

Report

Consulting Project 2018/19:

Manufacturing process of superconducting magnets: Analysis of manufacturing chain technologies for market-oriented industries

Project partner: CERN

Contact person: Dr. Johannes Gutleber

Project team:

Heinrich Hartig

Matthias Hausberger

Frederik Ledermüller

Ferdinand Mayrhofer

Daniel Schreiber

Supervisors: Barbara Mehner, Linn Kretzschmar

Carried out at the Vienna University of Economics and Business
Department of Strategy and Innovation

Vienna, 28 January 2019



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement EASITrain No 764879.

Table of Contents

- Table of Contents ii
- Table of Figures.....iv
- List of Tables.....v
- Table of Abbreviationsvi
- Executive Summaryvii
- 1 CERN Introduction 1
- 2 Project Description.....2
 - 2.1 Challenges.....2
 - 2.2 Aims3
- 3 Methodology.....4
 - 3.1 Manufacturing Chain Analysis4
 - 3.2 Technology-Competence-Leveraging5
 - 3.2.1 Step 1: Identification of the technology’s use benefits5
 - 3.2.2 Step 2: Search for application fields5
 - 3.2.3 Step 3: Assessment according to benefit relevance and strategic fit6
 - 3.2.4 Step 4: Detailed analysis of application fields.....7
- 4 Technology Description8
 - 4.1 Evaluation of the Manufacturing Chain.....8
 - 4.2 Most Valuable Processes9
- 5 Use Benefits of the Technologies 13
 - 5.1 Superconducting Rutherford cable..... 13
 - 5.2 Thermal Treatment 14
 - 5.3 Vacuum Impregnation with Epoxy CTD-101K..... 15
- 6 Application Fields..... 16
 - 6.1 Assessment of application fields 16
 - 6.2 High Potential Application Fields 18
 - 6.2.1 Scrap metal recycling..... 18
 - 6.2.2 Generators for wind turbines.....21

Superconducting magnet manufacturing technologies for market-oriented industries	Report
6.2.3 High-voltage power lines.....	22
6.2.4 Hybrid electric power-trains for cruise ships and aircraft.....	24
6.2.5 High-activation level radioactive waste management.....	25
6.2.6 Low-activation level radioactive waste management.....	26
6.3 Medium Potential Application Fields.....	28
6.3.1 Superconducting Rutherford cable.....	28
6.3.2 Thermal treatment.....	32
6.3.3 Vacuum impregnation with novel epoxy CTD-101K.....	34
7 Recommendations.....	36
References.....	ix
Table of Interviews.....	xiv
Appendix A: Magnet Manufacturing Process.....	xvi
Appendix B: Features and Benefits for each Technology.....	xix
B.1 List of features of the superconducting Rutherford cable.....	xix
B.2 List of use benefits of thermal treatment.....	xix
B.3 List of use benefits of vacuum impregnation with epoxy.....	xix
Appendix C: Benefit Relevance and Strategic Fit Calculation.....	xx
C.1 Ranking of application fields.....	xx
C.2 Superconducting Rutherford cable.....	xx
C.3 Thermal treatment.....	xxi
C.4 Vacuum impregnation with CTD-101K.....	xxii
Appendix D: Application Fields.....	xxiv
D.1 Low potential application fields.....	xxiv
Appendix E: Insights from Interviews and User Community Search.....	xxviii
E.1 Interviews.....	xxviii
E.2 User Communities.....	xxxvii

Table of Figures

Figure 1: Milestone plan	4
Figure 2: Illustration of the manufacturing chain of superconducting magnets	8
Figure 3: Superconducting Rutherford cable composed of 28 strands (Lackner 2017).....	10
Figure 4: CERN's oven for the Thermal treatment (Lackner et al., 2016)	11
Figure 5: Part of a superconducting magnet impregnated with epoxy (Hahn, 2016)	12
Figure 6: Assessment of all application fields.....	17
Figure 7 (left): Layout of scrap metal recycling facilities at Recco Non Ferro Metals B.V. (2018).....	18
Figure 8 (right): Scrap metal recycling process of Recco Non Ferro Metals B.V. (2018)	18
Figure 9 (left): Profile of the nacelle of a wind turbine (Superconductor Technologies Inc., 2018).....	21
Figure 10 (right): Comparison of the generator's size with using a copper cable and a superconducting cable (Superconductor Technologies Inc., 2018)	21
Figure 11: Hybrid-electric powertrain in the aircraft model of Zunum Aero (Zunum Aero, 2017).....	24
Figure 12: Illustration where the novel epoxy CTD-101K might be used for radioactive waste containment.....	25
Figure 13: Low-activation level radioactive waste disposal (Deegan, 2011).....	27
Figure 14: Electric vessel EC 110 developed by PortLiner (PortLiner, 2018).....	28
Figure 15 (left): Winding Structure of Accelerating Magnets (Weisend, 2010).....	xvii
Figure 16 (right): Typical Winding of an Electromagnet (Michael Müller Spulenwickeltechnik GmbH)	xvii
Figure 17 (left): Manufacturing of End-Spacers (Lackner, 2017).....	xvii
Figure 18 (right): Application of End-Spacers (Weisend, 2010)	xvii
Figure 19: Assessment of application fields for the superconducting Rutherford cable.....	xxi
Figure 20: Assessment of application fields for thermal treatment	xxii
Figure 21: Assessment of application fields for vacuum impregnation with CTD-101K.....	xxiii

List of Tables

Table 1: Calculation of rating for processes – costs are based on Schoerling (2017).....	9
Table 2: Overview of relevant Use Benefits for each technology.....	13
Table 3: Scale for Benefit Relevance and Strategic Fit.....	17
Table 4: Overview of high, medium and low potential application fields according to their assessment	18
Table 5: Melting points of the most important metals used (Lenntech BV, n.d.).....	20
Table 6: Full list of features and use benefits of the production of the Rutherford cable.....	xix
Table 7: Full list of features and use benefits of the Thermal Treatment.....	xix
Table 8: Full list of features and use benefits of the vacuum impregnation with epoxy.....	xix
Table 9: Ranking of all application fields.....	xx
Table 10: Calculation of Benefit Relevance - Superconducting Rutherford cable.....	xx
Table 11: Calculation of Strategic Fit - Superconducting Rutherford cable.....	xxi
Table 12: Calculation of Benefit Relevance - Thermal Treatment.....	xxi
Table 13: Calculation of Strategic Fit - thermal treatment.....	xxii
Table 14: Calculation of Benefit Relevance - Vacuum impregnation CTD-101K:.....	xxii
Table 15: Calculation of Strategic Fit - Vacuum impregnation with CTD-101K.....	xxiii
Table 16: All application fields - overview.....	xxiv

Table of Abbreviations

AC	Alternating current
BR	Benefit Relevance
BSCCO	Bismuth strontium calcium copper oxide
CERN	Conseil Européen pour la Recherche Nucléaire
CNC	Computer numerical control
EU	European Union
e.g.	for example
FCC	Future Circular Collider
FCC-hh	A future circular high-energy hadron-hadron particle collider
HTS	High-temperature superconductor
IEEE	Institute of Electrical and Electronics Engineers
K	Kelvin
LHC	Large Hadron Collider
LTS	Low-temperature superconductor
MRI	Magnetic resonance imaging
Nagra	National Cooperative for the Disposal of Radioactive Waste
Nb ₃ Sn	Niobium-tin
NbTi	Niobium-titanium
R&D	Research and development
SCM	Superconducting magnets
SF	Strategic Fit
T	Tesla
TCL	Technology-Competence-Leveraging
YBCO	Yttrium barium copper oxide



Executive Summary

Context

An international consortium of more than 150 organisations worldwide is studying the feasibility of future particle collider scenarios to expand our understanding of the inner workings of the Universe. The core of this Future Circular Collider (FCC) study, hosted by CERN, an international organisation near Geneva (Switzerland), is a 100 km long circular particle collider infrastructure that extends CERN's current accelerator complex. As a first step, an intensity frontier electron-positron collider is assumed. The ultimate goal is to build a proton collider with an energy seven times larger than the Large Hadron Collider (LHC). Such a machine has to be built with novel superconductive magnet technology. Since it takes decades for such technology to reach industrial maturity levels, R&D has already started. The superconducting magnet system is considered the major cost driver for construction of such a proton collider. A good cost-benefit balance for industrial suppliers is considered an important factor for the funding of such a project.

Aim

The aim of this investigation was to **identify the industrial impact potentials of the key processes needed for the manufacturing of novel high-field superconducting magnets and to find innovative additional applications for these technologies outside the particle-accelerator domain**. Suppliers and manufacturing partners of CERN would benefit if the know-how could be used for other markets and to improve their internal efficiency and competitiveness on the world-market. Eventually, being more cost-effective in the manufacturing and being able to leverage further markets on a long-time scale will also reduce the cost for each step in the manufacturing chain and ultimately lead to lower costs for the superconducting magnet system of a future high-energy particle collider.

Method

The project is **carried out by means of the Technology Competence Leveraging** method, which has been pioneered by the Vienna University of economics and business in Austria. It aims to find new application fields for the three most promising technologies required to manufacture novel high-field superconducting magnets. This is achieved by gathering information from user-communities, conducting interviews with experts in different industries and brainstorming for new out-of-the-box ideas. The most valuable application fields were evaluated according to their Benefit Relevance and Strategic Fit. During the process, 71 interviews with experts have been carried out, through which **38 new application fields were found with credible impacts beyond particle accelerator projects**. They relate to manufacturing “superconducting Rutherford cables” (15), “thermal treatment” (10) and “vacuum impregnation with novel epoxy” (13).

Results

A short description of all application fields that were classified as “high potential” can be found here:

Superconducting Rutherford cable

- **Aircraft charging:** Commercial airplanes only spend around 45 minutes on the ground at a time to load and unload passengers. For future electric aircraft this time window would be too small to charge using conventional cables. The superconducting Rutherford cable could charge an electric plane fast and efficiently.
- **Electricity distribution in hybrid-electric aircraft:** On a shorter time scale, hybrid-electric aircraft is an appealing ecological technology with economic advantages. In this case, electricity for the electric engines is produced by a generator. Cables with high current densities are needed inside the aircraft to distribute the energy. The superconducting Rutherford cable could be a candidate for this task.
- **Compact and efficient electricity generators:** Using the superconducting Rutherford cable, small and light engines and generators can be constructed. One end-use example is for instance the generation of electricity using highly-efficient wind turbines.

Thermal treatment

Heat treatment is needed during the production of superconducting magnet coils. In this processing step, the raw materials are reacted to form the superconductor. This processing step is used for certain low-temperature superconductors as well as for certain high-temperature superconductors.

- **Scrap metal recycling:** Using a large-scale oven with very accurate temperature stabilisation over long time periods, melting points of different metals can be selected. This leads to more efficient recycling of scrap metal. It also permits a higher degree of process automation and quality management.
- **Thermal treatment of aluminium:** Thermal treatment of aluminium comprises technologies like tempering and hardening. The goal of this technique is to change the characteristics of aluminium and alloys containing aluminium. End-use applications include for instance the automotive and aerospace industry, where such exact treatment is necessary.

Vacuum impregnation

- **Waste treatment** companies currently face challenges because new legislation requires more leak-tight containers. Novel epoxy resin developed for superconducting magnets in particle colliders also needs to withstand high radiation levels. Therefore, this technology can be useful in the process of managing highly-activated radioactive waste.

1 CERN Introduction

CERN, the European Organisation for Nuclear Research based in Geneva, Switzerland, is the largest fundamental research laboratory in the world. CERN's mission is to conduct research to understand the fundamental inner working of nature by investigating the smallest scales with experimental methods. This fundamental physics research permits acquiring knowledge that increases our understanding of what our universe consists of and how this complex system works. CERN operates the world's largest particle accelerator complex. The most powerful particle accelerator is the Large Hadron Collider (LHC). The LHC is located in a 26.7 km tunnel that spans the French and Swiss territory in the Geneva region (CERN, 2015). This machine accelerates hadrons (protons and ions) close to the speed of light and brings them to collision. The results of this process are captured at the four interaction points by particle detectors. The data are subsequently analysed by an international team of scientists with the help of specialised computer programs that run on a world-wide computing grid.

Since CERN's foundation in 1954, the organisation has grown to an internationally unique research institution which is financed by its 22 member states with an annual budget of ~ CHF 1.2 bn (~ EUR 1.1 bn) (CERN, 2013). Today, the laboratory including scientist and the administration has about 2,500 staff members and about 12,000 annual external users (CERN, 2018).

2 Project Description

To deepen the still incomplete understanding about our universe, CERN hosts an international study for potential future particle colliders with complementary research targets. One of these particle colliders considered by the Future Circular Collider (FCC) study would rely on an entirely novel, much more powerful superconducting magnet technology. Today, this technology is not yet existing. It needs to be developed in a focused R&D programme that federates universities, research centres and industrial partners from all over the world. In the following part, the challenges for such a highest energy, future circular hadron-hadron collider (FCC-hh) are described and the aims of this project highlighted.

2.1 Challenges

The concept of the FCC is a particle collider in a 100 km long, circular underground structure that would be located in the Geneva basin. FCC-hh would use 16 Tesla strong superconducting magnets, twice the field of the currently used LHC magnets (8.3 T). The primary cost driver for construction of such a machine are the projected high costs of the superconductors, since this technology does today actually not exist. The main cost drivers for the cable are the needed raw materials as well as the ultra-high-precision manufacturing of the magnet coils. Moreover, manufacturing techniques are still not meeting to the needs of such a project. Therefore, significant investment in research and development is needed in numerous, complementary domains.

The key issues are that only few companies active in the relevant domains exist worldwide and those companies see the investment in R&D for advanced manufacturing technology for CERN as extremely risky. Other application fields for these technologies that would permit increasing the benefits for those companies are difficult to find. The technologies do not yet exist and therefore markets do not yet exist.

There exists consensus among technology experts that High Temperature Superconductors (HTS) are likely to eventually replace Low Temperature Superconductors (LTS) in the industrial application domains due to the reduced cooling needs. Therefore, this domain is subject to focused research. Those materials also excel through increased physical properties like higher current density and magnetic field (Lackner, 2018). From an economic point of view, HTS will outperform LTS if series-produced. However, the current demand for both conventional NbTi and emerging Nb₃Sn superconducting LTS is around 610 tons per year in comparison to HTS materials like BSCCO and YBCO which is less than 1 ton per year (Bottura, 2018). The main challenge here is to find industries that can afford LTS now and are not waiting for a breakthrough in HTS. In addition, to generate economic benefit for industries, pathways need to be identified that are used both, for the production of magnets using advanced LTS and for future HTS.

2.2 Aims

The main aim of this research project is to identify the key advantages of the processes needed for the manufacturing of the superconducting magnets (both LTS and HTS based) and to find innovative alternative applications for these technologies. Furthermore, the project aims to support suppliers and manufacturing partners of CERN to find possible markets and use cases of the technologies and manufacturing processes used for manufacturing novel superconducting magnets.

3 Methodology

This part of the report gives a detailed overview of all tools, methods and techniques that were used as well as the structure of the project.

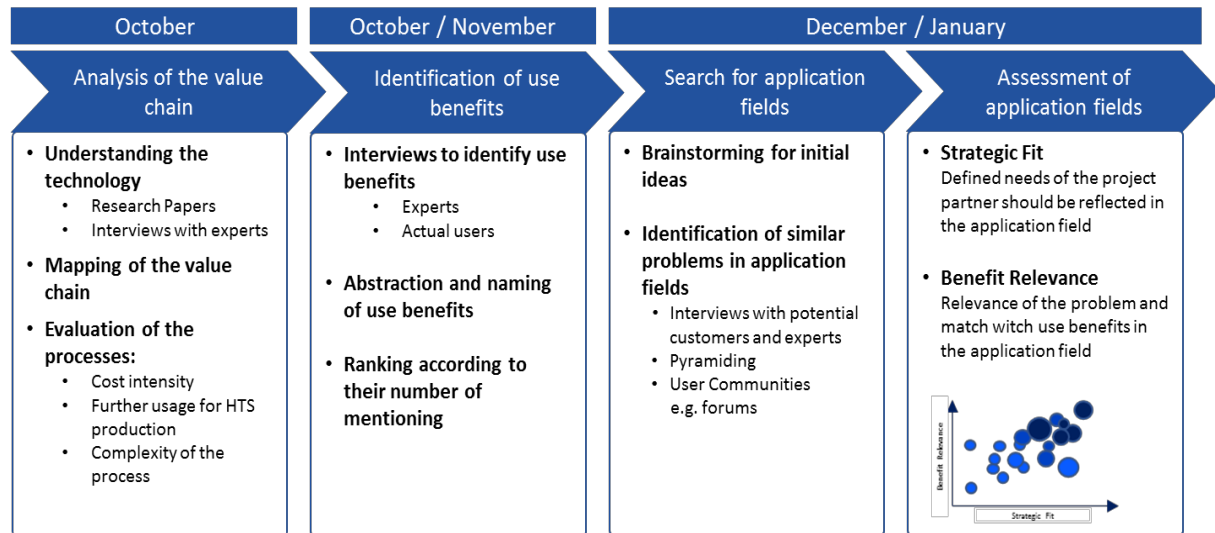


Figure 1: Milestone plan

3.1 Manufacturing Chain Analysis

In the initial phase of the project, the manufacturing chain of the technology and its processes are analysed. Part of this phase is the mapping of technologies and processes to generate an overall picture for a better understanding of the whole manufacturing chain. In order to identify the value of each process, quantifiable factors are taken into account. Based on those factors, the processes are ranked according to their value:

- **Cost intensity (C)**
 - relation of each process to the overall costs of manufacturing a magnet, divided into conductor costs, assembly costs, and parts cost based on Schoerling (2017)

The value for cost intensity of each process is between 0 and 1.

- **Features of the process (F)**
 - the more features, the higher the chance that an alternative application field will be found

In order to normalise the feature impact, the highest number of features is represented as value 1, and all other feature amounts are proportional to it.

- **Uniqueness of the process (U)**

This factor indicates, how widespread the technology in the industry is, according to experts. The uniqueness is qualitatively assessed as follows:

- Unique means that the process is used by CERN or one of its collaboration partners.

- Tailor-made means that the process it is developed by a company specifically for CERN.
- Established means the process is already used by industries.
- It is possible that the process can eventually be eliminated from the manufacturing value chain (low uniqueness).

The uniqueness of a process is indicated with a scale ranging from 0 (the process can be eventually be eliminated from the value chain) to 3 (unique). The resulting index of uniqueness is created as a proportion with respect to the highest value for the process found (3).

The following formula is used to calculate the value for each process in the manufacturing chain:

$$\text{value of a process} = C + F + U$$

The formula gives each of the three factors the same weight. For instance, a high number of features alone will not significantly influence the overall rating. The results of this analysis are the most valuable processes which will be further analysed in this project (see 4 on technology description).

3.2 Technology-Competence-Leveraging

The main phase of the project consists of the Technology-Competence-Leveraging process, a method developed by Keinz and Prügl (2010), which is based on different tools and divided into four sequential steps. This specific method proves to be a perfect fit for this research as it aims to leverage the benefits of given technologies and helps to find significant alternative application fields more easily (Keinz and Prügl, 2010).

3.2.1 Step 1: Identification of the technology's use benefits

This step aims to identify the use benefits of the technologies and processes based on interviews experts and current users. Only the previously defined most valuable processes are considered to identify the use benefits. The outcome of the first TCL step is a broad list with different features of each technology. The results are specific for each technology, so it is necessary to abstract the features to a more general form for further usages. In order to do so, the features will be reformulated to generalised use benefits.

3.2.2 Step 2: Search for application fields

First, creativity techniques are used to find potential starting points in various application fields to search for new applications (Keinz and Prügl, 2010). Brainstorming is used to generate ideas based on the main benefits of each technology as well as a list of potential areas of application.

After brainstorming, all identified ideas are clustered and sorted. Subsequently, interviews with potential users take place to collect evidence for the applicability in alternative areas of application. A potential area of application is characterised by the solution of an existing and relevant problem through the technology or process and the possible need of as many use benefits as possible.

One of the techniques used in this step is *pyramiding*, which is a search process with the aim to find eventually that expert who knows the most about his specific area of knowledge. This is achieved by interviewing persons who act in the same area of knowledge and then forwarding the interviewer to the next person for further questions. Those experts who know most about their specific area of knowledge are likely to know someone in a different area of expertise and enable us to contact them. The method achieves best results if experts from industries far away from the starting industry are contacted (Keinz and Prügl, 2010).

Another technique is to contact *user-communities of specific-industries*, which are asked to advise on specific topics regarding application fields. One reason why user-communities are contacted is the high number of professional users, who can easily give advice on whom to contact to get in touch with an expert in the desired area of application. The following communities are consulted:

- IEEE Council on Superconductivity
- Different scrap metal forums
- The Romoe forum for restoration and conservation
- Different physics forums

The outcome of this step should be around 30 to 40 alternative areas of application (Keinz and Prügl, 2010) in order to provide representative, credible results.

