I.FAST

Innovation Fostering in Accelerator Science and Technology

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Workshop :

CRITICAL MATERIALS AND LIFE CYCLE MANAGEMENT: THE EXAMPLE OF RARE EARTHS – CURSE OR BLESSING?

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ABSTRACT

The last accelerator upgrades show that it is possible to significantly save grid energy by using permanent magnets instead of the classical electromagnets. At DESY the upgrade of PETRA foresees a new magnet lattice to achieve low beam emittance, and with the given parameters only permanent magnets allow to realise such lattice.

But advantages of permanent magnets don't come for free. Key materials in permanent magnets are Rare Earth Elements (and cobalt), which are mostly mined and processed in China under precarious conditions for people and environment. Additionally, the recycling of these materials is not yet established in an industrial scale and is just beginning. The workshop raised awareness for

these problems and explored ways for solutions and suggestions how the accelerator community can contribute to tackle these challenges.

For more information on IFAST, its partners and contributors please see https://ifast-project.eu/

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Executive summary

In the realm of I.FAST work package 11 Task 1 Sustainable Concepts and Technologies for RIs a workshop on the criticality of Rare Earth Elements was organised. The technical development of magnets for RIs is currently focussing on permanent magnets, which in turn need rare earth elements (REE) and cobalt to be produced.

Life cycle assessment (LCA) and recycling of Rare Earth Elements (REE) as a key material for permanent magnets were covered at the workshop. The program included talks about diverse points in the problematic material and alternatives and also discussions about LCA and recycling of REE.

Research institutions with accelerator facilities, politics, supplier as well as industry companies active in this field were represented at the workshop.

The discussion about solution pathways of certification along the Chain of Custody (CoC) made clear that the currently available standards are not sufficient and slow in development, still there are good approaches and starting points. First more awareness amongst accelerator physicists and engineers need to be built up. Second: all accelerator centers shall work on developing and establishing a first level of criteria to be put into tenders for procurement – preferably together.

The second discussion about recycling made clear that there are several technical solutions for the recycling of old magnetic material but the problems lie somewhere else. The problematic part of the life cycle are the collection and dismantling. The products are very divers, the REE part is often very small and almost always glued or coated which makes the recycling process more costly. There is no waste management for magnets. This needs to be solved to make REE recycling a successful business case.

1 Introduction

In accelerator operation magnets play an important role for bending and focusing the charged particle beams as well as for generating the radiation for photon science in insertion devices. Today various designs exist. Electro magnets are tunable but have a large power consumption, need more space and introduce vibrations through the integrated water cooling circuits. Alternatives include high temperature superconducting (HTS) magnets that require low power in their circuits, but need cryo-cooling and last but not least permanent magnets. Permanent magnets need no power in

operation and they are much smaller than electro magnets for comparable magnetic field. But in terms of sustainability the used materials, specifically Rare Earth Elements (REE) and cobalt in permanent magnets are problematic.

In the last decade, the sustainability of materials and technical components has come under increasing scrutiny. Life Cycle Assessments (LCA) examine the evolution of a product from cradle to grave. NGO´s help to investigate ecological and sociological conditions in mining and processing countries, especially for magnet materials in China and the Democratic Republic of Congo (DRC). Teams at many European institutions are working on LCA for REE. They identified the mining, processing and recycling as most problematic processes. Research institutes like Fraunhofer, HU Pforzheim and many others are working together with suppliers and industries in joined projects for finding solutions in recycling.

Within the I.FAST work package "Sustainable concepts and technologies", an international workshop was organised to review the criticality of REE and to bring together the different stakeholders for an exchange of ideas and new collaborations. The workshop was held at DESY (Hamburg, Germany) on the 6-7-8 February 2023. A number of experts from public and private sector participated in the meeting and in the discussions around REE. The organizing committee was formed by Andrea Klumpp (DESY), Denise Völker (DESY) and Mike Seidel (PSI). The scientific program committee was chaired by Denise Völker (DESY).

This workshops follows in a series of successful workshops on the initiative of the EUCARD and ARIES EU-funded programs.

2 Content of the Workshop Program

The workshop started on Monday February the 6th with a general overview. Two talks focused on permanent magnets at accelerator facilities (Jens Völker - HZB and Andrea Klumpp - DESY), three on the topic of contemplation of REE in the context of sustainability (Julius Neu - INKOTA, Ben Shepherd - STFC and Sabine Langkau - Fraunhofer ISI) and two on sustainability challenges and real world implementation (Amit Lotan - environ and Alexander Bidmon - HZDR).

