufacturers.

Also, it should incorporate the ideal of shared responsibility as a key system function for things like collection and consumer education, and also, should ensure that recycling is done responsibly and results, probably most importantly, in convenient collection opportunities for the consumer.

In lieu of a blanket Federal mandate, CEA recommends a Federal framework that authorizes implementation of a harmonized cross-State consumer electronics recycling system in which specific States mutually agree with the consumer electronics industry to enact such a program. CEA and its members are working to develop the infrastructure to do this, and we look forward to working with this Committee and Congress in order to make that a reality nationwide.

And, second, I will also recommend that the Federal Government should continue to set a good example by ensuring that all Federal electronics are responsibly recycled. And to help address shortfalls in the CRT recycling market, the Federal Government should step up procurement of materials such as recycled CRT glass whenever the economies make sense and, also, when it is safe and environmentally sound and the function of those recycled materials meets government specifications.

Thank you very much for the opportunity to testify today.

Chairman CARPER. Thank you.

Do you pronounce your name Skurnac?

Mr. SKURNAC. Yes, sir.

Chairman CARPER. Skurnac, OK. Great. Thank you.

Welcome, Mr. Skurnac.

**TESTIMONY OF STEPHEN SKURNAC,[1] PRESIDENT, SIMS RECYCLING SOLUTIONS, INC.**

Mr. SKURNAC. Thank you very much, Mr. Chairman, and thank you for the opportunity to testify today.

My name is Steve Skurnac. I am the President of Sims Recycling Solutions, and by way of background, Sims is the largest e-recycler in the world. We process approximately 1.4 billion pounds a year of e-waste in 42 facilities in 14 countries.

In the United States, we have 12 facilities. We have about 2,000 employees here in the United States.

So e-recycling is a big job creator. It is a big industry on a global basis, and it presents significant opportunities for further business growth.

As you have heard from the other speakers, though, it is not without a significant amount of complexity and an awful lot of issues, particularly domestically here in the United States, and I will try and address some of those today without reiterating the points that have already been made.

We have had comments about the size of the marketplace. The numbers are all over the map, but nonetheless, the United States is estimated to generate anywhere from 5 to 10 million tons a year of e-waste, and a lot of that still remains in storage for the reasons you have heard. There is not an incentive to bring it out into the marketplace for recycling.

This is significant because electronic scrap presents significant opportunity to recover valuable commodities from the material contained therein. There is also significant opportunity for businesses and consumers to benefit from reuse of equipment. It is refurbished, repaired, put back into the marketplace, either domestically or in developing markets where they do not necessarily have access to that technology.

The issue, though, that has to be understood is that electronics, particularly older equipment, does contain hazardous components that need to be removed in a responsible recycling environment. Otherwise, they can cause significant environmental harm if it is not recycled responsibly. And that makes the issue a bit more complex and turns it more from a pure commodity collection and recy-

[1] The prepared statement of Mr. Skurnac appears in the Appendix on page 109.

cling into something that requires a sophistication of service offering and certainly some scrutiny in terms of how the material is actually recycled in the marketplace.

Now, with the notable exception of the United States, most developed countries in the world actually have Federal rules designating electronic scrap as some type of special waste within their economy.

And what that means is they arrange for it to be collected on a mandatory basis. It is banned from landfills. There are mechanisms in place to have it recycled domestically in those countries. And there are pretty rigorous reporting requirements to go along with it. And that is an environment that I say we operate in generally except in the United States.

Now, in the United States, the only rules that apply from a management point of view, as Walter indicated, apply to cathode ray tubes, where recycling rules and export rules are very strict with respect to that material.

So there is still an awful lot of room to work on regulatory perspectives because what we have ended up with is a patchwork of State mandates which are creating confusion for consumers, certainly difficulty for manufacturers of equipment and, frankly, difficulty for recyclers having to juggle and jump back and forth between jurisdictions that have different rules applied to them.

If it is not being stored, it has three homes. Obviously, it can end up in a landfill. There are many States in the United States that still allow landfill of e-waste. It can end up with a domestic recycler, or of course, it can be exported for recycling out of the country, typically to developing countries.

If it ends up with a domestic recycler, typically, it will be handled in a very responsible fashion because there are two certifications available to recyclers in the country, both of which have very high standards and both of which will indicate to consumers and to manufacturers that those recycling companies have achieved a very high level of sophistication in their operation and that the material will be handled in a responsible fashion.

And you have heard through the Executive Order that there was a mandate that the government agencies must use certified recyclers to manage e-scrap coming from Federal agencies.

There is no doubt that the volumes are continuing to grow around the world and in the United States, but the outlook for electronics recycling is not as rosy as simply saying that volume will continue to grow, the reason being is that the material——

Chairman CARPER. When you say volume, are you talking about the volume of materials that can be recycled or the volume of materials that have been recycled?

Mr. SKURNAC. No, the volumes that are coming into the market to be recycled, so discarded electronics that consumers are bringing out.

The single biggest issue that we have domestically in the United States—and Walter has alluded to this—is the collection incentive; that is, to get this material that is stored in homes into the recycling chain, into the hands of recyclers.

The cost of it is exorbitant, and it is not something that you can simply say, well, the manufacturer should pay for it; consumers should pay for it; recyclers should pay for it.

It is a complicated issue because it depends where it is. It depends how much cost is involved in recycling it. It depends what kind of material is being recycled.

Obviously, from a recycler's point of view, if we see cell phones, laptops, and old computer units, that has a significant amount of inherent value associated with it. If we get televisions, if we get old printers, there is not enough commodity value, or in fact, there is a negative commodity value associated with it. So, suddenly, the cost of acquiring that material and getting it through the recycling chain has a real bearing on how much of the material actually gets collected on an ongoing basis.

The other item that I think government needs to consider—and certainly, all consumers should as well—is that in today's technology everything that we tend to carry around in our pockets or have in our home contains a significant amount of personal or private data. And, when that material is discarded, it is critically important that the consumer or corporation or government agency understands how that data will be erased from the equipment and not end up being sold into foreign markets where, whether it is private information of consumers or private information from the government, it ends up being discoursed in a public way because it simply was not managed properly.

So, fundamentally, I think we are faced with some key discussion points.

What government-led programs, in addition to the ones that are in place now, should be initiated to further collection and to drive more recycling infrastructure in place?

What do we do with the notion of e-waste going into landfills domestically because it is still a viable route in a lot of States in the United States? And there are many arguments back and forth about whether that is a viable route for this material from a treatment point of view.

And how do we protect consumers and businesses from unwanted leaks of private information through the recycling supply chain when material does go out and consumers that do not have the sophistication or have not taken care of erasing all of that private information that they have on all of their devices?

So we would really like to continue this discussion on an ongoing basis, both with the Committee and with members of government because we think that all of the stakeholders—manufacturers, recyclers, Federal, State and government agencies and environmental groups—all have a vested interest in doing a better job of recycling and figuring out a path forward.

Thank you.

Chairman CARPER. Thank you, Mr. Skurnac.

Let me start with the first question to you, if I could. How old were you yesterday?

Mr. SKURNAC. How old was I?

Chairman CARPER. Yesterday.

Mr. SKURNAC. Yesterday? Fifty-three.

Chairman CARPER. And today?

Mr. SKURNAC. A day older, sir. Fifty-four.

Chairman CARPER. Happy birthday.

Mr. SKURNAC. Thank you very much.

Your staff did a good job. Thank you.

Chairman CARPER. No, I knew this. [Laughter.]

Mr. SKURNAC. I could not think of a better way to spend my birthday. Thank you.

Chairman CARPER. I bet you could, but we are delighted you are sharing it with us.

I want to drill down, if I can, on the role of the Postal Service and whether or not there is the kind of opportunities that I hope there is.

But before I do that, let me just say that I have been very much involved in past years in strengthening Corporate Average Fuel Economy (CAFE) standards, fuel efficiency standards, for cars, trucks and vans. Several of you mentioned that the Federal Government—and maybe other governments as well—us, as individuals, have a responsibility to set an example. It should not be like do as I say but do as I do.

When we were working with fuel efficiency standards, we said, what is the role of the Federal Government to try to make sure that when these vehicles are made, created by manufacturers and car companies, somebody is going to buy them.

So we said, well, one of the things we could do is buy some ourselves to help create a market.

Another thing that we could do is to offer tax credits. If somebody buys a highly energy efficient vehicle, then they get a tax credit to help buy down the price of the car.

Those were the kinds of things that we thought we could do.

I am trying to think about how we do the same kind of thing here to make a market. What is the role for the government to contribute and to be responsible legislatively, with our tax code, our regulations, just setting a good example?

I want to come to you, Mr. Day, for the second question, and that is I just want you to explain to me.

Let's say if I were a private citizen and I was not one of the Federal agencies that you mentioned.

Did you say there were 11? Eleven Federal agencies that are involved in this project?

Mr. DAY. Yes, Senator, 11.

Chairman CARPER. And did you say one was Interior?

Mr. DAY. I can give you the full list if you want.

Chairman CARPER. All right, real quickly.

Mr. DAY. Read through it quickly? OK, the Postal Service, Department of Interior; Federal Aviation Administration (FAA); Department of Agriculture (USDA); Department of Energy; Alcohol, Tobacco and Firearms (ATF) ; Housing and Urban Development (HUD); Federal Energy Regulatory Commission (FERC); Department of Homeland Security (DHS); Small Business Administration (SBA); and Department of Commerce.

Chairman CARPER. All right. Now, if I had a member of my family who worked at one of those agencies, could they participate in the program?

Mr. DAY. Yes, Senator, absolutely. I have done it myself. It is very easy to use.

Chairman CARPER. Just explain it very simply. How does it happen?

Mr. DAY. This is the key. We need to communicate.

So what we do is we send the information out. You can actually Google it and find your way there.

It is on the Postal Service website. So, if you were to Google Federal recycling, you would go straight there. But, on top of that, we communicate out what the link is.

Once you go to the link, very easy. It is going to ask you what agency you work for to confirm that you work for one of these 11 agencies. It will then ask you to simply certify yes, I work for this agency.

It will then ask you for—on the next web page will be your name and address information because we are going to then connect you to print a shipping label that will allow you, free of charge, to ship whatever item you are sending back to the vendor. It will ask that.

And then the next thing it will ask you is, what do you want to ship?

Now what I have personally used it for are printer cartridges and for some old hard drives that I did not need any longer, and those are two separate things.

And it will tell you how to package it, give you the shipping label, put it on the box.

And then the final step on the final page is it will ask you, would you like to schedule a delivery, or if it is small enough I can just put it out in the box for my carrier to pick up with the rest of the mail that day.

It is very simple.

Chairman CARPER. When you say schedule the delivery, what does that mean?

Mr. DAY. So, if you are concerned about what you have in that box, particularly if it might be a laptop, a tablet, or a hard drive, you can actually, through the Postal Service—it is connected to our website—schedule one of our letter carriers to come pick it up.

Chairman CARPER. OK. All right.

So we schedule a pick-up, not a delivery?

Mr. DAY. I am sorry. Yes.

Chairman CARPER. All right. Good. OK.

How is it going?

Mr. DAY. It is going slow. As I indicated, since we started, we have about 15,000 items. We would have hoped to be beyond that.

I think it is what some of the other witnesses testified. It is about awareness. It is getting people to do it.

It is about perceived value of the item. I, personally, will tell you I am guilty. I have some electronic goods in my basement that are completely out of date, and yet, if I wanted to, I could plug them in and turn them on and still use them though I will never do that again. So I have just got to bring myself to do it.

So we have to get past that with a lot of people, but I think what we are offering is making it easy. And that is another part of it, just making it convenient.

Chairman CARPER. Let me ask our other four panelists. Just stay focused on the Postal Service for now and think out loud about how this could be made more successful. And I do not care—Ms. Pulley, you go first.

Ms. PULLEY. Well, it is one of the things that we do. We have various national programs.

And we spend a lot of time thinking how best to communicate to individuals the recycling opportunities and to make them feel that it is easy. So I think there are potentially opportunities to work with the Post Office to help communicate that not only to government employees, but I think more broadly to the public.

So maybe you get something in the mail that tells you about the program. You go to the Post Office, and you see it advertised. Your neighbor then talks about it. It is those kinds of things.

Chairman CARPER. Your organization may already be coordinating and collaborating with the Postal Service on this pilot. Are you? If so, how? And, if not, is it something you might consider?

Ms. PULLEY. We currently are not. In all fairness, though, we have had one conversation about it because I, personally, did not realize it until a couple of months ago that they were offering this. And so it is something that we will definitely pick up.

I mean, there are things like America Recycles Day, which I know you are aware of, but there are opportunities that we can clearly leverage to raise the visibility.

I am happy to followup and explore those opportunities.

Chairman CARPER. Others, please. Mr. Kampschroer.

Mr. KAMPSCHROER. I think two things.

I think from an individual's point of view there is a great hesitancy to give up a machine that has data on it. So the knowledge of how the data are protected through this whole period so that I can feel very comfortable as a person saying, OK, I have not wiped all of my kids' stuff off of the computer that I no longer use—I can rely that this chain of custody exists all the way through the recycler.

I happen to know this myself, but I can tell you that most of the people in my neighborhood do not.

I think there is a second opportunity, which is especially in the States that have requirements and have recycling and so on, to get them to be the messengers. And I think they would be motivated to do that because every piece of equipment that they do not have to recycle reduces State and local government expenses.

And I think that this is an opportunity to really get more of a national understanding of how the Postal Service can be the connector for a more national approach to the management of the waste.

So those are a couple of thoughts.

I think it is, I have to say, a terrific program. I would love to see it available for everybody and not just Federal agencies and their employees.

Chairman CARPER. Thank you. Mr. Alcorn.

Mr. ALCORN. Thank you.

Our focus is primarily in the consumer market. And, although the Postal Service's program does go somewhat into the consumer market, we really have focused on the larger devices and making sure there are opportunities for the heavier——

Chairman CARPER. Before you do that, again, just go back to my question. I want you to think out loud.

We have a lot of smart people at this table. Just think out loud on maybe some perspectives or some ideas that the Postal Service has not thought of.

Mr. ALCORN. Well, that is actually my point. There are a lot of people that are trying to collect the smaller devices, like what the Postal Service is doing.

It is a pretty competitive market, particularly when you talk about the newer mobile devices. Pretty much every major retailer has trade-in programs, and so we are actually seeing sort of a sea change on the smaller devices where actually somebody will pay you for them.

So I think beyond the Postal Service's program for the Federal agencies—I think getting out in the consumer market; we welcome it. We would love to see that happen.

We encourage all opportunities for consumers to recycle, but it is going to be a little bit of a competitive marketplace.

Chairman CARPER. OK. All right. Mr. Skurnac.

Mr. SKURNAC. Thank you.

Well, I have one idea, and Tom may have thought about it from a Postal Service point of view, and it relates a bit to what Walter said. Instead of going door to door as they do—obviously, they are there delivering the mail every day—if they had their postal stations set up as drop-off points in the community, you give consumers an opportunity to bring bigger and bulkier items on their own, if they can, down to the postal station where you can consolidate it.

Now, of course, the Postal Service is running trucks throughout their massive network across the country every day. Continue to consolidate and bring bigger volumes of this stuff back to regional distribution centers where certified recyclers, qualified recyclers, with the Postal Service, now have access to large quantities of material that the Postal Service has effectively done the consolidation for them along the way.

That actually takes the bigger, bulkier, older stuff out of the household, which tends to be more problematic than some of the smaller, lightweight, easier to sort of hand pick-up equipment.

Like I say, they may have already thought about that. I do not know. But that is certainly something that comes to my mind given the incredible distribution and reverse logistics network that they have available to them.

Chairman CARPER. Mr. Day, would you just react to some of these ideas, and feel free to say those are the worst ideas I have ever heard.

Mr. DAY. Senator, I will not say that.

I will start in reverse. I think it is a very interesting concept of not just using our network to the individual household but also our 33,000 retail facilities. We have actually done some of that, but it still has been focused on smaller products. The larger products would be an interesting opportunity.

We certainly do have the reverse logistics and the transportation in place, but in general, the volume, the size, the weight of what we handle is 70 pounds or less on an individual package basis. It would be a bit more experimental to take a look at doing something bigger.

I know from a personal standpoint my wife and I had to dispose of one of our original big-screen TVs. I happen to live in Fairfax County, Virginia, and it was rather expensive to get it picked up curbside. So we decided to transport it ourselves, but it was not the easiest thing, and even then it cost us a few dollars.

So there certainly is a need out there. I know, as a citizen who has tried to do the right thing it is not always easy and it is not always cheap.

Chairman CARPER. All right. Do you want to react to any other ideas?

Mr. DAY. Certainly, we need to collaborate to get the word out, hopefully, as the legislation moves forward, if we do get some of the freedom and flexibility to expand this product, certainly beyond just the Federal Government to the State and local governments, but really to get it to the individual consumer.

What the program speaks of, and the lesson we have already learned from what we are doing in the Federal sector, is communication is the key. You have got to get the word out. You have got to make people aware of what it is, how it is and what the benefits are. That is the key, and so we are more than willing to collaborate with any group.

So, within the Federal sector, to be more effective with the existing program, within the general industry and the individual consumers, to get the word out—that is the key.

I find, as someone who was guilty in the past but now do it right, it is literally, how do you get people to that trigger point where they actually start to do it?

And, once you do it and realize how easy it is, then it is just easier to do. But it is that first step of getting the stuff out of the basement, out of the garage, and properly disposing of it.

Chairman CARPER. I am just going to think out loud. Our sons, who are both Boy Scouts—turns out, Eagle Scouts. And I remember trying to figure out with them what their Eagle Scout projects would be, and I think there is probably a good Eagle Scout project in this.

We celebrate, in Delaware, Earth Day every year, every spring, as we do across the country. And one of the things I oftentimes do is I will choose a particular focus for Earth Day and try to highlight that, and I could see us doing something like that in Delaware this year around electronic recycling.

And there are probably any number of other ways—the idea of having this hearing, and we will do a fair amount of communications following up from the hearing.

Senator Boozman who is my wing man, is a co-chair of the Recycling Caucus in the Senate. He and I can work together. We have some other folks that are in the Recycling Caucus, and maybe get them to sort of amplify the message.

There is a lot that we can do, and it is not just the government that needs to do it.

The 25 percent—and I do not care who answers this one, but the 25 percent or so of electronic stuff that we buy and eventually dispose of—obviously, only a fraction of it is going to be picked up by the Postal Service and transported by the Postal Service. We will say one percent because I know it is less than that.

But just walk through for us the ways that the other 24 percent would be handled. Some could be basically taken and sold if it is still good to use. Some could be stripped down and pull the components out and that sort of thing.

But just give us some idea of that 24 percent that would be left. Roughly, how is it disposed of and reused?

Mr. SKURNAC. Yes, I will comment first, Senator.

There are a number of ways that it gets collected. In States that have programs—as Walter indicated, half of the States now have State-run programs that mandate some form of collection and recycling of e-scrap.

Typically, there will be collection entities. Some are private enterprises. In a lot of States, they are municipal-county facilities, transfer stations, solid waste companies, that will collect the e-scrap as it is dropped off by consumers, and then they will deliver it to recyclers for processing. And, in some cases, private recycling companies will do their own collection, either through collection events, weekend e-scrap drop-offs or just have regular drop-off facilities in order to get the material.

Some of it, unfortunately, is just exported as is out of the country. There is an export trade, if you like, where people will buy e-scrap and put it in ocean containers and send it overseas.

There are two issues with that. One, of course, is there are domestic jobs that are not existing here in the country as a result of that, and two, nobody is really sure what is happening to it when it is exported. So we have to share that concern and sort of think about how we manage that going forward.

The other way that material shows up to recyclers is through corporations that run their own recycling programs, and they go out of their way to take back their own products. And I will let Walter deal with that because it is a very viable and vibrant part of the industry where you have manufacturers who are taking on sustainability programs to go and collect their own equipment in the marketplace and take it back from their customers.

Mr. ALCORN. Thank you, Senator, for the question.

Chairman CARPER. Sure.

Mr. ALCORN. I think one of the things that we have seen develop over the last few years is an expansion of the collection infrastructure. Like in my testimony, we now have 8,000 different locations around the country that our industry sponsors.

If you have electronics, I would recommend going to GreenerGadgets and looking for a place nearby where you can recycle. For example, Best Buy will take back all your electronics at no charge at this point. So, in all——

Chairman CARPER. Roughly, how long have they been doing that?

Mr. ALCORN. They started about 5 years ago. They used to charge $10 for the bigger stuff. They dropped that, I believe, 3 years ago.

Chairman CARPER. They dropped it entirely?

Mr. ALCORN. Dropped it entirely, so there is no charge.

Chairman CARPER. Why do you suppose they did that?

Mr. ALCORN. Well, they figured out how to incorporate this into their business model, which is something we encourage companies to do. They figured out getting people into the door is worth the pain and hassle and expense of running a recycling program.

Chairman CARPER. This reminds me of we have shared jurisdiction on cyber policy here in the country in this Committee.

And a fellow from the National Institute of Standards and Technology (NIST), which has been very much involved in developing standards for helping us deal with cyber attacks, Pat Gallagher was his name, I think, and he testified here once. I think he said, when good business policy and good cyber policy are one and the same, we know we are on the right track.

And it sounds like Best Buy has figured out how good business policy and good environmental stewardship can coincide. They are on the right track.

Do you think other companies are looking at Best Buy and thinking maybe they are on to something?

Mr. ALCORN. Yes. What has happened is some of the other big retailers have gotten into taking back smaller devices. And Staples, actually, they have gotten into the business of taking back computer equipment. They do not take back TVs, but they really do not sell TVs.

So we look at those two companies as models that we encourage.

Also, our nonprofits, like Goodwill that Brenda mentioned earlier and their partnership with Dell. A very strong——

Chairman CARPER. Would you explain that partnership, please?

There is a Goodwill about a mile from our house. We visit them often.

Mr. ALCORN. It is called the ReConnect program.

Chairman CARPER. I just took them a printer.

Mr. ALCORN. Ah, and they took it? That is good. OK.

By the way, in Delaware, you also have the Delaware Solid Waste Authority who has an excellent program and has for a number of years.

Chairman CARPER. I was just at their recycling center where they recycle all—we have single-stream in Delaware.

We were going, oh, gosh, 30 years ago, to an earlier effort to try to do single-stream, and we just did not have the ability to sustain the operations of the facility and finally gave up on it. And we finally figured it out pretty well now.

Mr. ALCORN. Well, specifically with the Goodwill——

Chairman CARPER. As you know, they do not put the electronics along with the stuff in single-stream, though.

Mr. ALCORN. Right. That is right. That is a separate system.

But the Goodwill program in working with Dell—that is something that has developed really over the last decade, and Goodwill will take computer equipment. Dell backs them up and helps cover their costs and also provides outreach and promotion for the recycling program.

We like those business models very much. We like those efforts, and we are encouraging more.

Chairman CARPER. Who is your executive director, chief executive officer (CEO), or president of your association?

Mr. ALCORN. Gary Shapiro is our CEO.

Chairman CARPER. Was Dave McCurdy ever your CEO?

Mr. ALCORN. He was not. He was with a different association, but we know him.

Chairman CARPER. OK. Good.

Anybody else? I have another question, but I want to make sure I have heard from everybody on this.

Please, go ahead.

Mr. KAMPSCHROER. I just thought I would give you sort of a sense of the order of magnitude within the Federal Government.

Chairman CARPER. Yes, please, I would like to hear that.

Mr. KAMPSCHROER. So, in the last year we measured, about 23 percent of the equipment was actually transferred to other agencies for further use, 23 percent again was surplussed and sold for parts or for reuse, 50 percent was given to schools or other educational——

Chairman CARPER. Fifteen?

Mr. KAMPSCHROER. Fifty.

Chairman CARPER. To where? Schools?

Mr. KAMPSCHROER. To schools. And then only 4 percent was actually recycled. So there is a lot of secondary use of equipment going on—of Federal equipment.

Chairman CARPER. When one of my sons was in college, he spent a summer working for Apple out in California, and the next year I was out at Apple and just wanted to visit with Visitor Operations and try to learn more about what they were doing. It was maybe—I do not know—4 or 5 years ago.

And it was interesting during my visit at Apple. I stayed for an hour or two, and they spent the whole time just talking about the thought and the consideration they give to the materials that are in the equipment that they build and sell.

Looking at this—and this is, of course, sustainability and what can be harvested from those devices when they are disposed of—I was struck by how much time and energy and thought they have given to this.

I am sure there are other manufacturers who have a similar bent. Could you share some of those with us?

Mr. ALCORN. I will take that one on. Thank you for the question, Senator.

That is something that we have seen a number of companies step up—Apple is first and foremost, probably, on that particular issue—and spend a lot of time and effort to take care of their supply chain and the materials that are used and that go into their products.

It is a very dynamic industry. The technology is changing very quickly. Innovation really powers the industry to move forward, and one of the innovations is something that I like to call dematerialization, where we are seeing products get smaller. Using less material.

I mean, it used to be the big TV set in a console, and it was super heavy. And now they get hung on the wall, with better technology, better performance and using less energy.

We actually have documented a number of case studies in a sustainability report that CEA published and I entered into our written testimony, that really talks about some of these examples, not just on the recycling side but also on design and energy efficiency and other issues like that.

Chairman CARPER. OK. Thank you.

Anybody else want to say something before I change the subject just a little bit?

[No response.]

All right. I mentioned earlier fuel efficiency standards, CAFE standards, and what can the government do to try to make a market, that sort of thing.

Let me just ask. I will not ask this for Mr. Kampschroer or Mr. Day but for Ms. Pulley, Mr. Alcorn, and Mr. Skurnac. What do you see as the role of the Federal Government, or the roles of the Federal Government, in this space? Do you want to go first, Mr. Skurnac?

Mr. SKURNAC. Well, at the risk of repeating the comment, I think it needs to lead by example, and I was very encouraged——

Chairman CARPER. Did you all just hear that clock back there making a noise? Are we back in session?

All right. We are going to start voting pretty soon, but we are going to go probably another 10 to 15 minutes.

Mr. SKURNAC. I will just make one quick——

Chairman CARPER. No. You have plenty of time.

Mr. SKURNAC. One quick comment with regard to what Kevin was referring to—I think that getting the data from the government in terms of their efficacy of the Executive Order and the programs and what happens to the material, who is managing it, how it is being recycled and/or refurbished or reused will be terrific information for everybody to have access to because it will show us just how much traction the Federal Government on its own has with trying to do the right thing with the equipment.

I mean, they are the largest purchaser of IT equipment and, by definition, the largest creator of e-scrap at the end of its useful life. So it will be very interesting and useful for all of us stakeholders and the industry to find out exactly what is happening with that equipment.

Chairman CARPER. All right. Thank you. Mr. Alcorn.

Mr. ALCORN. Thank you.

And I would just expound a little bit on an idea of a different type of affirmative procurement. There are—not just CRT glass, although CRT glass is the most obvious one. There are some materials coming out of the electronics recycling stream where there are not strong markets. There is not intrinsic demand in large measure.

And I think that is something that is really called for in the Federal National Strategy from 2011—and that is something we would like to see the Federal Government step up their efforts really, to look to see where they could buy recycled materials in lieu of virgin materials, particularly for items like CRT glass.

It is not obvious a lot of times if there is a fit, but certainly, we have seen some of that done already, and we would encourage more of it.

Chairman CARPER. Good. Ms. Pulley.

Ms. PULLEY. I would just add also, as the others have indicated, the leading by example.

And one thing I would add, it has been mentioned a couple times, but I think also helping to inform constituents about the importance of it, as you do.

But also, to make sure that the importance of using a certified recycler—I want to reiterate a point that was made earlier because it is so important with the data that are on personal electronic devices.

Chairman CARPER. I think I know why that is important, but tell us again.

Ms. PULLEY. Just because, as was mentioned earlier, when people have all kinds of financial data and other personal information, and then they turn over a computer to be recycled, if it is not with a certified recycler—I mean, there are horror stories about electronics being sold in third-world countries and not for the computer but for the data that are on the computer.

So it is an issue that—as you continue this dialogue about what you can do, it is important to remember that one because I think there is some additional work to do in that area.

Chairman CARPER. I always look for ways to incentivize behavior. So, if we want to incentivize folks in other countries to pay top dollar for these items, we could sort of imply, or let them think, that there are data.

Ms. PULLEY. Maybe. Well——

Chairman CARPER. And then clean everything up and then sell it to them.

Ms. PULLEY. I totally like your line of thinking about incentivizing. We like that.

Maybe we can talk about a study very specific to recycling——

Chairman CARPER. We call that bait and switch, I think.

Ms. PULLEY. But another one where there is the opportunity—Walter, I hope you do not mind—we want it to be embedded in the business model for manufacturers and retailers, and we are seeing that.

But to continue to look for ways that it could also be communicated so not only is that convenience factor overcome, but there are various touch points in communication about recycling with the customer, as I said previously.

When you go buy a new car, what is the first thing they ask you? Not how much you want to spend, but hey, have you got an old car to sell?

And so just those kinds of things that we could work with manufacturers and retailers on that—those are the other things that I would look at.

Chairman CARPER. I have an old car, but I am not ready to sell it yet. My wife always says to me, when are you going to buy a new car?

Ms. PULLEY. What about those CAFE standards?

Chairman CARPER. It is a 2001 Chrysler Town and Country minivan, and I bought it the year that I stepped down as Governor, and it just went over 361,000 miles—original engine, original transmission, original owner.

Someday we will recycle it, but not soon.

Mr. Day, do you want to jump in here, or Mr. Kampschroer?

Mr. DAY. In terms of what the Postal Service can do?

Chairman CARPER. Well, we are talking about the role of the Federal Government in the space. We are trying to set a good example. We are trying to partner with the Postal Service.

Anything else come to mind?

Mr. DAY. Well, I do not think you can stress enough that setting a good example. I think the President, through the Executive Orders, and what the Federal agencies are doing—it is just a matter of following through on that.

And, as has already been said, it will be important to see that, and my understanding is we will see that on what the agencies do through the Council on Environmental Quality. We have an annual Office of Management and Budget (OMB) scorecard, and so that is dated, and it is out there.

It is more than saying we are going to do it. We have to demonstrate we are going to do it.

And I know the Postal Service is. We are not just promoting this to do it for other agencies, but we are doing it ourselves.

Chairman CARPER. OK, Mr. Kampschroer.

Mr. KAMPSCHROER. I think just one last point is really a reiterated one. The proposed rule that we will publish next week will require agencies to submit the data at a much more detailed level than is currently being collected and submitted. So we will have a much better handle on what the potential markets are, and that will allow the market to react with the potential for business opportunities.

We found that to be true in Energy.Data.gov, where we have put our utility consumption data out there and have gotten private sector individuals who figured out ways that we had not figured out, how to more cost effectively manage the Energy budget.

So, hopefully, the same thing will happen here.

Chairman CARPER. OK. Thank you.

You hear that clock again making noise. That means that we are about 7 or 8 minutes into a fifteen-minute vote.

I am going to ask one more quick question, and then we will leave the record open for additional questions from my colleagues and from me.

But, the last question. I like to talk about the three Cs that are secrets to a vibrant, long marriage between two people—communicate, compromise and maybe collaborate.

I think one of you mentioned three Cs that were similar, though. I think one was communicate. Was that right?

Ms. PULLEY. Absolutely.

Chairman CARPER. And I think another one might have been convenience.

Ms. PULLEY. Absolutely.

Chairman CARPER. And there was a third. What was it?

Ms. PULLEY. Cause, or the motivational factor.

Chairman CARPER. Cause, yes. OK.

All right. Good.

I will kind of relate to that and touch on that again but one of the biggest challenges that we face in moving ordinary Americans toward—what are some of the biggest challenges toward moving us toward a recycling-first mentality?

And so, just think about that. Challenges. Lack of convenience. People do not even know about it, so lack of information.

But think about that and then give us just some thoughts. When we have that old cell, or we have that old computer, or we have that old TV, not the cathode ray tube, but what is just maybe one good idea from each of you on how we can better ensure that people say, I am not going to just throw this away or whatever or leave it in the basement?

Give me one great idea, Mr. Skurnac, on your birthday. This will be your gift to us.

Mr. SKURNAC. Well, I think the simplest thing we can do for those individuals is to impress upon them the fact that there is so much of their lives in that equipment that they have, and it does not need to stay in the garage or in their basement. It does need to be recycled because they are valuable commodities, and it makes a lot more sense to recycle it than to let it sit somewhere and collect dust.

But, if that message gets out—and everybody today on the panel has talked about getting the message out.

If the message gets out that says, look, we can recycle this. There are responsible people that can do it. We have an easy and convenient way to get it from you. You need to get rid of it and get the valuable components back into commerce—we will come a long way, absolutely.

Chairman CARPER. All right. Thank you.

I just thought of an idea. In schools that our boys have gone to and then others we are aware of, we do recycling drives. We have done Campbell's Soup cans, with the labels and stuff. We have done newspapers and bottles and stuff like that, and aluminum cans.

Have you ever heard of a school that has maybe 1 day a week, 1 day a year, or 1 day a quarter, something like that, where they invite folks to take stuff out of their garages and basements and bring it to the school, where they work with the solid waste authorities there to pick it up and take it out, and the schools make some money?

Anybody? Is that too far-fetched an idea?

Just very briefly because we are running out of time.

Mr. ALCORN. Well, on electronics, I think that happened a lot in the past, or it happened some in the past, not so much recently.

But I think you raise the schools issue, and that gets to my idea. I am not sure it is a new idea completely. But, frankly, getting recycling into the curriculum is really important. I mean, that changed the world in the late eighties when that happened with recycling in general, and that is something we have been working on a little bit at the Consumer Electronics Association.

But when kids hear that, yes, these old electronics should be recycled and, hey, here is a way to find out how, and they bring that home to their parents, it makes a huge difference.

Chairman CARPER. OK. Good. Please.

Ms. PULLEY. I was just going to add.

Chairman CARPER. Just 30 seconds, and then I have to run.

Ms. PULLEY. I would just say it is—going back to your original question. We work with schools all the time. There are issues about the schools being drop-offs for electronics per se. We can talk about that at another time. OK?

But I think turning up the volume, as we have said today, so that we make it a social norm. And there are many different pressure points that we could do that, whether it is curriculum or talking about it. Those are things that I continue to look at, but that would be my key recommendation.

Chairman CARPER. OK. Thanks.

Mr. Day, just real fast.

Mr. DAY. I will just keep the theme. I mean, I have been very impressed with——

Chairman CARPER. You are on message. You are what we call on message.

Mr. DAY. It is what universities are doing today. I mean, colleges and universities—as I talk to the younger employees coming into the Postal Service, fresh off of university campuses, they get it. I think if there is anything we are going to see as the generations move forward; they do get it.

And maybe it is our generation that has not gotten it yet, but we just need to keep pushing that.

Chairman CARPER. OK. Great. Thanks. Mr. Kampschroer, last word.

Mr. KAMPSCHROER. I think really emphasizing the value of something that has no value to the person. It has value elsewhere. So move it to where it has value. I think people get excited about that.

Chairman CARPER. Good. All right.

Well, I just want to thank Mr. Kampschroer and thank you, Mr. Day. Thank you, Ms. Pulley. Mr. Alcorn, thank you for joining all of us for the celebration of the 54th anniversary of Mr. Skurnac's birth.

What we hope to do here today, on this day, is to spread the news. Spread the good news that we are hearing about, and I am, frankly, excited about.

And I thank you all for helping us to do that.

The three Cs. Ms. Pulley, tell us the three Cs one more time.

Ms. PULLEY. Right. It is convenience that we have talked about a lot today, clearly communication, but then finding the right way and the right message to communicate, which is give the cause so you have an emotional connection.

Chairman CARPER. That is great.

All right, the hearing record will remain open for 15 days. That is until March 14, at 5 p.m., for the submission of statements and questions for the record.

With that, this hearing is adjourned.

Again, our thanks to each of you. Happy birthday.

[Whereupon, at 2:08 p.m., the Committee was adjourned.]

# APPENDIX

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**Opening Statement of Chairman Tom Carper**
**"Recycling Electronics: A Common Sense Solution for Enhancing Government Efficiency and Protecting Our Environment"**
**February 27, 2014**

*As prepared for delivery:*

Good afternoon. I'd like to thank today's witnesses and guests for joining us to talk about how properly recycling electronics can preserve our environment, contribute to economic development, and help our government become more efficient. This is an issue that is of great interest to me, and should be to anyone who owns a home or a business.

The Consumer Electronics Association estimates that Americans own 28 electronics per household. If I were a betting man, I would bet that everyone in the room has at least one electronic device with them today, and countless more at home and at the office. You've probably asked yourself, what am I supposed to do with this device once I'm done with it?

Throughout my life, recycling has always been a top priority for me, and it's something that I have strived to encourage both through my personal efforts but also as a public official. You could say it is a true passion of mine. I am a proponent of recycling because it helps us preserve our limited resources and reduce our landfill input; all while creating good-paying, American jobs.

Along with Sen. John Boozman, I serve as co-chair of the Senate Recycling Caucus. We are committed to raising awareness of the many benefits of recycling. Most Americans are familiar with traditional municipal recycling efforts that encourage individuals to recycle paper and other household goods. But there's more to recycling than just tin cans and milk jugs.

Today's hearing will specifically take a look at electronics recycling, and how the federal government can help lead the way when it comes to expanding good practices that will save resources and cut down on potentially dangerous materials piling up in our landfills.

The federal government is the nation's largest purchaser of electronics and subsequently the largest disposer of such devices. This provides our government with the opportunity and responsibility to ensure that it recycles electronics in the safest, smartest way possible.

I believe the challenges and opportunities presented by electronics recycling draws a parallel to President Clinton's 1993 executive order requiring the U.S. government to purchase recycled paper. By harnessing the power of market forces through the Federal government's increased demand for recycled paper, this executive order in turn helped lower the price of recycled paper for everyone else.

In the case of electronics recycling, the Obama Administration's creation of the National Strategy for Electronics Stewardship is a great first step. The National Strategy seeks to leverage the purchasing power of the federal government to support responsible purchasing, management, and recycling of electronics within the federal government.

Today, witnesses from the public and private sector will help us examine how the government can lead by example when it comes to electronics recycling. Our witnesses will also discuss how the government can improve and increase electronics recycling across the country and look at the promise and challenges in increasing electronics recycling efforts in the United States.

We will also hear from the U.S. Postal Service about what it is doing to help in this effort. I'm particularly interested in hearing how the Postal Service can use its unique distribution network to make more money in this area.

I often say, anything I can do, I know I can do better. Recycling electronics is a perfect example. Our environment benefits from avoiding volumes of landfill waste, and American jobs are created as the demand for recycling opportunities increase. That's what I like to call a win-win.

I look forward to an informative discussion today of an issue that will undoubtedly only grow in significance as we continue to increasingly rely on electronic gadgets and need to dispose of older electronic equipment. Thank you again to our witnesses for being here today and I look forward to hearing your testimony.

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Statement for Record from Senator Levin
February 27, 2014

Thank you, Chairman Carper, for holding this hearing on recycling electronics. Recycling is an integral part of protecting our environment. In addition to the economic and environmental considerations of recycling, I want to highlight an important aspect of disposal practices for electronics related to our national security.

On May 21, 2012, the Senate Armed Services Committee released a report, "Inquiry into Counterfeit Electronic Parts in the Department of Defense Supply Chain." This report was issued after a year-long investigation that found counterfeit parts, mostly from China, flooding the defense supply chain. Much of the material used to make those counterfeits was electronic waste shipped from the United States and the rest of the world to China. The committee found that the Defense Department lacks knowledge about the scope and impact of counterfeit parts in the supply chain, that counterfeit parts cause risk to national security and our military personnel, and that unvetted distributors and weaknesses in the testing regime for electronic parts create vulnerabilities in the supply chain. The FY2012 National Defense Authorization Act included provisions to address many of these weaknesses, including preventing the importation of counterfeit parts into the United States, and improving counterfeit avoidance practices.

It is critical that we develop a better understanding of where electronics wind up after they leave our homes and workplaces. I look forward to learning from witnesses about challenges and opportunities to interject transparency into the disposal chain for electronics. Better data and transparency in the front end of disposal chain can both lead to more efficient and effective recycling efforts and decrease the likelihood of counterfeit parts entering supply chains.

# U.S. General Services Administration

Kevin Kampschroer
Deputy Agency Senior Sustainability Officer

Senate Committee on Homeland Security and Governmental Affairs
Recycling Electronics: A Common Sense Solution for Enhancing Government Efficiency and Protecting Our Environment
February 27, 2014

Good morning Chairman Carper, Ranking Member Coburn, and Members of the Committee. My name is Kevin Kampschroer, and I am the Deputy Senior Sustainability Official at the U.S. General Services Administration (GSA). Thank you for inviting me to testify about electronics recycling and the opportunities this area provides for increased environmental stewardship by the Federal government.

E-waste is the largest growing waste stream in the country. According to the most recent Environmental Protection Agency (EPA) estimates, more than five million tons of electronics were in storage.[1] Of those, 2.37 million tons were ready for end-of-life management, yet only twenty-five percent were collected for recycling.[2]

The Administration is committed to reducing e-waste and realizing efficiency by standardizing procedures across the government. As the world's largest consumer of electronics — $80 billion in FY 2010[3] — e-waste is a significant opportunity for the Federal government. In 2009, the President issued Executive Order 13514 which, among other things, called for the Federal community to promote electronics stewardship. The Administration also established an Interagency Task Force on Electronics Stewardship (the Task Force) led by GSA, the Environmental Protection Agency (EPA) and the White House Council on Environmental Quality (CEQ). The President charged the Task Force with developing a National Strategy for Electronics Stewardship (the Strategy), which the Task Force released in 2011.

Today, I look forward to discussing the development of the Strategy, its important tenets, and GSA's efforts as a member of the Task Force to help enact those provisions to address this critical challenge.

*The Strategy —*

GSA has always had programs for the disposal of excess equipment, including electronics, but these programs were not designed with the specific challenges of e-waste in mind. Before the Strategy, there was no standardized government-wide plan to properly evaluate or dispose of electronics that could no longer be used as originally intended.

To help develop the Strategy, the Task Force, made up of sixteen agencies,[4] including GSA, EPA and CEQ, hosted several listening sessions with industry stakeholders (electronics manufacturers and recyclers), the non-governmental organization community, State and local governments and customer agencies. In addition, the Task Force solicited public comments through the Federal Register and Regulations.gov. The Strategy was released on July 20, 2011.

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[1] http://www.epa.gov/osw/conserve/materials/ecycling/manage.htm. Estimates are from 2009. *Id.*
[2] *Id.*
[3] GAO-12-74 Electronic Waste, page 1. http://www.gao.gov/assets/590/588707.pdf.
[4] For a full list of Task Force members, visit: http://www.epa.gov/epawaste/conserve/materials/ecycling/taskforce/faq.htm.

The Strategy details the Federal government's plan to enhance the management of electronics throughout the products' lifecycle — from design to eventual reuse or recycling.

The Strategy set forth several items to be addressed over the coming years: development and publication of proper government-wide policy and guidance on the reuse and disposal of electronics including the use of certified recyclers for proper management of used electronics, acquisition of more sustainable electronics that can be easily reused and are designed to have a minimal end-of-life environmental impact, and transparency of newly-collected data regarding Federal government procurement, reuse, and disposal of electronics.[5]

*Reuse and Disposal of Electronics —*

On February 29, 2012, GSA published Bulletin B-34 in the Federal Management Regulations, presenting a specific list of options to consider when excess electronics are identified. Excess electronics should first either be offered to other Federal agencies for reuse through GSAXcess, or transferred to schools and other educational organizations. In FY 2013, $32 million worth of equipment was transferred among agencies through GSAXcess and in the first quarter of FY 2014, $2.6 million worth of equipment was transferred.[6]

Through GSA's Computers for Learning Program, agencies may transfer excess computers and related peripheral equipment to schools and educational nonprofit organizations.[7] In FY 2013, $72 million worth of equipment was donated through this program and in the first quarter of FY 2014, $12.7 million worth of equipment was donated.[8] Approximately thirty agencies participate in GSA's Computers for Learning Program each year.

Electronics not transferred through GSAXcess or donated to schools are declared surplus and are eligible to be donated through GSA's Federal Surplus Personal Property Donation Program to State and local governments and nonprofit organizations. In FY 2013, $4.6 million worth of equipment was donated through this program and in the first quarter of FY 2014, $513,000 worth of equipment was donated.[9]

Additionally, if electronics are not transferred or donated, the agency may sell, or, if a take-back provision exists,[10] return the electronics to the original vendor. GSA is incorporating these

[5] The Strategy lists four goals: (1) Build Incentives for Design of Greener Electronics, and Enhance Science, Research and Technology Development in the United States; (2) Ensure that the Federal Government Leads By Example; (3) Increase Safe and Effective Management and Handling of Used Electronics in the United States; and (4) Reduce Harm from US Exports of E-Waste and Improve Safe Handling of Used Electronics in Developing Countries.
[6] GSAXcess. Valuations are based on original acquisition value.
[7] Under E.O. 12999, agencies may also transfer computers and related equipment directly to schools.
[8] GSAXcess.
[9] GSAXcess.
[10] GSA is incorporating some of these provisions in our contracts, such as in the Federal Strategic Sourcing Initiative (FSSI) Print Management Program

provisions into many of our contracts, and is also developing government-wide guidance about incorporating take-back requirements into all contracts.

Under GSA's policy, Bulletin B-34, non-functional electronics should ultimately be directed to a third-party certified electronics recycler and should not be sent to landfills or incinerators. Furthermore, all electronics recyclers listed on GSA's Schedules must be third-party certified.[11]

*Acquisition of More Sustainable Electronics —*

Another goal of the Strategy is to promote the purchase of green electronics to reduce their life cycle environmental impact. GSA continues to improve our contract vehicles in order to simplify Federal agencies' acquisition of green electronics.

Currently, there are over 120,000 Energy Star products offered across several GSA Schedules.[12] Focusing on Information Technology products, GSA is currently revising Schedule 70 (IT Equipment) to encourage vendors to provide Energy Star and EPEAT-registered electronics. Additionally, used and refurbished electronics are already offered on Schedule 70 — $50 million worth of used and refurbished electronics were sold in FYs 2010-2013 and $2.5 million were sold in the first quarter of FY 2014.[13]

Within the GSA *Advantage* online shopping portal, environmental icons (such as Energy Star) are used to show the various attributes of listed products. Additionally, GSA has developed an easy to use, web-based, Green Procurement Compilation tool which consolidates and displays products designated for Federal procurement by the EPA and the Departments of Energy and Agriculture as more sustainable. Each item's listing includes the item's environmental certifications, where to buy the product and how to find vendors through GSA's offerings.

In addition to the GSA Schedules, the National IT Commodities Program and the FSSI Print Management Program also offer Energy Star and EPEAT-registered electronics. Both solutions require vendors to report their sales of Energy Star and EPEAT-registered electronics. This reporting assists our customer agencies track their purchases of sustainable electronics.

With GSA's internal acquisitions, we are committed to meeting the goals outlined in the Strategy. In FY 2013, we purchased $4.3 million worth of Energy Star and EPEAT-registered products from various GSA procurement vehicles.

[11] Schedule 899 (Environmental Services).
[12] GSA *Advantage*. Energy Star products include: Copiers on Schedule 36 (Office, Imaging, and Document Solutions); Appliances on Schedule 51V (Hardware Superstore); Audio/Visual equipment on Schedule 58I (Professional Audio/Video Telemetry/Tracking; Recording/Reproducing and Signal Data Solutions); Camera battery chargers on Schedule 67 (Photographic Equipment); and Refrigeration equipment on Schedule 73 (Food Service, Hospitality, Cleaning Equipment and Supplies, Chemicals and Services).
[13] Schedule 70.

Additionally, we have been deploying Energy Star servers and workstations at GSA since 2001. Servers and personal computers have been EPEAT-compliant since 2005 and EPEAT Gold since 2009, meaning that the equipment is built with reduced amounts of lead, mercury and other sensitive materials, incorporates recycled materials, and is manufactured in ways that simplify disassembly and reuse.

*Transparency* —

Transparency is a crucial part of the Strategy and one of the most challenging aspects of the plan. Currently, although many e-waste recycling programs exist, there are no guidelines to measure their use government-wide. GSA, working with other Federal agencies, is considering a policy that will include a requirement for agencies to submit data for all disposed electronics. This data, which could be publicly available on Data.gov, would provide greater transparency into Federal agencies' performance against the goals of the Strategy.

*Conclusion* —

The Federal government, as the largest purchaser of information technology in the world, has a unique responsibility to be a leader in the management and disposal of electronics. GSA plays an important role in helping agencies meet the goals set forth in the National Strategy for Electronics Stewardship, through policy guidance and responsible acquisition, donation and disposal of electronics. We have a lot more work ahead of us and hope to continue to make progress on this important issue.

I am pleased to be here today, and I am happy to answer any questions you may have. Thank you.

UNITED STATES
POSTAL SERVICE

**STATEMENT OF**
**CHIEF SUSTAINABILITY OFFICER**
**THOMAS G. DAY**
**BEFORE THE**
**COMMITTEE ON HOMELAND SECURITY AND GOVERNMENTAL AFFAIRS**
**UNITED STATES SENATE**

**FEBRUARY 27, 2014**

Good morning, Chairman Carper and members of the Committee. Thank you, Mr. Chairman, for calling this important hearing on recycling electronics. My name is Thomas G. Day, and I am the Chief Sustainability Officer of the United States Postal Service, a position I have held since June 2011. Working closely with departments throughout the Postal Service, our vendors, and the mailing industry, my team sets policies and assists in the areas of environmental compliance, sustainability, and energy initiatives.

I am pleased to be here today to provide an overview of the USPS BlueEarth™ Federal Recycling Program (BlueEarth Recycling Program). This new program offers participating federal agencies and their employees a free and easy solution to securely and efficiently recycle unwanted lightweight electronic devices in an environmentally friendly way. Improper disposal of electronic waste is an acknowledged worldwide environmental problem, and this program aims to increase the percentage of used electronics that are recycled. Recycling used electronics also helps preserve and reuse strategic minerals that are in short supply.

## PROGRAM OVERVIEW

Federal agencies can enroll in the BlueEarth Recycling Program to recycle unwanted small electronics and printer cartridges, free of charge, through the mail. Some examples of electronic items eligible for recycling include cell phones and accessories, laptops, tablets, and cameras. This program is designed to supplement an agency's existing recycling programs. Currently, there are 11 participating federal agencies. There are no costs to agencies to implement this program, and there is a very simple process for them to launch it on a national level. The program has two components. Agencies can recycle government-owned small electronics and printer cartridges at the agency location, and employees of participating agencies can dispose of their own personal small electronics and printer cartridges from home.

The BlueEarth Recycling Program is web-based. An employee from a participating agency selects his or her agency name and the device information on the website. The individual then packages the device and prints a shipping label, free of charge, from the website. The shipping includes free package tracking. In the course of normal delivery, a postal letter carrier picks up the package while completing his or her route. A certified recycler receives the item, wipes the data as appropriate, and ensures it is either securely recycled or remanufactured for resale opportunities. The recycler receives the residual value of the recycled products, which funds the transportation costs via U.S. Mail to the recycler's destination.

The recycler is responsible for removing data associated with the electronic devices, wiping the data in accordance with the data sanitization standards of the National Association for Information Destruction (NAID) and the Department of Defense (Standard 5220.22-M). A certificate is issued confirming such action.

Through the BlueEarth Recycling Program, federal agencies receive recycling activity reports with data to assist them in meeting the documentation requirements of Executive Order 13514. Under this executive order, U.S. agencies must employ environmentally sound practices for the disposition of all agency excess or surplus electronic products.

USPS BlueEarth™ is a branded suite of customer services and product initiatives from the Postal Service designed to provide sustainability solutions and innovations to our customers. The Postal Service is perfectly positioned for this program because we are using our existing delivery network—making it a financially and environmentally-efficient way to recycle. Recycling programs help prevent e-waste from ending up in landfills, which can be dangerous to the environment and to human health.

Besides providing the ability to simply, securely and cost-effectively recycle e-waste, the BlueEarth Recycling Program also increases mail volume and postage revenue. A short, informative video of the program can be found on YouTube (http://bit.ly/1h6mVSy).

**PROGRAM SUCCESSES AND CHALLENGES**

The BlueEarth Recycling Program was launched in April 2013. Eleven agencies are currently enrolled, including the Postal Service. While we are encouraged by the number of agency agreements signed thus far, usage of the program has been low. Rather than continuing to pursue additional participating agencies, our current focus is on developing promotional and educational materials to expand the use of the program at these existing agencies. We plan to roll out this new promotional campaign this spring.

So far in Fiscal Year 2014, the BlueEarth Recycling Program collected and recycled approximately 15,000 items. The most popular items being recycled have been printer cartridges and toner, smartphones, laptops, and cell phones. The most active agencies have been the Postal Service, followed by the Department of Energy and the Department of the Interior.

In addition to the postage revenue the Postal Service receives for transporting recycled items, there is a profit sharing component of the program. The Postal Service and its recycler have an agreement to split any profits generated from the disposition of the recycled items. This profit is calculated after all costs associated with recycling have been accounted for. So far, no profits have been distributed, but we expect to turn a profit for the month of February, as the startup costs of the program were completely paid off in January.

**IMPACT OF PENDING LEGISLATION**

A study commissioned by the Postal Service showed a large potential market for electronics recycling by mail in both federal and consumer markets. There are some hurdles that stand in the way of full potential. Section 411 of Title 39 (US Code) restricts the work the Postal Service can do with commercial entities and state and local governments. Pending Senate postal reform legislation would allow potential expansion of the program to the state, local, and tribal government level.

**CONCLUSION**

Mr. Chairman, we look forward to working with you and the rest of the Committee to expand the recycling of e-waste throughout the nation, and especially to take advantage of the Postal Service's natural fit in its receipt, transportation, and delivery. This concludes my remarks. I would be pleased to answer any questions you may have.

KEEP AMERICA
**BEAUTIFUL**

**"Recycling Electronics: A Common Sense Solution for Enhancing Government Efficiency and Protecting Our Environment."**

**Statement of Brenda Pulley,**
**Senior Vice President of Recycling**
**Keep America Beautiful**

**Before the Homeland Security and Governmental Affairs Committee**
**United States Senate**

February 27, 2014

Chairman Carper, Ranking Member Coburn, and other members of the Committee, thank you for your interest in recycling – and for purposes of today – electronics recycling.

In a society where each American produces 4.4 pounds of trash each day, there is a critical need to raise awareness and ultimately provide the motivation to change behaviors to position recycling as a daily social norm.

My name is Brenda Pulley and I am the Senior Vice President for recycling at Keep America Beautiful. On behalf of Keep America Beautifu,l we appreciate this opportunity to re-ignite the dialogue on recycling and share information about how to increase recycling participation.

Keep America Beautiful is a leading national non-profit organization that brings people together in their communities to transform public spaces into beautiful places. Whether it is a waterway cleanup, restoring a vacant lot or enhancing recycling, we work to build and sustain vibrant communities. Founded over 60 years ago, our legacy is based on executing actionable strategies in environmental education and behavior change. We are most known for helping to abate litter in the 60s and 70s, and while that is still much of our work, today we are also very focused on engaging individuals and businesses to reduce waste and recycle more.

A challenge that spurs our work is the fact that the national recycling rate for municipal solid waste hovers at around 34% -- and this is for typical household recyclable items like cans, bottles, other packaging material, yards trimmings etc. There are some estimates indicating that the recycling of electronics is around 20%. Whatever the exact number, we believe the recycling rates for electronics and other commonly generated waste materials can be made much higher.

While recycling is considered one of the easiest environmental behaviors for the general public to perform, it is actually riddled with complexities.

To increase recycling of any goods, the key elements of a sustainable recycling market and infrastructure to collect and process material—have to be in place. Further, there must be market demand for the recycled materials to be used in the manufacture of new products.

The good news for the electronics sector is that there is a market for the recovered scrap; this has led to investment to build the infrastructure to collect and process used electronics. The existing system has significant room for improvement, but it is important to note that the electronics sector has many market-based and technological factors at work to support the post-recovery economic use of electronic products.

However, the critical link to electronics recycling is capturing these materials to feed into the recycling system, and doing this relies on businesses or individuals to take action. For individuals this means participating in a special drop off recycling event, or other drop off locations or mail in opportunities. Because the nature of the infrastructure for recycling electronic goods requires individual action, what we ask ourselves is "What can we do to make recycling second nature?"

Behavioral psychologists indicate that recycling behavior can be positively influenced. Further, there has been some research conducted to date to identify factors that can most effectively encourage recycling behavior most effectively.

Summarizing the research, surveys and "in the field" learnings to date, at KAB, we categorize three key areas for improvement as:

- Convenience
- Communication
- Cause (make an emotional connection)

Addressing the convenience factor has the greatest potential to increase recycling participation. We need to build better infrastructure to offer recycling opportunities proximate to the actions or behaviors that generate the recyclable material. So, using beverage containers as an example, this could involve placing recycling bins where the consumption will most likely occur, such as in office break rooms, at a local sports field, or at an airport. For electronics recycling, the challenge is even greater – you are trying to capture material that may have been purchased 7 years earlier not 7 minutes. The creation of easy access to recycling – such as at retail locations where consumers go to replace their obsolete electronics (Best Buy and Staples currently offers such collection) is an excellent example of overcoming the convenience barrier. Special collection events where you have a specific date and time of collection, often accompanied with significant promotion about the event, have proven effective, particularly where other options are not readily available. One of our KAB affiliates in a Georgia community with a population of around 100,000 residents has been hosting used electronics collection events twice a year for 7 years. 50,000 – 70,000 pounds are collected at each event.

Another key factor is better communication. Consumers need to be informed on what, where and when the material can be recycled. In recent consumer research KAB conducted, potential recyclers indicate they want easily accessible information regarding what and where to recycle.

While consistent and clear information can make it easier to recycle, there is evidence that increasing knowledge doesn't mean individuals are motivated to engage in the behavior. We recommend that information and knowledge be combined with a "cause" or making it matter to recycle to induce behavior change. It is critical to strike the emotional chord with consumers. And, at Keep America Beautiful that is the approach we have taken in our most recent efforts.

In partnership with the Advertising Council, we recently released a national advertising campaign designed to motivate Americans to recycle every day. Based on our consumer research, we learned that when people understood that they could give their garbage another life – help it become something new, they wanted to take the extra step to recycle. Thus the campaign is based on the theme: "I want to be recycled" and each ad provides examples of what a plastic bottle, an aluminum can, and so on can become when recycled. I invite the committee members to find out more about the campaign and encourage their municipalities to utilize the campaign assets which are located at: http://iwanttoberecycled.org/

In addition to convenience, communication and cause there are some other known strategies that have been identified as effective at changing behavior. A few of these include: goal setting, social modeling and commitment.

There is research evidence that indicates that making a commitment to take an action – the more specific and public the better -- results in an increase in that action.

Additionally, there are several studies that indicate social modeling or norming has great potential to increase pro-environmental behavior (much of this work has been done in the health and energy sectors). For recycling, the most powerful social norms are those that are at the same time both ubiquitous and deeply ingrained. Take the example of the seat belt – it is simply what we do because our society expects us to do it and has created many touch points to remind us to do it. Or for a recycling example, a study conducted among 600 households on curbside recycling – when residents were provided descriptive normative feedback – information about the percentage of their neighbors that had recycled that day and the amount of material recycled – there was a 19% increase in recycling among the residents.

As stakeholders interested in increasing recycling – we are taking these learnings and further apply them. For example, at Keep America Beautiful, in addition to conducting new behavioral-based research, we strive to incorporate these known approaches in our various national recycling programming – America Recycles Day, or our programs targeted to certain sectors – schools, college campuses or recycling at work. For the members of this Committee, as public officials, you have a powerful role to lead by example and be seen recycling, or talk about recycling in a positive way to your colleagues and constituents.

Now before I get to a few recommendations for your consideration, I would like to add that used electronics recycling has an additional unique aspect that influences how recycling is perceived by consumers. Specifically – electronics have a perceived value. That perceived value causes people to store their old televisions, computers and printers in basements and garages rather than readily recycle them. So we do need to identify ways to overcome this barrier to recycling. For example, when purchasing a new laptop there could be prompts on the packaging, prompts on the new product instructions about recycling the obsolete product, better yet, that sales person when selling a new product can prompt the new purchaser on the recycling of the old product. These kinds of prompts at point of purchase and knowing that the used electronics will be recycled can help overcome this "perceived value" barrier. This is also an interesting aspect about a partnership between Dell and Goodwill Industries. Goodwill locations are now drop-off points for not just clothing and other household items, but also electronics. Not only is it more convenient for donors to bring along their used electronics for donation as they are dropping off other household items, donors know that their used electronics will go to good use. Thus making it easier to donate them for reuse and recycling.

Yes, while a simple action, recycling is complex and the recycling of electronics has some unique factors to consider. However, we have the benefit of a growing body of behavioral and market research, and, while there is more to learn, there are informed approaches we can take now to increase recycling participation by motivating environmental behavior. Here are some recommendations:

Recommendations:

1. Increase awareness to make recycling a daily social norm:
   For members of the committee to lead by example, such as to talk about electronics recycling and the importance of using a certified recycler to ensure proper handling of the data and equipment. Attend electronics collection events that occur in your states, publicly pledge to recycle and invite your constituents to do the same.
   Encourage municipalities to use the national "I want to be recycled" campaign to raise awareness and make that emotional connection to recycling.
2. Engage the industry – manufacturers and retailers: Encourage OEMs and retailers to continue to make recycling collection more accessible and to provide information about

recycling embedded throughout their various communications with consumers -- in advertising, on product packaging and set of instructions, at point of purchase, etc. For example – when you go to buy a new electronic good – you are asked if you have one to recycle.

3. Design products for recycling: Encourage OEM's to factor in end-of-life recyclability of new products and packaging.
4. Conduct a study: Conduct a study specific to identifying the barriers for individuals to recycle electronics and approaches on how to most effectively overcome those barriers.

Thank you to the members of this committee for the opportunity to share information regarding what we know about engaging individuals to recycle more. I look forward to further exploring actions that can be taken to increase recycling participation and answer any questions you may have at this time.

**Before the Committee on Homeland Security and Governmental Affairs**
**United States Senate**

**Recycling Electronics:**
**A Common Sense Solution for Enhancing Government Efficiency and Protecting Our Environment**

**Statement of Walter L. Alcorn**
**Vice President of Environmental Affairs and Industry Sustainability**
**The Consumer Electronics Association**

**February 27, 2014**

## Introduction

Senator Carper, Senator Coburn and Members of the Committee:

My name is Walter Alcorn and I am the Vice President for Environmental Affairs and Industry Sustainability for the Consumer Electronics Association® (CEA).

The Consumer Electronics Association (CEA) is the technology trade association representing the $208 billion U.S. consumer electronics industry. More than 2,000 companies enjoy the benefits of CEA membership, including legislative advocacy, market research, technical training and education, industry promotion, standards development and the fostering of business and strategic relationships. CEA also owns and produces the International CES – The Global Stage for Innovation. All profits from CES are reinvested into CEA's industry services. Find CEA online at www.CE.org, www.DeclareInnovation.com, www.GreenerGadgets.org and through social media.

By extending information and entertainment to everyone – regardless of income or geographic location – our members' products have improved lives and changed the world. America stands as the global leader in innovation, ingenuity and creativity, and the competition and falling prices characteristic of our industry continue to bring benefits to consumers.

We understand that a primary responsibility shared by manufacturers of consumer electronics lies in product design. The innovation and rapid evolution inherent in the technology industry have resulted in dramatic design changes in product form and function, and a decrease in our industry's overall environmental footprint with smaller and lighter products.

Advances in technology have been accompanied by large reductions in the consumption of energy, fewer materials of potential concern, and other positive environmental benefits. The big television that used to sit on the floor in a wooden console now hangs safely on the wall with two or three times the viewing area and a far superior picture quality – and using a fraction of the electricity. And the personal computer system that came in multiple, heavy pieces now goes with you wherever you go – and might even fit in your pocket.

Furthermore, manufacturers use significant amounts of recycled content, such as glass, plastics and metals, in the production of new devices. Detail of these and other environmental initiatives in the consumer electronics industry are highlighted in the *CEA*

*2013 Sustainability Report* provided with this written testimony and available at www.ce.org/sustainability.

Electronics Recycling Goals

While older consumer electronics (CE) may have reached the end of their lives or be out-of-date, many contain materials and components that would be a waste to be completely discarded. Most consumer electronic products contain valuable materials, such as metals and plastics that can be resold in the commodities market by recyclers.

CE manufacturers and retailers recognize this and support electronics recycling efforts like never before. In April 2011 a dozen leading CE companies met at the Best Buy store on Wisconsin Avenue in Washington, DC to create the eCycling Leadership Initiative and issued an unprecedented national challenge to recycle responsibly one billion pounds of electronics annually by 2016 – the "Billion Pound Challenge." Achievement of this stretch goal would be a three-fold increase over the amount of CE recycled by our industry in 2010. Backing up this commitment is the issuance of annual reports on our industry's progress, which we have published the past two years (attached to this written testimony and available at www.ce.org/ecycle), and the third annual report scheduled for this April.

Electronics Recycling Results

In April 2013 CEA reported 580 million pounds of CE recycled responsibly by our industry in third-party certified recycling facilities – an increase of 25 percent over the previous year and about halfway to our billion pound goal. Our manufacturers and retailers provide more than 8,000 public, ongoing collection locations around the country – all of which can be found through an online zip code locator created by CEA at GreenerGadgets.org. CEA also created and distributed public service announcements for radio and television, reached out to consumers through traditional and social media on numerous occasions, and incorporated full implementation of a national recycling system into our organizational goals. According to a 2012 CEA survey 63 percent of all consumers know how and where to recycle their old electronics – up from 58 percent two years earlier, still not high enough but moving in the right direction.

In 2013 CEA published the second annual report of the eCycling Leadership Initiative and recognized 13 companies for their leadership in recycling consumer electronics. Last fall CEA awarded the first industry eCycling Leadership Awards to four companies with exceptional recycling performance – Best Buy, Dell, HP and Samsung. CEA salutes these and other companies in our industry that are working to make recycling electronics as easy as purchasing new ones.

Challenges

Collecting used electronics for recycling continues to present the largest operational challenge. According to our research the average household contains 28 distinct electronic products, and re-aggregating these products when they are ready for the electronics collection and recycling systems continues to be a daunting challenge. However, two new hurdles have emerged during recent years.

First is the patchwork of diverging state electronics recycling programs and laws. Exactly half of the U.S. states have enacted some form of electronics recycling mandate and, unsurprisingly, no two states have the same program. For CE manufacturers there are now 21 separate registration forms to fill out, 19 different annual state registration fees to pay, 15 state-specific annual recycling reports to file – all with different calendars and deadlines - and lots of wasted energy and resources going towards administrative activities instead of collection and recycling. We need a national framework for electronics recycling in the United States and CEA strongly supports legislation authorizing an industry-driven, harmonized system for recycling consumer electronics.

Second is the market challenge for recycling leaded glass from old Cathode Ray Tube, or CRT, televisions and computer monitors. Until about a decade ago the demand for old CRT glass to make new CRT displays was strong. However, as is common in our industry, new and better technologies like LCD, plasma and LED hit the market and have displaced the older, lower-quality CRT technology. CRT sales plummeted and now there is only one factory in the world producing new CRT displays. Not surprisingly this has meant much weaker demand for recovered CRT glass.

CEA has recognized this and in May, 2013 hosted a cross-stakeholder meeting at CEA's offices to daylight and discuss the current operational and regulatory situation for recycling CRT glass. CEA also has co-sponsored two crowd-sourcing challenges to find new recycling approaches and applications for CRT glass, first in conjunction with the

Environmental Defense Fund (EDF) in 2012 and again last year in partnership with the Institute for Scrap Recycling Industries (ISRI). Winners of these challenges included a CRT glass processing system from NuLife Glass – who is now building a CRT processing facility near Buffalo, New York – and a proposed solution from an independent scientist for using recycled CRT glass as a component for vitrification of nuclear waste. While CEA recognizes that these technologies and applications hold promise much more needs to be done to promote these and other approaches to ensure adequate market demand for CRT glass.

How to Increase Responsible Recycling

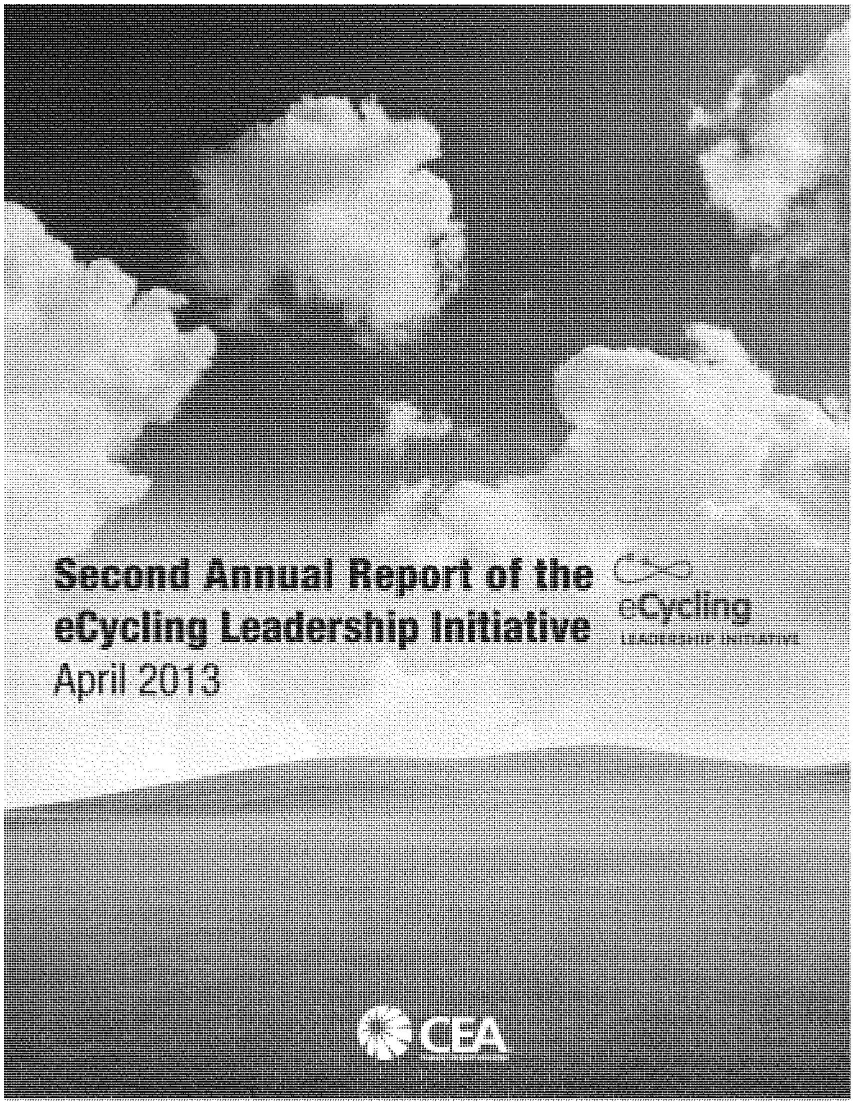
CEA recommends the creation of a national, harmonized industry-driven framework for recycling consumer electronics to facilitate more efficient electronics recycling. A national framework should be structured to maximize the use of market forces and ensure a level playing field across CE manufacturers, incorporate the ideal of share responsibility for key system functions like collection and consumer education, ensure that recycling is done responsibly, and result in convenient collection opportunities for the consumer. In lieu of a blanket federal mandate CEA recommends a federal framework that authorizes implementation of a harmonized, cross-state consumer electronics recycling system in specific states when mutually agreed to by a CE industry representative organization and state officials. CEA and its members are working to develop the operational infrastructure for an industry representative organization and look forward to working with this Committee and others in Congress to improve the U.S. system for recycling consumer electronics.

The federal government should also set a good example by ensuring that all federal e-waste is responsibly recycled. And to help address shortfalls in the CRT recycling market, the federal government should step up procurement of materials such as recycled CRT glass whenever the economics make sense, is safe and environmentally sound, and function of those recycled materials meets government specifications.

**Conclusion**

Finding a solution to this public policy challenge is a priority for CEA and our industry. As we continue to make strides in eco-friendly design initiatives, lead the consumer electronics industry on environmental issues and be a part of the effort to educate consumers about electronics recycling, CEA stands ready to work with Congress and all interested parties to reach a common-sense, national solution that makes recycling as convenient as possible for all Americans.

Thank you again for the opportunity to share CEA's position on this important public policy issue. I look forward to addressing any questions you may have.


Second Annual Report of the
eCycling Leadership Initiative
April 2013
eCycling
LEADERSHIP INITIATIVE
CEA

**Unprecedented National CE Recycling Effort**
The eCycling Leadership Initiative is a nationwide effort by the consumer electronics (CE) industry to achieve several key goals:

- Improve consumer awareness of the available collection sites currently sponsored by our industry;
- Increase the amount of electronics recycled responsibly to one billion pounds annually by 2016;
- Increase the number of collection opportunities available to consumers; and
- Provide transparent metrics on eCycling efforts.

The eCycling Leadership Initiative represents a collaboration between consumer electronics manufacturers, retailers, collectors, recyclers, non-governmental organizations and governments at all levels, spearheaded by CEA.

**Billion Pound Challenge**
As part of the eCycling Leadership Initiative, on April 13, 2011, CEA and a dozen leading consumer electronics companies issued an unprecedented national challenge to recycle one billion pounds of electronics annually by 2016 – the "Billion Pound Challenge."

**National Issue Needs National Approach**
Electronics recycling is a national issue that merits a national approach. In order to promote transparency of our metrics related to this effort, CEA is publishing this second annual report to measure the progress of the eCycling Leadership Initiative in 2012 from 2011. The first annual report can be found at CE.org/eCycle. We plan to continue to report on our progress in the coming years regarding the eCycling Leadership Initiative and the Billion Pound Challenge.

**Making Recycling Easy**
CEA research confirms that a household in the U.S. has an average of 24 CE products in the home, and consumer electronics are widely used in virtually every community in the United States. Given the widespread marketplace penetration of CE products, CEA supports a national approach to eCycling to make recycling electronics as easy as purchasing them, for all consumers, in every state in our nation.

**eCycling Leadership Initiative Participants**
The second year of the Initiative included increased participation from major CE manufacturers and retailers. This year, the qualifying companies are listed in tiers based on the relative level of their recycling efforts.