3.2.3 Step 3: Assessment according to benefit relevance and strategic fit

All identified areas of application are evaluated according to their benefit relevance and strategic fit based on Keinz and Prügl (2010). In the following parts, an exact definition of both and how they are calculated is given, and which elements are part of it are explained.

Benefit relevance

Benefit relevance is defined through the number of relevant benefits and the relevance of current problems in a potential application area (e.g. when an irrelevant problem is solved, or the number of use benefits for this area is low, the benefit relevance is low).

The following formula calculates the benefit relevance for each area and shows how important the defined use benefits are for it.

benefit relevance

$$= (\text{number of relevant benefits}) / (\text{number of defined benefits})$$

$$* \text{relevance index}$$

The relevance index is defined as follows, and all elements are weighted the same:

- Relevance of the problem
- Problem is more important in the future

- Current solutions for the occurring problem are not sufficient
- The range of affected people by this problem

The evaluation is based on a 3-point-multi-item-scale:

- 0 = low¹ or false
- 1 = medium¹ or partly right
- 2 = high¹ or completely right

Strategic fit

The definition of the *strategic fit* for this project is based on a variety of needs (from project partner side) which should be reflected in the alternative areas of application. In this project, the following factors are included and evaluated in this calculation:

- Market fit = alternative areas of application showing a high market potential (niche markets with low volumes should not be taken into account).
- Time horizon = time to market, the lower the time needed to enter the market the better it is for CERN. Therefore a low time to market means that technologies can easily replace existing solutions or solve current problems.
- Technical fit = technology can be used in the application field with little or no adaptation.

For calculating the strategic fit, the following formula is used:

$$\text{strategic fit} = (\text{market fit} + \text{time horizon} + \text{technical fit})/3$$

All factors are evaluated based on a 3-point-multi-item-scale:

- 0 = false or long time
- 1 = partly right or medium time
- 2 = completely right or short time

The results of this assessment are the base for the final recommendation of the project team and are the base for further detailed analysis in a follow-up project.

3.2.4 Step 4: Detailed analysis of application fields

The final step is to analyse the findings from step three with a particular focus on their market potential. This can be performed through a market analysis, a SWOT analysis and a competitor analysis (Porter's 5 Forces). Due to the limited amount of time, the final step four is not part of this project. It will be carried out for one technology in a followup project.

¹ Only for relevance of the problem and range of affected persons

4 Technology Description

In this chapter, CERN's process of building a superconducting magnet using advanced superconductors is depicted with a manufacturing chain model focusing on the Nb₃Sn LTS technology. Based on that, the following paragraph focuses on three important processes and explains the reasons for that selection.

4.1 Evaluation of the Manufacturing Chain

Looking at this particular magnet manufacturing process, those technologies which are chosen for further analysis are highlighted in green colour. To understand the reasons for the selection of each process, this chapter also demonstrates all calculations underlying the decision process.

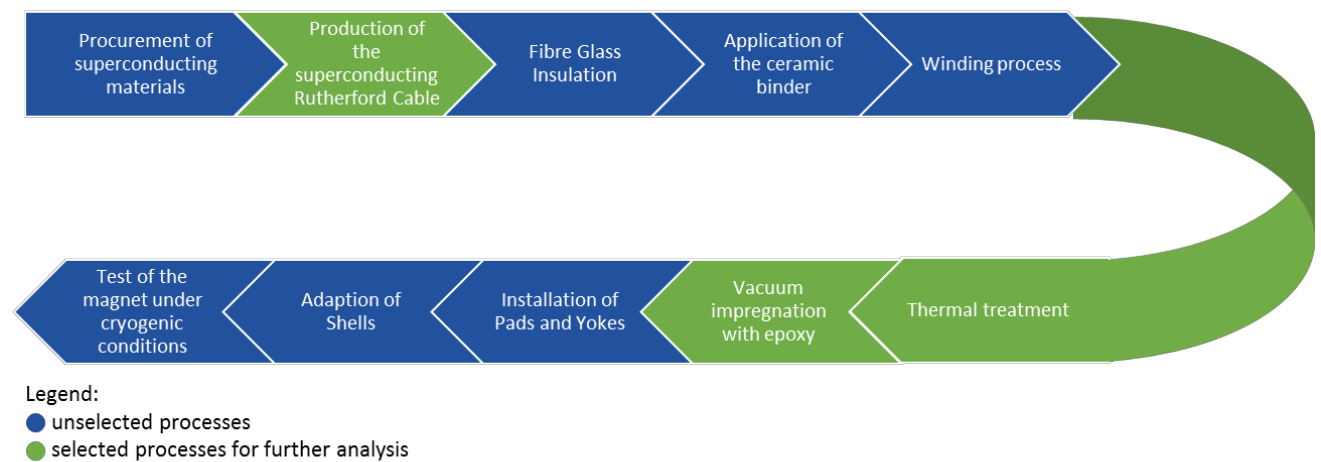


Figure 2: Illustration of the manufacturing chain of superconducting magnets

Table 1 describes the criteria that were used in order to identify the most valuable processes. The first criterion is the three different cost drivers: Parts costs which include fibreglass isolation, pads and yoke for the collaring as well as the aluminium shell. The assembly costs which consist of tooling processes like winding, heat treatment, vacuum impregnation, welding, and testing (Schoerling, 2017). In this category, especially labour costs account for most of the total costs (Schoerling, 2018).² Finally, the conductor costs for Nb₃Sn material appear only in the **wire production and represent around 40 % of the overall costs** (Schoerling, 2017).

² A research team of the Technical University Tampere is currently working specifically in this field to reduce the assembly costs (Schoerling 2018). Therefore, analysis of the assembly costs is not part of this project.

Process	Features	Features Index (F)	Uniqueness of the process	Uniqueness Index (U)	Cost Driver (C)	Rating	Rank		
Wire production	1	0.11	Established	1	0.33	c	0.40	0.84	8
Rutherford cable production	9	1.00	Unique	3	1.00	b	0.36	2.36	1
Fiberglass isolation	2	0.22	Established	1	0.33	a	0.25	0.80	9
Ceramic binder application	1	0.11	Can be eliminated if necessary	0	0.00	a	0.36	0.47	11
Winding	3	0.33	Unique	3	1.00	a	0.40	1.73	4
Thermal treatment	6	0.67	Tailor-made	2	0.67	b	0.36	1.69	2
Vacuum impregnation with novel epoxy	7	0.78	Tailor-made	2	0.67	a	0.25	1.69	2
Collaring/pads/yoke	2	0.22	Unique	3	1.00	a	0.25	1.47	5
Aluminium shell assembling	1	0.11	Established	1	0.33	a	0.36	0.80	10
Welding	3	0.33	Established	1	0.33	b	0.36	1.02	7
Testing	1	0.11	Tailor-made	2	0.67	b	0.40	1.17	6

a = Parts cost	T€	420	0.2485
b = Assembly cost	T€	600	0.3550
c = Conductor cost	T€	670	0.3964
Overall cost	T€	1,690	1.0000

Chosen processes for TCL

Table 1: Calculation of rating for processes – costs are based on Schoerling (2017)

The second criterion for assessing the most valuable processes is the number of mentioned features of the technologies based on interviews with experts in these areas. The more features mentioned, the higher the likelihood that the technology is valuable for other industries. However, it is not guaranteed that more features will lead to more application fields. Because of simplicity reasons, the assumption was made that more features increase the value of a technology.

The last criterion is based on the uniqueness of the processes assessed by conducting interviews with experts at CERN and companies which are currently offering these products or services. Unique processes are those which are only done by CERN and need completely new equipment as well as the necessary knowledge competence. A tailor-made process is one where the industry currently is capable of producing it with major changes in the production facilities. It is not as complicated as a unique process but requires a significant order quantity from CERN to be profitable for the industry. For established processes, sub-contractors are easily available which implies that most applications for other industries are already developed and high cost-reduction is not as likely to occur anymore.

Taking into account all factors with equal weighting, the number of features had the highest impact on the overall rating whereas the cost driver criterion had the least effect because the three different drivers ranged only from 24.9% up to 39.6%. In the end, the **Rutherford cable** (and its production process), the **heat treatment**, and the **vacuum impregnation were chosen as the most valuable processes**.

4.2 Most Valuable Processes

In this section, the three processes and technologies with the highest potential for other industries according to the method described in chapter 3 Methodology are displayed. The technical dimensions of the technologies are explained.

Superconducting Rutherford cable

The production of the Rutherford cable with its complex spooling and twisting technique is the most expensive element in the manufacturing process of a superconducting magnet. The estimated costs of

the production of a Rutherford cable are about 40 (Schoerling, 2017) to 60% for a Nb₃Sn magnet (Rossi, 2015). Furthermore, the analysis of the Rutherford cable is not only chosen due to its cost-intensity but also because of its highly-precise and challenging production with the superconducting material Nb₃Sn. The rectangle/trapezoidal shape of the cable, consisting of 28 superconducting strands, is unique and tailor-made according to Berger (2018). The current density of the superconducting Rutherford cable is 13,750 A on a profile area of 22.5 mm² (611A/mm²) at 1.9 K (Lackner, 2017). To compare the current density of the Rutherford cable with a regular cable, a common copper cable's current density is physically limited to 5 A/mm² (Tsuei *et al.*, 1974). This means that the Rutherford cable conducts 122 times higher current density than a copper cable. A significant **cost driver for the production of the superconducting Rutherford cable is the missing demand for it besides accelerator magnets, leading to a very small overall demand as well as an expensive production.** With the more widespread use of the Rutherford cable as well as **automation of the (mass) production process, the production costs can be reduced significantly.**



Figure 3: Superconducting Rutherford cable composed of 28 strands (Lackner 2017)

Thermal treatment

The Rutherford cable, which is wound on the coil with the support of a ceramic binder, is very fragile at that moment. By heating the entire coil for more than 150 hours at temperatures between 210 °C and 665 °C, niobium and tin form the superconducting intermetallic Nb₃Sn compound (Scanlan, 1986). The oven, which can reach a temperature of 900 °C, is 10.5 meters long and has a volume of 10,000 l. In comparison, blast furnaces in the steel industry use ovens reaching temperatures from 200 °C to 1,600 °C, yet with far less precision (Berger, 2018). For CERN's oven, argon is used as a protective gas in order to protect the metal from oxidation (Rossi, 2015). 16 heating zones inside the oven allow a temperature uniformity of +/- 3 °C (Lackner *et al.*, 2016). Compared to other industries, for instance, the steel industry, CERN can heat its material much more precisely as conventional ovens can only assure a maximum variation of +/- 10 °C (Berger, 2018; Dickert, 2018). **By finding more demand for this specific oven, CERN could reduce production costs for their superconducting magnets and**

would also benefit from increasing the utilisation rate of their oven, which is currently 20% (Ohnweiler, 2019), as the oven can be used for other applications.



Figure 4: CERN's oven for the Thermal treatment (Lackner et al., 2016)

Vacuum impregnation with novel epoxy CTD-101K

As a next step in the production of a superconducting Nb_3Sn magnet, the vacuum impregnation with epoxy resin is isolating the coil to stabilise the intermetallic Nb_3Sn compound further. The chronology with the vacuum impregnation following the process of the thermal treatment is necessary to avoid quality problems for instance crack building on the surface. Furthermore, it is used to avoid movement of the single strand on the coil. Another reason for the usage of the novel epoxy resin (CTD-101K) is the brittleness of Nb_3Sn (Auchmann, 2018b).

The impregnation temperature and pressure are much lower than in the first thermal process and only reach a temperature of 100 °C (Auchmann, 2018a). The special requirements of the resin are that it has to withstand around 2 K and radioactive radiation without cracking. Five gallons (77 lbs.) of this type of epoxy resin cost \$ 1,280 (Tupper, 2002). **CERN would indirectly benefit from more demand for the novel epoxy through economies of scale** since epoxy manufacturers only produce specific blends in large quantities. As CERN only needs small amounts for research purposes at the moment, their resources are often scarce (Auchmann, 2018b).

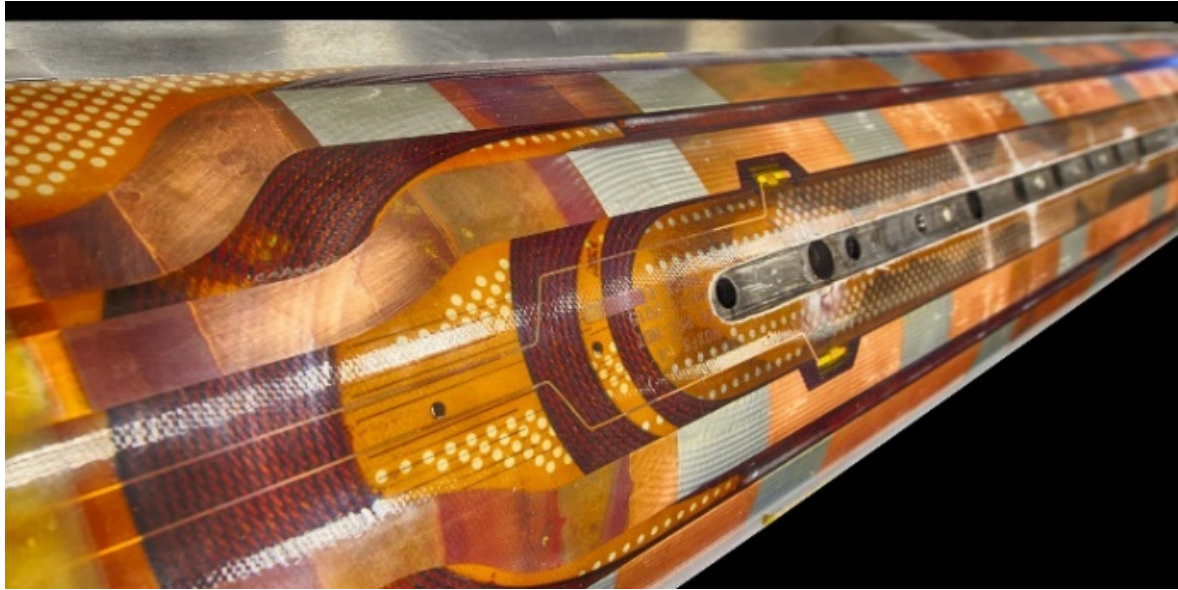


Figure 5: Part of a superconducting magnet impregnated with epoxy (Hahn, 2016)

All other processes are identified as not reasonable for taking them into account for further evaluation. They either are so unique that they are only relevant for the use of particle accelerators, or those processes are performed especially at such a high level of precision that it would not be beneficial to use them in other industries. Besides, assessing application fields of more than three production processes would exceed the scope of this project.

5 Use Benefits of the Technologies

To identify the features from an expert and user point of view, 13 experts and current users have been contacted for the first step of TCL. Ten use benefits are derived from the process' features and defined as specific advantages to existing solutions.

In a second step, the most important features in each of the analysed processes are abstracted, generalised and reformulated as use benefits for further use in this project. An explanation for each of the chosen use benefits is given later on. A full list of all mentioned features can be found in Appendix B.

Superconducting Rutherford cable	Thermal treatment	Vacuum impregnation with novel epoxy CTD-101K
<ul style="list-style-type: none"> ● Efficient transport of electricity ● Precise placement to save space ● Enabling ultra-high-precision applications 	<ul style="list-style-type: none"> ● Homogenous heating ● Fast temperature changes ● No fluctuation in quality ● Less corrosion because of protective gas 	<ul style="list-style-type: none"> ● Useful for easily breakable materials ● 100% surface sealing ● Withstand nuclear radiation

Table 2: Overview of relevant Use Benefits for each technology

5.1 Superconducting Rutherford cable

Concerning the production of the Rutherford cable, CERN is able to perform this task differently than the corresponding industry which implies several benefits for CERN's technology. The following part explains the use benefits derived from the features of the superconducting Rutherford cable.

Efficient transport of electricity

The first use benefit "efficient transport of electricity" is abstracted from several features. First of all, the Rutherford cable allows a 122 times higher current density on the same cross-section than a copper cable. Moreover, the Rutherford cable is a lot more efficient because superconductivity means that no electricity losses through heat are avoided.

Precise placement to save space

The superconducting Rutherford cable has a different shape than other cables as it is rectangular instead of round. The advantage of being rectangular is that it can be wound around coils without any empty spaces in between which means a higher current density on the same space or a reduced number of windings which reduces the overall size of a coil. In general, a rectangular cable which is not designed to conduct electricity benefits from this kind of shape in industries where space is a limiting factor.

Enabling ultra-high-precision applications

The ultra-high precision manufacturing needed for the production of the superconducting Rutherford cable leads to a significant gain in know-how about these processes at CERN. This knowledge can be useful for other industries using similar ultra-high precision manufacturing processes as CERN can support those industries to produce their highly precise products.

5.2 Thermal Treatment

The industrial oven is needed for the thermal treatment of the coils in order to make them superconducting. Four benefits were identified which are unique for this type of oven.

Homogeneous heating

The use benefit homogeneous heating is abstracted from every single particle being thoroughly heated within the oven. Moreover, the Nb₃Sn is heated at a very uniform temperature throughout the whole material resulting in all parts of the superconducting magnet receiving the same treatment and no variations in superconducting abilities (Auchmann, 2018a). Additionally, the high temperature removes every soldered joint according to Auchmann (2018a).

Fast temperature changes

Firstly, the oven can heat materials in stable intervals within a short time between each interval. During a heat treatment, the temperature can be changed at a rate of 50 °C per hour (Lackner *et al.*, 2016). As a consequence of the continuous heating, the oven has the ability to quickly react to deviations from the ideal temperature to reach the perfect temperature within the +/- 3 °C range (Ohnweiler, 2019). This makes the thermal treatment very flexible as common ovens for example in the steel industry cannot change temperatures that quickly with the required precision. Overheating is common in those industries but lead to degradation in the materials (Hörtnagl, 2018).

No fluctuation in quality

The use benefit that the materials do not have any fluctuation in quality is driven by two different features that were already mentioned before. Firstly, the material is heated very homogeneously at a range of +/-3 °C as no deviations in material quality are tolerated. Secondly, the very long heat treatment of more than 200 hours at a precisely controlled constant temperature results in the use benefit of no fluctuation in quality, and quality deviations are minimised.

Less corrosion because of protective gas

The feature that argon is used in the oven to minimise corrosion is important as thermal treatment processes with oxygen would lead to a significant shrinkage of the materials especially copper (Rossi, 2015; Ohnweiler, 2019). Argon as a protective gas is used to prevent this natural process which enables almost zero degradation of the Nb₃Sn (Auchmann, 2018a).

5.3 Vacuum Impregnation with Epoxy CTD-101K

The vacuum impregnation with the special epoxy resin is carried out to stabilize the brittle coil. Both the process as well as the specific epoxy and its benefits were investigated.

100% surface sealing

The use benefit to enable a 100% sealed surface is abstracted from two different features of the novel epoxy resin CTD-101K. Firstly, with CERN's know-how, the distribution of the epoxy is exact and uniform. Secondly, the feature of an impregnation without any crack allows increasing the stability of the sealed material. A perfectly sealed surface without any cracks can be created (Auchmann, 2018a).

Withstand high levels of ionising radiation

The novel epoxy resin CTD-101K can withstand radioactivity which is outstanding for a resin because it is an organic material which is usually affected by radiation (Auchmann, 2018b; Ulrici, 2018). The benefit of withstanding radiation gives new possible applications as more and more materials are made of epoxy resin. It has to be mentioned that there is a significant difference between the ability to withstand radioactivity and protect from radioactivity because the application fields differ significantly from each other.

Useful for easily breakable materials

The use benefit that the novel epoxy resin CTD-101K can be used for easily breakable materials arises from two features. At first, the epoxy can enhance the stability of ceramic materials, as it fills the small gaps between material, which is especially relevant for the strands of the superconducting Rutherford cable (Auchmann, 2018b). The novel epoxy resin CTD-101K is therefore used to increase the stability of the intermetallic compound Nb₃Sn.

6 Application Fields

The following chapter firstly explains why specific application fields were chosen. Secondly, the application fields are explained starting from highest to lowest potential.

Based on the defined methodology to find and define new application fields, **43 persons have been interviewed (82 persons contacted in total)**, and **three user communities were consulted**. The results of this step led to **38 application fields for the three technologies**. Viewed separately, for the superconducting **Rutherford cable 15 application fields**, for the **heat treatment 10 application fields** and the **vacuum impregnation with novel epoxy 13 application fields** have been identified.

Application fields, which show a high strategic fit and benefit relevance are listed in this chapter as high potential application fields as well as medium potential application fields which show uncertainties according to feasibility in this area. A detailed description of each high potential and medium potential application field can be found as well as the reasons for this classification, e.g. uncertainty and feasibility factors. In appendix C, descriptions of low potential application fields can be found.

6.1 Assessment of application fields

The following graphic visualises the potential of application fields for each technology according to their benefit relevance and strategic fit. Detailed theoretical information on both factors can be found in the methodology chapter. The colours of the bubbles in the graphic represent the three technologies: green for the superconducting Rutherford cable, red and orange for thermal treatment and blue for vacuum impregnation with novel epoxy. The complete set of calculations is part of Appendix D.

