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DELIVERABLE D5.1

IMPACT POTENTIALS OF EASITRAIN RESEARCH ON SOCIETY AND INDUSTRY

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Abstract:

This document presents impact potentials of the research performed for the creation of future research infrastructures, industry and medical domains in the EASITrain project. For the different technologies a catalogue of potential applications and end-use cases is established, which can serve as input to develop estimations for market valorisation. The description includes cost and performance improvement potentials. All beneficiaries have contributed to the development of this deliverable. The aim of the catalogue is to present key industrial impact potentials by outlining new application fields as well as known application fields with strong economic growth potential. The catalogue is based on research projects carried out by the Vienna University of Economics and Business (WU) in cooperation with CERN between 2017 and 2019.

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GLOSSARY

SI units and formatting according to standard ISO 80000-1 on quantities and units are used throughout this document where applicable.

C	Celsius
FCC	Future Circular Collider
FFV	Fresh fruit and vegetable
HLW	High Level Radioactive Waste
i.e.	Id est (in other words)
ILW	Intermediate Level Radioactive Waste
K	Kelvin
LHC	Large Hadron Collider
LLW	Low Level Radioactive Waste
MWF	Metalworking Fluids
NMR	Nuclear Magnetic Resonance
R&D	Research and Development
UPS	Uninterruptable Power Supply
USD	US-Dollars

1. INTRODUCTION

An international consortium of more than 150 organizations worldwide is studying the feasibility of various future particle collider scenarios to expand our understanding of the inner workings of the Universe (see http://cern.ch/fcc). At the core of this Future Circular Collider (FCC) study, hosted by CERN, is the idea of a 100 km long circular particle collider infrastructure that extends CERN's current accelerator complex with an integral research program that spans 70 years (see http://fcc-cdr.web.cern.ch). After a first phase with a high-precision lepton collider, the ultimate goal is to build a proton collider with an energy seven times larger than the Large Hadron Collider (LHC). Such a collider has to be built with superconducting magnet technology that remains yet to be developed. Since it takes decades for such a technology to reach industrial maturity, research and development efforts are well underway. The EASITrain project trains a new generation of leading engineers to advance this field of research and associated technologies.

Benefits derived from this technology research go beyond building research infrastructures to answer of fundamental research questions. A crucial question is how, apart from learning more about our universe, can the society benefit directly from a new particle collider project? While not apparent at first glance, the research about new high technologies comes with profound economic impact on other industries and the knowledge acquired from developing these technologies needs be spread and appropriated to benefit the public.

With this report, we reach out to industries outside of the particle collider domain as well as suppliers and manufacturing partners of this consortium and present them with new market opportunities based on the technologies developed for the collider. We believe that these parties can benefit from the know-how being used to either enter new markets or improve the companies’ efficiency and competitivity in existing ones. Higher cost effectiveness and leveraging further markets additionally translates into lower manufacturing costs of a future high-energy particle collider, ultimately creating a win-win situation for all parties.

1.1. OPEN INNOVATION

Scientific literature on innovation and innovation management claims that we are in the midst of a paradigm shift from closed to open innovation. While (corporate) innovation used to be an endeavour solely driven by the focal organisation, scientists and practitioners alike observe a strong trend towards opening up (corporate) innovation processes. The underlying idea of open innovation is to integrate external stakeholders in all phases of the innovation process (from ideation to marketing new ideas, concepts, or solutions) in order to leverage their creative potential and complementary skills. An ever-growing number of scientific studies find evidence for open innovation approaches that outperform traditional, closed innovation processes with regard to effectiveness and efficiency.

Open innovation is defined as “the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively” (Chesbrough, 2003). According to this definition, open innovation does not only facilitate the collection of innovation-related knowledge from outside the organisation to solve problems or create new products or services; it also covers outbound innovation activities, i.e., leveraging own technological resources to exploit (new) market opportunities beyond the organisation’s current target markets. A systematic approach to identifying and evaluating new applications to existing technologies is the “Technological Competence Leveraging” method, which will be described in the next sub-chapter. Based on open innovation methods like crowdsourcing, the TCL method has proofed to be a valuable tool in knowledge and technology transfer activities.