The following companies distinguished themselves in the recycling of consumer electronics in 2012:

**Initiative Leaders (top performers who operate at the highest level of effort)**

Apple
Best Buy
Dell
hp
Samsung

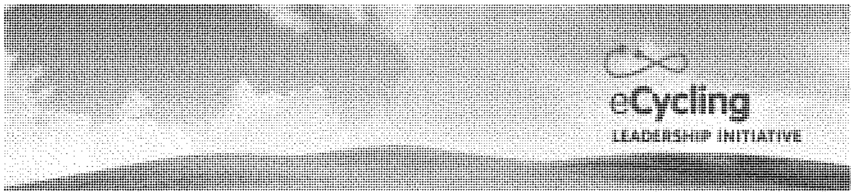
**Initiative Performers (initiative participants who operated at a high level of effort)**

acer
Funai
lenovo. For those who do.
Panasonic
Sharp
VOXX International Corporation

**Initiative Participants**

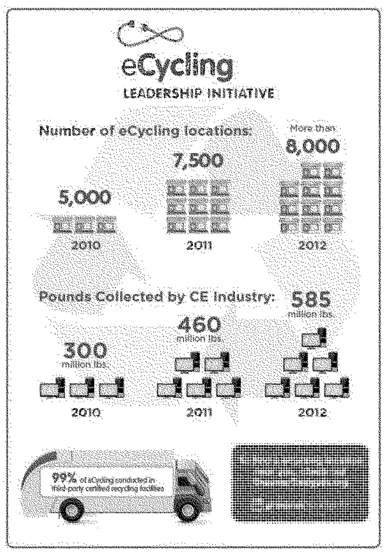
LG
Toshiba Leading Innovation >>>

CEA applauds these companies for demonstrating leadership in the responsible recycling of used consumer electronics. For more information on this initiative, please go to CE.org/eCycle.




**More than 8,000 Collection Locations**

There are now more than 8,000 locations available to consumers in the U.S. These locations include retail stores that recycle electronics such as Best Buy and Staples, local government sites and charities, processing centers, and other recycling drop off locations that are sponsored by consumer electronics manufacturers and retailers. In April 2010, CEA estimated that CE manufacturers and retailers sponsored approximately 5,000 ongoing drop-off locations for consumers to recycle their old electronics. These locations are included in search results from the zip code locator on GreenerGadgets.org.




**585 Million Pounds in 2012**

In 2012, our industry arranged for more than 585 million pounds of consumer electronics to be recycled. That is an increase of more than 25 percent over 2011 (460 million pounds), and a total increase of almost 100 percent over 2010 (300 million pounds). To calculate these industry-wide totals, CEA collects recycling data from manufacturer and retailer programs and aggregates the results.

When manufacturers and retailers have the freedom to choose their recyclers they do so with great care. By the end of 2012, 99 percent of eCycling by our eCycling Leadership Initiative participants was conducted in third-party certified recycling facilities.

**GreenerGadgets.org for Consumers**

In the fall of 2011, CEA launched GreenerGadgets.org to educate consumers about eCycling and energy consumption. The site was created to help make the process of recycling electronics as easy as possible for consumers. By simply punching in a zip code, consumers can locate the closest responsible recycling opportunity sponsored by the CE industry and/or third-party certified recycler.

GreenerGadgets.org provides a widget for managers of other websites to use the zip code locator on their websites at no charge. By utilizing the GreenerGadgets widget, you help to educate people on how to properly recycle used electronics and help ensure reusable resources do not go to landfills or get dumped in developing countries.

CEA has promoted the site through online ads, social media and traditional media outreach. CEA will continue with these efforts, as well as with the cultivation of meaningful partnerships to promote electronics recycling.

Recyclebank

Recently, CEA formed a partnership with Recyclebank, an innovative online rewards site with more than four million members. Recyclebank members will be able to earn rewards points for recycling electronics through the GreenerGadgets.org recycling tool.

**Challenges and Opportunities**

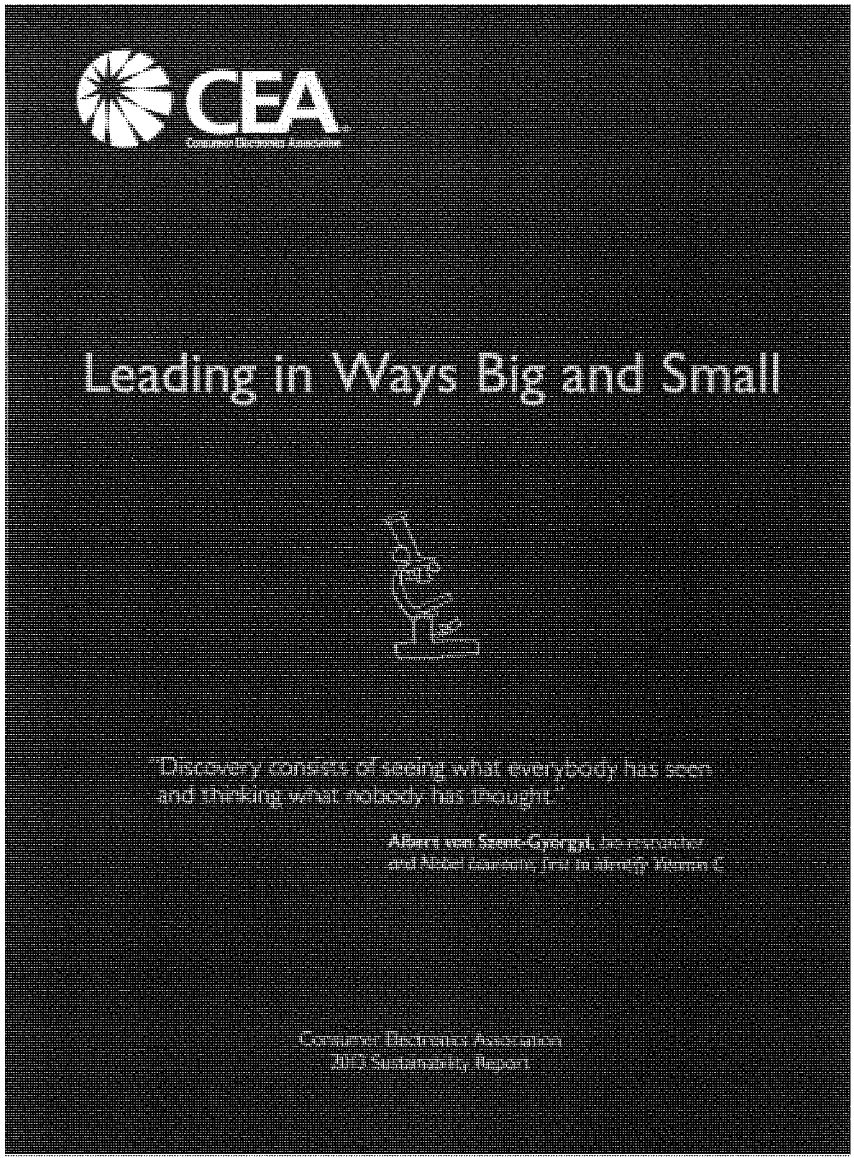
Beyond the ongoing challenge of collecting old or unused CE products located in virtually every household in the country, the industry is seeking ways to recycle and find new uses for old cathode ray tube (CRT) glass.

As CRT technology has been displaced in the television and computer market by liquid crystal display (LCD), light-emitting diode (LED) and plasma displays, the demand for old CRT glass to make new CRT glass has waned. Since CRT glass is now the largest portion of the CE recycling stream, there is a greater need for new, environmentally sound, economically sustainable uses for this material. To identify financially viable, environmentally conscious proposals for using recycled cathode ray tube (CRT) glass, CEA partnered with the Environmental Defense Fund in 2012 to create the CRT Challenge, a crowdsourcing initiative to find new, innovative ways to recycle this glass.

**Future Years**

As consumer electronics companies continue to ramp up recycling-related activities in 2013 and beyond, CEA will broaden outreach efforts to consumers about where they can recycle their old electronics responsibly. Visit GreenerGadgets.org for information and opportunities on how to participate in this industry-wide recycling initiative.

Suggestions for how we can improve the eCycling Leadership Initiative and meet our Billion Pound Challenge are welcome. Send comments to Walter Alcorn, CEA vice president of environmental affairs and industry sustainability, at walcorn@CE.org. If you are a member of the media interested in these issues, please contact Samantha Nevels, CEA coordinator of policy communications, at snevels@CE.org.


CEA
Consumer Electronics Association
Leading in Ways Big and Small
"Discovery consists of seeing what everybody has seen and thinking what nobody has thought."
Albert von Szent-Györgyi, bio-researcher and Nobel Laureate, first to identify Vitamin C
Consumer Electronics Association
2013 Sustainability Report

International CES Attendees ●

**2,000+**
Members Worldwide

# About The Consumer Electronics Association

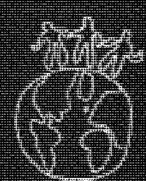
The Consumer Electronics Association (CEA)® is the technology trade association representing the $203 billion U.S. consumer electronics industry. More than 2,000 companies enjoy the benefits of CEA membership, including legislative advocacy, market research, technical training and education, industry promotion, standards development and the fostering of business and strategic relationships. CEA is the industry authority on market research and forecasts, consumer surveys, legislative and regulatory news, engineering standards, training resources and more. CEA is also engaged in consumer education and collaborative partnerships to help meet the challenge of building a more sustainable and eco-efficient tomorrow.

CEA owns and produces the International CES® – The Global Stage for Innovation, the world's largest innovation event. Each year the International CES brings together more than 150,000 retail buyers, distributors, manufacturers, market analysts, importers, exporters and press from 150 countries. Find more about the International CES® at **CESweb.org**. Find CEA online at **CE.org**, and **DeclareInnovation.com**. Find information on CEA's environmental programs and policies at **CE.org/green** and **GreenerGadgets.org**.

**150,000+**
International CES
Annual Attendees

**$203B**
Industry
Economic Impact

# In Ways Big and Small



The Consumer Electronics Association and its members are working to build a more sustainable future – leading through innovation, collaboration and a commitment to consumers and communities.

# A Letter from Leadership

"Consumers increasingly want innovative, eco-friendly products, and our industry is really delivering."

**Gary Shapiro**, *President and CEO*
*Consumer Electronics Association*

Our world faces significant opportunities and challenges in building a more sustainable planet. Consumer electronics (CE) companies and CEA® are leading the way with a wide range of initiatives – big and small – to leverage the power of innovation to reduce the environmental impacts of our industry.

CE products play a vital and unprecedented role in today's world. Our products educate, inform, entertain and connect people around the corner and around the globe. No longer is information simply generated from above and disseminated to the masses – information is created and shared in all different directions in transformative ways.

Great features and applications are not enough to ensure the long-term success of our industry. We are committed to embedding sustainable practices in how products are designed, manufactured, distributed, sold and handled at their end-of-life.

Each year brings new scientific and engineering breakthroughs to make products more energy efficient, less resource-intensive and more recyclable. Consumers increasingly desire innovative, eco-friendly products, and the CE industry is delivering. This report highlights company-specific initiatives and achievements since our last CE industry sustainability report in 2010. This report also highlights key sustainability areas like electronics recycling. Leveraging new partnerships, CE manufacturers, retailers and others are working with governments, NGOs and stakeholders to increase significantly the recycling of consumer electronics. In 2011, CEA announced the eCycling Leadership Initiative to increase the amount of consumer electronics being recycled to one billion pounds annually by 2016. So far, our industry is on track, recycling 585 million pounds of CE in 2012. The CE industry also believes that the quality of recycling is just as critical as the quantity, so we are committed to using vendors that employ only the highest recycling standards, including third-party certification systems R2® and e-Stewards®.

One of CEA's most important roles is to channel the commitment and expertise of our members to tackle environmental and resource challenges. CEA organizes industry working groups and multi-stakeholder consortia to collect data, develop industry standards and measure industry performance to advance sustainability and understand environmental impacts. In late 2012, for example, CEA, the National Cable & Telecommunications Association (NCTA) and 15 industry-leading video providers and device manufacturers signed an unprecedented Set-Top Box Energy Conservation Agreement that will result in annual residential electricity savings of $1.5 billion or more.

In addition, CEA released a comprehensive study of CE energy use in U.S. homes in late 2011 and will issue a revision of this well-received report in the near future. CEA also created a multistakeholder group to revise test procedures for measuring power consumption for televisions and set-top boxes.

The emergence of new tools for consumers to find such products is an exciting industry development. The U.S. Environmental Protection Agency's ENERGY STAR® program continues to guide consumers toward more energy-efficient products. Since 2011, all televisions sold in the United States must display an EnergyGuide label that quantifies energy use in terms consumers understand: dollars per year.

CEA also plays an expanding role in consumer education. CEA's GreenerGadgets.org website informs consumers and users of CE products about how they can make smarter choices that save energy, reduce waste and ensure responsible recycling at end-of-life.

CEA's role as the producer of the International CES® serves as not only the focal point for global innovation but also a case study for how to bring more than 150,000 people together sustainably with fewer environmental impacts. CEA is setting an example by recycling more than 75 percent of show materials, and repurposing CES badge holders for future use. It's an ideal example of how smart and small decisions can add up to big wins for communities and the environment.

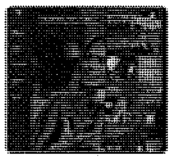
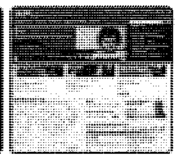
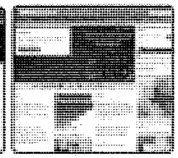
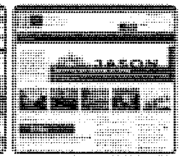
The Set-Top Box Energy Conservation Agreement will result in annual residential electricity savings of **$1.5 billion or more**.

Leveraging the brightest minds in our industry and working collaboratively with a broad range of stakeholders, CEA and our industry partners continue to launch initiatives and forge partnerships that provide innovative and sustainable solutions for consumers, communities and our planet.

Gary Shapiro
President and CEO

Walter Alcorn
Vice President Environmental Affairs & Industry Sustainability

Douglas Johnson
Vice President, Technology Policy

# Leading Change Through Collaboration

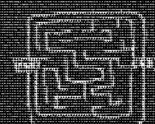
Bringing together stakeholders with diverse interests but common goals is the essence of collaboration – and at CEA we consider it essential to achieving progress. That's why we have been a driving force behind initiatives that bring together business, government, the scientific community, nongovernmental organizations (NGOs), consumers and other stakeholders to meet the challenge to build a more sustainable future.

Many of the most effective solutions with the broadest impact are voluntary programs – initiatives that harness transformative technology to drive efficiency and reduce environmental impacts. For example, CEA and CE companies have long been strong supporters of the U.S. Environmental Protection Agency's ENERGY STAR program. In the more than two decades since its inception, ENERGY STAR has achieved dramatic savings in energy use and reductions in greenhouse gas emissions. In addition, CE companies have embraced the principles of affirmative procurement through tools such as the Electronic Product Environmental Assessment Tool (EPEAT) – and deliver tens of millions of EPEAT-certified products to consumers and business customers each year.

CEA has also been a leader in bringing together many of the brightest minds inside and outside our industry to develop standards, testing protocols and processes to measure and report the environmental and social impacts of electronics. Our efforts support ground-breaking research to measure efficiency improvements of electronic devices – analyses that can help guide even greater improvements going forward.

Whether it is by acting jointly with the National Cable & Telecommunications Association (NCTA) to greatly increase the efficiency of set-top boxes, or working side by side with retailers, recyclers and state and local governments to significantly expand electronics recycling, our commitment to collaborating for the public good will continue. These partnerships are crucial in order to meet the sustainability challenges before us. There is much more we can achieve together. Going forward, CEA is committed to continuing to grow its leadership and serve as a catalyst for change and progress.

# Sustainable Product Life Cycle



"How wonderful it is that nobody need wait a single moment before starting to improve the world."

**Anne Frank,** *13-year-old Jewish victim of the Holocaust and famous diarist*

# Bigger Capabilities, Smaller Impacts

Each of us has within our grasp the opportunity to improve our world – sometimes in small ways centered on our individual choices and lifestyles – and at other times through decisions that can positively impact others and on a big scale.

For leaders in the CE industry, the opportunity to create a better world starts by asking important questions that address every phase of the product life cycle: How do we expand capabilities while reducing environmental impacts? Can we add features while lowering power usage? What's the best way to reduce material inputs and conserve resources during manufacturing and shipment? What new technologies allow us to create products that use more recycled material – and also make them more recyclable at end-of-life? Are there better strategies to reduce the amount of CE products entering the waste stream?

Finding answers to these questions, and many others, is the ongoing focus of CE designers, engineers, sustainability experts, marketers and front-line personnel. Our journey remains far from complete, but throughout our industry exciting progress is underway.

# Lighter, Greener, More Recyclable

## Sustainable Product Design

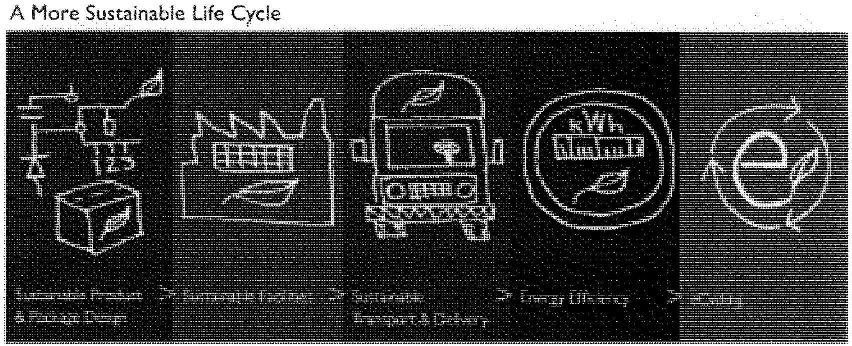
Achieving greater eco-efficiency starts at the earliest phases of product design. A deliberate design imperative is necessary in order to develop CE solutions that require fewer resources, use less power, reduce or eliminate toxic substances and can be readily recycled at end of life. Increasingly, CE companies employ Life Cycle Assessment (LCA) as one of several valuable Design for the Environment (DfE) tools to guide better choices from the earliest stage of product development.

The LCA methodology helps product designers better understand the environmental impact of raw or recycled materials, manufacturing processes, component selection and packaging. LCA insights reveal the most meaningful opportunities for improvement – changes that will truly "move the needle" in the effort to achieve greater eco-efficiency.

Design also influences how recyclable a product will be once it reaches the end of its operational life. More and more, CE product engineers and designers weigh those considerations as they select materials and assembly techniques – decisions that can facilitate easy disassembly and reclamation of product components, years after the device was manufactured.

In the past, and before new technologies displaced older ones like cathode ray tube technology, toxic substances, including lead, mercury, arsenic, cadmium, obsolete brominated flame retardants (BFRs) and others, could routinely be found in CE devices and/or their packaging. Industry innovation as well as more stringent government regulation around the world has led to a dramatic reduction in materials of concern in CE products. CEA has developed an important tool, the Joint Industry Guide (JIG) – Material Composition Declaration for Electrotechnical Products, to help facilitate compliance with these restrictions and with material disclosure requirements across the global supply chain. (To learn more, visit CE.org/jig)

### A More Sustainable Life Cycle

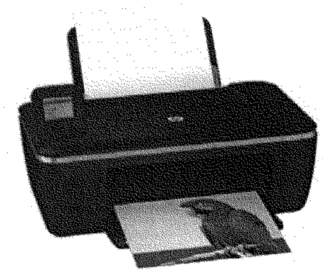


# Designed With Tomorrow in Mind

Plastics play an integral role in most CE devices. They are used in cases, covers, internal structural and mechanical parts and in multiple other applications. In some CE product portfolios, plastic can constitute 25 percent of the materials contained in devices. Virgin plastics and resins are derived from petroleum and natural gas – requiring the extraction of those natural resources and generating CO2 emissions in the process. Reducing the use of virgin material, and increasing the use of recycled plastic (from both postconsumer and postindustrial sources) represents a big opportunity to enhance eco-efficiency. CE companies are implementing an array of strategies to rapidly expand the use of recycled material. Companies like **Samsung Electronics** – which in one year more than quadrupled the percentage of recycled plastics in its products – are achieving meaningful results.

As the industry continues to increase its use of recycled plastics, a gating item is the need to ensure that recycled materials deliver the strength, durability and other performance characteristics required in sophisticated electronics devices. For **Sony**, the work of their engineers to develop **SoRPlas** (Sony Recycled Plastic) is expanding the possibilities of recycled material – and bringing the company closer to its goal of a zero environmental footprint.

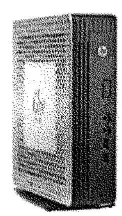
SoRPlas has proven to be a viable alternative to virgin polycarbonate plastic. In this innovative manufacturing process, plastic scrap from leftover optical discs, transparent sheets and used water bottles is crushed, washed and converted to SoRPlas. Traditional recycled plastics contain about 30 percent recycled material. Setting the bar higher, in SoRPlas the recycled content can be as high as 99 percent – and the one percent remainder includes Sony's original flame retardant that provides superior flame resistance while eliminating the need for brominated flame retardants (BFRs). This breakthrough material can be found today in Sony's digital still cameras and other Sony products.



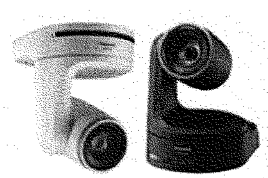
The HP Deskjet 3050A e-All-in-One contains 25 percent postconsumer recycled plastic. HP is also reducing the amount of material reaching the waste stream through a "closed-loop" recycling process in which original HP ink and LaserJet toner cartridges are reduced to raw materials that can then be used to make new cartridges as well as other metal and plastic products. In just two years, HP shipped 600 million inkjet cartridges containing recycled plastic derived from this process.

# Big Gets Light

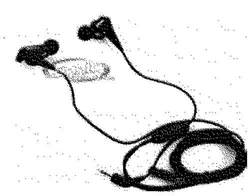
Devices that are smaller and lighter are also more resource efficient – that's why reducing product mass can create significant environmental benefits. CE designers and engineers are focused on bringing to market a new generation of products that have big features but require fewer resources to build *and* reduce GHG emissions during manufacturing. In addition, industry research and development teams are exploring the vast potential of nanotechnology, which holds long-term promise for creating solutions that require significantly less virgin material input.



**HP Thin Client, HP t610**
**HP** is taking important strides to use materials more efficiently through innovations in technology and product design. For example, HP Thin Client computing devices can require up to 50 percent less material to produce than a traditional HP desktop PC. They deliver true PC-like performance for remote or cloud computing environments.



**Panasonic AW-HE120**
Used for teleconferencing, sports, government video and other applications, **Panasonic**'s HD rotatable integrated camera offers a solution that is 60 percent smaller in size and mass compared with the conventional model. Equipped with broadcast-quality sensors, digital signal processing and a high-performance lens, the camera's reduced size and mass also improves its pan and tilt functionality



**Sony XBA-NC85D**
In the past, conventional noise-cancelling headphones required a cord-mounted control box to house components such as a processor and microphone. **Sony** found a more elegant solution – smaller and lighter headphones that relocate these components into the ear bud housing. The design also saves resources by eliminating the need for replaceable batteries.

# Leading Through Green Purchasing

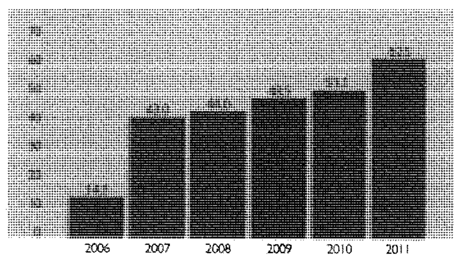
Since its inception in 2006, industry and consumer acceptance of the Electronic Product Environmental Assessment Tool® (EPEAT) – the Green Electronics Council's global rating system for environmentally preferable electronics – has grown exponentially. Initially designed primarily as a tool for procurement professionals in business and government settings, EPEAT ratings today are used by growing numbers of individual consumers. In 2011 more than 532 million EPEAT-registered products sold worldwide.

Using the IEEE 1680 industry standards developed by a cross-section of stakeholders during the past decade, the EPEAT system measures electronics products according to more than 50 required and optional life cycle performance criteria. Bronze, Silver and Gold ratings are reached based upon meeting ascending numbers of these checkpoints. These measures include design, production, energy use and recycling, among others. Importantly, all manufacturer claims are validated by ongoing independent verification, including unannounced, publicly reported audits.

Although used to date primarily as a purchasing tool for institutional buyers, the potential for EPEAT in the CE industry is exciting. Today approximately 50 manufacturers are EPEAT participants. In the United States, at the end of 2011 there were nearly 3,000 individual products registered. That number is expected to continue to grow rapidly; in 2012 and 2013 new IEEE standards were adopted to include imaging equipment and televisions.

## EPEAT-Registered Products U.S. Sales Growth

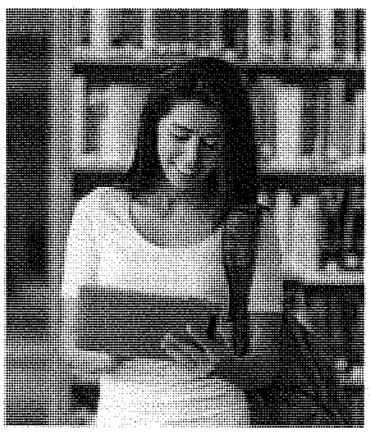
2006-2011 [in millions]




The environmental benefits of EPEAT purchasing have been significant. The Green Electronics Council calculates that in the United States in 2011 EPEAT purchasing reduced the use of toxic materials by 1,053 metric tonnes, and greenhouse gas emissions by more than one billion metric tonnes of carbon equivalent. Those totals are commensurate with removing nearly 750,000 average passenger cars from the road for a full year.

In 2012, **Best Buy** customers purchased more than 1.5 million EPEAT-qualified products – energy savings equivalent to powering nearly 15,000 homes for one year.

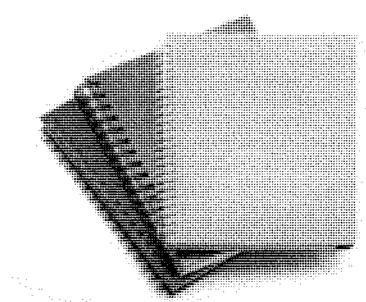
# Read the Screen, Save the Trees



It's a simple idea with a powerful impact. Migrating the content of product guides and operating manuals from analog to digital formats greatly reduces the need for voluminous printed materials – conserving resources and eliminating the energy and GHG emissions required to produce them. From manufacturers of smartphones, cameras and televisions to publishers of electronic games, CE companies are finding smarter, greener ways to convey information to those who use their products. For some devices, that means shrinking the printed manual to a basic overview of features, with more detailed product information embedded in the device or available via the Internet. For other products, printed manuals have been eliminated altogether.

**LG Electronics**, for example, replaced the hard copy manual for its S5ype smartphone with an entirely online edition. Televisions are also fertile ground for this trend. As TVs gain new capabilities and features, their printed manuals have also expanded – sometimes to hundreds of pages. Not only is moving this content to a digital format preferable from an environmental perspective – it also makes information easier to find. In its current line of HD televisions, **Samsung** incorporates e-manuals, available on screen, that provide answers to most consumer questions. Some **Sony** BRAVIA™ LCD TV models include an i-manual button on the remote, which allows the user to view a list of help topics and makes information instantly available.

The potential for resource savings is not restricted to operating manuals for CE devices alone. With their light weight, long battery life and expansive memory capacity, today's tablet computers are proving to be an ideal solution to replace bulky – and financially and environmentally costly – paper manuals.



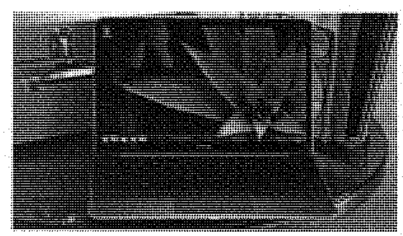
# Designing For Tomorrow Today

An important characteristic of ecologically sound product design is planning for how a device can be responsibly recycled at end of life. Choices of materials, components, fasteners, device architecture and the recycling technology ultimately employed all will play a role in determining the degree to which resources in a device can be reclaimed.

Close collaboration between manufacturers and recyclers can help product designers gain a better understanding of the current challenges in recycling electronics. For some CE companies, training programs are in place to enable personnel to learn by dismantling an end-of-life device themselves. This hands-on experience helps design engineers gain deeper insights into how future products can be made more recyclable. Techniques like marking the number and position of screws, and labeling the materials and flame retardants used in plastic parts, can all contribute to easier reclamation.

**HP** is one of many CE companies targeting greater recyclability in the design of its products. HP designs products to use common fasteners and snap-in features and to avoid applying glues and adhesive welds where feasible. These measures make it easier for recyclers to dismantle products and to separate and identify different plastics. Most HP PCs are more than 90 percent recyclable by weight, and workstations and the Elite and Pro series desktop PCs have a chassis that can be easily disassembled for upgrade to extend product life and for recycling at end of life.

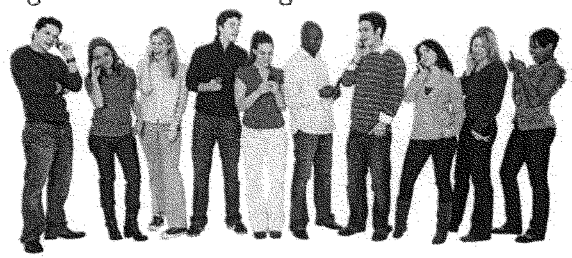
For **Dell**, close collaboration with recyclers helps guide the selection of materials that can ultimately be reclaimed. The Dell XPS 13 Ultrabook™, launched in fiscal 2012, uses an innovative polymer-reinforced carbon fiber base that helps keep it cool to the touch. Before entering final design and production, Dell worked with its recycling and asset recovery partners to ensure this new material would meet the recyclability criteria for new green label standards such as IEEE 1680.1.



Dell XPS 13 Ultrabook

# It Doesn't Have to End Here

## Extending the Life of Existing Electronics

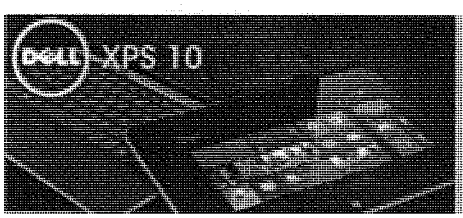


There is perhaps no better way to reduce waste and conserve precious resources than to lengthen the operating life of CE products currently in use. A single smartphone may contain 50 different chemical elements – many of which are not economically viable to recover during recycling. Finding ways to repair, refurbish or update these devices is both economically sound and environmentally smart.

**DIRECTV** is one company at the forefront of this effort. Central to the company's operating model is a commitment to refurbish used equipment recovered from customers' homes. That approach reduces the number of new receivers built and the resources required to produce and ship them. In fact, DIRECTV refurbished more than eight million receivers and 650,000 pieces of other electronic hardware in 2012 alone.

America's largest electronics retailer, **Best Buy**, is playing an important role to help extend the life of existing devices. The company's Geek Squad® repair service extends the life of products and reduces the volume of electronics reaching the waste stream. Best Buy has also invested in one of the most in-depth parts catalogs in the repairs industry. The Best Buy PartStore™ offers nearly five million new and used parts available to technicians and customers in the United States and Canada, including access to parts taken from nonworking units.

**iFixit** is a socially motivated, dynamic company that also serves as the hub of a global repair community – thousands of technicians and volunteers working together to make the world better by teaching people how to fix things. iFixit offers tools and parts, and leverages the expertise of its community to produce thousands of repair guides for hundreds of devices – phones, computers, game consoles, tablets, cameras and more. And regular "tear down" analyses provide consumers with detailed assessments of how repairable or recyclable a new device will be.




### Dell XPS 10 Receives Top Score for Tablets

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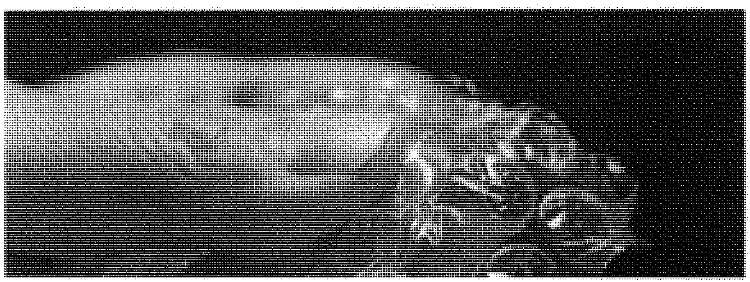
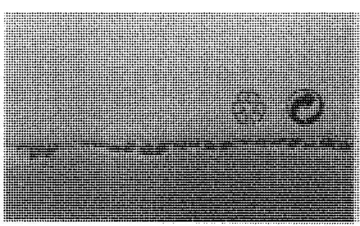
# Big Gets Small

## Sustainable Packaging Design



The beauty of green packaging is the echo chamber of positive effects it creates from the factory floor to the consumer's home. Smaller, lighter and more efficient package designs not only require fewer resources to produce – their benefits resonate throughout the supply chain. These packages require fewer ships, planes, railcars and trucks to transport; less space in warehouses, distribution centers and retail locations; reduced waste after purchase; and less energy at every step of the process.

For CE companies, shrinking packaging mass and volume is a key focus. So, too, is reducing environmentally unfriendly content and expanding the use of recycled and renewable material. **Best Buy** is committed to a goal to eliminate packaging materials that are considered toxic or create challenges in the material-recovery processes. In fiscal 2013, the company eliminated an additional 12 million tons of PVC plastic from its retail packaging and more than 20 tons of expanded polystyrene foam from its Exclusive Brands TV packaging. For Best Buy that approach also means choosing, whenever possible, paper-based materials rather than plastic, eliminating or reducing PVC, using postindustrial and postconsumer recycled cardboard, and applying nonsolvent coatings and organic inks.



### LG Electronics: Documenting Recycled Pulp in Packaging

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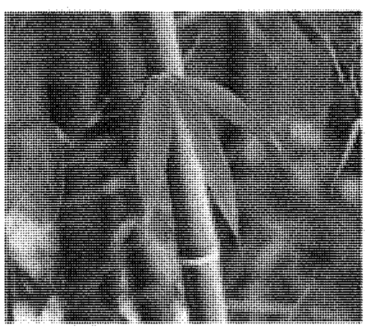
# Recyclable and Renewable



By sourcing packaging materials from unexpected sources like bamboo, mushrooms and wheat straw, Dell has become a leading innovator in sustainable packaging design. This breakthrough strategy to leverage fast-growing, renewable organic material is aligned to help meet the company's ambitious goal – to create a waste-free packaging stream by 2020. Achieving this objective requires:

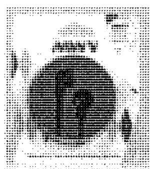
- That 100 percent of Dell packaging be sourced from sustainable materials or material that was formerly part of the waste stream; and,
- Ensuring that 100 percent of Dell packaging is either recyclable or compostable at the end of its life.

Dell launched its renewable packaging initiative with bamboo. Sourced in China near its manufacturing facilities, bamboo is used to create cushions and trays for laptop and tablet products. Actually a type of woody grass, bamboo is rapidly renewable – and can regrow at a rate of more than one inch per hour. The material is also highly recyclable and can be treated like cardboard at the recovery stage.

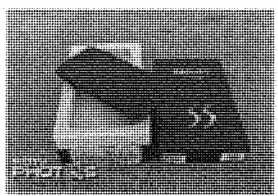
What if you could leverage natural processes to grow packaging rather than manufacture it from petroleum or natural gas? That's the big idea behind Dell's mushroom-based packaging. The company's team worked with sustainable packaging innovator Ecovative Design to develop mushroom packaging for Dell servers. The product is grown using mycelium, a fungal network of threadlike cells that is combined with agricultural waste like cotton hulls. Within a week, strong, durable packaging material emerges from this organic process – perfect for cushioning and bracing Dell's valuable high-performance servers. After its work is done, the mushroom packaging is fully compostable.

In 2013 Dell added to its renewable packaging portfolio when it announced it will begin using a new sustainable material – wheat straw – in its cardboard boxes for notebooks originating in China. Many Chinese farmers currently treat this byproduct of wheat harvesting as waste and burn it for disposal, contributing to environmental degradation. Dell will incorporate the straw in its boxes, starting with 15 percent by weight and ramping up as operations scale. The remainder of the box will primarily come from recycled content fiber. During pulping, the wheat straw goes through an enzymatic process – modeled after the way cows digest grass – that uses 40 percent less energy and almost 90 percent less water than traditional chemical pulping.

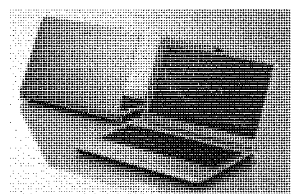
# Leading With Less



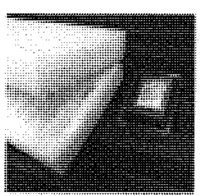
MeadWestvaco's **Natralock®** utilizes a tear-resistant paperboard that is as durable and secure as traditional clamshells – but much more eco-efficient. Natralock packages use 70 percent less plastic and require 55 percent less energy to manufacture. And they provide consumers with an easy and safe opening experience.



In 2012, **LG Electronics** set new guidelines to reduce the weight and volume of packaging while increasing reuse and recycling and launched a new green packaging development process. The results were immediate. For new TV products released in 2013, LG was able to reduce packaging materials by nearly five percent – despite increased product size – and packaging materials in mobile phones by more than 20 percent.



By designing the packaging for the **Sony®** VAIO S series so that each component serves two functions, Sony succeeded in trimming the number of packaging components used and shrinking the package size, thereby reducing the total package weight. Both the inner and outer boxes are designed to be reusable.



**HP** is collaborating with suppliers of 100 percent recycled foam cushions to broaden industry adoption of these materials – and build the infrastructure to recycle them. The company worked with Sealed Air Corporation, a major provider of recycled packaging foam, to expand its "closed-loop" recycling process globally. Today, HP commercial desktop PCs in North America are packaged with foam cushions made from 100 percent recycled plastic content.

# Big Features, Smaller Power Needs

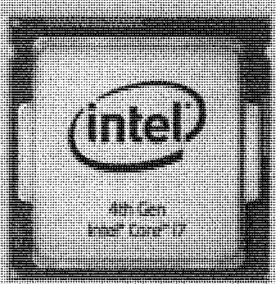
## Sustainable Product Use

Consumer electronics devices enhance our daily lives in many respects – providing entertainment, information and connecting us in ways that enrich our personal lives and make our work more productive. Those robust capabilities also require electricity. Yet, considering that the typical American household contains 24 electronic devices, it is perhaps surprising that a study by Fraunhofer USA found that CE devices account for only 13.2 percent of residential energy consumption in the United States.

Throughout the CE industry and across every product category, the drive for even greater energy efficiency in devices is underway – and achieving results. A product that consumes less power costs consumers less to operate and accounts for fewer GHG emissions during its lifespan.

Today, engineers and designers are focused on several clear targets of opportunity for power savings. These include reducing or eliminating power needs in standby mode, improving the efficiency of power adapters and charging devices, and developing a new generation of processors and other components that require less electricity.

Manufacturers of game consoles, for example, have increased energy efficiency through smaller chips which require less power and diminish the need for other components designed to address heat remediation, such as fans, radiating fins and insulation. Current models of all three console systems demonstrate lower energy consumption than previous versions. Today's **Microsoft** Xbox 360 uses less than half the energy of the 2005 launch model for game play and navigation mode. The current **Sony** PlayStation® 3 model uses just around 35 percent as much power for game play mode and navigation mode as its 2006 predecessor. The **Nintendo** Wii, which has the lowest energy usage of the three systems, uses 22 percent less power in active gaming and 43 percent less power in standby mode than the 2006 Wii model.




### Haswell's Big Leap Forward

Processors serve as the central nervous system of laptop computers, and making them more energy efficient offers a big payoff – reduced power consumption overall and longer battery life when unplugged. In 2013, Intel took a big leap forward in power efficiency with the introduction of its fourth Generation Intel® Core™ Processor – codenamed "Haswell." The new chip draws 50 percent less power than previous iterations of Core processors during power-intensive activities like watching a movie. Haswell's power consumption in standby mode has also dropped precipitously – it's now 20 times lower than its 2011 predecessor, "Sandy Bridge." [illegible] will provide the biggest battery life increase in Intel's history. Reduced electricity demands and longer battery life in millions of next generation laptops – Haswell presents the opportunity to create a win-win for people and planet.

# Pointed in the Right Direction

Televisions are by far the largest source of power usage among CE residential devices – representing slightly more than one-third of the energy required by CE products in American homes. Today's digital sets have much larger screen sizes than the cathode ray tubes (CRTs) of a generation ago, yet in many cases, today's flat panel digital sets consume less energy than their analog predecessors. Today's digital televisions also include features like HD, 3D and Internet connectivity. As a result of the work of CE product engineers, the digital models reaching consumers today are achieving much higher levels of energy efficiency.

Engineers have developed improved technologies to make the display panel more efficient. In plasma applications those improvements include optimizing the xenon/neon gas mixture, driving circuits, electrodes and the panel cell structure. In LCD and LED applications, enhancements produced better management of image contrast, with blacker blacks – and darkened areas that require less power draw. Every digital TV operates on direct current (DC) internally – and a DC power supply must convert the AC power supplied by the utility grid. Advancements in power supply design, better power management algorithms and other improvements today are lessening internal power losses.

These changes, and others, are earning big energy savings dividends for consumers. A 2011 study by TIAX found that between 2003 and 2010, active mode power density in LCD TVs fell by 63 percent, and the study's measurement for standby mode showed even greater reductions of 87 percent. Plasma models showed comparable reductions: active power demands fell by 41 percent while standby power dropped by 85 percent.

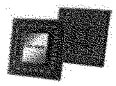
Increased consumer awareness of power-efficiency performance is also driving progress. The U.S. Environmental Protection Agency's (EPA) ENERGY STAR Program began qualifying TVs in 1998, and in 2011 consumer education was further enhanced when the U.S. Federal Trade Commission (FTC) initiated EnergyGuide labels for TVs with support and participation by the consumer electronics industry. These informative labels describe a model's estimated yearly energy cost and provide a comparison to the annual energy cost of other televisions with similar screen sizes.

# The Power of Innovation

It's not only TVs that are becoming more energy efficient. CE companies are leveraging breakthrough technology to reduce power requirements in devices big and small.

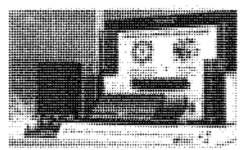
**Greener Ways to Cool**

**Dell**'s PowerEdge 12th generation servers include significant new features for energy-efficient computing. A notable enhancement: reductions in fan power during normal server operation. It now takes less power to cool the PowerEdge R720 server than it does to run a typical nightlight.



**Smarter Power, Longer Battery Life**

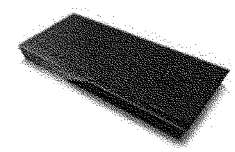
In 2011, **AMD** launched a new class of processor, the APU, which integrates a central processing unit (CPU) with a discrete-level graphics processor onto a single chip. This breakthrough architecture makes computing applications such as multimedia, productivity and simulations run faster, allowing PCs to transition to lower-power idle/sleep/off states for longer periods of time. Other power savings features include AMD AllDay™ power designed to extend notebook battery life. A carbon footprint study conducted by AMD found the integrated APU design provides an average 40 percent savings in GHG emissions, as compared to previous-generation products that were not integrated on a single chip. In 2013, AMD introduced "system on a chip" APUs for tablets and other mobile computing devices that provide additional power savings.



**The Sweet Sound of Savings**

**Sony** engineers applied their R&D talents to take advantage of a NASA discovery: magnetic fluid, a liquid that can be attracted by a magnetic field. Sony's consumer application? The world's first speakers to replace traditional dampers with magnetic fluid suspension. Found in Sony's Blu-ray Home Theater System, the speakers consume approximately 35 percent less power than traditional designs* – while delivering great sound.

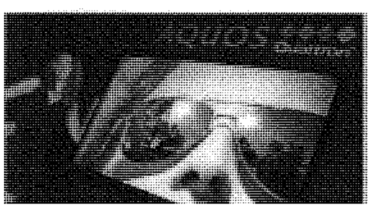
*Energy consumption of magnetic fluid speakers alone, compared to that of conventional speakers at equivalent volume of +2dB noise level.



**How Low Can You Go?**

**Panasonic's Blu-ray Disc Recorder**

Thoughtful product design has enabled **Panasonic** to bring to market an exceptionally energy-efficient Blu-ray disc recorder, the DMR-BRT220. Its annual power consumption is only 18.9 kWh – or less than 2.2 watts per hour of operation. The recorder's energy efficiency, resource savings and recycling-oriented design helped it earn the demanding Eco Mark designation from the Japan Environment Association, a rating standard aligned with the requirements of ISO 14020 and ISO 14024.



**Sharp's Quattron Technology**
**Energy Efficiency at Every Size**

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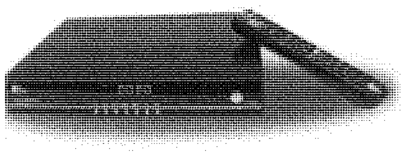
# Efficiency From Top to Bottom



When fully implemented, the **Set-Top Box Energy Conservation Agreement** will produce annual residential energy **savings of $1.5 billion or more.**

What does it take to make one of today's most essential CE devices more energy efficient? For CEA and its industry partners, it's a new kind of collaboration – bringing together industry leaders with a unified commitment to drive down energy costs for consumers and reduce GHG emissions.

Today's set-top box (STB) enables a wide variety of digital services in millions of American homes every day. These devices receive and decode signals for playback on televisions, and many incorporate features such as high-definition programming, video on demand, digital video recording (DVR) and even home networking. STBs offer powerful capabilities – but they have, until now, also required surprisingly large amounts of electrical power. In fact, on a per-unit basis, cable set-top boxes rank third in power consumption among CE devices – exceeded only by televisions and desktop computers.

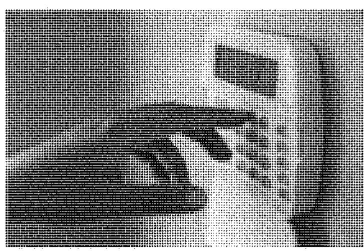
In 2012 CEA worked in concert with the National Cable and Telecommunications Association (NCTA) and the nation's top cable, satellite and telco providers and with STB manufacturers to launch a major new initiative to drive significantly higher levels of STB energy efficiency. Just how big is this voluntary commitment? When fully implemented, the Set-Top Box Energy Conservation Agreement will produce annual residential energy savings of $1.5 billion or more.

Achieving those savings required an ambitious approach. The voluntary agreement requires that at least 90 percent of all new set-top boxes purchased and deployed after 2013 will meet EPA ENERGY STAR 3.0 efficiency levels. The initiative also calls for cable operators to download "light sleep" capabilities to more than 10 million currently installed DVRs, for telco operators to offer light sleep functionality, and for satellite providers to include an automatic power-down feature in 90 percent of STBs deployed.

These engineering and performance improvements are particularly important since many legacy devices, which are configured to continuously communicate with the service provider, draw similar amounts of power whether in active or off/standby mode. Newer designs that incorporate hardware and firmware enhancements that reduce power draw meaningfully improve environmental performance and reduce operation costs.

The 15 signatories of the agreement include 10 of the largest service providers as well as the largest STB manufacturers: **Cisco, EchoStar Technologies** and **ARRIS**. We were excited to help forge this partnership, which will produce billions of dollars in energy savings and significantly reduce GHG emissions.

# Energy Savings That Hit Home – And Away From Home



It's not only manufacturers and retailers that are leading the drive toward greater eco-efficiency in consumer electronics. Across the United States, installation and integration professionals are playing an important role by helping residential and commercial customers identify solutions and strategies to reduce energy consumption and operate more efficiently.

In Maryland, **Bethesda Systems** is meeting a growing demand for solutions that save energy through more efficient lighting, climate control and sophisticated systems to enable remote systems monitoring. Bethesda Systems Co-founder Jon Stovall's deep interest in green solutions allows him to help customers meet their energy-efficiency goals.

Small businesses and residential customers alike have found that the savings can be profound. At a popular Bethesda sports bar, outdated lighting was both costly and labor-intensive – with employees replacing up to 15 bulbs per week. After a comprehensive LED retrofit installed by Bethesda Systems, the tavern benefited from reduced maintenance and better-quality light – and meaningful energy savings. Energy costs were reduced by $5,000 a year and, thanks to utility rebates, the project achieved a seven-month return on investment.

Strong partnerships with local utilities enable Bethesda Systems to offer customers advice on how to maximize their energy savings incentives.

Residential customers can also leverage new technology to reduce energy usage, so Bethesda launched the LED Diet, an enterprise that helps homeowners transform their residence into a high-efficiency home. LED "Dieticians" research and test hundreds of LEDs to find the very best bulbs and fixtures and offer comprehensive services that can provide increased energy efficiency every hour of every day.

Dan Fulmer, CEO and Founder of **FulTech Solutions**, uses his company's Jacksonville, FL, headquarters to spread the message to customers about the opportunities for greater eco-efficiency. Their showroom/office serves as "Exhibit A" of the potential of innovative new monitoring and control technologies. The completely integrated system includes access control, security, HVAC, audio, video, digital signage and more. Crestron smart sensors adapt to individuals' habits and "know" when to shut off office LED lights. "When our customers visit, we can show them how little interaction is needed with our building management system. Passivity is key; the less interaction required, the better energy management systems will work. We, people, tend to forget things," said Fulmer.

The FulTech headquarters has earned an ENERGY STAR score of 96, increasing from 91, since 2009 installation, and the company spends only $250 a month in utilities for 5,000 square feet of office space with a small warehouse. Fulmer has replicated this high-tech system for several customers, and market interest continues to grow. "It's our own unique design, and a real-world example of what can be done when a system is properly integrated and programmed."

# Never More Ways to Save the ENERGY STAR Way

**18,000 organizations**
in ENERGY STAR Program

**1.8 billion tons**
of GHG emissions prevented

**$230 billion**
saved in utility bills in 2012

In 2012 the U.S. Environmental Protection Agency's (EPA) ENERGY STAR program, a voluntary energy-efficiency initiative, celebrated its twentieth year of saving consumers money while protecting the environment. At every step, CE companies have engaged as strong partners of this program, one that has served as a catalyst for positive change to protect our environment and human health.

2012 EPA data reveals that the environmental benefits from the ENERGY STAR program have nearly tripled in the last decade. More than 18,000 organizations are partners in the program, working collaboratively to prevent more than 1.8 billion tons of GHG emissions and saving over $230 billion in utility bills in 2012 alone.

ENERGY STAR arms consumers and business customers with unbiased, objective information to better inform their purchasing decisions. It is clear that consumers have responded: more than 4.5 billion ENERGY STAR products have been purchased since 1993. Moreover, public awareness of the program and its value is high. A 2012 research study commissioned by the Consortium for Energy Efficiency reported that 87 percent of U.S. households recognized the ENERGY STAR label – making it one of the most valuable brands in U.S. markets.

The program's strong recognition and credibility have had a strong influence on consumer purchasing decisions. A 2011 CEA consumer research study found that 85 percent of consumers said energy consumption was "important" or "very important" in making their purchase decisions – surpassed only by price and features in their decision making.

In 2013, Samsung Electronics earned the program's highest award **ENERGY STAR Partner of the Year – Sustained Excellence.** The recognition was earned by offering 1,435 ENERGY STAR-qualified models across multiple product categories as well as Samsung's efforts in training, consumer education, recycling and labeling practices.

# eCycling

## Leveraging the Opportunity to Lead

**Saluting Top Performers**

In the second annual report of the eCycling Leadership Initiative in 2013, we recognized five leaders – top performers who operate at the highest level of effort to address the eCycling challenge:

CE devices play an increasingly important role in our daily lives – in fact, research shows that approximately 24 separate electronic devices can be found in the typical U.S. home. Laptops, Blu-ray players, game consoles, smartphones and tablets – they perform diverse functions but all share a common future – they will eventually reach end of life. With rapid product development cycles and robust consumer demand for the latest capabilities and features, the challenges associated with e-waste are changing nearly as fast as CE technologies.

Individually, many CE manufacturers and retailers have implemented high-impact programs to encourage the diversion of their products from the waste stream at end of life. At CEA, we support and applaud those efforts – but we also know more needs to be done, and on a collective basis.

In 2011 that recognition drove the creation of the eCycling Leadership Initiative. It is an unprecedented national CE recycling effort structured to achieve several key goals:

- Improve consumer awareness of the more than 8,000 available collection sites currently sponsored by our industry, which can be found on CEA's www.GreenerGadgets.org;
- Increase the amount of electronics materials recycled responsibly to one billion pounds annually by 2016;
- Increase the number of collection opportunities available to consumers; and
- Provide regular, transparent metrics on eCycling performance.

Spearheaded by CEA, the eCycling Leadership Initiative represents a unique collaboration between consumer electronics manufacturers, retailers, collectors, recyclers, nongovernmental organizations and governments at all levels.

**A National Approach to a National Issue**

Consumer electronics are widely used in virtually every community in the United States. Given the widespread marketplace penetration of CE products, CEA supports a national approach to eCycling. We are working to make recycling electronics as easy as purchasing them, for all consumers in every state in our nation.

**CEA's CRT Challenge: Seeking New Solutions**

[illegible]

# A Partnership That Breaks New Ground

Salt Lake County, UT, like many other American communities, is seeking new solutions to the challenge of proper collection and processing of electronic waste. Successful diversion of this material from the waste stream requires both effective public education and the infrastructure and capacity to responsibly recycle end-of-life electronics.

At CEA we believe that voluntary, collaborative partnerships between industry, government and community stakeholders offer the best path to reach the goal we all seek – keeping electronics out of landfills and maximizing the responsible recycling of end-of-life material. Today, Salt Lake County's partnership with **Samsung Electronics** is demonstrating just how successful that approach can be. And it may serve as a national model of what can be accomplished when industry and government work together.

Through this innovative partnership, Samsung provides support for the Salt Lake County Health Department's (SLCHD) e-scrap activities that serve a community of 1.8 million people in the Salt Lake City (SLC) area. The company supports collection operations at five permanent locations. The collaborative program between SLCHD and Samsung also includes 17 one-day public e-waste collection events, including curbside pickups, held throughout the community each year. Some events, such as the one which takes place at the University of Utah in April, include incentives for participants – such as sweepstakes for free Samsung products for those who sign the ENERGY STAR pledge, which reminds pledge takers to consider ENERGY STAR when purchasing consumer products. ENERGY STAR is a climate-change mitigation program that creates opportunity for consumers to help the environment, while reducing energy consumption and costs for consumers through use of high-quality, energy-efficient products.

According to Dorothy Adams, who directs the Health Department's Household Hazardous Waste Program, public reaction has been strong for the county's e-waste initiatives and the prize drawings associated with the ENERGY STAR pledge. "Very seldom do people come into government offices with such excitement, happy to win a Samsung product from the recycling event and ENERGY STAR pledge drive. We got many emails saying that it was a nice touch that they were rewarded essentially for taking the time to responsibly recycle their electronic scrap," said Adams.

In 2012, the county collected more than half a million pounds of electronic waste – constituting about 42 percent of the program's hazardous household waste volume for the year. Consistent public education about the environmental benefits of eCycling is a strong program component. "Our volumes continue to grow, and as we make it more convenient we collect more material," said Adams.

Mike Moss, Director, Corporate Environmental and Regulatory Affairs for Samsung Electronics America, said the company's commitment to Salt Lake County and to its broader recycling program "emerged out of the strong efforts of SLCHD to partner with Samsung to solve the e-waste issues in a collaborative and effective manner. It's all about a shared responsibility, everyone working together to create a solution. We believe that reaching out to the community through programs, like our e-waste program with the greater Salt Lake City area through SLCHD, offers a great opportunity to create positive business and environmental results for the area, and for Samsung."

Added Adams, "Samsung has been a wonderful partner. We look for that partnership to continue, because it is meeting a very important need in our area. We see this as a real model, and we're hopeful it expands to other communities in the state."

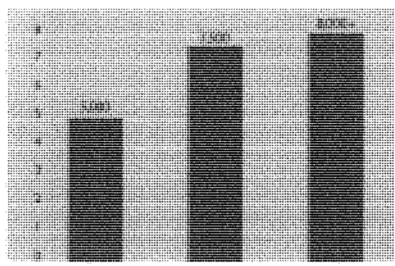
# eCycling Points of Progress

eCycling LEADERSHIP INITIATIVE

greener gadgets

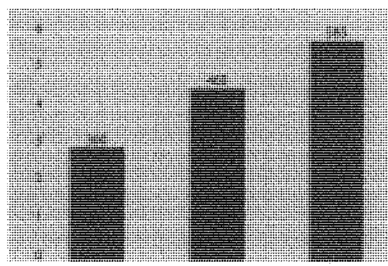
## Number of eCycling Locations Nationwide

Increased 60 percent in three years

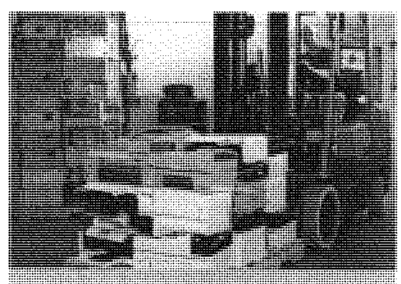



## Pounds Collected by CE Industry

Increased 95 percent in three years [in millions]




**Assuring Responsibility at Every Step**
Collecting increasing volumes of e-waste is only the first step toward conserving resources and preventing environmental damage. Today, too much of our domestic e-waste is exported overseas and into the informal sector – often in developing nations where it is processed in ways that damage the environment and public health. CE companies like **Best Buy, Samsung** and many others are setting higher standards for the processing of waste by collectors and recyclers. These and many other CE companies are requiring as an initial screen that their recycling partners be certified by e-Stewards, R2 or both – third-party entities that establish standards for responsible handling of recovered materials that draw heavily from manufacturer/vendor due diligence and auditing processes pioneered during the 1990s and 2000s.



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# Avoiding the Landfill

## An Old Desktop Computer's Final Hours

In fiscal 2013, **Best Buy** collected and responsibly recycled 96 million pounds of consumer electronics. But what happens behind the scenes when a consumer brings in, for example, an old desktop computer to their local Best Buy store? After the unit is brought in, it is boxed for shipment to one of Best Buy's recycling partners – each provider must have earned certification by either R2 or e-Stewards. At the recycling facility, components are sorted into various waste streams.

The keyboard heads straight to the shredder, but other components require more processing. The CPU's hard drive is removed and connected to a device to erase all its data. As an additional step to ensure data privacy, the drive is snapped with a hole punch to destroy it. Only then is it directed to the shredder with other CPU components. The high-tech shredder uses sophisticated technology to separate the steel, aluminum and precious metals from the plastic. Meanwhile, the CRT is saw cut along the frit line, and the panel glass is removed from the funnel glass and the frit before the bare CRT is crushed. The glass pieces are cleaned, then both streams are crushed for eventual smelter processing.

Visit here (insert video link) to learn more about what goes on behind the scenes in Best Buy's eCycling operations.

In fiscal 2013, Best Buy collected and responsibly recycled **96 million pounds** of consumer electronics.

# New Life for Older Devices

Another important contributor to diverting CE products from the waste stream is a robust secondary market for used devices. Several CE companies are taking the lead to help grow this burgeoning retail sector – which in 2011 was estimated to be worth $13 billion in annual sales.

Through buybacks, trade-ins, refurbishments and resales, consumers have the opportunity to monetize their old devices, and purchasers can access technology more inexpensively. Moreover, through secondary market activity, hundreds of thousands of products do not reach landfills or recycling collection centers.

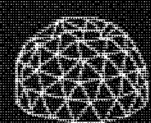
In 2012, **NextWorth**, a technology and recommerce company, collected more than 350,000 devices nationwide. NextWorth provides omni-channel trade-in programs for leading retailers and OEMs including nearly 1,500 locations at Target stores nationwide. In 2013, NextWorth will collect between 750,000 and one million devices and has collected more than two million devices since inception.

**Brightstar** operates global device buyback and trade-in programs, offered through major wireless operators and retailers. And **Best Buy** manages a portfolio of refurbished products, available at Best Buy stores or through secondary markets.

When electronics are repurposed, individuals and companies are understandably concerned about hard disk drives that often contain sensitive data, such as financial records, social security numbers or medical files. Solutions offered by companies such as **Aleratec, Inc.** address this problem. Aleratec's hard disk drive duplicators permanently delete sensitive information from used hard drives. Using Secure Erase or third-party-certified overwrite technology, the data are completely sanitized, thus preventing confidential information from falling into the wrong hands. And the duplicators offer a more sustainable alternative to hard disk drive destruction.

**$13 billion** estimated sales of used devices in 2011

# Sustainable Operations



"I look for what needs to be done. After all, that's how the universe designs itself."

**R. Buckminster Fuller**, *a renowned twentieth century visionary and inventor, most notably of the geodesic dome*

# Leading the Drive Toward Eco-Efficiency

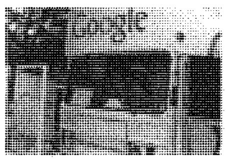
As we confront the challenge of climate change, what needs to be done is clear – but not always easy to achieve. For the CE industry it means we must perform our work more eco-efficiently – discharging less carbon into the atmosphere as we deliver on the promise of ever more capable technology to inform, educate and entertain millions of consumers here and around the world.

To that end, many CE companies have taken a leading role to design facilities, processes and supply chains that are more resource efficient, that require less energy and water, and that produce less waste. This effort includes a large and growing commitment to energy from renewable sources. It also encompasses more efficient transportation for products and for the people who design, manufacture and sell them. And it means investing to boost efficiency at the massive data centers that are crucial to connecting our wired world.

Today and in the years ahead, bold, continuous innovation will be the key factor as our industry strives to find new ways to deliver greater value while continuing to reduce or eliminate harmful environmental impacts.

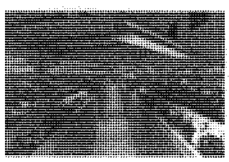
# Targeting Eco-Excellence

Across the CE industry, leaders are making smart choices to operate more sustainably – in their facilities and throughout their logistics and operations.



### Googling a More Sustainable Commute

**Google** has built a green transportation system incorporating biodiesel shuttle buses and the largest corporate electric vehicle charging infrastructure in the United States. GFleet – a car-sharing program for employees – includes the newest generation of plug-in vehicles. Combined, these efforts result in a net annual savings of more than 5,400 metric tons of CO2 – the equivalent of avoiding 40 million vehicle miles.



### Hyper-Efficient Data

**HP**'s award-winning Wynyard trade data center is powered by 100 percent renewable energy – and is one of the most efficient general-purpose data centers in the world. Features such as ambient air cooling, white walls and a reflective roof add to its high levels of energy efficiency.

### Less Running on Empty

**Best Buy** has reengineered its fleet operations to reduce "empty miles" – the distance driven with no products on a truck – by back-hauling e-waste to distribution centers, where it is collected by the company's recycling partners. In its first year of implementation, the initiative reduced empty miles traveled by more than 560,000.

### Designed for Conservation

The **Plantronics**' Santa Cruz, CA, headquarters was designed to meet the standards of California's **Savings by Design** program. At the facility, low-flow plumbing fixtures, waterless urinals, drought-tolerant plant materials and a smart irrigation system combine to conserve 550,000 gallons of water per year.

### An Investment in LEED

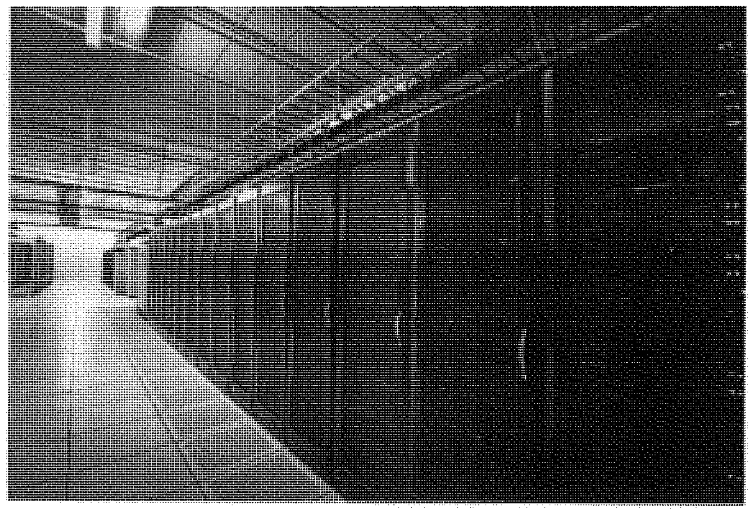
Now under construction in Newark, NJ, **Panasonic**'s new U.S. headquarters is being built to the exacting environmental standards of the U.S. Green Building Council's Leadership in Energy and Environmental Design – LEED. The external shell of the facility will be LEED-certified Gold and the interior will be LEED Platinum.

### Renewable Leadership

As part of **Samsung**'s participation in the EPA's Green Power Partnership , Samsung purchases more than 25 percent of its power (more than 25.5 GWh) from renewable energy sources. Included in this mix is an array of solar panels on the rooftop of its Rancho Dominguez, CA, facility, which generates more power than the facility consumes.

**AMD**'s newest data center, located in Alpharetta, GA, was awarded a LEED Commercial Interiors certification and was powered by 100 percent renewable wind energy in 2012.

# Big Data, Big Opportunities



Data centers have been with us since the advent of the mainframe computer more than half a century ago. Today, their importance and relevance to our daily lives has grown exponentially along with the explosion of digital information. Sending an email, downloading an app, streaming a movie, performing a web search – these and countless other daily tasks today rely on data centers. And the projected growth of cloud-based storage and services will likely expand their role yet further.

Data centers and the millions of servers they house are essential to today's wired world – and they are also big consumers of energy. Consider that a typical server remains on every hour of every day – that is 8,760 hours a year of energy consumption. The electricity to run a single server can cost $1,000 a year and, when the associated energy costs to cool the facility and convert power are included, that amount can double.

A 2011 Stanford University study found that the global electricity consumption of data centers grew by approximately 56 percent between 2005 and 2010 and today represents as much as 2.5 percent of total electricity use in the United States.

**$1,000** – estimated electricity cost for one server for one year

**56%** – estimated increase in global data center electricity consumption [2005-2010]

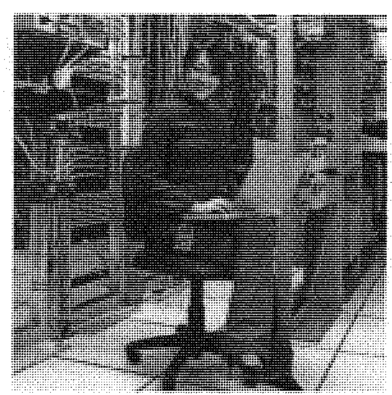
**2.5%** – estimated total U.S. electricity consumption for data centers

Big Data, Big Opportunities *continued*

**The trajectory of data traffic and storage is clearly upward.** However, CE company teams are working today to bend the curve of data center energy demands in a new direction. They are taking strides to make their own facilities much more energy efficient, and they are helping their business customers save energy and money through better design strategies.

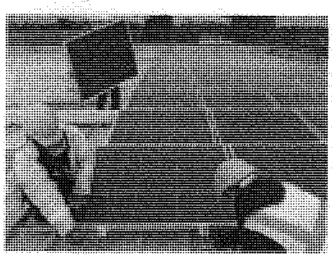
- **Google** is one of the leaders of this effort. Their massive data centers employ best practices like taking advantage of evaporative cooling, increasing ambient center temperatures to 80 degrees, eliminating water chillers and optimizing power distribution.
- At its Western Technology Center in Quincy, WA, **Dell** employs heat-wheel technology that maximizes the use of outside air, which reduces the center's overall energy and water demands. This is in addition to other energy-efficient and low-carbon features, such as taking advantage of fresh-air cooling during much of the year, and most of the facility's electricity comes from renewable sources.
- **AMD** has teamed up with Clarkson University, HP and other partners to research effective ways to power data centers from renewable energy sources. The goal is to build a distributed computing network by co-locating renewable energy sources such as wind and solar with containerized data centers like HP's Performance Optimized Data-center, which is driven by AMD Opteron™ microprocessors.
- **HP** is addressing the need for lower cost and more efficient server technology with its **Project Moonshot** initiative – a multiyear program designed to offer extreme low-energy server technologies. Rather than designing a server for all uses, Moonshot designs are optimized for the specific type of software and operation they will be running, thereby reducing energy use by up to 89 percent and costs by up to 63 percent. In fact, HP is using Moonshot's servers to power the company's primary web presence (HP.com), which gets more than 300 million hits per day. These Moonshot servers are so energy efficient that the total power consumed by the servers powering HP.com is equal to that consumed by 12 60-watt lightbulbs.

Today, **Microsoft** is using electricity market analytics to increase the use of renewable energy sources in data centers and reduce its carbon emissions by up to 99 percent. The work involves analyzing algorithms that rate different criteria on the electric grid, like current, carbon emissions and the rate at which renewable energy is being integrated to power the grid. This analysis can help determine the best time to perform Microsoft's highest-energy-consuming computation, scheduling moveable computation at times when the grid is being powered by renewable energy sources or, alternatively, relocating computation to areas of the grid where renewable energy sources are being utilized. These measures can help reduce the overall carbon footprint associated with cloud computing.



# Powering Innovation – Renewably

Coupled with innovative efficiency measures for facilities and equipment, CE companies are working to lower GHG emissions through a growing commitment to renewable energy. These large-scale investments are reducing their carbon footprint, supporting breakthrough sustainable energy technologies and helping to build stronger long-term market demand for green power. In addition, CE companies are designing and manufacturing some of the most promising new innovations to generate power renewably. Taken together, these commitments are moving us toward a more renewable and responsible energy future.



**Plantronics** investments in solar arrays and sun tubes, which harness natural light to save energy, have offset 80 percent of the energy consumption at the California headquarters buildings that house the panels. In addition, solar panels at its Tennessee facility have produced electricity savings of 32 percent monthly.

**LG Electronics** is both a major provider and deployer of photovoltaic systems. In 2012 the company supplied solar panels to customers in 32 countries – and sold 1.6 million high-efficiency panels between 2010 and 2012. At its new U.S. headquarters in Englewood Cliffs, NJ, the company will install an 85,000-square-foot solar array system, expected to generate more than 1,000 MWh of electricity annually.

By the end of fiscal 2013, 16 **Dell** facilities were purchasing 100 percent of their electricity needs from renewable sources such as wind, water and solar – an increase from seven facilities in fiscal 2012. These include Dell's headquarters in Round Rock, TX, which has purchased 100 percent renewable electricity since 2007. Overall, Dell sourced 22.6 percent of its electricity from renewables, and has been on the U.S. EPA's Green Power Partnership Top 50 list since 2008.

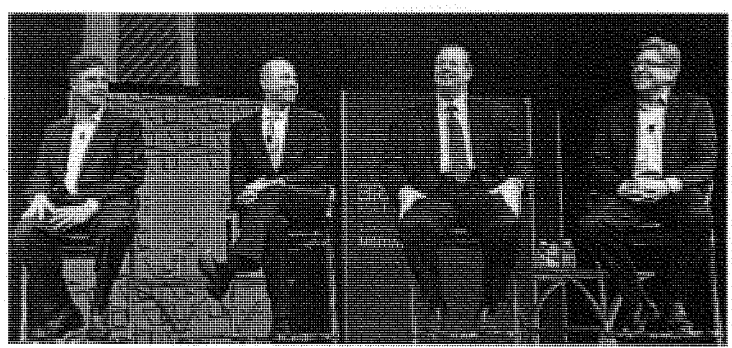
A leader in both photovoltaic and fuel cell technologies, **Panasonic** has a diverse portfolio of renewable energy solutions. Their HIT240/233 panels are designed for residential use and boast the world's highest energy conversion efficiency rate. Panasonic was also the first to offer a household fuel cell cogeneration system – which leverages the electrochemical reaction between oxygen and hydrogen.

In 2013, **Intel** was recognized for the fifth consecutive year as the largest voluntary purchaser of green power in the United States, according to the U.S. EPA's Green Power Partnership rankings. Intel has committed to purchase a total of approximately 12.4 billion kWh of green power from 2008 through 2013, which is equivalent to the greenhouse gas emissions impact of taking 1.8 million cars off the road for one year.

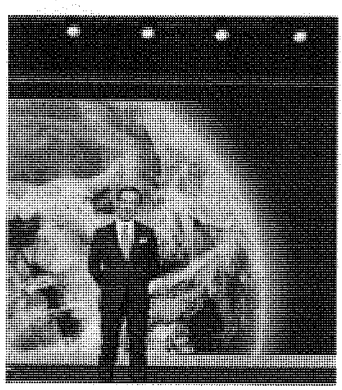
**HP** has installed more than 1,400 rooftop solar panels at its data center in Suwanee, GA. The solar array is estimated to generate approximately 450,000 kWh per year, enough to power the center's noncritical facilities.

# International CES

## Little Things That Make the World's Biggest Trade Show Even Greener



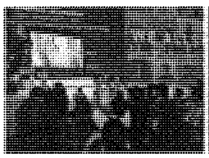
The Brand Matters keynote at the 2013 International CES brings together executives from the world's top brands to discuss how technology and digital platforms are impacting marketing and brand strategy on a global scale.

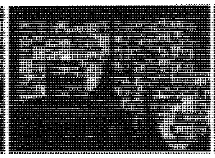


Panasonic's Mr. Kazuhiro Tsuga delivers the opening keynote at the 2013 International CES.

As owner and producer of International CES, the world's largest innovation event, CEA is committed to making this global event both a venue to spotlight more sustainable solutions – and an event that raises the bar for eco-friendly operations. The 2013 CES drew nearly 3,300 exhibitors and more than 152,000 industry professionals – providing the ideal setting to demonstrate that there are no limits to environmental innovation.

International CES *continued*





## All Together, At Once – a Big Ecofriendly Idea

When CES attendees from across the world connect with one another, build new relationships and get business done in a single location, they collectively avoid nearly two million miles in business travel. And with more than 36,000 industry leaders from 150 countries in attendance, CES has become truly a global village of innovation.

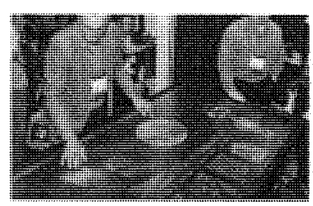
## Green Starts With Knives, Forks and Spoons

No detail is too small to enhance the eco-efficiency of CES – even the eating utensils supplied by our catering partner Aramark are made of biodegradable organic products. We review every aspect of operations to identify greener alternatives.

Environmentally friendly cleaners are used instead of harsh chemicals. A closed-loop recycling process that reclaims the previous year's vinyl banners is used to produce 190,000 show badge holders. By adopting better digital alternatives, production of print materials has been reduced by nearly 50 percent from six years ago. Show floor carpeting is made from recycled materials, and turnkey exhibitor booth packages use recyclable panels and soy ink printing. And the reuse/recycle rate for solid waste generated at the show stands at 75 percent. These efforts have spurred one trade publication to designate CES as "North America's Greenest Show."