Abstracts:

Permanent magnets are state-of-the-art magnetic sources for undulators and wigglers in current synchrotron light sources. They combine compact magnetic energy sources with precision and stable magnetic parameters. In combination with the increasing productions efficiency and cost reduction of those PM blocks, they are a more and more interesting technology for accelerator magnets in next generation synchrotron radiation sources. PM based accelerator magnets offer the opportunity for a more compact and stable magnetic lattice, as well as a drastic reduction in energy consumption. In this talk existing and upcoming accelerator projects with their magnet developments will be presented. (J. Völker)

DESY is planning a major upgrade for the PETRA accelerator and with this the number of permanent magnets will be greatly increased. Petra IV and the planned PM magnets are shortly presented and reasons and challenges for the decision for permanent magnets are reflected. (A. Klumpp)

Germany is the 5th largest consumer of raw materials worldwide with more than 99% of all metals being imported. The presentation explores the societal and environmental impacts of mining of focusing on the case of cobalt in the Democratic Republic of Congo. It argues that in order to tackle problems like human rights violations, environmental destruction and climate crisis we need a paradigm shift in how we handle our planet's natural resources (raw material transition/Rohstoffwende) (J. Neu)

Electromagnets are traditionally used in particle accelerators to control the beam. It's possible to replace them with permanent magnet (PM) devices. This talk examines the environmental impact of electromagnet devices vs PM ones, using a few examples from the CLARA accelerator at STFC's Daresbury Laboratory. The CO_2 cost of electromagnet devices is typically dominated by the energy use in its operational phase. (B. Shepherd)

We look at the most pressing environmental issues related to rare earth elements for magnet applications according to LCA results. Moreover, we analyze the mitigation potential of different solution strategies with a scenario approach. (S. Langkau)

How to model Life Cycle Assessment in general and specifically in the electronic industry and get full in depth Environmental Impact Results. A study case for the production of smart meter will be presented. (A. Lotan)

Due to the high energy costs and chemical reagent consumption associated with rare earth extraction in conventional systems, the Magsolex project aims to find a new approach to this critical problem by using a magnetic field assisted solvent extraction method. An interferometer is used to characterize and study the reactions underlying the processes for a single rare earth element, with the further goal of developing a full-color interferometer to study a ternary rare earth mixture. (A. Bidmon)

The second day focused on the two possible solution pathways of certification along the Chain of Custody (CoC) and the recycling and reuse of old magnets. The first session was on certification. At first three impulse talks were given (P. Zapp - Jülich, M. Erdmann - BGR, Lutz Berners - Berners consulting). The sustainability problems in the Life cycle of REE, possible solutions along the CoC and a concrete example of a certification scheme were presented.

Abstracts:

Rare earth elements (REEs) are important raw materials for green technologies. However, their mining and processing are often not environmentally sustainable. The presentation provides an overview of the environmental impacts of current primary REE production based on published Life cycle assessment (LCA) results. Existing major REE deposits in China, Australia, and the US as well as an alternative European RE mineral are compared and improvement strategies are discussed. (P. Zapp)

Several international initiatives have established commodity-unspecific assurance and certification frameworks for mining and mineral supply chains that can also be applied to parts of the rare earth supply chain. This presentation highlights the major ESG risks in rare earth mining and processing, how they can be audited through existing sustainability standards, and present recent developments for more sustainable rare earth supply chains. (M. Erdmann)

Sourcing RE magnets that fulfil sustainability criteria presents numerous challenges. Using the example of a medium-sized German family company, the talk explores the current possibilities for reducing environmental, social and governance risks in the supply chain and gives an overview of practical approaches for increasing sustainability in magnet procurement. (L. Berners)

In the following fishbowl discussion with the presenters of the impulse talks and members of the audience discussed approaches for auditing and certification along the CoC in more detail. All participants were invited to join the discussion.