1.2. TECHNOLOGY COMPETENCE LEVERAGING

Finding new market opportunities for existing technologies can be challenging (Herstatt & Lettl, 2004). This is particularly true for technologies, which are developed for a purpose that is distant from the everyday needs of citizens, such as fundamental research and technologies for research infrastructures. One tool to help overcome this obstacle is Technology Competence Leveraging (TCL) pioneered by Keinz and Prügl (2010). With the help of this method (which is based on open innovation principles such as crowdsourcing), new application fields for a given technology can be identified and evaluated, leading to the discovery of new market opportunities. By combining creative and analytical tools, TCL systematically triggers the discovery of new fields of applications following four sequential steps:

Identification of the technology´s use benefits

The goal of this step is to pinpoint the use benefits (or features) of the technologies and processes based on interviews with experts and actual users. Since the technologies should be used in other industries, we have to know what exactly the technology can do. Which problems does the technology solve? The outcome of this step is a list with generalized features of each technology.

Search for application fields

During the second step, we focus on finding new application fields for each technology's set of benefits. To do that, we trigger divergent thinking with creativity techniques like brainstorming and search for industries that might have similar problems like the ones solved by the technologies. All ideas are clustered and evaluated based on interviews with potential users to prove their applicability.

Assessing Benefit Relevance and Strategic Fit of the application fields

Once we have established a list of relevant application fields, they are evaluated according to their benefit relevance and strategic fit. These concepts rate the ideas concerning their marketability. While benefit relevance assesses the relevance of the problem to be solved, strategic fit measures the fit of a given idea to the producing company and its resources, capabilities and culture.

Assessment of market potential

In the final step in TCL, the market potential is analysed by identifying how to derive value from a particular idea, for whom, how to generate income and which key partners are needed to implement the idea. Based on the analysis, the market potential of a new application field can be estimated and, if promising, further steps into the marketing of the ideas can be taken.

TCL proved to be a very useful tool to identify new market opportunities for technologies involved in manufacturing superconducting magnets. In total, 65 new application fields could be identified using this method. A selection of the most promising ones are presented in the following chapter.

2. CATALOGUE OF APPLICATION FIELDS

2.1. BACKGROUND INFORMATION

In this chapter, application fields for technologies that relate to the manufacturing of high-field superconducting magnet. In addition to known markets, where demand for superconducting technologies is already established and which are known to exhibit promising growth potential, the chapter gives an overview over industries, where superconducting technologies are likely to play a role in the future. The ideas for the application of superconducting technologies described in this chapter are at different stages of development and range from already operating prototypes to first ideas. However, all of these application fields have in common that high technologies involved in developing a new circular collider would solve highly relevant problems in respective markets that how growing economic potential.

Starting in 2017, the Institute for Entrepreneurship and Innovation at the Vienna University of Economics and Business conducted research projects to identify and analyse the potential of new application fields outside of the particle collider domain for superconducting magnets and important steps of their manufacturing value chain. The superconducting **Rutherford cable**, the furnace for the **thermal treatment** as well as the CTD-101k **epoxy resin for vacuum impregnation** of the superconducting magnets were identified as the most valuable parts of the manufacturing process due to their uniqueness and cost intensity. Consequently, this report provides descriptions of application fields for those manufacturing technologies additionally to the superconducting magnet itself. This chapter provides an overview over the selected, most promising application fields, defines the problems they solve in specific industries and elaborates on their performance improvement potentials.