## Building a Lasting Legacy

CEA has established a tradition of investing in projects that support sustainability in the City of Las Vegas and benefit the local community. In 2013, $50,000 donations were awarded to Green Chips, a local sustainability group to fund a solar installation project, and to the city's Convention and Visitors Authority for the installation of electric vehicle charging stations at the convention center.



# Reaching Higher

## [Key Accomplishments]

CE companies are setting aggressive goals to deliver higher levels of environmental and social performance. Important milestones have been reached; more progress is required to reach some of the most ambitious objectives.

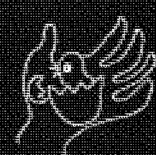
| COMPANY | GOALS AND PROGRESS |
|---|---|
| Best Buy | Reduce absolute carbon emissions in North America by 20 percent by 2020 from a 2009 baseline. Best Buy is more than 75 percent toward attainment. Since the goal was set, absolute carbon has been reduced by 16.8 percent, and 223 million kWh have been saved by conservation and efficiency improvements. Best Buy was recognized by the Carbon Disclosure Project with a score of "96" and a performance band of "A" in the Carbon Disclosure Performance Leadership Index (CDLI). |
| | To collect one billion pounds of consumer electronics and appliances for recycling by the end of calendar year 2014. More than 700 million pounds of consumer electronics and appliances collected to date. In fiscal 2013, 96 million pounds of consumer electronics were collected. |
| Dell | Offer EPEAT-registered models in the United States and Canada for all newly offered commercial and end-user computing products by the close of fiscal 2013. Progress: achieved. |
| | To increase electronics take-back volume totals to a worldwide cumulative one billion pounds of collected equipment by 2014. By 2013 Dell had attained this goal. |
| Google | Google uses huge quantities of servers and other equipment to power its operations. The company has attained its goal of recycling 100 percent of the electronic equipment that leaves its data centers. Since 2007, Google has repurposed enough outdated servers to avoid buying 300,000 new replacements. |
| | To power the company with 100 percent renewable energy – that is the ambitious long-term goal Google has established for eco-efficiency. By 2013, renewable power was used to power more than 30 percent of its operations. |
| HP | Reduce greenhouse gas emissions from product transport by 180,000 tonnes of $CO_2e$ from the end of 2008. HP has met and exceeded this goal by implementing network enhancements, warehouse consolidations, mode changes and route optimization programs. |
| | Complete the phase-out of bis (2-ethylhexyl) phthalate (DEHP), dibutyl phthalate (DBP) and benzyl butyl phthalate (BBP) in newly introduced personal computing products by the end of 2012. Goals achieved: all HP personal computing products to be newly introduced in 2013 meet these requirements. |
| Panasonic | In its effort to reduce the amount of newly extracted resources used in its products, Panasonic set a fiscal 2012 target that 12 percent of all resources used be from recycled materials. The amount of recycled content in its products that year – 14.7 percent – exceeded the goal, and the company used approximately 8,000 tons of recycled plastic for its products during the year. |
| | In addition to its efforts to reduce carbon emissions, Panasonic established a goal to reduce GHGs other than $CO_2$ – these gases are mainly used as etching and cleaning gases in semiconductor factories. In fiscal 2012 the company had achieved a 60 percent reduction of these emissions from its 1995 baseline level. |

# Targeting More Progress

Looking to the future, many CE companies have established goals and objectives to take their environmental performance to a higher level.

| COMPANY | GOALS |
|---|---|
| LG Electronics | Reduce greenhouse gas emissions from its U.S. operations by 50 percent by the end of 2020. |
| Panasonic | Increase to 16 percent the amount of postconsumer recycled content materials contained in new product lineup by 2018. |
| AMD | By 2017, to avoid 10 percent of GHG emissions and achieve 10 percent avoidance in manufacturing water use, based on a 2012 baseline, through conservation efforts. |
| Sony | By 2050, to achieve a zero environmental footprint throughout the life cycle of its products and business activities – a plan Sony calls its "Road to Zero." The company has established mid-term targets to be met by fiscal 2015 on the path toward this ambitious long-term objective. |
| DIRECTV | DIRECTV reduced its carbon footprint 10 percent relative to its 2011 baseline. This single-year reduction allowed DIRECTV to surpass its 2015 emissions reduction goal several years ahead of schedule. |
| Samsung | By 2015 to decrease the volume of waste generated per unit of production by 10 percent a year, and to increase its waste recycling rate to 95 percent. Samsung now recycles waste glass, waste plastics and organic sludge that were incinerated or landfilled in the past. |
| Microsoft | By fiscal 2013 achieve carbon neutrality and net-zero emissions for Microsoft's data centers, software development labs, offices and employee travel by increasing energy efficiency and purchasing renewable energy. The initiative also includes implementing an internal carbon fee that makes the company's business divisions financially responsible for the cost of their carbon emissions. |

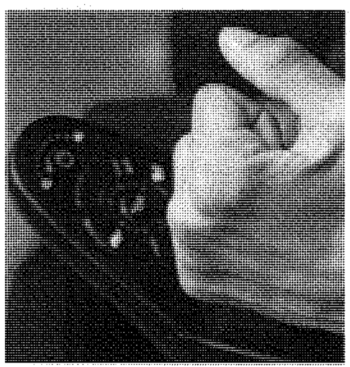
# Sustainable Society



"It is our collective and individual responsibility to protect and nurture the global family, to support its weaker members and to preserve and tend to the environment in which we all live."

**The Dalai Lama**, a simple Buddhist monk and spiritual leader of Tibet

# Tough Challenges, Big Solutions



When leveraged to its fullest, technology can be a key catalyst for progress for people and communities. The opportunity for technology to improve lives is profound – whether as a conduit for learning, commerce and creativity, as a means to improve the lives of the disabled, or to help deliver better health care to millions.

Many of today's brightest minds can be found at CE companies – men and women working to envision new solutions that address these challenges. The innovations emerging today from CE research laboratories are opening new possibilities to enrich the lives of millions of our fellow citizens.

Those efforts do not end with technological innovation. Individually and collectively, CE companies and their employees are engaged in strategies and initiatives to build a more sustainable society. This work is being carried out through volunteerism, charitable giving, mentoring youth, attacking hunger and by helping to ensure fair treatment of those whose work contributes to the products we offer.

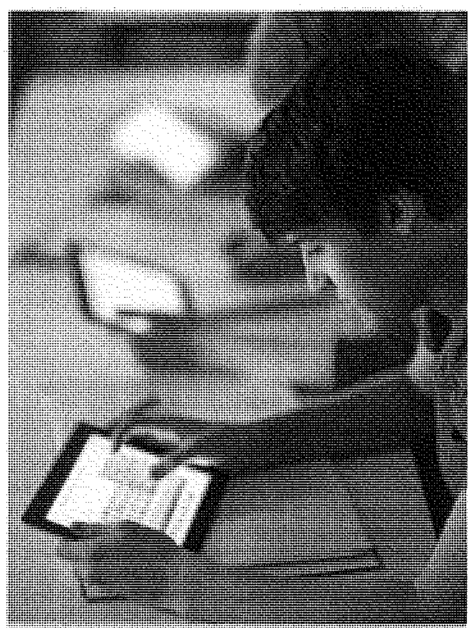
Increasing opportunity and meeting human needs is a job for all of us, and our industry is committed to expanding possibilities for every member of the global family.

# Doing More for More

Research indicates that too many American teenagers have little or no access to the kinds of technology that can improve their academic performance, strengthen their skills and put them on a path toward a bright career future. And even for teens who have some access to some technology tools, too often it is limited to passive consumption rather than active content creation. To address this need, **Best Buy** has developed a new initiative to provide greater access to the technological tools, resources and opportunities teens need to develop twenty-first century technology skills.

**Best Buy Teen Tech Centers** provide an engaging environment where teens can develop technology skills through hands-on activities such as filmmaking, music production, graphic design, robotics, mobile applications and game development. As teens undertake these projects, they hone new skills that can be applied both in the classroom and in the workplace. Best Buy is currently piloting the program with nonprofit partners in Chicago, Miami, San Antonio and Minneapolis.

To help design effective programming, support the center staff members and monitor results, Best Buy worked in collaboration with the **Intel Computer Clubhouse Network**, (ICCN). Now in its twentieth year of service, ICCN is a program of the Museum of Science, Boston that, with the support of the MIT Media Lab, reaches 25,000 youth annually through 100 clubhouses worldwide.



**Two Million by 2018: Panasonic's Goal for Youth**

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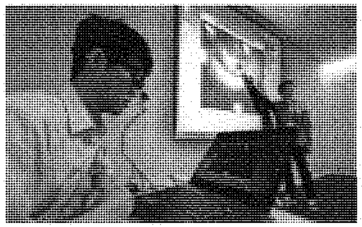
# Big Ideas That Change Lives

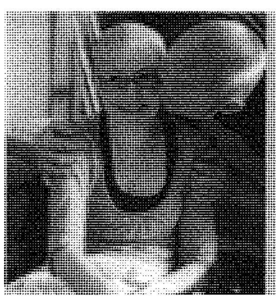


Innovative breakthroughs often begin with two simple words: What if? Recently, engineers at **Samsung Electronics** posed that very question: What if we could develop a mouse for the disabled that was inexpensive – and simple enough to be assembled with common electronic components? The result was "eyeCan," an eye-tracking mouse that can be built for a fraction of the cost of existing systems.

Samsung established the Creative Development Research Institute to provide opportunities for employees to pursue creative new ideas that take full advantage of their talents and professional passions. At the Institute, risk-taking is encouraged, and employees are accepted into the program to pursue a project for an entire year.

eyeCan, launched in 2012, was the first big idea to emerge from this creative environment. eyeCan enables individuals with profound paralysis, including those with Lou Gehrig's disease (ALS) and locked-in syndrome (LIS), to communicate with and through computers. The device, built on an open-source platform, tracks the user's eye movements to enable them to write emails and text messages, search the web and even play computer games.

The idea of an eye-tracking mouse is not new, but the breakthrough comes in the eyeCan's much lower cost. Using only a pair of eyeglasses, a web cam and a few other inexpensive electronic components, volunteers and family members can assemble their own eyeCan and access free software. This exciting work can be done for a small fraction of the expense of similar commercial devices – which can cost up to $10,000. The eyeCan team's motto describes its innovation well: "One blink, a connection to the world."



### High-Performance Computing: A Crucial Weapon to Fight Pediatric Cancer

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# See, Act, Lead

The philanthropic commitment of CE companies involves both significant cash contributions as well as donations of technology and expertise to address human needs.

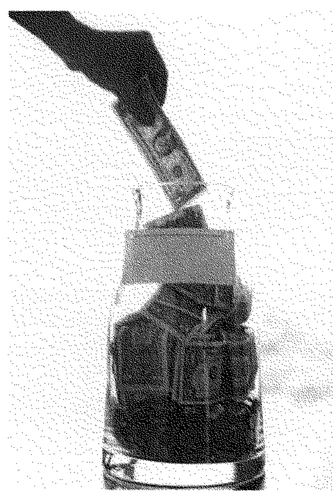
Through its Community Grants program, **Best Buy**'s retail teams across the United States choose nonprofit organizations within their communities that help teens develop twenty-first century technology skills necessary to excel at school and inspire future career choices. In fiscal 2013, the program awarded $2.75 million to more than 500 nonprofits nationwide.

**Microsoft** acts on its belief that software can help nonprofits overcome obstacles and improve their service to communities. Each year the Technology for Good program donates hundreds of millions of dollars in software to these organizations. In fiscal 2012, those contributions reached 62,200 nonprofits – a 33 percent increase from the previous year.

With the **DIRECTV** GOES TO SCHOOL® program, qualifying state-accredited K–12 schools can receive a free DIRECTV® system and a programming package – SCHOOL CHOICE® – specially designed to enhance and complement classroom lessons. This package includes a combination of news, educational and informational programming to accompany teacher instruction.

From helping to prevent deforestation to conserving the rights of indigenous populations, **Google** Earth Outreach has supported over 4,000 partners through software grants, technical support and training. By using Google Earth to visualize data and stories, these organizations have been able to promote their cause to hundreds of millions of people worldwide. The program is but one component of Google's donations of technology that totaled $1 billion in 2012.

**BlackBerry** supports its employees' efforts to give back to communities through Proud2Be, a set of internal programs which provide several opportunities to support nonprofit organizations through fundraising drives and volunteerism. Through their Proud2Be Program, BlackBerry donated to 294 organizations around the world.



# Caring That Knows No Boundaries

CE companies and their emaployees are focusing philanthropic and volunteer efforts on human and community needs not only in North America – but also in every region of the globe.

**Giving Babies in Africa a Better Chance – Right From the Start**

Today's antiretroviral ARV therapies offer excellent treatment outcomes for infants born with HIV – but they are effective only if a child is diagnosed early. Without rapid treatment, half of these newborns will not live to see their second birthday. Early testing and rapid delivery of test results are key to saving the lives of thousands of infants born with HIV in Africa each year.

**HP**, through a partnership with the Clinton Health Access Initiative and the Ministries of Health in Kenya, Uganda and Nigeria, is leveraging technology to speed up testing and improve outcomes for thousands of children. Six modern HP data centers linked to Kenya's national laboratories provide a platform to accelerate HIV test data transmission. With financial and technical support provided by HP, students at Strathmore University in Nairobi developed a custom database application to make HIV test results quickly available online – enabling real-time tracking and analysis. Faster information and faster treatment – today, technology is working wonders for thousands of African newborns.

For over five years **Dell** worked with Conservation International on a major reforestation initiative in Madagascar. Dell supported Conservation International's work with indigenous populations, programs which encourage sustainable agricultural practices and water use and protect the natural infrastructure. The project was also designed to protect some of the last remaining habitats of lemurs, found only in Madagascar.

**Making STEM a Priority**

As part of its commitment to advancing education in science, technology, engineering and math (STEM), **BlackBerry** has partnered with JA-YE Europe, Europe's largest provider of entrepreneurship education programs. The initiative supports STEM innovation camps, which provide real-life, technology-based business challenges for the students to tackle with Blackberry employee volunteers. Over 900 students from Italy, Spain, South Africa, France, Sweden and the U.K. have participated in these innovative events.

# Actions Speak

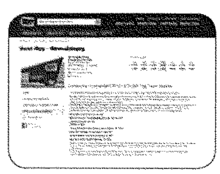
**Changing the World – Through Teamwork with Boys & Girls Clubs of America and ENERGY STAR**

An important way to reduce energy consumption and protect the climate is for each of us to choose new ways to live and play more energy efficiently. The EPA's "Save the World – Start With ENERGY STAR" pledge initiative is designed to help drive those positive behaviors. To date more than 3.2 million Americans have signed on. **Samsung**'s unique partnership with ENERGY STAR and the Boys & Girls Clubs of America (BGCA) is contributing to that success. This grassroots initiative leverages the efforts of thousands of boys and girls as they reach out to their peers, neighbors and family members to "take the pledge" to reduce energy use and address climate change.

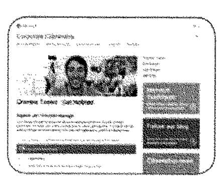
According to Marvin Laster, Director of Character and Citizenship Programs for BGCA, "Through our programs with the EPA and with Samsung's help, we have been able to engage more than 150 clubs throughout the United States. Club members have been enthusiastic and taught others in their communities about energy conservation, through the ENERGY STAR pledge and through other creative BGCA initiatives. The kids understand the importance of why we need to change the world by saving energy." Thanks to Samsung, BGCA clubs have an opportunity to compete for Samsung PCs, laptops, TVs, tablets and other valuable technology at their individual clubs.

Noted John Godfrey, Vice President, Communications Policy and Regulatory Affairs, government Samsung Electronics America, "By bringing Samsung, ENERGY STAR and BGCA together through the ENERGY STAR pledge and other BGCA initiatives related to climate change awareness, we've really made a difference in teaching young people and their families about saving energy and household costs, while helping the environment. Actually, Samsung is the number-one manufacturing partner of ENERGY STAR in signing up people for the pledges."

Learn more about Samsung's partnership with ENERGY STAR and Boys & Girls Clubs of America.



At **Best Buy** in 2012, more than 18,000 U.S. employees volunteered in excess of 100,000 hours to causes and organizations for which they are passionate. "Tag Team Awards" encourage employee involvement. The program provides monetary donations to nonprofit organizations to which employees donate their time.



**Microsoft**'s Volunteer Manager brings nonprofit needs and volunteer skills together. In 2012 more than 10,000 employees and 2,000 nonprofit organizations were registered; employees donated more than 431,000 hours of service.

# Meeting a Growing Need

Even in a land of abundance, hunger can be found all around us, and in every community there are those who lack access to adequate nutrition. The U.S. Department of Agriculture reports that nearly 15 percent of U.S. households do not have consistent access to enough food for a healthy, active life. And the number of households in severe need is growing – now standing at more than one in 20.

CE companies and their employees are stepping forward with solutions to the problem of hunger – supporting food banks, feeding kitchens and other community-based programs through financial support and volunteer effort.

**Haier** and its employees are strong supporters of the Food Bank For New York City. Their contributions include 75 employee community kitchen volunteers, a cash match of consumer donations and a Virtual Food Drive targeted to attendees at the International CES.

The **Plantronics** commitment to the Second Harvest Food Bank of Santa Cruz County, CA, began in 1997. During the last 16 years the company has donated more than three million pounds of food to local families in need.

In 2013, **Sony Pictures** combined its financial support with the contributions of participating food growers to donate over 80,000 pounds of fresh produce to Feeding America's nationwide network of food banks in support of the motion picture release of *Cloudy with a chance of Meatballs 2*. The campaign, part of Hunger Action Month, also invited consumers to support Feeding America's work on behalf of 61,000 community agencies nationwide, and a custom animated PSA was created with the Ad Council urging consumers to take action to end hunger.

In 2012, **BlackBerry** employees supported 22 food banks, donating 30,000 pounds of food globally – which helped feed 800 people in need for an entire month.

# Enabling Progress Through People

Organizations prosper and drive continuous innovation when they can leverage the talents of a fully engaged and highly motivated workforce. Providing opportunities for employees to contribute, excel and advance in their careers is how good companies become great, and great companies remain on top. Leading CE companies recognize this opportunity – as well as the importance of tapping the energy and passion of their employees to achieve their organization's sustainability objectives.

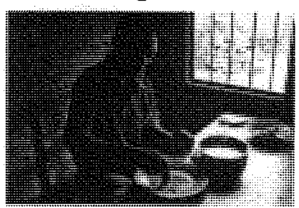
The **Sony Electronics** Green Workspace Certification (GWC) is designed to help all employees take measurable actions to reduce their personal environmental impact at work – decisions that can help reduce Sony's overall impact as well. GWC is structured to give employees a clear picture of how they can influence both eco-efficiency and cost performance. Team members are presented with opportunities for simple but impactful actions they can take in their daily work lives to make a positive difference. Accomplishments are recognized with incentives and, at the highest personal level (Tree), 50 trees are planted in the employee's name.

For **Dell**, a key driver of team member engagement is its Connected Workplace program. It enables one in five global team members to arrange their work in a flexible manner – including work from home and part-time arrangements, variable hours and job sharing. The program is not only good for employee well-being, it's good for the environment – avoiding an estimated 13 million kWh of energy and 6,785 metric tons of GHG emissions annually.

The **HP** Sustainability Network was created to help employees learn about, demonstrate and share environmental practices that benefit their professional and personal lives. With thousands of members, it is one of the largest employee network groups in the company. Local chapters coordinate a wide range of efforts, including alternative commute programs, local volunteering efforts, on-site composting and educational workshops.

# Responsible Sourcing

## Addressing Conflict Minerals



The problem of conflict minerals, the sources of tin, tantalum, tungsten and gold mined in the Democratic Republic of Congo and surrounding countries, is a serious concern to every person and organization committed to human rights and environmental protection. Efforts to exert control over these valuable resources have led to armed conflict and serious human rights abuses in the region. In the United States, legislative and regulatory actions are underway in an effort to stem the flow of conflict minerals. CE companies are undertaking a number of actions to address what clearly is one of the most significant environmental and social concerns in the global supply chain.

**BlackBerry** is taking aggressive and meaningful steps to address the problem through a variety of initiatives. The company is an active member of the EICC®–GeSI Extractives Work Group, an organization focused on developing practical traceability solutions that companies can implement to help prevent the use of minerals sourced from conflict mines. A major initiative has been the launch of a Conflict-Free Smelter (CFS) program, which seeks to identify smelters and refiners that can verify they are not processing minerals sourced from conflict mines.

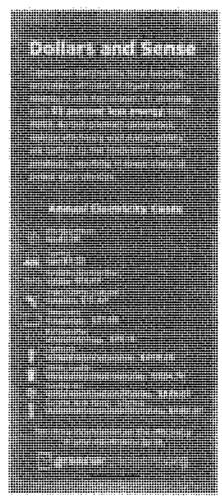
BlackBerry is also a participant in the pilot of the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas. In 2012 the company launched its program with a request sent to more than 170 direct suppliers of materials to provide information regarding their minerals sourcing practices. The company is also a member of the Public-Private Alliance for Responsible Minerals Trade, a program launched by the U.S. Department of State in 2011. The Alliance brings together governments, companies and NGOs to support supply chain solutions in the DRC and other countries in the region.

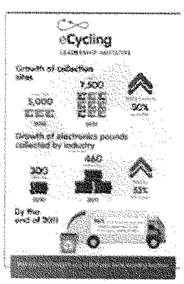
Solutions For Hope is a project created to deliver verifiably conflict-free tantalum material from the DRC in accordance with the OECD Due Diligence Guidance. BlackBerry is a participant in this effort, which utilizes a "closed pipe" strategy in which tantalite ore mined from sites within the DRC is traced along its secure supply chain to the smelter. This program helps ensure that tantalum used in BlackBerry products is derived from conflict-free sources, and also provides economic opportunities to the small artisanal miners who rely upon this work for their livelihoods.

# Leading Through Consumer Education

Knowledge is power. At CEA we believe that by empowering consumers with actionable information on how to live green, buy green and recycle responsibly, we can help millions of people lower their energy consumption, shrink their carbon footprint, reduce waste – all while saving money.

Providing that knowledge is the big idea behind GreenerGadgets.org – CEA's online resource for consumers who want to live and work more eco-efficiently. Our research shows that 60 percent of consumers are concerned about their energy bills and energy consumption – but many lack the information they need to make smarter choices. At GreenerGadgets.org consumers find valuable tools like an interactive calculator that lets them compute the energy consumption of their CE devices based upon type, quantity and the number of usage or charging hours. Online visitors can access valuable tips on how to operate their existing products more efficiently. And they can learn how to make their next purchase a greener purchase – including links to EPEAT-registered and ENERGY STAR-labeled devices.



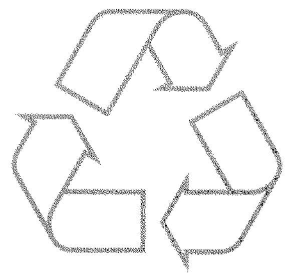




### Spreading the Word About Responsible Recycling

Public education is central to our strategy to help divert more end-of-life CE products from the nation's waste stream. At GreenerGadgets.org consumers learn more about the importance of responsible eCycling – and they can find a responsible recycling collection location in their community by using our zip code search tool. The database of electronics recyclers is created in partnership with the National Center for Electronics Recycling (NCER), a non-profit dedicated to the development and enhancement of a national infrastructure for electronics recycling in the United States. As of September 2013, there are more than 8,000 locations nationwide, from Bar Harbor, ME, to Honolulu.

# Strong Partners, Essential Message

Recyclebank calculates that it has motivated its members to recycle nearly **four billion pounds of material** – an amount that continues to grow every minute of every day.



As part of an ongoing effort to build increased awareness of CEA's consumer education efforts and GreenerGadgets.org, we have partnered with **Recyclebank** – an innovative company that motivates individuals and communities to live more sustainably.

Recyclebank's more than four million members earn points for taking everyday green actions – points they can redeem for valuable products, services and offers from their commercial partners. Points are earned by taking green actions like reading and learning about environmental concerns, making a greener purchase, using fewer resources or recycling materials responsibly. Recyclebank calculates that it has motivated its members to recycle more than 3.5 billion pounds of material – an amount that continues to grow every minute of every day.

Recyclebank is an important point of referral to drive more and more visitors to GreenerGadgets.org – where its members can earn points for actions such as looking up an eCycling location or learning how to save energy when they purchase and operate a CE product. Looking ahead, we believe it is a partnership that will continue to benefit more and more consumers – and the planet as well.

# About This Report

CEA's 2013 Sustainability Report is our third, issued biennially, profiling the sustainability challenges, opportunities and performance of our member companies, of the consumer electronics industry generally and of CEA and its internal operations. This report addresses industry activities during calendar years 2011, 2012 and portions of 2013.

By necessity, this report does not attempt to document the activities, initiatives and performance of all of our 2,200 member companies. Such an effort, while valuable, would be of a size and complexity far beyond the scope of this project. In this year's report we have chosen not to aggregate greenhouse gas (GHG) and electricity usage data reported by the 10 largest companies in our membership. The composition of that group has changed since our last report, reporting practices and periods are not consistent across all companies, and any comparison to previously published aggregated metrics would therefore be unhelpful or even misleading.

The content of this year's report is drawn from reports, case studies and data submitted by CEA members; from interviews with industry representatives and public stakeholders; from academic, governmental and NGO sources, including the U.S. Environmental Protection Agency and the Green Electronics Council; from media accounts; and from the public corporate sustainability and corporate responsibility reports published by CEA members.

In many instances, additional information concerning members' operations and performance is available on their corporate websites or can be found within their own sustainability reports.

In an effort to conserve natural resources, this report was designed for distribution in interactive form, including mobile-friendly formats, or via a downloadable personal document format (pdf).

We value your feedback. For comments, suggestions or questions about this report, please contact: Samantha Nevels at **snevels@ce.org** or 866-858-1555.

# For More Information Contact

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Testimony of Stephen Skurnac

Sims Recycling Solutions

Before the Senate Committee on Homeland Security and Government Affairs

"Recycling Electronics: A Common Sense Solution for Enhancing Government Efficiency and Protecting Our Environment"

February 27, 2014

Good morning, I am Stephen Skurnac, President of Sims Recycling Solutions. Thank you, Mr. Chairmen and committee members for the opportunity to speak to you today about electronics recycling.

By way of background, Sims Recycling Solutions is the world's largest electronics recycler, processing more than 700,000 tons per year at 42 facilities in 14 countries and generating revenues approaching US$1B annually. We operate facilities in developed regions such as North America, the EU, Australia and New Zealand as well as developing countries such as India, South Africa and Dubai. This global perspective gives us unique insight to a variety of electronics recycling business models and government led initiatives. I have personally been involved with electronics recycling since 1991 and prior to that I was employed in the mining and metals industry.

Electronic waste is one of the world's fastest growing waste streams. According to statistics published by the StEP (Solving the Ewaste Problem) organization, sponsored by the UN University almost 48.9 million metric tons of used electrical and electronic products were produced last year – an average of 7 kg for each of the world's 7 billion people. StEP also estimates that by 2017, the total annual volume will be 33 per cent higher at 65.4 million tons. The US share is currently estimated at 10 million tons. A study by the US EPA looked at data available for 2009 and estimated that 5 million tons of e-waste was in storage and only 25% of the available e-waste was actually recycled. Studies by MIT and the National Center for Electronics Recycling (NCER) suggest much higher recycling rates but also much lower total volumes. The discrepancies are based on different calculation methods and different data pools but it is clear that e-waste volumes are significant and growing enormously.

Electronic waste is both a significant environmental hazard to human health and the environment if not managed properly and also a significant source of commodity raw materials if recycled properly. In addition, used electronic items that are still functioning can be re-used by all manner of consumers in virtually every country where new technology may be too expensive or difficult to acquire.

With the notable exception of the United States, most developed countries treat discarded electronics as a special waste requiring easy and convenient collection from consumers, domestic recycling without export of whole unprocessed equipment and reporting of volumes and materials collected and recycled.

The mechanisms to achieve this vary by country but generally there is national legislation covering the key principles and a robust marketplace involving collection organizations, logistics providers, recyclers and equipment manufacturers.

In the United States, federal rules are in place to manage the export of cathode ray tube (CRT) glass from old televisions and computer monitors but there are no federal laws mandating collection or recycling activities of e-waste. Many individual states have implemented e-waste recycling programs designed to encourage the collection and recycling of certain types of common personal electronics with a general stipulation that manufacturers should be liable for the bulk of the cost of collecting and recycling the old electronics.

E-waste in the United States that is not being stored has three main destinations: domestic landfill, delivery to a domestic e-waste recycler or export to processors in foreign markets. As part of their recycling initiatives, some states have banned e-waste from landfills due to the potential to leach toxic constituents such as heavy metals. Export of e-waste is legal and unrestricted with the exception of federal rules governing CRT devices. Domestic recyclers number over 1,000 and many are certified to one or both of the nationally recognized certification programs for e-recycling. The certification assures that the material will be managed in an environmentally sound manner with transparency as to recycling processes and destinations of commodity products leaving the certified recyclers premises. Domestic recycling also generates significantly more jobs and ancillary benefits than export oriented recyclers.

While volumes of e-waste continue to grow, both globally and certainly in the United States, the success and continued growth of the domestic electronics recycling industry is not as certain due to a confluence of factors. Vast amounts of e-waste remain in storage in homes and businesses due to a lack of awareness of recycling options and more significantly, a convenient and cost neutral collection mechanism. The cost of collection is often overlooked when analyzing the recycling supply chain but it is a significant burden to market participants that must somehow be incorporated into the overall cost mechanism. This issue has been starkly brought to light in New Jersey as the 2011 state law requiring collection and recycling of e-waste has run into problems due to a lack of clarity on funding requirements. The end result is e-waste piling up at county collection centers or some county programs stopping the collection of e-waste because they have no recyclers willing to take the material. The solution requires input from all stakeholders but consensus will be difficult due to competing interests and the need for financial support of the program.

Export of e-waste is an ongoing concern in that some material is still exported to developing countries where significant harm to human health and the environment occurs due to unsophisticated recycling methods. The MIT study suggested this export stream represented only 8% of e-waste but by their own admission the export data was unreliable and the 8% certainly represents the lower end of export volumes. The illegal trade in e-waste has even prompted Interpol to organize a special unit specifically to track and prosecute illegal waste activities.

Finally, used electronic items that are still in reasonable working condition are actively sourced and traded in both domestic and international markets and this segment of the industry is expected to continue to grow as more consumers replace relatively new gadgets with the latest offerings from manufacturers. Older equipment, however, that does not have reuse value presents a challenge to recyclers given the complex mix of commodities contained in the material and the investments required to build and operate recycling facilities.

A further item of concern for any business or consumer that discards electronics is the personal or business confidential data that is contained on the storage devices within the equipment. Certified recyclers will erase or destroy this data during the reuse or recycling processes. Collectors, traders, exporters and un-certified recyclers offer no such guarantees. Managing this data erasure requires additional investment in skills and equipment and while it is a strong component of corporate recycling contracts it is often overlooked in consumer or government sponsored programs. The uncontrolled release of private data through mis-management of e-waste can result in personal identity theft right through to national security issues if government equipment is not managed properly.

Fundamentally, the US is faced with some key discussion points with respect to domestic e-waste.

What decisions should be made with respect to banning e-waste from all landfills in that it contains hazardous components, and technology and business entities exist to reclaim the commodities and prevent environmental damage?

What government led programs, if any, should be initiated or continued to encourage the collection and recycling of e-waste from consumers?

How do we protect consumers and businesses from unwanted leaks of private information through the discarding or recycling of e-waste?

As the largest generator of e-waste in the country, the federal government has taken steps to try and manage its e-waste through certified recyclers. This is a positive step towards responsible recycling and promoting the development of the recycling industry. However, the efficacy of these programs is largely unknown at this time.

Electronics recycling firms such as ours are extremely interested in furthering the development of the e-recycling industry. Manufacturers, recyclers and federal, state and local governments all have a vested interest in responsible recycling. We look forward to continued dialogue with all stakeholders.

Thank you for your time.

# Statement of Barbara Kyle
## National Coordinator
## Electronics TakeBack Coalition
Submitted to the
Senate Committee on Homeland Security and Government Affairs with respect to the hearing held on February 27, 2014
"Recycling Electronics: A Common Sense Solution for Enhancing Government Efficiency and Protecting Our Environment"

RE: Written Testimony on Recycling Electronics

Chairman Carper, Ranking Member Coburn, and Members of the Committee:

I am writing with respect to the February 27, 2014 hearing held by the Homeland Security on "Recycling Electronics: A Common Sense Solution for Enhancing Government Efficiency and Protecting Our Environment."

I am the National Coordinator of the Electronics TakeBack Coalition, a national coalition of environmental and consumer organizations that promote sustainability in the electronics industry, including responsible reuse and recycling of used electronics. We are pleased to see the Committee's interest in this important issue, and how the federal government could promote more e-waste recycling, and more responsible e-waste handling by consumers, governments, and recyclers alike.

As others have testified at this hearing, the e-waste problem is growing. We consume new electronics at an astonishing rate, often replacing old products even though they still work, because we want the newer, faster products with new features. This is particularly true with smart phones and tablet computers, which is where new technology is introduced all the time. While our recycling rate has improved slightly, we need to do much more to keep these products, containing many toxic materials, out of our landfills.

We believe that the most important priorities should be to encourage the following:

1. **Increasing volumes of e-waste recycling**. It's important to understand that the biggest factor responsible for increased volumes of e-waste recycling in recent years is the growing collection of state e-waste laws, particularly those with performance requirements. My organization pays close attention both to state e-waste laws and manufacturers' recycling efforts. It's become abundantly clear that most manufacturers (with some notable exceptions, including Dell, Samsung, and Best Buy) do ONLY what the laws require them to do. Nothing more. While many manufacturers claim to have vibrant takeback programs, closer inspection shows that most have few collection sites in states with no takeback laws (or weak laws). This Committee should be cognizant of this. Therefore, for those who want to ensure and advance recycling in the e-waste area, it's crucial that the federal government not do anything that undermines these valuable state programs.
   The Electronics TakeBack Coalition is concerned that anyone in Congress contemplating crafting potential federal takeback legislation would likely set a much lower bar than many States have already enacted, and this would be done under the guise of changing from a so-called patchwork system to a federal set of standards. In this scenario it reasonable to expect that

such a federal standard would be lower, not higher, than what the states are doing. It would be supported by industry associations and others proclaiming themselves champions of recycling, but who don't actually support the policies that are working in many states. Such a bill would be an unfortunate step backwards. This would actually result in less recycling in some states, not more. While ETBC is sure that is not the goal of this Committee, nevertheless, this concern bears noting for the record. Let us be clear: All previous efforts to reach agreement among stakeholders on concepts for federal legislation on takeback have revealed that most of the industry will not support laws with strong performance requirements. Therefore, ETBC encourages the federal government not to pursue federal takeback legislation at this time, not to take a clear and unfortunate step backwards, while claiming to support recycling efforts in this area. The states are the laboratories that are showing the way, and they should not be preempted continuing the progress they have made.

2. **Ensure that still-working devices are directed into reuse channels**. While ETBC s wants to improve the U.S.' fairly low rates of recycling, ETBC believes we also need to increase the amount of reuse of working products that have been cast aside even though they continue to function properly. That means we need to get them into proper reuse channels fairly soon after the initial owner stops using them, and before they become obsolete. As the representative from Keep America Beautiful testified, consumers often set these items aside because they know they still work, but they don't understand the real environmental value of making sure they get reused. We believe it would be helpful if the EPA or other member of the Interagency Task Force on Electronics Stewardship, or another appropriate entity, could produce a report that quantifies the environmental benefits of reuse compared to recycling used electronic products, and buying used products compared to buying new products. There is little "hard data" available on this topic for advocates, businesses, and governments to use to promote efforts aimed at reuse.
3. **Make electronics easier to repair and refurbish**. Many devices, like mobile phones and mobile computers, are getting smaller and thinner. The industry likes to say that it is decreasing the environmental footprint of its products by using less material. That is partly true, but what they don't mention is that many companies are making these products much more difficult to take apart (without destroying them), more difficult to repair, and to allow second, and third "lifetimes" for these products. This is a trend that entities promoting and encouraging reuse (like the gadget repair network called iFixit) have identified as a significant problem that is getting worse. There are some stakeholder processes to develop purchasing standards currently under development (under the EPEAT program), and they are attempting to include criteria that address this problem. While some federal agencies participate in these processes, the GSA does not. As the federal government's purchasing arm, GSA should participate as a purchasing stakeholder in these processes, to encourage inclusion of strong criteria on reuse, refurbishment, and recycling. This is a specific recommendation on which the Committee should focus.
4. **Responsible e-waste processing.** While we want to increase the volume of e-waste we collect for recycling, we need to be sure that what gets collected is handled in a responsible, environmentally sound way, that doesn't harm workers or communities. This is a significant issue with e-waste handling, because some collectors sell untested and non-working electronics to brokers or other entities who export it to developing nations (often in violation of those countries laws), where the toxics inside can and do cause significant harm to the people handling those products. Some people argue that as long as something has commodity value,

then it should be exported. But that position ignores the reality that much of this trade is both taking away U.S. jobs, as well as causing serious harm in the countries where we export it. The harm has been well documented in areas like Guiyu in China, and in Ghana. An export policy, such as embodied in HR 2791/S2090, the Responsible Electronics Recycling Act, is a logical policy that would ensure that this problematic stream of e-waste is handled initially by U.S. companies. Instead of shipping whole, non-working products to developing nations, these products would be disassembled here in the U.S. (or in other developed countries) where laws protect workers and communities from exposure to toxic chemicals. Then the cleaned, separated materials could, of course, eventually be exported as higher value commodities. Commenting on the basic concepts in this legislation, the ITC noted that changing the law in the way suggested by these bills, would lead to more recycling activity in the United States, and more exports of processed commodities. More recycling activity means more jobs. More jobs and more exports make this a no-brainer.

5. **Responsible handling of used federal electronics – using e-Steward certified recyclers, no auctions**. As the largest purchaser of electronics in the country, the federal government is also the largest generator of e-waste. So improvements in what the federal government does with its own used products would be helpful.
    a. **Use e-steward recyclers.** The GSA does now use certified recyclers, but there is a difference between the two certification programs. We recommend that the GSA use recyclers certified to the stronger e-Stewards standard, which does not permit practices like exporting unused/untested e-waste to developing countries. This would be a case of the federal government truly leading by example.
    b. **No auctions.** Once you auction off used electronics, you are giving up any control of what happens to it. The GSA does auction some surplus used electronics. This is a practice that should be discontinued.

Thank you for the opportunity to comment on this important issue. If we can be of any further assistance to the Committee, please don't hesitate to contact us.

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**US Senate Committee on Homeland Security and Governmental Affairs**
**Recycling Electronics: A Common Sense Solution for Enhancing Government Efficiency and Protecting Our Environment**
**Wednesday, February 27, 2014**
**Statement for the Record**
**Submitted by:**
**Institute of Scrap Recycling Industries**

The Institute of Scrap Recycling Industries (ISRI) appreciates the opportunity to file a statement for the record of the Feb. 27 hearing on *Recycling Electronics: A Common Sense Solution for Enhancing Government Efficiency and Protecting Our Environment*. ISRI represents more than 1,700 companies nationwide that process, broker and industrially consume scrap commodities, including metal, paper, plastics, glass, rubber, electronics and textiles. As the fastest growing segment of the recycling industry, ISRI represents upwards of 400 companies that handle used electronics products (UEPs) at more than 675 locations throughout the U.S. and around the world. ISRI supports safe, responsible recycling of UEPs, which is good for the environment and good for our economy in the US. ISRI is committed to working with government agencies, industry and non- profits across the US to spur increased electronics recycling.

The United States is the world's largest market for electronics, thus generating large quantities of used electronic products each year, estimated between 7-8 million tons. The recycling of UEPs is currently flourishing in the US, with tremendous growth over the last 10 years. Latest figures show this maturing segment of the industry provides a boost of approximately $20.6 billion to the U.S. economy (up from less than $1 billion in 2002) and employs more than 45,000 full time employees (up from 6,000 in 2002), recycling over 4.4 million tons (up from less than 1 million

These UEPs are collected from both consumers and businesses, evaluated for their value, and then classified as working electronic products and parts to be refurbished and resold, or as non-working goods to be recycled into scrap commodities either in the United States or abroad. Commodity metals, plastics, and glass are used as raw materials in manufacturing processes and circuit boards are sent to smelting facilities to recover gold and other precious metals.

The overwhelming majority of UEPs are recycled in the United States. The Dec. 2013 MIT/NCER study funded by the EPA found that more than 90% of used electronics collected domestically are recycled in the US. Similarly, a 2013 USITC report (*Used Electronic Products: An Examination of US Exports*: Investigation No. 332-528, Feb. 2013) (USITC report), found that 93% are being reused and recycled in the US. Of the 7% that are being exported, only a small amount is being sent overseas for disposal.

ISRI's comments focus on three opportunities to spur the US electronics recycling market: *(1) Increase collection of UEPs from households; (2) Design new electronics products for recycling; (3) Maximize the role of the federal government.*

***(1) Increase Collection of UEPs from Households***

Increasing the amount of household recycling and preventing UEPs from being disposed of in landfills provides the largest opportunity to increase recycling of UEPs and increase jobs in this industry. One of the biggest challenges and opportunities is raising consumer awareness about how to responsibly recycler their UEPs.

Currently, the US market is driven by UEPs collected from businesses and commercial interests. This stream of high quality, uniform equipment comprises about 75% (3.3 million tons) of the UEPs being recycled. In the alternative, the Environmental Protection Agency estimates that only 25% (1.1 million tons) of UEPs from households and residences are being recycled. This is despite the fact that the consumer market is the largest market for new electronic products. Based on these numbers, ISRI estimates that there is another 3 million tons or more of household UEPs still moving to landfills or remaining in our closets, basements, and garages.

**Educate the Consumer about Recycling**

A 2013 Harris Interactive Poll found that consumers lacked knowledge about recycling of used electronics. The Harris survey found nearly 70% of American adults have recycled at least one type of small electronics product in the past. Such products include: ink or toner cartridges, cell phones, desktop monitors, laptops, printers, computers, keyboards, and a mouse. Yet, that still leaves nearly 75 million Americans (31%) who have never recycled UEPs, primarily because they did not have the right information. This figure includes 39% of younger adults ages 18-34 who have never recycled any small electronics. Among the reasons given for not recycling (respondents had the option of choosing multiple reasons)

- 26% did not know where to recycle electronics;
- 16% did not know how to recycle them securely;
- 14% did not know their device(s) could be recycled;
- 12% thought it was too much trouble to recycle; and
- 6% thought the device(s) were supposed to be disposed of in the trash.

The survey also found that despite the lack of information regarding electronics recycling, 97% of American adults would recycle their small electronics. Armed with such information, ISRI has embarked on several collaborative initiatives to increase consumer awareness on how to responsibly and safely recycle UEPs.

**Earth911/ISRI Education Effort**

ISRI and Earth911, a subsidiary of Quest Resource Holding Corporation, formed a partnership designed to educate the public about the importance of recycling and living a lower-waste lifestyle. The strategic partnership brings together the knowledge of ISRI's industry experts and Earth911's ability to reach and engage an audience of more than nine million readers interested in reducing waste and learning more about recycling. The partnership will have several key components, including ISRI provided content for

Earth911's website, monthly newsletters, and a series of educational infographics. Additionally, the two organizations will conduct quarterly polling to gather data on the public's view of recycling. ISRI members will also be featured in the Earth911 Recycling Guide to help consumers find nearby recyclers.

ISRI is working with Earth911 on a new public awareness initiative called Project Reboot. Project Reboot is designed to increase and encourage the safe and secure recycling of household electronics. The campaign aims to bring together businesses, corporations, and civic groups to educate the public on the need to responsibly recycle electronics. Year-long education efforts will not only focus on the need to recycle electronics, but also on the importance of doing so responsibly. Emphasis will be placed on recycling electronics through a certified recycler who operates at the highest level of environmental, health, and worker safety standards, and guarantees secure destruction of all personal data. In addition, there is an electronics recycling pledge, social media components (including an interactive Facebook page), print materials to promote safe recycling habits, recycle and reuse tips, and more.

**JASON Project**

ISRI is currently working with The Jason Project to develop school curriculum to help teachers and students understand both the importance of recycling and the recycling industry. The campaign includes branded, standards-based, K-12 curricular experiences; interactive Web-based experiences to enhance student engagement; classroom posters featuring ISRI's key educational messages; a leveraged national distribution network; strategies for school visits to ISRI facilities; age-appropriate lessons for grades K-4, 5-8, and 9-12; for each grade band, a two to four page classroom lesson based on life cycle for each commodity; and much, much more.

**Keep America Beautiful/ISRI PSA**

Last year, ISRI partnered with Keep America Beautiful (KAB) in support of an Ad Council administered public service advertising campaign titled "I Want to Be Recycled," whose goal is to restart the conversation about recycling. In a society where each American produces 4.4 pounds of trash each day, this campaign aims to raise awareness and ultimately provide the motivation to change the occasional recycler into an everyday recycler.

ISRI believes that, combined with other collection programs such as the USPS Blue Earth Federal Recycling Program, these initiatives will help to raise consumer awareness about the value of recycling UEPs in a responsible and safe manner.

***(2) Design New Electronics Products for Recycling***

When manufacturers design their products for recycling, they provide valuable renewable resources for the manufacture of new products and prevent landfill dumping. Begun more than 25 years ago, ISRI's Design for Recycling® (DfR) initiative encourages manufacturers to think about the ultimate destiny of their products during the design-stage of a product's development. ISRI advocates for the design and manufacture of goods that at the end of their useful life can be recycled safely and efficiently.

There are several market based programs, consistent with ISRI's DfR policy, that have demonstrated success in improving the design of UEPs: US EPA's Environmentally Preferable Purchasing (EPP) Program, the Electronic Product Environmental Assessment Tool (EPEAT®), which was developed under an EPA grant, and the EPA's Design for the Environment (DfE) Program.

There are a number of existing design challenges. For example, original equipment manufacturers (OEMs) use of mercury. The new technology in flat screen monitors utilizes a system of lamps containing mercury powder. These mercury lamps are very time consuming to remove or replace, which makes this new technology difficult to recycle. Similarly, some of the cell phone batteries with small traces of mercury take up to five minutes to remove. And laptops contain tiny mercury lamps that are very difficult to locate and remove. In the end, it takes a lot of extra time to recycle in the proper manner. This drives up the labor costs, which makes recycling these products less profitable. The EPP, EPEAT®, DfE, and DfR® will help to avoid these additional costs and improve recycling efficiency.

Collectively, these programs encourage, and have already spurred, the design, manufacture, procurement, and use of greener electronics, as well as the recycling of used and end-of-life electronics. ISRI welcomes the opportunity to further work collaboratively with other stakeholders to develop a market-based approach to greening the life-cycle of electronics.

***(3) <u>Maximize the Role of the Federal Government</u>***

ISRI supports President Obama's National Strategy for Electronics Stewardship (National Strategy), which details the federal government's plan to improve the management of electronics products throughout its lifecycle. ISRI applauds the National Strategy and encourages the federal government to continue to actively implement its recommendations. There are a number of goals within the National Strategy that ISRI feels could positively impact this market.

**Build Incentives for Design of Greener Electronics**

As the largest procurer of new electronics products, the federal government can use its purchasing power to reward manufacturers that have designed their products for recycling. As mentioned above, the EPP, EPEAT®, and DfE Programs have already demonstrated their effectiveness in addressing such impediments. The federal government should use and leverage these existing programs to further encourage the design, manufacture, procurement, and use of greener electronics standards.

**Ensure a Competitive Market**

A competitive market is vital to the health of this maturing industry. As the federal government becomes the largest market holder of UEPs, it is vital to ensure a competitive and open-market process that allows electronics recycling companies to compete for such contracts. While_ISRI is encouraged by the National Strategy's commitment to make convenient, and cost effective collection of UEPs from the federal government and from agency employees, as seen in the US Postal Services Blue Earth Federal Recycling Program, we need to make sure that the flows of such collected UEPs are redistributed in a competitively bid market.

**Utilize Certified Electronics Recyclers**

The National Strategy requires the federal government to only use companies that have been certified to independent third party certifications, such as R2:2013 and the Recycling Industry Operating Standard (RIOS)™ or their equivalents. The R2/RIOS™ certification is solely for electronics recyclers to demonstrate to customers that electronics are being recycled with the highest standards for data privacy, environmental controls, employee health and safety and corporate responsibility. These programs have changed the landscape of the industry and most feel that being certified is now a cost of doing business as an electronics recycler. As an example of this tremendous progress, the R2 program alone has grown from just one (1) facility being certified in 2009 to now 519 facilities in 14 countries. ISRI strongly supports this effort and is committed to promoting the benefits of such certifications not only here at home but abroad.

**Generate Better Market Data**

The federal government is in a unique position to quantify the amount of UEPs generated by the federal government and its employees. As mentioned above, there are a number of recent studies that begin to define the value and volume of UEPs that are being collected and recycled in the United States (USITC). ISRI remains committed to furthering these goals. However, as we pursue these goals, we need to make sure that individual privacy rights and confidential business information is considered for recyclers before requiring any additional tracking requirements.

In the alternative, ISRI supports efforts to develop new custom Harmonized Tariff System definitions to identify and separately track sub-categories of UEPs that are likely not being tracked:

- Functional, used/second-hand electronics equipment being exported for direct resell;
- Repairable electronics equipment being exported for repair, refurbishment or remanufacturing; and,
- Non-repairable electronics equipment being exported for manual and mechanical recycling

**Enforce Existing Laws**

In order to reward companies that are committed to playing by the rules, there must be a penalty for violating the law. Before policymakers contemplate the need for new laws, we need to commit resources and dollars to enforce existing laws.

Perhaps the most significant enforcement opportunity is to enforce the federal Cathode Ray Tube (CRT) rule. Predominately because of lead contained in the CRT's found in older televisions and monitors, there is a negative costs to recycle these UEPs. Therefore, as the US market has become hyper-competitive in securing greater volumes of UEPs, agreeing to take CRTs for a cheaper or no costs option, some companies have begun to stockpile CRTs in warehouses across the US and, at times, abandon them. Abandoning unprocessed CRTs is not only irresponsible, it is illegal. ISRI supports efforts by the federal government to ensure that the CRT rule is properly enforced to address this growing problem.

There is also an opportunity for the federal government to work with the existing certification programs, such as R2 Solutions for R2:2013, ISRI Services Corporation for RIOS™ et al, to ensure that any company knowingly stockpiling CRT glass or sending CRT glass to be stockpiled will have their certification suspended or revoked and, as a consequence, become non-eligible to bid for government contracts.

In addition to the CRT rule, electronics recyclers must adhere to the Resource Conservation and Recovery Act (RCRA), the Clean Air Act, the Clean Water Act, the Comprehensive Environmental Recovery, Compensation, & Liability Act ("CERCLA" or "Superfund"), and occupational health and safety requirements within OSHA. In addition, electronics recyclers must adhere to state requirements, as well as US export laws and regulations and the import requirements of foreign countries.

**Conclusion**

ISRI thanks the Homeland Security and Governmental Affairs Committee for the opportunity to submit comments for the record. The US electronics recycling industry has come a long way in the past ten years, but there is still much work to be done. ISRI and its members stand ready and willing to work with any and all stakeholders to further spur this market. It is our commitment and goal to continually improve this segment of the recycling industry, not only here at home but abroad, until it, too, can sustain itself in the global recycling economy.

Testimony of Umicore USA Inc.
before the
Senate Committee on Homeland Security & Governmental Affairs
March 12, 2014

Mr. Chairman, Ranking Member, and Members of the Committee, thank you for the opportunity to submit testimony in response to the February 27 Committee hearing entitled "Recycling Electronics: A Common Sense Solution for Enhancing Government Efficiency and Protecting Our Environment."

Introduction

We would like to begin with a brief introduction to Umicore. We are a global materials technology company with annual turnover of over $13 billion and 25% of revenues coming directly from the recycling of valuable metals from global waste streams. Umicore has developed technology for the responsible and efficient recycling of precious-metals-bearing materials, such as so-called e-scrap fractions produced from electronic waste, by-products from the non-ferrous metals industry, and spent industrial and automotive catalysts. Our end refining process extracts 17 different metals, which makes it unique in the industry. The economic viability of this process is based not only on our unique technology but also on the economies of scale we are able to achieve by sourcing e-scrap and other materials from around the world.

In addition, Umicore produces metals-based advanced materials that go into many of the products at the cutting edge of renewable energy, automotive, and electronics innovation, including rechargeable batteries for laptops, mobile phones and electric vehicles; emission-control catalysts for passenger cars; photovoltaic systems; and fuel cells. Around the world, Umicore employs over 14,000 people, including 678 in the United States.

Opportunities and Challenges

We would like to express our support and thanks for the attention and enthusiasm Chairman Carper has demonstrated on the issue of electronic waste recycling. The Chairman has been a peerless leader for all things recycling, and we are excited to continue working with him on the issue. We share the belief that there is tremendous opportunity in both championing government leadership in electronic waste management and developing smart public policies to enhance the collection and recycling of electronic waste in the United States. For this reason, we are equally excited and supportive of the continuing federal government efforts, including the United States Postal Service's "Blue Earth Program" and the President's National Strategy for Electronics Stewardship. We look forward to seeing the updated version of the 2011 National Strategy report when it is available.

During the February 27th hearing, we were encouraged to see a number of critical issues raised and novel ideas proposed by witnesses on the hearing panel. Electronic waste management is highly complex for multiple reasons, beginning with the large number of actors involved and, at least in the United States, the large number of state policy frameworks. With 25 different state policy frameworks guiding the management of electronics disposal, we believe that any efforts to create harmony between state regimes should be encouraged in order to help reduce this complexity. For this reason, Umicore is supportive of the Consumer Electronics Association's (CEA) efforts to pursue a "National Harmonization Framework," and looks forward to working with the CEA and the Committee on exploring the idea further.

As Chairman Carper noted in the hearing, the landfilling and inappropriate recycling of electronic waste pose environmental and security risks. But we would argue that, most importantly, the landfilling and inappropriate recycling leave significant unrealized opportunities for economic growth and job creation.

The United States is the Saudi Arabia of above ground mines for electronic waste. According to EPA, only 25% of electronics ready for end-of-life management in the United States are being collected, with an unknown portion of that amount recycled according to R2 or E-Steward certification standards. Therefore, a massive opportunity still remains for realizing the substantial value embedded in the millions of tons of electronic waste sitting in basements, closets, and drawers around the country, not to mention in what continues to be sent to landfills and exported for recycling, but without using best available technology.

The National Strategy for Electronics Stewardship demonstrates that the federal government understands that as the largest buyer of electronics in the United States, it has a responsibility for not only purchasing "green" but also handling those electronics appropriately at end of life. In this sense we see a common set of goals between the United States and the European Union where the European WEEE directive (Waste Electrical and Electronic Equipment Directive) aims to increase the collection rates and maximize the recovery of valuable materials from a broad range of equipment. There are also other laudable efforts that have called attention to the importance of environmental performance, from the manufacturing stage of electronics through the product's useful life until its disposition (e.g. Green Electronics Council and their EPEAT program).

To lead by example in the management of electronic waste streams, current federal government efforts have focused on various aspects of the four steps involved in responsible recycling.

- *On (1) Collection*, the United States Postal Service's "Blue Earth Program" is a novel approach to simplifying and centralizing collection efforts. We are very supportive of the program, and we continue to offer our assistance and guidance to the U.S. Postal Service and this Committee when needed. We believe the program holds great potential for eventual economy-wide application when it will assist in increasing collection and responsible recycling through making the disposal process easy, safe, and understandable for the general public. Additionally, the GSA's efforts hold great promise: procuring green electronics that comply with EPEAT standards, increasing participation in take-back programs with OEMs, and the newly announced efforts to increase the ability to track electronic devices through the life cycle, from manufacturing to end of life.

- *On (2) Dismantling/Sorting* and *(3) Pre-processing:* As noted in the testimony by the GSA, all electronics at the end of life stage are required by way of bulletin B-34 to be sent to certified recyclers. These standards, administered by both E-Stewards and R2, ensure that end-of-life electronics are processed with concern for environmental, health, and safety standards.

- *On (4) End Refining:* With only a handful of facilities in the world capable of large scale proper handling and end refining of precious-metals-bearing electronic waste materials (which have gone through collection, dismantling/sorting, and pre-processing), it is critically important that end-of-life electronic waste materials ultimately reach these facilities. In this way the recovery of precious metals and other critical and non-critical metals can be maximized. At current collection rates in the U.S., there is insufficient feed for a large scale end-refining facility in this country. The U.S. needs for end refining of precious-metals-bearing electronic waste are well met by existing facilities around the world. While there is no certification in place yet for the end refining process, Umicore is working with industry groups in the EU towards creating one. Work has begun at the European Commission level on this topic and CENELEC (European Committee for Electrotechnical Standardization) has been charged with the task.

It is important to note the opportunities for job creation in the United States within the electronic waste recycling chain and related industries. Thousands of jobs are available in collection, dismantling, sorting, and pre-processing, involving various levels of expertise.

<u>Recommendations</u>
Umicore encourages the Committee and respective government agencies leading electronic waste management efforts to do all they can to ensure responsible recycling in all four steps of the recycling process, including end refining.

- The *USPS* is taking steps to ensure that materials collected through its Blue Earth pilot program are responsibly managed, and we look forward to continuing work with them on that effort.

- The *GSA* has the responsibility to ensure that all federal government electronics are handled appropriately throughout the full recycling chain. We encourage GSA to continue its education of federal employees – whether or not their agencies are participating in Blue Earth - concerning proper disposal of their devices through appropriate channels.

We also encourage continued attention to the management of electronics that are donated, sold, or given back to vendors by the federal government. We are certainly supportive of the repurposing and reuse of electronics when possible. According to the GSA's oral comments during the hearing, roughly 50% of discarded electronics are donated to schools or educational non-profits and 23% are sold back to original vendors, while 22% are repurposed and only 4% are recycled. Therefore it seems the majority of discarded electronics are leaving the government's oversight regarding appropriate recycling. It could be helpful if the U.S. Government could develop tracking mechanisms for the electronics that they donate, as it continues to be important to ensure proper end-of-life handling even after those electronics leave government hands.

Policymakers, witnesses from the hearing, and other stakeholders have offered a number of promising ideas that we believe may be worth pursuing. These include: the Senator's idea to pilot an "electronic waste" drive on a regular basis akin to canned food drives; CEA's idea to develop a "National Harmonization Framework" for state electronic waste recycling regimes and their notion of developing school curriculum around electronic waste recycling; Keep America Beautiful's thoughts on training the sales force at electronics retailers to encourage recycling; Earth911 Inc.'s recent prize-winning idea to develop barcodes for electronic devices to better identify materials for end of life[1]. There are many avenues for both the federal government and the private sector to work in concert to improve electronic waste management in the U.S., much of which is possible within existing statute and program funding.

Thank you again for the opportunity to submit testimony. We look forward to our continued work with the Chairman, the Committee, and federal agencies involved on this issue.

[1] http://www.marketwired.com/press-release/earth911-wins-recycling-innovators-forum-contest-otcqb-irhc-1830376.htm

# Global In-Use Stocks of the Rare Earth Elements: A First Estimate

Xiaoyue Du and T.E. Graedel

Center for Industrial Ecology

Yale University

## Supplementary Information

**Product Applications of the Rare Earths**

Stocks of the rare earths reside in products that provide services, and it is therefore necessary to understand how the different rare earths are distributed into different industrial sectors and specific product groups in order to calculate aspects of the stocks in use. In the table below, the principal applications of each of the rare earths are indicated in percentage form. These are approximations, based on extensive information from published and unpublished sources, and should be regarded as order of magnitude estimates rather than definitive information.

Supplementary Table 1. Principal applications involved in in-use stocks (2007). The information is from refs. S1-S4.

| | | | |
|---|---|---|---|
| Ce | Automobile catalytic converters (35%) | Metallurgy (31%) | Glass additives (16%) |
| La | Catalysts (30%) | Metallurgy (22%) | NiMH batteries (14%) |
| Nd | Computers (29%) | Audio systems (22%) | Wind turbines (13%), automobiles (13%) |
| Pr | Computers (27%) | Audio systems (21%) | Wind turbines (12%), automobiles (12%) |
| Dy | Computers (33%) | Audio systems (26%) | Wind turbines (15%), automobiles (15%) |
| Tb | Lighting (27%) | Liquid crystal displays (20%) | Computers (15%) |
| Sm | Defense (70%) | NiMH batteries (30%) | |
| Y | Lighting (45%) | Liquid crystal displays (33%) | Glass additives (12%) |
| Eu | Lighting (51%) | Liquid crystal displays (37%) | Plasma (12%) |
| Gd | Computers (32%) | Audio systems (25%) | Wind turbines (15%), automobiles (15%) |
| Ho | Magnetics (100%) | | |
| Er | Fiber optics (75%?) | Lasers (20%?) | Optical glass (5%?) |
| Tm | X-ray (75%?) | Lasers (20%?) | Electronics (5%?) |
| Yb | X-ray (75%?) | Lasers (20%?) | Electronics (5%?) |
| Lu | Electronics (80%?) | Medical (20%?) | |

**Disaggregation of Rare Earth Production Data**

Rare earth production is generally reported as the sum of rare earths rather than the amounts of the individual elements. Because this is unsatisfactory for many purposes, we have disaggregated the composite quantities into those for the individual elements. To do so, we combine data on the distribution of the rare earth elements in the different mines or mining areas with the quantities of output from those mines. The information of distribution in eight mines is listed in Supplementary Table 2 after transferring the content of REO into REE from the literatures. By multiplying the annual production of each mine (S1, S2) by the distributions, the production of individual rare earth element can be computed yearly from 1995 to 2007. This provides an estimate of the flow into production of each of the rare earth metals.

As is the case with all industrial processes, losses occur during fabrication and manufacturing, and these decrease the flows from the production stage. No information is available regarding the magnitude of these losses. We estimate that the outflows from manufacturing are 90% final products (manufactured goods) and 10% discards (of which 93% is in the form of scrap and 7% as industrial waste). These efficiencies are typical of modern industrial fabrication and manufacturing (e.g., S7).

Supplementary Table 2. RE distribution in individual mines or regions. The information is from refs S1, S18, S19, S20.

| Country | China | | | | | | | | USA |
|---|---|---|---|---|---|---|---|---|---|
| Mine | Bayan Obo, Inner Mongolia | Mianning, Sichuan | Longnan, Jiangxi | Xunwu, Jiangxi | | Shandong | Nangang, Guangdong | SE Guangdong | Mountain Pass, CA |
| Mineral type | bastnasite | bastnasite | Ion adsorption type ore | | average | bastnasite | monazite | xenotime | bastnasite |
| La | 21.32 | 26.85 | 1.86 | 32.40 | 17.13 | 30.24 | 19.61 | 1.02 | 28.31 |
| Ce | 40.76 | 38.82 | 0.89 | 2.85 | 1.87 | 38.88 | 34.76 | 2.44 | 39.97 |
| Pr | 4.22 | 3.40 | 0.89 | 6.13 | 3.51 | 3.27 | 3.39 | 0.50 | 3.59 |
| Nd | 14.23 | 11.11 | 2.97 | 25.87 | 14.42 | 9.35 | 14.57 | 3.00 | 10.29 |
| Sm | 1.03 | 1.27 | 2.02 | 4.59 | 3.30 | 0.68 | 2.59 | 1.90 | 0.69 |
| Eu | 0.16 | 0.22 | 0.32 | 0.44 | 0.38 | 0.11 | 0.09 | 0.17 | 0.09 |
| Gd | 0.61 | 0.57 | 4.94 | 3.65 | 4.29 | 0.46 | 1.74 | 4.34 | 0.17 |
| Tb | 0.01 | 0.07 | 0.96 | 0.39 | 0.68 | 0.12 | 0.60 | 1.02 | 0.00 |
| Dy | 0.02 | 0.19 | 6.52 | 1.54 | 4.03 | 0.00 | 0.70 | 7.93 | 0.00 |
| Ho | 0.03 | 0.03 | 1.40 | 0.24 | 0.82 | 0.00 | 0.10 | 2.27 | 0.00 |
| Er | 0.03 | 0.05 | 3.73 | 0.77 | 2.25 | 0.00 | 0.26 | 4.90 | 0.00 |
| Tm | 0.04 | 0.02 | 0.53 | 0.11 | 0.32 | 0.00 | 0.00 | 1.14 | 0.00 |
| Yb | 0.05 | 0.04 | 2.93 | 0.54 | 1.74 | 0.03 | 2.11 | 5.27 | 0.00 |
| Lu | 0.06 | 0.00 | 0.41 | 0.11 | 0.26 | 0.00 | 0.12 | 1.58 | 0.00 |
| Y | 0.34 | 0.72 | 51.10 | 8.43 | 29.76 | 0.60 | 1.89 | 46.69 | 0.08 |

**Details of disaggregation of "metal flows into use" into product categories**

This study has explored the global flows into use for rare earth metals from 1995 to 2007, and the in-use stocks in 2007. Two sets of historic data were utilized to achieve the results: production data from China, the U.S., and elsewhere, and end use information from various sources.

For the in-use stocks, the end use information is collected from different sources (S1-S4). This information records the annual distribution of end uses in each country in percentages: these are the nine product sectors containing essentially all the REE. The nine end use sectors are metallurgical applications, catalysts, automobile catalytic converters, glass, permanent magnets, polishing powders, NiMH batteries, phosphors, and agricultural applications. The amounts of rare earth elements used in each sector are computed by multiplying the distribution percentage by the total amount of end use.

The nine sectors are further disaggregated into eighteen specific products using data on the distribution of intermediate products among final products (S5, S6). For example, permanent magnets are used in 6 major products: automobiles, family appliances, wind turbines, magnetic resonance imaging, audio systems and computers. The same method is adopted for the sector of "phosphors" for lighting, liquid crystal displays, and plasma displays.

A lifetime model helps to estimate the in-use stocks by assuming that all the rare earth elements stay in the use stage for the time period of their products' life spans. Each product has an average in-use lifetime shown in Supplementary Table 3. Consequently the outflows can be calculated using equation (3). Hence, the top-down method is employed to estimate the in-use stocks for individual rare earth elements. The in-use stock equals to the difference between the inflows and outflows over a time span from 1995 to 2007. The method is presented in equation (4).

**Lifespans of Applications**

Because stocks represent the cumulative difference between material flows entering use and those leaving use, the lifetimes of those uses are needed as part of the stocks computation. Supplementary table 3 lists the lifetimes we used in the calculations, and the sources from which that information was derived.

Supplementary Table 3. Lifespans of applications

| Applications | Lifespan (year) | Reference |
|---|---|---|
| Metallurgical additives and alloys | 30 | S7 |
| Automobile catalytic converters | 10 | S8 |
| Computers | 10 | S9, S10 |
| Fluid catalytic cracking | 5 | S11 |
| UV cut glass | 10 | Average of application lifetimes |
| NiMH batteries | 5 | Average of application lifetimes |
| Audio systems | 10 | Modified from ref. S12 |
| Wind turbines | 20 | S13, S14 |
| Automobiles | 14 | S8 |
| Polishing powders | 1 | Dissipated after use |
| Optical glass | 5 | Average of application lifetimes |
| Cathode ray tubes | 5 | Modified from ref. S12 |
| Defense applications | 15 | Average of application lifetimes |
| Flat panel displays | 10 | Modified from refs. S12, S15 |
| Family appliances | 15 | S7 |
| Fertilizers | 1 | Dissipated after use |
| Magnetic resonance imaging | 10 | Adjusted from ref. S16 |
| Compact fluorescent | 1 | S17 |

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(Note: In a number of cases, the information needed in this study was not available in refereed literature, but was derived from a variety of other sources. We list all sources here for the convenience of the reader, regardless of provenance.)

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# Global In-Use Stocks of the Rare Earth Elements: A First Estimate

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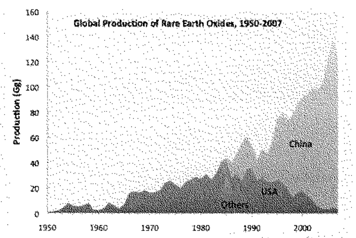
Supporting Information

ABSTRACT: Even though rare earth metals are indispensible in modern technology, very little quantitative information other than combined rare earth oxide extraction is available on their life cycles. We have drawn upon published and unpublished information from China, Japan, the United States, and elsewhere to estimate flows into use and in-use stocks for 15 of the metals: La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, and Y. Here, we show that the combined flows into use comprised about 90 Gg in 2007; the highest for individual metals were ~28 Gg Ce and ~22 Gg La, the lowest were ~0.16 Gg Tm and ~0.15 Gg Lu. In-use stocks ranged from 144 Gg Ce to 0.2 Gg Tm; these stocks, if efficiently recycled, could provide a valuable supplement to geological stocks.




## 1. INTRODUCTION

The rare earth elements (REE) are a group of metals comprised of yttrium, 14 elements of the lanthanide series (promethium, whose isotopes are radioactive with short half-lives, is absent from REE ores and is generally excluded), and sometimes scandium. Because of their unique physical and chemical properties, they are used in a growing number of applications and have become indispensible for a number of critical technologies. For example, scandium is a currently unmatched ingredient in solid oxide fuel cells and aluminum alloys, neodymium is vital to high-performance permanent magnets, and yttrium is a promising raw material for superconductors and laser technology.[1] When these intermediate products are incorporated in final products such as wind turbines, hybrid electric vehicles, or defense applications, the rare earths provide performance that is currently irreplaceable by alternative materials. These and other technical innovations will strongly influence future demand for rare earths.[1,2]

Since 1990, China has played a dominant role in REE mining production; other countries are almost completely dependent on imports from China with respect to rare earth resources. China also has become a major REE user in its manufacturing industries. The result has created a perfect storm in which mining dominance by China, rapid increases in global REE demand, and Chinese promotion of domestic downstream processing industries make a reliable REE supply on the global market problematic (e.g., refs 2,3). However, the continued increase in the use of rare earths during the past 15 years has built a substantial reservoir of in-use stocks, which have the potential to supplement virgin stocks in the future. In the present work, we calculate flows into use for the individual rare earths, and use that information to estimate the current in-use stocks.

## 2. METHODOLOGY

**2.1. Material Flow Analysis.** According to the principles of Material Flow Analysis (MFA), a metal cycle comprises four principal stages: production, fabrication and manufacturing (F&M), use, and waste management and recycling (WM&R).[4] A generic framework is presented in Figure 1 to illustrate the cycle. The stages within the system are linked to each other by flows, the system within a particular cycle is associated with other regions by imports and exports at each stage, and all of the rare earth elements are linked through a common processing stage.

Apart from the flows shown on the diagram, the stocks of metal within the reservoirs are also important constituents of the cycles. The stocks that exist at the production and F&M stages are relatively small in magnitude and are transient. In contrast, tailings, in-use stocks, and discards are larger, and continue to accumulate. In-use stocks, in particular, play a crucial role as a growing repository of metal.

In-use stocks for a number of metals have been estimated regionally and globally. Such stock estimates for iron have been generated for the United States,[5] New Haven,[6] Connecticut, USA,[7] and Beijing.[8] Copper stocks have been estimated for the U.S.,[9] North America,[10] and the world.[11] Higher spatial resolution estimates have been made for Switzerland,[12] Stockholm,[13] Cape Town,[14] Australian cities,[15] New Haven,[6] and Connecticut.[16] Aluminum in-use stocks have been generated globally [17] and regionally.[18] The results of these studies demonstrate the enrichment of metals in modern society and the importance of the realization of current reservoirs created by human activities.

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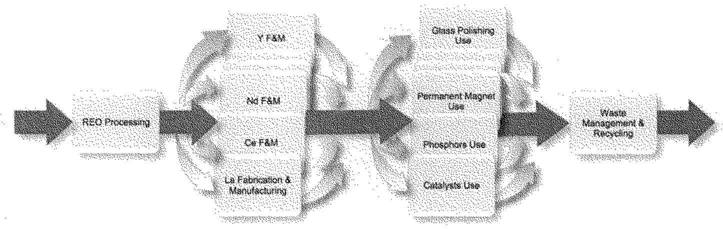


**Figure 1.** Life cycle of the rare earths at the global level. The processing step is where the rare earth oxides (REO) are refined and separated into the individual elements. The fabrication and manufacturing stage is comprised of the transformation of the group of elements into intermediate (capacitors, phosphors, permanent magnets, etc.) and final (catalysts, wind turbines, computers, batteries, etc.) products. A few of the unique fabrication and manufacturing stages are indicated on this representational figure, as are a few of the final products. The use stage is where final products are employed. After use, the products are discarded into the waste management and recycling system.

Data in the present study are from the U.S. Geological Survey, the Japan Oil, Gas and Metals National Corporation (JOGMEC), the Metal Economics Research Institute in Japan, and the China Society of Rare Earths, as well as industry contacts. Relevant literature published in Chinese or Japanese was also extremely helpful. Because the U.S. was and China is now the main REE producer in the world, analysis of the production life-cycle stage relied largely on data from the U.S. and China. In the same fashion, because the U.S., Japan, and China are the three major fabricators and manufacturers in the rare earth market (constituting some 90% of world demand in 2006) [19,20] in-use stocks for these three countries are regarded as representative of global stocks.

**2.2. Production Stage.** Production is the processing step in which rare earth oxides are refined and separated into the individual elements. Statistics on production are given as the total of rare earth oxides.[21,22] Those data are first converted to total REE content by multiplying by the individual REE/REE oxide atomic weight fraction. The resulting statistics are then disaggregated into values for the individual elements, given two separate types of information: the average distributions of the rare earth elements in the ores of individual mines, and the year-to-year production of each of the mines, or

$$\Phi_{m,k} = \sum_j f_m \varphi_{m,j} P_{j,k} \qquad (1)$$

where $f_m$ is the REE/REE oxide atomic weight fraction for element $m$, $\Phi_{m,j}$ is the flow into manufacturing of REE $m$ in year $k$, $\varphi_{m,j}$ is the fraction of element $m$ in the ore of mine $j$, and $P_{j,k}$ is the REE production of mine $j$ in year $k$. Because about 25% of the rare earth content of ores is lost to tailings and about 5% to slag, calculating $\Phi_{m,k}$ permits processing losses to be estimated as well.

Almost the entire supply of REE since 1995 has come from eight mines: Mountain Pass in the U.S. and seven mines in China. The production histories of the mines are given in refs 21 and 22. Elemental distributions of the different mines are given in refs 21−24. The data are summarized in Table S2 of the Supporting Information.