The size of each bubble is defined by the number of times the application field was mentioned during the interview process and is an indicator of the importance of an application field with restricted relevance.

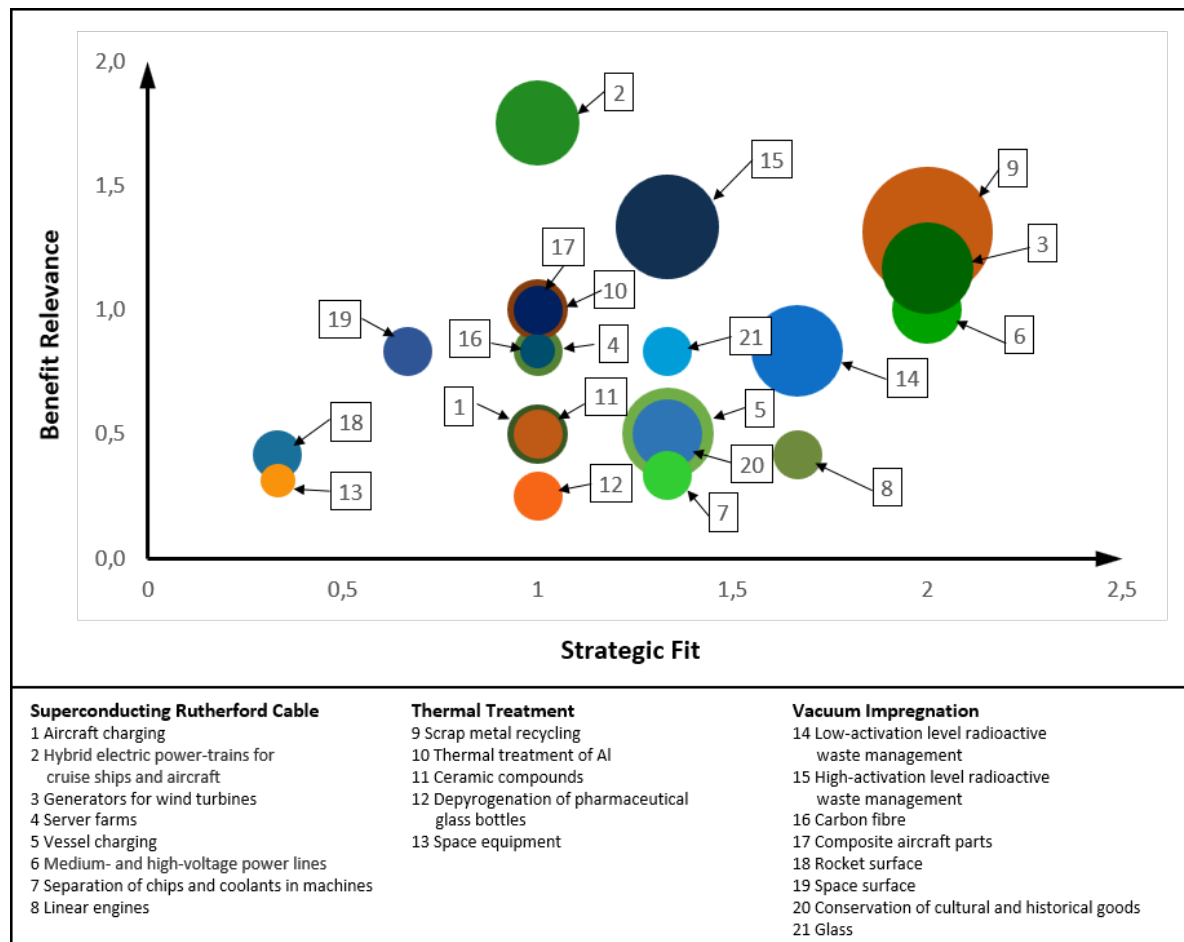


Figure 6: Assessment of all application fields

The assessment of all evaluated application fields is based on strategic fit and benefit relevance. The following table explains the classification of high, medium and low for Strategic Fit and Benefit Relevance:

	Benefit Relevance	Strategic Fit	Sum of BR and SF
High	1.0 – 2.0	1.0 – 2.0	2.5 – 4.0
Medium	0.5 – 0.9	0.5 – 0.9	1.5 – 2.4 ³
Low	0 – 0.4	0 – 0.4	0 – 1.4

Table 3: Scale for Benefit Relevance and Strategic Fit

The following table ranks the high, medium and low potential application fields. A detailed ranking of all application fields can be found in Appendix D.

³ Every application field, which is not facing a specific problem that can be solved through CERN's technologies or where current technologies are sufficient is classified as low potential application field, no matter of the sum of BR and SF.

High potential	Medium potential	Low potential
<ul style="list-style-type: none"> Scrap metal recycling Generators for wind turbines High-voltage power lines Hybrid electric power-trains for cruise ships and aircraft High-level radioactive waste management Low-level radioactive waste management 	<ul style="list-style-type: none"> Superconducting Rutherford cable <ul style="list-style-type: none"> Electric vessel charging Separation of chips and coolants in machines Aircraft charging Thermal treatment <ul style="list-style-type: none"> Thermal treatment of Al Ceramic compounds Vacuum impregnation with novel epoxy CTD-101K <ul style="list-style-type: none"> Conservation of cultural goods and art 	<ul style="list-style-type: none"> Linear engines Server Farms Depyrogenation of pharmaceutical glass bottles Space equipment Glass Composite aircraft parts Carbon fibre Satellite surface Rocket surface

Table 4: Overview of high, medium and low potential application fields according to their assessment

6.2 High Potential Application Fields

6.2.1 Scrap metal recycling

The importance of recycling is prevalent and will increase in the future, as implementing environmentally friendly production technologies is a key factor to improve overall sustainability. Therefore, it is necessary to recycle resources, especially aluminium which is nowadays reused to protect the environment. Another reason for recycling metals is that many materials, such as cobalt or platinum, are rare (in terms of quantity) and reusing them will ensure that these materials are still available for the industry. The specific use case here is the melting of finished goods to regain the raw materials. As an example, **aluminium-magnesium engines can be recycled using a high-precision oven as both metals have different melting points below 1.000 °C** (Bauer, 2018b) which is the maximum achievable temperature for this technology (Ohnweiler, 2019).



Figure 7 (left): Layout of scrap metal recycling facilities at Recco Non Ferro Metals B.V. (2018)

Figure 8 (right): Scrap metal recycling process of Recco Non Ferro Metals B.V. (2018)

Problem description

Bauer (2018a) explained the problem of the scrap recycling process as time- and cost-consuming. Current solutions are operating with gas instead of electricity which harms the environment. Moreover, specific products like magnesium engines cannot be recycled at the time because no protective gas is used during the recycling process (Bauer, 2018b). Furthermore, several ovens are needed to split the metals in its pure forms.

Current solutions

Current solutions for scrap metal recycling consist of several different process steps, which means that each sub-process is done by a specific machine or oven.

“The first step in this long process is to shred all metals into small pieces. Further steps include melting or other processes to separate the pieces” (Bauer, 2018a).

Melting metals requires, today, different ovens for different metals which is a rather inefficient method to perform the recycling process (Bauer, 2018a).

Potential of the technology within the application field

Using CERN’s oven leads to a **reduction of process steps by simply using only one to split the metals by melting them on individual temperatures with high accuracy** (Recco Non Ferro Metals B.V., 2018, 2018; Hollnsteiner, 2018). Specifically, those ovens enable separating the metals with individual melting points, for instance, the melting point of lead is 327 °C, whereas aluminium melts at 660 °C and silver at 962 °C (Lenntech BV, n.d.). **All mentioned metals, for example, are used in mobile phones and therefore recycling those metals will become even more important in the future** as many of those metals are very rare (Informationszentrums Mobilfunk, n.d.). *“In particular the recycling of aluminium cans is of immense output as only in the United States 56 billion cans were recycled in 2016”* (Institute of Scrap Recycling Industries Inc., 2016).

CERN’s skill to heat up to the same temperature throughout the whole oven can be supportive for the scrap metal recycling businesses as this will improve the quality in which the melting process can be performed in. The community of the Scrap Metal Forum (2018) also sees high potential for the technology in the recycling industry. Scrap metal recycling is an important environmental issue as 145 trillion tons of scrap appear every year, of which around 50% are metallic (Institute of Scrap Recycling Industries Inc., 2018).

Restrictions and need for adaptation

Since the melting points of commonly used metals vary between 200 °C and 2,000 °C, an extension of CERN’s technology is needed to melt metals above 1,000 °C. The following table displays the melting points of commonly used metals:

Metal	Melting point in °C
Tin	232
Cadmium	321
Lead	327
Magnesium	639
Aluminium	660
Silver	962
Gold	1064
Copper	1083
Iron	1535
Palladium	1552

Table 5: Melting points of the most important metals used (Lenntech BV, n.d.)

Benefit relevance and strategic fit

The problem in this application field was mentioned by experts operating in the scrap metal recycling industry, for instance, Berger (2018), Bauer (2018a) and Dickert (2018). Moreover, the forum members of the Scrap Metal Forum (2018) mentioned the application field which results in 14 mentions in total. Generally, the problem is highly relevant and will be much more important in the future. The range of affected people is large. By taking the relevant benefits and relevance index into account, the benefit relevance for the scrap metal recycling is high (1.3).

The strategic fit is also high (2), resulting from a low time to market and only little need for adaptation. The market for this solution is big in terms of scrap volume.

Based on the sum of benefit relevance and strategic fit (3.3) this application field is part of the high potential application fields since this technology can solve the problem of the industry in an efficient and effective way.

6.2.2 Generators for wind turbines

Generators are used to transform kinetic energy into electricity. Therefore, generators are used in nearly all kinds of power plants and ensure our electricity supply.

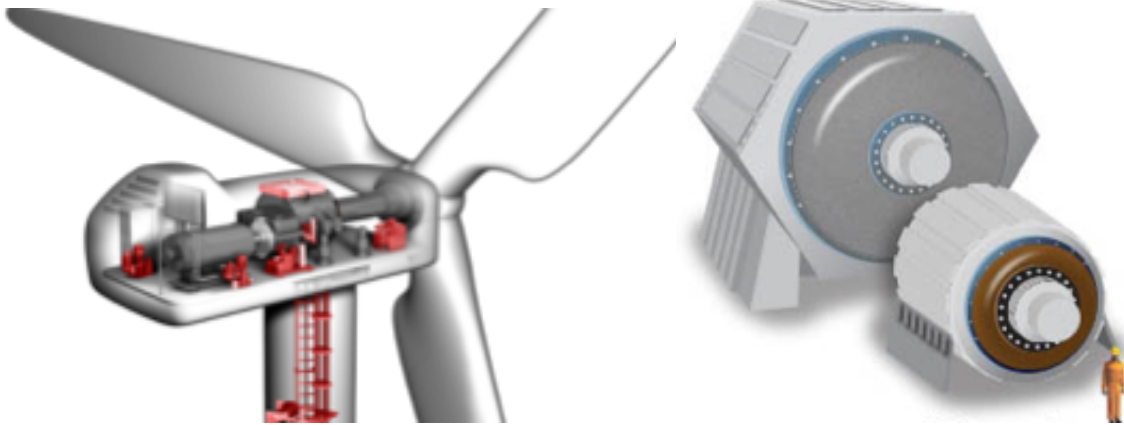


Figure 9 (left): Profile of the nacelle of a wind turbine (Superconductor Technologies Inc., 2018)

Figure 10 (right): Comparison of the generator's size with using a copper cable and a superconducting cable (Superconductor Technologies Inc., 2018)

Problem description

Current generators with conventional copper wires cannot be built as powerful, small or lightweight to fully exploit the potential of the wind powering the generators. Current types of wind turbines are limited by their size of the generator (onshore) and the weight of the nacelle (offshore).

“The size is mainly a problem for onshore wind turbines, as transport of the generator to the wind turbine tower with special shipment is costly and complicated”

(Bührer, 2018).

For offshore wind turbines, weight is currently the limiting factor.

Current solutions

Currently, the constraints in size and weight do not allow large and powerful generators over 6.5 megawatts to be built in areas where these limitations are significant (Superconductor Technologies Inc., 2018). Due to the leverage of a high mass (the generator) on the top of the wind turbine tower, the construction has to be very robust. Moreover, the size of the wind turbine towers is limited as the construction is more expensive the higher and more stable the tower has to be.

Potential of the technology within the application field

This application field has already been identified by CERN before, yet it was verified by this research. Firstly, due to the effects of the superconducting material, superconducting generators can achieve a 2-8% higher efficiency compared to conventional generators over a greater speed range (Schmickler, 2010). Secondly,

“[...] using superconducting materials, engines and generators can be constructed smaller and lighter, depending on the requirements of the generator” (Bührer, 2018).

In the field of wind turbines, these benefits lead to less weight or a smaller size of the nacelle and allow a significantly simpler and cheaper construction of the tower. Additionally, wind turbines can be constructed larger and more powerful with a higher output, which is especially relevant for offshore wind turbines (Kellers, 2015; Bührer, 2018).

Restrictions and need for adaptation

An issue for applying superconducting generators can be the additional cooling facilities. Superconducting wind generators are only efficient if additional weight and effort for cooling are smaller than the efficiency gain of using a superconducting generator. With LTS material, the energy needed for cooling down to around 4 K could exceed the total energy production of the generator (Bührer, 2018; Schmickler, 2010). However, superconductors are the only way to physically reach more than 6.5 megawatts (Superconductor Technologies Inc., 2018). The other restriction is currently the high price for superconducting material, making this technology only economically feasible in specific cases as of now (Bührer, 2018). *“However, by spreading the use of superconducting materials, the price of this technology can be reduced significantly”* (Schörling, 2018).

Benefit relevance and strategic fit

As most of the use benefits of the superconducting Rutherford cable, such as the efficient transport of electricity, the flexibility and the precise placement are valuable for this application field, the benefit relevance is considered as high (1.2). Moreover, companies promote superconductors as a valuable solution (Superconductor Technologies Inc., 2018) and experts like Bührer (2018) confirmed the relevance of this application field.

As the application of superconducting generators has already successfully been tested by the EU-funded EcoSwing superconducting wind turbine project (Kellers, 2018), the application field has the highest possible Strategic Fit (2.0). However, the high costs of the superconducting material and the cooling facilities currently limit the widespread use of these technologies. Further R&D has to be conducted in this field to increase the number of applications, which consequently will reduce the costs of the superconducting materials.

Moreover, superconducting generators have also been tested in the hydropower station in Hirschaid (Germany) and as engines for cruise ships (Schmickler, 2010).

6.2.3 High-voltage power lines

High-voltage power lines are used to transport electricity over long distances. Due to the ohmic and inductive resistance of the material (usually aluminium or copper), it heats up, and energy gets lost.

Problem description

Long AC high-voltage power lines have high losses up to 40 % for a 1,000 km line (Merschel, 2017). Therefore, landlines are only economically efficient up to 600 km and buried cables only up to 80 km (Wagner, 2017). Moreover, the capacity in cable ducts, which are mainly used in cities to transport electricity, is limited (Guttek, 2017; Expo Fortschrittmotor Klimaschutz GmbH, n.d.).

Current solutions

Currently, many cables or frequent transformer stations are used to transport large amounts of electricity. Especially in cities, the large transformer stations need lots of valuable space (Nexans, 2012). For very long distances, high-voltage direct current lines are used, despite their downsides in conversion, switching, control, availability, and maintenance leading to costly converter stations to transform the electricity back into the normal AC network.

Potential of the technology within the application field

Superconductors can replace all kind of landlines and buried cables to transport electricity without losses. This would improve the energy efficiency of the electricity grid and enable new energy sources to be exploited, such as the Sahara. The DESERTEC project, for example, aims to produce electricity in the desert and then transmit it to Europe in order to supply Europe with “clean energy.”

In Essen, the AmpaCity project replaced five 110 kV cables by one 10 kV superconducting cable, leading to a major space saving in the cable ducts of the city (Guttek, 2017). Moreover, by replacing high-voltage 110 kV cables with a medium-voltage 10 kV superconducting cable, resource- and land-intensive transformer stations could be abolished in city centres, freeing up very valuable space in city areas (Nexans, 2012). *“In general, superconductors can have a vast impact on inner-city networks and will be a major driver for their transformation”* (ARD, 2014).

AmpaCity showed that the operation of the superconducting cable and the cooling facilities for the liquid nitrogen required only half of the energy of the previous 110 kV cable-system (Expo Fortschrittmotor Klimaschutz GmbH, n.d.).

Restrictions and need for adaptation

The most significant issues still are the cooling technologies, as liquid nitrogen requires frequent cooling stations. Currently, the technology is being used for short cable distances and can only be used for longer distances if being built with several smaller segments. According to Bühler (2018), the maximum length for one segment is limited by the cooling capacity of the (liquid) cryogen which is 1 km. Therefore, significant improvement in cooling technologies, as well as an advancement in superconducting materials, has to be made that materials with a higher critical temperature can be used for high-voltage power lines (Bühler, 2018).

Benefit Relevance and Strategic Fit

Having in mind the expensive cooling technologies and the need for further developments in superconductors' technologies, the Benefit Relevance is high (1.0). Due to the fact that the industry is already experimenting on the technology and that significant progress could have been observed in the last years (Noe, 2017), the Strategic Fit is the highest possible (2.0).

6.2.4 Hybrid electric power-trains for cruise ships and aircraft

Another application field for the Rutherford cable occurs for cables in a hybrid-electric aircraft or cruise ship. Aircraft powered by a hybrid-electric powertrain need an electric cable that conducts a high current density to transfer the power from the electricity generator to the engines (Noe, 2017). This concept of hybrid-electric powertrains is currently used for cruise ships because current battery technologies are not sufficient to operate those ships purely electrical, and will likely to be relevant for aircraft in the future. Furthermore, with current hybrid-electric technologies (the reduction of weight through a Rutherford cable not included), the fuel consumption can be reduced by 12 % just because of the interaction of the electricity generator and the non-electric engine (Donateo and Spedicato, 2017).

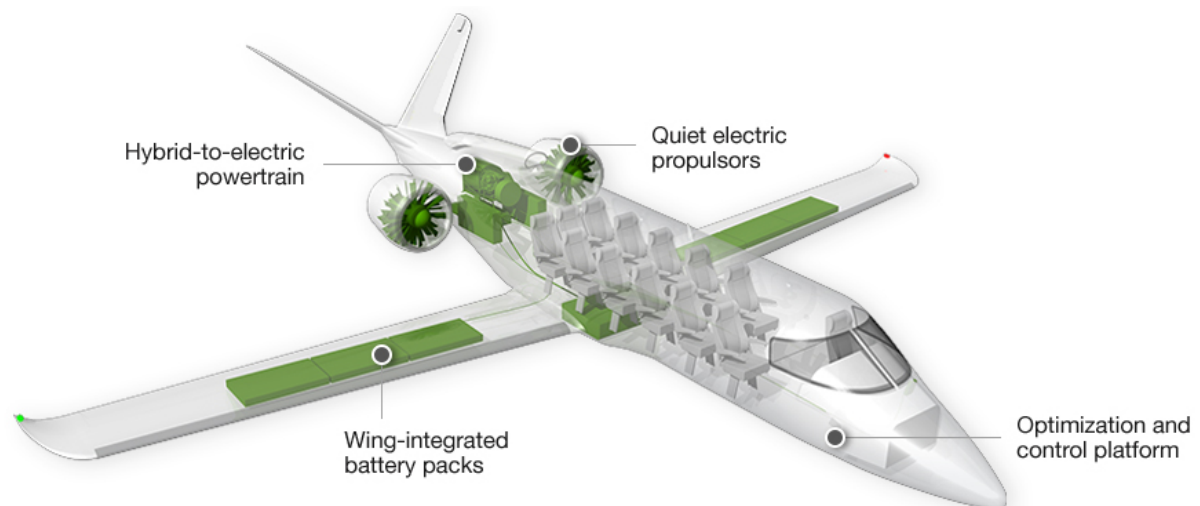


Figure 11: Hybrid-electric powertrain in the aircraft model of Zunum Aero (Zunum Aero, 2017)

Problem description

At the moment, several thick and therefore heavy and bulky cables would be necessary to transport the required amounts of current density within the aircraft or cruise ship, increasing the weight and reducing the usable space of the aircraft or cruise ship significantly. For example, a reduction of 35 kg of weight will mean an annual reduction of 80 tonnes of kerosene just for Lufthansa Cargo only (Bundesverband der Deutschen Luftverkehrswirtschaft e.V., n.d.). This results in savings of € 60,000 in fuel expenses with the current kerosene price standing at € 0.60 (Portschy, 2018).

Current solutions

Currently, bulky and heavy copper cables are used to transport the power from the electricity generator to the engines. Their weight leads to increased fuel consumption.