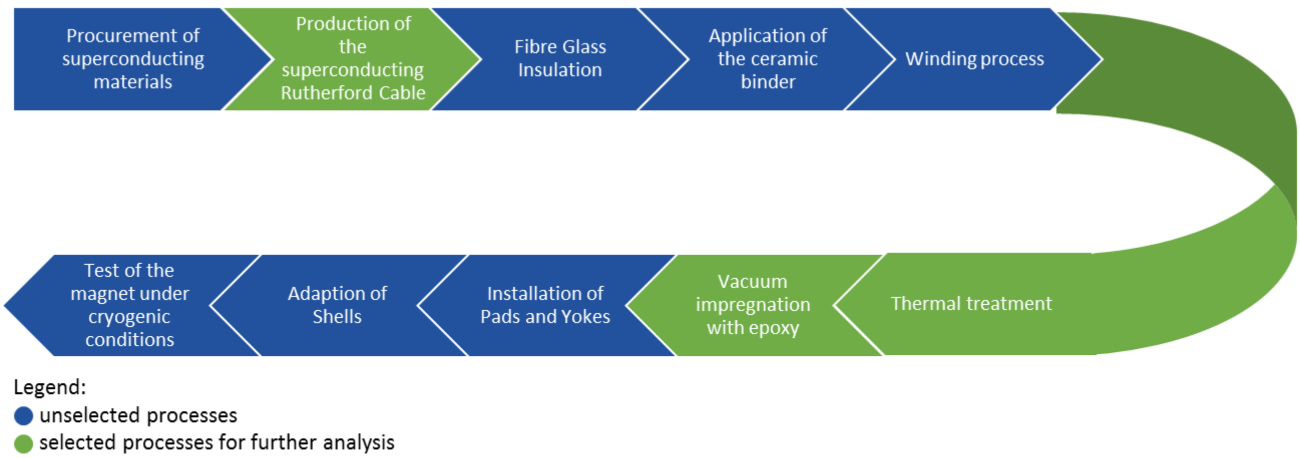


Figure 1: Processes in the manufacturing chain of superconducting magnets

2.2. COMPACT CYCLOTRONS FOR CANCER TREATMENT

Cyclotron particle accelerators are employed to fight cancer by accelerating energized ionizing particles and directing them towards tumors in order to kill the tumor cells (Kofler, Kindl, Spiess, Aschauer, Drahoss, von Aufschnaiter and Gutleber, 2017). Compared to traditional cyclotron technologies operating with conventional magnet coils, superconducting cyclotrons have the advantage that they are much more compact, light and consume less power, thus significantly reducing overall operating costs. Due to the smaller size, superconducting cyclotrons can be integrated more easily in existing hospitals (Kofler et al., 2017). In addition, the high beam extraction efficiency enables the superconducting cyclotron to produce high dose rates, effectively treating deep-seated tumors, as well as reducing dispersion of the energy around the tumor, decreasing the negative impact on healthy tissue (Kofler et al., 2017). Finally, compact cyclotrons built from superconducting materials open up the possibility to offer light ion beams in addition to protons. While clinical experience is gathered slowly with only a handful of custom-built particle accelerators world-wide (e.g. MedAustron in Austria, HIT in Germany, CNAO in Italy and NIRS in Japan), this advancement is considered a promising next step in effectively treating problematic and pediatric cancer cases.

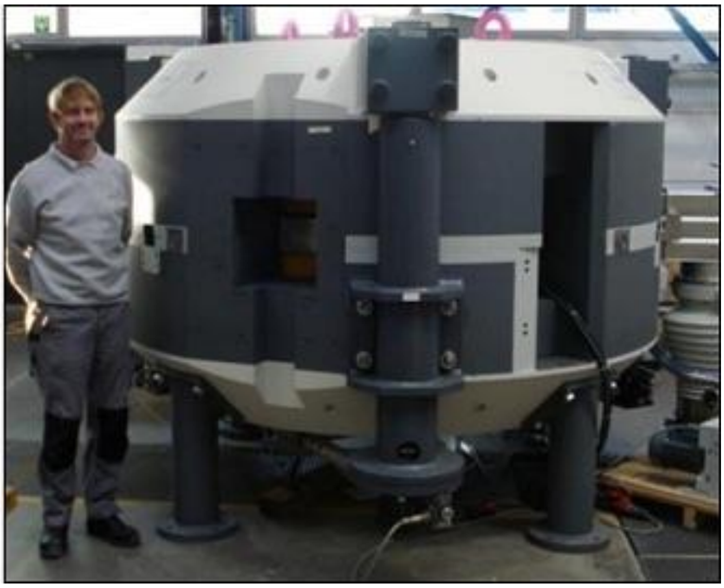


Figure 2: Mevion's S250 compact superconducting proton cyclotron built from Nb3Sn wire weighs "only" 20 t.