**2.3. Fabrication and Manufacturing Stage.** As is the case with all industrial processes, losses occur during fabrication and manufacturing, and these decrease the flows from the production stage. No information is available regarding the magnitude of these losses. We estimate that the outflows from manufacturing are 90% final products (manufactured goods) and 10% discards (of which 93% is in the form of scrap and 7% as industrial waste). These efficiencies are typical of modern industrial fabrication and manufacturing (e.g., ref 4).

**2.4. Use Stage.** REE flows from manufacture into use rely on data for the distribution of individual REE into products (Table S1 of the Supporting Information).[21,22,25,26] The approach involves multiplying these percentages by the total rare earth use in each country and aggregating the flows for the same sector in three countries to derive the global flows into use for seventeen major end use sectors: metallurgical additives and alloys, automobile catalytic converters, computers, catalysts, glass additives, nickel metal hydride batteries, audio systems, wind turbines, automobiles, polishing powders, lighting, defense applications, liquid crystal displays, family appliances, fertilizers, magnetic resonance imaging, and plasma. The calculation is complicated by the fact that a number of product applications utilize more than one of the REE. For example, permanent magnets typically contain Nd, Pr, Dy, Gd, and Tb in proportions of ~70%, ~25%, 5%, 2%, and 0.2%. The magnets see use also in automobiles, electric toys, wind turbines, computers, domestic appliances, and speakers. In each case of this type, the appropriate REE compositions are applied in deriving the elemental distributions in those use sectors. (Details of the disaggregation are in the Supporting Information.)

China, Japan, and the U.S. constitute about 90% of global product manufacture involving the rare earths. The product distribution differences among the countries are substantial. Automobile catalytic converters accounted for 32% of rare earth use in the U.S. in 2007, the second biggest use being in metallurgical additives and alloys (around 21%). Japan used 28% and 27% of total rare earths on permanent magnets and polishing powders, and 15% on automobile catalytic converters. The most dramatic changes in recent REE use have occurred in China. China has traditionally employed rare earths in applications such as metallurgical additives and alloys, petroleum refining, and glass and ceramics, but new applications in China have grown significantly since 2002. The end use history in China from 1995 to 2007 [21] demonstrates the dramatic increase in these new applications, primarily permanent magnets, polishing powders, nickel hydride batteries, phosphors, and automobile catalytic converters.

**Table 1. Flows into Use and in-Use Stocks Calculated for the Rare Earth Elements in 2007**

| element | flows into use (Gg/yr) | in-use stock (Gg) |
|---|---|---|
| La | 21.9 | 86 |
| Ce | 27.9 | 144 |
| Pr | 4.1 | 50 |
| Nd | 14.8 | 137 |
| Sm | 2.1 | 3.3 |
| Eu | 0.3 | 0.4 |
| Gd | 2.2 | 3.6 |
| Tb | 0.3 | 0.7 |
| Dy | 1.7 | 8.6 |
| Ho | 0.3 | 2.1 |
| Er | 0.9 | 3.9 |
| Tm | 0.2 | 0.2 |
| Yb | 0.7 | 0.7 |
| Lu | 0.1 | 0.6 |
| Y | 12.3 | 6.9 |

**2.5. End of Life.** When products containing rare earths are discarded, the quantity of material in use is diminished. The lifetime model used to estimate end of life flows is based on the assumption that all the rare earth elements stay in the use stage for the time period of their products' life spans. Each product group has an average in-use lifetime, which can be used to compute these outflows, and thus the outflows of each of the rare earth elements. We utilize the lifetimes given in Table S3 of the Supporting Information, and calculation outflows as

$$F_{\mathrm{Out},m,k} = F_{\mathrm{In},m,k-t_i} \qquad (3)$$

$F_{\mathrm{Out},m,k}$ is the outflow of element $m$ in year $k$ from the use stage, $F_{\mathrm{In},m,k-t_i}$ is the inflow of element m in year $k - t_i$, and $t_i$ is the lifetime of product $i$.

**2.6. In-Use Stocks.** The top-down method [27] is employed to estimate the in-use stocks for individual rare earth elements in this study. To satisfy the conservation of mass, stock changes in a particular reservoir must equal the difference between all inputs and all outputs over a time span $(t_0 - t)$. For a continuous case, the in-use stock is given by the integral equation:[27,28]

$$S_m(t) = \int_{t_0}^{t} \left(\sum_i F_{\mathrm{In},m,i}(t) - F_{\mathrm{Out},m,i}(t)\right)\mathrm{d}t + S_m(t_0) \qquad (4)$$

where $S_m(t)$ = stock at time t; $S_m(t_0)$ = stock at time $t_0$; $F_{\mathrm{In},m,i}$ = flow into use of element $m$ in product application $i$; $F_{\mathrm{Out},m,i}$ = flow out of use of element $m$ in product application $i$.

## 3. RESULTS

**3.1. Flows Into Use.** In 2007, China produced 120.8 Gg of rare earth oxides from three mining regions: Bayan Obo, Inner Mongolia (69 Gg); Mianning, Sichuan Province (6.8 Gg); and Jiangxi Province (45 Gg),[21] and lost approximately 36 Gg of rare earths to tailings and 7 Gg to slag. The Chinese production constituted 97% of the global total. Other rare earth oxide producers in 2007 were India (2.7 Gg), Brazil (0.65 Gg), and Malaysia (0.38 Gg).[21,22] Even though rare earths have not been mined in the U.S. since 2001, small amounts of rare earth concentrates previously generated at Mountain Pass, CA, were domestically processed in 2007 into lanthanum concentrate and didymium (75% neodymium, 25% praseodymium).[22]

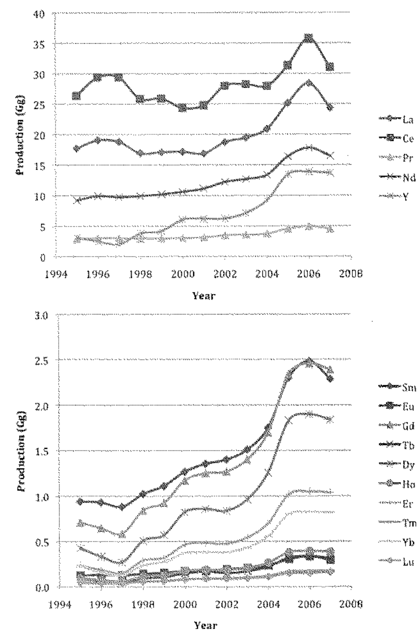


**Figure 2.** Estimated global production of selected rare earths during the period 1995−2007.

Similarly, rare earth production during the period 1995−2007 was evaluated; this demonstrated the rapid production increases during that period: from 65 Gg in 1995 to 107 Gg in 2007 (both figures are for rare earths, not their oxides). The year, 2006 had the highest production, 111 Gg. These annual REE flows were then disaggregated into those of the individual elements. The 2007 results are given in Table 1.

Figure 2 shows two groupings of the results, with the principal product sectors into which the rare earths flowed in 2007 indicated by color. Four elements (La, Ce, Nd, and Y) constitute about 85% of the total REE flows into use. Their dominance has slightly dropped (from 91% to 85%) in the 12-year history because of emerging applications for other REE elements.

Ce has been the REE metal with the largest flow into use for the 12 years, the amount growing from 24 Gg in 1995 to 28 Gg in 2007. However, this rate of growth is relatively small compared to those for the other three elements. Flows of La increased from 16 Gg to 22 Gg, Nd from 8 Gg to 15 Gg, and Y from 3 Gg to 12 Gg.

Flows into use for the other REE are significantly lower. Those for Pr, Sm, Gd, and Dy are only a few Gg per year. Annual flows into use in 2007 for Er, Ho, Tm, Eu, Yb, and Lu are at or below about 1 Gg/yr.



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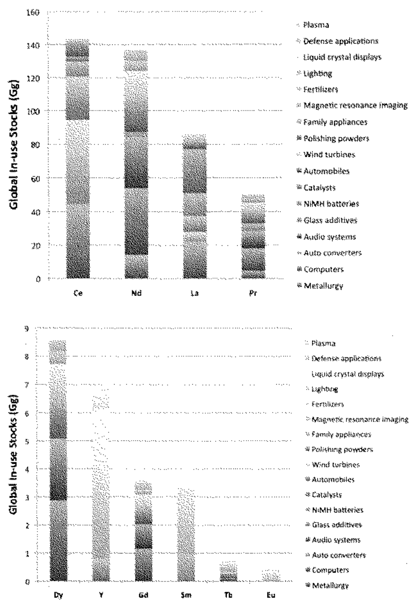


Figure 3. Global in-use stocks of selected rare earths, by application (2007).

**3.2. In-Use Stocks.** The estimated in-use stocks of the REs, computed using eq 4 in the Methodology section, are given in Table 1. Because these are derived from knowledge of the product sectors containing the REE, the product constitution of these stocks is known. Figure 3 illustrates the in-use stocks for selected REE elements in 2007. In-use stocks ranged from 144 Gg Ce to 0.2 Gg Tm, and summed to 448 Gg total. 137 Gg Nd is the second largest in-use stock. Together, Ce and Nd stocks constituted nearly 63% of the total. 86 Gg La and 50 Gg Pr reside in stocks, as do 8.6 Gg Dy, 6.9 Gg Y, 3.6 Gg Gd, 3.3 Gg Sm, 0.7 Gg Tb, and 0.4 Gg Eu.

Among the uses making up the Ce in-use stock, automobile catalytic converters and metallurgical uses constituted 50 Gg and 45 Gg, about 30% each of the total. Twenty-six Gg Ce is stored in glass additives. Both the nickel hydride battery and polishing powder stocks of Ce were 9 Gg.

Nd in-use stocks were 137 Gg, being approximately 31% of total REE stocks. Nd's stocks reside largely in computers (40 Gg), audio systems (31 Gg), wind turbines (18 Gg), and automobiles (18 Gg). 86 Gg La are primarily stored in catalysts (26 Gg, 30%), metallurgical additives and alloys (22 Gg, 26%), nickel hydride batteries (14Gg, 16%), and glass additives (10 Gg, 12%). Pr in-use stock is 50 Gg including 13 Gg in computers, 10 Gg in audio systems, 6 Gg in wind turbines and 6 Gg in automobiles. The quantities of in-use stocks for the other REE are significantly lower.

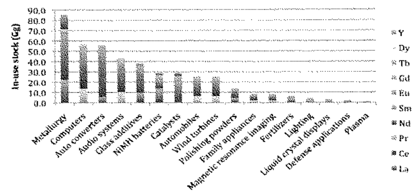


Figure 4. Rare earth in-use stocks in principle applications, by element (2007).

Stocks for Ho, Er, Tm, Yb, and Lu in 2007 are roughly estimated by aggregating the flows into use within the lifespan of their major applications. Ho has no commercial use except in magnetics, so the stock is roughly estimated as 2.1 Gg, the total of 10 years flow into use. Er's principal use involves fiber optics, lasers, and optical glasses; therefore about 3.9 Gg is in stock if we assume a 5 year lifespan for the optical glasses. Tm is primarily used in X-ray applications and lasers; the stock is thus only about 0.2 Gg because of the modest lifetime of the radiation tube. A similar analysis gives 0.7 Gg stock for Yt. Because of the rarity and high price, lutetium has very few commercial uses so the stock of Lu is roughly approximated as the total of 5 years flows into use, or 0.6 Gg. Table 1 presents estimated flows into use and in-use stocks for the rare earth elements in 2007.

The Figure 3 data can be rearranged to show in-use REE stocks by product sector (Figure 4). The sector with the largest in-use REE stocks is metallurgical applications – mainly in the form of "mischmetal" (an alloy with approximate composition of 50% Ce, 25% La, and the remainder mostly Nd and Pr). With the growing demand for Nd and Pr in magnets, current processing sometimes recovers those elements individually, leaving a mischmetal composition consisting almost entirely of Ce and La. The sector with the next highest REE stock is computers, which contain Nd, Pr, Dy, Gd, and Tb. Automobile catalytic converters rank the third among the rare earth stocks with mostly Ce. Six other product sectors also have significant in-use stocks: audio systems (mostly Ce), glass additives (Ce and La), nickel metal hydride batteries computers (Nd, Pr, Dy and Tb), catalysts (predominantly La), automobiles (Nd and Pr), and wind turbines (Nd and Pr). Together, REE in these nine product sectors constitutes nearly 88% of the total in-use REE stocks. (Table S1 of the Supporting Information shows the principal applications involved in in-use stocks in 2007.)

## 4. DISCUSSION

This study has explored the global flows into use for rare earth metals from 1995 to 2007, and the in-use stocks in 2007. Two sets of historic data were utilized to achieve the results: production data from China, the U.S., and elsewhere, and end use information from various sources.

Figure 2 clearly demonstrates the evolution of REE use in recent years. The overall amount has increased from about 80 Gg of in 1995 to about 120 Gg in 2007 (expressed as rare earth oxides). For some of the less abundant REE, however (Sm, Gd, Dy, Er, Yb) the use has at least tripled during that interval, a result that emphasizes that, whereas REE can often be treated as a group so far as geology is concerned, their employment in modern technology very much depends on the chemical and physical properties of the individual elements.

In-use stocks of the REE totaled around 440 Gg in 2007, with most of the stock in four elements: La, Ce, Nd, and Pr. That stock is some four times the 2007 annual extraction rate, which suggests that REE recycling may have the potential to offset a significant part of REE virgin extraction in the future. In addition to providing some limitations to supply risk, recycling could minimize the environmental challenges present in REE mining and processing.[3,29,30] Recycling REE is challenging, however. Recycling appears possible for metallurgical applications, automobile catalysts, and magnets in wind turbines and automobiles, where REE are used in fairly large quantities. As seen in Figure 4, however, these applications mostly utilize the "big four" REE: La, Ce, Nd, and Pr. The recycling potential for other REE, which are used in small but carefully selected amounts in imaging, displays, defense, and similar applications, appears to be quite low.

As stated in the Introduction, China currently dominates the mining and processing of virgin REE ores. Corporations and governments seeking to minimize supply risk in the next few years do not have many promising options, but one is to encourage reuse and recycling of REE as the products containing them are discarded. Additionally, designers can attempt to redesign products or substitute other materials for REEs if adequate product performance can be maintained. Over the longer term, the likely opening of REE mining in Mountain Pass in the U.S. [29] and Mount Weld in Australia [31] in the next few years will eventually provide a more geographically dispersed extraction picture. Nonetheless, so long as rates of use continue to increase, REE availability, especially for the less abundant REE, will continue to be a challenge.

As is the case with many materials, but perhaps especially with REE, a comprehensive picture of the use and loss is not easy to acquire. Individuals or corporations involved in the life cycle flows of these metals typically know one part of the cycle very well- mining of ore, or purification of metal, or sales of specific products- but not of the entire sequence of acquisition, use, and eventual loss. Our contribution in the present work is to characterize, albeit rather approximately, the quantity of rare earths being used in primary use sectors, and the stocks of rare earths that currently exist in products providing service. The results provide general guidance for the potential of in-use stocks to be reused and thus to go on providing the excellent product performance for which REE are known.

## ASSOCIATED CONTENT

**Supporting Information.** Additional information on product applications of the rare earths, methodology details and lifespans of applications. This material is available free of charge via the Internet at http://pubs.acs.org.

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# Recycling as a strategy against Rare Earth Element Criticality: A systemic evaluation of the potential yield of NdFeB magnet recycling

*Jelle H. Rademaker, René Kleijn, Yongxiang Yang

**Supporting Information**

## Table of Contents

**ABBREVIATIONS**

Dy = dysprosium
EOL = End-of-Life
EV = Electric Vehicle
HDD = Hard Disk Drive
HEV = Hybrid Electric Vehicle
Nd = neodymium
PHEV = Plug-in Hybrid Electric Vehicle
REO = Rare Earth Oxide
REPM = Rare Earth Permanent Magnet

# SECTION A – METHODOLOGY

A1 – Calculation model EOL potential Wind and Automotive [Global & EU-27]

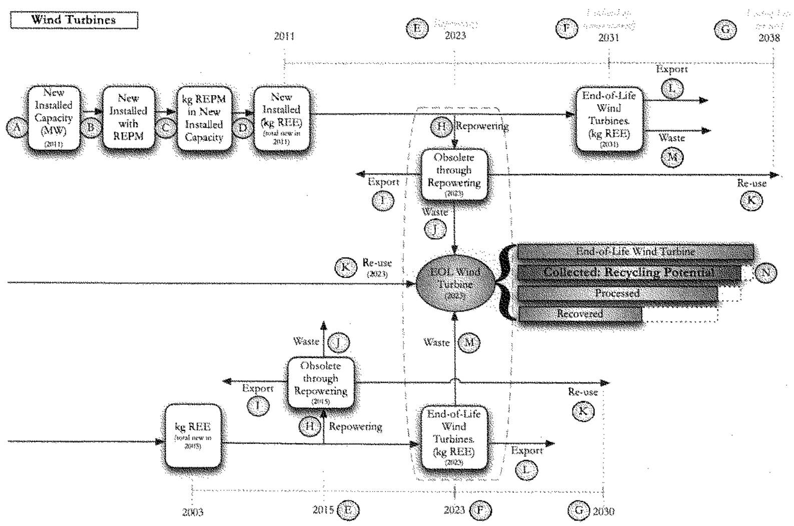


**Figure S1 – Calculation model for EOL potential of REO in REPMs in Wind Turbines**

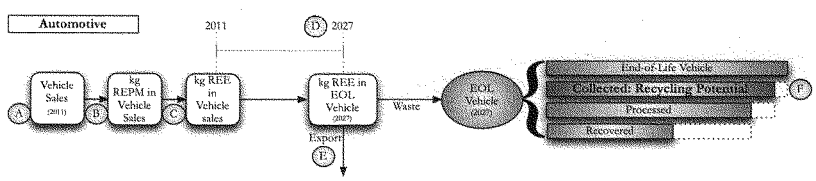


**Figure S2 – Calculation model for EOL potential of REO in REPMs in Plug-in Hybrid Electric Vehicles (PHEVs), Hybrid Electric Vehicles (HEVs) and Electric Vehicles (EVs)**

# SECTION B – INPUT DATA

In this Section, the main input data is shown. For more detailed information or questions, please contact the authors or request a full report on all data input (Rademaker, 2011).

B1 – Baseline Scenario: Wind [Global & EU-27]

| Label | Description | Value | |
|---|---|---|---|
| | | **EU-27** | **Global** |
| A | Historic data and Forecast on New Installed Wind Turbine Capacity | *See Table S3,S4,S5* | *See Table S2* |
| B | Share of REPM turbines | 2010: 10%<br>2020: 15%<br>2030: 20% | 2010: 10%<br>2020: 22.5%<br>2030: 30%<br>2040: 40% |
| C | kg of NdFeB-magnet per MW | 700 | 700 |
| D | Composition of NdFeB-magnet | 29 Nd, 6% Dy | 29 Nd, 6% Dy |
| E | Average time until repowering | 12 years | 12 years |
| F | Life-time of typical REPM wind turbine | 20 years | 20 years |
| G | Life-time of reuse | 15 years | 15 years |
| H | Share of Installed capacity that is being replaced through the process of repowering | *See Table S6,S7* | *See Table S6,S7* |
| I | Exported turbines | 0% | 0% |
| J | Share of repowered turbines of which the lifetime is not extended; waste | 20% | 20% |
| K | Share of repowering turbines that is reused | 80% | 80% |
| L | Share of end-of-life wind turbines that is exported | 0% | 0% |
| M | Share of end-of-life turbines that is regarded as waste | 100% | 100% |
| N | Collection Rate | 100% | 100% |

**Table S1 – Key assumptions EOL Potential of REEs from REPM Wind Turbines**

(A) Historic data and Forecast on New Installed Wind Turbine Capacity [Global]

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| **New Installed Capacity** | 39.9 | 44.5 | 49.7 | 55.5 | 61.6 | 66.0 | 70.5 | 74.5 | 79.0 | 84.3 |
| **Onshore repowering** | 0.2 | 0.3 | 0.5 | 0.7 | 1.3 | 1.3 | 1.5 | 2.5 | 3.4 | 3.8 |
| **Total Annual Installed Capacity** | 4§ | 44.8 | 50.2 | 56.2 | 62.9 | 67.3 | 72.0 | 77.0 | 82.4 | 88.1 |
| | **2021** | **2022** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** |
| **New Installed Capacity** | 84.7 | 87.0 | 89.5 | 92.7 | 92.9 | 96.7 | 100.3 | 102.3 | 101.7 | 112.6 |
| **Onshore repowering** | 6.5 | 7.3 | 8.1 | 8.2 | 11.5 | 15.3 | 19.9 | 26.6 | 36.6 | 35.8 |
| **Total Annual Installed Capacity** | 91.2 | 94.3 | 97.6 | 100.9 | 104.4 | 112.0 | 120.2 | 128.9 | 138.3 | 148.4 |
| | **2031** | **2032** | **2033** | **2034** | **2035** | **2036** | **2037** | **2038** | **2039** | **2040** |
| **New Installed Capacity** | 110.2 | 107.4 | 104.0 | 99.9 | 95.2 | 95.2 | 95.0 | 94.6 | 93.9 | 93.1 |
| **Onshore repowering** | 40.1 | 44.8 | 50.2 | 56.2 | 62.9 | 67.3 | 72.0 | 77.0 | 82.4 | 88.1 |
| **Total Annual Installed Capacity** | 150.3 | 152.2 | 154.2 | 156.1 | 158.1 | 162.5 | 167.0 | 171.6 | 176.3 | 181.2 |

**Table S2 – New Installed Wind Power Capacity, incl. repowering. Baseline Scenario: 2011-2040 [Global]. Adapted from (GWEC & Greenpeace, 2010)**

(A) Historic data and Forecast on New Installed Wind Turbine Capacity [EU-27]

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009[1] | 2010[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **New Installed Capacity** | 4.5 | 4.5 | 5.7 | 5.3 | 5.7 | 6 | 7.4 | 8.3 | 8.4 | 8.4 | 9 |
| **Onshore Repowering** | 0 | 0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1[2] | 0.1[2] |
| **Total New Installed** | 3.2 | 4.5 | 5.8 | 5.4 | 5.8 | 6.1 | 7.5 | 8.4 | 8.5 | 8.5 | 9.1 |

**Table S3 – New Installed Wind Power Capacity EU-27. Historic Data: 2000-2010. (EWEA, 2009) & (GWEC, 2011)**

[1] (GWEC, 2011)

[2] Repowering figures not reported by (GWEC, 2011), so taken from (EWEA, 2009) forecast

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| **New Installed Capacity** | 11.3 | 11.4 | 11.3 | 11.6 | 12.4 | 13.1 | 13.6 | 14.4 | 14.0 | 15.4 |
| **Onshore Repowering** | 0.2 | 0.3 | 0.5 | 0.7 | 1.0 | 1.3 | 1.9 | 2.6 | 3.5 | 4.2 |

| Total New Installed | 11.5 | 11.7 | 11.8 | 12.3 | 13.4 | 14.4 | 15.5 | 17.0 | 17.5 | 19.6 |
|---|---|---|---|---|---|---|---|---|---|---|

**Table S4 – New Installed Wind Power Capacity in the EU-27: 2011-2020 Forecast (EWEA, 2011)**

| | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|---|---|---|---|---|
| New Installed Capacity | 18.4 | 20.5 | 20.3 | 20.1 | 18.9 | 17.6 | 16.3 | 15.8 | 15.7 | 15.1 |
| Onshore Repowering | 4.7 | 5.6 | 5.6 | 6.3 | 7.1 | 7.9 | 8.2 | 8.1 | 8.5 | 9.0 |
| Total New Installed | 23.1 | 26.1 | 25.9 | 26.4 | 26.0 | 25.5 | 24.5 | 23.9 | 24.2 | 24.1 |

**Table S5 – New Installed Wind Power Capacity in the EU-27: 2021-2030 Forecast (EWEA, 2009)**

(H) Share of Installed capacity that is being replaced through the process of repowering [Global & EU-27]

In Table S1 to S5 the new installed capacity through repowering is shown. Each newly installed MW through repowering replaces an, typically lower, amount of MW of old turbines. This is deducted by taking the 'repowering factor': the ratio of new installed capacity over removed installed capacity.

| Source | Repowering Factor | Year |
|---|---|---|
| (EWEA, 2011) & (EWEA, 2009) | 1 | 2000 to 2030 |
| (Deutsches Windenergie-Institut, 2010) | 3.26 | 2010 |
| Dataset from (Deutscher Städte- und Gemeindebund, 2009) | 2.7 | 2000 to 2009 |

**Table S6 – Repowering factor [2011-2030]**

A higher repowering factor is an indicator of technological development: higher capacity to replace outdated turbines. As developments in wind turbines are expected to slow down in the long term, the following repowering factor was assumed:

| | 2011 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| Repowering Factor | 3 | 3 | 2 | 1 | 1 |

**Table S7 – Repowering factor [2011-2030]**

B2 – Baseline Scenario: Automotive [Global & EU-27]

| Label | Description | Value |
|---|---|---|
| | | **Global & EU-27** |
| (A) | Historic data and Forecast sales of (P)HEVs and EVs [Global] | *See Table S9 to S14* |

| | | |
|---|---|---|
| (B) | kg of REPM in the electric motor per vehicle | HEV: 0.01182kg/kW motor power<br>EV: 1.5 kg/vehicle |
| (C) | Composition of REPMs | 29% Nd, 9% Dy |
| (D) | Life-time of average vehicle | 16 |
| (E) | Exported Hybrid Electric Vehicles | 0 |
| (F) | Collection Rate | 100% |

**Table S8 – Key assumptions EOL Potential of REEs from REPM Automotive**

(A) Historic data and Forecast sales of (P)HEVs and EVs [Global]

| | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|---|---|---|---|---|
| **(P)HEV** | 17700[1] | 25969 | 38100 | 55899 | 82012 | 120325 | 176535 | 259005 | 380000[2] | 446880 |

**Table S9 – Estimation of global historic Sales (P)HEVs from 1998 to 2007.**

[1] (Greencarscongres.com, 2010)
[2] (Nylund, Aakko-Saksa, & Sipila, 2008, p. 96)

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|
| **(P)HEV** | 525274 | 735424 | 939296 | 1216103 | 1673392 | 2075072 | 2321509 | 2681174 | 2848047 |
| **EV** | 301 | 3774 | 22985 | 53953 | 101846 | 171464 | 237448 | 292592 | 357536 |

**Table S10 – Forecast on global HEV, PHEV and EV sales from 2009 to 2016. (J.D. Power, 2010)**

| | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|---|---|
| **(P)HEV** | 4015746 | 5662202 | 7983705 | 11250000 | 12605625 | 14124603 | 15826617 |
| **EV** | 430473 | 518290 | 624021 | 750000 | 852525 | 969065 | 1101536 |
| | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** |
| **(P)HEV** | 17733725 | 19870639 | 22265051 | 24947989 | 27954222 | 31322706 | 35100000 |
| **EV** | 1252116 | 1423281 | 1617843 | 1839002 | 2090394 | 2376151 | 2700000 |

**Table S11 – Forecast on global HEV, PHEV and EV sales from 2017 to 2030. Calculated from (McKinsey&Company, 2009).**

(A) Historic data and Forecast sales of (P)HEVs and EVs [EU-27]

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|---|
| **Prius** | 709 | 2,320 | 841 | 859 | 8,136 | 18,758 | 22,778 | 32,171 | 41,495 |
| **Lexus RX400h** | | | | | | 21,484 | 20,936 | 18,200 | 16,586 |
| **Lexus GS 450h** | | | | | | | 1,970 | 2,768 | 2,539 |
| **Lexus 600h + 600hl** | | | | | | | | 780 | 1,862 |
| **Total** | 709 | 2,320 | 841 | 859 | 8,136 | 40,242 | 45,684 | 53,919 | 62,482 |

**Table S12 – European Historic Sales of HEVs (Hybridcar.com, 2009)**

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|
| **(P)HEV** | 81,067 | 82,472 | 136,092 | 190,929 | 296,710 | 395,417 | 441,720 | 577,842 | 600,734 |
| **EV** | 100 | 500 | 1,000 | 5,000 | 8,000 | 15,000 | 25,000 | 40,000 | 50,000 |

**Table S13 – Forecast on EU-27 HEV, PHEV and EV sales from 2009 to 2016. (J.D. Power, 2010)**

The sales data from Hybridcar.com and J.D. Power differ for the year 2008, while both reports were made after the year 2008 and should have had a similar sales figure. To align both data sets, the figure for 2008 was averaged between both sources, resulting in an estimated 71,745 unit sales for 2008.

| | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|---|---|
| **(P)HEV** | 883,680 | 1,299,893 | 1,912,142 | 2,812,500 | 3,151,406 | 3,531,151 | 3,956,654 |
| **EV** | 69,500 | 96,605 | 134,281 | 187,500 | 213,188 | 242,394 | 275,602 |
| | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** |
| **(P)HEV** | 4,433,431 | 4,967,660 | 5,566,263 | 6,236,997 | 6,988,555 | 7,830,676 | 8,775,000 |
| **EV** | 313,360 | 356,290 | 405,102 | 460,601 | 523,703 | 595,450 | 675,000 |

**Table S14 – Forecast on EU-27 HEV, PHEV and EV sales from 2017 to 2030. Calculated from (McKinsey&Company, 2009) and (European Automobile Manufacturers Assocation, 2010).**

B3 – Baseline Scenario: HDDs [Global & EU-27]

| Label | Description | Value |
|---|---|---|
| | | **Global & EU-27** |

| | | |
|---|---|---|
| A | Historic data and forecast on PC sales | *See Table S16, S17* |
| B | Historic data and forecast on the subdivision of Desktops and Portables in PC sales | *See Table S18 to S21* |
| C | Percentage of Desktop with HDD | 100% |
| D | Percentage of Portable with HDD | From 100% in 2010 to 58% in 2020 and 14% in 2030 |
| E | kg REPM per HDD from Desktop | 0.015 kg |
| F | kg REPM per HDD from portable | 0.002 kg |
| G | Average lifetime of desktops and portables | Desktop: 10 years<br>Portable: 6 years |
| H | Exported PCs outside region | 0% |
| I | Composition of REPM | 29% Nd and 0% Dy. |
| J | Waste | 100% |
| K | Collection Rate | 50% |

**Table S15 – Key assumptions EOL Potential of REEs from REPM in HDDs in PCs**

(A) Historic data and forecast on PC sales [Global]

| | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Worldwide** | 136 | 140 | 168 | 196 | 204 | 227 | 260 | 288 | 296 | 319 |
| | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
| **Worldwide** | 350 | 385 | 414 | 426 | 456 | 500 | 541 | 571 | 590 | 626 |
| | **2021** | **2022** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** |
| **Worldwide** | 679 | 725 | 766 | 790 | 829 | 887 | 946 | 976 | 1020 | 1053 |

**Table S16 – Forecast Sales Worldwide. In million units. (Yu, Williams, Ju, & Yang, 2010) (Williams, 2011)**

(A) Historic data and forecast on PC sales [EU-27]

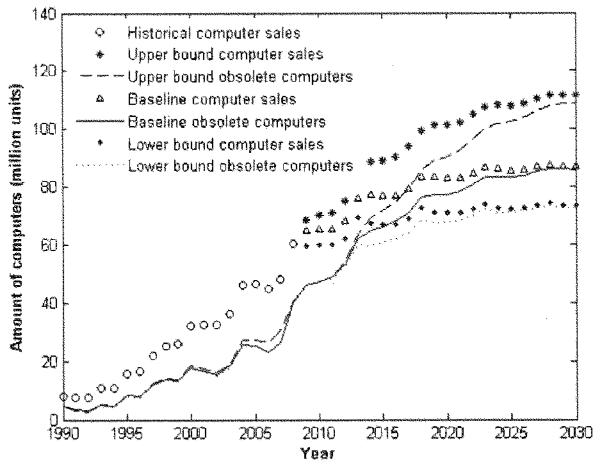


**Figure S3 – Forecasting computer sales and generation of obsolete computers in Western Europe (Yu, Williams, Ju, & Yang, 2010)**

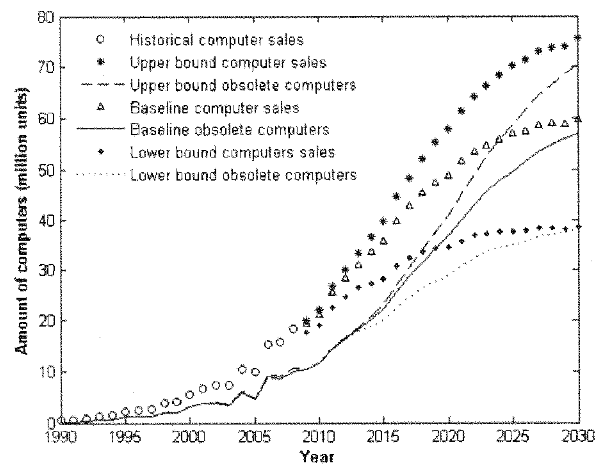


**Figure S4 – Forecasting computer sales and generation of obsolete computers in Eastern Europe (Yu, Williams, Ju, & Yang, 2010)**

| | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Western Europe** | 32.5 | 32.5 | 36.3 | 45.9 | 46.6 | 45.0 | 48.2 | 60.3 | 64.7 | 65.3 |
| **Eastern Europe** | 6.7 | 7.3 | 7.4 | 10.5 | 9.9 | 15.3 | 15.8 | 18.3 | 19.3 | 21.2 |
| **Total WE+EE** | 39.2 | 39.8 | 43.7 | 56.4 | 56.5 | 60.3 | 64.0 | 78.6 | 84.0 | 86.5 |
| -10% | | | | | | | | | | |
| **Total EU-27** | 35.3 | 35.8 | 39.3 | 50.8 | 50.9 | 54.3 | 57.6 | 70.7 | 75.6 | 77.8 |
| | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
| **Western Europe** | 65.4 | 68.0 | 76.0 | 77.3 | 76.6 | 76.7 | 79.3 | 83.5 | 83.4 | 82.8 |
| **Eastern Europe** | 28.3 | 31.1 | 33.6 | 35.8 | 39.7 | 42.7 | 45.3 | 47.5 | 48.9 | 28.3 |
| **Total WE+EE** | 96.3 | 107.1 | 110.9 | 112.3 | 116.4 | 122.0 | 128.7 | 130.9 | 131.6 | 96.3 |
| -10% | | | | | | | | | | |
| **Total EU-27** | 86.7 | 96.4 | 99.8 | 101.1 | 104.8 | 109.8 | 115.9 | 117.8 | 118.5 | 86.7 |
| | **2021** | **2022** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** |
| **Western Europe** | 82.7 | 84.6 | 86.5 | 86.2 | 85.4 | 85.7 | 86.9 | 87.5 | 87.0 | 86.8 |
| **Eastern Europe** | 51.5 | 53.4 | 54.6 | 55.9 | 57.0 | 57.5 | 58.7 | 59.0 | 58.8 | 59.9 |
| **Total WE+EE** | 134.2 | 138.0 | 141.0 | 142.0 | 142.4 | 143.2 | 145.6 | 146.5 | 145.8 | 146.7 |
| -10% | | | | | | | | | | |
| **Total EU-27** | 120.8 | 124.2 | 126.9 | 127.8 | 128.1 | 128.9 | 131.0 | 131.8 | 131.3 | 132.0 |

**Table S17 – Forecast Sales EU-27. In million units. From Figure S3 and Figure S4 from (Yu, Williams, Ju, & Yang, 2010)** (Williams, 2011)

As can be read from Table S17, the regions Western Europe and Eastern Europe are added up. Some countries were part of this category that are not in the EU-27. The data is transformed to match the EU-27 using a GDP relation.

(B) Historic data and Forecast on the subdivision of Desktops and Portables in PC sales [Global]

| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|
| **Desktop** | 162 | 153 | 145 | 136 | 148 | 154. | 156 | 157 | 156 |
| **Portable** | 66 | 97 | 143 | 169 | 209 | 249 | 292 | 340 | 396 |
| **Total** | 227 | 250 | 288 | 305 | 357 | 403 | 448 | 497 | 553 |
| | | | | | | | | | |
| **Desktop** | 29% | 39% | 50% | 55% | 58% | 62% | 65% | 68% | 72% |
| **Portable** | 71% | 61% | 50% | 45% | 42% | 38% | 35% | 32% | 28% |

**Table S18 – Desktop/Portable composition in Historic and Forecast PC Sales: 2006-2014. Compiled from (IDC, 2009) and (IDC, 2010)**

* Extrapolated (backwards)
** Calculated by combining 2008 sales and growth rate of 2007 to 2008

In older forecasts and sales figures, for example one from 2006, IDC did not account for portables and PCs sale separately. It is therefore backcasted, assuming rapid development of the portables and knowing from IDC reports that from 2004 onwards the portables were a main driver of growth in the PC market.

| | *2001* | *2002* | *2003* | *2004* | *2005* | | |
|---|---|---|---|---|---|---|---|
| ***Desktop*** | *96%* | *93%* | *91%* | *77%* | *80%* | | |
| ***Portable*** | *4%* | *7%* | *9%* | *13%* | *20%* | | |
| | ***2015*** | ***2016*** | ***2017*** | ***2018*** | ***2019*** | ***2020*** | ***2020-2030*** |
| ***Desktop*** | *24%* | *22%* | *20%* | *19%* | *18%* | *18%* | *18%* |
| ***Portable*** | *76%* | *78%* | *80%* | *81%* | *82%* | *82%* | *82%* |

**Table S19 – Desktop/Portable composition in PC Sales: 2001-2005 and 2015-2020.**

(B) Historic data and Forecast on the subdivision of Desktops and Portables in PC sales

| | **2006*** | **2007**** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** |
|---|---|---|---|---|---|---|---|---|---|
| **Desktop** | 37 | 34 | 31.4 | 28.4 | 29.3 | 29.3 | 28.8 | 28.4 | 28.1 |
| **Portable** | 25 | 29.4 | 34.2 | 42.6 | 49.1 | 56.4 | 64.1 | 72.7 | 81.6 |
| **Total** | 62.00 | 63.42 | 65.6 | 71 | 78.4 | 85.7 | 92.9 | 101.1 | 109.7 |
| **Desktop** | 60% | 54% | 48% | 40% | 37% | 34% | 31% | 28% | 26% |
| **Portable** | 40% | 46% | 52% | 60% | 63% | 66% | 69% | 72% | 74% |

**Table S20 – Desktop/Portable composition in Historic and Forecast PC Sales: 2006-2014. Compiled from (IDC, 2009) and (IDC, 2010)**

* Extrapolated backwards
** (Businesswire, 2006)

In older forecasts and sales figures, for example one from 2006, IDC did not account for portables and PCs sale separately. It is therefore backcasted, assuming rapid development of the portables and knowing from IDC reports that from 2004 onwards the portables were a main driver of growth in the PC market

| | *2001* | *2002* | *2003* | *2004* | *2005* | | |
|---|---|---|---|---|---|---|---|
| ***Desktop*** | *92%* | *86%* | *81%* | *74%* | *67%* | | |
| ***Portable*** | *8%* | *14%* | *19%* | *26%* | *33%* | | |
| | ***2015*** | ***2016*** | ***2017*** | ***2018*** | ***2019*** | ***2020*** | ***2020-2030*** |
| ***Desktop*** | *24%* | *22%* | *20%* | *19%* | *18%* | *18%* | *18%* |
| ***Portable*** | *76%* | *78%* | *80%* | *81%* | *82%* | *82%* | *82%* |

**Table S21 – Desktop/Portable composition in PC Sales: 2001-2005 & 2015-2030. Extrapolated from Table S20**

B4 – Lower-bound and Upper-bound Scenarios: Wind, Automotive, HDD [Global]

*Wind Turbines*

| Label | Assumption | Lower bound | Baseline | Upper bound |
|---|---|---|---|---|
| A | **New installed capacity** | 2020: 26 GW<br>2030: 41 GW | 2020: 88 GW<br>2030: 148 GW | 2020: 120 GW<br>2030: 185 GW |
| B | **Share REPM** | 2020: 15%<br>2030: 20% | 2020: 22.5%<br>2030: 30% | 2020: 25%<br>2030: 35% |
| N | **Collection Rate** | 80% | 100% | 100% |

**Table S22 – Key assumptions Wind**

*Automotive*

| Label | Assumption | Lower bound<br>(P)HEVs, EVs | Baseline<br>(P)HEVs, EVs | Upper bound<br>(P)HEVs, EVs |
|---|---|---|---|---|
| A | **Penetration rate in unit sales** | 2020: 3.75%, 0.0025%<br>2030: 9.75%, 0.75% | 2020: 15%, 1%<br>2030: 39%, 3% | 2020: 24%, 2%<br>2030: 52%, 8% |
| B | **kg REPM in motor** | 2020: 0.5, 0.75<br>2030: 0.5, 0.75 | 2020: 1.02, 1.5<br>2030: 1.02, 1.5 | 2020: 1.02, 1.5<br>2030: 1.02, 1.5 |
| F | **Collection rate** | 80% | 90% | 100% |

**Table S23 – Key assumptions Automotive**

*HDDs in PCs*

| Label | Assumption | Lower bound | Baseline | Upper bound |
|---|---|---|---|---|
| A | **Unit sales** | 2020: 510<br>2030: 737 | 2020: 626<br>2030: 1053 | 2020: 716<br>2030: 1254 |
| C | **Percentage of Desktop with HDD** | 2020: 76%<br>2030: 39% | 2020: 100%<br>2030: 100% | 2020: 100%<br>2030: 100% |
| D | **Percentage of Portable with HDD** | 2020: 33%<br>2030: 1% | 2020: 58%<br>2030: 14% | 2020: 76%<br>2030: 39% |
| J | **Collection rate** | 40% | 50% | 85% |

**Table S24 – Key Assumptions HDD**

# SECTION C – ADDITIONAL RESULTS

C1 – Additional Outcomes [EU-27]

*Neodymium*

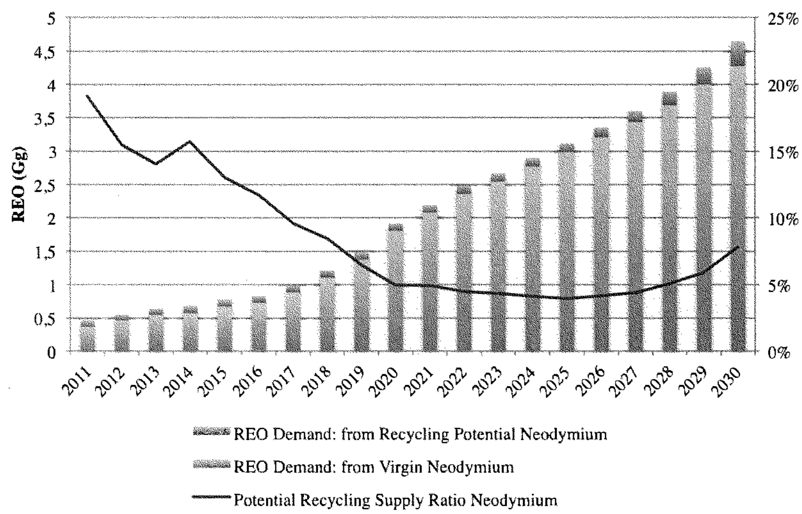


**Figure S5 – Potential recycling supply neodymium [EU-27]**

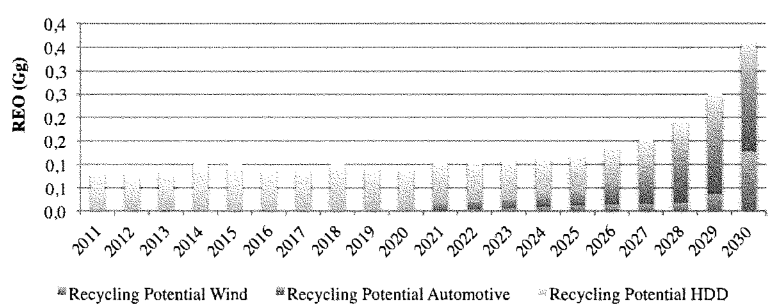


**Figure S6 – Summary of potential recycling supply neodymium by source [Wind, Automotive & PCs] [EU-27]**

*Dysprosium*

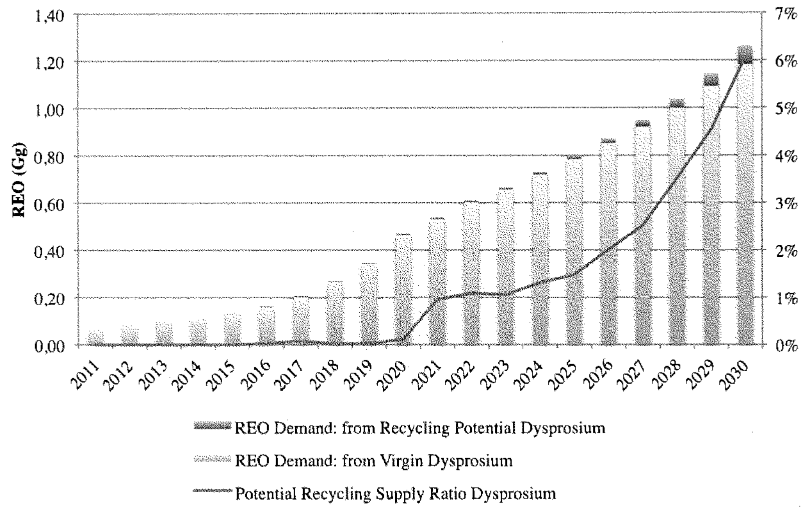


**Figure S7 – Potential recycling supply dysprosium [EU-27]**

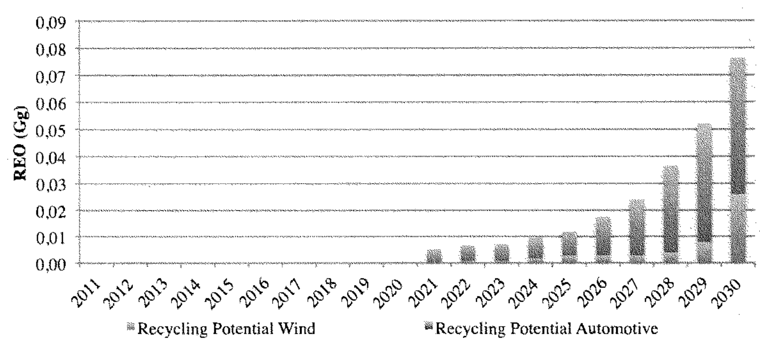


**Figure S8 – Summary of potential recycling supply dysprosium by source [Wind & Automotive] [EU-27]**

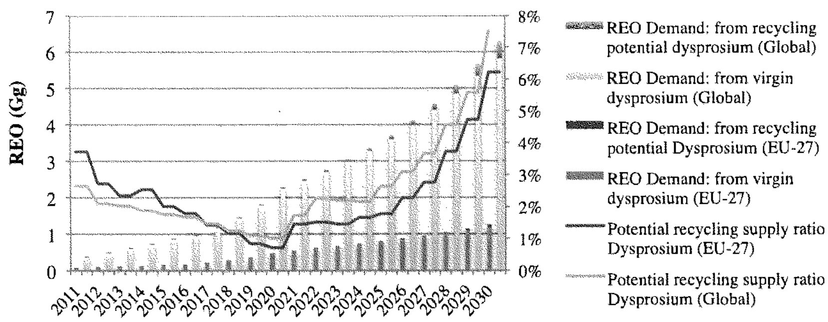


**Figure S9 – Potential recycling supply dysprosium [Global & EU-27, NdFeB magnets only]**

C2 – In-Use Stock [Global & EU-27]

*Neodymium*

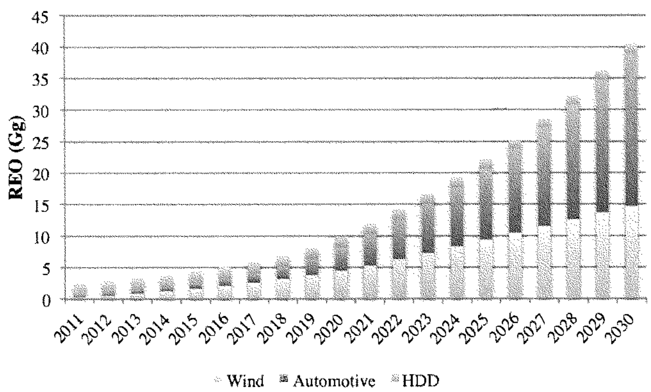


**Figure S10 – In-Use Stock neodymium [EU-27]**

*Dysprosium*

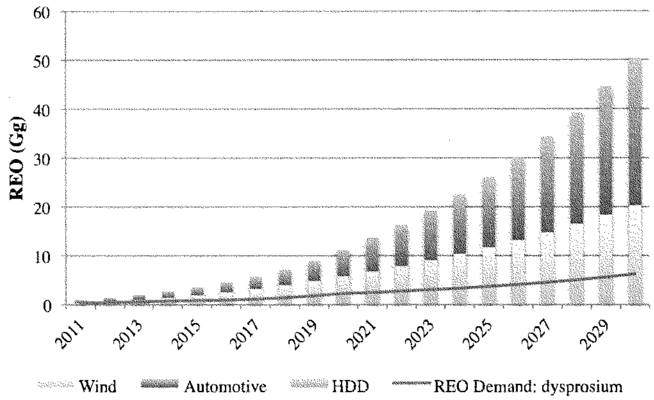


**Figure S11 – In-Use Stock dysprosium [Global]**

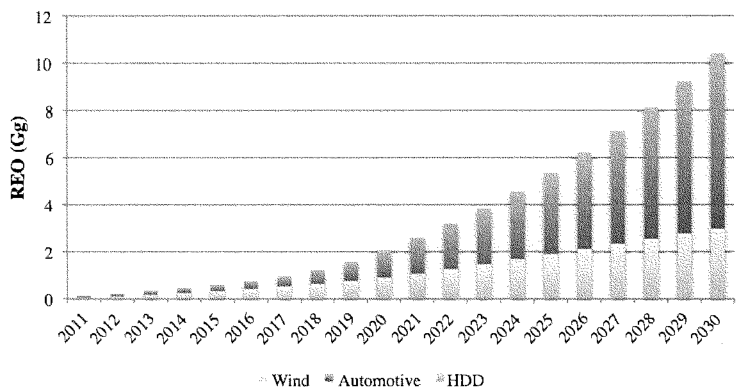


**Figure S12 – In-Use Stock dysprosium [EU-27]**

C3 – Scenarios: Lower bound, Baseline and Upper bound [Global]

*Neodymium: Wind, Automotive & PCs*

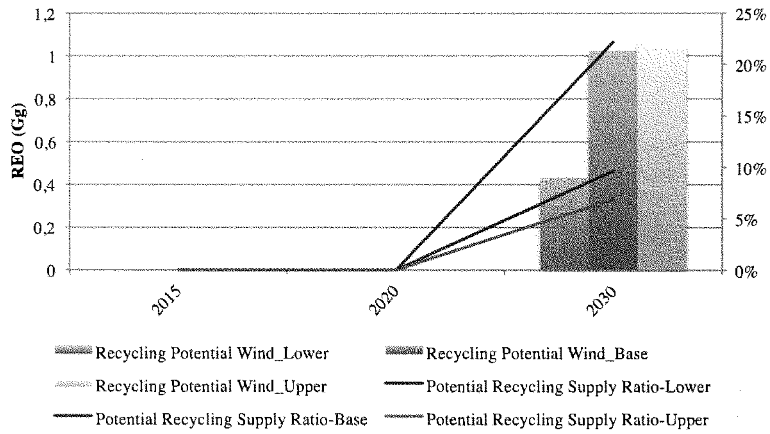


**Figure S13 – Potential recycling supply neodymium from Wind Turbines [Lower bound, Baseline & Upper bound] [Global]**

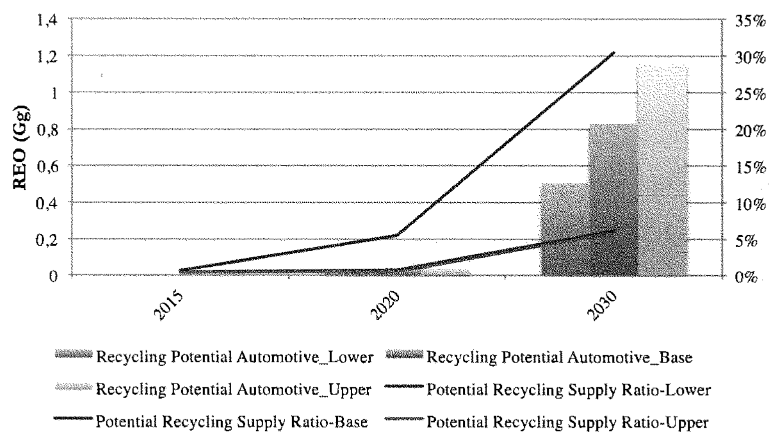


**Figure S14 – Potential recycling supply neodymium from Automotive [Lower bound, Baseline and Upper bound] [Global]**

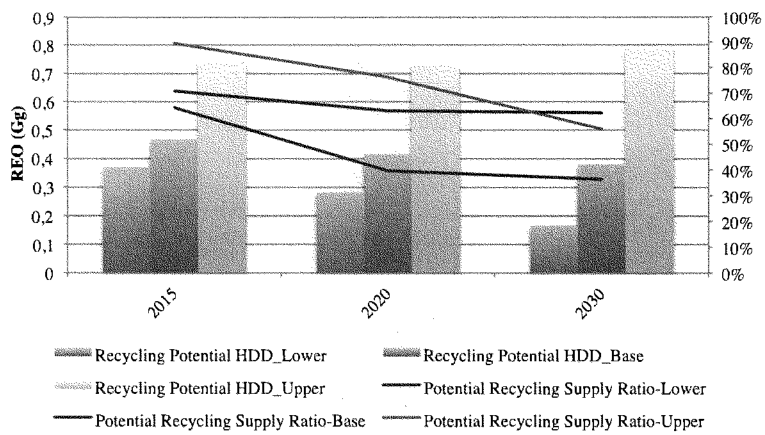


**Figure S15 – Potential recycling supply neodymium from HDDs in PCs [Lower bound, Baseline and Upper bound] [Global]**

*Dysprosium: Wind & Automotive*

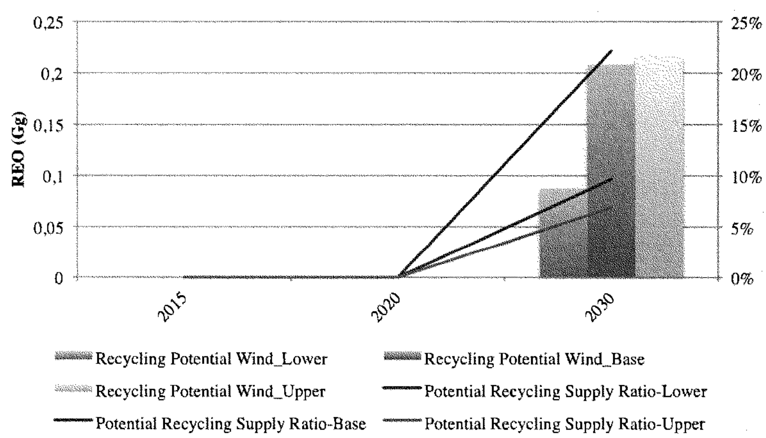


**Figure S16 – Potential recycling supply dysprosium from Wind Turbines [Lower bound, Baseline and Upper bound] [Global]**

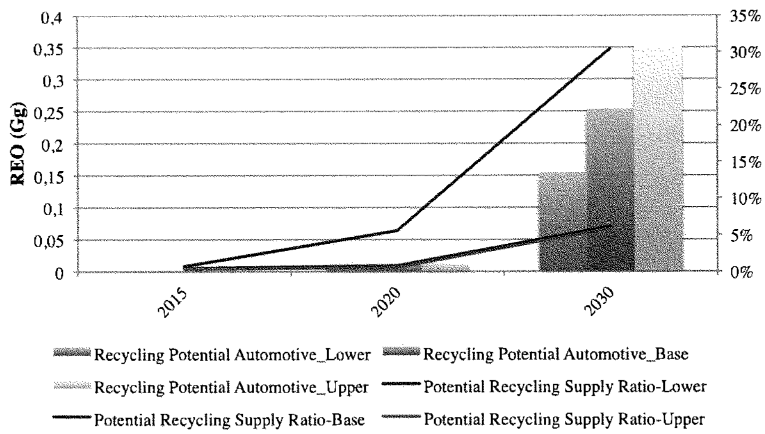


**Figure S17 – Potential recycling supply dysprosium from Automotive [Lower bound, Baseline and Upper bound] [Global]**

*Neodymium & Dysprosium: Totals*

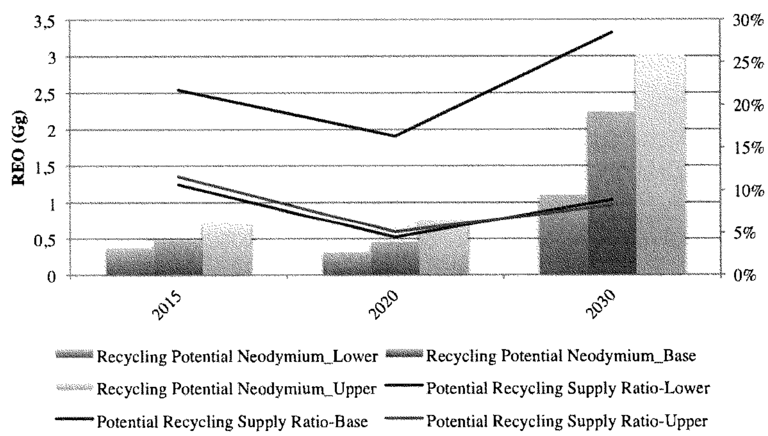


**Figure S18 – Potential recycling supply neodymium [Lower bound, Baseline and Upper bound] [Global]**

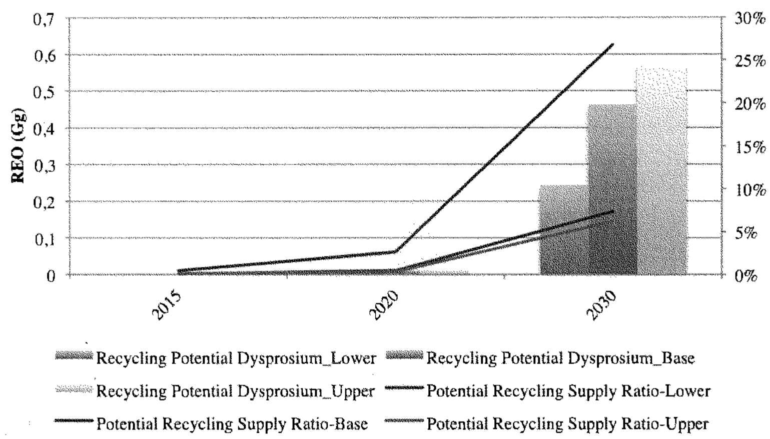


**Figure S19 - Potential recycling supply Dysprosium [Lower bound, Baseline and Upper bound] [Global]**

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The Greens | European Free Alliance
in the European Parliament

Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

# Study on Rare Earths and Their Recycling

**Final Report for The Greens/EFA Group in the European Parliament**

**Darmstadt, January 2011**

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*Note: Within the scope of this study, Öko-Institut has used and assessed numerous primary sources in a carefully neutral fashion, complying all the time with established principles of research. Nevertheless Öko-Institut cannot guarantee that the forecasted will actually occur, particularly in the case of the supply-and-demand-balance, since – as the study shows – there are numerous factors of influence which can change at short notice.*

# I List of Contents

## List of Conclusions

## List of Figures

## List of Tables

## List of Abbreviations

| | |
|---|---|
| °C | degree Celsius |
| a | anno = year |
| AFP | Analytical fingerprint |
| BAM | Barium magnesium aluminate |
| CAT | Cerium magnesium aluminate |
| Ce | Cerium |
| CFL | Compact fluorescent lamps |
| Co | Cobalt |
| Dy | Dysprosium |
| e.g. | exempli gratia = for example |
| e-bikes | electric bikes |
| EC | European Commission |
| EIB | European Investment Bank |
| EL | electro-luminescence |
| ELV | End of life vehicle |
| e-mobility | electric mobility |
| Er | Erbium |
| etc | et cetera |
| Eu | Europium |
| EU-27 | Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Germany, Denmark, Estonia, Spain, Finland, France, United Kingdom, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Poland, Portugal, Romania, Sweden, Slovenia, Slovakia |
| EV | Electric Vehicle |
| FCC | Fluid cracking catalyst |
| Gd | Gadolinium |
| GMEL | Greenland Minerals and Energy Ltd. |
| $H_{ci}$ | coercivity |
| HCl | Hydrochloric acid |
| HDD | Hard disk drive |
| HEV | Hybrid Electric Vehicle |
| HID | High intensity discharge (lamp) |
| Ho | Holmium |

| | |
|---|---|
| HREE | Heavy Rare Earth Element |
| HTS | High temperature superconductor |
| JOGMEC | Japan Oil, Gas and Metals National Corporation |
| JORC | Australasian Joint Ore Reserves Committee |
| K | Potassium |
| kW | Kilowatt |
| La | Lanthanum |
| LAP | Lanthanum phosphate |
| LCD | Liquid crystal display |
| LED | Light Emitting Diode |
| Li-ion battery | Lithium ion battery |
| LREE | Light Rare Earth Element |
| Lu | Lutetium |
| MFA | Material flow analysis |
| mg | Milligram |
| Mio | Million |
| MRI | Magnetic resonance imaging |
| n.d. | No data available |
| Nd | Neodymium |
| NdFeB | Neodymium ferrium boron |
| nGy/h | Nanogray per hour (Gamma dose rate) |
| $NH_3$ | Ammonia |
| $NH_4^+$ | Ammonium ion |
| Ni | Nickel |
| Ni-MH battery | Nickel metal-hydride battery |
| OLED | Organic light emitting diode |
| PHEV | Plug-in hybrid electric vehicle |
| Pm | Promethium |
| Pr | Praseodymium |
| R&D | Research and development |
| Ra | Radium |
| REE | Rare earth element |
| REO | Rare earth oxide (common trade unit) |

| | |
|---|---|
| RMB | Renminbi = official currency of the People´s Republic of China; principal unit is Yuan |
| Sc | Scandium |
| Sm | Samarium |
| SOFC | Solid oxide fuel cell |
| SSD | Solid state drive |
| SSEEC | Solid state energy efficient cooling |
| t | Metric tons |
| Tb | Terbium |
| Th | Thorium |
| Tm | Thulium |
| TREO | Total rare earth oxide |
| U | Uranium |
| UK | United Kingdom |
| UNEP | United Nations Environment Programme |
| VCM | Voice-coil-motor |
| WEEE | Waste Electrical and Electronic Equipment |
| Y | Yttrium |
| Yb | Ytterbium |
| YOE | Yttrium europium oxide |

# EXECUTIVE SUMMARY

The focus of this study for the Greens/EFA Group in the European Parliament lies on the development of a European strategy for a sustainable rare earth economy. It particularly addresses the recycling, the substitution and the efficient use of rare earths and develops a strategy towards a green rare earth economy.

The rare earth elements under analysis in this study by Öko-Institut include the 17 elements yttrium (Y), lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu) and scandium (Sc) and the role they play in the case of green technologies.

The chapters 1 to 9 provide a comprehensive overview of methodological approaches to assess the criticality as well as global aspects such as rare earth mining, processing, trade, environmental impacts, applications, current and future demand and the expected demand-supply balance. Each chapter culminates in a conclusion, by means of which the reader can gain a quick overview of its contents. These data are not summarised in the executive summary. Instead, the executive summary focuses on the main target of the study, the development of a European strategy for a sustainable rare earth economy.

**Background**

During recent years technological innovations resulted in manifold applications using rare earths which lead to a steep increase in their demand. A relevant share of the increasing demand is caused by so-called "green technologies" which are designed to contribute to environmental protection in terms of reduction of the energy consumption, the further development of renewable energy carriers or air pollution control. There is serious concern that the demand of some individual rare earth elements such as neodymium, praseodymium, dysprosium, terbium, lanthanum, yttrium and europium might exceed the present supply within a few years. Even if China imposes no export restrictions it is to be expected that the increasing demand up to 2014 can only be met if further mines in addition to the two planned mines in Australia and USA are opened. The two mines in Australia and the USA have already obtained approval from the national authorities and started construction works so that large scale operation can commence around 2012.

The high demand and the expected supply shortages, additionally triggered by Chinese export restrictions, lead to a significant increase in rare earth prices. This steep increase is not only a burden for manufacturers and consumers. It offers the chance to address the problem of today's rare earth supply in more depth and to build up a sustainable rare earth economy in all relevant sectors. The low prices in the past lead to a significant waste of resources. Until now, there has been almost no recycling of rare earths. The new prices might be a starting point to building up recycling systems for rare earth compounds. Similarly, science and industry are beginning to conduct research and development on options for a substitution of rare earth.

The high public interest in this issue further revealed the high environmental burden in the surrounding of the Chinese mines and processing plants. If the EU demands rare earth compounds for their green technology, it is up to the EU to contribute to a "greener" rare earth supply. The contradiction between the "green" application of rare earth and their high environmental pressures in production calls for action to be taken particularly by Europe, America and Japan where – besides China – the majority of the rare earths are consumed.

The action in the fields of recycling should be started now without further delay as it will take a minimum of five to ten years for the first large-size implementation to take place. The research for substitution options and efficiency should also be reinforced as soon as possible as it takes some years to move from successful research to industrial implementation.

**Analysis of the substitution of rare earths and their efficient use**

The examination of substitutions for scarce REE has shown that there is quite rarely a simple substitution of a REE compound by another compound. In most cases substitution requires a totally new product design. The identified options for substitution in the case of the major green applications are summarised below:

- Rare earths are currently used in around 14 % of newly installed **wind turbines** with a gear-less design and technical advantages in terms of reliability. A supply shortage of rare earths would lead to a shift to alternative turbine types. Further research on a higher reliability of traditional techniques with gears would support this substitution.
- Rare earths are used in permanent motors of **hybrid electric vehicles** and **electric vehicles**. Substitutions based on alternative electric motor designs are principally available. However, R&D is required for a higher performance of existing electric motor types and for the realisation of new motor concepts.
- Most new **energy-efficient lighting systems** contain rare earths (compact fluorescent lamp, LED, plasma display, LCD display). Substitutions are rare, particularly for compact fluorescent lamps. R&D is required for alternative phosphors with high efficiency and high light quality.
- Automotive **catalysts** contain cerium, and catalysts for petroleum cracking and other industrial processes contain lanthanum. Substitutions are rare, and R&D is urgently required for alternative catalysts.

Concerning a **higher efficiency** of the rare earth use, R&D is urgently needed in all fields of application and is also needed on the supply side to enable higher efficiencies in mining, beneficiation and processing. One example for high losses in the production chain is the traditional magnet production in China.

**Nanotechnology** is considered to be applied in some green applications in order to raise the efficiency by nano-sized rare earths. An attendant risk assessment is highly recommended.

**Analysis of the current recycling activities of rare earths**

Only a few industrial recycling activities are currently implemented for rare earths. Until now, there has been no large scale recycling of rare earths from magnets, batteries, lighting and catalysts. Principally, the recycling processes for the rare earths are quite complex and extensive if re-use is not possible and a physical and chemical treatment is necessary. Most of the recycling procedures are energy-intensive processes. The main post-consumer activities – the recycling of rare earths from electric motors and hard disks and other electronic components – will require intensive dismantling.

Several constraints for a wider recycling of rare earths were identified: the need for an efficient collection system, the need for sufficiently high prices for primary and secondary rare earths compounds, losses of post-consumer goods by exports in developing countries and the long lifetime of products such as electric motors in vehicles and wind turbines of 10 - 20 years before they could enter the recycling economy.

**Advantages of recycling**

The recycling of rare earths has several advantages in comparison to the use of primary resources:

- Europe is one of the globally large consumers of rare earths. Increasing amounts of waste from final products containing rare earths are arising in Europe. These **valuable resources** should be returned to the industrial metabolism by "urban mining".
- The **dependency on foreign resources** will be reduced by supplying the European market with secondary rare earth materials.
- Apart from a few specialised industries and applications, the **know-how** in rare earth processing is quite low in Europe. The building up of know-how in recycling will widen the competency of enterprises and scientific institutions in Europe concerning rare earth processing.
- The processing of secondary rare earths will be **free from radioactive impurities**. The mining and further processing of primary rare earths is involved in most cases with nuclear radiation coming from radioactive elements of the natural deposits.
- The recycling requires some energy carriers and chemicals. On the other hand it saves significant amounts of energy, chemicals and emissions in the primary processing chain. It is to be expected that most recycling processes will have a **high net-benefit** concerning **air emissions**, **groundwater protection**, **acidification**, **eutrophication** and **climate protection**.

**Strategy for the development of a European rare earth recycling scheme**

Öko-Institut suggests that a recycling scheme as illustrated in Figure 1 should be developed.

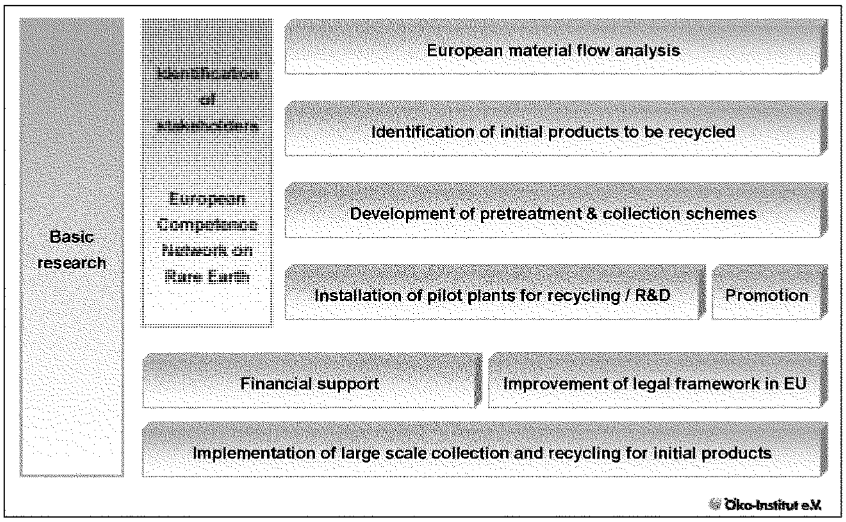


Figure 1 Steps towards a European rare earth recycling scheme

The main steps prior to large-scale implementation are described here in brief:

- A **European Competence Network on Rare Earths** with all relevant stakeholders such as recyclers, manufacturers, public authorities, politicians and researchers is seen as essential for a successful implementation.
- **Basic research** is necessary, as only a few companies in Europe are involved in rare earth refining and processing at the beginning of the added-value chain.
- A **European material flow analysis** (MFA) is necessary in order to identify in more detail the main material flows and waste streams and the main manufacturers and actors in the added-value chain. Currently, national research institutions have to rely on estimates from a few experts outside of Europe.
- The next step is the **identification of initial waste streams** on the pre-consumer and post-consumer level, e.g. waste from the magnet and lighting production, magnets from used electric motors, used lamps and screens, re-use of large magnets and recycling of spent catalysts.

- The treatment of many relevant wastes is already regulated by the Waste Electrical and Electronic Equipment Directive (hereafter WEEE), the EU End of Life Vehicles Directive (ELV) and the EU Battery Directive. Thus, the collection of rare earths containing wastes has to be integrated in existing **collection** schemes.
- The development of **pilot plants** is accompanied by large-scale R&D projects which aim to gain more insight into the complex chemical processes and the required sophisticated equipment.
- Recycling plants bear high **financial risks** due to the required high investment and the high uncertainty of the future price development of rare earths. Therefore, it should be analysed whether the European Investment Bank (EIB) could reduce financial risks for investments in rare earth recycling.
- A recycling scheme of rare earths not only requires adequate logistic and technical preconditions but also an appropriate **legal framework**. Hence, an important step will be the adaption of the legal EU framework in order to optimise post-consumer rare earth recycling. Potential relevant directives which should be verified in terms of modification for the support of a rare earth recycling scheme are the Ecodesign Directive, the WEEE Directive, the ELV Directive and the Battery Directive.

**Recommendations for international activities**

The development of a sustainable rare earth supply for Europe concerning environmental, social and security aspects requires a solid international co-operation. Important partners for the EU in facing this challenge are not only China but also Japan and the United States. Öko-Institut suggests three selected activities:

- Öko-Institut proposes an **EU-China co-operation** on sustainable mining which is designed as a large-size co-operation focusing on the sustainable mining of rare earths at one specific site with the target to optimise the efficiency, the environmental performance, the remediation of contaminated sites and the potential recovery of rare earths from old tailings. The EC would supply co-funding and expertise, and China would agree on an adequate rare earth supply.
- Green technologies call for "green metals", and Europe should support a sustainable mining. Worldwide, there are manifold **initiatives for sustainable mining**. Among them are certification schemes addressing different problems such as environmental aspects, small-scale mining, safety issues and human rights. There is increasing interest in politics and industry on certified minerals, and today's mining companies could be interested in certification schemes or similar co-operations with EU participation in order to highlight their environmental efforts.
- The high pressure on the opening of new mines outside of China by the steeply increasing demand raises the concern that new mines could be opened which do not

keep minimum environmental standards. One case could be the **Kvanefjeld deposit in Greenland** where the residues from the ore concentration (tailings) shall be stored in a natural lake with connection to the sea. The EU and the European Environmental Agency (EEA), which has a general co-operation with Greenland, should appeal clearly to the Greenlandic authorities to act carefully and responsibly.

# FINAL REPORT

## 1 Introduction

In the last seven years international discussions about mineral resources with a special focus on metals have gained a new dimension.[1] Driven by the growth of the global economy and the enhanced pace of the emerging economies (China, India, Brazil, etc.), the global demand for many metals is increasing rapidly and the most forecasts predict further growth of metal consumption. Besides well-known mass metals like steel or aluminium, new challenges in the field of the so-called critical metals are under serious concerns. The EC defines the "criticality" of raw materials in its recent publication "Critical raw materials for the EU" (EC 2010): *"This means that raw material is labelled "critical" when the risks of supply shortage and their impacts on the economy are higher compared with most of the other raw materials."*

It could be stated that in many cases the discussions about critical metals are linked with new innovations and technologies – very often in the field of green technologies like electric vehicles, wind power, PV and many others. Therefore in many relevant publications synonyms like "green minor metals", "specialty metals", "technology metals" and "rare metals" are used for the term "critical metals". As part of the activities of the EC's "Raw Materials Initiative", the Ad-hoc Working Group on defining critical raw materials ranked 14 raw materials at EC level as the most critical metals (EC 2010). This group of 14 raw materials contains the whole group of rare earth elements (REE).

The rare earth elements under analysis in this study by Öko-Institut for the Greens/EFA Group in the European Parliament include the 17 elements: yttrium (Y), lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium[2] (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu) and scandium (Sc).