Results:

The lively discussion made it clear that the standards currently available are inadequate and slow to develop, but that there are good approaches and starting points. The first step is to raise awareness among accelerator physicists and engineers. Second: all accelerator centres purchasing PM should work - preferably together - to develop and establish a first set of criteria to be specified in the procurement tenders. The experts from the workshop can advise and consult on that. Taken together, the impact on the producers' CoC will be larger. These criteria will start with transparency, auditability and initial questions on the biggest issues (such as acidification potential or global warming potential). In the coming years these criteria will become more stringent. As ideas around certification along the CoC need strong political processes, the Accelerator Centres will involve their political partners and funding agencies. The second working session on recycling had the same setting like the first. The impulse talks reported about recycling projects like susmagpro (https://www.susmagpro.eu/) or discovery (https://tu-freiberg.de/fakult5/inemet/forschung/aktuelle-projekte/dyscovery) and presented recycling approaches and identified problems in the processing of the recycling (Jürgen Gassmann - Fraunhofer IWKS, Carlo Burkhardt - HU Pforzheim, Daniel Vogt - TU Freiberg).

Abstracts:

Magnetic materials are key components in our everyday life. They are used in a variety of applications in robotics and information technology, as well as in the ongoing “green” energy and mobility transition. Here, materials with the highest demand on performance are needed, making rare earth magnets like Nd-Fe-B the benchmark material of choice. However, sustainability and stability of supply have to be taken into account, whenever this material is used.
One option to reduce the dependency on the Asian supply monopoly and to increase sustainability of the material, is the implementation of the circular economy for Nd–Fe–B permanent magnets. The recycled magnets compete well with those made from primary materials, that is, in terms of magnetic properties and in terms of production costs. They excel by far rare earth permanent magnets made from primary materials regarding the environmental footprint. Questions to be solved for a circular economy are the dismantling of products after their end-of-life, for bringing scrap magnets back to the market. (J.Gassmann)

Rare earth magnets (neodymium-iron-boron magnets), the strongest type of permanent magnets available, are widely used in the manufacture of modern technology products. They are used in electronics, wind turbines, electric motors and other fields. Unfortunately, most neodymium magnets available on the EU market come from third countries and are currently considered the most critical group of materials in the EU in terms of supply risk.
The EU-funded SUSMAGPRO and REEsilience (REEsilience) projects aim to develop sustainable and resilient supply chains from recycled neodymium magnets and new sources with high ESG standards. This presentation will discuss the challenges and opportunities for more sustainable magnet production in Europe by providing an overview of the targeted material sources, the techniques used for separation and segregation of EOL magnets, and the manufacturing technology of sustainable magnets. The talk will also discuss the current development stages of the project pilot plants and the two university spin-offs, HyProMag Ltd. and HyProMag GmbH, and provide an outlook on the path to series production. (C.Burkhardt)

Rare Earth permanent magnets (REPM) are powerful magnets and widely used on the market. The amount of REPM in applications range from grams (electronic applications) to several tons (wind power generators). The major supply of REE for the EU is coming from China and other third party countries. The reuse and recycling of end-of-life (EOL) magnets is important to meet the future demands of the EU in terms of green energy tranformation. Within the EIT RawMaterials funded project DysCovery, the entire route of EOL magnet recycling will be demonstrated. Spent NdFeB and SmCo are hydrometallurgically processed. Pure RE salts will be refined via molten salt electrowinning and new magnets based on recycled material will be produced and tested. Activities of the collaborations DysCovery, REEsilience and other research will contribute to new recycling strategies for the EU. (D.Vogt)

In the fishbowl discussions that followed, the moderator took questions from the audience. All participants were invited to participate in the discussion.

Results:

The discussion showed that there are several technical solutions for recycling old magnetic material, but the problems lie elsewhere. Even the possible lower quality of recycled material can be easily overcome by simply adding a little new material. The problematic part of the life cycle is collection and dismantling. The products are diverse, the REE content is often very small and almost always bonded or coated, making the recycling process more costly. There is no waste management for

magnets. This also makes the economics of such recycling techniques a challenge. Almost all products containing REE magnetic materials are not designed to be recyclable, including those used in undulators and other magnets for accelerators. This needs to be addressed to make REE recycling a successful business case. Also, the development of accelerator magnets (as well as all other technical components in the lattices) will have to focus more on recyclability in the future. (As an aside, some old DESY undulators have been donated to these scientific projects, which are researching recycling techniques).

On the last day in the morning session Vanessa Grattoni (XFEL), Ciro Calzolaio (PSI) and Samuele Marotto (Universita Deggli Studi di Milano) presented HTS Magnets as alternatives for permanent and electro magnets.