The following table compares the key parameters of various cyclotrons for particle therapy (Derenchuk, 2013).

Machine	**Manufacturer**	**Type**	**Particles**	**Size**	**Weight**
C230	IBA, Sumitomo	Normal conducting	Protons	4.3 m	220 t
SC PC	Varian	Superconducting	Protons	3.1 m	90 t
IUCF main stage	Indiana University	Normal conducting	Protons	9 m	2 000 t
S250	Mevion	Superconducting	Protons	1.8 m	20 t
S2C2	IBA	Superconducting	Protons	2.5 m	50 t
C400	IBA	Superconducting	Protons Carbon ions	6.6 m	700 t

Table 1: Key parameters of various cyclotrons for particle therapy

Currently, only very few cyclotrons leverage superconductivity. However, recent developments indicate that the industry is shifting towards newer, more advanced technologies and exhibits high growth potential. According to expert interviews conducted as part of the university project in 2017, utilizing superconducting cyclotrons would increase the accessibility of particle therapy for patients worldwide significantly due to reduced treatment costs. Until 2013, less than 120 000 patients were treated with either proton or carbon ion therapy and until 2014, less than 20 000 patients received novel treatment with carbon ions (Kofler et al., 2017, Jermann, 2015). As soon as superconducting cyclotrons become a standard in the particle therapy industry, chances for recovery will substantially increase for many patients, in particular children (Kofler et al., 2017).

Important industry players such as Varian Medical Systems Inc., IBA Worldwide, Hitachi, and Sumitomo Heavy Industries Inc. are progressively focusing on research and development and strengthening their leadership by acquiring smaller players. The global particle therapy market is expected to grow 8% annually until 2026 and new advancements in efficiency and efforts in reducing the size will accelerate adoption rates (Transparency Market Research [TMR], 2019). The demand for particle therapy technologies is mainly driven by hospitals, particularly specialty clinics will face increased patient flows due to the high prevalence of lung cancer and other prominent cancer diseases (Transparency Market Research [TMR], 2019). In conclusion, the particle therapy industry offers lucrative business development opportunities due to the high rate of adoption of this type of therapy, increasing dedication of health care budgets and governmental initiatives pushing this type of cancer treatment (Transparency Market Research [TMR], 2019).

2.3. UNINTERRUPTIBLE POWER SUPPLY

Between 2003 and 2012, the cost of power outages caused by natural disasters in the US amounted to 18 - 33 Billion USD per year (Qazi, 2017). Taking into consideration this economic loss and the fact that weather conditions, which cause more than 30% of all power outages, are becoming more extreme, the importance of uninterruptable power supply (UPS) is increasingly gaining importance (Bie, Lin, Li and Li, 2017). Aiming to avoid downtime, most industries such as the manufacturing industry, financial corporations, the healthcare sector and IT services are strongly dependent on continuous power supply and thus, deploy UPS systems. These systems minimize damages and ensure a constant supply of power, also protecting against under- and overvoltage (Kofler et al., 2017). Current solutions such as ordinary batteries, flywheels and super capacitors, come with disadvantages including long recharging times (batteries), low energy storage (super capacitors), efficiency losses (flywheels) or short runtime (super capacitors & flywheels) (McCluer & Christin 2008). Systems using superconducting materials can significantly increase the efficiency in the power storage process due to their properties: They exhibit a high current capacity on a small scale, thus generating a strong magnetic field, are able to store energy long term and can instantly release this energy, making them a valuable alternative to traditional energy storage devices (Kofler et al., 2017). As aforementioned, commodity flywheels have a considerable self-discharge rate, which is neither economical nor sustainable. Superconducting flywheels or coils have significantly lower idling energy loss. They use magnetic levitation and operate in vacuum.