The large group of the REE is sub-divided into the heavy rare earth elements (HREE) and the light rare earth elements (LREE). Unfortunately there is no worldwide accepted definition for which REE belongs to the HREE or the LREE group. Therefore, crosschecks of data from different sources which refers to facts and figures and so on about HREE and LREE have to be carried out very carefully to avoid failures and misinterpretations (this holds especially for the contribution of yttrium). For this study Öko-Institut uses the definition of the USGS (USGS 2002), which defines yttrium (Y), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu) as HREE and lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), samarium (Sm), europium (Eu), and scandium (Sc) as LREE.

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1 See, for instance, the special website developed by Öko-Institut: www.resourcefever.org.

2 Promethium does not occur in nature as no stable isotope exists.

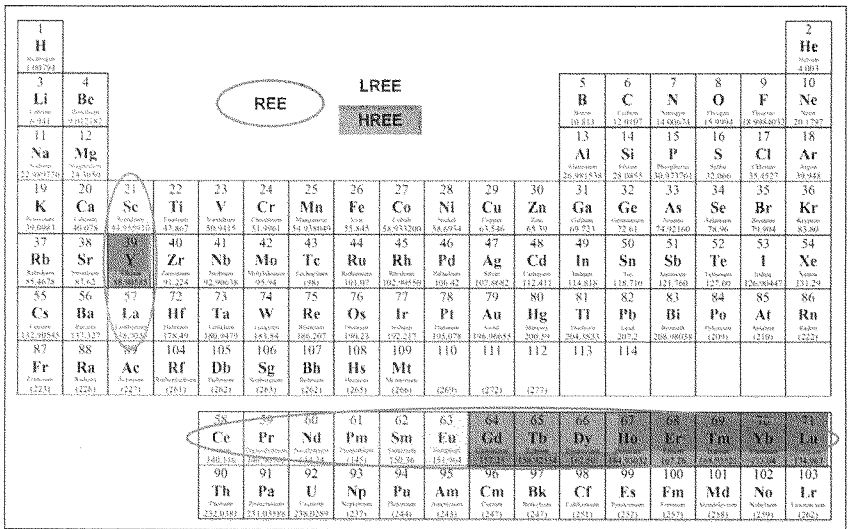


Figure 2 Rare earth elements and their position in the periodic table

Nevertheless, within the "Study on Rare Earth Metals and Recycling" Öko-Institut provides facts and figures, results and interpretations for the different REE as far as is possible. This approach recognises the fact that a handling of the criticality of the REE as a group of 17 elements or as sub-groups (HREE and LREE) is not sufficient for the numerous challenges and tasks regarding green technologies, demand growth, possible supply scarcities and environmental issues of mining and recycling.

## 2 Methodologies for determination of criticality

Against the background of rapid demand growths, increasing prices and possible supply restrictions of certain metals with high potential for future technologies having received increasing attention by media, scientists, enterprises and the politics, several classification systems to rank the numerous raw materials and metals have been developed in recent years. It should be mentioned that the purpose of these studies is not always the same und therefore a one-by-one comparison of the results could not be undertaken. In most cases a national or regional point of view is the driving force behind the classifications systems for criticality. For an overview the methodological approach of the report "Minerals, Critical Minerals and the U.S. Economy" (National Academies 2008) and the approach of the Ad-hoc Working Group on defining critical raw materials (EC 2010) are selected. Finally an approach of Öko-Institut for the UNEP will be briefly introduced.

In 2008 the National Academy of Sciences released a comprehensive report with the title "Minerals, Critical Minerals and the US Economy" (National Academies 2008). The motivation for this study is reflected by the following excerpt of the study's preface: *"In the twenty-first century, the nature of the concerns over Earth resources has shifted once again. Energy and mineral commodity prices are relatively high for the first extended period since the 1970s, driven primarily by unexpectedly large demand growth in China, India, and other countries. At the same time, while the United States remains an important producer of energy and mineral resources, the extraction and production of these resources overall has shifted away from the United States toward other nations; U.S. import dependence for many commodities has increased and has raised concerns about reliability of the foreign supply."* The driving force for the US study was clearly the assessment that the US economy faces increasing dependence on raw materials imports. So, the whole study and including the released criticality matrix has to be considered in the context of this motivation.

The US approach is based on two dimensions of criticality; **importance in use** and **availability**. The dimension of importance in use reflects the idea that some non-fuel raw materials are more important in use than others. The authors pointed out that the possibility of substitution is the key here. The second dimension, availability, includes several medium- to long-term considerations: geologic, technical, environmental, social, political and economic factors have to be taken into account. In addition, the consideration of the reliability or risk of supply in the short term is important. On this basis the authors have developed a two-dimension criticality matrix. The criticality matrix, as established in this report, allows evaluation of the criticality of a given mineral. A specific mineral or mineral product can be placed on this matrix after assessing the impact of a potential restriction on the mineral's supply (importance in use: vertical axis) and the likelihood of a supply restriction (availability: horizontal axis). The degree of criticality increases as one moves from the lower-left to the upper-right corner of the matrix. The committee used a combination of quantitative measures and expert (qualitative) judgement in implementing the matrix methodology. The rare earths were determined by this methodology (as one of five out of 11 minerals or mineral groups) to fall in or near the critical zone of the criticality matrix.

The US approach was applied in a report on the critical materials strategy from the US Department of Energy in 2010 (DOE 2010). It focuses on nine individual rare earth elements and the metals gallium, tellurium, lithium, indium and cobalt and their importance to the clean energy economy.

In July 2010 the EC published the report "Critical raw materials for the EU" which was worked out by the Ad-hoc Working Group on defining critical raw materials (EC 2010). The EC report provides a pragmatic approach based on various existing methods. In line with other studies, the report puts forward a relative concept of criticality. This means that raw material is labelled "critical" when the risks of supply shortage and their impacts on the economy are higher compared with most of the other raw materials. It considers three main aggregated indicators or dimensions, i.e. the **economic importance** of the considered raw material, its **supply risk** (for instance restrictive measures from resource-rich countries) and an **environmental country risk** assessing the potential for environmental measures that may restrain access to deposits or the supply of raw materials. These three aggregated indicators are calculated for each raw material.

41 different raw materials were assessed by the Ad-hoc Working Group with this criticality approach based on the three main aggregated indicators/dimensions. In a first step the 41 raw materials are positioned in a two-dimensional matrix comparable with the US approach (see above). The vertical axis reflects the positioning of the materials in relation to the supply risks that have been identified. The production of a material in few countries marked by political and economic instability, coupled to a low recycling rate and low substitutability, will result in a very high supply risk. The results show for the rare earths the highest rank among all 41 assessed raw materials.

The horizontal axis reflects the positioning of the material in relation to its importance to the EU. For this dimension the rare earths are in the midfield. From this two-dimensional matrix a list of 14 different raw materials including the rare earths are assessed as critical, because they are of high economic importance and have a high supply risk. Finally the environmental country risk – the third indicator – was used to finish the determination of criticality. However, the overall result for the group of 14 was not altered by this indicator. It is important to note that the rare earths were ranked as the raw material with the highest environmental country risk among all assessed 41 raw materials.

In 2009 Öko-Institut completed a study for UNEP entitled "Critical metals for future sustainable technologies and their recycling potential" (Öko-Institut 2009). For the classification of selected "green minor metals" with a potential for sustainable technologies an own classification system with the three main pillars "demand growth", "supply risks" and "recycling restrictions" was developed. To enable extensive classification and differentiation of the different metals, the following sub-criteria are taken into account by Öko-Institut:

- **Demand growth**
  - Rapid demand growth: > 50% increase of total demand until 2020
  - Moderate demand growth > 20% increase of total demand until 2020
- **Supply risks**
  - Regional concentration of mining (> 90% share of the global mining in the major three countries)
  - Physical scarcity (reserves compared to annual demand)
  - Temporary scarcity (time lag between production and demand)
  - Structural or technical scarcity (metal is just a minor product in a coupled production and inefficiencies occur often in the mining process, production and manufacturing)
- **Recycling restrictions**
  - High scale of dissipative applications
  - Physical/chemical limitations for recycling
  - Lack of suitable recycling technologies and/or recycling infrastructures
  - Lack of price incentives for recycling

In contrast to other ranking systems this classification system are not based on a national point of view, which means the results are universal and not specific to a single country or region. The availability of all REE could prove to be very critical following this approach for the period up to 2020 (for details see: Öko-Institut 2009). Within the REE group the availability of several elements could prove to be even more critical as the result of this report suggest.

As a group the REE have already been ranked highest in terms of criticality by the EC in July 2010 (EC 2010) and in previous assessments conducted by other organisations. This classification is justified without any doubt. For this study for the Greens/EFA Group in the European Parliament in late 2010 Öko-Institut has chosen an in-depth analysis approach for the individual REE, because the REE schematic rankings of the whole group of REE are not sufficient to produce detailed results as a basis for strategies. Based on the detailed results the proposed strategies for Europe regarding the REE are summarised in Chapter 12.

***Conclusion on methodologies for determination of criticality***

*In recent years, several classification systems were developed to rank numerous raw materials and metals in terms of their criticality. Examples of such ranking systems are the report "Minerals, Critical Minerals and the U.S. Economy" by the National Academies 2008, the approach of the European Ad-hoc Working Group on defining critical raw materials (EC 2010), the approach of Öko-Institut for the UNEP and the recently published analysis of criticality of nine rare earth elements and five other metals by the US Department of Energy (DOE 2010). Due to their expected scarcity rare earths are taken into account in these reports.*

*There is a consensus in all approaches that some rare earth elements are critical or near-critical in terms of the supply risk and their importance for green technologies. Consequently, a more in-depth analysis which evaluates the criticality of the individual rare earth elements is necessary in order to produce detailed results as basis for political strategies.*

# 3 Reserves

## 3.1 Global reserves

USGS (2010a) estimates the global reserves of the sum of all rare earth oxides to be at 99 000 000 t REO. This is quite high compared to the estimated world production of 124 000 t REO (USGS 2010a) in 2009. Hereby, the reserve is defined by the USGS as "the part of the reserve base which could be economically extracted or produced at the time of determination." On the contrary, the reserve base not only comprises the resources that are currently economic (= reserves) but also marginally economic reserves, and some of those that are currently sub-economic. The reserve base was estimated to amount to 150 000 000 t REO by USGS (2008). In 2009, reserve base estimates of the USGS were discontinued.

It is to be expected that both the reserve base and the reserve will increase in the years ahead because the steep increases in REO prices lead to the exploration of new deposits. For example, the Chinese Ministry of Commerce announced in October 2010 that a new large rare earth deposit was found in Central China (MOFCOM 2010a). The rare earth reserves by country based on USGS (2010a) are shown in the following figure.

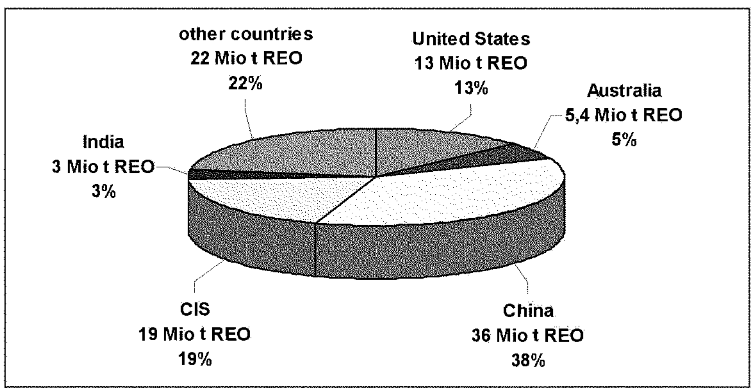


Figure 3 Global rare earth reserves by country estimated by USGS (2010a)

Though the Chinese produce more than 95% of the global production, their share of the reserves is much lower at 38 %. Large deposits are also found in the USA, Australia and states of the former Soviet Union.

However, the figures on the total reserves which refer to the sum of all rare earth elements do not reflect the need for a detailed look on the supply of individual elements. As discussed later in the study, shortages will be expected for some REE and their specific reserves are of importance.

The following chapters will provide some reserve estimations for the group of heavy rare earth elements as well as Chinese reserve estimations. Unfortunately, the USGS, Chinese, Australian and Canadian institutions have different definitions of reserves, reserve base and resources, which make it difficult or even impossible to compare the different national reserve and resource statistics. International attempts to harmonise the classification[3] are not developed in so far that they already provide harmonised reserve data on rare earths.

## 3.2 Reserves in China

Ministry of Environmental Protection (MEP 2009) presents data from the Chinese Society of Rare Earths (CSRE 2002) which indicate that China has 52 million tons of proved industrial reserves. The data are presented in Table 3-1.

Table 3-1 Distribution of REE reserves in tons REO (MEP 2009)

| Provinces and regions | Industrial reserves | Measured reserves | Inferred reserves |
|---|---|---|---|
| Bayan Obo, Inner Mongolia | 43.5 million | 106 million | >135 million |
| Shandong | 4 million | 12.7 million | >13 million |
| Sichuan | 1.5 million | 2.4 million | >5 million |
| Seven Southern Provinces | 1.5 million | 8.4 million | >50 million |
| Others | 1.5 million | 2.2 million | >3.7 million |
| Total | 52 million | 131.7 million | >206 million |

Additionally, geologists have discovered a large reserve of rare earths in central China's Hubei Province at the foot of Mountain Laoyin in Shiyan City (MOFCOM 2010a). The amount of the newly-found deposit was not known at the time this study was written. Therefore it is not included in the above statistics.

The Chinese statistics use their own classification for data on reserves which differs from the USGS classification. This might be the main reason of the difference to the USGS data, which estimate the (economical) Chinese reserve to amount to 36 Mio t REO, whereas the Chinese estimate their "industrial reserves" to amount to 52 Mio t REO. The table clearly

[3] E.g. the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) and UN Framework Classification (UNFC) for Energy and Mineral Resources

shows that the major reserves are in Inner Mongolia at Bayan Obo, where the world largest rare earth mine is already in operation.

The next figure shows the regional distribution of the Chinese reserves.

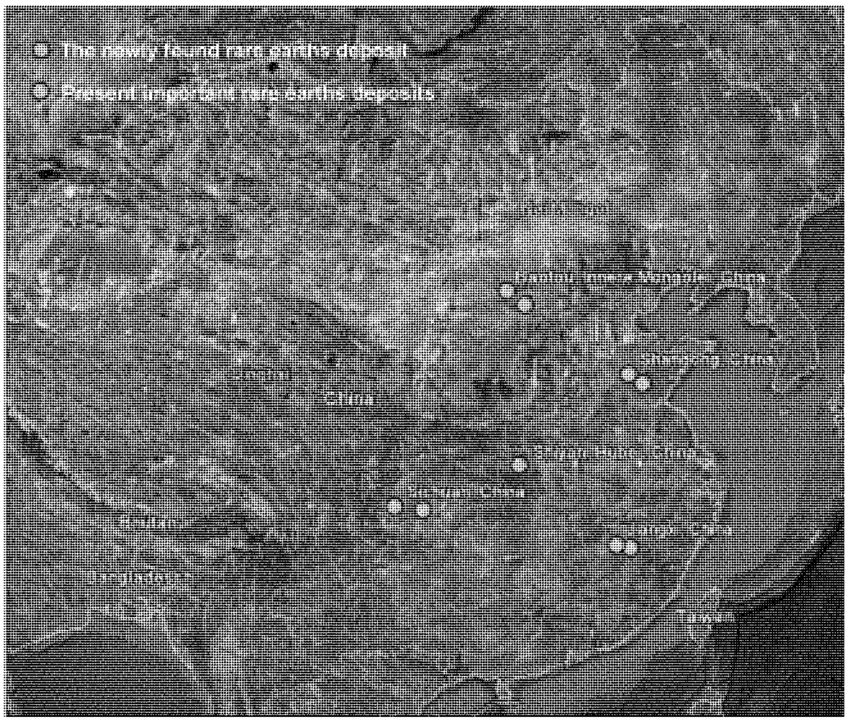


Figure 4 Distribution of major rare earth resources in China

The next table shows the average grades of the ores and the types of minerals from the different provinces.

Table 3-2 REE resources in China: types of minerals and ore grades (Lin 2009)

| Province | Mineral | REE | Grades in % REO |
|---|---|---|---|
| Inner Mongolia, Baotou, Bayan Obo | Bastnaesite and Monazite | Light REE in Iron-Nb-LREE deposit | 6 |
| Seven provinces, Southern China | Ion adsorption deposit | Middle and heavy REE | 0.1-0.3 |
| Sichuan | Bastnaesite | Light REE with high grade | 6-8 |
| Shandong | Bastnaesite | La, Ce, Pr, Nd with high grade | 7-10 |

The Chinese describe the distribution of rare earth resources in China simply as "North Light, South Heavy". That means that light rare earth resources (La, Ce, Pr, Nd, Sm, Eu) are mainly found in the north of the country, while in the south middle or heavy rare earths (Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Sc, Y) are concentrated. The HREEs are extracted from ion adsorption deposits located in the seven provinces in the South of China (Jiangxi, Guangdong, Fujiang, Guangxi, Hunan, Yunnan and Zhejiang) (MEP 2009). The regional distribution of the HREE deposits is given in Table 3-3.

Table 3-3 The distribution of ion adsorption deposits in the South of China (MEP 2009)

| Province | Jiangxi | Guangdong | Fujian | Guangxi | Hunan | Yunnan and Zhejiang | Total |
|---|---|---|---|---|---|---|---|
| Ratio in % | 36 | 33 | 15 | 10 | 4 | 2 | 100 |

An overview of the ore composition of the different rare earth containing minerals is given in Table 3-4.

Table 3-4 Components of China's major rare earth minerals in REO% (Wang 2009)

| Rare earth oxides | Bastnaesite | Monazite | Xenotime | Ion adsorption deposits | |
|---|---|---|---|---|---|
| | | | | Longnan, Ganzhou, Jiangxi Province | Xunwu, Ganzhou, Jiangxi Province |
| **LREE** | | | | | |
| $La_2O_3$ | 27.00 | 23.35 | 1.20 | 2.10 | **29.84** |
| $CeO_2$ | **50.00** | **45.69** | 8.00 | 1.00 | 7.18 |
| $Pr_6O_{11}$ | 5.00 | 4.16 | 0.60 | 1.10 | 7.41 |
| $Nd_2O_3$ | 15.00 | 15.72 | 3.50 | 5.10 | **30.18** |
| $Sm_2O_3$ | 1.10 | 3.05 | 2.15 | 3.20 | 6.32 |
| $Eu_2O_3$ | 0.20 | 0.10 | <0.20 | 0.30 | 0.51 |
| **HREE** | | | | | |
| $Gd_2O_3$ | 0.40 | 2.03 | 5.00 | 2.69 | 4.21 |
| $Tb_4O_7$ | — | 0.10 | 1.20 | 1.13 | 0.46 |
| $Dy_2O_3$ | — | 1.02 | 9.10 | 7.48 | 1.77 |
| $Ho_2O_3$ | — | 0.10 | 2.60 | 1.60 | 0.27 |
| $Er_2O_3$ | 1.00 | 0.51 | 5.60 | 4.26 | 0.88 |
| $Tm_2O_3$ | — | 0.51 | 1.30 | 0.60 | 0.27 |
| $Yb_2O_3$ | — | 0.51 | 6.00 | 3.34 | 0.62 |
| $Lu_2O_3$ | — | 0.10 | 1.80 | 0.47 | 0.13 |
| $Y_2O_3$ | 0.30 | 3.05 | **59.30** | **62.90** | 10.07 |

The next figure illustrates the major element distribution for China's largest deposit, Bayan Obo in Inner Mongolia, which mainly consists of bastnaesite. Its element distribution is representative for many light rare earth deposits.

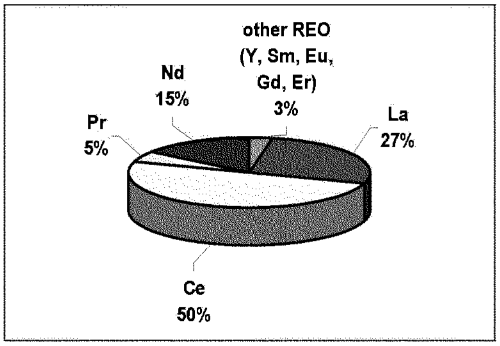


Figure 5 Rare earth composition of bastnaesite at Bayan Obo/Inner Mongolia (Wang 2009)

The ore composition is dominated by light rare earths, mainly cerium, lanthanum and smaller amounts of neodymium and praseodymium. Heavy rare earths such as gadolinium only occur in very small shares. Concerning the heavy rare earths, the seven provinces in the South of China which mainly possess heavy rare earths hold 1.5 million tons of industrial reserves. These reserves are quite small compared to the overall reserves in China and only have a share of about 3 % of the total reserves (see Table 3-1).

The next figure shows the major element distribution for two Chinese ion adsorption deposits in Jiangxi Province containing significant HREE:

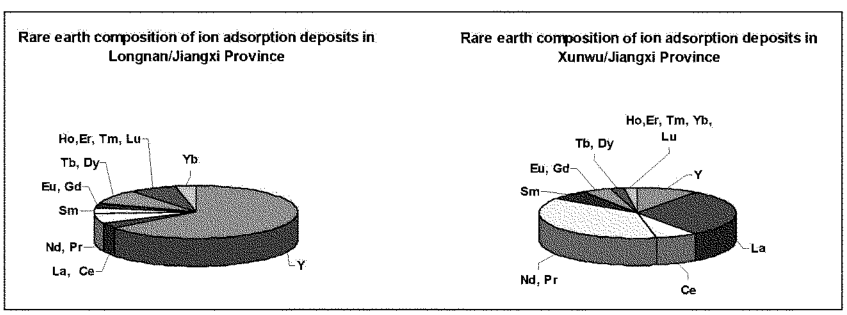


Figure 6 Rare earth composition of two ore deposits in the Jiangxi Province in southern China (Wang 2009)

The two figures for the ion adsorption deposits in the Chinese Jiangxi Province show the large variety of HREE compositions.

The only global production and reserve statistics for individual elements are available for yttrium. USGS (2010b) estimates that the Chinese reserves of yttrium amount to 220 000 t REO, which is equivalent to 41 % of the global reserves. The global mining of yttrium was around 8 900 t in 2008, with 8 800 t originating from China (USGS 2010b). Thus, the calculated ratio between economical reserves and actual production is around 25. For the total Chinese reserves of all REE, the picture is completely different: There is an annual production of around 120 000 t in 2007/2008 versus an economical reserve of 36 Mio t (based on USGS definition). This makes a factor 300. This comparison convincingly shows that the overall reserves are not the crucial issue. Instead, the pressing issue is the scarcity of some individual rare earths. As shown later, yttrium is one of the elements for which potential supply shortages are forecasted.

### 3.3 Reserves outside of China

Global reserves of all rare earth elements

Table 3-5 presents the reserve estimates of the USGS for the different countries. The main reserves outside of China occur in the United States, Australia, the states of the former Soviet Union and other states. Due to the lack of precise reserve estimations the sum of "other countries" is quite high at 22 Mio t. There are a number of countries where larger deposits are known. Among them are Canada, Greenland, South Africa and Malawi (BGS 2010). More details on the deposits of the United States are presented in USGS (2010f).

Table 3-5 Rare earth reserves by countries according to USGS (2010a)

| | | |
|---|---|---|
| **China** | **36** | Mio t REO |
| **United States** | **13** | Mio t REO |
| **Australia** | **5.4** | Mio t REO |
| **CIS (former Soviet Union)** | **19** | Mio t REO |
| **India** | **3.1** | Mio t REO |
| **Brazil** | **0.65** | Mio t REO |
| **Malaysia** | **0.38** | Mio t REO |
| **Other countries:** | **22** | Mio t REO |
| Canada, Greenland, South Africa, Malawi, Vietnam et al. | | |
| **Total outside of China** | **64** | Mio t REO |
| **World total** | **99** | Mio t REO |

**Reserves in the European Union**

There is only limited information on European rare earth deposits. The major findings are listed below:

- The British Geological Survey (BGS 2010) states that there has been no systematic, comprehensive evaluation of REE resources in Britain. Though small occurrences are known, they have no demonstrated economic potential.
- Oakdene Hollins (2010) cites news published on the website Metal Pages (2009) that there are possible exploration activities in Ireland.
- The German Federal Institute for Geosciences and Natural Resources (BGR 2009) records a potential rare earth output of a maximum of 1 400 t per year as by-product of iron mining in the north of Sweden.
- The BGR (2009) reports on a German deposit in Saxony with probable resources of about 40 000 t REO with an average grade of 0.5 %.
- Orris & Grauch (2002) cited in BGR (2009) mention reserves in Norway and Turkey.

**Reserves of yttrium**

Globally, there are no reserve estimations for individual REE except for yttrium. The estimations for yttrium are presented in Table 3-6.

Table 3-6 Yttrium reserves by countries according to USGS (2010b)

| | | |
|---|---|---|
| China | 220 000 | t REO |
| United States | 120 000 | t REO |
| Australia | 100 000 | t REO |
| India | 72 000 | t REO |
| Malaysia | 13 000 | t REO |
| Brazil | 2 200 | t REO |
| Sri Lanka | 240 | t REO |
| Other countries | 17 000 | t REO |
| Total outside of China | 320 000 | t REO |
| World total | 540 000 | t REO |

**Reserves of light and heavy rare earths**

Principally, all deposits contain much more LREE than HREE. The chemical composition of the most important deposits is already described in literature, e.g. in USGS (2010a) with a detailed share of the individual elements or in aggregated manner in Oakdene Hollins (2010), and will not be repeated here in detail. However, representative examples for ore compositions were given in Chapter 3.2 for some Chinese ores.

Most of the deposits have a content of yttrium and other HREE of only a few percentages (see Table 3-4). The next figure gives an overview of the reserves of selected deposits outside of China which are compliant to the Australian JORC code or to the Canadian standard. The JORC code implies for the related deposits that appropriate assessments and studies have been carried out, including the consideration of mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors. In order to be compliant with the JORC code, the assessments must demonstrate that an extraction could reasonably be justified. The data are published by the Australian mining company Alkane (2010b).

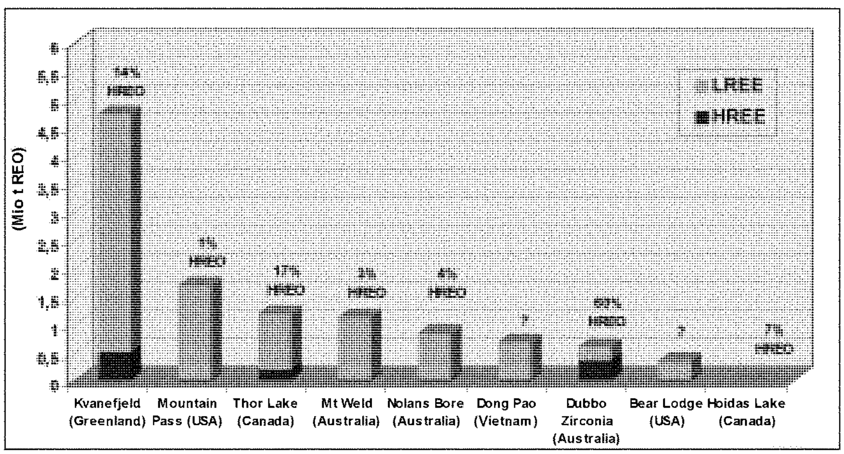


Figure 7 Reserve estimations of selected deposits which are compliant with the JORC code according to Alkane (2010b)

The major shares of the selected reserves of HREE are located at three sites according to Alkane (2010b): Kvanefjeld/Greenland, Thor Lake/Canada und Dubbo-Zirconia/Australia. The sum of these selected reserves is around 9.3 Mio t LREO and 800 000 t HREO (Alkane 2010b). Thus, the selected LREE reserves exceed the HREE reserves approximately by the factor twelve. The major element comprising around two thirds to the HREE-fraction is yttrium. The other HREE arise in much lower concentrations[4].

Further information on deposits where advanced exploration activities such as feasibility studies, laboratory tests or even construction works are already taking place is given in Chapter 4.3.

[4] The Kvanefjield deposits contribute 7.7 % Y, 0.2 % Tb, 1.1 % Dy, 0.2 % Ho, 0.6 % Er, 0.1 % Tm and 0.5 % Yb according to GMEL (2010b). The Dubbo project and the Canadian Thor Lake project would produce an HREE with a share of Y amounting to around 2/3 (Alkane 2010a, Scott Wilson 2010).

### *Conclusion on reserves*

*The US Geological Survey (USGS) estimates the global reserves of the sum of all rare earth oxides to amount to 99 000 000 t REO. This is quite high compared to the estimated world production of 124 000 t REO in 2009. Hereby, the reserve is defined by the USGS as "the part of the reserve base which could be economically extracted or produced at the time of determination." Unfortunately, there are different definitions of "reserves", "reserve base" and "resources" globally which makes the comparison of different data sources difficult. Due to a lack of harmonised data this study refers to data from different classification schemes such as USGS estimations of global reserves, estimations on heavy rare earth elements (HREE) according to the Australian JORC code and data on Chinese reserves according to Chinese definitions.*

*The overall global reserves are spread with larger reserves in the United States, the states from the former Soviet Union, China, Australia, India, Canada, Greenland, South Africa, Malawi and other countries. However, the analysis showed that the total sum of reserves is not relevant for the forecast of shortages of individual REE. Hence, an individual analysis for selected rare earth elements is necessary.*

*Principally, all deposits contain more light rare earth elements (LREE) than heavy rare earth elements (HREE). Mostly only a few percentages of the rare earths are HREE. Among them are the potentially critical elements dysprosium (Dy), terbium (Tb) and yttrium (Y). According to the chosen definition for this study the LREE comprise eight REE, among them are the widely used lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd) and europium (Eu).*

*Presently, no data on overall reserves of HREE are available. An estimation from the Australian Mining company ALKANE for nine potential mines outside of China (one deposit in Greenland and Vietnam, two deposits in the USA and Canada, three deposits in Australia) calculates economically available reserves of HREE of about 800 000 t and reserves of LREE of about 9.3 Mt. Furthermore, quite large reserves of HREE and reserves of LREE are located in China. Concerning European rare earth deposits, there is only limited information on a few potential sites, and no extensive explorations are known.*

# 4 Mining data

## 4.1 World production

The world production of rare earths in 2008 and 2009 according to USGS (2010a) is shown in Table 4-1[5].

Table 4-1 World production of rare earths 2008 and 2009 (USGS 2010a)

| Country | t REO per year | Share |
|---|---|---|
| China | 120 000 | 97.0% |
| Brazil | 650 | 0.5% |
| India | 2 700 | 2.1% |
| Malaysia | 380 | 0.3% |
| Other countries | n.d. | |
| **Total** | **124 000** | **100 %** |

The table illustrates clearly the dominance of the Chinese production. The development of the rare earth production is shown in Figure 8.

[5] The table does not include the illegal production in Chinese mines. Kingsnorth (2010) estimates 10 – 20 000 t REO from illegal or uncontrolled mining.

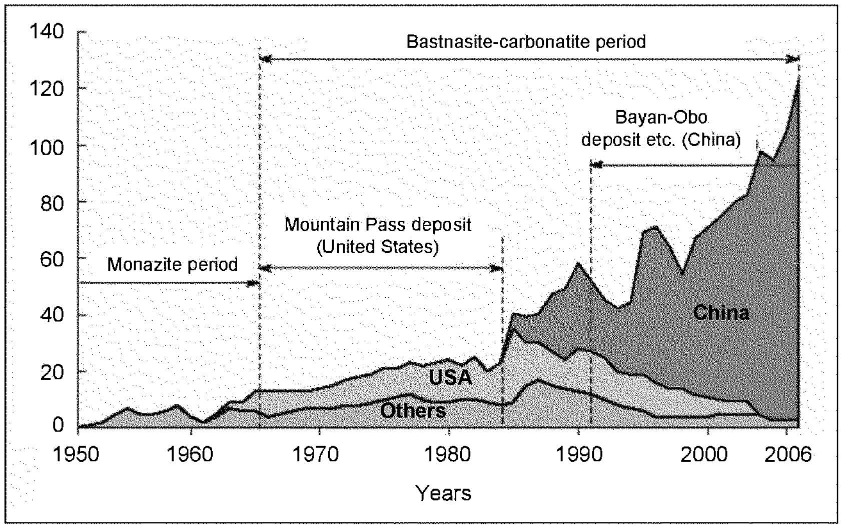


Figure 8 Global production of rare earth oxides [in thousand t] (Angerer et al 2009)

The figure points out the steady increase in the rare earth production and the continuous increase of the Chinese market share, particularly since 2002, when the American mine was closed due to environmental problems and low competitiveness because of low Chinese prices.

## 4.2 Mining in China

The following table shows the production of rare earth concentrates in China. The rare earth concentrates are the output from the concentration plants which are located next to the mine in order to produce a concentrate from the mined low-grade ore. The next step is the transport of the concentrates to the further processing and refining plants where different rare earth compounds are produced. The statistics on the output of these processing plants are given in Chapter 5.1.

Data sources are the Journal of rare earth information, the Chinese Society of Rare Earths and the National Development and Reform Commission (MEP 2009)[6].

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6 When verifying the data, it was found that the total value is not equivalent to the single values in sum. The differences range between -100 and +400 tonnes. Nevertheless, it was decided that the original data would still be used since it was not clear whether the deviation occurred due to a typing error, is just a rough estimate or whether there are differences because other types of minerals like xenotime were cut off.

Table 4-2 Chinese production of rare earth concentrates from the different types of minerals from 2000 to 2007 in t REO

| Year | Bastnaesite-Monazite-mixed type | Bastnaesite | Ion Adsorption deposits | Total |
|---|---|---|---|---|
| 2000 | 40 600 | 12 500 | 19 500 | 73 000 |
| 2001 | 46 600 | 9 400 | 24 700 | 80 600 |
| 2002 | 55 400 | 13 000 | 20 000 | 88 400 |
| 2003 | 54 000 | 15 000 | 23 000 | 92 000 |
| 2004 | 46 600 | 21 701 | 30 000 | 98 310 |
| 2005 | 49 000 | 25 709 | 44 000 | 118 709 |
| 2006 | 50 377 | 37 000 | 45 129 | 132 506 |
| 2007 | 69 000 | 6 800 | 45 000 | 120 800 |

The total production in 2008 and 2009 remained constant at around 120 000 t REO (USGS 2010a). In addition to the Chinese legal production as presented in Table 4-2, Kingsnorth (2010) estimates 10 – 20 000 t REO from illegal or uncontrolled mining, and the China Securities Journal (2010) reports illegal exports of about 20 000 t REO in 2009.

The increase of the production figures of ion adsorption deposits from 19 500 t in 2000 to 45 000 t in 2007 is very remarkable. It reflects the increasing demand of the HREE. On the other hand this sharp growth enhances the pressure on the very limited reserves of ion adsorption deposits.

In May 2010, the notice on the consultative draft of "Entry Criterions for Rare Earth Industry" (MIIT 2010) was published by the Ministry of Industry and Information Technology of China. The aim is to improve the current situation of the rare earth industry in terms of lower environmental impacts, higher efficiencies and optimised management practices as well as closing regulation gaps. According to the 2009-2015 Plans for Developing the Rare Earth Industry from the Ministry of Industry and Information Technology (MIIT2009), China will not be issuing any new mining licenses of rare earths for the years from 2009 to 2015.

The mining technologies, their ecological impact and future policy issues are described in more detail in Chapter 7.3.

## 4.3 Mining activities outside of China

Currently, only a few amounts of rare earths come from other countries than China as presented in Table 4-1 (2 700 t from India, 650 t from Brazil and 380 t from Malaysia). Additionally, DOE (2010) indicates a Russian production of 2 470 t REO in 2009. Due to the high demand for rare earth and the decreasing Chinese export, there are many activities aimed at the opening of new mines outside of China.

The most advanced mining projects are re-opening of the Mountain Pass mine in California by Molycorp Minerals and the new rare earth mine at Mt Weld in Australia by Lynas with processing in Malaysia. Their operation is scheduled to begin in 2012 and 2011, respectively. When operating at full capacity they will each produce around 20 000 t REO light rare earths. Their technologies and environmental aspects are described in Chapter 7.4.

The next table gives an overview of further mining projects which are in an earlier stage. The table provides information on the potential annual production, the content of HREE and the stage of preparation. However, it is not certain whether these mining projects will be realised. There are many obstacles to overcome, such as technological challenges, environmental problems, funding of the capital intensive facilities and the approval procedures. If the environmental equipment is not appropriate, there are high environmental risks which are outlined in Chapter 7. The main technological challenges arise in the further processing of the rare earth ores and their separation. There is a marginal know-how in the countries outside of China, and the chemistry of rare earths is quite complex. Compared to the difficult processing, the mining and the first concentration step is quite similar to the mining of other metals and easier to handle.

Table 4-3 Selected current pre-mining activities outside of China (compiled by Öko-Institut)[7]

| Country | Deposit | REO Output [t per year] | HREE Content (%TREO) | Stage of Implementation |
|---|---|---|---|---|
| Australia | Mt. Weld | 10.000 - 21.000 | 3% | Mine in operation; Construction of concentration plant |
| | Nolans | 20.000 | 4% | Metallurgical Tests |
| | Dubbo | 2.500 - 3.200 | 60% | Construction of Pilot Plant |
| Canada | Nechalacho / Thor Lake | 3.000 - 10.000 | 20% | Prefeasibility study |
| | Hoidas Lake | 1.000 - 5.000 | 4% | Metallurgical test finished |
| | Benjamin River | | 30% | Drilling |
| | Douglas River | | 99% | Drilling |
| Greenland | Kvanefjeld | 10.000 - 40.000 | 14% | Prefeasibility Study |
| India | Manavalakurichi, Chavara et al. | 7.000 | | |
| Kazakhstan | | | | |
| Kirghizia | Kutessay II | | 50% | Feasibility Study (Re-Opening) |
| Malawi | Kangankunde | 5.000 | | |
| Mongolia | several | | | |
| South Africa | Steenkampskraal | ≈ 5.000 | 8% | Feasibility Study |
| | Zandkopsdrift | 20.000 | | Prefeasibility Study |
| USA | Mountain Pass | 10.000 - 20.000 | 1% | Re-Opening |
| | Bear Lodge | | 2% | Scoping Study |
| | Bokan-Dotson Ridge | | 17% | Drilling |
| | Deep Sands | ≈ 5.000 | 15% | Analysing drill results |
| | Elk Creek | | | exploratory stage |
| | Pea Ridge Iron Ore | | | Re-opening of iron mining |
| Vietnam | Dong Pao | | | |

7 The data are compiled from manifold data sources (GWMG 2010a, GWMG 2010, RES 2010, Lynas 2010b, Oakdene Hollins 2010, Byron Capital Markets 2010, BGR 2010, GMEL 2010a, GMEL 2010b, USGS 2009b, Goldinvest 2010, Molycorp 2010, Ucore 2010, Thorium 2010, Wings 2010b, Bojanowski 2010 and home pages of the involved mining companies).

Additionally, BGS (2010) reports about some further projects which are in an early exploration state in Canada, USA, Namibia, Australia and Malawi. The German company Tantalus Rare Earths AG started the geological sampling at a potential deposit in Madagascar (Tantalus 2010). Japanese companies are involved in the development of rare earth mining in Kazakhstan, Vietnam and India (BGS 2010, BBC 2010, Reuters 2010, DOE 2010).

The time span needed in order to start the operation of a mining including the concentration of the ore depends on many site-specific factors. Based on the examples of the modernization at the Mountain Pass and the new implementations of Mt Weld, the following time ranges can be estimated which are required for the implementation of new mining projects. However the time schedules for specific mines may vary significantly because every mining has its specific challenges (environmental issues, type of mineral, type of mining, ore grade, financial equipment, social context, etc.):

- Feasibility studies, metallurgical tests, pilot plan: around four years
- Installation of the mining equipment: around one year
- Installation of the concentration plant to enrich the low-grade ore from the mine: around two years
- Installation of rare earth processing plants from concentrated ore: around four years

The approval procedure also requires several years and usually runs parallel to the project development and implementation. The operation of the Mountain Pass requires more than 20 permissions concerning environmental issues, building, work safety and others (Molycorp 2010b). Oakdene Hollins (2010) estimates a minimum time of 6 – 10 years before a mine starts operation. USGS (2010f) gives an overview of the time needed for the approval procedure and the construction work since the discovery of the deposit. The time spans vary significantly from 5 to 50 years.

Another aspect concerning the opening of new mines and rare earth processing plants is the high investment. Oakdene Hollins (2010) cites a document from an OECD workshop in 2009 with the estimate that typically capacity costs are more than 30 000 US$ per ton of capacity for separated REE. The figures are in the same range as data on investment compiled by Lifton (2010a) on mining and processing companies and their need of financial investment for the development of the rare earth production including processing: Molycorp (Mountain Pass, USA) more than US$ 500 million, Avalon Rare metals (Thor Lake, Canada): C$ 900 million for the Northwest Territories project, Lynas (Mt Weld, Australia): US$ 500 million, Arafura Resources (Nolans, Australia) more than US$ 500 million. The major investment costs in this context arise from the processing. USGS (2010f) also confirms the need of large sources and capitals and outlines that already the pre-mining activities (exploration, metallurgical process development, approval procedure) cause high expenses.

The specific production costs per unit of processed rare earth also show just a small contribution from the mining: Lynas (2010a) estimates the contribution of the overall cash costs for process rare earth oxides (finished REO) as follows: Mining 4 %; concentration of the ore 21 %, shipping from Australia to Malaysia (9 %) and refining and processing 66 %.

***Conclusion on mining***

*The world production of rare earths was around 124 000 t REO per year in 2008 and 2009 according to data from the US Geological Survey (USGS). This is quite low compared with the annual primary production of other metals, e.g. 39 Mt aluminium or 22 Mt copper. More than 97 % of the production and a large share of the further processing are located in China. Small amounts are produced in Malaysia, Brazil, India and Russia. Additionally, around 20 000 t REO were illegally produced in China and are not included in the above given USGS data.*

*Due to the high demand for rare earths and the decreasing Chinese exports, there are many activities aimed at the opening of new mines outside of China. The most advanced mining projects are the re-opening of the Mountain Pass mine in California by Molycorp Minerals and the new rare earth mine at Mt Weld in Australia by Lynas with processing in Malaysia. Their operation is scheduled to begin in 2012 and 2011, respectively.*

*Additionally, there are numerous further mining projects which are in an earlier stage in Australia, Canada, USA, India, Kazakhstan, Kirghizia, Malawi, South Africa, Vietnam and Madagascar. However, it is not certain whether these mining projects will be realised. There are many obstacles to overcome, such as technological problems, environmental problems, funding of the capital intensive facilities and the approval procedures. The time span needed in order to start the operation of a mining including the concentration of the ore depends on many site-specific factors and is estimated to take a minimum of six to ten years.*

# 5 Global rare earth processing

## 5.1 Rare earth processing in China

In terms of separation and smelting technologies, China owns internationally advanced rare earth technology. Since 1972, China has been conducting investigations on separation and smelting technologies of rare earth. It is the only country in the world that can provide rare earth products of all grades and specifications, stated Lin Donglu, Secretary General of the Chinese Society of Rare Earths in an interview by Xinhua News Agency's finance magazine (Beijng Review 2010). By now, there are about 24 domestic enterprises for rare earth mining and 100 rare earth enterprises (11 among them are joint ventures) for separating and smelting as well as refining production in China according to The Explanation of Compiling Emission Standards of Pollutants from Rare Earths Industry. Three major extraction areas are located in Inner Mongolia, Sichuan and seven provinces in the South of China, mainly in Jiangxi. Their technologies are described in Chapter 7.3.2.

China not only produces the rare earth containing intermediate products such as metals, alloys or carbonates but also manufactures most of the final products, e.g. phosphors, LEDs, catalysts, Ni-MH batteries, magnets. China's government encourages its enterprises to extend the manufacturing of these products with a higher value using high-technology at the end of the process chain in order to supply the growing Chinese market as well as for export.

### 5.1.1 Production statistics

Figure 9 gives an overview of the rare earth oxide production in China in 2006 and the contribution of specific elements. The detailed figures are presented in Table 5-2.

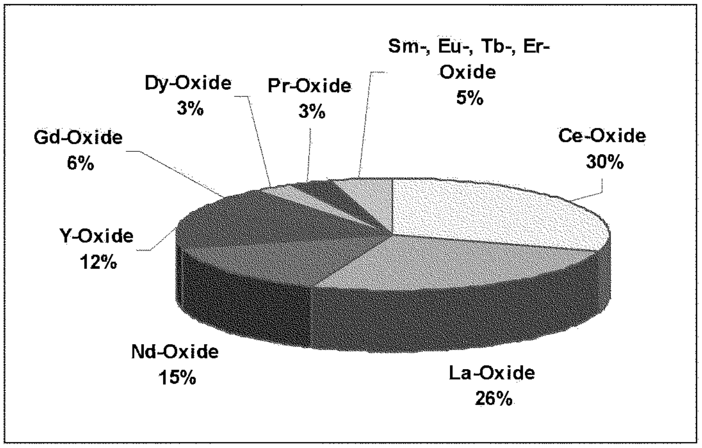



Figure 9 Share of individual rare earth oxides at the Chinese production in 2006 (MEP 2009)

The following tables show the production of rare earth chloride, carbonate and selected oxides, metals and polishing powder in China, respectively. Data sources are the Journal of rare earth information, the Chinese Society of Rare Earths, and the National Development and Reform Commission (cited in the Explanation of Compiling of Entry Criterions for Rare Earth Industry from 2009 (MEP 2009)).

Table 5-1 Production of rare earth carbonate and chloride from 1987 to 2006 in t REO (MEP 2009)

| Year | Rare earth carbonate | Rare earth chloride |
|---|---|---|
| 1987 | — | 3 870 |
| 1988 | 221 | 4 054 |
| 1989 | 362 | 6 088 |
| 1990 | 237 | 4 490 |
| 1991 | — | 5 341 |
| 1992 | 256 | 7 280 |
| 1993 | 2 100 | 9 560 |
| 1994 | 2 849 | 11 656 |
| 1995 | 6 461 | 15 191 |
| 1996 | 6 260 | 15 711 |
| 1997 | 9 897 | 11 971 |
| 1998 | 13 338 | 12 071 |
| 1999 | 15 005 | 13 579 |
| 2000 | 16 673 | 15 089 |
| 2001 | 18 339 | 16 296 |
| 2002 | 20 007 | 18 107 |
| 2003 | — | — |
| 2004 | 3 800 | 9 800 |
| 2005 | 5 548 | 4 626 |
| 2006 | 4 846 | 4 846 |

Table 5-2 Production of major rare earth oxides from 1986 to 2006 in t REO (MEP 2009)[8]

| Year | $La_2O_3$ | $CeO_2$ | $Pr_6O_{11}$ | $Nd_2O_3$ | $Sm_2O_3$ | $Eu_2O_3$ | $Gd_2O_3$ | $Tb_4O_7$ | $Dy_2O_3$ | $Er_2O_3$ | $Y_2O_3$ | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 66 | 160 | - | 44 | 12 | 3 | 30 | - | - | - | 100 | 415 |
| 1987 | 126 | 142 | 25 | 122 | 40 | 4 | 18 | 2 | 3 | - | 214 | 696 |
| 1988 | 227 | 169 | 32 | 204 | 50 | 6 | 21 | 2 | 5 | - | 339 | 1 055 |
| 1989 | 272 | 201 | 68 | 331 | 75 | 11 | 34 | 3 | 25 | 4 | 506 | 1 530 |
| 1990 | 274 | 277 | 106 | 505 | 105 | 14 | 37 | 5 | 51 | 2 | 468 | 1 844 |
| 1991 | 564 | 406 | 150 | 905 | 111 | 12 | 39 | 9 | 83 | 12 | 471 | 2 762 |
| 1992 | 474 | 464 | 111 | 834 | 99 | 12 | 50 | 11 | 67 | 24 | 498 | 2 644 |
| 1993 | 210 | 703 | 74 | 907 | 73 | 17 | 24 | 10 | 75 | 27 | 476 | 2 596 |
| 1994 | 655 | 1 352 | 157 | 1 355 | 136 | 32 | 48 | 12 | 124 | 44 | 854 | 4 769 |
| 1995 | 1 342 | 2 680 | 580 | 2 036 | 208 | 30 | 83 | 17 | 212 | 43 | 1 274 | 8 505 |
| 1996 | 1 548 | 3 503 | 400 | 3 090 | 252 | 40 | 102 | 29 | 255 | 28 | 2 033 | 11 280 |
| 1997 | 1 678 | 4 181 | 570 | 5 256 | 165 | 41 | 120 | 28 | 262 | 32 | 2 211 | 14 544 |
| 1998 | 2 888 | 4 950 | 762 | 6 200 | 248 | 125 | 90 | 64 | 292 | 98 | 2 675 | 18 392 |
| 1999 | 3 249 | 5 568 | 859 | 6 950 | 275 | 140 | 101 | 72 | 328 | 110 | 3 009 | 20 661 |
| 2000 | 3 954 | 6 190 | 990 | 8 500 | 322 | 162 | 117 | 83 | 365 | 123 | 3 344 | 24 150 |
| 2001 | 5 367 | 7 177 | 1 104 | 8 800 | 359 | 181 | 131 | 88 | 401 | 135 | 3 678 | 27 421 |
| 2002 | 5 832 | 7 425 | 1 143 | 9 000 | 372 | 187 | 135 | 96 | 438 | 147 | 4 013 | 28 788 |
| 2004 | 8 400 | 9 630 | 350 | 2 200 | 922 | 208 | 170 | 69 | 120 | 180 | 5 200 | 27 449 |
| 2005 | 18 750 | 15 580 | 2 470 | 2 096 | 739 | 342 | 683 | 388 | 128 | 967 | 5 591 | 47 734 |
| 2006 | 19 730 | 22 579 | 2 297 | 11 343 | 1 586 | 368 | 4 625 | 607 | 2 311 | 954 | 9 027 | 75 427 |

8 When verifying the data, it was found that the total value is not equivalent to the single values in sum. It has a maximal difference of 106 t. Nevertheless, it was decided that the original data would still be used since it was not clear whether the deviation occurred due to a typing error or just a rough estimate or whether there are differences because other types of rare earth oxides were cut off.

Table 5-3 Production of polishing powder and metal alloys from 1987 to 2006 in t REO (MEP 2009)

| Year | Polishing powder | Rare earth metal alloys |
|---|---|---|
| 1987 | 160 | n.d. |
| 1988 | 100 | n.d. |
| 1989 | 83 | n.d. |
| 1990 | 232 | 1 154 |
| 1991 | 334 | 1 149 |
| 1992 | 312 | 2 267 |
| 1993 | 418 | 4 059 |
| 1994 | 568 | 3 139 |
| 1995 | 665 | 4 112 |
| 1996 | 632 | 2 860 |
| 1997 | 600 | 3 307 |
| 1998 | 530 | 4 501 |
| 1999 | 1 800 | 5 063 |
| 2000 | 2 400 | 5 626 |
| 2001 | 3 200 | 6 389 |
| 2002 | 3 500 | 6 751 |
| 2004 | 4 900 | 13 200 |
| 2005 | 6 092 | 7 213 |
| 2006 | n.d. | 9 166 |

Table 5-4 Production of major single rare earth metals from 1987 to 2006 in t REO (MEP 2009)

| Year | La | Ce | Pr | Nd | Sm | Y | Dy | Total |
|---|---|---|---|---|---|---|---|---|
| 1987 | 22 | — | — | 29 | 6 | — | — | 57 |
| 1988 | 36 | 13 | — | 37 | 9 | 5 | — | 100 |
| 1989 | 2 | 9 | — | 108 | 5 | 2 | — | 127 |
| 1990 | 51 | 13 | — | 171 | 2 | 3 | — | 240 |
| 1991 | 6 | 2 | — | 145 | 1 | 2 | 6 | 161 |
| 1992 | 106 | 28 | — | 401 | 4 | 24 | 18 | 580 |
| 1993 | 11 | 12 | — | 469 | 6 | 4 | 4 | 506 |
| 1994 | 14 | — | — | 195 | 10 | 5 | 13 | 237 |
| 1995 | 59 | — | — | 393 | 21 | 1 | 19 | 494 |
| 1996 | 170 | — | — | 368 | 6 | — | 24 | 568 |
| 1997 | 185 | — | — | 1 200 | 7 | — | 37 | 1 429 |
| 1998 | 220 | — | 137 | 1 600 | 20 | — | 127 | 2 104 |
| 1999 | 248 | — | 154 | 1 800 | 23 | — | 143 | 2 368 |
| 2000 | 275 | — | 171 | 2 000 | 25 | — | 159 | 2 630 |
| 2001 | 303 | — | 188 | 2 200 | 28 | — | 175 | 2 894 |
| 2002 | 330 | — | 206 | 3 000 | 30 | — | 191 | 3 757 |
| 2004 | 380 | — | — | 3 900 | 350 | — | 780 | 5 410 |
| 2005 | 1 184 | — | — | 6 980 | 184 | — | 62 | 8 410 |
| 2006 | 2 034 | — | — | 7 032 | 489 | — | 1 280 | 10 835 |

### 5.1.2 The Chinese policy concerning the rare earth processing industry

To protect rare earth resources and develop in a sustainable way, China started a comprehensive series of regulations and standards. New policy statutes were made and promulgated including a mid- and long-term Development Plan for the Rare-Earth Industry and Rare-Earth Industrial Development Policy. The major plans and regulations concerning the management and capacities are described below. The environmental aspects are presented separately in Chapter 7.3.7.

#### 5.1.2.1 Entry criteria for rare earth industry

In May 2010, the Ministry of Industry and Information Technology of China issued the notice on the consultative draft of "Entry Criterions for Rare Earth Industry" (MIIT 2010). This regulation clearly stipulates the minimum limitation of production scales, operation and technological equipment, the minimum capital ratio of fixed assets, as well as thresholds and requirements in terms of environment protection to assist the rare earth industry in sustainable development. One effect of this regulation is a concentration of the rare earth industry which forces small companies to merge with other enterprises.

Concerning production scales at the separation and processing level, the production capacity of separation and refinement of mixed types of ores should not be less than 8 000 t REO per year. The production capacity of separating and refining of bastnaesite should not be less than 5 000 t REO annually.

As regards production scales at the metal refining level, the production capacity of enterprises should not be less than 1 500 t per year. Furthermore, the capital ratio of fixed assets investment should account for at least 40 % of total investment.

The environmental standards determined in the regulation are presented in Chapter 7.3.7.

#### 5.1.2.2 The 2009-2015 plans for developing the rare earth industry

This development plan is a mandatory planning compiled by the Ministry of Industry and Information Technology of China. According to the 2009-2015 Plans for Developing the Rare Earth Industry, rare earth industry in China will divide into three large districts: South, North and West (MIIT 2009). As for light REE mining, the focus is located in Inner Mongolia (Northern district) and Sichuan (Southwest district), with some development in Shandong as far as needed. The heavy REE mining is concentrated in the southern districts such as Jiangxi, Guangdong, Fujian and Hunan (China Net 2010). The aim of the Plan is to simplify management of China's rare earth resources by "designating large districts". Because of the scattered distribution of rare earth resources, it is difficult to carry out an efficient oversight of the industry (Hurst 2010).

According to the mandatory planning, from 2009 to 2015, the whole production of refined rare earth metals should range between 13 000 and 15 000 tons annually. The production capacity of separating and smelting enterprises should be between 12 000 and 15 000 tons.

Moreover, China is undergoing consolidation – mergers and acquisitions by large companies and closing of small plants. For the years from 2009 to 2015, China will not be issuing any new mining licenses of rare earths. During this period, the existing rare earth enterprises should put emphasis on improving the level of technical equipment, environmental protection and management capability. Meanwhile, mergers and acquisitions (M&As) in rare earth industry are promoted. Furthermore, a plan has clearly been specified to close down a number of small and illegal as well as inefficient separating and smelting enterprises in order to gain more control. It was reported that the government planned to cut down the number of enterprises from 100 at the moment to 20 (China Net 2010).

As for the monitoring aspect, the Ministry of Industry and Information Technology will oversee the industry by creating an examination and inspection system for rare earth extraction to guarantee that national directive plans are being implemented and executed.

## 5.2 Rare earth processing outside of China

Figure 11 on page 36 presents the shares of the different EU member states at the total rare earth compound imports of the EU-27. It shows that the main importers (import from outside the EU) in 2008 were France (38 %), Austria (24 %), the Netherlands (16 %), United Kingdom (8 %) and Germany (8 %). This corresponds to the location of the main rare earth processing industries in Europe. Selected industrial activities are listed below:

Table 5-5 Selected industrial activities in rare earth processing in Europe

| Country | Selected companies | Products |
|---|---|---|
| France | Rhodia (formerly Rhone-Poulenc) | automotive catalysts, phosphors |
| Austria | Treibacher Industrie AG | catalysts, glass polishing powder, glass fusion, pigments and ceramic glazes, pharmaceutical products |
| Netherlands | Walker Europe | magnet production |
| | Goudsmit Magnetic Systems | magnet production |
| United Kingdom | Magnet Applications | magnet production |
| | Arnold magnetic Technologies | magnet production |
| | Less Common Metals Limited (subsidiary of Great Western Mineral Group) | alloys with rare earths |
| Germany | Vacuumschmelze | magnet production |
| Estonia | Silmet Rare Metals | rare earth separation, rare earth metal production |

The list of European companies above shows that there are only a few industrial activities on rare earth refining and processing. The European companies are mainly involved in manufacturing processes for semi-finished or finished products which contain REE like magnets, alloys, automotive catalysts, etc.

Most of the core rare earth refining and processing activities are located in China and some processing is carried out in Japan. One example for the dominance of the Chinese rare earth processing is the permanent magnet production. There are only a few capacities for the refining of the intermediate products (alloys) in Japan and no capacities in Europe and the United States. Concerning the final magnet production, there are a small number of permanent magnet producers in Europe, whereas the United States is not currently producing neodymium permanent magnets. There is only one samarium cobalt magnet producer in the United States (GAO 2010).

The next figure shows the process steps and the national shares of the global processing of permanent neodymium magnets (data compiled from Molycorp (2010c) and GAO (2010)):

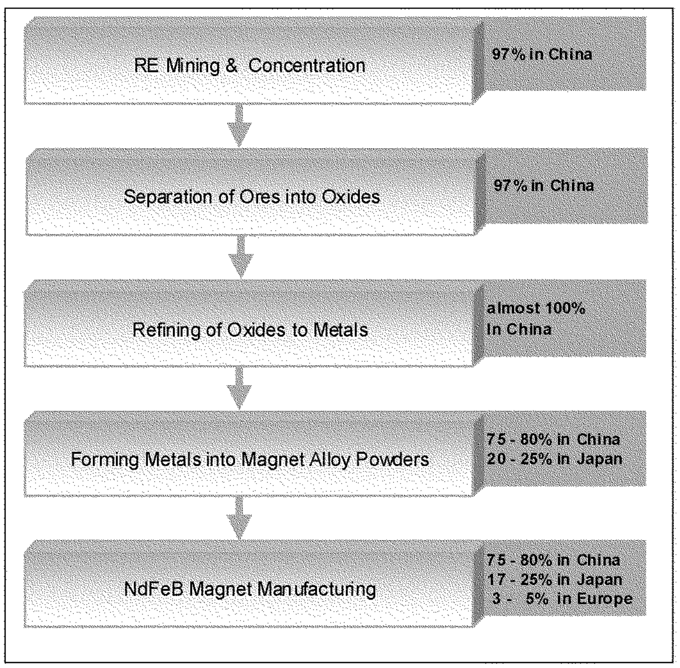



Figure 10 Process steps and national shares of neodymium magnet production (GAO 2010, Molycorp 2010c)

Even if some shares of the Chinese production were overestimated as there are some smaller processing facilities outside of China, the figures show very clearly the key fact that there is little processing technology for the first steps of rare earth processing and refining outside of China. The American company Molycorp Minerals is planning to resolve this problem by re-opening their rare earth mine and concentration plant at the Mountain Pass in California and complementing it with the whole rare earth processing chain including a neodymium permanent magnet production.

***Conclusion on global rare earth processing***

*In terms of separation and smelting technologies, China owns internationally advanced rare earth technology. It is the only country in the world that can provide rare earth products of all grades and specifications. China not only produces rare earth containing intermediate products but also manufactures most of the final products. China's government encourages its enterprises to extend the manufacturing of finished products with a higher value using high-technology at the end of the process chain.*

*According to the "Entry Criterions for Rare Earth Industry" and the "2009-2015 Plans for Developing the Rare Earth Industry", the rare earth industry in China will be divided into three large districts in order to undergo consolidation with mergers and closing of small plants. For the years from 2009 to 2015, China will not be issuing any new mining licenses of rare earths. During this period, the existing rare earth enterprises should put emphasis on improving the level of technical equipment, environmental protection and management capability. Furthermore, a plan has clearly been specified to close down a number of small and illegal as well as inefficient separating and smelting enterprises. An examination and inspection system shall also be created.*

*Besides China, Japan is able to carry out some rare earth processing. In Europe, there are only a few industrial activities on rare earth refining and processing. The European companies are mainly involved in manufacturing processes for semi-finished or finished products which contain REE like magnets, lighting systems, alloys, automotive catalysts, etc.*

# 6 Rare earth trade

## 6.1 Global rare earths imports

The major importers of rare earths compounds in 2008 were Europe, USA and Japan (BGS 2010). The amounts of imported rare earths according to the national statistical offices are given in the next table. It should be noted that the different regions use a different statistical framework.

Table 6-1 Imports of rare earth compounds of Europe, United States and Japan in 2008

| | Imports | Share of imports from China | Data source | Compounds included in the statistic |
|---|---|---|---|---|
| EU 27 | 23 013 t | 90 %[9] | Eurostat 2010 | Metals, intermixtures or interalloys of rare-earths, Sc and Y<br>Compounds of rare-earth metals, mixtures of these metals, Y or Sc |
| USA | 20 663 t | 91 % | USGS 2010c | Rare-earth and Y compounds, Rare-earth metals, Mixtures of rare-earth chlorides, Ferrocerium and other pyrophoric alloys |
| Japan | 34 330 t | 91 % | Trade Statistics Japan 2010 | Cerium-, Lanthanum- and Yttrium Oxide, other cerium compounds, others |

In total, according to these figures, 78 006 t of REO containing compounds were imported in 2008 by EU 27, Japan and USA. Of these, around 71 000 t were imported from China.

The next figure shows the share of the European member states in terms of the total imports of rare earths compounds from outside the EU-27. Imports from other EU member states are not included.

[9] The statistics from Eurostat provides no data on the origin of the imports to Austria. The share of Chinese imports in terms of total imports of all EU-27 members besides Austria is 90%.

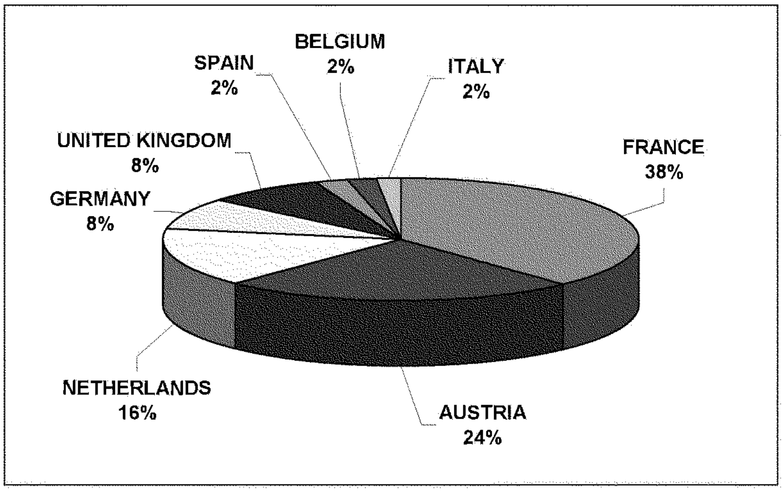



Figure 11 Share of different EU countries in the total rare earth compounds imported by the EU-27 (Eurostat 2010)

Figure 11 shows that the main importers of the EU-27 in 2008 were France (38 %), Austria (24 %), the Netherlands (16 %), the United Kingdom (8 %) and Germany (8 %).

## 6.2 Global rare earth exports

### 6.2.1 Chinese rare earth exports

In order to try to protect rare earth resources and promote the sustainable, rapid and healthy development of the rare-earth industry in China, the State Development Planning Commission of China has issued the Interim Provisions on the Administration of Foreign-funded Rare Earth Industry, which has been effective since 1$^{st}$ August 2002. It is clearly stipulated that foreign enterprises are prohibited to invest in mining and extraction of rare earth minerals in China. As for the separating and smelting areas, only joint-venture enterprises are allowed for foreigners. Foreign capitals are, however, encouraged in the fields of intensive processing and investigation regarding applications of advanced materials out of rare earths in China.

Figure 12 pictures the development of the Chinese export volume from 1979 to 2008 according to Chen (2010). Generally speaking, the exportation of rare earth increased gradually along the years. In 2006, the volume reached a peak with 57 400 tons and then declined from 2007 onwards.

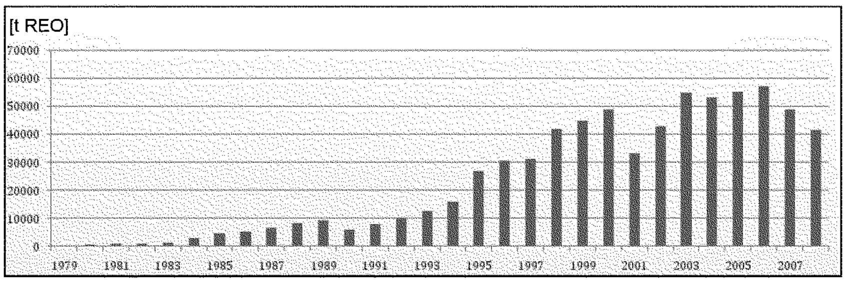



Figure 12 Gross exportation volume of rare earths from 1979 to 2008 in China (Chen 2010)

The export of rare earths decreased by 29 % in 2010 compared to 2008, as shown in Table 6-2.

Table 6-2 Chinese rare earths exports of state and foreign-invested enterprises from 2008 - 2010 (MOFCOM 2010b)

| | **2008** | **2009** | **2010 (Approved exports)** |
|---|---|---|---|
| Chinese-invested enterprises (t REO) | 34 156 | 31 310 | 30 258 |
| Foreign-invested enterprises (t REO) | 8 210 | 16 845 | |
| Total (t REO) | 42 366 | 48 155 | 30 258 |
| **Reduction in % compared to 2008** | **0%** | **14%** | **-29%** |

A detailed breakdown of the exportation volume between the first and second half-year is shown in Table 6-3. These data originally refer to announcements of the Ministry of Commerce of the People's Republic of China Department of Foreign Trade. The table shows the export quota realised by domestic Chinese-invested enterprises for 2008, 2009 and the first half of 2010. For the second half of 2010, the given amount of 7 976 tons also includes the foreign-invested enterprises.

Table 6-3 Export quota only for domestic Chinese-invested enterprises for 2008, 2009 and the first half of 2010 (MOFCOM 2010b)

| Time coverage | 2008 | 2009 | 2010 |
|---|---|---|---|
| The first half of the year (t REO) | 22 780 | 15 043 | 16 304 |
| The second half of the year (t REO) | 11 376 | 16 267 | 7 976* |
| Total (t REO) | 34 156 | 31 310 | 24 280 |
| **Reduction compared to 2008** | | **-8%** | **-29%** |

* For the second half of 2010, the given amount of 7 976 tons also includes the foreign-invested enterprises.

From 2009 to 2015, the rare earth export quota issued by China's Ministry of Commerce could be restricted to 35 000 tons according to the 2009-2015 Plans for Developing the Rare Earth Industry. The aims of control of rare earth exports are to regulate the current non-transparent situation of rare earth industry, to protect resources and the environment and to guarantee the supply of the rising domestic demand. Meanwhile, China is promoting renewable energy and green technology. The domestic demand for rare earth could therefore increase rapidly, as rare earth is related closely to the green industries such as wind turbines or electric vehicles.

All data given in the tables and figures above do not include the illegal exports from China. According to news on 9 October 2010 from China Securities Journal (2010), it was estimated that in 2009 about 20 000 t REO of rare earths were smuggled to foreign countries illegally, besides legal exports. Compared to the illegal quantity in 2008, 2009 presents an increase of 10 %. Thus, the sum of legal and illegal exports would be around 60 500 t in 2008 and around 68 000 t in 2009. A comparison of the Chinese exports with the import data of the major importers are quite informative: The import statistics from Japan, USA and EU as presented in Table 6-1 indicate rare earths imports from China of around 71 000 t in 2008. These high imports support the estimate for illegal exports in the magnitude of 20 000 or even more t REO yearly.

### 6.2.2 Non-Chinese rare earth exports

The main non-Chinese exporters of semi-products of rare earths are Japan, USA and Europe. These countries import primary material mostly from China and export processed semi-products. The following table shows the exports in 2008. For Europe, exports within the EU-27 are not included.

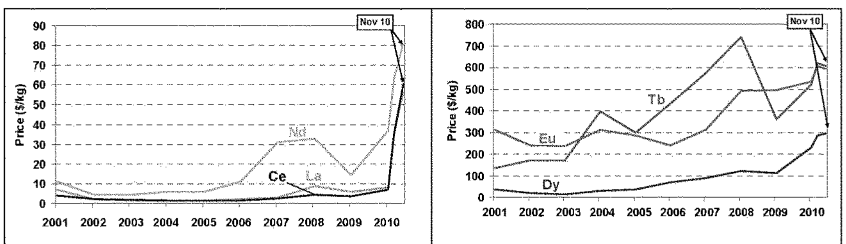
Table 6-4 Exports of semi-products of rare earths of Japan, USA and Europe in 2008

| | Exports of rare earth compounds in 2008 | Data source | Compounds included in the statistic |
|---|---|---|---|
| EU 27 | 4 704 t | Eurostat 2010 | Metals, intermixtures or interalloys of rare-earths, Sc and Y<br>Compounds of rare-earth metals, mixtures of these metals, Y or Sc |
| USA | 8 253 t | USGS 2010c | Rare-earth and Y compounds, rare-earth metals, mixtures of rare-earth chlorides, ferrocerium and other pyrophoric alloys |
| Japan | 8 997 t | Trade Statistics Japan 2010 | Cerium-, lanthanum- and yttrium oxide, other cerium compounds, others |

The main destination countries for Japanese exports are South Korea (33 %), China (17 %), Taiwan (15 %), Thailand (14 %) and USA (9 %).

## 6.3 Development of prices

Figure 13 shows the development of some selected rare earths oxides from 2001 to 2010.




a) Lanthanum, cerium and neodymium oxide b) Europium, dysprosium and terbium oxide

Figure 13 Prices for lanthanum, cerium, neodymium, europium, dysprosium and terbium oxides from 2001-2010

The figure shows the moderate price development up to the end of the decade and the steep increase due to the increased global demand and the reduction of Chinese exports. The steep price increase not only affects the REE for which supply shortages are forecasted but also less scarce REE such as cerium. The detailed prices of selected rare earths metals and rare earth oxides are shown in Table 6-5 and Table 6-6.

Table 6-5 Prices of selected rare earths oxides on 22 Nov 2010*

| Rare Earth Oxide | Price ($/kg) |
|---|---|
| Cerium | 59 – 62 |
| Dysprosium | 284 – 305 |
| Erbium | 84 – 94 |
| Europium | 585 – 605 |
| Gadolinium | 43 – 46 |
| Lanthanum | 55 – 58 |
| Neodymium | 79 – 83 |
| Praseodymium | 71 – 80 |
| Samarium | 33 – 35 |
| Terbium | 595 – 615 |
| Yttrium | 53 – 70 |

*Data compiled from www.metal-pages.com and www.asianmetal.com; free-on-board; min purity 99% (Y min 99.999%)

Table 6-6 Prices of selected rare earths metals on 22 Nov 2010*

| Rare Earth Metal | Price ($/kg) |
|---|---|
| Cerium | 43 – 55 |
| Dysprosium | 372 – 415 |
| Europium | 710 – 800 |
| Gadolinium | 53 – 56 |
| Lanthanum | 42 – 46 |
| Neodymium | 97 – 100 |
| Praseodymium | 84 – 106 |
| Samarium | 44,50 – 53 |
| Terbium | 750 – 792 |
| Yttrium | 61 – 63 |

*Data compiled from www.metal-pages.com and www.asianmetal.com; free-on-board; min purity 99% (Y min 99.999%)

***Conclusion on rare earth trade***

*China is the world leading exporter of rare earths. The exports in 2009 amounted to about 48 000 t REO legal exports plus additional illegal exports of around 20 000 t REO. The major importers of rare earths compounds were Europe, USA and Japan, importing a total of 78 000 t of rare earths containing compounds in 2008. Of these, more than 90 % were imported from China.*

*China reduced the official exports in 2010 by 29 % compared to 2008 (around 30 000 t REO in 2010) and announced further export restrictions for 2011. This policy and the increasing demand for rare earths lead to a steep increase in the prices of most rare earth elements.*

# 7 Environmental aspects of rare earth mining and processing

## 7.1 Overview of the main process steps in mining and processing

The diversity of the deposits results in a wide variation in mining and processing technologies. Often, rare earths are exploited as a by-product of other metals. Examples are the largest rare earth mining at Bayan-Obo, where the main output is iron. Furthermore smaller REE extractions are by-products from titanium or uranium mining operations (BGS 2010). The most often practiced processing technique of the crude ore after mining is the concentration (also called beneficiation) by milling and flotation. This technique is used at Bayan-Obo, at the Sichuan mine, at Mountain Pass and in the short term also at Mt Weld. The next figure shows the main process steps in REE mining and beneficiation.

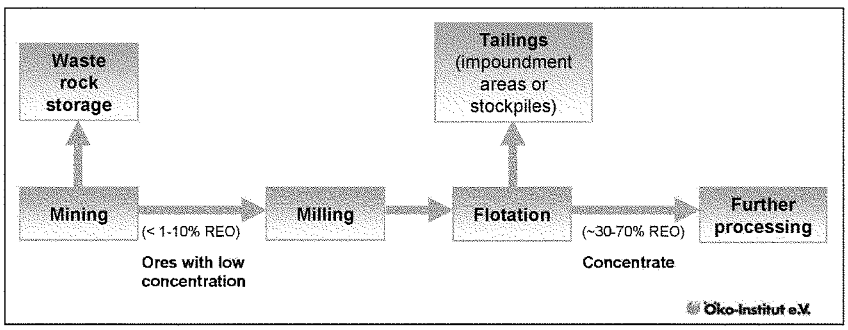



Figure 14 Main process steps in REE mining and processing

The first step, the **mining**, most frequently takes the form of open pit mining. However, there are also deposits which would require underground mining, e.g. the Canadian deposit at the Thor Lake.