Potential of the technology within the application field

For this reason, the potential to use the Rutherford cable is the reduction in weight of an aircraft or cruise ship because the same amount of electricity can then be transported through a smaller and lighter superconducting Rutherford cable. The achievable weight reduction and consequently decrease in fuel consumption by the use of a lighter superconducting Rutherford cable instead of a heavy copper remains uncertain. Further research is necessary to calculate the maximum possible efficiency gain.

Restrictions and need for adaptation

To assess the efficiency of using the superconducting Rutherford cable for hybrid-electric powertrains in an aircraft and cruise ships, the total weight loss, including the additional cooling facilities, has to be taken into account (Noe, 2017). Further advancement in lighter cooling technologies as well as in superconducting materials will increase the diffusion of this technology.

Benefit relevance and strategic fit

The problem is highly relevant as hybrid electric power-trains are already widespread in cruise ships and likely to become a standard in the aviation industry. In particular, with a view on environmental protection regulations, hybrid electrical aircraft will become necessary for the airline industry to be able to meet the emission targets. This leads to a high Benefit Relevance (1.8). Furthermore, the market fit is very high, as the potential market use of the Rutherford cable in hybrid-electric aircraft would be large in particular with regards to the possible growth in this market. As hybrid electric power-trains are already used for cruise ships the time to market is low. Moreover, there is a low need for adaptation caused by the strict weight limitations of the aircraft. This all leads to a high strategic fit (1.0).

6.2.5 High-activation level radioactive waste management

The high-activation level radioactive waste management is responsible for waste with a long half-life (few millennia), most of which result from nuclear power plants like plutonium. Plutonium e.g. has a long half-life of 24,110 years, so it needs to be stored away from civilization for the next 240,000 years.



Figure 12: Illustration where the novel epoxy CTD-101K might be used for radioactive waste containment

Problem description and current solution

At the moment, it is not possible to store the waste permanently under the claimed conditions. The current solutions are designed in a way that the waste is stored in facilities which are specialised in dealing with high-activation level radioactive waste. It is necessary that the containers, which are the critical element in the storing process, are absolutely leak-tight for a long time (Ulrici, 2018).

“The problem which arises now is that regulations, especially in Germany, are getting stricter regarding the requirements for radioactive waste containers” (Stein, 2018).

Stein (2018), project manager at Nagra, described the problem that companies in Germany suffer from the strengthened legislation and that their containers do not fulfil the legal requirements any longer. The sealing of the containers is not able to handle the radioactivity for the demanded time.

Potential of the technology within the application field

Stein (2018) explained that the usage of the novel epoxy as a material to seal the containers might be a possible solution for the strengthened requirements in Germany. Advantages of this technique would be that the containers are permanently sealed off and the characteristics of the novel epoxy are well designed for use in application fields connected to radioactivity.

Restrictions and need for adaptation

There could be a need for adaptation in terms of characteristics of the novel epoxy when it comes to withstanding radioactivity and for the application process of the epoxy.

Benefit Relevance and Strategic Fit

The problem in this field was mentioned nine times by experts for example Stein (2018) and Ulrici (2018) and forum users of the physics forum. Furthermore, the problem is highly relevant now and will become more important in the future, as the range of people affected by the storage of radioactive waste with a long half-life is large. By taking the relevant benefits and relevance index into account, the benefit relevance for the high-activation level radioactive waste management is high (1.3).

The strategic fit, which results from a medium time to market and some need for adaptation, is also high (1.3). The market for this solution is high in terms of volume according to Stein (2018).

Based on the sum of benefit relevance and strategic fit (2.6) this application field is part of the high potential application fields for vacuum impregnation with novel epoxy.

6.2.6 Low-activation level radioactive waste management

The low-activation level radioactive waste management includes the treatment of substances and waste with a low half-life (around 40 years). An example for an industry where low-activation level radioactive waste is produced is contaminated equipment in hospitals, especially in the radiology department (Hanson, 2001).

Problem description

The biggest problem that arises through the low-activation level waste disposal is that current solutions for waste management are not absolutely leak-tight. This can result in contamination of the environment. Furthermore, the waste can have an adverse effect on the groundwater for surrounding neighbourhoods.

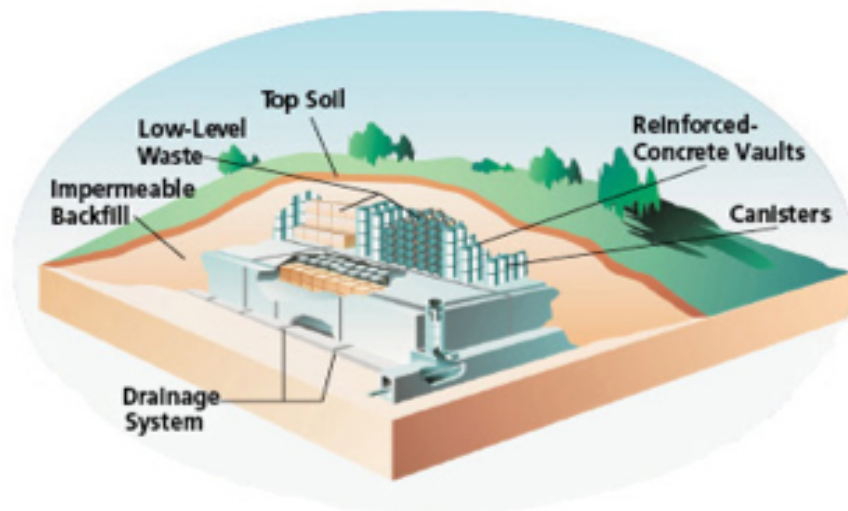


Figure 13: Low-activation level radioactive waste disposal (Deegan, 2011)

Current solutions

According to Ulrici (2018), waste that arises in CERN's facilities consists mainly of low-activation level radioactive waste and is stored in special facilities in sparsely populated areas in France, where the legal requirements are fulfilled with the current solution. Low-activation level radioactive waste is often stored by using this method (Ulrici, 2018).

Potential of the technology within the application field

To solve the current problem, the novel epoxy could be used to make the storage facilities leak-tight and save the water from pollution. On the other hand, using the epoxy to seal the waste could possibly increase the number of possible areas to store low-activation level radioactive waste. As the novel epoxy resin can withstand radioactivity, it can be used as filling material in radioactive waste containers to protect the shell of those boxes.

Furthermore, there is a high potential that laws in the EU are getting stricter in the near future, as it is already observable in Germany (Stein, 2018). The whole application of epoxy in this field would lead to an increase in corporate social responsibility.

Restrictions and need for adaptation

There could be a need for adaptation in terms of the characteristics of the novel epoxy when it comes to viscosity (low viscosity is required to reach every tiny gap on the surface) and for the application process of the epoxy.

Benefit Relevance and Strategic Fit

The problem in this application field was mentioned seven times by experts of the industry, such as Stein (2018) and Ulrici (2018), and forum members of the physics forum.

Furthermore, the problem will be much more important in the future as radioactive waste is permanently accumulating. At the moment, current solutions are sufficient, but the rising awareness of protecting the environment will lead to an increased need to solve this issue. The range of affected people is not clearly distinguishable because of different legislations and missing information about radioactive waste disposals. By taking the relevant benefits as well as the relevance index into account, the benefit relevance for the low-activation level radioactive waste management is medium (0.8).

The strategic fit, which results from a medium time to market and possibly only little need for adaptation, can be considered as high (1.7). The market for this solution is high in terms of volume according to Ulrici (2018).

Based on the sum of benefit relevance and strategic fit (2.5), this application field is part of the high potential application fields for vacuum impregnation with novel epoxy.

6.3 Medium Potential Application Fields

6.3.1 Superconducting Rutherford cable

Electric vessel charging

Instead of powering vessels with heavy fuel oil, they can also be driven electrically. Just like aircraft charging, the superconducting Rutherford cable can also be used to charge them electrically.



Figure 14: Electric vessel EC 110 developed by PortLiner (PortLiner, 2018)

Problem description

The shipping industry seeks to keep the time docked at the harbour as short as possible. Especially cargo ships usually only enter the harbour to load and unload their cargo. According to Krüger (2019), cargo vessels remain between 1 to 5 hours in the harbour. The maximum duration in the harbour is 2 days in case a big scale vessel (length more than 300 m) being a fully loaded. Consequently, this will mean that the charging for an electric vessel needs to be within this 1 to 5 hours' time frame. Those requirements

cannot be met with the current technologies because a medium sized vessel (length between 100-250 m) would need more than 24 hours, which

“would cause big cargo ports like the port of Hamburg to create by far less container turnover and additional costs for personnel to swap the batteries” (Krüger, 2019).

Current solutions

The electric vessels currently developed, such as the ones of the EU-funded Dutch start-up Portliner, are manufactured with two options of recharging them. The first (and currently most efficient) option would be to exchange modular batteries when docking at the harbour. The modular battery is a container in which batteries are stored. Those containers are then exchanged in the harbour with a full battery (Port of Rotterdam, 2018). The second option is to charge the vessel (with an integrated battery) with a copper cable instead of swapping batteries. However, this approach would not be sufficient to charge the vessel in the required amount of time (1 to 5 hours). Currently, the first option of swapping batteries has an advantage compared to the slow direct charging.

Potential of the technology within the application field

To solve this problem, the superconducting Rutherford cable will be used to charge the vessels because it is an efficient way to transport the required amount of electricity through a cable within time at the harbour. Furthermore, it would reduce the personnel costs that currently arise in the battery swapping option.

Restrictions and need for adaptation

“[...] battery technology is simply not competitive and still requires significant further evolution in terms of performance and cost reduction before it could be preferable to current fuel options” (Lloyd’s Register Group Limited and University Maritime Advisory Services, 2017)

Up to now, no solutions for electric vessels’ battery capacities have been found that allows them to travel long distances. Therefore, an adaptation including an improvement of the battery technologies will be necessary, but research is already conducted by several businesses (Enevale Corporation, n.d.) to improve battery capacities. At the time, attempts have been made only to build short- and medium distance electric vessels such as PortLiner (2018).

Benefit relevance and strategic fit

The problem is highly relevant as the costly and time-consuming removal of the battery can be avoided by charging it directly. By taking the relevant benefits and the relevance index into account, the benefit relevance for the electric vessel charging is medium (0.5).

The strategic fit is high (1.3) because the time horizon was assessed to be medium-term. Additionally, the market fit is medium too, because it is unsure whether electrical vessels will prevail. Furthermore,

the technical fit is high because there is a low need for adaptation once battery technologies are capable of charging at the same current as the Rutherford cable.

Separation of chips and coolants in machines

Modern CNC (computer numerical control) machines and other equipment in the manufacturing industry are producing a variety of products made of materials like iron or aluminium. During the process where chips (kind of waste) accrue, heat arises from the tools and coolants need to be applied to hinder the materials from overheating and damaging the equipment.

Problem description

All machines suffer from the same problem that splitting the chips and coolant after usage is a cumbersome process. The result is a kind of soup which contains waste and coolant, and complex filtering techniques are needed in order to reuse the coolant.

Current solutions

Today, all machines use sieves to separate chips and coolant, but this method leads to problems, e.g. the sieve is plugging through the mixture of coolant and material chips. This can cause damages to the tools or long maintenance times. Current solutions, therefore, are not sufficient.

Potential of the technology within the application field

The solution to this problem is using a linear magnetic field to separate the chips from the fluid. The result would be a clear separation of the coolant and the waste (chips of the material) and allows reusing of the coolant. Consequently, the magnetic field would lead to a shortening of the maintenance time. *“The linear magnetic field is created through the special winding technique of CERN”* (Noe, 2018). Another important fact in terms of market potential for this technology is that almost every iron editing related process, which is not a thermal process, is done by CNC machines.

Restrictions and need for adaptation

The main issue in using linear magnetic fields in machines is the limitation that only ferromagnetic (iron, cobalt and nickel) materials are separable. Materials such as aluminium cannot be divided from coolants by using this technique.

Benefit Relevance and Strategic Fit

The problem was mentioned two times by experts in this field like Lechner (2018). Furthermore, the problem is highly relevant because existing solutions are not sufficient, but it is not clear if the problem will be more important in the future. By taking the relevant benefits and relevance index into account, the Benefit Relevance for the separation of chips in machines is low (0.3).

The high strategic fit (1.3) results from a low time to market and a medium need for adaptation (just the problem of working with materials like aluminium must be managed). *“There is, unfortunately, uncertainty about the size of the market for such a solution”* (Noe, 2018).

Based on the sum of Benefit Relevance and Strategic Fit (1.8), this application field is part of the medium potential application fields, and it is not clear if this method could be realised and solve the industries' problems.

Aircraft charging

Currently, the awareness, in particular in Europe, to protect the environment has grown due to increasing carbon dioxide emissions. One particular pollutant of carbon dioxide is the aviation industry with about 4.9 % of the worldwide carbon dioxide emission (Bund für Umwelt und Naturschutz Deutschland e.V., n.d.). Consequently, the two major aircraft manufacturers Boeing and Airbus noticed the potential of developing electric aircraft, as this aligns with their aim to reduce carbon dioxide emissions. Therefore, Boeing financially supports the start-up Zunum Aero which plans to introduce the first electric aircraft by 2022 (Zunum Aero, 2017).

Problem description

“One current problem is that the charging of the electric aircraft is not quick enough as a commercial aircraft usually remains only 45 minutes to one hour at the airport to load and unload passengers as well as preparing it for the next takeoff”

(Salm-Reifferscheidt, 2019).

At the moment, aircraft spend most of their time in the air as they are not productive on the ground. The problem is that those 45 minutes to one hour would be too short to fully charge the battery.

Current solutions

Current solutions to charge an electric aircraft in a short amount of time do not exist. Instead, Zunum Aero has developed bays for modular battery packs for easy removal. This means that the empty batteries are swapped against full batteries instead of charging them between arrival and departure. Generally, all the personnel needed to handle aeroplanes is an enormous expense not only logistically but also financially. As explained by Salm-Reifferscheidt (2019): “those battery swaps would even increase this effort as additional staff is needed to coordinate all battery exchanges on an airport.” To simply plug the aircraft to the power grid can be undertaken much easier. Not only is the charging process itself quicker, but also the organisation can be performed more time- and cost-efficient (Salm-Reifferscheidt, 2019).

Potential of the technology within the application field

Using the superconducting Rutherford cable to charge electric aeroplanes could accelerate the charging as it allows a 122 times higher current density than a conventional copper cable. Finally, the Rutherford cable could make electric aeroplane feasible in the future (e.g. the Zunum Aero project) and would help to reduce the carbon dioxide emission of the aviation industry.

Restrictions and need for adaptation

Similar to the vessel batteries,

“[...] current battery technology would not withstand the high current flow of the Rutherford cable, so further development of battery technologies will be necessary”

(Noe, 2018).

Currently, a lot of research is conducted to improve the battery storages to withstand fast charging cycles.

Benefit relevance and strategic fit

The solution can be of immense importance in the future as the airline industry is expected to grow rapidly by 4.4 % p.a. over the next 20 years (AIRBUS S.A.S., 2018). This results in a need for new aircraft with a total value of \$ 5.8 trillion (AIRBUS S.A.S., 2018). Electric aircraft are an effective solution to reduce carbon emissions of this industry which leads to a medium Benefit Relevance (0.5).

The strategic fit is high (1.0), which can be explained by the fact that the Rutherford cable can be used in the near future (low time to market). However, the need to adapt the current battery technologies remains.

6.3.2 Thermal treatment

Thermal treatment of aluminium

Thermal treatment of aluminium comprises technologies like tempering and hardening. The goal of this technique is to change the characteristics of aluminium and alloys containing aluminium.

Problem description

Aluminium, as opposed to steel, needs uniform temperatures of +/- 2 °C because “[t]emperature uniformity is very important to the quality of the forming process” (Wang *et al.*, 2015, p. 357). The uniform temperature is needed to, “[...] improve the mechanical and physical properties of the aluminium alloy, including strength, hardness and corrosion resistance.” (Shen *et al.*, 2016, p. 1720).

Aluminium is mainly used in the form of alloys (e.g. magnesium, manganese, copper, etc.) which can be adjusted in their characteristics through hardening and tempering processes. Especially tempering needs exact temperatures to increase toughness and reduce stress, roughly 121 °C (the tempering temperature has to be below the critical point at a specific pressure). In contrast to the tempering process, alloys of aluminium need constant temperatures of up to 400 °C over an extended period of time for their forming process. Typically between 24 to 48 hours are required by different industries like the automotive one (Cina, 1973).

Current solutions

At the moment, ovens with gas are used for thermal treatment of aluminium because they can quickly react to the needed temperature changes.

Potential of the technology within the application field

The thermal treatment technology of CERN has the same characteristics like fast temperature changes that are needed for treatment of aluminium. Moreover, the volume of the oven is sufficient to produce large quantities or pieces.

Restrictions and need for adaptation

There are no restrictions or need for adaptation to use the process for the thermal treatment of aluminium. The oven needs to be modified only to the specific type of products which can be done easily according to the manufacturer of the oven (Ohnweiler, 2019).

Benefit Relevance and Strategic Fit

The problem in this field was mentioned three times by experts of the industry like Anonymous (2018), a technical employee at Ebner Industrieofenbau. Furthermore, the relevance of the problem and sufficiency of current solutions is not clearly identifiable at the moment. According to the calculation, the Benefit Relevance is high (1.0).

The high Strategic Fit (1.0) is resulting from a low time to market and no need for adaptation. The market for this solution is high in terms of aluminium usage volume.

Based on Benefit Relevance and Strategic Fit this application field is part of the medium potential application fields, but it is still not clear if the current solutions are sufficient for the industry.

Ceramic compounds

Ceramic compounds have to be treated thermally with temperatures of up to 1.400 °C either for technical use cases or for household applications. The size of ovens used at ceramic manufacturers can reach a maximum of 6,000l which is 40 % less than the one used at CERN (Hörtnagl, 2018). However, the current energy source is gas as opposed to electricity (CERN). The reason why electricity is not common for recycling furnaces is that it is a more expensive source of energy, but it allows a higher precision of temperature uniformity.

Problem description

Ceramic compounds have to be heated thoroughly, but in order to save time, the oven is “overheated” to fasten the process which results in significant shrinkage of the ceramics. The material input is, therefore, higher than needed.

Current solution

In the current situation, ovens heat with a much higher temperature of up to 1,400°C but with a lower uniformity. In order to measure the shrinkage, a reference piece is inserted, and the difference in sized is observed there.

Potential of the technology within the application field

A benefit for the ceramic industry would be an oven which is as precise as in the case of CERN with +/- 3 °C because shrinkage occurs during the thermal treatment if the temperature is higher than necessary. CERN's oven could reduce the shrinkage and therefore material cost for ceramic manufacturers who need heat treatment up to 1,000 °C which is mainly needed for sanitary and dishes but also for some technical ceramic applications. Another benefit is the large size of the oven (10,000l) which allows more products to be processed at the same time, as opposed, e.g. to the maximum size of the oven at the Austrian ceramic manufacturer "STEKA Werke" which is around 6,000 l.

Restrictions and need for adaptation

The main restriction is the limited temperature. An adaptation is necessary concerning the protective gas because a number of applications need nitrogen as opposed to argon used at CERN.

Benefit Relevance and Strategic Fit

The problem in this field was mentioned two times. The problem of shrinkage in ceramic compounds will be more important in the future as ceramics have a high number of future applications like artificial hips, brake discs, thermostats, isolations, and lamp sockets (Hörtnagl, 2018). The total strategic fit is high (1.0) whereas the benefit relevance is low (0.5).

6.3.3 Vacuum impregnation with novel epoxy CTD-101K

Conservation and restoration of cultural goods and art

Cultural goods (ancient ceramic, frescoes, sculptures, etc.) and art are vulnerable to damages through external conditions.

Problem description

One of the major challenges in this sector is to protect historical goods from external factors, such as humidity, dust or other damaging factors.

Current solutions

Current solutions comprise several different techniques to restore and conserve cultural goods which include (but are not limited to) special glues, tapes and papers as well as boxes with sealed closures (Klug-Conservation, n.d.).

Potential of the technology within the application field

Using the novel epoxy for the conservation of historical goods could improve the quality of the protection in this sector (Haupt, 2018; Hollnsteiner, 2018). Especially the absolute surface sealing helps to protect the goods from humidity and dust. Another fact is that for example vases can easily be restored with the novel epoxy.

Restrictions and need for adaptation

For using the epoxy in this application area, it is necessary that the epoxy is transparent when it is used. Further research needs to be conducted to identify the exact need for adaptation.

Benefit Relevance and Strategic Fit

The problem in this field was mentioned 4 times by experts of the industry. The relevance of the problem, its solutions and affected people by the problem is not clearly defined after interviewing several experts. Therefore the benefit relevance is medium (0.5)

The strategic fit is high (1.3) which results from a medium time to market and low need for adaptation. The market for using the novel epoxy in this application field is very small according to Haupt (2018).

Based on benefit relevance and strategic fit this application field is part of the medium potential application fields for vacuum impregnation with novel epoxy.

7 Recommendations

The recommendations are divided into three parts, beginning with the specific application fields for the selected technologies. In the second part, potential companies for a cooperation with CERN are mentioned and in the third part, further R&D on the selected technologies is suggested.