Abstracts:

The undulator group at the European XFEL has started an R&D project dedicated in developing advanced superconducting undulators (SCUs) concepts. The project consists of two parts: the first one focuses on building up know-how in the design and construction of NbTi-based SCU coils, which are commercially available and established in other laboratories. The second part focuses on applying high-temperature superconductors (HTS) to SCUs . HTS based on Rare-earth barium copper oxides (ReBCO) are a very attractive option. Compared to the low-temperature superconductors (NbTi and Nb3Sn), ReBCO offer higher critical temperature, higher magnetic fields and critical currents at low temperature. I will give an insight into the concept of a hybrid undulator (HybriSCU) based on both NbTi and ReBCO and the first efforts made in the geometry design of an SCU based only on ReBCO. In addition, I will address current limitations related to the ReBCO technology in the undulator field. (V.Grattoni)

Large accelerator facilities have a considerable energy consumption largely due to the numerous resistive magnets used in the medium- and high-energy beamlines. Considering the duty cycle of the machine and the cost of energy, new designs based on superconducting magnets have become increasingly attractive as possible alternatives to the use of energy-intensive resistive solutions. High Temperatures Superconductor coils, made in REBCO (rear earth copper oxide) or MgB2 conductors, can sustain the losses of the ramped magnets thanks to their high energy margin due to the large critical temperature. The research team of University of Milan and INFN-Milano (LASA) is currently developing superconducting magnet designs optimized for replacing the resistive coil of energy-intensive magnet and cope with the strain sensitive behaviour of the HTS and MgB2 material. We will show examples taken from magnets installed in research facilities like CNAO and PSI upgraded to superconducting configurations using conduction cooling solutions at 10-20 K of operating temperature improving the sustainability of such research infrastructures and maximizing the energy saving factor.(S.Mariotto)

After a short question round the workshop was wrapped up with a summary and highlights from the individual presentations.

3 Workshop Statistics

The workshop was organised as an in-person three day meeting at DESY in Hamburg. In total 16 presentations were grouped in 4 thematic sessions. Two discussion rounds in fishbowl style occured. There were 65 registered participants. The talks are documented on the Indico website:

Critical Materials and Life Cycle Management: The Example of Rare Earths – curse or blessing? (6-8 February 2023): Timetable · DESY-Konferenzverwaltung (Indico)

4 Summary and Conclusion

The relevance of energy efficiency and sustainability is broadly acknowledged at all institutions worldwide with accelerator driven research infrastructures. Magnets present an important accelerator subsystem with potential to improve energy efficiency. There are different types of magnets with its advantages and disadvantages. In our workshop we focused on permanent magnets and its most important material, the Rare Earth Elements (REE). REE are associated with many negative ecological, environmental and social impacts in producing and processing countries. The workshop pointed out that a technical component must be considered not only from the point of view of energy efficiency. The entire life cycle has to be kept in mind.

We should be aware of sustainability from the cradle to the end of the life of the component and the recycling of the material. In the workshop we learned a lot about LCA and how it is possible, even as a small customer, to change the conditions in mining and processing and how accelerator facilities can introduce standards from the beginning of the process chain. The recycling of used magnetic materials is an important adaptation tool to reduce dependency on raw material producing countries such as China. Large quantities of recycled material (scrap) are not yet available, but this will change in the next decade. Further research must be done on the recycling process itself to make it profitable and sustainable, but also on the collection process and material separation. All new magnet designs have to be designed with recyclability in mind. In this context, several new networks and collaborations were established at the workshop.

The exchange on these topics needs to be continued. Some aspects in both areas were not addressed, in particular the certification process needs to be better elaborated and criteria for accelerator centres need to be developed.

5 Relation to Other IFAST Work

The development of permanent magnets is subject to several other work packages and tasks in *I.FAST*, for example in WP 11 Task 3. But the awareness to widen the R&D of RIs to critical materials is valid to almost all other parts of *I.FAST*.

Solutions and questions raised in this workshop therefore shall be communicated in the wider *I.FAST* context. For example, the question of recyclability of technical component is so far not

widely integrated into R&D. And approaches to include sustainability criteria for a technical component material in tenders will be integrated into all procurements. This starts with raising awareness.

Annex: Glossary

Acronym	Definition
REE	Rare Earth Elements
LCA	Life cycle assessment
CoC	Chain of Custody