In open pit mining, before reaching the ore rich in the metals to be extracted, the **overburden material** (soil and vegetation above the bedrock) as well as the **waste rock** (not ore-bearing or having a too low concentration of the ore) need to be removed and are stockpiled.

The second step after mining of the crude ore is **milling**. The ore is crushed and subsequently ground to fine powder in the mill with the aim of creating a high surface which is needed for the further separation.

The third step is the separation of the valuable metals from the rest of the ore by physical separation methods. The most commonly used method is **flotation**, which requires a lot of water and chemicals (flotation agents) as well as a high amount of energy (see, for example, Canino et al. 2005). The input into the flotation is the milled crude ore with usually low concentrations (grades) of REO (often between 1 and 10 %). The product of the flotation is an enriched concentrate with a higher REE-percentage (in the range of 30 – 70 %). The huge waste streams, called **tailings,** are a mixture of water, process chemicals and finely ground minerals. Usually, the tailings are led to **impoundment areas**, which can be either artificial reservoirs or even natural water bodies (e.g. lakes). They are surrounded by dams.

Finally, the concentrate undergoes **further processing**. It is transported to a refinery which can be off-site. There the REE are further extracted and separated into the different elements as required. This separation of individual REE is particularly difficult due to their chemical similarity.

An alternative mining technology is the in-situ leaching technology which is used in the Chinese HREE mining from ion adsorption deposits. It is introduced in Chapter 7.3.5.

## 7.2 Environmental risks

The next figure gives an overview of potential dangers for the environment if the mining and processing is carried out without or with insufficient environmental technologies. The red flashes in the figure symbolise the main risk spots. The size of the flashes is an indicator for the severity of the risk.

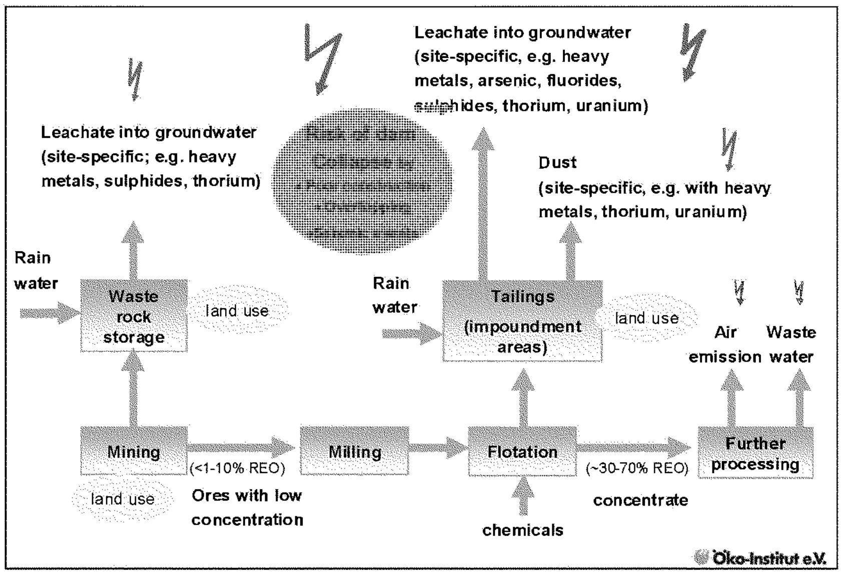



Figure 15 Risks of rare earth mining without or with insufficient environmental protection systems

The major short- and long-term risks are constituted by the **tailings**. The tailings consist of small-size particles with large surfaces, waste water and flotation chemicals. Usually, they remain forever in the impoundment areas where they are exposed to rain water and storm water runoff. During this continuous exposure to water, toxic substances can be washed out. If the ground of the impoundment areas is not leak-proof, there will be steady emissions to groundwater. Another serious risk is the storm water run-off when heavy rain falls occur and the impoundment areas are not able to store the huge amounts of storm water. Then, large amounts of untreated toxic water will pollute surrounding water bodies and soils. The composition of polluting water is site-specific as it depends on the composition of the host minerals and the used flotation agents. However, in most cases, the tailings include radioactive substances, fluorides, sulphides, acids and heavy metals. It is important to note that most of the rare earth deposits contain uranium, thorium and their further decay products. Only very few known deposits are free from radioactive substances. An ecological disaster will occur if the dam collapses and the highly toxic water and sludge flood the surroundings. There are several risks which might cause a dam collapse: the dam might fail due to overtopping from storm water, collapse due to poor construction or burst due to seismic events. These risks require a long-term monitoring as the dams must not only remain stable during the mining operation, but also keep intact over decades and centuries after the closure of the mine.

A similar risk is given by the **waste rock stockpiles**. They are also exposed to rain water, and toxic substances such as radioactive substances, fluorides, sulphides, acids and heavy metals will be washed out and spread into water bodies and soil, if no water management and water treatment is installed. In most cases, the potential release is lower than in the tailings, as the rock consists of coarse minerals whereas the tailings consist of finely milled particles.

Another environmental risk is the **open pit** itself, particularly after the closure of the mine. It will be exposed to rain water, which will wash out toxic and radioactive substances as described above for the waste rock stockpiles.

Besides the manifold risks due to toxic and radioactive water emissions, the mining and processing also causes serious **air emissions** if no adequate measures are taken. A main risk factor for the workers and the neighbourhood are wind-blown dust particles containing thorium or other radioactive substance. Further toxic substances in the dust might be heavy metals. The dusts arise from different sources: the mine and the mining operations, the milling, the transportation and storages as well as from the wind-blown dust particles from the waste rock stockpiles or the tailings. The two last-mentioned sources are a long-term risk if no adequate post-operative treatment will be implemented after the closure of the mine.

Further environmental harm is connected to the **land-use**. It covers the mine, the storage of the waste rocks, the tailings, the whole infrastructure and the surrounding areas, which are affected by pollution during the mining operation as well as after the mine closure. Another environmental burden is the **large water consumption**, particularly if the mining is carried out in dry areas.

The **further refining** of the rare earth concentrate is a very energy-intensive process and causes serious **air emissions** (e.g. $SO_2$, HCl, dust, radioactive substances) if no abatement technologies are installed. Depending on the used energy carriers, high $CO_2$-emissions will arise and contribute to **climate change**.

Furthermore, **radioactive waste** arises in most cases, as the majority of the rare earths deposits also contain thorium and/or uranium. The radionuclides are partly separated in the flotation and partly remain in the tailings. The other part enters the further processing with the concentrate and is subsequently separated. A safe disposal is required in all cases.

Table 7-1 summarises the major environmental risks:

Table 7-1 Major risks of REE mining and processing with insufficient environmental techniques

<table>
<tr><th>Risk</th><th>Affected compartments</th><th>Relevant toxic compounds</th></tr>
<tr><td>Overtopping of tailings dam</td><td>groundwater, surface water, soil</td><td rowspan="10">Water emissions:<br>• in most cases radionuclides, mainly thorium and uranium;<br>• heavy metals;<br>• acids;<br>• fluorides;<br>Air emissions:<br>• in most cases radionuclides, mainly thorium and uranium;<br>• heavy metals;<br>• HF, HCl, $SO_2$ etc.</td></tr>
<tr><td>Collapse of tailings dam by poor construction</td><td>groundwater, surface water, soil</td></tr>
<tr><td>Collapse of tailing dam by seismic event</td><td>groundwater, surface water, soil</td></tr>
<tr><td>Pipe leakage</td><td>groundwater, surface water, soil</td></tr>
<tr><td>Ground of tailing pond not leak-proof</td><td>groundwater</td></tr>
<tr><td>Waste rock stockpiles exposed to rainwater</td><td>groundwater, surface water, soil</td></tr>
<tr><td>Dusts from waste rock and tailings</td><td>air, soil</td></tr>
<tr><td>No site-rehabilitation after cease of mining operation</td><td>land-use, long-term contaminated land</td></tr>
<tr><td>Processing without flue gas filters</td><td>air, soil</td></tr>
<tr><td>Processing without waste water treatment</td><td>surface water</td></tr>
</table>

Beside the impacts mining has on the environment, mining also entails social impacts which have to be carefully considered when planning and realising mining projects.

## 7.3 Environmental aspects of mining and processing in China

### 7.3.1 Overview

China currently operates several large mines and a large number of small – partly illegal – mines, the environmental problems of which are briefly described below in order to give a quick overview. Further environmental aspects are given in the following chapters.

- The **Bayan-Obo Mine** in Inner Mongolia is the largest rare earth mine in the world. The main product is iron ore, light rare earths are a side product. The surface mining extracts a bastnaesite-monazite-mix containing LREE and also thorium. There are severe environmental problems and health hazards in mining, concentration and further processing. Another large open-pit mine for LREE based on bastnaesite is the **Sichuan mine**. Here, the bastnaesite also contains thorium (MEP 2009).
- Heavy rare earths are mined from **ion adsorption deposits** in southern China. They belong to the few known deposits without radioactive accompanying elements. Nevertheless, there are serious environmental problems. The mining is carried out with in-situ leaching, a technique which requires no surface and no underground mining (Cheng & Che 2010). Holes are hereby drilled into the ore deposit. Then, the leaching solution is pumped into the deposit where it makes contact with the ore. The solution bearing the dissolved ore content is then pumped to the surface and processed. The Chinese government regards the in-situ leaching technology as more environmentally sound than other leaching technologies such as pond and heap leaching (MIIT 2010). However it should be noted that this leaching procedure is also problematic because it is not controllable hydro-geologically.
- There are **numerous small illegal mines** in China. There are estimations that around 20 000 t REO were illegally mined and smuggled outside of China. Probably, most of these mines have no environmental technologies at all, and there are reports of serious environmental damages and health hazards in their surroundings (Bork 2010, Zajec 2010).
- In the course of the **extracting, separating and refining processes**, a large number of chemical materials are applied, leading to a huge amount of waste gas, waste water and solid waste. Most facilities do not have sufficient treatment systems. Some small rare earth smelting separation facilities even do not have any system for environmental protection at all (Chen 2010).

The Chinese government is aware of these challenges and is willing to raise the environmental standards. Details on the mines, the processing and the Chinese environmental policy are presented in the next chapters.

### 7.3.2 Implemented technologies for mining and processing in China

Table 7-2 provides an overview of present mining and separation as well as refining methods in China's rare earth industry, differentiated according to the three types of minerals dominating in China.

Table 7-2 Overview of mining, extraction and separation methods adopted in China's rare earth industry (compiled based on MEP 2009)

| Minerals | Mining & Beneficiation | Decomposition of rare earth concentrate | Separation and Refining of REO | Extraction of rare earth metal |
|---|---|---|---|---|
| 1. Bastnaesite-monazite-mixed type (Bayan Obo mine, Inner Mongolia) | Surface mining: the ore is Iron-Niobium-REE deposit.<br>The ore is crushed into gravel size and transported to the mill factory. Through low-intensity magnetic separation to high-intensity magnetic separation up to flotation process, rare earth concentrates (with 30-60% grade of REO) are produced as a co-product by main product iron. | Two following methods are used:<br>a) acidic method<br>REO are roasted at 400°C and 500°C in concentrated sulphuric acid to remove fluoride and $CO_2$. Then the solution is leached in water and filtered to remove the impurities. REEs are then leached in extraction agents like ammonium bicarbonate $(NH_4)HCO_3$ precipitation and hydrochloric acid. REE chlorides ($RECl_3$) are achieved. This method is used for 90% of products.<br>b) alkaline method | For successive separation, liquid-liquid extraction is adopted mainly based on P507 ($C_{16}H_{35}O_3P$) and HCl. Then the solvent is precipitated by ammonium bicarbonate $(NH_4)HCO_3$ or oxalic acid $C_2H_2O_4$. The precipitate $(RE_2(C_2O_4)_3$ or $RE_2(CO_2)_3)$ is heated and REO are formed by oxidation. | Light rare earth metals are extracted by molten salt electrolysis based on chloride or oxide.<br>The middle and heavy rare metals such as Sm, Eu, Tb and Dy are obtained by metallothermic reduction in vacuum. The reaction is carried out at 1450-1750°C and needs an inert gas like Argon. |
| 2. Bastnaesite (Sichuan) | Surface mining: the ore is alkali granite type rare-earth elements deposit. The ore is crushed into gravel size and transported to the mill factory. Two methods are adopted:<br>-from gravity separation to magnetic separation<br>-from gravity separation to flotation separation | The rare earth concentrates achieved a grade of 70% REO. The present treatment process of Sichuan bastnaesite in the industry is oxidating roasting-hydrochloric leaching process. The roast is carried out at 600°C to remove $CO_2$. The RE concentrates are leached in hydrochloric acid, precipitated by sodium hydroxide solution and leached in hydrochloric acid again. REE chlorides ($RECl_3$) are achieved. | | |

Continuation of

Table 7-2 Overview of mining, extraction and separation methods adopted in China's rare earth industry

| Minerals | Mining & Beneficiation | Decomposition of rare earth concentrate | Separation and Refining of REO | Extraction of rare earth metal |
|---|---|---|---|---|
| 3. Ion adsorption deposits (seven provinces in the South of China) | Currently used mining method is ISL (In-Situ Leaching), which is a typical flow process coupled with chemical reaction and solute transport. Heap leaching and ponding leaching have been banned due to massive vegetation damage.<br>The minerals are firstly leached in ammonium sulphate $(NH_4)_2SO_4$ through ion exchanging reaction. Then rare earth concentrates are obtained by precipitation with ammonium bicarbonate $(NH_4)HCO_3$ or oxalic acid $C_2H_2O_4$.<br>Rare earth concentrates with a grade of 92% REO are achieved. | | Concentrates are leached in hydrochloric acid (HCl)<br>Extraction is carried out in P507 ($C_{16}H_{35}O_3P$)-system. This extraction reagent 2-ethylhexyl 2-ethylhexyl phosphate (P507) is widely used to extract and separate rare earth metals. | see above |

### 7.3.3 Bayan Obo mine

The iron-niobium-LREE deposit at Bayan Obo is the largest discovered ore resource in the world. The primary product is iron. Rare earth is a secondary product of this deposit.

After more than 40 years of mining, the Main and East ore bodies have been exploited to 35%. In the operation period up to 2005, the recovery rate of mineral resources was less than 10%. Bo et al. (2009) indicated that present recovery rates of mineral resources are higher, at around 60% by state-owned and 40% by individually-owned enterprises. The thorium resource has not been utilised according to the Draft of Emission Standards of Pollutants from Rare Earths Industry (MEP 2009)[10].

The tailings are transported to large nearby territories and piled up. The tailings impoundment/reservoir of the whole mining operations (iron ore and rare earth concentration plants) is twelve kilometres in length and covers eleven square kilometres. According to Bradsher (2010) this area is about 100 times the size of the alumina factory waste pond that collapsed in Hungary on August, 4th 2010 releasing 600 000 to 700 000 cubic metres of toxic red sludge into its surroundings (WISE-Uranium 2010).

The Chinese Draft of Emission Standards of Pollutants from Rare Earths Industry (MEP 2009) indicated that the amount of tailings from the iron and rare earth mining in Bayan Obo has reached 150 million tons.

[10] According to researches at Öko-Institut, there is no longer a demand for larger amounts of thorium. The former applications in lighting and welding electrodes are going to be phased out.

The radioactive element thorium (Th) is contained in tailings and residues. The measuring results presented by the Baotou Radiation & Environmental Management Institute in November 1998 showed that the average Th content is 0.0135% and the gamma-radiation dose rate of East, South, West and North ore bodies of Bayan Obo is 60.6-958.6 nGy/h, 54.5-546 nGy/h, 60.3-611.3 nGy/h and 49.7-599nGy/h, respectively, thus considerably exceeding the normal environmental conditions. It turned out that the environment was contaminated. The sample analysis of plants on $^{232}Th$, $^{238}U$, $^{226}Ra$, $^{40}K$ showed that the specific radioactivity in plant tests is a factor of 32 and in soil tests a factor of 1.7 higher than that of references. This provides evidence that plants and soil at Baotou region have been contaminated (MEP 2009).

The Explanation of Compiling of Emission Standards of Pollutants (MEP 2009) also stated that Th-containing dust is emitted in a range of 61.8 t per year during the crushing process. Considering the human health aspect, the Healthcare Research Centre has proved in a twenty-year follow-up study on health effects following long-term exposure to thorium dusts that the mortality rate of lung cancer has significantly increased for the workers in Baotou (Chen et al. 2004).

Furthermore, Buckley (2010) reports on groundwater pollution from the tailing pond which affects the wells of the nearby villages, the livestock and the agriculture and causes serious damage to the health of the inhabitants.

Processing 100 thousand tons of rare earth concentrates per year during the extraction phase, approximately 200 tons of $ThO_2$ contained in sludge are left over. Using the sulphuric acid-roasting method during the production of one ton of rare earth concentrate, between 9600-12000 $m^3$ of waste gas containing fluoride, $SO_2$, $SO_3$ and dust may be emitted. Furthermore, 75 $m^3$ of acid-washing waste water and one ton of radioactive residues are generated per ton (MEP 2009)

### 7.3.4 Sichuan mine

The recovery rate of the mining and the concentration plant of the Sichuan mine has been less than 50% (Cheng & Che 2010).

Oxidising roasting-hydrochloric acid leaching method is currently mainly adopted in the treatment process of Sichuan bastnaesite in the rare earth industry. The problem associated with this method is that the purity of the cerium produced is low. Furthermore, fluorine and thorium are dispersed into waste residues and waste water.

### 7.3.5 Ion adsorption deposits

The scarce HREE from ion adsorption deposits in the south of China has at present an average recovery rate of 75% by applying the in-situ leaching method. Between 1970 and 1999 the recovery rate was only about 26% by using the ponding leaching method (Cheng & Che 2010).

### 7.3.6 Waste water from REE separation and refining

Since saponification with ammonia is still used for rare earth refining, a large number of waste water is produced. To separate one ton of rare earth concentrate with a REE content of 92% REO, 1 – 1.2 tons of ammonium bicarbonate are needed (MEP 2009) .

Overall, it is estimated that within the whole rare earth refining industry approximately 20 000 – 25 000 thousand t of waste water are generated per year, based on the production data of 103 900 t REO in 2005. The $NH_3/NH_4^+$-content of waste water ranges roughly between 300 and 5000 mg/litre. That factor exceeds the limit set by the government by more than ten to even 200 times (MEP 2009).

### 7.3.7 Chinese environmental policy

In the past, few environmental concerns were taken into account during mining and processing, and an efficient use of resources was not taken into consideration. Altogether, with the increasing importance of rare earths in applications, China has realised the current problems in the rare earth industry and the urgent need for an efficient use of resources and better management practices. China also identified a lack of regulation. In order to protect its rare earth resources and to develop them in a sustainable way, China started a comprehensive series of regulations and standards. New policy statutes were made and promulgated including a Mid- and Long-Term Development Plan for the Rare-Earth Industry and the Rare-Earth Industrial Development Policy. The environmental aspects are described in the subsequent chapters. Further issues such as the intended structure of companies including the closure of small mines and processing facilities are presented in Chapter 5.1.2.

#### 7.3.7.1 Entry criteria for rare earth industry

In May 2010, the Ministry of Industry and Information Technology of China issued the notice on the consultative draft of "Entry Criterions for Rare Earth Industry" (MIIT 2010). This regulation clearly stipulates thresholds and requirements in terms of environment protection to assist the rare earth industry in sustainable development. It also foresees a restructuring of the rare earths industry. The major environmental aspects are:

- Mining of pure monazite minerals is banned due to the high-level radioactive elements and the resulting environmental damage.
- As for the operation and technological equipment, the facilities for the processing of bastnaesite and mixed minerals are obliged to install a complete treatment system for waste water, waste gas, and solid waste.
- Regarding ion adsorption deposits, ponding and heap leaching was banned due to massive environmental damage. Instead, the ISL- (In-Situ Leaching-) method shall be applied.

- Saponification with ammonia is banned from rare earth refining.
- Elementary metal refining should not adopt the process of electrolysing metals by their chlorides.
- With respect to the electrolysis system when using molten salt fluoride, facilities should be equipped with a treatment system capable of dealing with fluorine-containing waste water and waste gas.
- Fluor-containing solid waste should be disposed separately and must not be mixed with other industry residues.
- Requirements for an efficient electricity supply and specifications concerning the maximum energy demand per ton of rare earths produced are also indicated.
- Regarding the resource aspects, it is also required that the mining-loss rate for mixed rare earth minerals and bastnaesite should not be more than 10 %, while the ore dressing recovery rate of these ores should be not less than 72 %.
- The ore dressing recovery rate of ion adsorption deposits should not be less than 70 %.
- The recycling rate of ore dressing waste water of mixed rare earth minerals and bastnaesite should be not less than 85 %, while that of ion adsorption deposits should not drop below 90 %.
- The rehabilitation of plants and vegetation after mining of ion adsorption deposits should include at least 90 % of the affected area.
- The yield of refined rare earth metal should be more than 92 %.

#### 7.3.7.2 The 2009-2015 plans for developing the rare earth industry

This development plan is a mandatory planning compiled by the Ministry of Industry and Information Technology of China (MIIT 2009). The major aim of the plan is to simplify management of China's rare earth resources by "designating large districts." The environmental aspects included in this plan are:

- For the years from 2009 to 2015, China will not be issuing any new mining licences of rare earths. During this period, the existing rare earth enterprises should put emphasis on improving the level of technical equipment, environmental protection and management capability.
- The plan has clearly specified the shutdown of a number of small and illegal enterprises as well as inefficient separating and smelting enterprises in order to gain more control.
- As for the monitoring aspect, the Ministry of Industry and Information Technology will oversee the industry by creating an examination and inspection system for rare earth extraction to guarantee that national directive plans are being implemented and executed.

#### 7.3.7.3 Emission standards of pollutants from rare earths industry

The revision of Emission Standards of Pollutants from Rare Earths Industry was finalised by the Ministry of Environmental Protection of China in July 2010. It is estimated that this regulation will be effective soon. This standard sets specific thresholds (differentiated between existing enterprises and newly-established enterprises) for the amount of pollutants including waste water, waste gas and radioactive elements, especially thorium. In comparing these thresholds to those set in some industry countries, the Explanation of Compiling "Emission Standards of Pollutants from Rare Earths Industry 2009" found that certain thresholds in these emission standards were even more stringent than those in industrial nations.

### 7.3.8 Chinese research activities on clean production of rare earths

China actively endeavours to encourage and promote the national clean production towards a sustainable economic and social growth and development. This was reflected at the 6th International Conference on Rare Earth Development and Application in Beijing where Chinese experts presented many survey papers on clean-tech/green-tech applications (Lifton 2010b). Additionally, certain papers from the 2nd Academic Meeting on Rare Earths for Junior Scholars held by the Chinese Society of Rare Earths in 2008 analysed green or clean production of rare earth, besides investigating physical and chemical characteristics of rare earths in technical application. A website on patent information showed that 29 patents on the recovery of rare earths were taken out (Patent information 2010). The next paragraphs shortly summarise selected research projects:

- Che (2008) revealed in her study that the **tailings** from Bayan Obo lead to environmental damage and human toxicity. Furthermore, it means a waste of resources. Che (2008) discussed a **clean dressing process**, in which tailings are comprehensively utilised and which is "emission-free".
- The University of Science & Technology Beijing obtained a patent in 2009 for achieving **full recycling and clean production in the rare earth leaching** process by applying the sulphate roasting method (University of Science & Technology Beijing 2009). The green production technology realises direct transformation from sulphate to carbonate by using the transformation technology of double decomposition reaction in chemical processes according to the principle of mutual transformation between solid substances with different solubility products. Non-rare-earth-compounds (such as ammonium sulphate and ammonium carbonate) and the like are fully recovered at low costs. Simultaneously, waste water can be fully recycled and reused.

- The **scandium** extraction grade from Bayan Obo deposit is relatively low. Cheng (2008) showed that the extraction rate of $Sc^{3+}$ could reach 98 % by using liquid membrane emulsion technology.
- The present treatment of Sichuan bastnaesite in the rare earth industry is the oxidising roasting-hydrochloric acid leaching process. Luo et al. (2008) indicated that this method leads to pollution resulting from fluorine and thorium and generates cerium of low purity. Luo et al. (2008) demonstrated in their study that the oxidising roasting-sulphuric acid **leaching-extraction process** is a **promising alternative green process**, since it can not only produce high purity cerium, but also effectively realises the separation of fluorine and thorium. The results of their study indicated that stripping thorium from HEHEHP (2-ethylhexyl 2-ethylhexyl phosphate) is more efficient than stripping it from other phosphoric extraction agents. A thorium recovery of a maximum of 70 % could be obtained by a single stage stripping.
- In 2005, Grirem Advanced Materials Co., Ltd. developed an environmentally friendly hydrometallurgical separation processes. A **non-saponification solvent extraction** process based on hydrochloric acid and sulphuric acid was developed to separate **neodymium** and **samarium**. This method eliminates the generation of ammonia nitrogen waste water. The consumption of other extraction agents is decreased by 20 % due to a reduced number of processes which also imply greatly reduced costs (MEP 2009).
- The Beijing General Research Institute for Nonferrous Metals took out a patent in 2008 relating to a technological method for extracting and separating **quadrivalent cerium**, thorium and fluorine, as well as to a small extent trivalent cerium from rare-earth-sulphate solution. The synergistic extraction agents are based on P507 (2-ethylhexyl 2-ethylhexyl phosphate) or P204 (Di(2-ethylhexyl)phosphoric acid). Cerium, thorium, fluorine and iron are extracted into an organic phase. Then selective washing and back extraction are performed step by step. The advantages of this method are that the separation ratio of thorium is high, no emulsion is generated during the extraction process and all elements are extracted and separated in the same extraction system. With regard to the environment, since no ammonia saponification agent is adopted, there is no ammonia-nitrogen containing waste water, and fluorine and thorium are recovered (Beijing Nonfer-rous Metal 2008).
- Liu et al. (2008) studied green synthesis techniques of highly purified **dysprosium** iodide ($DyI_3$) for HID (High Intensity Discharge) lamps. The traditional synthesising method uses mercury iodide and dysprosium in a chemical reaction which pollutes the environment due to the poisonous mercury. A green synthesis was therefore investigated through a direct reaction between dysprosium and iodine in terms of reaction conditions. The results showed that anhydrous dysprosium iodide was synthesised with a purity of 99.95 % and a product yield of 88 %.

- In 2009, XIAN Technological University invented a method for an improved separation of heavy rare earth metals with an optimised membrane technology (XIAN Technological University 2009).

## 7.4 Environmental aspects of mining and processing outside of China

### 7.4.1 General outlook

The expected supply shortage of some REE has created manifold activities for the opening of new mines outside of China. Due to the tough timelines and the economic pressure, the incentive is quite high to implement new mining and processing facilities without considering the ecological impacts. Therefore, environmental aspects should be monitored attentively by the authorities and the public.

The following Chapters 7.4.2 and 7.4.3 provide an overview of two mining and processing projects which will probably start operation in 2011 and 2012: the Mountain Pass project in California (USA) and the Mt Weld project in the desert of Western Australia with further processing in Malaysia. These two projects passed national approval procedures, and it is to be assumed that major environmental aspects will be taken into account. However, the operation practice will not only depend on the installed technologies but also on the proper management and monitoring by the operating companies and the authorities.

The opening of new mines is discussed and exploration activities are carried out (drilling, laboratory tests and feasibility studies) on various other sites. One example is the Kvanefjeld deposit in Greenland which is presented in Chapter 7.4.4. Further countries where exploration activities are taking place are Canada, South Africa, Malawi, India and Vietnam, Kirghizia and Kazakhstan. There is some concern that some of these projects might be realised without sufficient environmental protection technologies.

In the past, xenotime from Malaysian placer deposits with very high contents of uranium (2 %) and thorium (0.7 %) was processed in Malaysia. Due to this high radioactivity level, the Malaysian processing industry failed and the plants were closed (Meor Yusoff and Latifah 2002, cited in BGS 2010). High levels of radioactivity also appear in monazite. Fortunately, the processing of beach sands containing monazite has been banned in Australia, China and Europe due to environmental concerns (Curtis 2009, cited in BGS 2010). However, nearly all deposits which are currently under exploration also have some more or less high contents of uranium and thorium and their decay products. The two outstanding exceptions are the ion-adsorption clay deposits in southern China as well as the Douglas River deposit in Saskatchewan, Canada (Kanasawa & Kamitani 2006, GWMG 2010a).

Against the background of the severe problems of accompanying radioactivity in mining, Kanazawa and Kamitani (2006) suggest that countries should examine geological structures similar to the ion-adsorption clay deposits in China in order to discover other radioactivity-free sources. Otherwise R&D for mineral separation, smelting and recovery should be promoted, including disposal of radioactive wastes.

The presence of thorium and/or uranium in the rare earth ores is not only of importance for mining and concentration but also for refining and further processing. In all process steps, radioactive wastes arise and have to be handled cautiously. An example for the arising of radioactive waste is the French company Rhodia Electronics and Catalysts which processes rare earths. This waste was classified and handled according the French law (ANDRA 2009).

Furthermore, the refining of the rare earth concentrate is a very energy-intensive process, causes air and water emissions and contributes to the global climate change.

### 7.4.2 Mountain Pass, California, USA

Due to environmental concerns as well as competition from lower-cost Chinese sources of rare earths beginning in the mid-1980s, production at the only mine of the United States at the Mountain Pass in California was stopped in 2002. Currently, the site is held by Molycorp Minerals, which is currently only generating revenue from products manufactured from its relatively small stockpile of rare earths. Molycorp Minerals plans the re-opening of the rare earths mining from 2012 to 2042 with an annual production of approximately 20 000 t. The average grade of the Mountain Pass ore is 8.2 % (using a cut-off grade of 5 %). The concentrate shall contain 68 % rare earths. The recovery rate shall be around 90 % according to Molycorp (2010a).

The planned re-opening required an extensive approval procedure which resulted in an approval in 2004. Smaller plant modifications and improvements are subject to a further permit procedure.

Due to the extensive public approval procedure, it is to be expected that the plant operation will run on an environmentally advanced standard, which will significantly reduce the environmental damage compared to old outdated techniques, if the management of the monitoring is carried out responsibly by the authorities and the operator.

The documents concerning the approval procedure are publicly available (Molycorp 2010c). According to Molycorp Minerals (Molycorp 2010a, 2010b) the major issues in terms of the environment are as follows:

- The ore at Mountain Pass contains 0.02 % thorium and 0.002 % uranium by weight, as uranium and thorium occur in the bastnaesite mineral. Therefore, radionuclides will be part of the tailings and the concentrate. For the permission of the new plant operation, Molycorp received a broad scope licence, which allows facility personnel to conduct the day-to-day management of radioactive materials under the oversight of a Radiation Safety Officer and a Radiation Safety Committee.
- Molycorp plans the installation of a salt recovery (recovery of hydrochloric acid, sodium hydroxide, sodium hypochlorite) and water recycling facilities in order to reduce the

water consumption. The aim is to reduce the fresh water consumption of the mid-1990s (when the mine had an output of 20 000 t REO per year) by approximately 90 %.

- The waste water generated from the mineral recovery operations as well as waste water from the treatment of pit water and ground water remediation systems would be evaporated in a series of on-site ponds.
- A groundwater remediation system will be operated.
- The open pit water will be pumped, treated and re-used. The facility is constructed with a series of storm water diversion ditches and settling ponds, along with a series of check dams and silt fencing to minimise erosion.
- The hazardous waste (mainly containing lead) shall be disposed of on exterior landfills for hazardous wastes.
- Flue gas treatment plants will be installed in order to reduce air emissions.
- The remediation of the area after mine closure was also part of the approval in 2004.

### 7.4.3 Mount Weld, Australia and processing in Malaysia

Lynas started mining (open pit) and the installation of a concentration plant at Mt Weld deposit in 2007. In 2008, about 800 000 t of ore with an average grade of 15 % REO were mined and stored. The concentration plant is supposed to start operation in 2011 and to produce a concentrate of around 40 %. Mining is planned for a period of eleven years whereas the concentration plant shall operate for 18 years. The production of REO-concentrate at Mt Weld shall start with 11 000 t REO per year and increase up to 20 000 t REO per year [Lynas 2010a]. The recovery rate will be around 63 %. The cut-off grade is set to 2.5 % [Lynas 2009]. Further processing will be carried out at the Lynas Advanced Materials Plant in Malaysia.

The Environmental Protection Authority of The Government of Western Australia provided the Ministerial Approval Statement to the Mining & Beneficiation Project at Mt Weld in 2006 (EPA 2006). In 2008, the Department of Environment and Conservation granted the works approval (DEC 2008). The documents include some information on the operating conditions. The main issues are listed below:

- The premises are located approximately 35 km from the next housing area and 20 km from a lake. The surrounding landscape is characterised by arid plains.
- Dust suppression techniques are required in order to ensure that dust emissions are of low significance.
- The tailings are stored in the tailing ponds. The tailing ponds will be equipped with an impervious layer on the base and on the walls. The authority state that they demand high standard of seepage management design. A groundwater monitoring system is required.

- Around 14 % of the water input to the tailing pond will be returned to the process plant.
- The tailing ponds will be deemed a contaminated site after plant closure.
- The pipelines will be controlled by electronic supervisory devices as well as by daily sight inspections.
- The tailings contain 500 ppm thorium oxide and 30 ppm uranium oxide. There are no details given on the management of the radioactivity. The approval refers to the management by the Radiological Council under the Radiation Safety Act 1999.
- The rehabilitation works of the overburden stockpiles have started (Lynas 2009).

Further processing of the concentrate with an output of up to 22 000 t REO per year will be carried out in Malaysia by the 100 % subsidiary of Lynas called Lynas Malaysia. The approval from the Malaysian authorities was obtained in 2008, and the construction works already started in 2008. The start of operation is scheduled for 2011. The environmental impact assessment for the Malaysian plant is not publically available via internet. Concerning the chosen location for the processing plant, Lynas argues that the processing of the Mt Weld material will be realised in Malaysia because of the good infrastructure, the skilled labour force with experience in the chemical industry and the nearby supply of the required chemicals.

### 7.4.4 Kvanefjeld, Greenland

Large resources of rare earths with a high content of HREE of about 14 % can be found in the Kvanefjeld region in southern Greenland, which is currently discussed for the joint mining of uranium and rare earths. Figure 7 on page 15 impressively shows the very large size of this deposit and its significant HREE contents in comparison to other deposits where premining activities also take place. The interested mining company is Greenland Minerals and Energy Ltd. (GMEL) with its head office in Perth, Australia, which plans to start construction work in 2013 and to initiate production in 2015.

A very critical point for environmental hazards in this project is the tailing's management. According to current considerations GMEL favour tailings disposal in the nearby natural lake Taseq (GMEL 2009). Following an extensive study Risø (1990) concluded that the outlet from contaminated water from Taseq would cause pollution of the whole fluvial system (from the lake, via rivers, into the ocean) with radioactive substances, fluorine and heavy metals. It is very doubtful if waste water treatment installations at the outlet of the lake are capable to manage the large amounts of water particularly in times of heavy rain or snow melting.

The extensive work on the Kvanefjeld deposit (the results of which were published by Risø in 1990) was conducted by Danish authorities and scientists up to the early 1980s and also form the basis of the GMEL planning activities (GMEL 2010c). This work was carried out with the focus of mining uranium only and provides very detailed considerations and analysis results concerning environmental impacts. Beside the tailings impoundment it identified the open pit and the waste dump as the most important sources of pollution. In the long term (> 100 years) the tailings pond will be the most critical point. Risø (1990) compared two options: the direct inlet of the tailings into the sea and the tailings disposal in the nearby natural lake Taseq (see above). The latter was considered even worse in terms of environmental impacts than the direct inlet into the ocean.

Though waste disposal in oceans was frequently practised in the past, the procedure is not acceptable at all either. Equally, inlet of toxic tailings into natural water bodies has to be banned completely and does not meet any environmental standards. The situation in Greenland seems particularly critical when considering the fact that the expected climate change – it is linked to melting of glaciers and unfreezing of permafrost soils – might alter water bodies and the stability of soils considerably.

The next paragraph gives a short overview of the planned technologies for the GMEL-Kvanefjeld project and the progress of the (pre-)feasibility studies and approval issues:

Mining shall be carried out in a conventional open pit followed by uranium extraction with the Carbonate Pressure Leach- (CPL-) technology. The CPL-residue can then be processed and the REO concentrated by froth flotation, leached with acid and then refined to produce rare-earth-carbonate. The nominal forecast annual production amounts to approx. 44 000 t REO and nearly 4 000 t of uranium oxide; the overall plant recovery rates are 34 % and 84 %, respectively (GMEL 2009).

In December 2009 and February 2010 GMEL presented the Interim Reports of the Pre-feasibility Study (GMEL 2010c, GMEL 2009). As the Greenland government has recently relaxed restrictions on uranium deposits, the company now envisages the realisation of a definitive feasibility study (WNN 2010). According to the same article the Greenland government has stressed that although radioactive elements may now be surveyed, their extraction is still not permitted. However, a comprehensive review process into the exploration and exploitation of the radioactive materials was announced by the Ministry for Industry and Raw Materials. In this context, the cooperation agreement between the government of Greenland and the European Environment Agency on environmental issues signed in November 2010 (EEA 2010) might lead to an exchange of expertise and contribute to a sustainable course of action concerning the Kvanefjeld deposit and mining activities in Greenland in general.

## 7.5 Resource efficiency

The specific environmental burden of mined and processed rare earths could be reduced significantly by higher efficiencies in all stages of the production. The first losses occur in the mining process when the cut-off grade is chosen too high. This means that minerals with lower REO-contents are not further processed. The cut-off grade is site-specific as it depends on the kind of minerals and its properties in the concentration process.

The next losses arise in the concentration process. The mines show quite different recovery rates (ratio between REO output and REO input of the concentration plant). The Mountain pass concentration plant shall operate with a high recovery rate of about 90 % due to a very fine grinding of the minerals. Lynas states that the plant at Mt Weld will have a recovery rate of 63 %. The recovery of Chinese mines is reported to have been very low in the past. Currently, they range from 40 to 60 % for flotation and about 75 % for the in-situ leaching method (see Chapter 7.3.3 to 7.3.5). However, a site-specific analysis is necessary in order to assess in detail if higher recovery rates are possible and improve the overall performance of the plant.

Further losses arise in all stages of further refining and processing. They are also plant-specific.

The Chinese government is aware of the high potential of higher efficiencies as described in Chapter 7.3.7. Further aspects concerning the efficiency of rare earths used in different fields of applications is discussed in Chapter 10.

***Conclusion on environmental aspects of rare earth mining and processing***

*The rare earth mining shows high environmental risks. The main risks are the tailings, which are a mixture of small-size particles, waste water and flotation chemicals and arise at the concentration of the mined ore. They are stored in impoundment areas. The tailing dam is exposed to manifold risks such as overtopping due to storm water, poor construction or seismic events. A failing dam leads to site-specific emissions such as thorium, uranium, heavy metals and fluorides. Generally, most rare earth deposits contain radioactive materials which impose the risk of radioactive dust and water emissions. Further potential damages are other air emissions, soil contamination, land use, etc.*

*There are serious environmental damages in the Chinese rare earth mines and their surroundings. The Chinese government intends to reduce the environmental harm by installing environmental technologies in the large mines and by reducing the numerous small illegal mines which probably have no environmental technologies at all. China also aims at higher efficiencies in mining and processing and is running some research projects on a sustainable rare earth economy.*

*The most advanced mines outside of China at the Mountain Pass in the United States and at Mt. Weld in Australia will provide environmental protection systems, which will significantly reduce the environmental damage compared to old outdated techniques, if the management and the monitoring are conducted responsibly by the authorities and the operators.*

*However, the global pressure for a steady rare earth supply might lead to further new mines outside of China with inacceptable environmental standards. One example of potential concern about environmental damage is the plan for joint mining of uranium and rare earths in Greenland. The interested mining company intends to store the tailings in a natural lake with connection to maritime waters.*

# 8 Applications and demand of rare earths

## 8.1 Overview of applications and their demand in 2008

Figure 16 shows the main application fields and the range of global demand estimates for the years 2006 to 2008 by volume in t REO/a. The total demand was around 124 000 t REO in 2008 (Kingsnorth 2010).

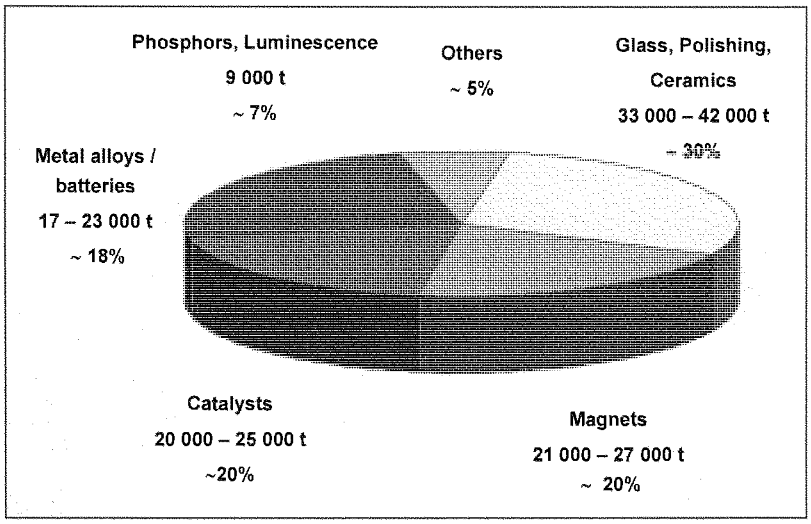



Figure 16 Global demand of rare earths by volume from 2006 to 2008, in t REO per year

The data in Figure 16 are compiled from various data sources such as the Australian consultant Kingsnorth from IMCOA, the mining company Great Western Minerals Group and the German Federal Institute for Geosciences and Natural Resources (Kingsnorth 2010, GWMG 2010b, BGR 2009). They refer, depending on the source, either to the year 2006, or to the year 2008. All these estimates do not include published documentation, which would enable more in-depth analysis and a plausibility check. Furthermore, all above-listed demand estimates and further estimations of the USGS for the US market refer to the demand estimates carried out by Kingsnorth from IMCOA. Up to now, larger research institutions and public bodies have not set up more detailed material flow analysis for rare earths, as has been elaborated for other metals. Such an analysis could provide more in-depth knowledge of the related application, but it requires a lot of manpower and the cooperation of experts from all sectors. This is especially true for rare earths, as they are used in many fields of high-tech applications and partly underlie confidentiality issues.

Figure 17 shows the same data as the previous figure and gives additional information on the used REE and specifies the kind of applications in more depth. The figure encompasses the different rare earths. The elements shown in a smaller font size play a minor role in comparison to the other elements shown in the figure.

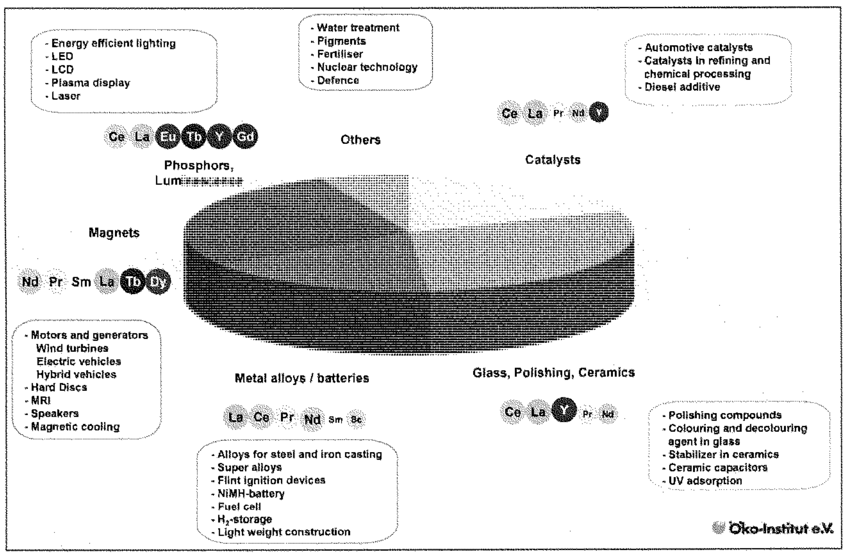



Figure 17 Global applications of rare earth elements (compiled by Öko-Institut)

The next figure shows the rare earth demand in terms of economic value according to Kingsnorth (2010). Due to significant differences in the used rare earth elements and the specific prices for the different applications, the demand distribution paints a somewhat different picture.

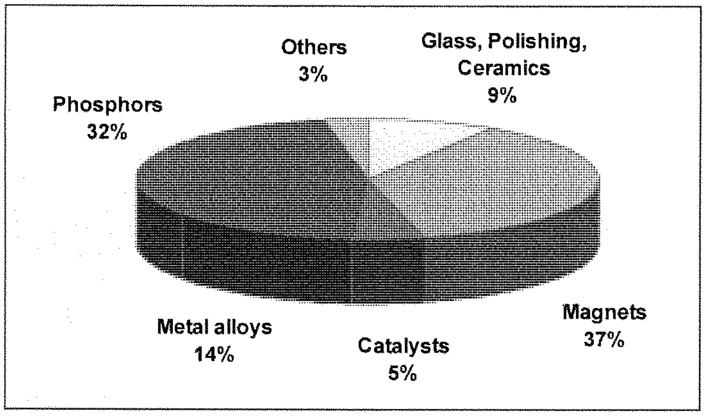



Figure 18 Global demand of rare earths in terms of economic value in 2008 according to Kingsnorth (2010)

Figure 18 shows that the most relevant fields of application economically are magnets and phosphors. For phosphors, expensive REE such as europium and terbium are used. For magnets, mainly neodymium and praseodymium (medium price) and dysprosium and terbium (high prices) are used. The applications glass, polishing, ceramics and catalysts are relevant in terms of their volume but less relevant in terms of their value. The main reason for this is that the cheaper REE cerium and lanthanum are used very frequently for these applications.

The demand for rare earths in China in 2008 is shown in Figure 19.

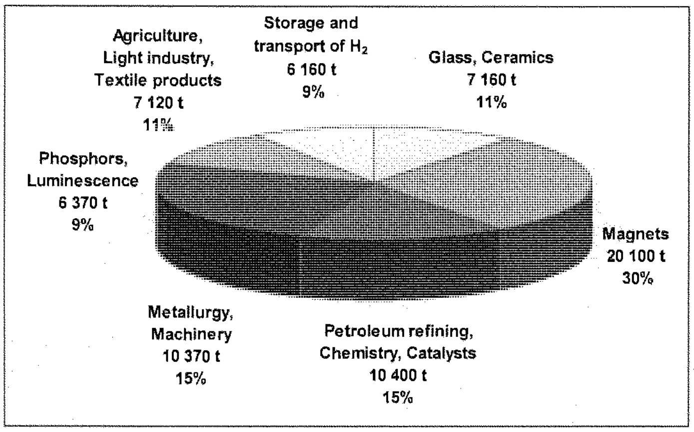



Figure 19 Demand of rare earths per volume in China in t REO in 2008 (Chen 2010)

Figure 19 indicates a higher share of permanent magnets for Chinese applications (30 %) in comparison to the estimated global demand (20 %, see Figure 16). A significant share of the Chinese permanent magnet is probably exported, as China is the only country worldwide which masters the whole magnet product chain as shown in Figure 10 on page 33.

Chen (2010) provides detailed information on the Chinese applications in 2007 and 2008. They are presented in Table 8-1. Furthermore, Chen points out that the consumption of rare earths in China has rapidly increased since 2004.

Table 8-1 Application of rare earths in China in 2007 and 2008 (Chen 2010)

| Technology | | 2007 | | 2008 | | Δ2008/2007 |
|---|---|---|---|---|---|---|
| | | t | % | t | % | % |
| Traditional materials | Metallurgy/Machinery | 10 994 | 15.2% | 10 370 | 15.3% | **-5.7%** |
| | Petroleum Refining/chemistry | 7 548 | 10.4% | 7 520 | 11.1% | **-0.4%** |
| | Glass/ ceramics | 7 872 | 10.9% | 7 160 | 10.6% | **-9.0%** |
| | Agricultural, light industry and textile products | 7 686 | 10.6% | 7 120 | 10.5% | **-7.4%** |
| | sub-total | 34 100 | 47% | 32 170 | 48% | **-5.7%** |
| Advanced materials | Luminescence | 4 490 | 6.2% | 2 870 | 4.2% | **-36.1%** |
| | Phosphors | 2 800 | 3.9% | 3 500 | 5.2% | **25.0%** |
| | Permanent magnets | 22 250 | 30.7% | 20 100 | 29.7% | **-9.7%** |
| | Storage and transport of Hydrogen, batteries | 6 200 | 8.5% | 6 160 | 9.1% | **-0.6%** |
| | Catalysts | 2 710 | 3.7% | 2 880 | 4.3% | **6.3%** |
| | sub-total | 38 450 | 53% | 35 510 | 52% | **-7.6%** |
| Total | | 72 550 | 100% | 67 680 | 100% | **-6.7%** |

The specific application fields are further described in the next chapters, and forecasts for their development are given.

## 8.2 Magnets

Rare earths are part of neodymium-iron-boron magnets (short forms: neodymium magnets, Nd-magnets) and samarium cobalt magnets. Both belong to the group of permanent magnets. The samarium cobalt magnets play only a minor role, as they were in many cases replaced by the more powerful neodymium magnets. Neodymium magnets are the strongest available magnets and exceed other permanent magnets such as samarium cobalt magnets by the factor 2.5 and other aluminium and iron based magnets by the factor 7 – 12. In ferrite magnets, small shares of lanthanum are included. These permanent magnets have low magnetic properties, but they are cheap, light, easy to magnetise and widely disseminated.

The strong neodymium magnets enabled the design of miniaturised application of electric devices such as small speakers (ear phones) and hard disks. Two further large fields of application are electric motors used in hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), electric vehicles (EVs)[11] and generators of wind turbines. Additionally,

[11] Hybrid electric vehicles (HEVs) combine an internal combustion engine and one or more electric motors, whereas electric vehicles (EV) run exclusively with one or more electric motors. A plug-in hybrid electric

neodymium magnets are used for industrial equipment such as lifters or magnetic separators. A new application which might be implemented on a larger scale in the years from 2015 is the magnetic cooling.

The share of magnets of the total rare earth application is around 20 % in terms of the global volume. The share of value is higher at around 37 %. The basic chemical formula of Nd-magnetic material is $Nd_2Fe_{14}B$, which comprises a mix of neodymium and praseodymium (~ 30 %) and mostly the additives dysprosium (~ 3 %) and terbium in even lower contents. Neodymium and praseodymium belong to the rare earths which have a medium price, whereas dysprosium and terbium are very expensive elements (for details on prices, see Chapter 6.3).

Technical details on the applications motors, wind turbines and hard disks are given in Chapter 10.2 and Chapter 11.1, where recycling aspects, options for a substitution and options for a more efficient use of the REE are discussed. The next chapters analyse the main factors influencing the development of the future demand.

The future demand for permanent magnets is significantly determined by the three applications electric motors for hybrid and electric vehicles, wind turbines and hard disks. The following chapters analyse the expected development of the main application fields.

### 8.2.1 Electric and hybrid electric vehicles

The demand development of Nd-magnets in the field of e-mobility depends on three main drivers:

- the future production of hybrid electric (HEV), plug-in electric vehicles (PHEV) and electric vehicles (EV),
- the future production of electric bikes,
- the future motor technology and the share of motors using Nd-magnets in EV, HEV and PHEV and
- the specific neodymium magnets demand per electric motor.

Byron Capital Markets (2010) makes a forecast which includes the major producers of HEVs (Toyota, Chevy, Nissan, Ford and Honda) and e-bikes. E-bikes are already used in large quantities in China. An average annual growth rate of 50 % is estimated. Despite this high growth rate, Byron Capital Markets (2010) only calculates a moderate overall demand in

vehicle (PHEVs) is a hybrid vehicle with rechargeable batteries, which can be plugged to an external electric power source for charging.

terms of HEVs even in 2015, because the assumed specific rare earth content of the electric motors is much lower in Byron's scenario than in scenarios of other experts. Byron assumes a demand of 193 g Nd per motor[12], whereas other experts expect up to 1.8 kg neodymium for the electric motor of the Toyota Prius. This means a difference in the baseline of a factor of 10!

Another uncertainty is the estimation of the number of hybrid electric vehicles. The number of hybrid electric vehicles to be sold is estimated by Byron Capital Markets to be 1.2 million HEVs and EVs in 2014; and to be 2.1 million by Iwatani (cited in Oakdene Hollins 2010). Optimistic scenarios by IEA (2009) and Fraunhofer ISI (2009) forecast 9 to 14 million sold HEV and EV for 2015.

Öko-Institut carried out an analysis of different scenarios for the development of e-mobility from different institutions (IEA 2009, Fraunhofer ISI 2009, McKinsey 2010, BCG 2009). The analysis revealed that the range of future scenarios is quite high. The projections for the year 2020 lie within the range of 9 to 33 million HEVs, EVs and PEVs sold in 2020. Electric vehicles are supposed to play a minor role up to 2015.

The annual sales of e-bikes are estimated by IEA (2009) to be more that 10 million. Byron Capital Markets (2010) estimates for 2010 and 2014 annual sales of 25 and 33 million e-bikes, mainly in China. Recent information delivered from Chinese experts to Öko-Institut confirms a current range of 20 – 25 million units for the annual production of e-bikes in China.

The main conclusion from these explanations is that the demand estimations for the rare earths in EV and HEV should be handled with caution, as there is a very high uncertainty in the economic development of the electric and hybrid electric vehicles market and the embedded technologies (type of motor, specific Nd-demand per motor, etc.). Two different scenarios outline the wide range of forecasts for the resulting Nd-demand: Byron forecasts an Nd-oxide demand of around 1 200 t in 2015. Oakdene Hollins (2010) calculate on the basis of the three projections developed by McKinsey (2009) and the assumption of 1 kg Nd per motor, the resulting Nd-oxide-requirement ranges from only 875 t in 2020 for a scenario with very slow growth of hybrid electric vehicles (only ~ 1 million HEV/EV in 2020) up to 23 000 t Nd-oxide demand in 2020 in a scenario with very high growth rates (~ 20 million HEV/EV in 2020). There is an additional uncertainty on the used motor technologies. The presented scenarios on the Nd-demand of future electric and hybrid electric vehicles assume that the motors are using permanent magnets. It is not considered that there are several

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[12] Byron Capital Markets assumes the use of sintered magnets of 650 g for a 55 kW motor, containing 193 g Nd and 24 g of Dy. According to Oakdene Hollins (2010), Lifton estimates 1 kg of Nd in the electric Prius motor, whereas Kingsnorth even estimates that 1.9 kg of Nd is required in the electric Prius motor. Angerer et al (2009) estimate the Nd-demand of 0.5 – 1 kg per hybrid electric vehicle.

options for motors without rare earths which are also favoured by manufacturers (see discussion in Chapter 10.2.1).

Nevertheless the e-mobility sector will be a driving force in terms of the demand growth of permanent magnets and rare earths like neodymium.

### 8.2.2 Wind turbines

Wind turbines are an important driver for the Nd-magnet demand. There are three different technologies for wind turbines and only one of them uses the Nd-magnets. All three systems are available on the market. The market share of current sales is estimated at 14 % for turbines with Nd-magnets (Fairley 2010). They work without gear, which makes them robust and a good candidate for off-shore applications. However, it is not clear how their market share will increase; different forecasts show a wider range (Oakdene Hollins 2010, Fairley 2010). Furthermore, a new technology based on high temperature superconductor (HTS) rotors is under research and development. In the superconductor material (Fischer 2010) there is no neodymium; instead yttrium is used. The possible substitution of wind turbines with Nd-magnets by the alternative generator systems is discussed further in Chapter 10.2.3.

Besides the market shares of the different technologies for the turbines, the global growth rate of wind turbines is a crucial driver. Figure 20 shows the current global capacity of wind power to be 175 GW in total.

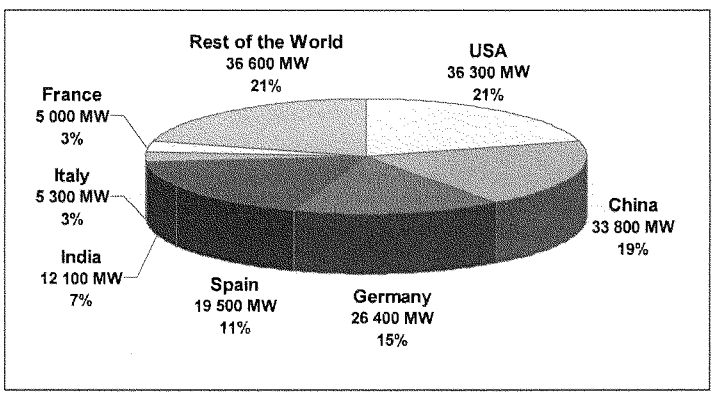


Figure 20 Global wind power capacities in June 2010 (WWEA 2010b)

Figure 21 presents the newly installed capacities in the first half of 2010. It shows convincingly that currently almost half of the new capacities are implemented in China.

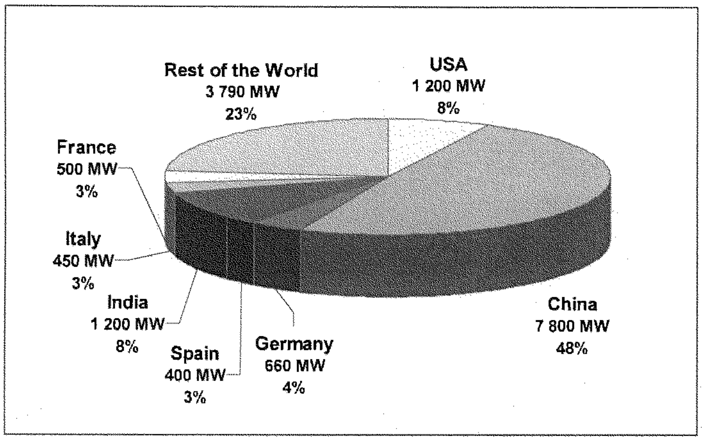


Figure 21 Newly installed wind power capacity in the first half of 2010 (WWEA 2010b)

The Chinese wind power is expected to continue to grow tremendously. The Chinese wind power capacity increased by almost 8 GW from the end of 2009 up to June 2010, corresponding to an increase of 30 % within half a year. According to Lifton (2010b) China plans to increase its wind power capacity dramatically up to 330 GW in 2020. This is the ten-fold capacity in relation to the current Chinese installations. In 2008 and 2009, the global newly installed capacities amounted to 27 GW and 38 GW, respectively (WWEA 2010a).

The calculated demand for the rare earths of different authors varies strongly due to different estimates of:

- the growth rates of installed wind power,
- the share of gearless turbines with neodymium magnets and
- neodymium, praseodymium, dysprosium und terbium required per kg of installed power.

These differences are described here in brief:

- High growth rates of newly installed global wind power capacities are part of different scenarios. For example, the forecast of Byron Capital Markets (2010) assumes high global growth rates of around 29 % yearly. Oakdene Hollins (2010) estimates an annual growth rate of newly installed wind power capacities of 22 % up to 2020. The corresponding forecasted total installed capacities in 2014 amount to 560 GW and 465

GW, respectively. Thus, a tremendous increase in comparison to the global capacity of 175 GW in June 2010 is forecasted.

- Byron Capital Markets estimates that 20 % of the turbines will be installed with permanent magnet-equipped generators, though it supposes that this figure is likely to be too high. Oakdene Hollins assumes a gearless contribution of 10 % up to 2014 and 20 % from 2015 onwards.
- There are different data on how much neodymium is necessary per installed MW electricity of the turbine. Lifton (2010b) estimates 667 kg neodymium-magnets per MW electricity, whereas the exploration company Avalon assumes 400 kg of neodymium magnet embedded per MW electricity (cited in Oakdene Hollins 2010).

The World Wind Energy Association counts the new installations in 2008 at 27 GW. Assuming a share of 14 % for gearless turbines with Nd-magnets and an average consumption of 400 kg Nd-magnet per MW electricity, the total Nd-demand in 2008 would have been about 450 t Nd and about 570 Nd-oxide, respectively.

Based on the forecast by Oakdene Hollins (2010), the Nd-demand for wind turbines is calculated as 1 200 t/a REO up to 2014 and 4 200 t/a REO from 2015 onwards. Summarizing the explanations above, it is to point out that it is currently not clear which direction the technology development will actually take. Therefore, for the wind turbines as well as for the electric vehicles, the forecasts should be taken into account with care, as there is a high uncertainty of the implementation of future techniques.

### 8.2.3 Hard disks and electronic components with Nd-magnets

According to the Japanese company Shin-Etsu (cited in Oakdene Hollins 2010) around a third of the Nd-magnets are used in hard disk devices. Öko-Institut estimates that around 1 700 t Nd (corresponds to 2 150 t Nd-oxide) were embedded in hard disks in PCs including laptops which were sold in 2008[13]. Here, some degree of substitution by the SSD technology which is described in Chapter 10.3 is expected. However, it is also expected that the substitution will occur gradually and will probably not affect all hard disk devices.

Furthermore, Shin-Etsu (cited in Oakdene Hollins 2010) estimates that about further 10 % of all neodymium magnets are embedded in optical and acoustic applications.

The future demand development of the permanent magnets in hard disks is probably almost linear to the sales of computers. The annual global growth of personal computers and particularly laptops is high. The market research institution Gartner forecasts a growth rate of 16 % for 2011 (Gartner 2010).

[13] Calculation based on 291 million computer sales in 2008 and measurements by A. Manhart at Öko-Institut of magnets from hard disks (22 g per magnet, corresponding at 5.9 g Nd per hard disks for Nd-share of 27 %).

The future demand development of permanent magnets in optical and acoustic devices is probably similar to the sales of electronic goods. Average growth rates in the electronics sector are estimated at 5 % for the period from 2010 to 2013 by the industry research firm RNCOS (Daily News 2010).

These figures imply that the demand of the applications hard disks and other electronics should not be underestimated, even if the possible growth rates for wind turbines and electric and hybrid electric cars might be higher.

### 8.2.4 Magnetic cooling

A new technology which is currently under development is the magnetic cooling. It is based on the magneto-caloric effect phenomenon, in which a reversible change in the temperature of magnetic materials occurs in the magnetisation/demagnetisation process. The technology promises high energy savings of 50 – 60 % in comparison to the traditional compression refrigerating machines (EEC 2010, Katter 2010, Jiang 2008). Possible applications are refrigerators in household and commercial appliances, industrial cooling, heat pumps and air-conditioning systems.

The European Union is currently supporting the research project SSEEC (Solid State Energy Efficient Cooling) in which several prototypes for air-conditioning are constructed. The aim is to develop magnetic cooling devices which are suitable for industrial use by the end of 2011 (Katter 2010).

Rare earths are needed for these devices for both the magnetic source and the refrigerant. As a magnetic source, the neodymium magnets are the best option (Katter 2010). BGS (2010) reports in addition that gadolinium is a suitable refrigerant. Research has been carried out in China on magnetic refrigerants based on gadolinium-silicon-germanium materials (Jiang 2008).

Katter (2010) of the German company Vacuumschmelze, which is a relevant permanent magnet producer, expects that it might take some years until magnetic cooling will achieve economical relevance. He identifies the high costs for the magneto-caloric materials and the high amount of Nd-magnets required for magnetic refrigeration as a major barrier to a wide dissemination. With approx. 200 million cooling machines being sold worldwide each year, it is to be assumed that the magnetic cooling will require a significant amount of rare earths if the magnetic cooling technology is to be widely disseminated.

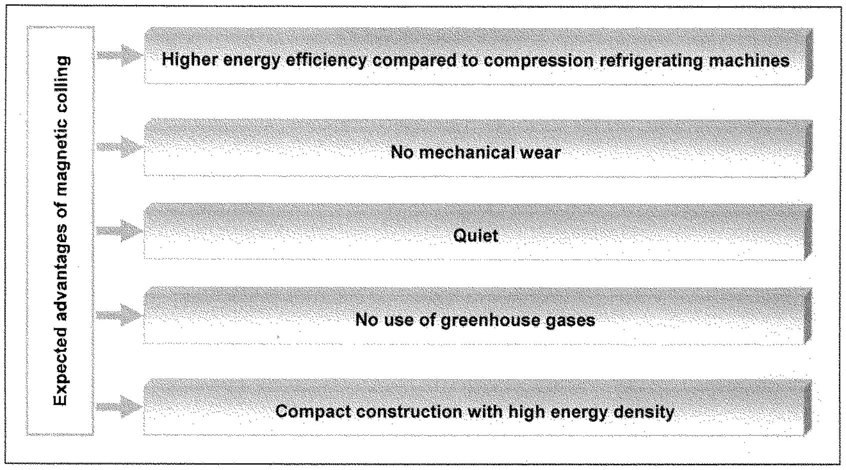


Figure 22 Expected advantages of magnetic cooling

### 8.2.5 Compilation of forecasts for the field of Nd-magnets

The analysis of a number of forecasts for the demand of rare earths in magnets shows a wide range as well as high uncertainty. The next table compiles the forecasts mentioned above in order to enable a general overview. Apart from the forecasts already mentioned, it includes an overall estimation by Fraunhofer Institut für System- und Innovationsforschung ISI & Institut für Zukunftsstudien und Technologiebewertung IZT (Angerer et al 2009) on the total Nd-oxide demand for permanent magnets in 2030. They estimate a demand of 21 000 - 35 200 t neodymium-oxide resulting from average global growth rates of between 7.5 % and 10 %. Thereby, their demand project is based on a significant lower estimate of the demand in 2006 (around 5 000 t Nd-oxide) than Kingsnorth (2010).

Table 8-2 Compilation of estimates for the demand of magnet applications (in t/a)

| Estimates / scenarios | | Nd-Oxide Demand | | | REO Demand |
|---|---|---|---|---|---|
| | Indicated year | Hybrid and electric vehicles | wind turbines | hard disk in PC | Total of all magnet applications |
| **Fraunhofer ISI**<br>**Demand in 2006** | 2006 | | | | 5 000 |
| **Öko-Institut**<br>**Hard Disks in PCs** | 2008 | | | 2 100 | |
| **Chen: Chinese demand** | 2008 | | | | 20 100 (China) |
| **Kingsnorth / IMCOA**<br>**Demand in 2008** | 2008 | | | | 26 250 (global) |
| **Byron Capital Markets**<br>(2.2 million HEV and 33 Mio. e-bikes) | 2014 | 1 029 | | | |
| **Oakdene Hollins:**<br>**Forecast for wind turbines** | 2010-14 | | 1 200 | | |
| **Kingsnorth / IMCOA**<br>**Demand in 2014** | 2014 | | | | 38 000 – 42 000<br>(global) |
| **Oakdene Hollins:**<br>**Forecast for wind turbines** | 2015-20 | | 4 200 | | |
| **Oakdene Hollins forecast based on McKinsey scenarios**<br>**(very low growth rate of electric cars)**<br>~ 1 million HEV | 2020 | 875 | | | |
| **Oakdene Hollins forecast based on McKinsey scenarios**<br>**(high growth rate of electric cars)**<br>~ 20 million HEV | 2020 | 23 000 | | | |
| **Fraunhofer ISI**<br>**Demand in 2030** | 2030 | | | | 20 000 – 35 200 |

This summary shows a significant gap between the high demand estimates by the Australian expert Kingsnorth (2010) and the Chinese expert Chen (2010) on the one hand and the sectoral analyses on the other hand. The sectoral analyses indicate a comparably low share of the wind turbines, a comparably low contribution from hybrid and electric vehicles (apart from the 2020 scenario by McKinsey, which assumes that hybrid electric vehicles will dominate the fleet) and a comparably low contribution from hard disks in computers.

The high Chinese demand estimate for 2008 compared to the global demand estimate for the same year provided in Kingsnorth (2010) is plausible, as China is the main magnet producer and produced not only for the domestic market but also for the export.

The comparison of the total demand estimates and the sectoral analysis might indicate higher shares of many magnet applications in other fields such as industrial equipment (e.g. lifters or magnetic separators), electronics, medical advices and other motor applications. One further aspect which is probably not considered in the sectoral analyses is the high loss of material in the magnet production. This issue is discussed in Chapter 10.2, which analyses options for a more efficient use of rare earths.

The situation regarding data uncertainty clearly shows that there is an obvious need for more reliable information. Precise analyses and reliable demand forecasts require a comprehensive material flow analysis to be undertaken by a research group with independent experts from all relevant application fields who have additional know-how of the specific national features.

### 8.3 Phosphors and luminescence

Almost all future energy saving lighting and display technologies, such as compact fluorescent lamps (CFL), fluorescent tubes, LEDs, OLEDs, EL foils, plasma displays and LCDs require the use of rare earths as phosphors, providing a high energy efficiency and high colour quality. In the past, many chemical elements and compounds are being studied for their use in luminescence. Among the substances being analysed, rare earths in particular seem to be most promising in terms of their high colour quality and good energy efficiency. It seems very unlikely that this performance will be achieved without the use of rare earths from the current perspective.

Thereby, the REE europium, samarium, terbium, cerium, erbium, dysprosium, thulium, gadolinium, and lutetium play a role as activators. The matrix or host lattices partly contain REE like yttrium, lanthanum or cerium.

The share of phosphors and luminescence in total rare earth application is around 7 % worldwide and around 9 % in China, in terms of volume. However, the share in terms of economic value is much higher at around 32 % according to the estimate provided in Kingsnorth (2010). One reason for the high value of the phosphors is the high price of europium and terbium, which both cost more than 700 US $/kg (see details on prices in Chapter 6.3) in November 2010.

Lynas (2010a) estimates that around 84 % of the phosphors are globally used for lighting, around 12 % for LCD and around 4 % for plasma displays. Hereby, 74 % are estimated to be used for red light, 25 % for green light and 0.5 % for blue light.

Informative figures are given on the relevance of europium and terbium in lighting appliances for the total demand of these elements by NEDO (2009). NEDO (2009) estimates that Japan is the world's leading consumer of terbium and europium with around 70 to 80 % of demand generated by the need for fluorescent powder.

The growth of rare earth consumption in the sector of lighting is determined by following parameters:

- The global overall growth including all types of lighting is estimated at 7 % per year by Philips (2008) for the years 2004 to 2011.
- Incandescent bulbs are going to be phased out due to their high energy demand. For example, the European Union, Australia, Canada and the United States banned the sale of incandescent bulbs in the years ahead in accordance with national law (Jaspersen McKeown 2008, DOE 2010). They will be replaced by other lighting systems, mainly by compact fluorescent lamps (CFL) and halogen lamps. Besides these types, there are numerous other lighting systems. Most of the energy efficient lighting systems include phosphors based on rare earths.
- Currently LEDs which also contain rare earths still play a minor role in lighting with a market share of 2.4 % in 2008. The main current uses were decorative effect lighting and orientation light; they are also starting to replace other lighting systems, e.g. automobile headlights. However, their development is progressing rapidly, and wider uses at very high efficiencies are to expect, particularly if the current comparably high prices begin to decrease. Trendforce (2010) assumes a growth rate of 32 % from 2008 to 2013 with a market share of about 8 % in 2013.
- Cathode-ray tubes which were used formerly on a large scale in TV sets and monitors are currently replaced by plasma displays and LCDs. Both techniques use rare earths. In 2008, around 130 million television sets with plasma and LCD displays were sold (DisplaySearch 2010). DisplaySearch (2010) forecasts an increase to approx. 280 million in 2014. This corresponds to an annual growth rate of 14 %.

These different aspects highlight that a considerable growth rate for energy efficient lighting systems with rare earth elements is to be expected. Kingsnorth (2010) assumes an annual growth rate of 4 – 6 % between 2008 and 2014. It is possible that this projected growth rate is too low and that higher growth rates will occur.

More technical details are given in Chapter 10.5 and Chapter 11.3, in which recycling aspects and options for a substitution of the REE are discussed.

### 8.4 Metal alloys / batteries

This application field comprises various uses which are summarised below (BGS 2010):

- One of the oldest applications is the use of cerium and lanthanum in pyrophoric alloys which are used in flint ignition devices for lighters and torches.
- Mischmetal and cerium are used as minor alloys for casting of steel and iron. They improve the stability of the casted product.
- REE (Y, La, Ce) which are added to heat-resistant superalloys can dramatically improve their performance.
- REE are used for the solid state storage of hydrogen where a metallic matrix of different metals absorbs a large amount of hydrogen at room temperature. This procedure is better than storage as cryogenic liquid or compressed gas in terms of safety, volume and energy saving.
- REE are used in Ni-MH batteries which in turn are used in hybrid electric vehicles (e.g. Toyota Prius) and portable appliances.
- Scandium-aluminium alloys are a suitable material for light weight construction. Due to the limited availability, it is mainly used in military aviation and not disseminated in civil aviation. Angerer et al (2009) estimate the current scandium supply at 5 t per year and report a new Australian mining project with the production target of 200 t scandium oxide.
- A new technology still under development is the solid oxide fuel cell (SOFC) which is regarded as the most promising fuel cell technology. Yttrium is contained in the electrolyte, and electrodes with mischmetal containing rare earths might improve their performance and reduce their costs (BGS 2010). There is also research on fuel cells for electric vehicles which could operate without the expensive platinum or palladium catalysts. The research also explores the incorporation of mischmetal containing rare earths in this context (BGS 2010).

The share of the global applications of metal alloys and batteries in the total rare earth demand is around 18 % in terms of volume. The global share of economical value is lower at around 14 %. Figure 19 on China shows a higher share of volume for $H_2$-storage (9 %) and for metallurgy (15 %). In this data the use of rare earths in Ni-MH batteries is integrated in the data for $H_2$-storage.

### 8.4.1 Ni-MH batteries

Ni-MH batteries are used in hybrid electric vehicles and in portable appliances. Besides nickel and cobalt, they contain a mix of lanthanum, cerium, neodymium and praseodymium. This mix is also called "mischmetal".

Pillot (2009) estimates that in 2009 the hybrid electric vehicles already had a larger share (57 %) in the total Ni-MH battery market in terms of value than the other applications (43 %). Since the HEV market is nascent, it could be expected that the demand for Ni-MH batteries will be dominated by the development of the HEV market in the years ahead. The resulting rare earth demand depends on several factors:

- The specific rare earth demand for a Ni-MH battery.
- The growth rate of hybrid electric vehicle market.
- The applied battery system is of high relevance as the alternative battery system – Li-ion batteries – use currently no or just small amounts of rare earths.