CERN should focus on the few highest potential applications fields, which were identified in this project. In particular the **scrap metal recycling is of significant interest because of its future relevance** at European-wide scale. **The society is evolving towards a circular economy where waste has to be transformed into raw materials. This opens the doors for future cooperation with a number of firms along the entire value chain in which thermal treatment can be a key element.**

New applications for the Rutherford cable also have high relevance in reducing the overall cost of a superconducting magnet because more demand for the cable means lower costs of raw materials. Similar patterns were observed during and after the construction of the LHC (Bührer, 2018). Two of the application fields (large-scale generators and power lines) were already known to CERN but were confirmed by experts in these fields. **To assess the market potentials of the various applications, the concluding step of TCL needs to be conducted. A scientific and engineering backed market feasibility study will support CERN to convince decision makers in the industry and helps to find new partners or increase the relationships with current ones.**

Current and **potential partners** of CERN which showed a high interest in leveraging their technology competence are **Carbolite Gero**, the manufacturer of the oven who wants to leverage their product, **RUAG Space**, which is a leading supplier of cryogenic facilities, wants to provide their knowledge for the new SCMs, **GNS**, a German manufacturer of radioactive waste containers that is interested in the epoxy resin, **ECO5**, an engineering consultancy which plans on- and offshore wind parks based on HTS generators, and **NAGRA**, a Swiss operator of final repositories for nuclear waste is interested in the possible usage of epoxy resin. It was observed that **companies who face a lower level of competition are more willing to share information and key insights** like the scrap metal recycling industry as opposed to aerospace manufacturers where only a handful companies supply a global market. **Cooperation is more likely if CERN highlights the results of this research by presenting the numerous potential applications of their technology.**

A recommendation on the observed technologies is that the **focus should be set on HTS** because of the **fewer limitations regarding the economic constraints** which arise from the lower cost for the cooling facilities both in size and costs (helium for LTS and nitrogen for HTS), as the costs for cooling LTS are between 100 and 1,000 times higher than for HTS (Bührer, 2018). The high upfront costs prevent geographically dispersed applications like power grids. Here, further research should be conducted, and cooperation with companies like Cryogenic Ltd are necessary to increase the technical applicability of LTS. More efficient refrigeration technologies are a further application enabler.

For the thermal treatment, Carbolite Gero is eager to find more customers beyond the superconducting magnet manufacturers. CERN could facilitate this process by presenting the application fields identified in this project which makes it more likely that the costs per oven for the mass production of the magnets will fall significantly. According to Auchmann (2018b), the vacuum impregnation process is not superb in comparison to the vacuum pressure impregnation. Much research was conducted by private companies, and it would be beneficial for CERN to cooperate with them to enhance the production of the superconducting magnets. Besides the vacuum impregnation process, the epoxy resin itself with its special characteristics has a high potential for other industries and an increasing demand for CTD-101K would lead to lower costs for CERN.

To sum it up, by conducting a market analysis for the industries mentioned above, new applications which are economically feasible can be exploited in order to establish the high-specialised processes in the industry. If the three researched technologies are recognised as a standard process for companies, the cost per magnet in the mass production will significantly decline.

References

- AIRBUS S.A.S. (2018), *Global Networks, Global Citizens: 2018 - 2037, Global Market Forecast*, 31707 Blagnac, France.
- ARD (2014), *Supraleiterkabel in Essen: Bilanz nach einem halben Jahr Betrieb, Tagesschau*, available at: https://www.youtube.com/watch?v=1dVB_XC9Qh0 (accessed 28 November 2018).
- Bottura, L. (2018), *Superconductivity in Big Science: a Strong driver for Industrial Innovation, Big Science Business Forum*, Copenhagen, Denmark.
- Bund für Umwelt und Naturschutz Deutschland e.V. (BUND) (n.d.), “CO₂-Emissionen des Luftverkehrs”, available at: <https://www.bund.net/mobilitaet/infrastruktur/luftverkehr/co2-emissionen/> (accessed 3 January 2019).
- Bundesverband der Deutschen Luftverkehrswirtschaft e.V. (n.d.), “CO₂ eingespart mit Leichtigkeit. Das Gewicht von Flugzeugen wird immer geringer”, available at: <https://www.klimaschutzportal.aero/verbrauch-senken/am-flugzeug/gewicht-einsparen/> (accessed 3 January 2019).
- CERN (2013), “Who funds CERN's research?”, available at: <https://voisins.cern/en/en-bref/who-funds-cerns-research> (accessed 7 November 2018).
- CERN (2015), “LHC Season 2. facts & figures”, available at: https://home.cern/sites/home.web.cern.ch/files/2018-07/factsandfigures-en_0.pdf (accessed 7 November 2018).
- CERN (2018), “About us - who we are”, available at: <https://home.cern/about/who-we-are> (accessed 7 November 2018).
- Cina, B. (1973), *Reducing the susceptibility of alloys, particularly aluminium alloys, to stress corrosion cracking* No. US3856584A, available at: <https://patents.google.com/patent/US3856584A/en> (accessed 3 January 2019).
- Deegan, G. (2011), “Low-Level Radioactive Waste. A Definition Based on What It Is Not”, available at: <https://public-blog.nrc-gateway.gov/2011/04/05/low-level-radioactive-waste-%E2%80%93-a-definition-based-on-what-it-is-not/> (accessed 28 January 2019).
- Donateo, T. and Spedicato, L. (2017), “Fuel economy of hybrid electric flight”, *Applied Energy*, Vol. 206.
- Enevate Corporation (n.d.), “Who We Are”, available at: <http://www.enevate.com/who-we-are/> (accessed 4 February 2019).

Expo Fortschrittmotor Klimaschutz GmbH (n.d.), “AmpaCity: Power grid revolution without resistance”, available at: <http://leistungsschau.klimaexpo.nrw/projekte-vorreiter/ampacity.html> (accessed 3 January 2019).

Guttek, M. (2017), “AmpaCity”, available at: <https://iam.innogy.com/en/about-innogy/innogy-innovation-technology/smart-grids/ampacity> (accessed 3 January 2019).

Hahn, R. (2016), “Physicists build ultra-powerful accelerator magnet. An international partnership to upgrade the LHC has yielded the strongest accelerator magnet ever created.”, available at: <https://www.symmetrymagazine.org/article/physicists-build-ultra-powerful-accelerator-magnet> (accessed 28 January 2019).

Hanson, B. (2001), “factsheet. What Is Low-Level Radioactive Waste?”, available at: <https://www.nj.gov/dep/rpp/llrw/download/fact10.pdf>.

Houston, S. (2018), “Advantages and Disadvantages of Composite Materials on Airplanes”, available at: <https://www.thebalancecareers.com/composite-materials-aircraft-structure-282777> (accessed 27 January 2019).

Informationszentrums Mobilfunk (IZMF e.V.) (n.d.), “Rohstoffe im Handy. die inneren Werte zählen”, available at: <http://www.informationszentrum-mobilfunk.de/umwelt/mobilfunkendgeraete/herstellung> (accessed 3 January 2019).

Institute of Scrap Recycling Industries Inc. (2016), “The Scrap Recycling Industry:. Aluminum, Copper, and Other Nonferrous Metals”, available at: https://www.isri.org/docs/default-source/commodities/nonferrous-fact-sheet_2018.pdf.

Institute of Scrap Recycling Industries Inc. (2018), *2018 Recycling Industry Yearbook*, Washington, DC.

Keinz, P. and Prügl, R. (2010), “A User Community-Based Approach to Leveraging Technological Competences: An Exploratory Case Study of a Technology Start-Up from MIT”, *Creativity and Innovation Management*, Vol. 19 No. 3, pp. 269–289.

Kellers, J. (2015), *Superconducting Direct Drive Technology for Next Generation Wind Turbines: A fresh breeze in renewables*, Bonn, available at: http://www.eco-5.de/images/downloads/news/2015-05-08_ECO_5_EcoSwing_Press_Release.pdf (accessed 3 January 2019).

Kellers, J. (2018), “EcoSwing Project”, available at: <https://ecoswing.eu/project> (accessed 13 January 2019).

Klug-Conservation (n.d.), “Preserving values, Preservation of cultural artefacts”, available at: <https://www.klug-conservation.com/> (accessed 5 February 2019).

- Lackner, F. (2017), *Engineering Superconducting Magnets at CERN*, International High School Teacher Programme.
- Lackner, F., Bourcey, N., Ferracin, P., Jozwiak, P., Ohnweiler, T., Revilak, P., Savary, F. and Triquet, S. (2016), “Analysis of Temperature Uniformity During Heat Treatment of Nb 3 Sn Coils for the High-Luminosity LHC Superconducting Magnets”, *IEEE Transactions on Applied Superconductivity*, Vol. 26 No. 4, pp. 1–5.
- Lenntech BV (n.d.), “Die Elemente des Periodensystems geordnet nach dem Schmelzpunkt”, available at: <https://www.lenntech.de/data-pse/schmelzpunkt.htm> (accessed 3 January 2019).
- Lloyd’s Register Group Limited and University Maritime Advisory Services (2017), *Zero-Emission Vessels 2030. How do we get there?: We're considering the driver that will make Zer-Emission Vessels viable., Low Carbon Pathways 2050 series*, available at: http://www.lrs.or.jp/news/pdf/LR_Zero_Emission_Vessels_2030.pdf (accessed 4 February 2019).
- Merschel, F. (2017), *Supraleiterkabel: eine Alternative für dicht besiedelte Gebiete*, Workshop, *Zukünftige urbane Verteilungsnetze*, Hamburg.
- Michael Müller Spulenwickeltechnik GmbH, “Baugruppen als Magnetspule”, available at: <https://www.mueller-spulen.com/baugruppen-als-magnetspule/> (accessed 24 October 2018).
- Nexans (2012), *RWE Deutschland, Nexans and KIT launch “AmpaCity” project: the world’s longest superconductor system to replace inner-city high-voltage cable: Field test in the RWE distribution network to highlight the technical and economic ad-vantages of superconductors over high-voltage solutions in congested areas*, Paris, available at: https://www.nexans.be/eservice/Belgium-fr_BE/navigatepub_146417_-31642/RWE_Deutschland_Nexans_and_KIT_launch_AmpaCity_pro.html# (accessed 13 January 2019).
- Noe, M. (2017), *Stand der Supraleitermaterial- und Anwendungsentwicklung in Deutschland*, 9. *Braunschweiger Supraleiterseminar*, Braunschweig.
- Port of Rotterdam (2018), *Electric container ships for Tilburg-Rotterdam route*, Rotterdam, available at: <https://www.portofrotterdam.com/en/news-and-press-releases/electric-container-ships-for-tilburg-rotterdam-route> (accessed 27 January 2019).
- PortLiner (2018), “PortLiner”, available at: <https://www.portliner.nl/> (accessed 3 January 2019).
- Portschy, P. (2018), “Kerosinpreis: So viel kostet ein Liter Flugbenzin”, available at: https://praxistipps.focus.de/kerosinpreis-so-viel-kostet-ein-liter-flugbenzin_101084 (accessed 27 January 2019).

- Recco Non Ferro Metals B.V. (2018), “Recco Non Ferro Metals B.V.”, available at: <https://www.nonferrousrecycling.com/> (accessed 23 November 2018).
- Rossi, L. (2015), “Manufacturing and Testing of Accelerator Superconducting Magnets”.
- Scanlan, R. (1986), “Survey of high field superconducting material for accelerator magnets”.
- Schmickler, D. (2010), *Zenergy Power GmbH: The superconductor energy technology company, Braunschweiger Supraleiterseminar*, Braunschweig.
- Schoerling, D. (2017), *Cost model 16 T magnets*.
- Shen, L., He, J.-j., Yu, S.-y. and Gui, W.-h. (2016), “Temperature control for thermal treatment of aluminum alloy in a large-scale vertical quench furnace”, *Journal of Central South University*, Vol. 23 No. 7, pp. 1719–1728.
- Stack Exchange Inc (2015), “Why not build rockets out of composite materials?”, available at: <https://space.stackexchange.com/questions/13257/why-not-build-rockets-out-of-composite-materials> (accessed 3 January 2019).
- Superconductor Technologies Inc. (2018), “Superconducting Motors and Generators”, available at: https://www.suptech.com/motors_and_generators_n.php (accessed 23 November 2018).
- Tsuei, C.C., Suenaga, M. and Sampson, W.B. (1974), “Critical current density of a superconducting copper-base alloy containing Nb 3 Sn filaments”, *Applied Physics Letters*, Vol. 25 No. 5, pp. 318–320.
- Tupper, M.L. (2002), “Quotation”, available at: https://ncsx.pppl.gov/NCSX_Engineering/ModCoil_TF-Coil_VVSA_Fab/Jobs1451_1459_1408/002-%20MC%20Materials/003-Epoxy/CTD-101K/PPPL%20101%20528%20Quote,%202002.pdf (accessed 22 November 2018).
- Wagner, H.-F. (2017), “Warum erfolgt Stromübertragung bei hohen Spannungen?”, available at: <https://www.weltderphysik.de/gebiet/technik/energie/strom/hochspannung/> (accessed 13 January 2019).
- Wang, Y., Gao, H., Li, Z., Ping, Y., Jin, Z. and Hong, Z. (2015), “Study of the temperature uniformity of aluminium billets heated by superconducting DC induction heaters”, *COMPEL: The International Journal for Computation and Mathematics in Electrical and Electronic Engineering*, Vol. 34 No. 1, pp. 357–370.
- Weisend, J.G. (2010), *Superconducting Magnets for Accelerators, First Biennial African School on Fundamental Physics and its Applications*.

Zunum Aero (2017), “Zunum Aero”, available at: <https://zunum.aero/#About-us> (accessed 3 January 2019).

Table of Interviews

- Anonymous (2018), *Interview with a technical expert at Ebner Industrieofenbau about the benefits of the CERN oven and how it could be used in other industries*, Vienna/Leonding.
- Auchmann, B. (2018a), *Interview with Bernhard Auchmann about Superconducting Magnet Manufacturing*, Vienna/Geneva.
- Auchmann, B. (2018b), *Interview with Bernhard Auchmann about production steps of superconducting Magnets at CERN and more detailed explanation of the selected processes*, Vienna/Geneva.
- Bauer, A. (2018a), *Interview with Anton Bauer about the Metal recycling and potential use of CERN's heat treatment for scrap metal recycling*, Vienna/Blumau.
- Bauer, E. (2018b), *Interview about superconducting magnet manufacturing as well as use benefits for process steps*, Vienna.
- Berger, W. (2018), *Interview with Walter Berger, Head of Innovation at voestalpine Metal Engineering GmbH, about cable winding and use benefits of the Rutherford cable*, Vienna/Leoben.
- Bührer, C. (2018), *Interview with Dr Carsten Bührer, Managing Partner of ECO5, about application field for superconducting wires as well as the Ecoswing (electric wind turbine) Project*, Vienna.
- Coatanea, E. (2018), *Interview with Eric Coatanea, professor at Tampere University of Technology, about the current findings of the value chain analysis of the superconducting magnet production at CERN*, Vienna/Tampere.
- Dickert, H.H. (2018), *Interview with Hans Henning Dickert, Head of Prozess Technology at Stahlwerk Georgsmarienhütte, about metal processing*, Vienna/Georgsmarienhütte.
- Haupt, M. (2018), *Interview with Mrs Marion Haupt about application fields using novel epoxy*, Vienna.
- Hollnsteiner, K. (2018), *Interview with Kurt Hollnsteiner about application fields*, Vienna.
- Hörtnagl, F. (2018), *Interview with Friedbert Hörtnagl about ovens in the ceramic industry*, Vienna.
- Kirchberger, L. (2018), *Interview with Lukas Kirchberger about epoxy in the aerospace industry*, Vienna/Johannesburg.
- Kronnerwetter, G. (2018), *Interview with Mag. Gunther Kronnerwetter about ovens used in the pharmaceutical industry*, Vienna/Seewalchen.
- Krüger, A. (2019), *Interview with Mrs Anette Krüger, press officer at the Hamburger Hafen und Logistik AG (HHLA)*, Vienna/Hamburg.

- Lackner, F. (2018), *Interview with Friedrich Lackner about the Manufacturing process of the Nb₃Sn magnets for the FCC*, Vienna/Geneva.
- Lechner, C. (2018), *Interview with Christoph Lechner about application fields for superconducting magnets*, Vienna.
- Noe, M. (2018), *Interview with Prof. Dr.-Ing. Mathias Noe about superconducting magnets and the magnet manufacturing process*, Vienna.
- Ohnweiler, T. (2019), *Interview with Dr Timm Ohnweiler, chief engineer and procurator at Carbolite Gero, the manufacturer of the oven for the thermal treatment for the Nb₃Sn coils at CERN, about the specifications of the oven at CERN and possible application fields*.
- Salm-Reifferscheidt, H.z. (2019), *Interview with Hugo zu Salm-Reifferscheidt, Head of ground services at Vienna International Airport AG, about airport organisation and how the airport would be affected by electric airplanes*, Vienna.
- Schoerling, D. (2018), *Interview with Dr Daniel Schöring about the CERN research on the cost model for 16T magnets*, Vienna/Geneva.
- Scrap Metal Forum (2018), *User-Community Search in the Scrap Metal Forum*, Vienna.
- Stein, M. (2018), *Interview with Dr Mario Stein, project manager for Inventory & Logistics at Nagra (National co-operative for the disposal of radioactive waste), regarding the usage of Epoxy resin for the disposal of radioactive waste*, Vienna/Wettingen.
- Ulrici, L. (2018), *Interview with Luisa Ulrici, responsible for radioactive waste management at CERN, about the radioactive waste management at CERN*, Vienna/Geneva.
- Zellhofer, M. (2018), *Interview with Martin Zellhofer, Head of R&D at Wittur elevator components, about current challenges in the elevator industry*, Vienna/Scheibbs.

Appendix A: Magnet Manufacturing Process

The focus of this review was set on the new superconducting material Nb₃Sn. Therefore, all previous process technologies which were established for the LHC based NbTi magnets, which are produced via a different process are not be considered in this report.

- 1) The first step in the manufacturing process is the procurement of the superconducting material (Nb₃Sn) which is not different from any other industrial procurement process. The quality management is straightforward and will not be considered any further. The raw materials are superconducting only after the thermal treatment which takes place several steps later.
- 2) Afterwards, the production of the superconducting wire happens where several different techniques can be used. Two out of four processes which have been developed are compared. While the *bronze process* is mainly applied by the MRI industry, the *internal Sn process* is used for the superconducting magnets. The basic unit of superconducting coils used in the particle accelerator magnets is the Rutherford cable. The Rutherford cable is a particular type of superconducting cable which is used to generate magnetic fields in particle accelerators. The most important characteristic of the cable is that it strongly influences the effectiveness and the stability of the magnetic field as well as the mechanical stability of the cable. The origin of these effects is the precise twisting of the cable.
- 3) The cable insulation is made out of fibreglass, because the polyimide insulation used in the NbTi process would not withstand the high temperature in the subsequent thermal treatment (Rossi, 2015) process. Furthermore, the issues (thickness and working conditions) with the polyimide insulation was an issue during the NbTi manufacturing process but were eliminated with the introduction of the fibreglass insulation technology. The insulation process is extremely important as even minor defects can lead to damage of the magnet during operation.
- 4) Before the Rutherford cable can be wound, a ceramic binder is needed because of the inflexibility of the new material (ceramic instead of metal). The binder completely evaporates during the thermal treatment (Auchmann, 2018a).
- 5) The production of the coils is a unique processes in the manufacturing (Auchmann, 2018a). Because of the complex winding process, several auxiliary materials have to be used to create a coil structure as displayed in Figure 15.

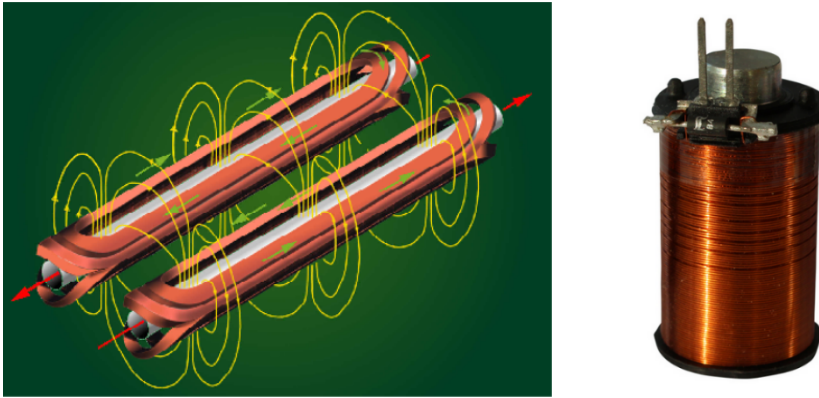


Figure 15 (left): Winding Structure of Accelerating Magnets (Weisend, 2010)

Figure 16 (right): Typical Winding of an Electromagnet (Michael Müller Spulenwickeltechnik GmbH)

Additionally, spacers needed in the winding process are manufactured with the selective laser melting technique (Lackner, 2017). The most crucial part of the winding process is the accuracy of the tools because even minor deviations from the specifications can render the produced magnet useless if the magnetic field quality does not meet the requirements. Also noteworthy is the layer jump, because in the existing process for NbTi, two layers of the Rutherford cable were placed on the pipe separately and connected by soldering afterwards. Because of the high temperature during the heat treatment, the coil has to be made out of one single cable. This also reduces the probability of failures during operation since no connection between two coil layers exists. The layer jump, where the second layer is put on top of the first one is difficult to manufacture and requires a particular process called the double pancake method. The technique is well established in industries where several layers of cable have to be wound on a coil.