The analysis conducted by Öko-Institut on the basic assumptions of published forecasts (Oakdene Hollins 2010, Kingsnorth 2010, GWMG 2010b, BGR 2009, BGS 2010, Lynas 2009) shows that the demand for rare earths arising for Ni-MH batteries in hybrid electric vehicles is widely overestimated in literature and information distributed on the internet. These overestimates are based on assumptions regarding the rare earth content of the Toyota Prius battery. Former estimates provided by Lifton (cited in Oakdene Hollins 2010) and Kingsnorth (2008) range from 10 to 15 kg of lanthanum for one Prius battery. Latest data from Öko-Institut (Buchert 2010) base on a life cycle assessment for Ni-MH batteries for hybrid electric vehicles based on data from Toyota. These data indicate that the battery of Prius II has a REO content of 2.9 kg per battery[14]. This implies an overestimate by the factor 4 in most published forecasts.

The growth rate for the sales of HEVs has already been discussed in Chapter 8.2.1, which analysed the rare earth demand of motors of HEV. The figures there illustrated the wide range of different scenarios based on technical, economical and political developments in the field of e-mobility in the years ahead.

The share of Ni-MH batteries in terms of the total hybrid electric vehicle batteries is currently very high because the market is dominated by the Toyota Prius, which is equipped with a Ni-MH battery. In 2008, the Prius had a market share of HEVs amounting to approx. 83 %. However, in the long term, Li-ion batteries will replace Ni-MH batteries due to several advantages described in Chapter 10.5, where the substitution of rare earth elements is analysed. Other manufactures will start producing HEVs with Li-ion batteries and Toyota

[14] The Prius battery has a weight of 35 kg and a share of 7 % of the rare metals. This makes a weight of 2.45 kg rare earth per car battery (corresponding to 2.9 kg REO).

announced that it will launch a newly developed Prius hybrid minivan with a lithium battery in 2011 (Reuters 2010b). The large Chinese market for e-bikes mainly operates with lead batteries.

#### 8.4.2 Other appliances

'here are no forecasts for the future growth of other applications such as pyrophoric alloys, ılloys for casting, metallic super alloys and the solid state storage of hydrogen. It is to be ıssumed that the growth rates will not be smaller than the growth rates of the steel industry. ts growth is estimated at 5.3 % for 2011 (Worldsteel 2010).

#### 8.4.3 Overall forecast

Kingsnorth (2010) estimates a rare earth demand in the field of metal alloys and batteries of 43 – 47 000 t REO in 2014, compared to a demand of 22 500 t REO in 2008. The average growth rate is given as between 15 % and 20 %. Possibly, this forecast and other demand analyses (Oakdene Hollins 2010, GWMG 2010b, BGR 2009 and Lynas 2010) contain overestimations due to the specific rare earth demand of Ni-MH batteries being set too high.

### 8.5 Catalysts

The rare earths cerium and lanthanum are widely used for catalysts. Cerium compounds are used in automotive catalysts and as diesel additives in order to improve a clean combustion. Lanthanum and cerium are important in the petroleum refining as fluid cracking catalysts (FCC). Further applications are used in chemical processing. The demand for rare earth as catalysts contributes to the total rare earth demand, constituting 20 % in terms of volume according to estimates of Kingsnorth (2009). Relatively low prices of lanthanum and cerium lead to a low share of value accounting for just 5 % in 2008 (Kingsnorth 2009). Nevertheless, these applications are highly relevant in terms of emission reduction, energy efficiency and the reduction of embedded precious metals (platinum, palladium and rhodium) in the catalysts due to an increased catalyst performance.

For the future, a further increase in the demand could be expected as the global stock of fuel driven vehicles increase steadily at approximately 3 % per year. Thus, the demand for automotive catalysts will grow as well as the demand for petroleum.

BBC Research (2010) forecasts an annual growth rate of 6 % for environmental catalysts. Kingsnorth (2010) forecasts an annual growth rate of 3 -5 % for all catalysts containing rare earths. Thus, he expects an increase in demand from about 25 000 t REO in 2008 to 30 - 33 000 t REO in 2014.

## 8.6 Glass, polishing and ceramics

The group "glass, polishing and ceramics" comprises many different uses. Table 8-3 presents the most frequent applications (BGS 2010, Avalon 2010):

Table 8-3 Overview of main applications in the group "glass, polishing and ceramics"

| Application | | Major REE |
|---|---|---|
| **Polishing** | | |
| | Polishing of high-quality glass surfaces<br>(mirrors, television and monitors, cathode ray tubes, panel display, glass platters in hard disks) | Ce |
| **Glass additives** | | |
| | Colouring of glass<br>(Ce – yellow and brown, Nd – red, Er pink) | Ce, Nd, Er |
| | Decolouring of glass | Ce |
| | UV-resistant glass<br>(glass bottles, sunglasses, cover of solar cells) | Ce |
| | Optics<br>(optical lenses, optical filters, coatings) | La, Gd, Pr |
| **Ceramics** | | |
| | Ceramic capacitors, semiconductors and other components for LCD and electronics | La, Ce, Pr, Nd |
| | Stabiliser for ceramic material | Y, Ce |
| | High-temperature superconductors | Y |
| | Pigments in ceramics | Pr, Y, Nd |
| | Refractory material | Y, Ce |
| | Laser | Y |
| | Dental ceramics | Ce |

The applications described have a high share of the total rare earth demand of about 30 % in terms of volume according the estimate from Kingsnorth (2010). Due to the manifold use of quite cheap cerium, the share of economical value was much lower at 9 % (estimated from Kingsnorth 2010).

Kingsnorth (2010) also gives more detailed estimates on the sectors for 2008:

- Glass polishing 15 000 t REO (44 %)
- Glass additives 12 000 t REO (35 %)
- Ceramics 7 000 t REO (21 %)

Compared to the global demand, the consumption in China is comparably low, totaling 7 160 t. It is likely that a high share of rare earths for these applications is used in Japan. The Japanese New Energy and Industrial Technology Development Organization (NEDO 2009) states that Japan is the world's leading consumer of cerium, and more than the half of demand is for abrasives. The main uses here are flat panel display for TV sets and hard disks in computers.

Angerer et al (2009) analyse an upcoming application: the use of yttrium-barium-copper-oxide (YBCO) as high temperature super conductor of the second generation. Associated advantages of this application are lower costs and a potentially higher performance. Angerer et al (2009) estimate that commercial use will begin around 2013/2014 and assumes that this application might transform the electricity industry significantly in the long term, coupled with an increase of the yttrium demand for this field. However, Angerer et al (2009) estimate the demand of super conductors for yttrium at only 75 t in 2030, which is very small compared to the global yttrium production of almost 9 000 t in 2009 according to USGS (2010b).

Cerium-doped covers of solar cells absorb UV radiation. Thus, they prevent the darkening due to UV radiation and increase the lifetime of the solar cells. Since these UV wavelengths are not used by solar cells, their efficiency is not lowered (JDSU 2009, Messer 2009).

The growth rates for glass polishing is supposed to be in the range of the growth rates for plasma and LCD displays and computers, which are around 14 and 16 %, respectively as discussed in Chapter 8.2 and Chapter 8.3 (DisplaySearch 2010, Gartner 2010). The growth rate of ceramic application might be in the range of the growth of electronics, which is estimated by the industry research firm RNCOS (Daily News 2010) at 5 % for 2010 - 2013.

Kingsnorth (2010) estimates an increase in the demand of the whole application group of less than 5 %. Hereby, he expects almost no growth for glass additives and moderate growth rates for polishing and ceramics (estimates vary from 2 - 4 % to 6 - 7 %). Possibly, this is an underestimation of the potential demand increase triggered by the booming markets of PCs and flat screens for computers and TV sets.

## 8.7 Others

The group "others" comprises many smaller uses which do not fit into the categories presented above. Table 8-4 presents selected applications (BGS 2010, Avalon 2010):

Table 8-4 Overview of main applications in the group „others "

| Application | Major REE |
|---|---|
| Pigments and paint<br>(for better light resistant, higher durability, corrosion resistance) | Ce, Y |
| Defence<br>(optics, surveillance, sonar transducer, microwave communication, laser, aircraft material) | Various REE |
| Fertilizer<br>(mainly in China, added to phosphate fertilizer) | Ce, La |
| Nuclear energy<br>(neutron absorber, reactor control) | Gd, Eu |
| Waste water treatment<br>(new application) | Ce |

The demand has a low share of the total rare earth demand of about 5 % in terms of volume (see Figure 16 and about 3 % in terms of value (Kingsnorth 2010).

Most of the defence applications are part of the large categories which were presented in the chapters above, as the defence sector requires equipment such as lighting, batteries, motors, electronics, computers and displays. Some further specific devices are listed here and in more detail in BGS (2010) and GAO (2010).

In co-operation with the United States Army Molycorp developed a portable device for purifying water. It further developed a material for the filtration of arsenic and other contaminants from process water (BGS 2010, Molycorp 2010c). Both applications require rare earths. In China, Sun et al (2008) analysed the use of $La_2B(B=Mn,Fe)TiO_6$ as a photocatalyst in the treatment of waste water containing phenol from the coal chemical production.

REE containing fertilizer is mainly used in China. BGS (2010) reports on REE compounds which are added to calcium superphosphate to create a "rare earth phosphate fertilizer" containing between 0.04 and 0.16 % REE. Research has shown that this fertilizer results in improved crop yields and less diseases of plants (Xiangshen et al (2006), cited in BGS 2010, Xu & Wang 2007).

Kingsnorth (2010) estimates an annual increase in the demand of the whole application group of 3 - 7 %, thereby increasing from 7 500 t REO in 2008 up to 9 000 – 12 000 t REO in 2014.

***Conclusion on applications and demand of rare earths***

*The following green technologies currently use rare earths:*

- *magnets (motors for e-mobility, wind turbines)*
- *automotive catalysts*
- *energy efficient lighting*
- *batteries for e-mobility*
- *industrial catalysts*

*Further fields of application are:*

- *metal alloys*
- *glass additives*
- *electronics*
- *ceramics*
- *polishing*

*In 2008, around 30 % of the global rare earth consumption was used in the glass, polishing and ceramics sectors. Around 20 % were used for permanent magnets, a further 20 % for automotive and industrial catalysts, another 20 % for metal alloys and batteries and around 7 % for lighting. However, larger research institutions and public bodies have not established in-depth material flow analysis for rare earth, and the available data are estimates from few experts.*

*The demand for all applications is expected to grow in the short and medium term considerably. Of these applications, the highest growth rates are projected for permanent magnets (particularly for wind turbines, hybrid electric vehicles and hard disks). The global demand of around 120 000 t REO in 2008 is expected to increase up to 170 000 – 200 000 t in 2014.*

# 9 Demand-supply balance

The supply risk of individual rare earths is indicated by the development of the future demand-supply balance. Most of the available forecasts refer to the year 2014 which is also used as a target year within this study.

In the following, the future demand and supply of the most relevant 11 REE are examined. For the group of holmium, thulium, ytterbium and lutetium, only aggregated data are available. Due to their limited supply (~ probably < 1 000 t/a), they are not yet significant. No data are given on promethium which is radioactive and therefore has only limited applications. Brief information is provided on scandium, which is produced in extremely low amounts (approx. 5 t annually), in Chapter 8.4 on page 77. A supply shortage is not to be expected for scandium according to the German Federal Institute for Geosciences and Natural Resources (BGR 2010a).

## 9.1 Future supply

The future supply depends on some key factors:

- development of the total Chinese REO production,
- development of the Chinese export quota,
- progress in installation works for Mountain Pass (USA) and Mt Weld (Australia),
- progress of other mining projects (approval, feasibility studies, construction work).

The development of the total Chinese production and the progress of mining projects outside of China are discussed in the following paragraphs. The relevance of Chinese export quotas and the progress of the advanced mining projects Mountain Pass and Mt Weld concerning the demand-supply balance are further discussed in Chapter 9.3.

**Future supply by China**

The total Chinese production in 2008 and 2009 amounted to approx. 120 000 t REO according to USGS (2010). Chinese data sources cited in the Explanation of Compiling of Entry Criterions for Rare Earth Industry 2010 specify a production of 120 800 t REO in 2007. In contrast, Kingsnorth (2010) estimates a legal production of 125 – 140 000 t REO in the years 2006 and 2008. In addition to these quantities of legal production, there are around 20 000 t REO which were produced illegally and seem not to be included in these data. The comparison of these figures shows that there are no accurate data on the current situation, particularly due to a relevant quantity of illegal production.

In the light of the Chinese 2009-2015 plan mentioned in Chapter 5.1.2, it is to be assumed that China's rare earth industry will undergo a phase of consolidation and will not significantly increase their REO production. This is in accordance with Lynas (2010a) which forecasts a Chinese production of 114 000 t in 2014, with 110 000 t coming from primary mining and a further 4 000 t coming from recycling. In contrast, Kingsnorth (2010) estimates a higher Chinese production of 160 – 170 000 t REO in 2014 without recycling. This constitutes a significant difference of 50 000 – 60 000 t REO in the forecast of the Chinese REO production.

The forecasted production of rare earths from the Chinese ion adsorption deposits containing HREE makes for a more uniform picture. Chinese data sources (MEP 2009) specify a production of 45 000 t REO in 2007. Kingsnorth (2010) similarly estimates a Chinese production of 40 - 50 000 t REO in 2014, whereas Lynas (2010a) assumes a lower production of only 30 000 t REO. The main conclusion derived from these figures is that the Chinese HREE production will probably not rise and eventually even decrease.

**Future supply outside of China**

Table 4-3 on page 22 provides an overview of current mining activities. Despite the high number of intended mining projects, only two of them are sufficiently advanced to have obtained approval from the authorities and construction work has begun: Mountain Pass in California, USA and Mt Weld in Australia. The processing for the latter is located in Malaysia.

Their nominal capacity is an output of 20 000 t REO for each location, respectively. Operation shall commence in 2011 in Australia/Malaysia and in 2012 in California. It is uncertain whether the mineral companies will succeed in operating their plants at full load in a short term because the chemistry of rare earth processing and refining is very complex.

Lynas (2010a) further assumes that India and Russia might be able to increase their capacities up to 12 000 t in 2014, and estimates secondary rare earths from recycling of almost 2000 t in 2014.

Neither Kingsnorth (2010) nor Lynas (2010a) expect the opening of further mines with larger capacities until 2014, except for India and Russia. This is in accordance with Table 4-3 on page 22 which was compiled by Öko-Institut and shows that the listed mines (besides Mountain Pass and Mt Weld) have reached the stage of feasibility studies or drillings. From this point, it will take some years before mining and processing on an industrial scale can take place. More details on the time frames needed were presented in Chapter 4.3 on page 20.

**Global supply forecast**

Table 9-1 presents the forecasts from Kingsnorth (2010) and Lynas (2010a) and their estimated production for individual rare earths. The forecast of Kingsnorth (2010) is supplemented by other figures from Kingsnorth which are cited in Oakdene Hollins 2010. As mentioned above, both forecasts assume that Mountain Pass and Mt Weld commence operation before 2014, and that - besides the consideration of Russian and Indian mines in the Lynas forecast - no other mining and processing projects will be ready for production until

2014. The main difference is the estimate of the future mining in China. Additionally, both forecasts do not include the illegally mined quantities. This is reasonable as the Chinese government intends to control the rare earth industry more strictly and prevent illegal mining.

Table 9-1 Forecasted supply in 2014 stated by Kingsnorth (2010) and Lynas (2010a)

| Company | IMCOA/Kingsnorth | LYNAS |
|---|---|---|
| Source | Kingsnorth 2010, figures in ( ) from IMCOA, cited in Oakdene Hollins 2010 | Lynas 2010a |
| | t REO | t REO |
| **China** | | |
| Bayan Obo Bastnasite | 80 - 100 000 | 60 000 |
| Sichuan Bastnasite | 20 - 40 000 | 20 000 |
| Ion Adsorption Clays | 40 - 50 000 | 30 000 |
| Monazite | 8 - 12 000 | |
| Recycling in China | - | 4 000 |
| **Total China** | **160 - 170 000** | **114 000** |
| **Outside China** | | |
| Mountain Pass | 20 000 | 20 000 |
| Mt. Weld | 21 000 | 22 000 |
| Nolans Bore | 0 | 0 |
| Thor Lake | 0 | 0 |
| Others (India & Russia) | 0 | 12 000 |
| Recycling outside China | 0 | 1 800 |
| **Total World** | **190 - 210 000** | **169 800** |
| **Forecast for individual elements in t REO:** | | |
| Lanthanum | 52 - 57 000 | 43 400 |
| Cerium | 80 - 85 000 | 66 500 |
| Terbium | 400 - 500 | 330 |
| Dysprosium | 1 800 - 2 000 | 1 700 |
| Yttrium | 9 - 13 000 | 9 500 |
| Praseodymium | (10 000) | 9 100 |
| Neodymium | (33 000) | 31 200 |
| Samarium | (4 000) | 3 500 |
| Europium | (850) | 450 |
| Gadolinium | (3 000) | 2 300 |
| Erbium | (1 000) | n.d. |
| Ho-Tm-Yb-Lu | (1 300) | n.d. |
| **Total** | **190 - 210 000** | **167 980** |

The difference in these forecasts mainly concern the supply of lanthanum and cerium due to different assumptions of the increase in production in the Chinese mines in Batou (Bayan Obo mine) and Sichuan, which mainly contain light rare earths.

## 9.2 Future demand

Table 9-2 presents the demand forecasts of Kingsnorth (2010) and Lynas (2010a) for the year 2014.

Table 9-2 Forecasted demand in 2014 by Kingsnorth (2010) and Lynas (2010a)

| Company | IMCOA/Kingsnorth | LYNAS |
|---|---|---|
| Source | Kingsnorth 2010, figures in ( ) from IMCOA, cited in Oakdene & Hollins 2010 | Lynas 2010a |
| | **t REO** | **t REO** |
| **Lanthanum** | 50 - 55 000 | 57 100 |
| **Cerium** | 60 - 65 000 | 59 000 |
| **Terbium** | 400 - 500 | 620 |
| **Dysprosium** | 1 900 - 2 300 | 2 800 |
| **Yttrium** | 10 - 14 000 | 10 700 |
| **Praseodymium** | (7 900) | 16 100 |
| **Neodymium** | (34 900) | 45 400 |
| **Samarium** | (1 390) | 1 200 |
| **Europium** | (840) | 560 |
| **Gadolinium** | (2 300) | 1 400 |
| **Erbium** | (940) | n.d. |
| **Ho-Tm-Yb-Lu** | (200) | n.d. |
| **Total** | **170 - 190 000** | **194 880** |

The magnitude of the forecasts is quite similar in both scenarios. The moderate differences stem from a range of generally high data uncertainties. Nevertheless, the trend is quite clear: The demand which was around 124 000 t REO in 2008 according to Kingsnorth (2010) is expected to increase rapidly within the next few years and continue to rise in the years after 2014 with similar growth rates, as many of applications are high-tech applications such as hybrid vehicles, wind turbines and energy efficient lighting which are only in the start phase.

## 9.3 Future demand-supply balance

The demand-supply balances resulting from the demand and supply forecasts presented above are shown in Table 9-3.

Table 9-3 Forecasted supply-demand balance for individual rare earths in 2014 by Kingsnorth (2010) and Lynas (2010a)

| Company | IMCOA/Kingsnorth | LYNAS |
|---|---|---|
| Source | Kingsnorth 2010, figures in ( ) from IMCOA, cited in Oakdene Hollins 2010 | Lynas 2010a |
| | t REO | t REO |
| Lanthanum | -3 000 bis + 7 000 | -13.700 |
| Cerium | +15 000 bis + 25 000 | 7 500 |
| Terbium | -100 bis + 100 | -290 |
| Dysprosium | -500 bis + 100 | -1.100 |
| Yttrium | -5 000 bis +3 000 | -1.200 |
| Praseodymium | (2 100) | -7 000 |
| Neodymium | (-1 900) | -14 200 |
| Samarium | (2 610) | 2 300 |
| Europium | (10) | -110 |
| Gadolinium | (700) | 900 |
| Erbium | (60) | n.d. |
| Ho-Tm-Yb-Lu | (1 100) | n.d. |

Despite some data uncertainties, the overall picture presented in Table 9-3 is quite clear: There will be shortages in **terbium, dysprosium, praseodymium** and **neodymium** at a high degree of probability, even if China imposes no export restrictions. The sectoral analyses of the magnet applications identified high growth rates in many affected applications such as wind turbines, hybrid vehicles, hard disks and electronics which strongly support the expectancy of future supply shortages.

Further potential shortages might occur for **lanthanum**, **yttrium** and **europium** with a high degree of probability. Lynas and partly also Kingsnorth (2010) forecast shortages for all three elements, based on the assumption that Chinese REO production will not significantly increase in the coming years. The analysis conducted by Öko-Institut as provided in the preceding chapters supports this expectation. Only the scenario of Kingsnorth (2010), which assumes a significant increase in Chinese production, results in a positive demand-supply balance for La, Y and Eu. The main drivers for the demand of these REE are energy efficient lighting (La, Y and Eu), catalysts (La), ferrite magnets (La), Ni-MH batteries (La) and ceramics (Y).

The supply risk for the HREE terbium and dysprosium seems to be the highest, as the Mountain Pass and Mt Weld mines will not produce relevant amounts of these metals; and potential Chinese supply constraints regarding HREE cannot be compensated by relevant production capacities outside of China. Furthermore, China will probably not increase its HREE production in the next few years, though the global demand increases steeply.

A relevant supply risk of the LREE neodymium and praseodymium is the complex processing technology required for rare earths refining which might lead to delays in implementation in California and Malaysia.

The negative supply-demand balance after 2014 might be attenuated, if further mines besides Mountain Pass and Mt Weld start production of HREE and LREE, significant improvements in resource efficiency are implemented (particularly increasing the recovery rates in the rare earth mining and reduction of production losses in the magnet production) and relevant substitutions are realised. Furthermore, efficient recycling systems are required. These issues will be analysed in more depth in Chapter 10 and 11.

Another important issue is the high pressure on the fast opening of new mines from manufactures which require rare earths for their finished goods, coupled with the expectation of investors to make profits with rare earth production as long as possible supply shortages exist. This situation might lead to the rapid opening of new mines with inadequate environmental standards. Chapter 7 illustrated clearly the environmental burdens of mines and processing plants which are poorly designed or managed. National authorities, investors and mining operators are asked to act responsibly in designing and operating these plants in order to develop a sustainable rare earth industry. This is particularly true as appropriate environmental technologies are available and awaiting application.

The U.S. Department of Energy published in December 2010 an analysis of the criticality of selected rare metals (DOE 2010). The highest criticality in terms of supply risk and the importance to clean energy production are the five REE **dysprosium**, **neodymium**, **terbium**, **yttrium** and **europium**, which are also seen as critical by Öko-Institut as outlined in the paragraphs before. The element **praseodymium** is seen as less critical by DOE (2010) though it is widely interchangeable with neodymium and is mostly used in neodymium / praseodymium mixtures as it is found in mineral ores. The criticality of **lanthanum** is estimated to be near-critical by DOE (2010) and as critical by Öko-Institut. Hereby, DOE (2010) projects an additional supply of these elements not only from Mountain Pass and Mt. Weld but also from five further new mines (Nolans Bore/Australia, Nechalacho/Canada, Dong Pao/Vietnam, Hoidas Lake/Canada and Dubbo Zirconia/Australia) up to 2015. Considering the long time spans needed to develop new mining projects including the further rare earth processing, this forecast seems to be quite optimistic. However, apart from the evaluation of the speed progress of new mining projects, the assessment of Öko-Institut and DOE (2010) show a broad consensus.

Finally, potential supply shortages for "green" applications are summarised in brief:

- There will be shortages of rare earths for the production of **permanent magnets** in the short term, with a high degree of probability. The relevant elements are **terbium**, **dysprosium**, **praseodymium** and **neodymium** and the applications wind turbines, hybrid vehicles and electric vehicles are concerned. However, there are options for their substitution which are discussed in Chapter 10.2.
- The production of **Ni-MH batteries** for hybrid vehicles might become limited due to shortages in **neodymium** and **lanthanum**. This will probably lead to an accelerated substitution of Ni-MH batteries by Li-ion batteries.
- There will be shortages of rare earths for the production of **lighting devices** in the short term, with a high degree of probability. Significant shortages are to be expected for **europium** and **terbium**. Furthermore, the supply with yttrium and lanthanum might also become scarce. Relevant applications are energy efficient lighting such as compact fluorescent lamps, fluorescent tubes, LED, plasma and LCD displays. An additional supply risk for most of these applications is the lack of adequate substitutes for many phosphors in the short term (see Chapter 10.5).
- **Catalysts** in refining and processing might suffer from a **lanthanum** shortage. Here again, no substitutions are available in the short term.
- Future **new technologies** such as magnetic cooling, wind turbines with high-temperature superconductors (containing yttrium) and efficient and cost efficient fuel cells (containing yttrium and mischmetal) might suffer from supply constraints slowing down their future dissemination.

The compilation shows that most green applications listed above are closely related to climate protection and reduction of the depletion of non-renewable energy carriers. They contribute to a more efficient use of energy or to energy production by renewable energy sources. This applies to motors and batteries for hybrid vehicles and electric vehicles, energy efficient lighting, wind turbines, magnetic cooling and fuel cells. Additionally, catalysts contribute significantly to the enhancement of process efficiencies and the prevention of air pollution.

***Conclusion on the demand-supply balance***

*Based on the foregoing demand and supply analysis, the future demand-supply balance for the year 2014 was analysed. It seems to be probable that the Chinese production will not increase significantly in the short term due to their planned course of consolidation. For the mining outside of China, it is probable that the mining projects Mountain Pass / United States and Mt. Weld / Australia will commence operation in the years ahead. The short-term implementation of further larger mines does not seem to be realistic.*

*Based on these assumptions, potential supply shortages for green applications can be identified:*

- *There will be shortages of rare earths for the production of* ***permanent magnets*** *in the short term, with a high degree of probability. The relevant elements are* ***terbium, dysprosium, praseodymium*** *and* ***neodymium****, and the applications wind turbines, hybrid vehicles and electric vehicles are concerned. However, there are options for their substitution.*
- *The production of* ***Ni-MH batteries*** *for hybrid vehicles might become limited due to shortages in* ***neodymium*** *and* ***lanthanum****. This will probably lead to an accelerated substitution of Ni-MH batteries by Li-ion batteries.*
- *There will be shortages of rare earths for the production of* ***energy efficient lamps and displays*** *in the short term, with a high degree of probability. Significant shortages are to be expected for* ***europium*** *and* ***terbium****. Furthermore, the supply with* ***yttrium*** *and* ***lanthanum*** *might also become scarce. An additional supply risk for most of these applications is the lack of adequate substitutes for many phosphors in the short term.*
- ***Catalysts*** *in petroleum refining and processing might suffer from a* ***lanthanum*** *shortage. Again, no substitutions are available in the short term.*
- *Future* ***new technologies*** *such as magnetic cooling, wind turbines with high-temperature superconductors (containing yttrium) and efficient and cost-efficient fuel cells (containing yttrium and mischmetal) might suffer from supply constraints slowing down their future dissemination.*

# 10 Substitution and efficient use of rare earths

## 10.1 Overview

Facing possible scarcities of natural resources and the challenge to search alternatives for substitution, there are two options in principle: substitution of the REE by another material or another design approach of the products or their applications. The analysis of substitutions for scarce REE has shown that a simple substitution of a REE compound by another compound is a quite rare case. In most cases substitution requires a totally new product design. The following sub-chapters describe the options for substitution concerning the main fields of applications: motors/generators, magnets in electronic devices, batteries, lighting/luminescence and catalysts.

## 10.2 Magnets for motors and generators

### 10.2.1 Motor and generator types

In this sub-chapter a short description of the current relevant motor and generator types is given. An overview of these technologies is required to understand the substitution potentials of rare earths.

**State of the art for electric motors for e-mobility:**

**Synchronous electric motor with a neodymium magnet**:

- Currently the motor type with the highest efficiency!
- Use in most electric vehicles, e.g. from Toyota, Mercedes, Honda and BMW,
- Increasing use in high performance generator of wind turbines (market share about 14 % according to Fairley (2010)),
- Compact size,
- Expensive.

**Asynchronous motor**

- Mostly used motor in industrial appliances; produced in high quantities,
- Use in some electric vehicles, e.g. Fiat Seicento Electra, Ford E-Ka,
- Good efficiency at nominal load, low efficiency at some operations conditions,
- Low costs,
- No need for neodymium,

- Simple construction,
- Lower efficiency and bigger size than motors with neodymium magnets.

__Alternatives:__

**Synchronous motor with electromagnets (external excitation)**

- No need for rare earths,
- Higher copper demand than permanent magnet motors (factor 3),
- Broader realisation possible in the short term or the medium term,
- Conti is developing such a motor for a power range of 5 to 120 kW.

**Permanent magnet motor with a SmCo magnet (synchronous motor)**

- SmCo (Samarium-Cobalt) magnets are the first generation in the family of rare earth magnets, NdFeB magnets belong to the second generation,
- These motors were used for high-performance applications before the construction of motors with neodymium magnets,
- Due to their high costs their application is restricted. With increasing Nd-prices they might become competitive,
- SmCo magnets have a much higher magnetic energy product than ferrite, but lower than that of neodymium magnets,
- They can operate at higher temperatures than NdFeB-magnets (Hatch 2010).

**Permanent magnet motor with ferrite magnet (synchronous motor)**

- Lower magnetic properties (factor 4), therefore more volume und more weight (Benecki 2007),
- Lower efficiency – there are R&D activities for higher efficiencies, e.g. (Fang et al. 2009),
- Lower price,
- R&D project in Japan (Kudling 2010).

**Reluctance motors**

Technical advantages and disadvantages according to Matoy (2008):

- Simple and robust construction,
- Noise problems (loud)!
- Low price,

- Due to serious noise development no application in electric vehicles or wind turbines.

**Hybrid motors (combination of permanent magnet and reluctance motor)**

Technical advantages and disadvantages according to Matoy (2008):

- Combines the advantages of both motor types,
- Needs less neodymium than the permanent motor,
- High potential for the future!
- Still in the R&D phase.

### 10.2.2 Substitution of rare earths magnets in motors for electric vehicles

The analysis of the different motor types shows that there are alternatives to permanent magnet motors containing rare earths. There are asynchronous motors which are currently used in electric vehicles (e.g. Fiat Seicento Electra, Ford E-Ka). Generally, asynchronous motors are the most widely used motor type, and though they are less compact and less efficient in some operation conditions than the permanent motors, they also show advantages such as simple construction methods and low costs. They are an alternative, at least in mild hybrid vehicles. Therefore, the German government has included the research on asynchronous motors in its national development plan for e-mobility (Bundesregierung 2009).

Besides the industrially available asynchronous motors, there are three other motor types which show a potential to be an alternative to pure Nd-containing permanent motors:

- The synchronous motor with electromagnets (external excitation). Broader realisation seems to be possible for the short or medium term. Conti is currently developing a motor for a power range of 5 to 120 kW.
- A permanent magnet motor with ferrite magnet is currently under development in Japan. The higher volume of the weaker ferrite magnet shall be compensated by another geometrical arrangement.
- Hybrid motors which are a combination of permanent magnet and reluctance motor might show a promising potential for the use in electric vehicles. They need less neodymium than the pure permanent magnet motors and tend to have a better performance than the permanent magnet motors. The German government has included the research on reluctance motors in its national development plan for e-mobility (Bundesregierung 2009).

### 10.2.3 Substitution of rare earths in generators for wind turbines

Currently, the global market share of wind turbines working with gear drive and asynchronous or synchronous generators is 86 %. They work with electro magnets and thus without permanent magnets and rare earths (Fairley 2010). There have been wind turbines without gear drives (direct drive turbine) since 1991. They usually work with neodymium containing permanent magnets. One of the advantages of these turbines is the absence of a gear, which facilitate higher efficiencies and higher reliabilities. Furthermore, due to the compact permanent magnet motor, the gearless wind turbines are lighter than the types equipped with a gear drive. Therefore, they are an attractive option for offshore plants. But also onshore plants are running without gears. The main obstacle for increasing market shares of gearless wind turbines are the high costs for the permanent magnets.

The international market share of gearless wind turbines is estimated at 14 % (Fairley 2010). However, in Germany the market share is already much higher; the company ENERCON, which completely shifted to gearless drives, has a market share of around 50- 60 % (Kettwig 2009). The trend indicates that more and more companies are offering gearless turbines, and large companies such as Siemens and General Electric are developing new gearless turbines for the offshore applications.

There are manifold discussions about the future development of the market shares of gearless drives. There are two key parameters: The first one is the question of how successful the gears will be improved in order to achieve a higher reliability for conventional turbines with gear drive technology. The second issue is the future development of the price and the availability of the permanent magnets (rare earths!) which might inhibit future growth rates of direct drive turbines.

If there are shortages in neodymium, the following alternatives could be drawn upon:

- "Classic" wind turbine technology with gears for onshore and offshore plants. An overview of the largest protoypes (year 2006) shows that four companies have developed off-shore prototypes with gear and asynchronous generator for a capacity of 4 – 5 MW (Koenemann & Tschierschke 2006).
- Magnetic direct drive turbines with SmCo-magnets. However, SmCo-magnets are quite expensive, and the resources are also limited.

Furthermore, a new technology based on high temperatures superconductor (HTS) rotors is now under development. At the moment it is not yet clear whether this technology might be able to replace the gearless wind turbines with Nd-magnets. However, following announcements of the company AMSC (Terra Magnetica 2009, Fischer 2010), the design and implementation of turbines with HTS technologies for plants with capacity of 10 MW and more are planned. Currently, most off-shore turbines operate up to 5 MW. Nevertheless, the superconductors used for this technology also require a rare earth element – yttrium. The basic HTS wire substrate is nickel tungsten. Various buffer layers are applied before the superconductor — yttrium barium copper oxide — and a very thin cap layer of silver is also applied. (Fischer 2010). The resource implications (yttrium, tungsten, silver etc.) of this new technology have to be considered very carefully in the years ahead.

#### 10.2.4 Substitution of dysprosium and terbium in permanent magnets

Most of the neodymium magnets consist of approximately 65 - 70% iron, 1 % bor, 30 % mix of neodymium/praseodymium, 3 % dysprosium and sometimes terbium (Oakdene Hollins 2010). High-performance applications (e.g. e-mobility) may even need a higher share of dysprosium.

The function of dysprosium is to enhance the coercivity (intensity of the applied magnetic field required to reduce the magnetisation of that material to zero) and thus the temperature tolerance, which is needed for applications with high temperatures such as motors or generators (Oakdene Hollins 2010). The use of dysprosium also tends to improve the corrosion resistance of the magnets (Avalon 2010).

The function of terbium is similar to that of dysprosium, but its use is limited to the very scarce supply and the high price. One particular quality of terbium is that it has less impact on the remanence (magnetisation left after an external magnetic field is removed, which should be low in order to achieve a high performance) than dysprosium according to Oakdene Hollins (2010).

Due to a forecasted supply shortage for dysprosium and terbium, industrial companies and researchers are looking for alternatives, but there is no decisive solution in sight. The following summarises different activities and options in this context:

- Benecki (2009) assumes that "magnet producers will likely be forced to offer NdFeB magnets with modified compositions, even if some performance is sacrificed. For example, a reduction of dysprosium or terbium content could result in an $H_{ci}$ (coercivity) reduction of 10-30%. Cost considerations may eventually dictate such compositional changes for some applications."
- Discussions with European magnet experts have shown that there is no commercially available substitute for dysprosium in neodymium magnets yet. An abandonment of terbium seems feasible for most applications which require no extremely high performance if the wider available dysprosium is applied to enhance the stability and the performance.

Furthermore, different research and development activities are being undertaken which focus on a better performance of the neodymium magnets with less dysprosium and terbium content than the current magnets. A research project of this kind is currently underway at St. Pölten University of Applied Sciences (Austria), in cooperation with the University of Sheffield (UK). The scientists are exploring the ideal composition and structure for high-performance permanent magnets intended for use in hybrid and electric car motors—specifically, how the proportion of dysprosium can be reduced without compromising the thermal stability of the magnets. By optimising magnets, the researchers suggest, hybrid and electric cars can be made economically competitive.

Another example is provided by Ames Laboratory, where researcher Bill McCallum is investigating how to lower the rare-earth content in the permanent magnets used in the traction motors of hybrid electric vehicles (Jenkins 2010).

Komuro et al. (2010) reports that effective processes have recently been developed to reduce the amount of terbium by sputtering or vaporising techniques for magnets which have a thickness of up to 10 mm. The terbium is diffused along grain boundaries in sintered neodymium magnets. The condensed terbium atoms near grain boundaries increase the coercivity without a large reduction of remanence. A new process for thicker magnets whereby the surface of the magnet powder is coated before sintering is described by Komuro et al (2010).

#### 10.2.5 Substitution of neodymium magnets by SmCo magnets

The production of SmCo magnets is a difficult and expensive multi-step process. Therefore, these magnets are only used in a small number of applications, and the majority of permanent magnets are neodymium magnets. A substitution of neodymium magnets by SmCo magnets is only an economically attractive alternative, if the SmCo magnets become cheaper and/or the price of neodymium magnets rise.

Apart from the steep increase of Nd-prices in 2010, there are two developments which might lead to SmCo magnets having a higher market share:

- The Northeastern University (2008) presents a new one-step production process which might result in much cheaper SmCo magnets: "Unlike the traditional multi-step metallurgical techniques that provide limited control of the size and shape of the final magnetic particles, the Northeastern scientists' one-step method produces air-stable "nanoblades" (elongated nanoparticles shaped like blades) that allow for a more efficient assembly that may ultimately result in smaller and lighter magnets without sacrificing performance."
- SmCo magnets need – in contrast to neodymium magnets – no coating. Therefore, particularly small SmCo magnets might become economical if the neodymium prices continue to rise. The reason is that the economical advantage of not coating the

magnets is more relevant for small magnets as the costs of coating do not change much when changing the size of the magnet (Trout 2007).

However, a substitution of neodymium magnets by SmCo magnets will be strongly limited due to the resource limits of samarium. The samarium supply is estimated at 4 000 – 5 000 t in 2012 whereas the neodymium supply is estimated at 30 000 – 40 000 t in 2012 (Oakdene Hollins 2010). The rare earth breakdown of the minerals of mines in China, Australia, Canada, United States and Greenland shows that all minerals contain significantly more neodymium than samarium (Oakdene Hollins 2010). Thus, there is no potential for an enhanced samarium supply which might be able to substitute a significant share of neodymium. Additionally, the high costs and resource limits of cobalt contribute to the high price of SmCo magnets (Co prices range from 30 – 130 $/kg in recent years[15]; annual production in 2009 around 61.000 t) according to USGS (2010d).

Another drawback is the high environmental and social burden related to the cobalt mining in Democratic Republic of the Congo where armed conflicts on resources take place. Around 40 % of the global cobalt production is currently mined in the Democratic Republic of the Congo (USGS 2010g).

### 10.2.6 Substitution of rare earths demands by enhanced process efficiencies

According to Benecki (2007) there are actions that the magnet industry can take to address rising REE prices. First, the classic Chinese production process of producing blocks of NdFeB and then cutting them to the desired shape wastes tons of Nd and Pr each year. The Chinese need to shift to "press to shape" manufacturing, the process that has been common in Japan and the West for decades. The Chinese need to reduce the waste of precious rare earth materials inherent in their traditional "slicing and dicing" process.

According to Bax & Willems (2010) nanocomposite magnets could constitute a new generation of magnets; DOE (2010) sees nano-structured permanent magnets as one high-priority research area. In this context, Öko-Institut proposes the incorporation of a case-specific risk assessment in their development of all applications of nanotechnologies (Öko-Institut 2007).

## 10.3 Magnets in electronic devices, mainly disk drives

Approximately one third of the neodymium magnets were used in hard disk drives in 2007, and around 10 % of magnets were used in optical and acoustic devices (Oakdene Hollins 2010). In this application field they are used for small motors, writing/reading heads, speakers and ear phones and sensors.

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[15] Compare with Nd-price in October 2010 of around 80 $/kg.

Most hard disk drive systems currently use a voice-coil-motor (VCM) to actuate the read/write recording arm assembly. This motor usually contains a neodymium magnet. In principle, hard disk drives (HDD) with VCM can be substituted by a new generation of data storage devices, the solid state drive (SSD). The SSD is a data storage device that uses solid-state memory to store persistent data. It uses microchips and contains no moving parts. Compared to traditional HDDs, SSDs are typically less susceptible to physical shock, quieter, and have lower access time and latency. SSDs use the same interface as hard disk drives, thus easily replacing them in most applications. SSDs are still significantly more expensive than HDDs, but there are already some laptops working with SDD and more computer manufacturers are beginning to offer SSDs. There is still a need for further research, but it is to be expected that new developments will lead to lower prices and increasing performance, particularly in terms of capacity, life time and safety (Marwan 2010). Benecki (2009) assumes that "as solid state drive utilisation increases, their costs (and prices) will decline and they will gradually replace the traditional magnet-consuming VCM we have taken for granted for so many years. Shortages of rare earths would simply accelerate this transition." However, it also seems possible that both technologies, HDD and SDD, will co-exist in the medium term. There are also hybrid drives commercially available which are a combination of a HDD and a SSD.

The partial substitution of dysprosium and terbium has already been discussed in chapter 10.2.4 (Substitution of dysprosium and terbium in permanent magnets). It is to be expected that the substitution of Dy and Tb is easier in these small-size applications than in permanent magnets for electric vehicles and generators, where operation temperatures are much higher.

The substitution of neodymium magnets by SmCo magnets is discussed in chapter 10.2.5 (Substitution of neodymium magnets by SmCo magnets). Due to constraints in price and availability, it will only be an option for a few sophisticated applications.

## 10.4 Batteries

Rare earths are used in Ni-MH batteries. Besides nickel and cobalt the MH-electrode contains a mix of different rare earth elements. The mixture varies between the manufacturers. Mostly, the main rare earths are lanthanum and cerium with additional input of neodymium and praseodymium (Luidold 2010).

Ni-MH-batteries are used in portable appliances (e.g. power tools) and hybrid vehicles (HEV) (e.g. Toyota Prius). Around 50% of the worldwide sales stem from use in HEV batteries.

The Ni-MH battery for hybrid vehicles is a mature technology and is used in the Toyota Prius with more than 2 million sales. However, there is little room for further improvements in energy power (limited energy and power density) and costs according to Bax & Willems (2010) which refer to a study conducted by the Rocky Mountain Institute. The future battery generations will be lithium-ion batteries. This trend is underlined by the fact that Toyota will start to equip the new Prius van with a lithium battery with a higher capacity in 2011. At the same time, the German government has set up a national development plan for e-mobility (Bundesregierung 2009). It also estimates that lithium-ion batteries have the highest potential for future energy storage systems. Additionally ZEBRA (high temperature) batteries, redox-flow and magnesium batteries and metal-air batteries might play an important role in the future. Thus, the broader use of Ni-MH batteries for hybrid vehicles is expected to phase out gradually. Pillot (2009) forecasts the market share of Li-ion batteries for HEV to rise to 35 % in 2020 (35 % in the base scenario and 60 % in the optimistic scenario). In 2009 the market share of Li-ion batteries for HEVs was approximately 2 %.

The trend for portable appliances is that Li-ion batteries gain increasing market shares. They have already largely substituted Ni-MH batteries in laptops and mobile phones and have relevant market shares in further applications such as cameras and power tools (ifeu / Öko-Institut 2010).

In summary, it is expected that the market share of Li-ion batteries will significantly increase in the years ahead. The use of Ni-MH batteries for HEV will phase out in the medium term. The same trend is to expect for most portable appliances. A shortage in rare earth supply might accelerate this development.

### 10.5 Lighting and luminescence

Phosphor materials emit light after absorption of energy. They are produced by dotting salt-like host lattices with metal ions in small concentrations. The colour of the light essentially depends on the properties of these metal ions, also called activators. As an example, in the following some metal ions and their corresponding colours are listed (Riedel et al. 2007):

Samarium ($Sm^{3+}$): red-violet

Europium ($Eu^{3+}$): red

Terbium ($Tb^{3+}$): green

Erbium ($Er^{3+}$): green

Thulium ($Tm^{3+}$): blue

Europium ($Eu^{2+}$): blue

Cerium ($Ce^{3+}$): green

Dysprosium ($Dy^{3+}$): yellow

White colour originates from the mixture of three colours. The temperature of the colour can be adjusted (warm or cold light), depending on the composition. As the spectra of the individual metals are limited, lamps with special requirements use up to eight phosphors, mainly lanthanides (Wickleder 2010).

Host lattices comprise compounds without rare earths such as $BaMgAl_{10}O_{17}$, BaFCl or $Zn_2SiO_4$ as well as compounds containing rare earths such as $Y_2O_3$, $La_2O_3$ and $CeMgAl_{11}O_{19}$.

The following chapters describe the main areas of application: fluorescent lamps, plasma displays as well as electro-luminescence with a focus on LEDs (light-emitting diodes) and

LCDs (liquid crystal displays). Other fields of application with smaller quantitative relevance are laser and X-ray technology where REE are used, too (e.g. neodymium for lasers[16]).

### 10.5.1 Fluorescent lamps

Fluorescent lamps encompass the group of tube-like lamps (fluorescent tubes), compact fluorescent lamps (CFL), high intensity discharge (HID) lamps, and low-pressure sodium vapour lamps.

In the following the chemical composition of the most frequent luminescent materials (= phosphors) used in these lamps (Wojtalewicz-Kasprzak 2007) is provided:

**Phosphors without rare earths:**

Halophosphate: CaO, $P_2O_5$, MnO, $Sb_2O_3$, F, Cl (white, blue)

**Phosphors with rare earths:**

Yttrium europium oxide (YOE): **~ 95 % $Y_2O_3$ , ~ 5 % $Eu_2O_3$ (red)**

Barium magnesium aluminate (BAM): $Al_2O_3$, BaO, MgO, **~ 2 % $Eu_2O_3$ (blue)**

Cerium magnesium aluminate (CAT): $Al_2O_3$, **~ 11 % $Ce_2O_3$, ~ 8 % $Tb_2O_3$**, MgO **(green)**

Lanthanum phosphate (LAP): **~ 40 % $La_2O_3$, ~ 16 % $Ce_2O_3$, ~ 11 % $Tb_2O_3$**, $P_2O_3$ **(green)**

Inexpensive fluorescent lamps use halophosphate (light yield ~ 75 - 80 lm/W, low-quality colour reproduction), while high-quality fluorescent tubes use a three band phosphor containing REE (light yield ~ 100 lm/W, good colour reproduction); they contain 2 % halophosphate or three band phosphor, respectively, in terms of weight. In compact fluorescent lamps the three band phosphor constitutes about 0.3 % in terms of weight (Wojtalewicz-Kasprzak 2007). Guarde et al. (2010) reported on high rare earths contents in fluorescent powders from the recycling of used fluorescent lamps and tubes, particularly yttrium with up to 9 % and smaller amounts of europium (up to 0.6 %), lanthanum (up to 0.5 %), cerium (up to 0.4 %), gadolinium (up to 0.3 %) and terbium (up to 0.2 %).

The summary above shows that all three band phosphors use REE as activators. In many cases the host lattice is also dotted with REE like yttrium, cerium or lanthanum. According to USGS (2010b) yttrium cannot be substituted by other elements in the use as phosphor. Considering various phosphors Jüstel (2007) concludes that phosphors containing REE are superior to other phosphors. However, he mentions manganese ($Mn^{2+}$) as a possible alternative to terbium. Regarding phosphor technology shift, Lynas (2010a) mentions a potential decrease of Tb consumption amounting to 40 %. A Japanese research project which started in 2009 aims at finding a substitute for Tb and Eu by using a high-speed

[16] Angerer et al 2009 estimate a very low demand of only 0.2 t Nd for use in laser crystals in 2030.

theoretical calculation method and combinatorial chemistry synthesis of materials (NEDO 2009). DOE (2010) states that there is no proven substitute for europium in fluorescent lamps and no proven substitute for europium as red phosphor in television screens.

Plasma displays make use of UV-rays and have a similar working principle as fluorescent lamps. Here, REE like europium, yttrium, terbium and gadolinium are used.

### 10.5.2 Electro-luminescence

Illuminants which are based on the phenomenon of electro-luminescence comprise LEDs (based on inorganic compounds), OLEDs (based on organic compounds) and EL-foils. LEDs or EL-foils are also used as backlight for LCDs.

In the medium term LEDs constitute a promising alternative to CFL. Their efficiency is already higher and a further drastic increase of their efficiency is expected. Wickleder (2010) states that various commercial LED-applications are already available. Nevertheless, to enable broader dissemination new phosphors capable of providing a better light quality need to be developed.

Currently, the REE gadolinium, cerium, terbium, europium, yttrium, lanthanum, samarium and lutetium are used in the host lattices and as activators.

Organic LEDs (OLEDs) are likely to be the next LED generation. Some commercial applications which also use REE like europium, terbium, samarium, lanthanum, gadolinium, lutetium, thulium and dysprosium are already on the market or are being developed (Huang 2010).

In future, LEDs might eliminate the need for lanthanum and terbium phosphors while continuing use of cerium and europium (DOE 2010). Future generations of OLEDs might even be free of all rare earths (DOE 2010).

## 10.6 Catalysts

Rare earths are used for industrial catalysts as well as for automotive catalysts. A very important example of rare earths used for industrial catalysts is FCC (fluid catalytic cracking) catalysts, which support refineries in the production of high quality products at high rates. Hykawy (2010) reports an estimate provided by G. Ragan from Albemarle, which assumes a global market of about 600 000 t for FCC catalysts with a rare earth content of approx. 2%, mostly lanthanum. This means an annual lanthanum demand of approx. 12 000 t for FCC catalysts. According to Hykawy (2010), P.Chang from BASF pointed out that lanthanum is crucial for FCC catalysts because it provides thermal stability and selectivity. Currently no substitutes for lanthanum in FCC catalysts are known, but experts state that there is an additional impetus for reduction or substitution due to the increasing prices of REE like lanthanum.

In automotive catalysts REEs (mostly cerium) are also responsible for enhanced thermal stability and emission reduction (Hykawy 2010). Currently no substitution materials are known for the REEs used for automotive catalysts.

***Conclusion on substitution and efficient use of rare earths***

*The analysis of substitutions for scarce REE has shown that a simple substitution of a REE compound by another compound is a quite rare case. In most cases substitution requires totally new product design. The identified options for substitution for the major green applications are summarised below:*

- *Rare earths are currently used in around 14 % of newly installed **wind turbines** with gear-less design and technical advantages in terms of reliability. A supply shortage of rare earths would lead to a shift to alternative turbine types. Further research into the higher reliability of traditional techniques with gears would support this substitution.*
- *Rare earths are used in permanent motors of **hybrid electric vehicles and electric vehicles**. Substitutions based on alternative motor designs are available. However, R&D is required to enable higher performance of existing electric motor types and to realise new electric motor concepts.*
- *Most new **energy efficient lighting systems** contain rare earths (compact fluorescent lamp, LED, plasma display, LCD display). Substitutions are rare, particularly in the case of compact fluorescent lamps. R&D is required for alternative phosphors with a high efficiency and high light quality.*
- *Automotive **catalysts** contain cerium, and catalysts for petroleum refining and other industrial processes contain lanthanum. Substitutions are rare, and R&D is urgently required for alternative catalysts.*

*Concerning a higher efficiency of the rare earth, **R&D** is urgently needed in all fields of application and is also needed to enable higher efficiencies in mining, beneficiation and processing. One example of high losses in the production chain is the traditional magnet production.*

*The use of **nanotechnology** in some green applications is being considered in order to increase the efficiency by nano-sized rare earth compounds. An attendant risk assessment is highly recommended.*

# 11 Recycling of rare earths – current situation

The recycling of rare earths could be stated as a very uncommon issue until today. A recent analysis of Öko-Institut conducted for UNEP on critical metals provided information on very small quantities of recycled rare earths with pre-consumer origins (permanent magnet scrap), but no indications of any post-consumer recycling of rare earth containing products could be found (Öko-Institut 2009). The reasons for this were quite dissipative applications, quite low prices of rare earths and a tendency of REE to move in the slags of smelter plants. Nevertheless the sharp increase of the rare earth prices in 2010 and the high media coverage of possible supply shortages and export restrictions by China have put the issue of recycling rare earths on the agenda worldwide. The following sub-chapters summarise the results of the intensive new analysis conducted by Öko-Institut in late 2010.

## 11.1 Recycling of rare earths from magnets

Research activities are being conducted on pre-consumer and post-consumer recycling in China and other countries. An important focus is the recycling of magnet scrap which arises in large amounts not only after consumption but already during the production.

- It is estimated that 20-30 % of the rare earth magnets are scrapped during manufacturing (Zhong et al. 2007). However, the recovery of the rare earths from production waste is not yet practiced (Shirayama Okabe 2009). Possible technologies are as follows (Oakdene Hollins 2010):
    - Re-melting the scrap and recover in an un-oxidised state. According to Oakdene Hollins (2010) the yields are expected to be low.
    - The recovery of the rare earth as oxide. However, the value of the oxidized rare earth is much lower than the value of the metallic rare earths, as the oxides have to undergo the energy-intensive reduction and refining process again.
    - Re-use of the magnetic materials for new magnets without a separation of the material mix.
    - Selective extraction of Nd and Dy directly from magnet scrap by using molten magnesium chloride as the selective extracting agent. Laboratory tests were carried out in Japan with temperatures of around 1.000 °C (Shirayama Okabe 2009).
- There are various studies in China on the recovery of rare earth metals from neodymium magnet scrap and waste. Wang et al. (2006) reported that $Dy_2O_3$ could be recovered to an extent of over 99 %. Furthermore, Tang et al. (2009) compared two methods employing $Na_2SO_4$ double-salt precipitation and oxalate secondary precipitation which achieve a recovery rate of $Nd_2O_3$ of more than 82 %. Zhang et al

(2010) researched a separation method based on the electrical reduction by using P507 extraction and comparing this with the traditional separation methods in terms of material consumption and costs. Test results showed that this newly electrical reduction technology may result in a recovery rate of 96.1 % of rare earth from neodymium magnet scraps und save 6 033 RMB (about 650 Euro) per ton of rare earth recycled.

- Shi (2008) invented a process for the recovery of neodymium from acid cleaning waste water which arises before NdFeB is electrically plated.
- Zakotnik et al (2009) recycled neodymium magnets from disk drives successfully by milling and re-sintering with the addition of 1 % new neodymium in a technical scale. Kawasaki et al (2003) developed a similar recycling process for sintered neodymium magnets by adding Nd-rich alloy powders to the ground magnet scrap powder before re-sintering.
- Current research is ongoing in Japan into the post-consumer recycling of rare earths from motors/generators (permanent magnets). Pyro-metallurgical and hydrometallurgical approaches are described which focus on the recovery of REE as metals. (Takeda 2009, Koyama 2009).
- Hitachi announced that it has developed a machine for the dismantling of neodymium magnets from hard disks and compressors (Clenfield Shiraki 2010). The machine has a capacity of 100 magnets per hour, about eight times faster than manual labour. The developed dismantling process shall commence operation in 2013.

## 11.2 Recycling of rare earths from batteries

- The Japanese JOGMEC's Metals Mining Technology Group has been creating technology to recover rare earths metals such as lanthanum and cerium from used Ni-MH batteries used for HEVs, and to refine the recovered metals for re-use in new batteries. The electrodes are first treated with a multi-element refinery process, then the separated reduction of the rare earths takes place (JOGMEC 2010). There are no references to the implementation of a plant of industrial size.
- The recovery of REE from Ni-MH batteries is examined by Luidold (2010). Despite other attempts to extract the REE out of slags from smelting operations by means of hydrometallurgical methods, this approach is aimed at the previous separation of the REE from the other materials.
- Researchers from Freiberg/Germany developed a hydrometallurgical process to recover rare earth metal from the slag of the pyro-metallurgical treatment of used Ni-MH batteries (Heegn 2009).
- The Chinese researchers Wu & Zhang (2010) studied the recovery of Ni, Co and rare earth (lanthanum, cerium, neodymium and praseodymium) from used Ni-MH batteries

by leaching with sulphuric acid. The tests showed recovery rates of 95 %. Gao (2009) also investigated the recovery of rare earth from spent Ni-MH batteries.

## 11.3 Recycling of rare earths from lighting and luminescence

There are some research activities and new patents in the field of post-consumer recycling. They are listed below:

- OSRAM holds a patent on the recycling of yttrium and europium from discharge lamps and fluorescent lamps (OSRAM 2009, Wojtalewicz-Kasprzak 2007).
- Guarde et al (2010) report on the recycling of fluorescent lamps and tubes and the output of a distilled powder fraction which contains up to 10 % rare earths. Currently this fraction is disposed (compare with more detailed figures in Chapter 10.5.1).
- Further research activities are being undertaken which focus on yttrium and europium recovery not only from lamps but also from TV tubes and computer monitors (Rabah 2008, Resende Morais 2010).
- A scientific overview of conceivable recovery methods for the recycling of rare earths fluorescent powder containing yttrium, europium, lanthanum and cerium is provided by the Chinese publication Mei et al (2007).

## 11.4 Recycling of rare earths from catalysts

The recycling of REE from spent catalysts (industrial as well as automotive catalysts) is not common due to relative low prices of REE in the past. A German source from 2001 reported that the 9 100 t (1998) of spent FCC catalysts from catalytic cracking processes in German oil refineries was completely used as cement additives (Hassan 2001), which means a recovery of the REE from the spent FCC catalysts was not an issue. It is an open question whether a recovery of the REE (mostly lanthanum) from FCC catalysts could be interesting from an economic point of view in the next years. This will mainly depend on the price development of lanthanum. From a technical point of view the large global mass flow of FCC catalysts – 600 000 t per year (Hykawy 2010) – with about 2 % REE content means an interesting REE potential for recycling from this specific application. It should be mentioned that Öko-Institut and Umicore (GFMS 2005), after in-depth investigations regarding the recycling flows of platinum group metals, came to the clear conclusion that the usual business-to-business relationships (e.g. between the catalysts suppliers and the oil refineries) are a very good pre-condition for very high recovery rates of the platinum group metals (almost 100 % collection rate of the spent catalysts). Nevertheless the development of a technically feasible and economically acceptable solution for the recycling of REE from FCC catalysts is a task for the future.

The recycling activities of the automotive catalysts focus worldwide on the recovery of the valuable platinum group metals (GFMS 2005). Therefore the recovery of the REE content (mainly cerium) from these catalysts has not yet become a focus. Currently the REE moves into the slags from smelter processes due to the high affinity of the REE to oxygen. It remains an open question whether a recovery of REE from spent automotive catalysts could feature in the future.

## 11.5 Recycling of rare earths from other applications

Further studies deal with highly specific recycling processes from cleaning water, ferrosilicon and waste from the aluminium production. They are briefly described below:

- Wang et al. (2005) conducted an investigation on recovering the rare earth metals from solid waste generated from aluminium production called red mud. The study firstly reviews the existing recovery methods of rare earth metals from red mud in China and abroad and secondly introduces the methods in Shanxi Aluminium Limited Company at the laboratory stage. There, red mud was roasted and rare earth metals were leached by HCl; finally scandium and other rare earth oxides were separated from liquid.
- Ferrosilicon which contains rare earths is used as a pre-alloy in the production of ductile graphite iron. Chen (2007) analysed the technological conditions of smelting rare-earth ferrosilicon by means of two thermal methods.
- The Japanese company Kosaka Smelting and Refining tries to develop ways to reclaim rare earths like neodymium and dysprosium from electronic scrap (Tabuchi 2010).

## 11.6 Challenges for an efficient rare earths recycling

The analysis shows that recycling plants and technologies are quite rare. The publications of the US Geological Survey from 2010 only mention rare earth recycling for small amounts of magnetic scrap (USGS 2010a) containing Nd, Pr and Dy and small amounts of yttrium from laser and garnet applications. Furthermore, there is no current industrial recycling process for the recovery of rare earths from Ni-MH batteries containing La, Ce, Nd and Pr (Oakdene Hollins 2010, Luidold 2010, Tabuchi 2010).

Oakdene Hollins (2010) provides an overview of the recycling activities of rare earth. Their conclusion is that a significant amount of research into the recycling of rare earth metals has been undertaken, most notably in Japan. The result of the research activities is that there are potentially a number of extraction processes but none of them has been developed commercially due to drawbacks on yields and cost. The evaluation provided by Oakdene Hollins (2010) is that the most attractive method is the treatment with liquid metals. They further state that most of the patents are from the early 1990s and that little progress was made in the following 15 years. Therefore they see a potential for further new developments.

Research conducted by Öko-Institut affirms the fact that few industrial recycling activities are being implemented. The latest publications show the following industrial recycling schemes:

- Sludge from shaping and grinding of magnet alloys is recovered (Shirayama Okabe 2009), probably in Japan.
- Recycling of yttrium is realised for small quantities, primarily from laser crystals and synthetic garnets (USGS 2010b).
- Magnets from MRI (magnetic resonance imaging for medical application) are being re-used (Shirayama Okabe 2009).

Principally, the recycling processes for the rare earths are quite complex and extensive if re-use is not possible and a physical and chemical treatment is necessary. Most of the recycling procedures are energy-intensive processes. The main post-consumer activities – the recycling of rare earth from motors and hard disks and other electronic components – will require intensive dismantling.

A large challenge for a closed-loop economy in the field of the rare earths is the recycling of the rare earths magnets, as it is the most important application with expected shortages in the rare earth supply. The following constraints have to be overcome:

- The transport of magnetic materials is restricted as their field can interfere with aircraft instruments. This requires demagnetisation before air transportation, other transport modes or regional recycling activities (Oakdene Hollins 2010).
- Most of the rare earth magnets are used in motors and HDD (hard disk drive). Here, the recycling requires a costly and extensive dismantling, as the magnet is quite small. Further, it has to be demagnetised before separation from the iron parts is possible. Additional work has to be conducted if the magnet is embedded in plastics.
- Electronic scrap is often recycled in classic pyro-metallurgical plants. Many metals can be recovered, but the rare earths are lost as they become a part of the slag which is currently not recovered.

General constraints for wider recycling of rare earths in most application fields are:

- The implementation of an efficient collection system has to be built up.
- Post-consumer goods such as end-of-life vehicles or electronic scrap are partly exported in developing countries. These exported goods will not be easily available for an efficient urban mining.
- Up to now, the prices for rare earths have been too low for the running of an economical recycling process, particularly when considering the complex dismantling and treatment processes and the quite high energy demand. Even increasing prices due to the current Chinese export restriction do not guarantee a long-term stability of

adequate prices for rare earths, which is a pre-condition for economic recycling processes.

- It will take a long time span for many of the devices containing rare earths to reach the end of their life time. In particular electric motors in vehicles and wind turbines should have life times of 10 – 20 years.

***Conclusion on current situation of rare earth recycling***

*Only a few industrial recycling activities are currently implemented for rare earths. Up to now, there has been no large-scale recycling of rare earths from magnets, batteries, lighting and catalysts. In principle, the recycling processes for the rare earths are quite complex and extensive if re-use is not possible and a physical and chemical treatment is necessary. The main post-consumer activities – the recycling of rare earths from motors and hard disks and other electronic components – will require intensive dismantling.*

*Several constraints for a wider recycling of rare earths were identified: the need for an efficient collection system, the need for adequate high prices for primary and secondary rare earth compounds, losses of post-consumer goods by exports in developing countries and the long life time of products such vehicles and wind turbines of 10 – 20 years before they enter the recycling economy.*

*At the same time, the potential supply shortages and the steep increase in prices of rare earths are providing for the first time the opportunity to address the problem of today's rare earth supply in more depth and to seriously build up a recycling economy. The advantages of rare earth recycling include the utilisation of European resources, independence from foreign resources and environmental benefits. A corresponding strategy for developing such a European recycling scheme is provided in the next chapter.*

# 12 Strategy for a sustainable rare earth economy

## 12.1 Background

In recent years tremendous changes have occurred in the global application of rare earths. Technological innovations and the research on rare earths resulted in manifold applications leading to a steep increase in the demand. A relevant share of the increasing demand is caused by so called "green technologies" which are designed to contribute to environmental protection by means of a reduction of the energy consumption, the further development of renewable energy carriers or air pollution control. There is serious concern that the demand of several different rare earth elements such as neodymium, praseodymium, dysprosium, terbium, lanthanum, yttrium and europium might exceed the current supply within a few years. Even if China imposes no export restrictions it is to be expected that the increasing demand can only be met if further mines are opened in addition to the two mines in Australia and USA which have already obtained approval from the national authorities and begun construction works so that large-scale operation can commence around 2012.

The high demand and the expected supply shortages, additionally triggered by Chinese export restrictions, lead to a significant increase in rare earth prices. This steep increase is not only a burden for manufacturers and consumers. It provides an opportunity to address the problem of today's rare earth supply in more depth and to develop a sustainable rare earth economy in all relevant sectors. The low prices in the past have led to a significant waste of resources. To date there has been almost no recycling of rare earths. The new prices might be a starting point for setting up recycling systems for rare earths.

Similarly, science and industry are beginning research and development into options for the substitution of rare earths. The Chinese export restrictions revealed the high vulnerability of the EU and other developed countries. Alternative technologies with less or without application of rare earths attract more attention. Research projects started which aim to develop green technologies and other applications which require no or less rare earths.

The high public interest in this issue has further revealed the high environmental burden in the surroundings of the Chinese mines and processing plants. If the EU demands rare earth technology for their green technology, it is up to the EU to contribute to a "greener" rare earth supply. The contradiction between the "green" application of rare earth and their high environmental pressures in production calls for action to be taken particularly by Europe, America and Japan where – besides China – the majority of the rare earths are consumed.

Action in the field of recycling should begin now without further delay as it will take a minimum of five to ten years for the first large-size implementation to take place.

The recycling of rare earths has several advantages compared to the use of primary resources:

- Europe is one of the largest consumers of rare earths worldwide. Increasing amounts of waste from final products containing rare earths arise in Europe. These valuable resources should be returned to the industrial metabolism by "urban mining".
- Dependence on foreign resources will be reduced by supplying the European market with secondary rare earth materials.
- Apart from a few specialised industries and applications, the know-how in rare earth processing is quite low in Europe because most of the European rare earth handling involves the subsequent processing of refined material. The upstream processes are mainly being carried out in China and to some degree in Japan. The building-up of know-how in recycling will widen the competency of enterprises and scientific institutions in Europe.
- The processing of secondary rare earths will be free from radioactive impurities. The mining and further processing of primary rare earths is associated with nuclear radiation coming from radioactive elements of the natural deposits in most cases. Therefore, primary rare earth processing generally produces radioactive waste.
- The recycling requires some energy carriers and chemicals. At the same time it saves significant amounts of energy, chemicals and emissions in the primary processing chain. The accurate net benefit for recycling is process-specific and can be identified by a life cycle assessment. It is to be expected that most recycling processes will have a high net-benefit concerning air emissions, groundwater protection, acidification, eutrophication and climate protection.

The next chapters will firstly address strategies for action within the European Union in order to promote a sustainable rare earth management. Related issues are the developing of recycling schemes and actions required for improvements concerning a more efficient use of rare earths and improvements of alternative applications which work without the use of rare earths. Secondly, aspects related to foreign affairs and the potential contribution of the European Union to an environmentally sound mining will be addressed.

### 12.2 Development of recycling schemes

Öko-Institut suggests taking action in the short term in order to establish a European recycling scheme for rare earths. The development and implementation might take some years. When a relevant amount of products containing rare earths which now enter the market reach the end of their life cycle and are available for recycling such an collection and recycling scheme should be implemented.

The next figure provides an overview of main steps toward a European recycling scheme as suggested by Öko-Institut.

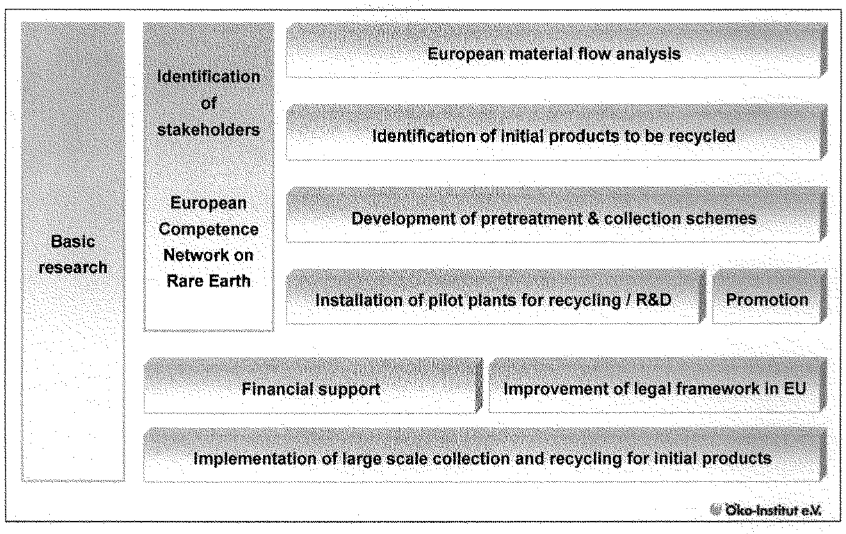


Figure 23 Steps towards a European rare earth recycling scheme

The different steps are described in more detail in the following.

### 12.2.1 European competence network on rare earth

A European network which comprises all relevant stakeholders on all levels is seen by Öko-Institut as indispensable for the development of a recycling scheme for rare earths. Relevant stakeholders are recycling companies, manufacturers of finished goods, producers of semi-finished goods, research institutions, public authorities and politicians. Similar national networks already exist. One example is the Dutch Materials Innovation Institute M2i which is a public-private partnership between industry, knowledge institutes and the government of the Netherlands (M2i 2009).

Öko-Institut therefore proposes that a European Round Table should be set up, which brings together all relevant stakeholders from science, circular economy and companies contributing to the value-added chain of products containing rare earths. The spectrum comprises a lot of different sectors such as rare earth refining, the production of industrial products (e.g. catalysts or polishing powder), the production of specialty products (e.g. optical high-tech devices) and the production of largely disseminated consumer products (e.g. compact fluorescent lamps).

### 12.2.2 Basic research on rare earth processing

Due to the fact that there is no rare earth mining in Europe and only a very few companies are involved in rare earth refining, there is a need for enhanced basic research in Europe on rare earth processing. This knowledge might be necessary in order to build up a large-scale urban mining on rare earths and to establish more independence from the process knowledge which is currently mainly available in China and Japan. The United States is currently planning to develop a knowledge base in order to be able to process the rare earths to be mined from the re-opened mine (Mountain Pass) from 2012 onwards. The current situation in magnet production is representative for other sectors. The large scale of China's know-how and capacity in all stages of production is clearly shown by Figure 10 on page 33.

The first step to building up more know-how on rare earths in Europe would be the detailed identification of gaps of knowledge and competences in Europe related to rare earth processing. As a further step Öko-Institut proposes the creation of chemical chairs which carry out basic research on rare earths and their sustainable management.

### 12.2.3 European material flow analysis

The key aim of a European material flow analysis is to close significant data gaps and to gain broader knowledge on the material flows in Europe related to rare earths. The analyses in the previous chapters have shown that little data is available on the manifold and mostly young applications using rare earths. The global demand and supply forecasts of national research institutions such as the American USGS, the British BGS and the German BGR have to rely on the knowledge and estimates of a few experts mainly outside of Europe. The data situation of the rare earth flows should be improved within Europe and globally in the near future. This is a critical point for a sustainable economy of rare earths as more in-depth knowledge is indispensable to facilitating a successful course of action in terms of recycling and a more efficient use of rare earths.

The first step to enabling a European material flow analysis is to identify the main manufacturers and actors in the added-value chain related to rare earths. This step is linked with the build-up of a European Competence Network. The next task should be to identify the main material flows and to estimate the amount of rare earths which will be embedded in specific waste streams and available for recycling. Close co-operation with the European rare earth processing industry is regarded by Öko-Institut as essential to obtaining robust results.

### 12.2.4 Identification of initial products

Building up the recycling scheme step by step and beginning with a couple of initial products suited to recycling is highly recommended. These products should encompass, for example, a large amount of rare earths, high economic relevance, a design allowing an easy dismantling or a high concentration of the rare earth in the waste stream. The material flow analysis will provide a more detailed picture of the rare earth material flows in products and waste streams.

Based on current knowledge, potential initial waste streams could arise on the pre-consumer level (waste arising during manufacturing) from the magnet production, the lighting industry, the upstream rare earth processing industry, the industry using polishing powder and the production of IT-devices and electronics.

In quantitative terms, the post-consumer waste will be much more relevant. The following products might prove to be appropriate initial products for a new recycling scheme when the end of their life cycle is reached: magnets from electric motors and generators (arising in wind power plants, hybrid and electric vehicles, hard disks and e-bikes), lamps (fluorescent lamps), displays (plasma display and LCD) and possibly automotive catalysts. Spent industrial catalysts are also a promising candidate.

### 12.2.5 Development of collection and pre-treatment schemes

Based on knowledge gathered from the material flow analysis and the selection of initial products, the next step will be to design a collection and pre-treatment scheme.

The treatment of many wastes which contain rare earths is already regulated by existing guidelines, e.g. the WEEE Directive, the ELV Directive or the Battery Directive. However, there are not yet specific regulations for rare earths. The specific requirements for collection schemes for waste containing rare earths have to be integrated in procedures already implemented. Another aspect is the consideration of required pre-treatments. For example, magnets have to be demagnetised before transportation, or batteries have to be discharged due to safety issues.

### 12.2.6 Development of pilot plants

The next step is to design pilot plants needed to learn more about the complex recycling processes. This step also comprises research activities on the specific recycling procedures. In most cases, it will be necessary to set up large-scale R&D projects as rare earth recycling often requires high-technology based on complex chemical processes and sophisticated equipments. Some ongoing or past R&D projects are described in Chapter 11. The overview shows the high complexity of most of the project tasks.

### 12.2.7 Financial issues

The investment in recycling plants bears a high risk for investors, as outlined below:

- Most of the recycling plants will require a high long-term investment due to the required complex technologies.
- There is a large number of mining projects with uncertainty about their realisation (see the overview provided in Table 4-3 on page 22). If a high number of projects were

realised, it could not be excluded that REE prices will decrease again in the medium to long term, thus depriving recycling of its economic basis.

- Generally, there is high uncertainty about the future price developments. Reliable data on the demand and the supply situation are scarce, the rare earth stocks of companies and nations are unknown and speculations on rare earths prices might cause turbulences on the trade markets.

Therefore, it should be analysed whether the European Investment Bank (EIB) could reduce financial risks for investments in recycling.

An example of financial instruments outside of Europe are programmes from the US Department of Energy which support the production of clean energy components and new vehicle technologies by providing loan guarantees, loans or tax credits (DOE 2010). The Japanese administrative institution JOGMEC promotes a stable supply of metal resources, providing funding for research and field survey, loan guarantees and financial assistance to mining projects, maintaining stockpiles and disseminating information on mineral availability issues (DOE 2010).