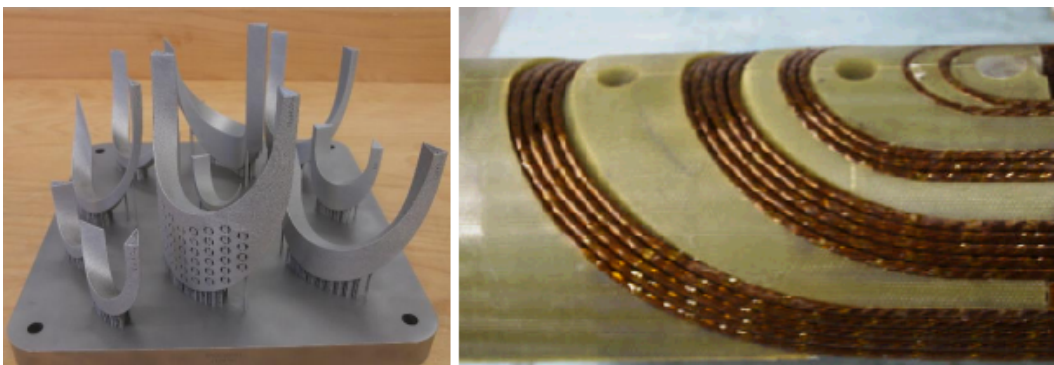


Figure 17 (left): Manufacturing of End-Spacers (Lackner, 2017)

Figure 18 (right): Application of End-Spacers (Weisend, 2010)

- 6) The Rutherford cable, which is wound on the coil with the support of glue is very fragile at that moment. By heating the entire coil for one to two weeks at 660 °C, the raw materials receive their superconducting properties due to the chemical process which takes place inside the cables.
- 7) After the heat treatment, the vacuum impregnation with epoxy is isolating the coil to stabilise the ceramic product further. The impregnation temperature at 100 °C and pressure are much lower than in the first thermal reaction process. Because of the “low” temperature, other electrical instruments like the quench heaters can be implemented into the coil.

- 8) After the coil is manufactured and impregnated, the collar packs can be installed. According to Auchmann (2018a), a new process was invented especially for the ceramic superconductors which eliminate the collars to a certain extent. Instead of collars, pads are put with high pressure around the coils. Furthermore, the yoke is put around the pads and has some bladders which are filled with water under high pressure (450 bar). After the water is pressed inside the bladders, “keys” are put between the yoke and the pads, which increases the pressure on the coil. After that, the water is removed, and the keys are keeping up the pressure. All steps are done at room temperature where the coil is fragile because adding pressure under working conditions is only possible to a certain extent. The pads and the yoke are only needed for superconducting magnets because solenoids which are winded traditionally stay in the position because of the own pressure. They do not have the “need” to break out Auchmann (2018a).
- 9) After the coil is surrounded by the pads and the yoke, the aluminium shell is put around the package. The shell is one single tube without any welding seams. The advantage of the aluminium shell is that it contracts much more than the iron yoke and the coil which further increases the pressure on the coil Auchmann (2018a).
- 10) However, because the aluminium shell is permeable for liquid helium, another shell (stainless steel shell) is put around the aluminium one. Two half shells are welded by a robot to keep the liquid helium inside the so-called cryogenic vessel.
- 11) The last step is testing the SCM in order to assess the performance. For this step, liquid helium has to be used to cool down the magnet to permit validation under operating conditions. After the test is done, the magnet will be transported to the customer.

Appendix B: Features and Benefits for each Technology

B.1 List of features of the superconducting Rutherford cable

Interview	Higher current density on the same profile	Bending/ winding is possible	Low inductivity	less Voltage needed to start the magnet	high efficiency as no energy is lost	Flexibility if non superconducting materials are used	compact method of construction	high tension through a small cable possible	shape of the cable
Forest		1			1				
Auchmann	1			1	1	1			1
Gehring					1				
Lackner	1	1		1	1				
Noe	1	1							
Coatanea					1				
Bauer	1	1	1			1	1		1
Hollnsteiner	1						1		1
Pleil	1						1	1	1
	6	4	1	2	5	2	3	1	4

Table 6: Full list of features and use benefits of the production of the Rutherford cable

B.2 List of use benefits of thermal treatment

Interview	High constant temperature over a long period	removes every soldered joint	heat the materials in stable intervals with short time between each interval	very uniform temperature throughout the whole material	continous heating
Forest	1		1		
Auchmann	1	1	1	1	1
Gehring	1				
Lackner	1		1	1	
Noe					
Coatanea					
Bauer	1		1	1	
Hollnsteiner					1
Pleil					1
	5	1	4	3	3

Table 7: Full list of features and use benefits of the Thermal Treatment

B.3 List of use benefits of vacuum impregnation with epoxy

Interview	Enhance the stability of ceramic materials	Impregnation without almost any crack	Uniform distribution of the epoxy	surface sealing possible	can withstand radioactivity	high pressure and low temperature resistance	more stability
Forest		1		1			
Auchmann		1		1	1	1	
Gehring							
Lackner		1	1				
Noe							
Coatanea	1			1	1	1	1
Bauer				1	1		
Hollnsteiner						1	1
Pleil						1	
	1	3	1	4	3	4	2

Table 8: Full list of features and use benefits of the vacuum impregnation with epoxy

Appendix C: Benefit Relevance and Strategic Fit Calculation

C.1 Ranking of application fields

	Rank within group and/or technology	Application Field	cumulated BR and SF
High potential application fields	1	Scrap metal recycling	3.3
	2	Generators for wind turbines	3.2
	3	High-voltage power lines	3.0
	4	Hybrid electric power-trains for cruise ships and aircraft	2.8
	5	High-activation level radioactive waste management	2.7
	6	Low-activation level radioactive waste management	2.5
Medium potential application fields	1	Electric vessel charging	1.8
	2	Separation of chips and coolants in machines	1.7
	3	Aircraft charging	1.5
	1	Thermal treatment of Al	2.0
	2	Ceramic compounds	1.5
	1	Conservation of cultural and historical goods	1.8
Low potential application fields	1	Linear engines	2.1
	2	Server Farms	1.8
	1	Depyrogenation of pharmaceutical glass bottles	1.3
	2	Space equipment	0.6
	1	Glass	2.2
	2	Composite aircraft parts	2.0
	3	Carbon fibre	1.8
	4	Satellite surface	1.5
5	Rocket surface	0.8	

Superconducting Rutherford cable
Thermal treatment
Vacuum impregnation with epoxy STD-100K

Table 9: Ranking of all application fields

C.2 Superconducting Rutherford cable

Superconducting Rutherford Cable	Nr.	Application Field	Benefit Relevance	times mentioned	Number of relevant Benefits	total amount of benefits	efficient transport of electricity	precise placement to save space	enabling ultra-high-precision applications	Relevance Index	Relevance of the problem	Problem is more important in the future	Current solutions for the occurring problem are not sufficient	Range of affected persons by this problem
	1	Aircraft charging	0.5	3	1	3	1	0	0	1.50	1	2	1	2
	2	Hybrid electric power-trains for cruise ships and aircraft	1.8	6	3	3	1	1	1	1.75	1	2	2	2
	3	Generators for wind turbines	1.2	7	2	3	0	1	1	1.75	1	2	2	2
	4	Server Farms	0.8	2	2	3	1	0	1	1.25	1	0	2	2
	5	Electric vessel charging	0.5	7	1	3	1	0	0	1.50	1	2	1	2
	6	Medium- and high-voltage power lines	1.0	4	2	3	1	1	0	1.50	2	2	0	2
	7	Separation of chips and coolants in machines	0.3	2	1	3	0	0	1	1.00	2	1	1	0
	8	Linear engines	0.4	2	1	3	0	0	1	1.25	1	1	1	2

Table 10: Calculation of Benefit Relevance - Superconducting Rutherford cable

	Nr.	Application Field	Strategic Fit	Market Fit	Time Horizon	Technical Fit
Superconducting Rutherford Cable	1	Aircraft charging	1.0	1	0	2
	2	Hybrid electric power-trains for cruise ships and aircraft	1.0	2	0	1
	3	Generators for wind turbines	2.0	2	2	2
	4	Server Farms	1.0	2	1	0
	5	Electric vessel charging	1.3	1	1	2
	6	Medium- and high-voltage power lines	2.0	2	2	2
	7	Separation of chips and coolants in machines	1.3	1	2	1
	8	Linear engines	1.7	1	2	2

Table 11: Calculation of Strategic Fit - Superconducting Rutherford cable

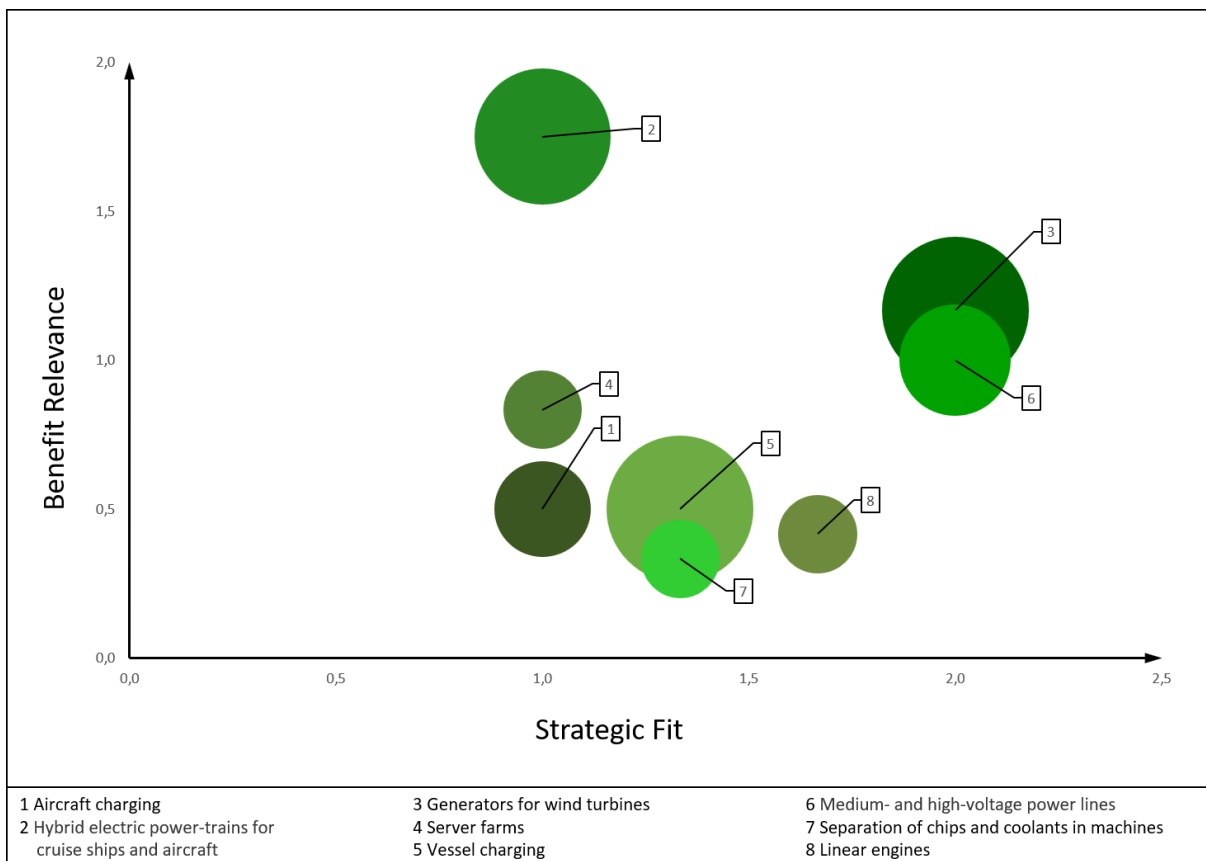


Figure 19: Assessment of application fields for the superconducting Rutherford cable

C.3 Thermal treatment

	Nr.	Application Field	Benefit Relevance	times mentioned	Number of relevant Benefits	total amount of benefits	Homogenous Heating	fast temperature changes	no fluctuation in quality	less corrosion because of protective gas	Relevance index	Relevance of the problem	Problem is more important in the future	Current solutions for the occurring problem are not sufficient	Range of affected persons by this problem
Thermal Treatment	9	Scrap metal recycling	1.3	14	3	4	1	1	0	1	1.75	2	2	1	2
	10	Thermal treatment of Al	1.0	3	4	4	1	1	1	1	1.00	1	1	0	2
	11	Ceramic compounds	0.5	2	2	4	1	0	0	1	1.00	1	1	1	1
	12	Depyrogeration of pharmaceutical glass bottles	0.3	2	2	4	1	0	1	0	0.50	0	1	0	1
	13	Space equipment	0.3	1	1	4	1	0	0	0	1.25	1	2	1	1

Table 12: Calculation of Benefit Relevance - Thermal Treatment

	Nr.	Application Field	Strategic Fit	Market Fit	Time Horizon	Technical Fit
Thermal Treatment	9	Scrap metal recycling	2.0	2	2	2
	10	Thermal treatment of Al	1.0	0	2	1
	11	Ceramic compounds	1.0	0	2	1
	12	Depyrogenation of pharmaceutical glass bottles	1.0	1	2	0
	13	Space equipment	0.3	0	0	1

Table 13: Calculation of Strategic Fit - thermal treatment

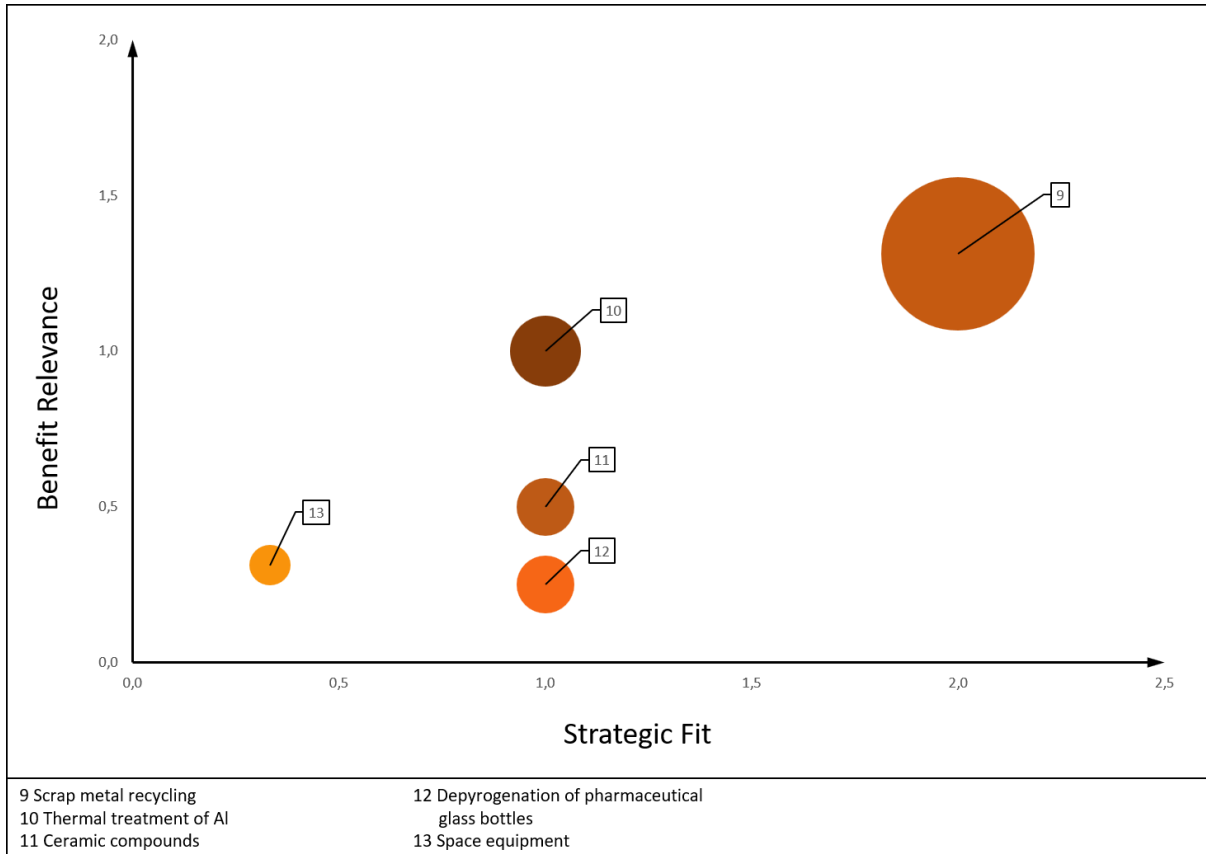


Figure 20: Assessment of application fields for thermal treatment

C.4 Vacuum impregnation with CTD-101K

	Nr.	Application Field	Benefit Relevance	times mentioned	Number of relevant Benefits	total amount of benefits	Useful for easily breakable materials	100% surface sealing	protection against radioactive erosion	Relevance index	Relevance of the problem	Problem is more important in the future	Current solutions for the occurring problem are not sufficient	Range of affected persons by this problem
Vacuum Impregnation with epoxy CTD-101K	14	Low-activation level radioactive waste management	0.8	7	2	3	0	1	1	1.25	1	2	1	1
	15	High-activation level radioactive waste management	1.3	9	2	3	0	1	1	2.00	2	2	2	2
	16	Carbon fibre	0.8	1	2	3	1	1	0	1.25	1	2	1	1
	17	Composite aircraft parts	1.0	2	2	3	0	1	1	1.50	2	2	0	2
	18	Rocket surface	0.4	2	1	3	0	0	1	1.25	1	2	1	1
	19	Satellite surface	0.8	2	2	3	0	1	1	1.25	1	2	1	1
	20	Conservation of cultural and historical goods	0.5	4	2	3	1	1	0	0.75	1	1	1	0
	21	Glass	0.8	2	2	3	1	1	0	1.25	1	2	1	1

Table 14: Calculation of Benefit Relevance - Vacuum impregnation CTD-101K:

Vacuum Impregnation with epoxy CTD-101K	Nr.	Application Field	Strategic Fit	Market Fit	Time Horizon	Technical Fit
	14	Low-activation level radioactive waste management	1.7	2	1	2
	15	High-activation level radioactive waste management	1.3	2	1	1
	16	Carbon fibre	1.0	1	1	1
	17	Composite aircraft parts	1.0	0	2	1
	18	Rocket surface	0.3	0	0	1
	19	Satellite surface	0.7	0	1	1
	20	Conservation of cultural and historical goods	1.3	0	2	2
	21	Glass	1.3	1	2	1

Table 15: Calculation of Strategic Fit - Vacuum impregnation with CTD-101K

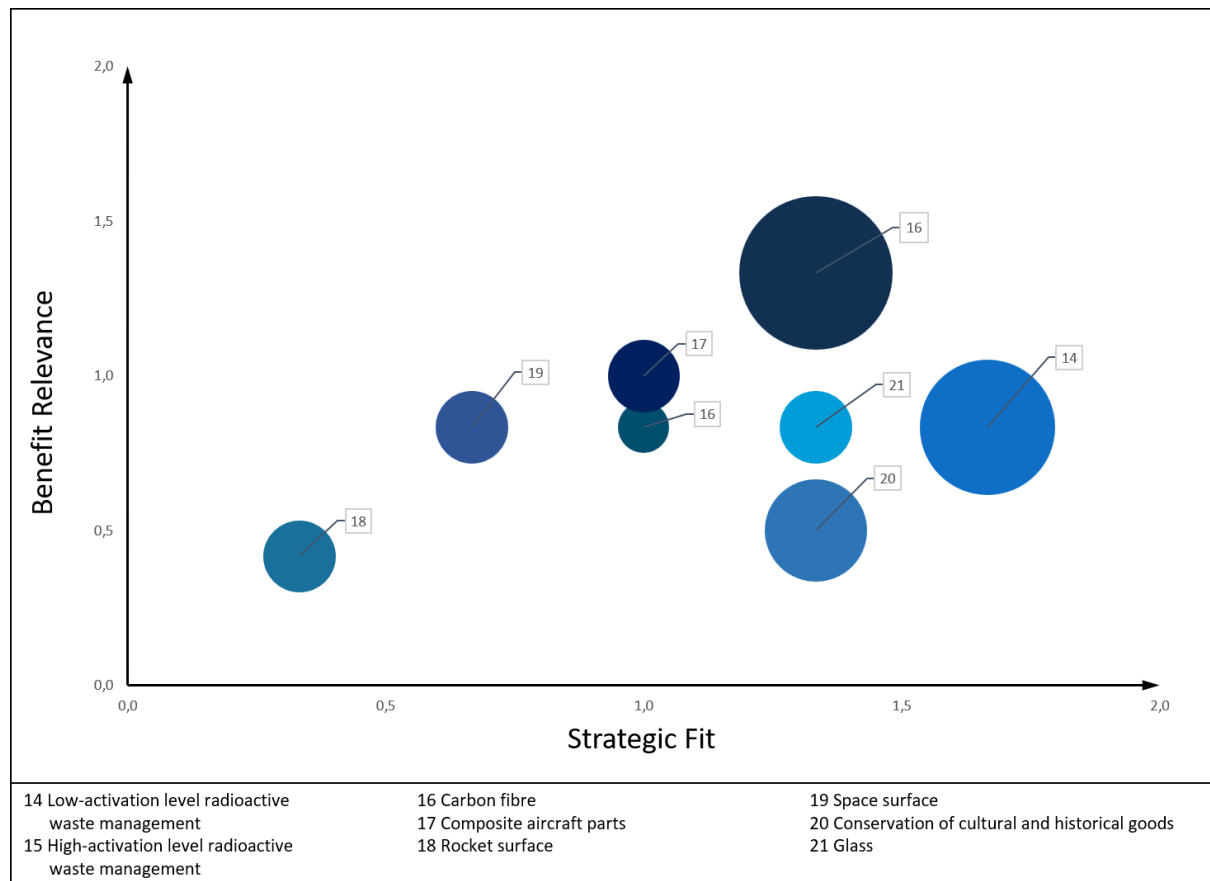


Figure 21: Assessment of application fields for vacuum impregnation with CTD-101K

Appendix D: Application Fields

List of all mentioned application fields for each technology.

Superconducting Rutherford cable	Thermal treatment	Vacuum impregnation with epoxy CTD-101K
1 Elevator cable 2	16 Scrap metal recycling 14	26 Carbon fibre 1
2 Cableway cable 1	17 Recycling of semiconductors 4	27 Glass 2
3 Aircraft charging 3	18 Ceramic compounds 2	28 Low-activation level radioactive waste management 7
4 Electric vessel charging 7	19 Thermal treatment of Aluminium 3	29 High-activation level radioactive waste management 9
5 Car charging 3	20 Electric Motors and Generator 1	30 Rocket surface 1
6 Generators for wind turbines 7	21 Titan industry 1	31 Space surface 1
7 Server farms 2	22 Steel industry 4	32 Railways 1
8 High-voltage power lines 4	23 Space equipment 1	33 Conservation of cultural goods and art 4
9 Train overhead cable 2	24 Depyrogenation of pharmaceutical glass bottles 2	34 Packaging material 2
10 Permanent magnets 1	25 Car industry 1	35 Screen protection 2
11 Aircraft electricity transportation 4		36 Car industry 1
12 Cruise ship electricity transportation 3		37 Circuit board 1
13 Chairlift 1		38 Aircraft wings 1
14 Separation of chips and coolants in machines 2		
15 Linear engine 2		

Table 16: All application fields - overview

D.1 Low potential application fields

D.1.1 Superconducting Rutherford cable

Linear engine

Linear engines are partly made out of superconducting materials like in the case of high-speed railways in Japan (e.g. Maglev). Moreover, roller coasters are also made with linear engines and subways could be another application field. However, superconducting materials are only needed in linear engines if high amounts of energy are needed (Lechner, 2018). However, because of resource constraints, no interviews were conducted in this large field because research focuses mainly on permanent magnets rather than on superconducting materials.

Server farms

Server farms are often located in colder regions in order to reduce cooling costs. Therefore, the superconducting Rutherford cable could be used to transfer energy to server farms more easily that require large currents like VPN and streaming service providers. The power supply of server farms is not the main issue where Rutherford cables might be useful. The cooling facilities would not be necessary if the CPUs were superconducting but much more research has to be conducted in this area in order to manufacture the first prototype.

Train overhead cable

Searching for application fields for the Rutherford cable, the idea was to use the Rutherford cable as a cable for train overhead cables. The reason for that idea was that the squared cable would increase the surface for the overhead cable from which trains receive their electricity through the pantograph. A squared cable does not promise such a significant outcome to be used for train overhead cables, as it is not possible to apply the pantograph parallel to the rectangular cable (Bauer, 2018b; Noe, 2018).

Elevator cable and chairlift

To fight the current issue of slipping of elevator ropes on the drive roll, a rectangular rope, made like the Rutherford cable might be useful. However, KONE, one of the largest elevator manufacturers worldwide, has already developed a rectangular composite rope (UltraRope™), having many additional benefits amongst diminishing slippings, such as reduced weight and increased durability (Zellhofer, 2018).

D.1.2 Thermal treatment

Depyrogenation of pharmaceutical glass bottles

In the pharmaceutical industry, heat treatment up to 280 – 320°C is used for the depyrogenation of glass bottles. This requires an extremely uniform heating process which allowed deviations of +/-1°C only. Moreover, the air in the oven needs to be cleaned through several filter cascades before it is being heated and used (Kronnerwetter, 2018). Therefore, the current technologies of the industry are already superior to CERN's technology.

Space equipment

As the thermal treatment for space equipment is optimised and highly efficient, CERN's oven does not provide any advantages and is therefore not suitable in this industry. The initial idea was that space equipment needs precise thermal treatment as a homogenous surface would not cause any weak points.

Laboratory ovens

In Laboratory, several probes have to be analysed and there heated for several hours. Uniform temperature is needed to reach a satisfactory result. However, they are usually way smaller than the oven from CERN and use different technology.

D.1.3 Vacuum impregnation with CTD-101K

Glass

Glass is, like ceramic compounds, a brittle material and needs further protection. This is achieved by providing thermal treatment to it or by using some sorts of polymeric materials. Epoxy resin, which might be a substitute for the polymeric materials, is not useful in this case because of its low viscosity in comparison to the current solutions.

Composite aircraft parts

This application field describes using the novel epoxy resin CTD-101K for composite aircraft parts. In order to reduce the weight of an airplane, aerospace manufacturers are using composite materials for parts such as the wings or the shell of the cabin. Today's aircraft structures are commonly made up between 50 to 70% of composite material (Houston, 2018). The binding polymer of the composite material that strengthens the mechanical stability of the aircraft part has to be able to withstand the changing circumstances (temperature changes, radioactivity, high pressure through the air), which an airplane is exposed to. As CTD-101K can withstand radioactivity and is applicable in temperatures ranging from -270 up to 100°C, it might be beneficial for aircraft manufacturers. Further research has to be conducted in order to assess if CTD-101K fulfils the strict regulations and requirements which are prevalent in this industry. Additionally, it remains unsure whether composite aircraft parts manufacturers face problems with their current epoxies. Due to the insecurities about the current solutions and the restrictions within this application field, this application field is ranked as low potential.

Carbon fibre

Carbon fibre is light but also extremely brittle and often finds its application when the task is to reduce weight. One example of the use of carbon fibre is the car industry, in particular in motorsports where the effect of reducing weight is tremendous regarding the speed and handling of racing cars. In order to make carbon fibre usable for everyday applications (e.g. in cars), it needs to be supported by the epoxy as it would break without any support. Because of the use of the novel epoxy, the mechanical strength of the carbon fibre application is increased as the novel epoxy with its strong bonding properties strengthens the bond of every single fibre. Furthermore, the novel epoxy does not suffer from fatigue behaviour which means the mechanical strength of the carbon fibre is ensured over a long period and the application can last longer as it is protected against external factors (similarly to the conservation of cultural goods), e.g. weather impacts like rain. Additionally, the novel epoxy does not react with a so-called addition reaction which means no additional products occur when strengthening the carbon fibre with novel epoxy. All in all, the epoxy enables a robust, stable and light product, for example, a car bonnet to stay with the example of carbon fibre for cars.

Circuit board

Circuit boards are a widely used product for cell phones and computers, but as epoxy resins is always designed for the needs of the industry, CTD-101K shows no advantage here. Moreover, the vacuum impregnation is a standardised process, and a technology transfer is therefore not useful.

Satellite surface

As satellites are exposed to high space radiation, the epoxy resin might be beneficial if the surface is treated with it. Unfortunately, the temperature changes in space from -270 to +120°C prevent the application of this type of resin which can only withstand temperatures up to +100°C.

Rocket industry

The rocket industry needs leak-tight resins that withstand radiation to protect the inside from outer space. A possible problem is the high temperatures during the launch of a rocket which epoxy resins cannot withstand (Stack Exchange Inc, 2015). Unfortunately, no rocket manufacturer was willing to conduct an interview for this research, leaving this possible application field blank. In general, only one company that is located in Europe produces space rockets for non-military usage (Arianespace).

Railways

The environment suffers from air pollution especially arising from big cities and their transportation systems. In particular the Underground and the tram are not as environmentally friendly as they seem, as 20% of a city's fine dust pollution is caused by the abrasion of the rail transport. The initial thought was to put epoxy resin onto the rail tracks to avoid fine dust pollution and make them resistant against abrasion. However, the epoxy would not withstand the moving pressure of the trains (Bauer, 2018b; Coatanea, 2018) which means that the epoxy cannot be used to protect the environment from the air pollution caused by the rail transport.

Surface sealing of aircraft wings

As the CTD 101K can seal surfaces perfectly, a use case for aircraft wings looked reasonable. However, this is not possible, as it would not stick well to metal surfaces or reduce the durability of composite surfaces and is therefore not used (Kirchberger, 2018).

Appendix E: Insights from Interviews and User Community Search

E.1 Interviews

Georg Angerer (19 November 2018)

Georg Angerer is employed by TGM and is teaching mechanics and quality management, with a broad knowledge in the heavy industry. According to Mr Angerer, thermal treatment could be easily used for scrap metal recycling. He referred to Recco Helig as one provider of such services. Furthermore, he mentioned that currently, the processes are highly complex in terms of different processes and time-consuming.

Anonymous (22 November 2018)

A technical expert at Voestalpine who is responsible for the thermal treatment of raw steel explained that the precision of the temperature has to be within $\pm 10^{\circ}\text{C}$. A more precise oven is not needed, but aluminium could be an application field. He referred us to Ebner Industrieofenbau as Voestalpine is a customer of them.

Anonymous (22 November 2018)

A technical expert at Ebner Industrieofenbau described the benefits of the CERN oven and how it could be used in other industries. He deeply explained the critical parameters like size, temperature, and protective gas for an industrial oven. Application fields like the thermal treatment of aluminium and ceramic compounds were mentioned in this interview. It has to be said that Ebner Industrieofenbau in Austria is a leading company for all kinds of industrial ovens.

DI Achim Artner (16 January 2019)

Mr Artner is the supply chain manager at RUAG Space, a manufacturer of satellite and rocket parts. He explained current developments of satellite technology as well as current challenges of the industry. He highlighted the focus of his plant on thermal isolation and smaller satellite parts. The main part of the interview was about the materials used for satellites. However, the result was that mainly Titan, aviation aluminium and (for some inner parts) synthetic materials are used, and no composite materials. Therefore, the novel epoxy withstanding radiation does not have an application in this field. Different heat treatment is also used in the manufacturing process of satellite parts, but the temperatures are only up to 150°C . Mr Artner emphasised that RUAG Space would be interested in further cooperation with CERN.

Bernhard Auchmann, PhD (23 October 2018 and 14 December 2018)

Mr Auchmann is a technical engineer at CERN. In the first one of two interviews on 23 October 2018, Mr Auchmann explained the differences between NbTi and Nb₃Sn magnets and the necessity of using novel epoxy for transporting the superconducting magnet. He further gave more insights into the whole

manufacturing process in detail and mentioned several benefits of the Rutherford cable. Lastly, he referred to Mathias Noe, whom we contacted shortly after the interview. In the second interview on 14 December 2018, many questions on the specified manufacturing processes “Rutherford cable”, “vacuum impregnation with novel epoxy” and “thermal treatment” could be answered by Mr Auchmann. In particular, he explained the importance of reducing production costs for the Rutherford cable, since they are too expensive to be profitable for most industries. However, the high-performance increase might be beneficial if costs are reduced. Furthermore, the homogenous thermal treatment can be easily modified to be used with other gases than Argon, which is currently used at CERN. Lastly, Mr Auchmann falsified the feasibility of the novel epoxy used at CERN for space and electronics industry, since they need more viscous epoxies than CTD-101K.

Anton Bauer (22 November 2018)

Anton Bauer is the managing director of the Metall Recycling GmbH in Blumau, Austria. He is an expert in the field of recycling with more than 50 years of experience in the field. The key insights of the interview with Mr Bauer were the explanation of how scrap metal could be separated by CERN's thermal treatment process. He also explained the actual process of metal recycling, the main points from his side were that the process is costly and time-consuming. He also pointed out that recycling will become more important in the future.

Univ.Prof. Dr Ernst Bauer (14 November 2018)

Prof. Bauer is head of the Institute of solid state physics and covered almost every field of superconductivity. In a first step, he explained the basics of phase diagrams and how this is affecting the thermal treatment of intermetallic compounds like Nb₃Sn. This was the cornerstone to understand the three different temperature levels inside the oven and that CERN's knowledge is to identify the right temperatures plus the right duration in order to transform raw materials into superconducting materials. In a next step, the cryogenic technology was demonstrated live in an experimental laboratory at TU Vienna. The main disadvantages of LTS were explained and how HTS could be used in industries like generators and power grids.

Dr Walter Berger (22 November 2018)

Dr Walter Berger is Director of Innovation at Voestalpine Metal Engineering GmbH who explained the benefits of a rectangle cable and what the benefits of the Rutherford cable are. He also sent a visual explanation of the winding process for such a cable and described the difficulties in the production of it.

Dr Carsten Bühner (20 December 2018)

Dr Carsten Bühner is the CEO of ECO 5, an engineering consulting firm that specialises on magnets, cryotechnology and power grid expansion. During the interview, he explained that economies of scale are a big problem for the market of superconducting magnets since there is not enough demand as of now.

Prof. Eric Coatanea, Ananda and Suraj (9 November 2018)

Eric Coatanea is a professor at the Tampere University of Technology in Finland. Together with doctoral students Suraj Panicker and Ananda Chakraborti, he explained how quality management could reduce the overall costs of superconducting magnets. Furthermore, we discussed several possible application fields for the Rutherford cable as well as its precision manufacturing. The processes “collaring/pads/yoke” and the potential use of novel epoxy for medical use (which was falsified) were explained. Lastly, the interviewed experts were asked to brainstorm on alternative application fields for vacuum impregnation with novel epoxy (nuclear industry, especially for high-level activation radioactive waste).

Hans Henning Dickert (24 November 2018)

Hans Henning Dickert is the Head of Product Assurance and Process Technology at steel manufacturer GM-Hütte. Information about the steel manufacturer can be found above at the interview with Felix Osterheider who forwarded us to Hans Henning Dickert. In particular two topics were discussed with Hans Henning Dickert. Firstly, he explained to us the differences in the oven technologies used in the steel industry and the oven used at CERN. Generally, there are many (hundreds) types of ovens existing which differ in size, temperature, gases used inside the oven, different installation space specifications, etc. Concerning the steel industry, the temperature within the oven needs to be quickly changeable. The fluctuation in between those changes is less important rather the speed this change can be implemented (CERN can adapt up to +/- 3°C; in the steel industry this is not necessary). CERN operates its ovens with a long heating process, compared to the steel manufacturers aiming to generate high turnover need to heat very fast. Secondly, Mr Dickert revealed information about Scrap Metal Recycling done at the German steel manufacturer. In general, he found this an amazing idea, and he said that other steel manufacturers are already working on introducing an oven to recycle all those scrap metals. However, the use of a Scrap Metal Recycling oven does not work for GM-Hütte as the metals they receive are too mixed up. For example, other Recycling companies already receive scrap metals already more separated in the different types of metal. If those Scrap Metals are too mixed up the recycling with a thermal treatment in an oven does not work as new alloys between the different metals can arise. However, he advised us to contact further steel manufacturers and aluminium producers in order to ask for their procedures to recycle scrap metal.

Frederick Forest (22 October 2018)

Frederick Forest is the technical director at SIGMAPHI, one of the main manufacturers of CERN’s superconducting magnets. In the one-hour interview with Mr Forest, he explained the main tasks of SIGMAPHI and gave a rough overview of the manufacturing chain of CERN’s magnets. The key insights of this interview were that some processes are rather general and can be used in other industries (vacuum impregnation, final assembly, part procurement), whereas other processes are specialised for CERN’s requirements and would need to be adapted (winding process).

Herbert Fried (24 November 2018)

Herbert Fried is Head of sales at Vornbäumen Stahlseile GmbH, a middle-sized German business in producing high load capacity wire ropes for ski lifts, elevators and cranes. In particular, Vornbäume Stahlseile GmbH supported all the difference in the production of a wire rope and an electric cable and also mentioned that due to those differences, it will be impossible to use an electric cable like the Rutherford cable for our application field elevator ropes. The reason is, similar to what Joachim Tepe had already mentioned, that electric cables do not withstand the high capacity in regards to weight and pressure on the cable. Furthermore, Herbert Fried gave us a small introduction into the compression technologies used by Vornbäumen and pointed to their website where further explanation to this compression and the winding of a wire rope is given.

Michael Gehring (29 October 2018)

Michael Gehring is the sales director at Bilfinger Noell GmbH, a German-based company for nuclear services and magnet technology. About one-third of CERN's LHC dipoles were built at Bilfinger Noell GmbH, which makes it one of the main manufacturers and leading experts in the field of superconducting magnet production. In the interview on 29 October 2018, Mr Gehring gave insights on the production process by Bilfinger Noell and emphasised the high precision which is needed (and might only be needed) for CERN's magnets.

Marion Haupt (20 November 2018)

Ms Haupt is working for the University of Applied Arts in Vienna as assistance at the Institute of conservation and restoration. She was very interested in using the epoxy for conserving and restoring cultural and historical goods. In order to help she referred to Ms Lenhart, an expert in the field.

Wolfgang Heidrich (20 January 2019)

Mr Heidrich is employed by GDA (Gesamtverband der Aluminiumindustrie) where he is the head of transport, mechanical engineering and standardisation. The interview with Mr Heidrich unveiled many important use cases where thermal treatment of aluminium plays an important role. He also described the current processes of thermal treatment with gas ovens. According to Mr Heidrich, CERN's oven has the potential for thermal treatment, if it is performing the way it is required for each different process (tempering or hardening).

Kurt Hollnsteiner (19 November 2018)

Kurt Hollnsteiner is employed by TGM (secondary education institution in Vienna, Austria), where he teaches machine and process engineering. He also has a lot of experience from previous employment in different sectors of the industry. Mr Hollnsteiner helped to point out some of the benefits of each of the technologies. According to Hollnsteiner, especially the homogenous heating of CERN's oven is really important to ensure the quality of the products. He also mentioned some applications fields which could be interesting for the project: conservation of cultural and historical goods as an application field for

vacuum impregnation with epoxy, aircraft and vessel charging for the superconducting Rutherford cable, using the epoxy for packaging equipment or transport reasons.

Friedbert Hörtnagl (23 November 2018)

Friedbert Hörtnagl is an engineer at STEKA Werke, an Austrian ceramic manufacturer, who explained the current solutions at his company and how the thermal treatment works. The size of the oven, the kind of protective gas used inside as well as the duration was mentioned. He recommended talking to companies in the hardening technique industry and to household ceramic manufacturers who also need thermal treatments in their manufacturing chain.

Karl Khevenhüller (20 November 2018)

Karl Khevenhüller is an entrepreneur from Austria who has, in particular, focused on renewable energy mainly on generating energy with wind turbines. His job in implementing wind park projects (the newest is in India) is to establish the contact between investors, wind turbine manufacturers, the owners of the land where the wind parc should be built and the government to subsidise those projects. He supported our assumption that the rotors produce that much kinetic energy that not all of it can be transformed into electricity through the generators. Even though wind turbines are the most efficient way to produce electricity (over 80% efficiency of the generators), the generators are not powerful enough to transform all this kinetic energy into electricity. Due to his business approach to those projects, he is not that involved into the technical understanding of the generators, but he explained us from an economical side the losses of generators and the need to improve those in order to make the wind turbines electricity production even more efficient.

Lukas Kirchberger (22 November 2018)

Mr Kirchberger is sailplane engineer and works at Jonker Sailplanes in South Africa. He explained the current processes of using epoxy in the sailplane and aircraft industry. The application of epoxy for composite materials is a very standardised process and very cheap. Moreover, if epoxy would be used in aviation for surface sealing, this would have negative effects on the stability of the parts and is therefore not possible and not used.