### 12.2.8 Legal framework

A recycling scheme of rare earths not only requires appropriate logistical and technical requirements but also an appropriate legal framework.

The first task of this step will be a screening in order to identify the sectors where the collection and treatment is already regulated and sectors where no regulation takes place, e.g. wind turbines.

The next step will be to adapt the legal EU framework in order to optimise post-consumer rare earth recycling. In this context, specific issues might be addressed, e.g. the obligation to conduct magnet recycling from dismantled wind power plants or the prevention of exports of valuable electronic scrap and catalysts to developing countries where no recycling of speciality metals takes place (compare Öko-Institut & Eurometaux 2010). Öko-Institut further proposes verification of whether the Ecodesign Directive (2009) and related regulations should be adapted in order to support the dismantling and recycling of rare earth components from energy-using products. Another issue which should be discussed for rare earth components in electronic devices and automotive applications are the overall recycling quotas which are required by the WEEE Directive, the ELV Directive and the Battery Directive. These compulsory quotas do not consider the ecological relevance of the recycled substances. Hence, the WEEE Directive and ELV Directive mainly support the recycling of the basic materials but not the recycling of scarce and precious metals which have a high ecological relevance but only contribute a low share in terms of volume. The rare earth recycling should be addressed by specific requirements, e.g. the obligation for dismantling of selected rare earth containing components.

Concerning the ELV Directive, Öko-Institut proposes the introduction of the obligation to dismantle the electric motors of hybrid electric and electric vehicles prior to the shredder. A more in-depth analysis (material flow analysis) should verify whether an obligatory dismantling of further smaller components would be justified.

### 12.2.9 Large scale implementation

The last step is the large scale implementation of the developed recycling schemes for the selected initial products. This step not only comprises the beginning of the rare-earth specific collection, pre-treatment, and recycling (refining plants in industrial scale) but also the monitoring of the performance, its optimisation and the outlook for widening the existing recycling scheme. To enable broader dissemination, the export of recycling technologies and the development of a wider product range might be considered.

***Conclusion on the development of a recycling scheme***

*Öko-Institut proposes the development of a recycling scheme based on the following steps prior to a large scale implementation:*

- *A **European Competence Network on Rare Earths** with all relevant stakeholders such as recyclers, manufacturers, public authorities, politicians and researchers is seen as essential to successful implementation.*
- ***Basic research** is necessary, as only a few companies in Europe are involved in rare earth refining and processing at the beginning of the added-value chain.*
- *A **European material flow analysis** (MFA) is necessary in order to identify the main material flows and waste streams and the main manufacturers and actors in the added-value chain. Currently, national research institutions have to rely on knowledge and estimates from a few experts outside of Europe.*
- *The next step is to **identify initial waste streams** on the pre-consumer and post-consumer level, e.g. waste from the magnet and lighting industry, neodymium magnets from electric motors, used lamps and displays, re-use of large magnets and recycling of spent catalysts.*
- *The collection and treatment of many relevant wastes is already regulated by the WEEE Directive, the ELV Directive and the Battery Directive. Thus, the **collection** of rare earths containing wastes has to be specified and integrated in existing collection schemes.*
- *Large-scale R&D projects can develop **pilot plants** in order to learn about the complex chemical processes and the required sophisticated equipment.*
- *Recycling plants bear **high financial risks** due to the required high investment and the high uncertainty of the future price developments of rare earths. Therefore, it should be analysed whether the European Investment Bank (EIB) could reduce financial risks for investments in recycling.*
- *A recycling scheme of rare earths not only requires appropriate logistic and technical requirements but also an appropriate **legal framework**. Hence, an important step will be to adapt the legal EU framework in order to optimise post-consumer rare earth recycling.*

## 12.3 Strategy for enabling a more efficient use of rare earth and substitution

The sectoral analysis as presented in the previous chapters has shown that the potential for an increase in the resource efficiency in the processing and the use of rare earth is quite different. It is likely that the knowledge and research on efficiency issues is not the same for all applications.

Most available information relates to magnet production and magnetic applications. The analysis showed that the traditional production technologies usually have high material losses whereas newer sinter technologies have much better material efficiencies. The high prices and the expected shortages of the minor elements dysprosium and terbium lead to some research activities aimed at achieving a similar performance with less specific input of these very scarce elements. This example shows that the research into efficiency issues in this context is in early stages. This is not surprising as the applications themselves are mostly very young. In the past, the major aim has been to develop workable applications. Now, the next phase, which focuses on improvements and high efficiency rates, is beginning.

The expected supply shortages even lead to serious considerations of how scarce rare earths can be substituted. According to the in-depth analysis presented in Chapter 10, alternatives seem to be feasible in some applications, whereas other sectors do not offer quick solutions. In most cases, rare earths cannot just be substituted by another element or another compound. Instead, the whole technical design of machines and applications has to be changed. For example, the alternative to an electric motor containing a neodymium magnet is an electric motor with a different mode of operation and a distinct design, which has specific advantages as well as disadvantages.

The screening of the different applications (see Chapter 10) showed that further R&D is necessary to develop feasible technologies for rare earth substitution in the field of green technology and to achieve higher material efficiencies.

The available information was the best for neodymium magnet applications such as wind turbines, electric vehicles, and hybrid vehicles and the Ni-MH batteries. The analysis showed that in principle alternatives are available. Nevertheless, intensive research is necessary to develop these alternative products in terms of high efficiencies, economic competitiveness and reliability. Examples are alternative electric motor types, operating either with traditional techniques which should be further improved or younger motor designs which need further research to reach the technical maturity for wider use. Another example is wind power. Here, gearless wind turbines using neodymium magnets still provide the smaller share of new installations. But a higher reliability is expected in large-size plants, particularly in off-shore plants. The main conclusion on these competing technologies is not to focus exclusively on the rare earth technologies but to work simultaneously on increasing the reliability of the traditional systems with gears and on improving the research of next generation technologies like high-temperature superconductors (HTS).

The analysis of the green technologies such as energy efficient lighting and catalysts showed in the first place that no fast solutions seem to be feasible without the use of rare earths. There are almost no options for alternative techniques which operate without rare earths and have an equal performance and economical competitiveness. Intensive research in these fields is highly recommended.

Another aspect to be considered in the improvement of efficiency is the future role of nanotechnology. The application of nano-sized rare earth compounds are being considered in green technologies such as magnets, batteries, fuel cells, $H_2$-storage and catalysts. The principal aims, the improvement of energy efficiency or material efficiency, is desirable. In order to avoid negative secondary effects, Öko-Institut proposes the carrying out of a corresponding risk assessment.

## 12.4 International aspects

Besides activities within the EU which aim to promote the recycling and the efficient processing of rare earths and to improve research on alternatives for substitution, the EU faces a tremendous task in terms of action on the international level. Even if the recycling of rare earths (for example) succeeds in the medium term in the EU (this would be a real success and progress), the global demand for primary rare earths will increase up to 2020 and beyond, driven by many applications in the field of green technologies.

The development of a sustainable rare earth supply for Europe concerning environmental, social and security aspects requires solid international co-operation. Important partners for the EU to face this challenge are predominantly China, and Japan and the United States.

In the next sub-chapters, selected potential international activities of the EU proposed by Öko-Institut are presented.

### 12.4.1 Co-operation with China on sustainable rare earth mining

Despite different new mining projects in other countries like USA, Australia etc., China will remain the world's largest producer of primary rare earths for the next decade at least. China's authorities are well aware that China is facing many challenges with regard to its rare earth mining and processing industry, which require a lot of investments, human resources and capacity building. Having examined the official Chinese government plans for the rare earth industry for the next years, this conclusion is well-founded and clear. Europe has a well-regarded knowledge and technology base and much experience in the field of environmental protection (e.g. decontamination of soils, landfills, mining areas, groundwater protection etc.) which should be offered to China to enable a fruitful and fair co-operation between the EU and PR China in the field of rare earths. The idea is to offer China a partnership: an exemplary re-cultivation of a large rare earth mining site in China on the one hand and an export of a certain amount rare earth compounds extracted and processed from this mining site to the EU on the other hand.

Such an EU-Chinese partnership on rare earth mining could include the following aspects:

- Signing of an official large framework agreement between the EC and the Chinese government,
- Installation of a common expert round table to define and select the first common project in practice: selection of an appropriate rare earth mining and processing site,
- Line-up and schedule for common activities, e.g. the enhancement of recovery rates for rare earths (mining and processing), reduction of environmental pressures from former mining activities (remediation of contaminated sites); assessment whether a second treatment of tailings (extraction of remained rare earths in the tailings) could be promising, reduction of environmental pressures of the current and future mining, concentration and processing activities, etc.,
- Definition of the practical steps in detail: negotiations about the contribution of European experts, institutions and companies,
- Agreement about the co-funding of investments by the EC,
- Agreement about the amount of rare earth exports to the EU,
- Outlook for further EU-Chinese projects within the partnership on rare earths.

The basic idea is to support China, which has supplied the world economy with rare earths for many years, to improve its rare earth industry in facing the challenges of the years ahead relating to the development of a sustainable rare earth economy.

### 12.4.2 Promotion of environmentally-friendly mining

The analysis of the environmental impacts from rare earths mining and processing as presented in Chapter 7 shows the high environmental burdens of mines which are not equipped with adequate environmental techniques. The high pressure on the opening of new mines by the steeply increasing demand raises the concern that new mines outside of China could be opened which do not keep minimum standards.

At the same time, the comparably young sector of rare earth mining and processing provides an opportunity to build up the new mining activities based on the experience of decades of mining of other metals. In these decades, environmental technologies have been developed after experiencing environmental hazards and health impacts. Today, these environmental technologies are available and should be strongly applied. An additional opportunity is provided by the fact that all future mines need completely new approvals; there is no reason for weakening environmental standards as is often practiced for existing installations.

As Europe uses a high share of rare earth in green technologies, it should consistently promote and support environmentally-friendly mining by means of its political instruments and its diplomacy. Chapter 4.3 provides some figures on the economical contribution of the mining to the added-value chain. It shows that the financial contribution from mining and beneficiation is smaller than the contribution from further processing. This implies that higher costs of an environmentally sound mining will not lead to significant price increases of rare earth compounds. This implies that higher costs of an environmentally sound mining will not lead to relevant price increases of rare earth compounds. When considering further that rare earths are usually found in very low concentration in final products, the consumer prices will probably not be seriously affected by higher costs resulting from environmentally sound mining.

During the last decade, manifold initiatives aiming at a sustainable mining have been developed. In the political arena and in industry there has also been increasing interest in the certification of sustainable raw materials (Manhart 2010). It should be discussed how rare earth mining can be integrated in existing schemes or whether an additional initiative specifically promoting "green and social rare earth mining" might be helpful. In order to give a picture of the wide range of approaches, selected initiatives on sustainable mining are summarised below (BGR 2007):

- The German Federal Institute for Geosciences and Natural Resources (BGR) developed in cooperation with authorities in Rwanda and Democratic Republic of Congo pilot projects on certified trading chains on tin, tantalum, tungsten, gold and coltan (BGR 2010b).
- The German Federal Institute for Geosciences and Natural Resources (BGR) developed an analytical fingerprint (AFP) which is able to determine the origin of a specific ore. The basic principle is that each deposit holds a specific "fingerprint" which can be detected in the laboratory not only for concentrates but also for refined products. BGR developed the AFP for tantalum (coltan) concentrates (BGR 2010b). There are further AFP activities for gold, platinum group metals, copper and cobalt (BGR 2007, BGR 2010b, Perelygin et al 2008).
- The Kimberley process – a co-operation of 71 nations – resulted in a certification system for diamonds and the implementation of a related EU directive. The major aim is to ban imports of diamonds whose revenues are used to finance civil wars.
- The International Council on Mining and Metals (ICMM) established in 2001 comprises 18 mining and metal companies as well as 30 mining associations and global commodity associations. Its aim is the sustainable development in the mining sector.
- The International Cyanide Management Code (ICMI) is an initiative for the certification of the gold mining industry with the aim of an environmentally sound handling of cyanide. It holds 28 members which covered around a third of the industrial gold production in 2006.

- The Green Lead project with co-operation from UNEP, national authorities and mining industries aims at the certification of lead-acid batteries which meet criteria concerning environment, health protection, work safety and social responsibility.
- The Initiative for Responsible Mining Assurance (IRMA) is a multi-sector effort, launched in Vancouver, Canada, in June 2006, to develop and establish a voluntary system to independently verify compliance with environmental, human rights and social standards for mining operations. Its target is mainly the mining for jewellery manufacturing.
- There are numerous initiatives focused on small-scale mining of diamond, gold and platinum.

Today's mining companies could be interested in a certification scheme or similar co-operations as a large number of mining projects are being planned. The worst case would be that technologically advanced mines would have to close again when other mining operators start to supply cheaper "dirty" rare earths. Therefore, the promotion of environmental sound mining is an international issue of tremendous urgency. One component of a certification scheme could be the analytical fingerprint which can be used to identify the origin of minerals if other control mechanisms prove to be insufficient.

### 12.4.3 Supporting sustainable development in Greenland

One selected example of environmental concern is the intended joint mining of rare earths and uranium from the Kvanefjeld deposit in Greenland which was described in Chapter 7.4.4. The prefeasibility study formerly launched by Danish authorities and the current project scheme which envisions the inlet of radioactive and toxic tailings in a natural lake with connection to sea water raises the concern of potential high environmental hazards concerning the lake, its surroundings and maritime waters, even if waste water treatment technologies are installed.

At the same time, the deposit contains high shares of the most scarce heavy rare earth elements (HREE); high profits are expected. Therefore, Öko-Institut highly recommends that Europe appeals clearly to the Greenland authorities to act carefully and responsibly. Furthermore, the co-operation agreement between the government of Greenland and the European Environmental Agency (EEA) signed in November 2010 should support a responsible course of action within this project.

***Conclusion on recommended international activities***

*Concerning international activities, Öko-Institut proposes three selected activities:*

- *Öko-Institut proposes an **EU-China co-operation** on sustainable rare earth mining and processing which could be designed as a large-size co-operation which focuses on the sustainable mining of rare earth at one specific site with the aim of optimising the efficiency, the environmental performance, remediation of contaminated sites and a potential recovery of rare earths from old tailings. The EC could supply co-funding and expertise, and China would agree on a defined amount of rare earth supply.*
- *Green technologies call for "green metals", and Europe should support sustainable mining. There are manifold **initiatives for sustainable mining** and certification schemes addressing social and environmental aspects. Today's mining companies are showing increasing interest in certification schemes or similar co-operations with EU participation in order to highlight their environmental efforts.*
- *The high pressure on the opening of new mines brought about by the steeply increasing demand raises the concern that new mines outside of China could be opened which do not keep minimum standards. One case in point could be the **Kvanefjeld deposit in Greenland** where the residues from the ore concentration (tailings) shall be stored in a natural lake with connection to the sea. The EU and the European Environmental Agency (EEA) should appeal clearly the Greenland authorities to act carefully and responsibly.*

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# Recycling as a Strategy against Rare Earth Element Criticality: A Systemic Evaluation of the Potential Yield of NdFeB Magnet Recycling

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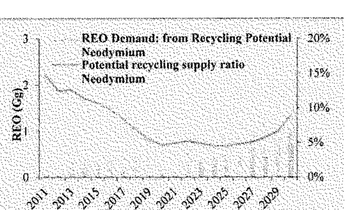
*Supporting Information*

ABSTRACT: End-of-life recycling is promoted by OECD countries as a promising strategy in the current global supply crisis surrounding rare earth elements (REEs) so that dependence on China, the dominant supplier, can be decreased. So far the feasibility and potential yield of REE recycling has not been systematically evaluated. This paper estimates the annual waste flows of neodymium and dysprosium from permanent magnets, the main deployment of these critical REEs, during the 2011–2030 period. The estimates focus on three key permanent magnet waste flows: wind turbines, hybrid and electric vehicles, and hard disk drives (HDDs) in personal computers (PCs). This is a good indication of the end-of-life recycling of neodymium and dysprosium *maximum potential yield*. Results show that for some time to come, waste flows from permanent magnets will remain small relative to the rapidly growing global REE demand. Policymakers therefore need to be aware that during the next decade recycling is unlikely to substantially contribute to global REE supply security. In the long term, waste flows will increase sharply and will meet a substantial part of the total demand for these metals. Future REE recycling efforts should, therefore, focus on the development of recycling technology and infrastructure.




## 1. INTRODUCTION

The rare earth elements (REE) group consists of yttrium, the lanthanides series and, in some definitions, scandium. Their unusual magnetic and optical properties make them crucial to a variety of highly technological applications. Kingsnorth's supply demand statistics indicate that "the supply and demand for individual REOs is not in balance" and that at least until 2020 it will remain so with shortages for neodymium (25%), dysprosium (23%), terbium (29%), and erbium (39%). Other REEs will be in excess.[1] The imbalance is partly caused by relatively low occurrence of certain REEs in mineral deposits versus higher occurrence of other REEs. Furthermore, with an 86% share of production in 2012[2] and various announced export quotas[1] China dominates the REE market. Fifty percent of the global REE reserves are in China.[2] With current and forecast supply shortages, and the geopolitical situation resulting from limited Chinese exports, REEs have a high "supply risk". This, along with their importance in various clean and high-tech applications, has led the EU and the U.S. to label certain REEs, such as neodymium and dysprosium, "critical" metals.[3,4] Recycling is often cited as one of the ways of reducing REE criticality.

The focus in this article is on high-performance sintered NdFeB magnets that deliver high levels of magnetic strength in relatively compact sizes. NdFeB magnets were first implemented in the 1980s and have become essential in applications crucial to the transition to a low-carbon economy. In 2008, rare earth permanent magnets (REPMs) accounted for 21% of all REE use in terms of volume and 38% in terms of value[5] and constitute the most important REE application with anticipated supply issues. At 10–15% per annum between 2010 and 2015, the highest expected growth rate of REE applications will be from NdFeBs.[6]

All NdFeB magnets contain neodymium (Nd). Sometimes terbium (Tb) is also added. Dysprosium (Dy) is introduced when it is necessary to increase the operating temperature.[7] Praseodymium (Pr) is generally added to replace neodymium at a lower cost. These are all considered "critical metals".[4] REE supply risks negatively impact the development of certain NdFeB applications, such as direct-drive wind turbine generators and high performance electric motors in hybrid electric vehicles.[8] At present NdFeB magnets cannot be substituted by other permanent magnets without some performance loss.[9] NdFeB magnets contain high concentrations of rare earths (see Table 1) from the magnets themselves.

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**Table 1. Key Assumptions in the Calculation of EOL REPMs Flows from Wind Turbines, Automotive Technology, and HDDs in PCs.**[a]

| | | automotive | | HDDs | |
|---|---|---|---|---|---|
| assumption | wind turbines | (P)HEV | EV | desktop | portable |
| percentage of sales or installed capacity that contains REPMs (%) | 2010: 10<br>2020: 22.5<br>2030: 30 | 100 | 100 | 100 | 2010: 100<br>2020: 58<br>2030: 14 |
| mass of REPM (kg) | 700 | <2008: 0.65−1.24<br>>2008: 1.02 | 1.05 | 0.0015 | 0.002 |
| composition[b] (%) | Nd: 29<br>Dy: 6 | Nd: 29<br>Dy: 9 | Nd: 29<br>Dy: 9 | Nd: 29<br>Dy: 0 | Nd: 29<br>Dy: 0 |
| lifetime[c] (years) | regular: 20<br>repowering: 12<br>incl. refurbishment: 15 | 16 | 16 | 10 | 6 |
| collection rate (%) | 100 | 100 | 100 | 50 | 50 |

[a]Refer to section B of the SI for more input data. [b]The neodymium content in the composition of the magnets is the sum of Nd and Pr. [c]HDDs: Including hibernation period.

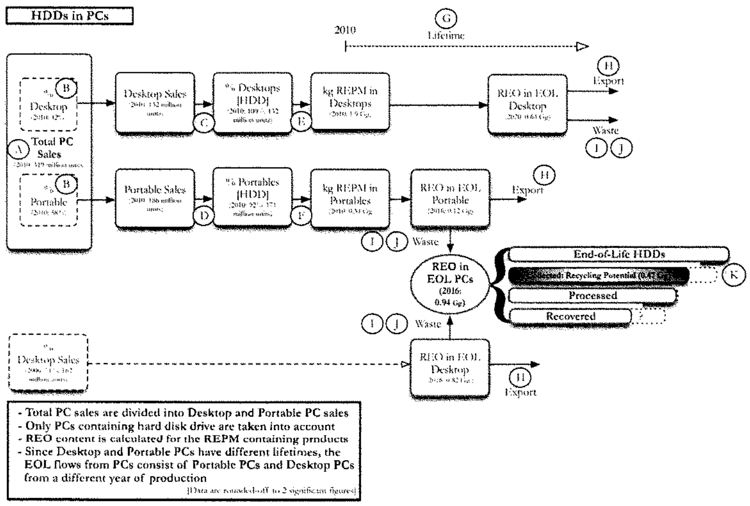


**Figure 1.** Calculation model for EOL potential of REO in REPMs in HDDs in PCs.

Their recycling is potentially technically feasible if efficient physical dismantling and separation techniques, and metallurgical separation and refining methods, are available in the future. No commercial recycling exists for rare earths derived from end-of-life (EOL) NdFeB magnets[10] nor for other rare earths derived from other EOL products.[11] Industrial recycling only exists for REE recovery from manufacturing scrap and waste.[12,13] This is mainly due to the relatively low prices of REEs in the past and the complex and dissipative use of REEs including the permanent REE magnet (REPM). There was simply no incentive in the past to develop industrial recycling technologies. Supply issues and in particular sharply rising prices for most REEs in recent years have created new REE recycling incentives, also economically.

However, REE recovery from NdFeB magnet scrap, mainly for relatively clean scrap, is being broadly investigated. Various separation and extraction technologies: hydrometallurgical, pyrometallurgical, electrochemical, and combinations of these, are being explored. For more detailed information on metallurgical recycling methods, see recent review articles.[12−14]

Recycling can potentially reduce dependence on virgin production[15] while altering the geographic distribution of REE supply. In 2007, the global in-use stocks of the rare earth elements Nd, Pr, Dy, and Tb in NdFeB magnets in computers, audio systems, wind turbines, automobiles, household appliances and MRI was estimated to be 97 Gg; four times the extraction level in that year.[16] These in-use stocks indicate opportunities for recycling in general but do not specifically quantify that potential. In the current literature there are no estimates concerning future end-of-life (EOL) REE flows.[10] Such quantification of future EOL flows is, however, the basis upon which the potential of a recycling strategy to reduce REE criticality can be assessed.

Du and Graedel estimated that in 2007 computer, wind turbine and automotive applications accounted for 66% of all NdFeB use.[16] This represents the bulk of all NdFeB use. Over 80% of the REE content in NdFeB magnets in the above-mentioned applications is in the form of neodymium and dysprosium[16] so considering these elements accounts for a substantial portion of NdFeB use. In terms of annual production data, in 2008 NdFeB magnets accounted for 76% of Nd use, 73% of Pr use, 100% of Dy use, and 11% of Tb use.[17] In this article, we estimate the future annual EOL flows and in-use stocks of neodymium and dysprosium in NdFeB magnets in wind turbines, electric motors in hybrid and electric vehicles, and hard disk drives in PCs between 2011 and 2030.

By quantifying the recycling potential, the results of this research will contribute to recycling in order to reduce REE criticality. Not only the data, but also the general trends in recycling will influence strategies on REE criticality.

## 2. METHODOLOGY

The metal life cycle consists of four principal stages or processes: extraction, fabrication and manufacturing (F&M), use, and waste management and recycling (WM&R).[15] These stages form the basis to material flows analysis (MFA). In this research, the inflow in finished products was taken as a starting point and transformed to forecast end-of-life flows that enter the WM&R stage. All forecasts were performed on two geographical scales: global and EU-27. This article mainly presents global results. Outcomes for the EU-27 are attached in the Supporting Information (SI) in sections C1 and C2. The forecast EOL flows are presented in terms of REO content ($Nd_2O_3$ and $Dy_2O_3$), which is a common form when trading rare earth elements as commodities. Here these oxides are simply referred to as neodymium (Nd) and dysprosium (Dy).

Figure 1 illustrates the EOL flow model predictions. Examples and data are given in brackets. The methodology is explained by discussing the forecast EOL hard disk drives (HDDs) from PCs. The calculation model for Wind turbines and Automotive motors is attached in the SI (Figure S1 and S2). The key assumptions are elucidated in Table 1 and section 2.3.

**2.1. Inflow in Finished Products.** The data on unit sales (automotive, HDDs in PCs) and newly installed capacity (wind turbines) comprised the main input and was based on industrial reports, sales forecasts and expert opinions.

A technological type distinction was made for automotive (plug-in hybrid electric vehicles and hybrid electric vehicles versus full electric vehicles) and HDDs (desktop versus portable). The data were then translated to neodymium and dysprosium content that enters the in-use stock.

In Figure 1, the inflow into finished products is based on a "baseline" sales forecast (A).[18] To determine the composition of the forecast waste streams, the percentage of desktop and portable PCs in the total sales (B) was extended to overall PC sales forecasts (A). EOL flows from portable and desktop PCs are calculated separately, because they have a different lifetime, rate of adoption of solid state drives (SSD), and REPM mass per unit product. The number of HDD-based desktops and portables (tablets excluded) is obtained by multiplying the forecast unit sales with the percentage of PCs that contain HDDs (C for desktops and D for portables). HDDs in other applications, such as data centers, are not included in this analysis. Multiplying the amount of HDD in desktops and portables by the REPMs mass per HDD (E for desktop, F for portable) results in the total amount of REPMs in the sold desktops and portables. Lastly, the inflow of neodymium and dysprosium into finished products is obtained by multiplying the total REPM mass by the composition (I) and converting the mass to the oxide equivalent: $Nd_2O_3$.

**2.2. End Of Life Stage.** The EOL flows in the WM&R stage were calculated on the basis of the flows into use and the lifetime of the applications. Export and reuse were also considered.

In Figure 1, the HDDs leave the in-use stock as EOL flows into the WM&R stage after a certain average lifetime (G). A part can be exported for reuse and informal recycling (H). The remainder (J) forms a waste stream of EOL desktops and portables. The maximum recycling potential is the share (K) that is collected for recycling from the waste stream of EOL flows. The collection rate is defined as the number of collected EOL HDDs from PCs, divided by the number of generated EOL flows from HDDs in PCs in that year.

**2.3. Key Assumptions.** Table 1 lists the key assumptions of this study. More input data can be found in the SI (section B).

Three scenarios were created, based on varying assumptions (SI section B4). The lower bound scenario assumed that growth would be slower both in applications (e.g., installed wind power) and REPMs in those applications (e.g., lower percentage of REPM-based turbine models). With the upper bound scenario, the opposite applied. Differences in collection rates were also accounted for. In this article the midrange scenario (i.e., baseline scenario) is presented. The lower-bound and upper-bound scenarios are attached in the SI (section B4 and C3).

The historic and forecast data of installed wind capacity were based on Global Wind Energy Council[19,20] and European Wind Energy Association reports.[21,22] The automotive forecast was mainly based on two reports: one by the global marketing information services company J.D. Power[23] and one by the global management consulting firm McKinsey & Company.[24]

In all three cases, there is a degree of uncertainty about how the industry will develop. The development of wind energy is embedded in a complex interplay of policy making, technological development, the economic climate and global events that influence public opinion (e.g., the Fukushima disaster). Similar factors shape the development of hybrid and electric vehicles, the main difference being the role of consumers, since vehicles are typical consumer products. The PC market is characterized by rapid and unforeseen developments (e.g., the success of tablets and solid state drives), as is typical in much of consumer electronics.

Uncertainties in technological development were analyzed on the basis of research reports, news articles, and expert opinion. Some of the issues related to the use of REPM magnets in wind energy technology are: certain producers, notably the German Enercon, produce non-REPM-based direct drive generators without performance loss; REPM-based direct drive generators are viewed as a new technology, which brings risks to investors,[25] engineers are reducing the need for dysprosium by using air-cooling;[26] finally, current and forecast REE supply issues bring risks for the manufacturing and maintenance of REPM-based wind turbine generators thus creating opportunities for other technologies. In the automotive industry, there are no commercially available substitutes for REPM-based electric motors that do not have significant performance losses. Research into non-REPM-based induction motors has however been announced and some success has been claimed.[27] In the HDD market, the influence of tablets on PC sales and the rate of implementation of the SSD in PCs are the main uncertainties. However, SSDs are expected to remain a more expensive storage medium. The impact of SSDs on HDD demand is, therefore, dependent on the future storage capacity requirements of PCs.[28] On PC sales, a lower bound scenario was performed (section B4 and C3 of SI).

The exact composition of NdFeB magnets differs per application. There is no clear composition data uniformity. The low neodymium estimate is 20%.[16] Estimates made by Shin Etsu, Great Western Minerals Group, Technology Metals Research and Avalon Rare Metals range from 28% to 31%.[29] It should be noted that in most applications, the NdFeB magnet also contains certain amounts of praseodymium (Pr), a cost-effective neodymium replacement with no significant performance penalties. The extent to which praseodymium is added is strongly influenced by price-developments and differs per year and producer. In our calculations, the Nd figures are the sum of Nd and Pr as listed in Table 1. We assumed the neodymium content to be 29%. The dysprosium content in NdFeBs per application is presented in Table 1.[30]

The collection rate is accounted for in the quantification of the recycling potential. For current rates, published statistics were our main source. For future collection rates we have taken the maximum feasible collection rate to obtain a maximum recycling potential. We have based our estimates on policy targets and educated guesses in line with the criteria influencing collection. One important criterion was the producer−user relationship, where a business-to-business relationship proved advantageous for collection rates.[10] The collection rates of industrial goods tend to be higher in business-to-business relationships, because of stakeholder awareness, limited ownership changes, use location, and economic recycling incentives.[11]

**2.4. Metrics and Terminology.** To gauge the significance of the forecast EOL quantities as a supply source they need to be related to new metal production. The recycling input rate[11] provides such a gauge and also includes factors such as new scrap recycling not included in this research, while "potential recycling supply ratio" (PRSR) is used here as an indication of the old scrap recycling potential: dividing collected EOL quantities in year $x$ by the inflow of metal for newly finished products in that same year $x$:

$$\text{potential recycling supply ratio (PRSR)} = \frac{\text{REO in collected EOL flows}}{\text{REO demand}}$$

The PRSR defined here is the "static" potential recycling ratio.[31] It compares the collected EOL products or scrap that is ready for recycling with the total production or demand for such metal in the same year. By contrast, a dynamic PRSR would compare the collected EOL products or scrap in a certain year to the total demand in the year of manufacturing of the EOL products. When there is more than one type of product and with very different life cycles – like a combination of REPM scrap from wind turbines, automotive motors and computer HDDs, it becomes impossible to use "dynamic" PRSR to quantify the total recycling ratio for a specific metal. When predicting the present and future potential recycling rate, "static" PRSR gives a better quantification of how important the recycled materials are compared to total demand at any time. Since it gives a more direct comparison for market demand than the inherent source of EOL products, static PRSR is used in this article to quantify the recycling potential.

"REO demand" is the term to indicate the REO content of newly finished product inflow. When REO content in collected EOL flows becomes input in finished products, there will be efficiency losses during the new metal production stage. Ideally, these losses are accounted for in the PRSR. However, due to an absence of accurate data on this process, these losses are not included. If they were included, either a lower amount of EOL flows would remain after new metal production, or a higher 'REO demand' would be needed as new metal production input. Either way, the actual ratio lowers proportional to the efficiency ratio of the new metal production process. This ratio is further lowered by losses in the preprocessing and end-processing of EOL products. These losses are not included as the practice of preprocessing and end-processing is still in an early stage of development and efficiencies of possible processes vary widely. When the EOL product collection rate increases, the PRSR increases proportionally.

When interpreting the data, it should be remembered that the PRSR will be lower, proportional to efficiency losses in new metal production and preprocessing and end-processing in the end-of-life stage.

## 3. RESULTS

Figure 2 shows that in the short term (<2015), the global recycling of 0.5 Gg neodymium from EOL wind turbine generators, hybrid and electric vehicles, and HDDs in PCs potentially covers 11−15% of the total REO demand. For dysprosium this is 0% (Figure 3), as EOL HDDs do not contain dysprosium and REPMs from wind turbines and hybrid or electric vehicles will not yet have entered waste streams. In the midterm (~2020), the sharp increase in the REO demand results in a lower PRSR: five percent for neodymium and around one percent for dysprosium. The forecast for total quantities in 2020 are 0.45 Gg for neodymium and 0.011 Gg for

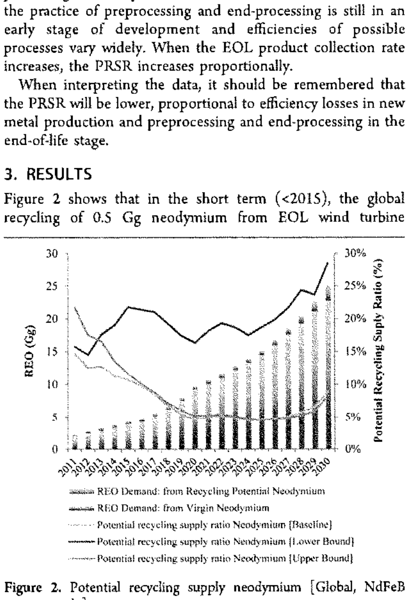


**Figure 2.** Potential recycling supply neodymium [Global, NdFeB magnets only].



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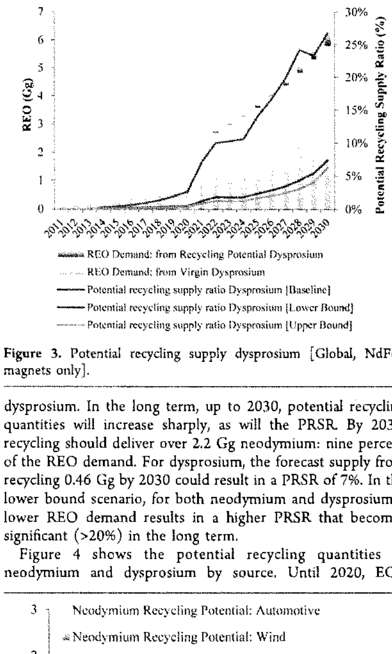


**Figure 3.** Potential recycling supply dysprosium [Global, NdFeB magnets only].

dysprosium. In the long term, up to 2030, potential recycling quantities will increase sharply, as will the PRSR. By 2030, recycling should deliver over 2.2 Gg neodymium: nine percent of the REO demand. For dysprosium, the forecast supply from recycling 0.46 Gg by 2030 could result in a PRSR of 7%. In the lower bound scenario, for both neodymium and dysprosium a lower REO demand results in a higher PRSR that becomes significant (>20%) in the long term.

Figure 4 shows the potential recycling quantities of neodymium and dysprosium by source. Until 2020, EOL

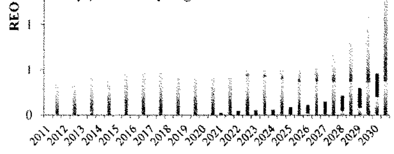


**Figure 4.** Global potential recycling supply neodymium and dysprosium by source [wind, automotive and PCs, NdFeB magnets only].

HDDs will be the main source for the recycling of neodymium. Due to their long lifetimes, it will not be until the late 2020s that wind turbine and hybrid vehicle recycling will slowly become a dominant source. Dysprosium will follow a similar trend.

Table 2 lists the data behind Figures 2–4. It adds data on how the potential recycling quantities per source relate to the REO demand of each source. It is clear that with neodymium the forecast amounts of EOL HDDs have the potential to supply around 50% of the required REO for new HDDs. This might create incentives for individual HDD manufacturers to collect and recycle EOL HDDs.

The analyses were also performed at EU-27 level. Recycling potential is especially important to the EU-27, as it is a region that typically consumes a large volume of products containing REEs but has few natural resources. Figure 5 shows the potential recycling results for neodymium in the EU-27, in comparison to the global scale. More EU-27 results are provided in Section C1 and C2 of the SI.

The potential recycling quantities follow a similar trend within the EU-27 to a global level. In the long term (2030), the potential recycling supply ratios should be slightly lower. Until 2020, the global REO demand will rise at a higher rate than within the EU-27, which results in a slightly higher EU-27 recycling supply ratio. This difference can be explained by the influence of the rapidly growing developing countries largely outside the EU-27.

With neodymium (see Figure 6), the in-use stock is steadily increasing. The constant upward trend indicates a further increase in EOL flows after 2030. A similar trend is found for dysprosium (Figure S11 of the SI). Until 2015, HDDs comprise a dominant part of the neodymium stock. From then onward wind turbines and the automotive sector become dominant categories.

The estimated global in-use stock of 11 Gg neodymium in 2011 is significantly lower than the estimated amount in previous research of 41 Gg neodymium (equivalent to 48 Gg neodymium-oxide) for "wind turbines", "automobiles", and "computers" in 2007.[16] Whereas Du and Graedel took Chinese production data on NdFeB magnets as their basis for calculations, we took the actual shipment and placement of applications as our premise.

In theory, the results of both approaches are expected to match. Differences within the product category definitions could partially account for the difference in results.

Quite how one can account for the difference remains unclear. The results therefore require detailed discussion. The modeling in this research was kept relatively straightforward and the input data fully transparent, thus making the results as a whole transparent to facilitate such discussion.

## 4. DISCUSSION

If climate change is to be tackled, society will need to switch in the next three to four decades to a carbon-lean energy system. Rare Earth Elements play a crucial part in this transition as they are vital to many high tech and especially green tech products and services including wind turbines, hybrid and fully electric vehicles and highly efficient lighting systems including LED. The supply of these materials is constrained by several factors. Although new operations are starting up worldwide, both the mining and the processing of these materials is still dominated by one single country: China. Furthermore new mining and processing operations are technically difficult, capital-intensive and commercially risky to initiate, and finally, REE recycling from postconsumer waste is still negligible. Increasing the postconsumer waste recycling rate is often advanced as one of the ways to reduce dependence on virgin production.

This study has explored EOL NdFeB magnet recycling in a bid to reduce the criticality of rare earth elements. The focus was on neodymium and dysprosium recycling from NdFeBs in three main REE applications: wind turbines, hybrid and electric vehicles, and HDDs in PCs.

**Table 2. Neodymium and Dysprosium Recycling Potential for REPM Magnets from Wind Turbines, Automotive, and HDDs (Global)**

| | 2011 | | 2015 | | 2020 | | 2025 | | 2030 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | quantity (Gg) | PRSR[a] (%) | quantity (Gg) | PRSR[a] (%) | quantity (Gg) | PRSR[a] (%) | quantity (Gg) | PRSR[a] (%) | quantity (Gg) | PRSR[a] (%) |
| wind (Nd) | 0 | 0 | 0 | 0 | 0 | 0 | 0.08 | 1 | 1.0 | 10 |
| wind (Dy) | 0 | 0 | 0 | 0 | 0 | 0 | 0.02 | 1 | 0.21 | 10 |
| automotive (Nd) | 0 | 0 | 0 | 0 | 0.04 | 1 | 0.23 | 3 | 0.83 | 6 |
| automotive (Dy) | 0 | 0 | 0 | 0 | 0.01 | 1 | 0.07 | 3 | 0.25 | 6 |
| HDDs (Nd) | 0.34 | 43 | 0.47 | 64 | 0.41 | 54 | 0.38 | 40 | 0.38 | 36 |
| total (Nd) | 0.34 | 15 | 0.47 | 11 | 0.45 | 5 | 0.69 | 4 | 2.2 | 9 |
| total (Dy) | 0 | 0 | 0 | 0 | 0.01 | 0 | 0.09 | 2 | 0.46 | 7 |

[a]PRSR= Potential recycling supply ratio (as defined in section 2.4).

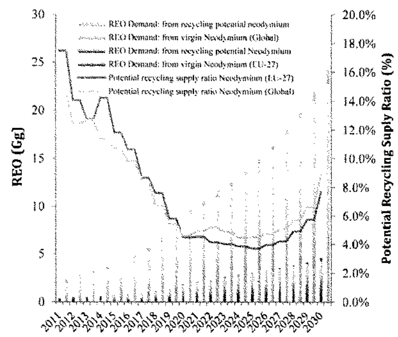


**Figure 5.** Potential Recycling Supply neodymium [global and EU-27, NdFeB magnets only].

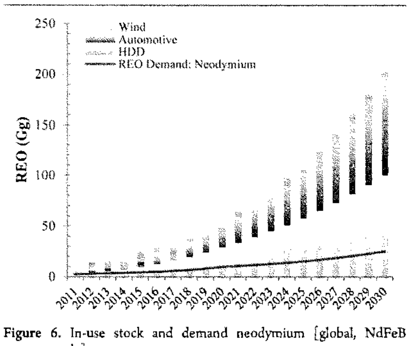


**Figure 6.** In-use stock and demand neodymium [global, NdFeB magnets only].

With the sharp increase in REO demand for emerging technologies, the potential recycling supply ratio for neodymium will drop to five percent toward the year 2020, whereas for dysprosium it will remain zero percent. Sharply increasing the potential recycling quantities and high in-use stocks will, in line with conclusions from previous research,[15,16] bring significant recycling potential in the long term (2030).

Results indicate that worldwide the recycling potential for the coming decades is limited when compared to the demand for finished products. Because of the low waste volumes, the advantages in economies of scale of recycling are unlikely to be achieved. The absence of mature processes for preprocessing and end-processing further reduces the current recycling potential. However, the forecast EOL volumes do offer opportunities for developing recycling technology through pilot projects. Such pilot projects will, in the long term, help to build a recycling industry for handling larger volumes.

Since the beginning of this decade, global governments and industries, in particular in Europe, Japan, and the U.S.A., have started to invest in developing REE recycling technology from the whole value chain perspective by increasing collection rate, improving physical separation efficiency, developing efficient metallurgical processes for recovery and refining REEs from potential secondary REE resources. The NdFeB magnet is one of the most important secondary resources for neodymium and the sole recycling source for dysprosium. Promising techniques are being developed, such as the successful powdering of NdFeB through hydrogen separation at room temperature and atmospheric pressure (decrepitation) to subsequently produce new sintered NdFeB magnets.[32]

For consumer products, one recycling challenge is the physical dismantling and up-concentration of small NdFeB magnets in diversified scrap. REPM in wind turbines and EV/HEV vehicles is much more easily dismantled and physically up-concentrated, and even reuse is possible after refurbishing. In general, efficient metallurgical separation and refining processes remain the main challenges. It is estimated that approximately five to ten years is required to set up a recycling practice.[10] Policy makers should therefore also explore other REE criticality reduction strategies, such as substitution and supply route diversification.

The presented results indicate a general trend that is typical for the emerging technologies metal market: sharply increasing demand and an EOL time-lag. Recycling will only become a significant lever after the time-lag and demand has stabilized. That does not, however, imply that there is no recycling potential for certain specific applications, actors (e.g., HDD producers) or regions (e.g., EU-27). In the latter case, it can decrease dependency on virgin materials or even create a surplus, given the fact that the REO content in collected EOL flows and the REO demand are not evenly distributed in geographic terms.

In this research the recycling potential was not calculated for audio systems, although they represented 24% of the in-use stock of Nd and Dy in NdFeB magnets in 2007.[16] Adding audio systems to the calculations could increase the forecast EOL flow totals but would not alter the main time-lagged EOL flow trends that the scenarios show.

Comparing the amount of REO in EOL flows to the demand for REO indicates the potential significance of recycling. Two important factors were excluded: first that REO that can be retrieved from EOL flows will be lower due to losses during the preprocessing and end-processing of old scrap. Second, there will be losses when manufacturing products containing REE. These losses were not included in our future REO demand calculations, so that the potential recycled material contribution to the total supply will be lower than estimated in this study. This further supports the main conclusion of this research concerning the limitations of recycling as an REE criticality reduction strategy.

We have presumed that growth in demand will not be influenced by supply constraints. However, supply constraints are forecast and could reduce demand when substitute materials and technologies are developed. Examples are NdFeB-free electric motors for use in cars and wind turbines with air-cooling, which reduce operating temperature and thus the need to add dysprosium to the NdFeB magnet.

Simply having a recycling strategy is unlikely to solve rare earth element supply chain issues. Billion dollar industries that rely on relatively small REE industry for primary supplies, depend just as much on subsequent steps in the REE supply chain. This is especially important since one country (China) dominates all subsequent steps in the REPM production chain.[6] Therefore, a recycling strategy should preferably be placed in the broader strategy of developing an industry in the smelting and refining of REOs, the fabrication of alloys and powders and the manufacturing REPMs.

Further research should focus on extending the forecast EOL flows to encompass more applications and on fine-tuning key assumptions through expert discussion and detailed industrial research. In our research, different key assumptions concerning lower-bound and upper-bound scenarios did not lead to divergent conclusions. Furthermore, in a more regional and dynamic mass flow analysis the EOL flows can be compared to actual regional REO consumption, rather than to the REO content in applications shipped in and out of regions. A regional potential recycling supply ratio could then be established to provide more specific data for policy makers. Finally, an option that deserves more attention is the possibility of storing certain EOL products with NdFeB magnets for future recycling when total volumes, REO prices and the state of recycling technology improves.

## ASSOCIATED CONTENT

### Supporting Information

Additional output graphs, methodology details, and input data for this article. This material is available free of charge via the Internet at http://pubs.acs.org

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### Notes

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RESEARCH AND ANALYSIS

# What Do We Know About Metal Recycling Rates?

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**Keywords:**

end-of-life recycling rate (EOL-RR)
industrial ecology
old scrap ratio (OSR)
recycled content (RC)
recycling input rate (RIR)
recycling metrics

Supporting information is available on the *JIE* Web site

## Summary

The recycling of metals is widely viewed as a fruitful sustainability strategy, but little information is available on the degree to which recycling is actually taking place. This article provides an overview on the current knowledge of recycling rates for 60 metals. We propose various recycling metrics, discuss relevant aspects of recycling processes, and present current estimates on global end-of-life recycling rates (EOL-RR; i.e., the percentage of a metal in discards that is actually recycled), recycled content (RC), and old scrap ratios (OSRs; i.e., the share of old scrap in the total scrap flow). Because of increases in metal use over time and long metal in-use lifetimes, many RC values are low and will remain so for the foreseeable future. Because of relatively low efficiencies in the collection and processing of most discarded products, inherent limitations in recycling processes, and the fact that primary material is often relatively abundant and low-cost (which thereby keeps down the price of scrap), many EOL-RRs are very low: Only for 18 metals (silver, aluminum, gold, cobalt, chromium, copper, iron, manganese, niobium, nickel, lead, palladium, platinum, rhenium, rhodium, tin, titanium, and zinc) is the EOL-RR above 50% at present. Only for niobium, lead, and ruthenium is the RC above 50%, although 16 metals are in the 25% to 50% range. Thirteen metals have an OSR greater than 50%. These estimates may be used in considerations of whether recycling efficiencies can be improved; which metric could best encourage improved effectiveness in recycling; and an improved understanding of the dependence of recycling on economics, technology, and other factors.

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## Introduction and Scope of Study

Metals are uniquely useful materials by virtue of their fracture toughness, thermal and electrical conductivity, and performance at high temperatures, among other properties. For these reasons, they are used in a wide range of applications in areas such as machinery, energy, transportation, building and construction, information technology, and appliances. Additionally, of the various resources seeing wide use in modern technology, metals are different from other materials in that they are inherently recyclable. This means that, in theory, they can be used over and over again, which minimizes the need to mine and process virgin materials and thus saves substantial amounts of energy and water while limiting environmental degradation in the process.

Recycling data have the potential to demonstrate how efficiently metals are being reused and can thereby serve some of the following purposes:

- Determine the influence of recycling on resource sustainability
- Provide information to governments, the metals industry, metal users, and the recycling industry on recycling rates and opportunities for change
- Provide information for research on improving recycling efficiency
- Provide information for life cycle assessments
- Stimulate informed recycling policies.

This article summarizes the results of a working group of the United Nations Environment Programme's (UNEP's) International Panel for Sustainable Resource Management (Resource Panel) on metal recycling rates. We discuss definitions of recycling statistics, review recycling information, identify information gaps, and discuss the implications of our results. The goal is to summarize available information (rather than to generate new data), highlight information gaps, and fill these gaps through informed estimates.

The elements investigated are not all metals, according to the chemical meaning of metal, as metalloids[1] have been included, whereas the radioactive actinides and polonium are excluded. From the alkali metals only lithium (Li) has been included because of its use in batteries, and from the alkaline metals all but calcium have been included. Furthermore, selenium has been included because of its importance as an alloying element and semiconductor. The selected elements (called "metals" hereafter) include the following:

- Group 1: vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), nickel (Ni), niobium (Nb), molybdenum (Mo)
- Group 2: magnesium (Mg), aluminum (Al), titanium (Ti), cobalt (Co), copper (Cu), zinc (Zn), tin (Sn), lead (Pb)
- Group 3: ruthenium (Ru), rhodium (Rh), palladium (Pd), silver (Ag), osmium (Os), iridium (Ir), platinum (Pt), gold (Au)
- Group 4: lithium (Li), beryllium (Be), boron (B), scandium (Sc), gallium (Ga), germanium (Ge), arsenic (As), selenium (Se), strontium (Sr), yttrium (Y), zirconium (Zr), cadmium (Cd), indium (In), antimony (Sb), tellurium (Te), barium (Ba), lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu), hafnium (Hf), tantalum (Ta), tungsten (W), rhenium (Re), mercury (Hg), thallium (Tl), bismuth (Bi).

For our purpose, the metals are designated as ferrous metals (Group 1), nonferrous metals (Group 2), precious metals (Group 3), and specialty metals (Group 4). The principal metals in each of these groupings are more or less according to popular use, but the less abundant or less widely used elements are not necessarily readily categorized (e.g., tellurium [Te] could equally well have been included in the ferrous metals).

Metals are predominantly used in alloy form, but not always, and recycling information that specifies the form of the metal is not commonly available. Thus, all information herein refers to the aggregate of the many forms of the metal in question (but as *metal*, rather than generally in a nonmetallic form such as a sulfate or oxide, e.g., barium sulfate [$BaSO_4$], titanium dioxide

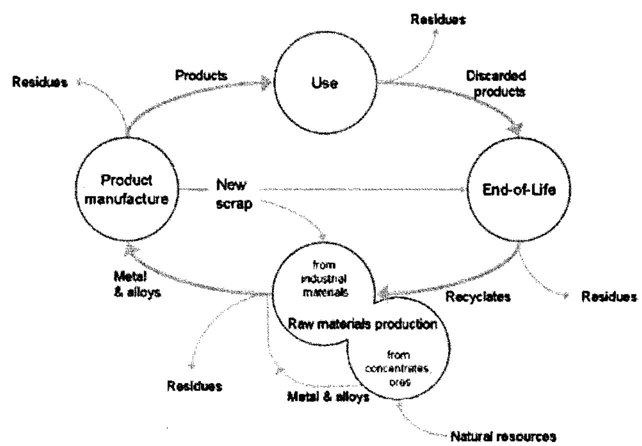


**Figure 1** The life cycle of a metal, consisting of production, product manufacture, use, and end of life. The loss of residues at each stage and the reuse of scrap are indicated. (After Meskers 2008.)

[$TiO_2$]). This distinction is addressed in the results where necessary.

## Metal Recycling Considerations

### *Metal Life Cycle*

Figure 1 illustrates a simplified metal and product life cycle. The cycle is initiated by choices in product design: which materials are going to be used, how they will be joined, and which processes are used for manufacturing. Choices made during design have a lasting effect on material and product life cycles. They drive the demand for specific metals and influence the effectiveness of the recycling chain during end of life (EOL). The finished product enters the use phase and becomes part of the in-use stock of metals. When a product is discarded, it enters the EOL phase. It is separated into different metal streams (recyclates[2] ), which have to be suitable for raw materials production to ensure that the metals can be successfully recycled. In each phase of the life cycle metal losses occur, indicated by the "residues" arrow in figure 1.

The life cycle of a metal is closed if EOL products are entering appropriate recycling chains, which leads to scrap metal in the form of recyclates displacing primary metals. The life cycle is open if EOL products neither are collected for recycling nor enter those recycling streams that are capable of recycling the particular metal efficiently. Open life cycles occur as a result of products discarded to landfills, products recycled through inappropriate technologies (e.g., the informal sector) whereby metals are not or only inefficiently recovered, and metal recycling in which the functionality (i.e., the physical and chemical properties) of the EOL metal is lost (nonfunctional or "open-loop" recycling; see below). A related distinction between open and closed material systems is made in life cycle assessment (ISO 2006), in which a material system is only considered closed when a material is recycled into the same use (Dubreuil et al. 2010).

### *Scrap Types and Types of Recycling*

The different types of recycling are related to the type of scrap and its treatment:

- Home scrap is material generated during material production or during fabrication or manufacturing that can be directly reinserted in the process that generated it.

Home scrap recycling is generally economically beneficial and easy to accomplish. It is excluded from recycling statistics and not further discussed here.

- New (or preconsumer) scrap (sometimes termed "prompt scrap") also originates from a fabrication or manufacturing process. As opposed to home scrap, it is not recycled within the same facility but rather is transferred to the scrap market. Because of its known properties, high purity, and value, its recycling is generally economically beneficial and easy to accomplish, although recycling becomes more difficult the closer one gets to finished products (e.g., rejected printed circuit boards). New scrap is typically included in recycling statistics.
- Old (or postconsumer) scrap is metal in products that have reached their EOL. Their recycling requires more effort, particularly when the metal is a small part of a complex product.
- Functional recycling[3] is that portion of EOL recycling in which the metal in a discarded product is separated and sorted to obtain recyclates that are returned to raw material production processes that generate a metal or metal alloy. Often it is not the specific alloy that is remelted to make the same alloy but any alloys within a certain class of alloys that are remelted to make one or more specific alloys. For example, a mixture of austenitic stainless steel alloys might be remelted and the resulting composition adjusted by addition of reagents or virgin metal to make a specific stainless steel grade.
- Nonfunctional recycling is that portion of EOL recycling in which the metal is collected as old metal scrap and incorporated in an associated large-magnitude material stream as a "tramp" or impurity elements. This prevents dissipation into the environment but represents the loss of the metal's function, as it is generally impossible to recover it from the large-magnitude stream. Although nonfunctional recycling is here termed a type of recycling, it leads to an open metal life cycle, as discussed above. Examples are small amounts of copper in iron recyclates that are incorporated into recycled carbon steel.
- Losses occur when metal is not completely captured through any of the recycling streams mentioned above. Losses also result from in-use dissipation, as in the corrosion of sacrificial zinc coatings on steel, loss of the metallic contents of vehicle brake linings, and unrecovered metal in mine tailings and refinery slags. Dissipation, tailings, and slag losses are not reflected in any of the recycling rate statistics in the present work.

## Defining Recycling Statistics

Recycling rates have been defined in many different ways, for many life stages; sometimes the term is left undefined. Attempts to rectify this situation (e.g., Sibley and Butterman 1995; Sibley 2004; Eurometaux 2006; Bailey et al. 2008; Reck and Gordon 2008; Dubreuil et al. 2010) have suggested more consistent approaches. In this article, we build on that work to define recycling efficiencies at EOL (collection, process efficiency, recycling rate) and in metal production (recycling input rate, recycled content, old scrap ratio).

At EOL, the recycling efficiency of a metal can be measured at three levels:

1. How much of the EOL metal contained in various discarded products is collected and enters the recycling chain (as opposed to metal that is landfilled)? (*Old scrap collection rate* [CR]).
2. What is the efficiency in any given recycling process (i.e., the yield)? (*Recycling process efficiency rate*, also called recovery rate; e.g., Van Schaik et al. 2004).
3. What is the EOL recycling rate (EOL-RR)? The EOL-RR always refers herein to functional recycling (unless noted differently) and includes recycling as a pure metal (e.g., copper) and as an alloy (e.g., brass).

In contrast, the nonfunctional EOL-RR describes the amount of metal that is collected but lost for functional recycling and that becomes an impurity or "tramp element" in the dominant metal with which it is collected (e.g., copper in steel; more examples are provided in

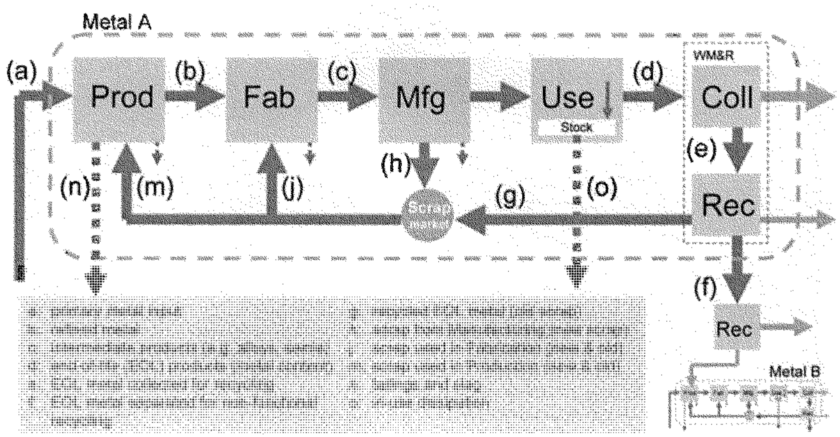


**Figure 2** Flows related to a simplified life cycle of metals and the recycling of production scrap and end-of-life products. Boxes indicate the main processes (life stages): Prod = production; Fab = fabrication; Mfg = manufacturing; WM&R = waste management and recycling; Coll = collection; Rec = recycling. Yield losses at all life stages are indicated through dashed lines (in waste management [WM] referring to landfills). When material is discarded to WM, it may be recycled (flow e), lost into the cycle of another metal (flow f, as with copper wire mixed into steel scrap), or landfilled. The boundary indicates the global industrial system, not a geographical entity. When metal is nonfunctionally recycled ("downcycled"), it enters the cycle of another metal, indicated by the minicycle in the lower right corner. A more detailed diagram of metal production and fabrication is provided in Appendix S1–6 of the Supporting Information on the Web.

Appendix S1–5 in the Supporting Information on the Web). The EOL-RR is strongly influenced by the least efficient link in the recycling chain, which is typically the initial collection activity.

Figure 2 provides a simplified metal life cycle on the basis of which the above-mentioned EOL metrics can be calculated:

1. Old scrap collection rate: CR = e/d
2. Recycling process efficiency rate = g/e
3. EOL-RR = g/d (refers to functional recycling only). Nonfunctional EOL-RR = f/d

In metal production, two other metrics are of importance: the recycling input rate (RIR) and the old scrap ratio (OSR). The RIR describes the fraction of secondary (scrap) metal in the total metal input of metal production—that is, flow c in figure 2 (as an approximation, primary metal input is calculated as extracted ore minus losses through tailings). The RIR is identical to the recycled content (RC) when the latter is calculated as follows (see Appendix S1–6 in the Supporting Information on the Web for further details).

4. $RC = (j + m)/(a + j + m)$

The calculation of RC is straightforward at the global level but difficult, if not impossible, at the country level. The reason is that information on the recycled content of imported produced metals is typically not available (flow b; i.e., the share of m/(a+m) in other countries is unknown), which in turn makes a precise calculation of the recycled content of flow c impossible.

The *OSR* describes the fraction of old scrap (g) in the recycling flow (g + h).

5. $OSR = (g)/(g + h)$

In combination with the recycled content, this metric reveals the quantity of metal from EOL products used again for metal production and product manufacturing and enhances understanding of the degree to which the use of scrap from various stages of the metal life cycle is occurring.

For a better interpretation of these metrics, we have to consider some influencing factors. The recycled content of metals depends on the amount of scrap available and on the scrap quality: The new-scrap availability depends on the degree of metal use and the process efficiency in fabrication and manufacturing. The old-scrap availability is a function of metal use a product lifetime ago, in-use dissipation over the product lifetime, and the efficiency of the EOL collection and recycling system. High growth rates in metal demand in the past, together with long product lifetimes (often several decades), result in available old-scrap quantities that are typically much smaller than the metal demand in production, which leads to RCs much smaller than 100%. Even a very efficient EOL recycling system would not provide enough old scrap for a high recycled content with a high OSR in this circumstance. Comparisons of RCs across metals are problematic due to different growth rates in metal use over time, different end uses with different respective lifetimes and different in-use dissipation rates, different production processes (which sometimes limit the amount of scrap used), and varying tolerances in metal production to scrap impurities (Van Schaik et al. 2004; Gaustad et al. 2010). The recycling process efficiency varies from metal to metal, depending on the metal or grade for which a process is optimized, and although it can be high it will never reach 100% due to thermodynamic and other limitations (Castro et al. 2004).

It is also important to note that recycling efficiency is highly product-specific. The form in which a metal is used (pure, alloyed, etc.), the quantity of a metal in a specific product, the design of a product (easy or hard to disassemble), and the monetary value of the metal all play a role. Scholarly studies that demonstrate these dependencies are rare—exceptions include the work of Van Schaik (2004) and Van Schaik and colleagues (2004) for automobiles and Chancerel and Rotter (2009) for electronics. Additional information can be found on industry group Web sites (e.g., Steel Recycling Institute 2010 for steel and International Copper Study Group 2004 for vehicles). Overall, however, the available product-specific sources do not treat very many sectors, products, or metals of interest, and, with the exception of the precious metals (see Appendix S1–3 in the Supporting Information on the Web), we are unable to address product sector-specific recycling rates in this study.

## Consensus Recycling Statistics

The set of global-average metal recycling statistics that we derive represents an order of magnitude estimate that was drawn from a review of the recycling literature and informed estimates by industry experts. The years for which figures are available vary, but many apply to the 2000–2005 time period. This literature review was followed by a workshop[4] in which experts discussed the relevance and accuracy of the published information, which is clearly of varying quality and differs by region, product, and available technology, all of which make it challenging to quote definitive values for any of the recycling metrics. For used or EOL electronics, automotive vehicles, and some other products, significant exports take place from industrialized to transition and developing countries, where the recycling process efficiency rate is often low. Additionally, for the base metals[5] and gold, especially, informal recycling in developing countries is extensive. Thus, no attempt was made to specify exact recycling rates; rather, the experts chose five ranges for recycling values in cases where familiarity with the recycling industry enabled such choices to be made, even in the absence or paucity of published data. Because of the independence of data sources and the underlying uncertainties, mass balance cannot always be achieved when one combines the results of the various metrics, nor should one expect to do so, and the consensus numbers compiled here by the experts need to be understood as a first comprehensive assessment that will require further review and elaboration over time. Nonetheless, we regard the magnitudes of the results to be approximately correct on a global average basis as of the time of publication of this article.

The detailed results of these exercises are presented in the Appendixes in the Supporting Information on the Web. The three periodic

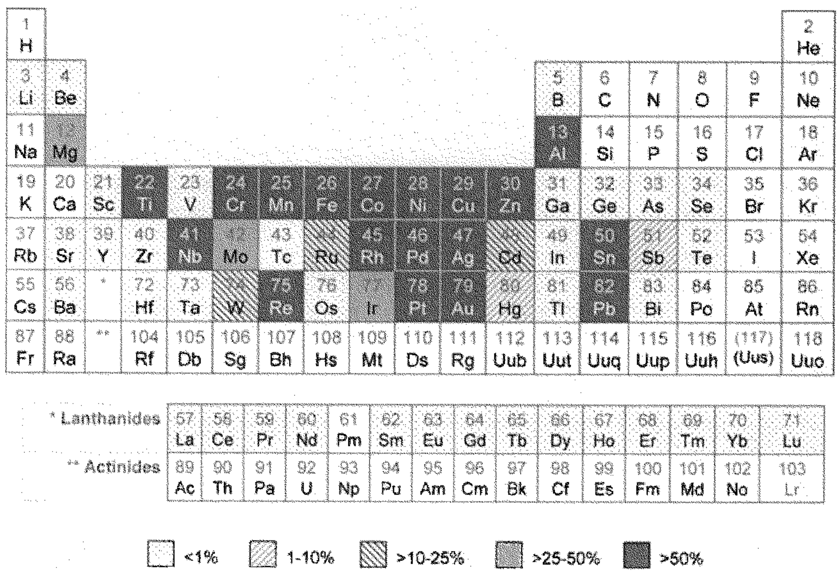


**Figure 3** The periodic table of global average end-of-life functional recycling rates (EOL-RR) for 60 metals, with the individual metals categorized into one of five ranges. Unshaded entries indicate that no data or estimates are available or that the elements were not addressed in this study. These evaluations do not consider metal emissions from coal power plants.

table displays in figures 3, 4, and 5 illustrate the consensus results in compact visual display formats.

The EOL-RR results in figure 3 relate to whatever form (pure, alloy, etc.) in which substance-specific recycling occurs. To reflect the level of certainty of the data and the estimates, data are divided into five bins: greater than 50%, 26% to 50%, 11% to 25%, 1% to 10%, and less than 1%. It is noteworthy that for only 18 of the 62 metals do we estimate the EOL-RR to be above 50%, and it was usually barely above that level. Another three metals are in the 26% to 50% group, and three more were in the 11% to 25% group. For a very large number, little or no EOL recycling is occurring.

Similarly, figure 4 presents the RC data in similar form. Lead, ruthenium, and niobium are the only metals for which RC is greater than 50%, but 16 metals have RC in the 26% to 50% range. This reflects a combination in several cases of efficient employment of new scrap as well as better than average EOL recycling.

The OSR results (figure 5) tend to be high for valuable materials, because these materials are used with minimal losses in manufacturing processes and collected at EOL with relatively high efficiency. Collection and recycling at EOL are relatively high as well for the hazardous metals cadmium, mercury, and lead, although significant losses certainly occur for these metals also (e.g., Hawkins et al. 2006). Overall, thirteen metals have OSRs greater than 50%, and another ten have OSRs in the range from 26% to 50%.

Where relatively high EOL-RRs are derived, the impression might be given that the metals in question are being used more responsibly than those with lower rates. In reality, rates tend to reflect the degree to which materials are used in large amounts in easily recoverable applications (e.g., lead in batteries, steel in automobiles). In contrast, when materials are used in small

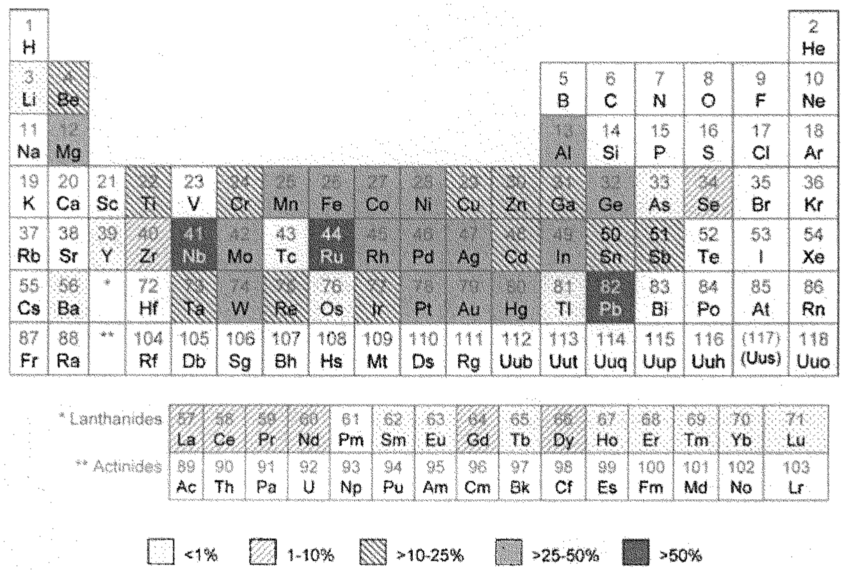


**Figure 4** The periodic table of global average recycled content (RC) for 60 metals, with the individual metals categorized into one of five ranges. Unshaded entries indicate that no data or estimates are available or that the elements were not addressed in this study.

quantities in complex products (e.g., tantalum in electronics), recycling is technically much more challenging.

## Implications of the Results

Can recycling efficiencies be improved? That is, can materials cycles be transformed from open (i.e., without comprehensive recycling) to closed (i.e., completely reemployed) or at least to less open than they are at present? A major challenge is that open cycles are typical for many metals in consumer goods, such as cars, electronics, and small appliances (Hagelüken 2007), due to the following:

- Product designs that make disassembly and material separation difficult or impossible.
- A high mobility of products and the unclear material flows that result. These are caused by multiple changes of ownership and sequential locations of use spread around the globe.
- A generally low awareness about the loss of resources, and missing economic recycling incentives due to low intrinsic value per unit. Nevertheless, the overall mass flows have a big impact on metal demand (Hagelüken and Meskers 2008).
- Lack of an appropriate recycling infrastructure for EOL management of complex products in many developing countries and emerging economies. In industrialized countries, many hibernating goods (products stored in drawers and closets and not yet discarded) and small devices that go into the trash bin (e.g., mobile phones) reduce significantly the recycling efficiencies.
- Recycling technologies that have not kept pace with complex and elementally diverse modern products.

Closed cycles are typical for many industrial goods, such as industrial machinery, tools, and process catalysts. Although the required recycling technology does not differ much from that

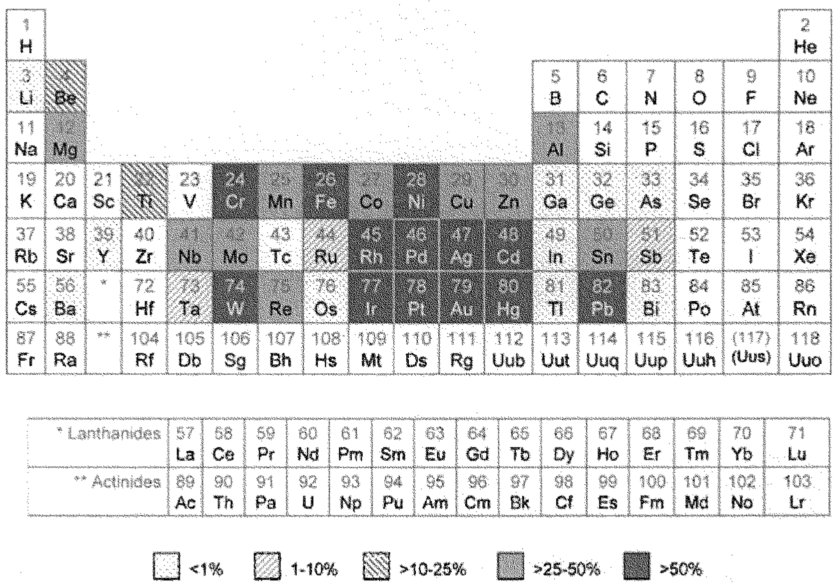


**Figure 5** The periodic table of global average old scrap ratios (OSR) for 60 metals, with the individual metals categorized into one of five ranges. Unshaded entries indicate that no data or estimates are available or that the elements were not addressed in this study.

for consumer goods, the recycling efficiencies are usually much higher due to a high awareness of the involved stakeholders, economic recycling incentives, transparent and professional handling throughout the product life cycle, and a rather limited change of ownership and location of use.

The recycling metrics represent average current global-level estimates. These metrics vary from year to year due to changes in a number of underlying factors: metal use a product lifetime ago, share of different end-use sectors, product lifetimes, product composition, product weight, and recycling efficiencies (Van Schaik et al. 2004; Reuter et al. 2005; Müller et al. 2006; Reck et al. 2010). In addition, even though recycling rate statistics at the country level are sparse, it is clear that metals with low global recycling rates must also have low rates within individual countries. As concerns continue to rise about absolute availability, trade barriers, and other potential supply constraints, it is in the interest of all countries to enhance their long-term sustainability by increasing recycling rates and thereby retaining metals rather than discarding or dispersing them, as is often the case at present.

In practice, the effectiveness of recycling is a consequence of three related factors. The first is economics, because the net intrinsic value of the discarded materials must be high enough to justify the cost and effort of recycling. When that value is not present, incentives such as deposit fees or other cost subsidies, usually based on legal requirements, may make it so, at least at the consumer level. The second factor is technology: Do the design of the discarded product and the ways materials are joined or merged enable or inhibit available recycling processes? The final factor is societal: Has a habit of recycling been established? Do public campaigns promote recycling targets? Can legislation, recycling fees, or other recycling policies prove effective? To the degree that these factors are addressed, improved rates of reuse and recycling are likely. Many of these issues are discussed in detail by Graedel and Van der Voet (2010).

Policies involving recycled content goals are intended to provide an incentive for recycling. Some argue, however, that this metric is only of limited relevance for metals because, unlike materials such as paper or some plastics, the availability of secondary metals (new or old scrap) is limited due to the often long lifetimes of metals in use (Atherton 2007). One could argue that the intent of such policies could better be achieved by encouragement of a high OSR (i.e., the old scrap in the recycled content). Such an approach would provide an incentive to increase the EOL-RR (i.e., increase the share of old scrap) and make fabrication processes more efficient (i.e., decrease the share of new scrap). In fact, many consider the EOL-RR to be the most important recycling metric (Recycling Project Team 2010).

A large research and data collection effort is needed in the case of many of the metals to locate missing information and to obtain more reliable recycling statistics. Measures of recycling performance are needed for informed policy directions and to evaluate the effects of public policy and societal performance. In addition, in-depth research is necessary to develop new recycling technologies and infrastructures for specific applications (especially emerging technologies). Nonetheless, it needs to be understood that due to the dissipative use of many metals and to fundamental thermodynamic limits (Castro et al. 2004; Van Schaik and Reuter 2004), it is not possible to recover everything, even in an optimized environment.

Despite the challenges of improving recycling rates, however measured, recycling generally saves energy and minimizes the environmental challenges related to the extraction and processing of virgin materials. The data presented in this report, and the discussions related to how the data are measured and how they might change over time given certain technological or societal approaches, provide information likely to be useful in moving society toward a more efficient level of resource utilization in the future.

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## Notes

1. A metalloid is an element with properties intermediate between those of a metal and those of a nonmetal.

2. This useful term is borrowed from the plastics recycling community.
3. This term was coined by Guinée and colleagues (1999).
4. The workshop was held in Brussels, Belgium, April 24–25, 2009. The attendees consisted of the authors of this article and those recognized in the Acknowledgments.
5. A *base* metal is a metal that oxidizes or corrodes relatively easily (e.g., iron, lead, zinc, and copper), in contract to *noble* or *precious* metals.

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## Supporting Information

Additional Supporting Information may be found in the online version of this article:

**Supporting Information S1:** This Supporting Information includes four sections on detailed review and resolution of recycling statistics, including ferrous metals (S1–1), nonferrous metals (S1–2), precious metals (S1–3), and specialty metals (S1–4). This Supporting Information also defines the system in figure 2 from the main article (S1–5) and discusses scrap use in metal production (S1–6).

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