Mag Gunther Kronnerwetter (21 November 2018)

Mr Kronnerwetter is Site Head and Managing Director of EBEWE Pharma, a subsidiary of Sandoz (Novartis) in Austria. Mr Kronnerwetter explained processes in the pharmaceutical industry where a precise heat treatment is necessary to depyrogenate glass bottles. However, their ovens reaching up to 320°C are already very precise ($\pm 1^\circ\text{C}$) and therefore there is no need for CERN's technology.

Anette Krüger (23 January 2018)

Anette Krüger is press officer of the Hamburger Hafen und Logistik AG (HHLA), which is the number 3 port in Europe after Antwerpen and Rotterdam with over 140 Mio. tonnes of container running through

the port each year. Anette Krüger explained that the cargo ships only remain between 1 hour to 5 hours in the port before leaving to the next destination. Meaning the time for the vessel to be fully charged is limited. However, there is more time to charge a vessel compared to charging an aircraft. The maximum time in the port for large vessels is up to two days. Furthermore, she mentioned that electric vessels would be an opportunity to reduce carbon dioxide emissions in this industry.

Dr Friedrich Lackner (2 November 2018)

Friedrich Lackner has been a technical engineer at CERN. The interview on 2 November 2018 gave us deep insights into the technical aspects of each manufacturing process of CERN's magnets. Several technologies (e.g. accelerating magnets) could be rejected for further analysis since they are too specific and only needed for CERN's research, whereas he emphasised big potential in the special thermal treatment, as well as the importance for CERN to reduce costs of the production of the Rutherford cable.

Dr Christoph Lechner (23 November 2018)

Dr Christoph Lechner is a researcher at the Institute of Production Engineering and Laser Technology at TU Vienna. His insights about special magnet windings techniques enabled us to identify the application fields of linear engines and CNC machines.

Eva Lenhart (21 November 2018)

Eva Lenhart is currently employed by the University for Applied Arts in Vienna, Austria, her focus and points of interest are in the conservation of cultural and historical goods. She explained current processes for conserving and restoring historic and cultural goods. She also thinks that epoxy could be used.

DI Robert Mayrhofer (23 November 2018)

Mr Mayrhofer is a member of the department of materials and head of development regarding material corrosion at Daimler (Mercedes Benz). He studied material science and has vast experience in this field. First, Mr Mayrhofer explained the structure and details of Nb₃Sn. Following, the interview was focussing on application fields for CERN's technologies, mainly in the automotive industry. Due to the detail heat treatment, the oven might possibly be used for the production of other intermetallic compounds relevant for other industries such as "gamma TiAl." 3D printing is used for prototyping smaller titan parts, as the CERN is doing it as well, but the process is too expensive for the automotive industry. A main issue of the industry is the weight of cables in electric vehicles, and at Daimler, it was calculated to replace conventional cables with superconductors. However, the cooling would need too much energy, and this was not economically feasible.

Michael Mischkot, PhD (19 November 2018)

Michael Mischkot was a researcher for Additive Manufacturing at the DTU - Technical University of Denmark and is Associate at McKinsey. The interview was mainly about current developments in the field of ultra-high-precision additive manufacturing and possible application fields.

Prof. Dr-Ing Matthias Noe (9 November 2018)

Mr Matthias Noe is head of the department for particle physics at the Karlsruhe Institute of Technology. He is president of the Society for Applied Superconductivity (ESAS) and member of many working groups focussing on large scale applications for superconductivity. The first part of the interview was focussing on superconducting Nb₃Sn and its unique manufacturing process. Moreover, current difficulties in the manufacturing of HTS were highlighted. Additionally, Mr Noe stated that manufacturing a Rutherford cable with HTS did not work out in a research project. Mr Noe was explaining the main difficulties of the production and stated this as the main issue that Nb₃Sn is not more widespread. The second part was focussing on different application fields for the manufacturing process steps. First, he explained why the rectangular train overhead cables will not work, and second, he introduces several new applications fields, such as the “Separation of chips and coolants in machines” as well as the “Hybrid electric power-trains for cruise ships and aircraft.”

Dr Timm Ohnweiler (14 January 2019)

Dr Timm Ohnweiler from Carbolite Gero is the project leader of the oven manufactured for CERN who deeply explained us the uniqueness of this product. In a first step, the details of size, temperature, and protective gas were explained in comparison to other products of the company. The technical issues which had to be solved to meet the requirements of CERN were discussed afterwards as well as the general concepts of industrial ovens.

Felix Osterheider (21 November 2018)

Felix Osterheider is the Managing Director of the steel manufacturer Georgsmarienhütte (GM-Hütte) in the north of Germany and has been sitting in the management board of this company for over 20 years until his retirement at the end of 2018. The steel manufacturer GM-Hütte is a medium to large manufacturer with 7000 employees and a turnover of nearly € 2 bn in 2017. GM-Hütte delivers its steel to all German automobile manufacturers who use GM-Hütte’s steel for the car gearboxes. Since he is not involved in the technical aspects of the steel production, he was able to roughly inform us about the way the raw steel production is made in GM-Hütte. Furthermore, he forwarded us to his colleague Hans Henning Dickert, who is more concerned with the technical circumstances under which the steel production is carried out.

Alexandra Pleil (19 November 2018)

Mrs Pleil is currently employed by TGM and teaching process engineering; she gained a lot of experience in the plastics and metal industry. During the interview, she came up with several ideas, where the technologies of CERN could be helpful, e.g. aircraft charging or transport of electricity. She also pointed out that the thermal treatment process is very useful to heat things to a constant temperature for a constant time, this could be very helpful for melting different metals, e.g. scrap metal recycling.

Mag Peter Sattler (30 November 2018)

Mag Peter Sattler is a Consultant at Horvath & Partner and is an expert for petrol engineering. According to him, potential application fields for the epoxy resin could be industrial glues where companies like Henkel operate in. An important question he raised was if the epoxy resin is carcinogenic because all household applications have to be free of such substances.

Dr Daniel Schörling (20 December 2018)

Dr Daniel Schörling is a project engineer at CERN and author of “Cost model 16T magnets” (2017). According to Dr Schörling, 10%-20% of all costs are due to quality management and quality control. The main cost driver is the niobium tin conductor of the Rutherford cable. Typically, production costs are three times more expensive than material costs due to the special production requirements of CERN. Lastly, he explained the cost differences between NbTi and Nb₃Sn, the latter being more expensive in every aspect.

Dr Mario Stein (20 December 2018)

Dr Stein is employed by Nagra where he is acting as project manager for inventory and logistics. Mr Stein gave further insights into dealing with low-activation level radioactive waste. Currently, Nagra is dealing with the waste of CERN. Furthermore, he explained the differences between legislation in France and Switzerland and the requirements of storing waste in those countries. The key insight of this interview was the referring to GNS, the responsible company in Germany for treating high-activation level radioactive waste. He explained the main problem of GNS that the current solutions do not meet the legal requirements of dealing with radioactive waste. According to Mr Stein, the vacuum impregnation and epoxy used at CERN are able to solve the problem of GNS.

Joachim Tepe (21 November 2011)

Joachim Tepe is managing partner of the German “Drahtseilwerk Tepe” a middle-sized German business producing wire ropes for ski lifts, ropes courses, elevator ropes and the automobile industry. With the help of Mr Tepe, we were able to find out more about the production of a wire cable and noticed that the production is very different from the production of a Rutherford cable. Even though production and the profile might look very similar at first, wire cables have manufactured differently as they have different requirements. Instead of conducting electricity, wire cables need to withstand high weight, pressure and need to be flexible. These characters are achieved by a process called “compression” which compresses a wire cable from a diameter of 12 cm to a diameter of 2,7 cm. This compression increases the cable’s strength in the form of carrying capacity enormously. Unfortunately, he explained to us that this compression process would not work for an electric cable in particular not for a rectangular Rutherford cable as with the current compression technologies, the Rutherford cable would lose its shape. As Drahtseilwerke Tepe is not implementing the compression process themselves, Joachim Tepe

forwarded us their direct supplier who is also located in Bad Iburg, Germany, Vornbäume Stahlseile GmbH.

Dr Luisa Ulrici (17 December 2018)

Dr Ulrici is in charge of radioactive waste management at CERN. During the interview, she explained the differences in dealing with low- and high-activation level radioactive waste management and how the radioactive waste of CERN is stored in special facilities in France and Switzerland. She also described the problem, that the containers are not absolutely leak-tight, but it is actually no problem because it is not prohibited by law that the containers are not absolutely leak-tight.

Philipp von Latorff (21 November 2018)

Philipp von Latorff is the Managing Director of Boehringer Ingelheim in Austria and serves in the management board. Boehringer Ingelheim is a large scale and multinational pharmaceutical company headquartered in Ingelheim an der Ruhr, Germany, and generates a turnover of €18bn. In the short interview, Mr von Latorff explained briefly how ovens are used in the pharma industry with a particular view to medicine research aiming to find new or better medicine. However, there are also many different other methods that can create a bacteria-free environment to conduct research for example through chemistry. Furthermore, ovens are commonly used to kill unwanted bacteria in the research samples and check the behaviour of the drug to outside influences for instance heat.

Martin Zellhofer (6 December 2018)

Mr Zellhofer is Head of R&D at Wittur Austria GmbH in Scheibbs, an elevator parts manufacturer. The focus of the interview was if a rectangular rope can be used for elevators and have benefits there. He clarified that KONE (KONE UltraRope) is already using rectangular composite ropes for elevators having additionally many other benefits.

Hugo zu Salm-Reifferscheidt-Raitz (10 January 2018)

Hugo zu Salm-Reifferscheidt-Raitz is head of ground service at the Vienna International Airport AG and responsible for ground services, in particular, the catering of the aircraft. In this interview, he explained to us the complexity of an airport organisation. About 50 different departments of the airport are involved with an aircraft to arrive at the airport until its departure (e.g. the tower, the air security, the catering, the unloading division of the airport, the refuelling, etc). Therefore, he explained how elaborate battery swaps for electric aeroplanes are and the advantage of charging those with a cable. Furthermore, we learned that aeroplanes only remain about 45 minutes to 1 hour on the ground before the departure. This showed us the need for very quick charging and made us understand that current battery technologies are not sufficient for this.

E.2 User Communities

E.2.1 *Scrap metal forum*

Post Title: Research Project in Cooperation with CERN and WU Vienna

- Daniel Schreiber (20 November 2018)

Dear Community!

Let me briefly introduce myself: I am a student at Vienna University of Economics and Business and currently working on a research project to identify application fields for technologies and processes developed by CERN. Throughout the searching process, many ideas came up during interview sessions with actual users. One of the ideas arisen was to use a heat treatment instalment of CERN to recycle metals.

Now I am writing to this community to ask some details regarding scrap metal recycling. In our opinion, the technology could work and help in this field, but as a business student, we do not have the required knowledge to understand this technical process entirely.

So my questions are:

Do you think this idea makes sense? What other ways do you think could be used to separate metals?

Which metals are possible to split through heat treatment into different stages?

What temperatures need to be reached and for how long is required to hold them?

Thank you very much for your help and willingness to help to support our project. If you have any questions or need further information regarding the technology feel free to contact me, I am happy and ready to answer every question arising.

Yours, Daniel

- Hills (20 November 2018)

Hi Dan,

First off ... Welcome to the forum!

Please ... try to understand ... many of us don't have your intelligence or level of education. Could you dumb it down for us? Wouldn't presume to speak for anyone else here but I barely have the IQ of a dog in comparison to world-class talent. It's a matter of different worlds. It's hard to bridge the gap sometimes.

Let me see if I can share my perspective:

I understand CERN as being the big collider project in Europe. Fearful people have been concerned that it might blow up the world. (They had similar concerns about the first A-bomb test.)

Okay ... now ... I think you're talking about some new kind of metals refining and reclamation process. Waay kool! Way to Go! I love your ideas!!

I don't know if it's anything like what you're doing, but I've always had a dream. It would be

super kool to invent a process -or- series of processes that could take in municipal waste and break it down into it's atomic or molecular components then sort them accordingly.

Just imagine ... that would be 100% recycling and might even be an exothermic process that could be used to create electricity.

We've got a similar process with municipal trash incineration. One of the things that's been proposed has been some kind of plasma process.

If you could ever develop a field that would break molecular bonds as the waste is passed through ... you would be sitting on a goldmine!

Alas ... I haven't been gifted with the intelligence to envision how such a thing could work. We do seem to live in an age of miracles!

- mikeinreco (20 November 2018)

Sounds very interesting, please keep us updated. I was always interested in things like this and tried many times to create such solutions.

- Patriot76 (20 November 2018)

Welcome to the forum and I hope as was mentioned above that you will keep us updated the best you can through the process. The first thing that comes to mind is copyrights and patents because as Hills pointed out you are diving into uncharted territory that could have a big impact on the earth as we know it. Presently metals are separated using both the melting point and their density. Going to the molecular level would allow for the transposing of trash into food, pollution into new chemical elements, etc. I know this is beyond what you are seeking, so a couple of sites to get you started have been added below.

<https://www.steelforge.com/literatur...elting-ranges/> and

https://www.simetric.co.uk/si_metals.htm

- Otto (21 November 2018)

Separating lead and aluminium from steel come to my mind as potential applications as well. I would look at conventional furnaces currently employed to do this. I take it you're simply looking at using an alternate source of heat energy to accomplish the separation.

- Recyclersteve (21 November 2018)

Bill Gates of Microsoft fame has talked about a project that would cost billions and would allow toilet waste to be recycled into drinkable water and fertilizer. But what about the toilet paper? Stay tuned...

For many many years, people have talked about alchemy, trying to convert lead into gold. Since lead is 90 cents a pound and gold is over \$1,200 per OUNCE, this process could lead to vast riches for someone who discovers it early on and keeps their mouth shut while selling their newfound gold holdings. The problem is that once the word got out about what happened, the price of gold would absolutely plummet.

It would be a very complicated situation fraught with all kinds of dangers. For someone who

discovered it, they could potentially be murdered. Why? There would be lots of very wealthy people who would lose lots of money.

And, of course, there is always the bluffing game. Someone with enough money and the stones to do such a thing (perhaps a George Soros or wealthy Prince type) could tell the world that they have discovered it. They could go on TV amidst lots of fanfare to do such a thing. This could be the case, even though they haven't actually figured out anything. So they would be totally lying. Why would they do this? They could have a short position in gold, in other words betting it will go down.

When it did plummet, they could not only cover their short position with a tidy profit but also buy additional gold at the artificially cheap price. Of course, this strategy of going long gold could backfire in a big way if someone else really did figure out how to convert lead into gold. I predict that someday there will be a movie made about this subject.

- Mikeinreco (22 November 2018)

First of all, thanks for your great idea! Well here is one movie I can remember about Da'Vinci's machine turning lead into gold (Hudson Hawk)

- Daniel Schreiber (22 November 2018)

Thank you very much for the warm welcome! also a big thank you for your input, it helped me a lot for further purposes!

One further question which arises: Would it make sense to use the heat treatment oven for recycling purposes? As a big advantage, I would also mention here that in this oven are special heating zones which can be controlled separately and the temperature can be held for a long time with high accuracy ($\pm 3^{\circ}\text{C}$)

Do you also know some companies which are currently dealing with such things, such as scrap metal recycling, browsing the web appeared not sufficient to me?

- Hills (22 November 2018)

Sorry for the derail!

This one's old tech. I've got it here at home via the septic system.

1: Our wastewater leaves the home and enters the septic tank. The septic tank catches about 95% of the solids and bio-degrades them.

2: The effluent, AKA greywater, leaves the tank and goes into a leaching field where it's leached into the soil.

3: The leachate gradually filters down through about 100' of granite bedrock into the underground aquifer.

4: Our drilled well, about 100' deep taps into the aquifer and our submersible pump sends the water back to the house.

A little freaky when you think about it ... but that's water cycle!

Municipal wastewater systems work in a similar way. The solids are separated and then used to

generate methane gas. The liquids are often dumped into the ocean. The sun hits the ocean, evaporates the water, and it's returned as rain & snow.

Alternatively, the wastewater could be filtered, treated, and reused using something like the Millipore system.

It might be better to filter seawater in places like the middle east where water is scarce. That's what they're currently doing.

Ancient Alchemy was really more of a spiritual metaphor. (You have to read between the lines sometimes.)

It was more about the process of conversion of the base human spirit (lead) into something worthy of entry into the kingdom of heaven (gold).

Modern-day Alchemy would be something far different. It would be about the mastery of manipulating matter and energy at will. See ... matter and energy are basically the same thing. ($E=Mc^2$) We already do that somewhat ... it's just that we haven't got it completely figured out just yet.

And yeah ... it really would upset the apple cart. The wealth wouldn't be in precious metals but rather in the knowledge of how to manipulate matter at will.

Just an opinion: I think you have to look around your environment and see where your energy sources are.

Take the middle east for instance: They have crude oil, natural gas from their oil wells, plenty of sunshine, and wind.

In places like Venezuela & Iran ... there's an abundance of LNG & LPG. They're oil producing nations but don't have refining capacity but do have these different flammable gasses coming off the wellheads. A lot of their vehicles are built to run on LNG & LPG.

Desalination plants and power generating plants utilize the oil resource in some way. They could build big solar still to purify their water. You know ... use solar energy to evaporate the seawater and then condense it back to liquid form. They could build a dual purpose solar furnace that produces electricity and purified water.

Iran also has the basic materials to run a nuclear energy plant. They have to mine the radioactive material and then refine it ... but it's a doable plan. (This one is controversial.)

Point being: It can go all different kinds of ways. It all depends on what you have on hand to work with. It's a wide-open field of opportunities.

- Sirscrapalot (24 November 2018)

I highly appreciate your Ideas @Daniel, hope to hear from your solution really soon!!

- Hills (24 November 2018)

I just can't help but feel that we might not be the best source of information for the OP. Most of us are scrappers and not refiners. There's always been a generally agreed upon the prohibition of discussions that have to deal with refining because of the dangers involved.

If we did set up a furnace to purify our metals into ingots ... our scrapyards probably wouldn't accept them.

What he's asking about is generally outside the range of our direct experience unless we've worked in an industrial foundry before?

- Stargate1 (27 November 2018)

I can't add anything than I looove your ideas and vision for this topic. Go on and share everything you find with us.

E.2.2 Romoe – Restauratoren Netzwerk

Post Title: Universitäres Forschungsprojekt im Bereich Konservierung

- Daniel Schreiber (19 November 2018)

Liebe Community,

derzeit arbeite ich im Rahmen eines Forschungsprojektes in Kooperation mit dem CERN und der Wirtschaftsuniversität daran Technologien des CERNs auf andere Anwendungsbereiche anzuwenden. In zahlreichen Interviews kamen Ideen auf, dass man eine spezielle Form des Epoxidharzes auch im Kunst- bzw. Archäologie Bereich einsetzen könnte.

Im Detail handelt es sich um ein sehr strapazierfähiges Epoxidharz, welches nach dem Auftragen einen besonderen Schutz vor eindringen unerwünschter Partikel oder ähnliches bieten kann. Weiters kann das Harz auch Umwelteinflüsse abwehren (bspw. Feuchtigkeit). Nun stellt sich meinem Team und mir die Frage, was Experten auf diesem Gebiet dazu sagen würden, wenn sie so eine Art der Konservierung zur Verfügung hätten? Interessant wäre auch zu erfahren bzw. Hinweise zu bekommen, wer denn Auskunft geben könnte oder aktuell solche Produkte anbietet, die genau jene Eigenschaften aufweisen.

Eventuell kann diese Technologie auch nicht eingesetzt werden, dann wäre es sehr hilfreich zu erfahren, warum nicht?

Sollten Fragen auftauchen, oder Interesse an mehr Informationen bestehen, stehe ich sehr gerne zur Verfügung! Weiter möchte ich gerne festhalten, dass es sich hier nicht um ein kommerzielles Projekt handelt, dieses Vorgehen dient lediglich Forschungszwecken für das CERN und seine Tätigkeiten.

Danke schon mal vorweg für Eure Unterstützung.

Daniel Schreiber

- Matthias Möller (21 November 2018)

Hallo Herr Schreiber,

bei der Holz sowie Metall Restaurierung werden bereits heute Epoxidharze für Verklebungen genutzt, zB. 2-Komponenten Epoxidharz als Spachtelmasse sowie als Gießharz bzw. Härter in Abformmassen.

Da die Harze auch eine wasserfeste und dauerhafte Imprägnierung erzeugen, kann darunter ein

Kunstwerk aber auch Schaden nehmen. Großflächig wird es daher eher selten verwendet. In Bereichen wie Bootsbau ist die Wasserfestigkeit jedoch vorteilhaft.

Das thermoplastische Harz, Reinacrylat "Paraloid B 72" wird eher verwendet, zB. in einer 15% Lösung in Ethylazetat.

Bei der Konservierung/Restaurierung gibt es immer mehrere Faktoren die berücksichtigt werden müssen. In den meisten Fällen muss eine Licht- und Alterungsbeständigkeit, der Ausdehnungsfaktor beachtet, eine Atmungsaktivität oder eine Reversibilität gewährleistet werden.

Ich hoffe diese Information hilft Ihnen etwas weiter.

Freundliche Grüße, Mathias Möller