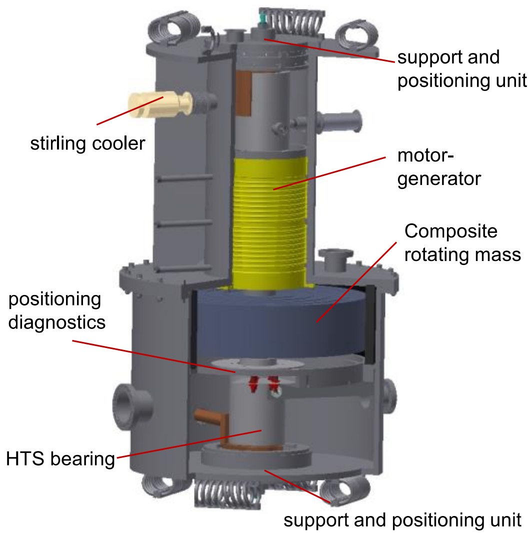


Figure 3: Drawing of 250 kW/3 kWh superconducting flywheel energy buffering system developed by project partner Bilfinger Babcock Noell GmbH (BNG) to bridge limited-duration power interruptions and to ensure high power quality.

Like many other industries, the growth of the UPS industry is influenced by climate change, which has a major impact on energy consumption behaviour. The UPS market is seeking to adopt environmentally-friendly technology to save energy through higher efficiencies of the systems. Due to rising political interest in these matters, legal regulations like stronger taxation of energy consumption and higher eco-standards provide further incentives towards ecological compliance (Kofler et al., 2017). Based on interviews with industry experts from the data center industry, UPS systems have an average lifetime of 15 years; with batteries having the lowest: In static systems, which represents 97% of the market, they need to be replaced after 5 years (Kofler et al., 2017).

In 2017, the uninterruptable power supply market generated a value of 7 226 Million USD and it is estimated to have an annual growth rate of 8.3% until at least 2025 (Market Research Future, 2018). While the application of superconducting technologies in the UPS market is still in its R&D phase, recent developments show that there is an increasing interest in the technology from the UPS market's perspective: In 2015, the Japanese Railway Technical Research Institute (RTRI) developed the world's largest superconducting flywheel power storage system, which is currently in test operation (Wang, 2017). With big players such as Boeing dedicating their R&D efforts towards implementing superconducting flywheel technology, a shift in the UPS industry seems to approach quicker than anticipated (Strasik, Hull, Mittleider, Gonder, Johnson, McCrary & McIver, 2010).

2.4. HYBRID-ELECTRIC POWERTRAINS FOR CRUISE SHIPS AND AIRCRAFT

In the aviation and maritime industry, the usage of a Rutherford cable can reduce the reliance on fossil fuels as a source for power. According to a report by KPMG, worldwide airline fuel costs increased by more than 11% from 2018 to 2019, representing 24% of total operating costs (O'Mara, 2019). However, for hybrid-electric propulsion, these industries currently utilize heavy copper cables that conduct a high current density to transport the power from an electricity generator to the engines (Noe, 2017). Due to the quantity and size of current cable technologies, these cables come with significant weight, affecting the power demand and leading to increased fuel consumption. For example, a reduction of 35 kg of weight represents a reduction of 80 tonnes of kerosene annually for Lufthansa Cargo, saving the company 60,000€ per year (Bundesverband der Deutschen Luftverkehrswirtschaft e.V., n.d.; Potschy, 2018). Considering that a modern aircraft features around 110 – 483 km of wires: Using superconducting Rutherford cable can save a company Millions of Dollars due to its lightweight characteristic (Bellamy, 2014): In comparison, a thirty-centimetre-long bundled superconducting wire weighs 16 grams, while its copper pendant weighs 12 kg (Pluta, 2014). However, in order to assess the total fuel efficiency, the total weight loss - including the additionally required cooling facilities - has to be taken into account (Noe, 2017). To successfully implement this technology, further research should be conducted to increase the efficiency of cooling facilities and energy storage in the aircraft.

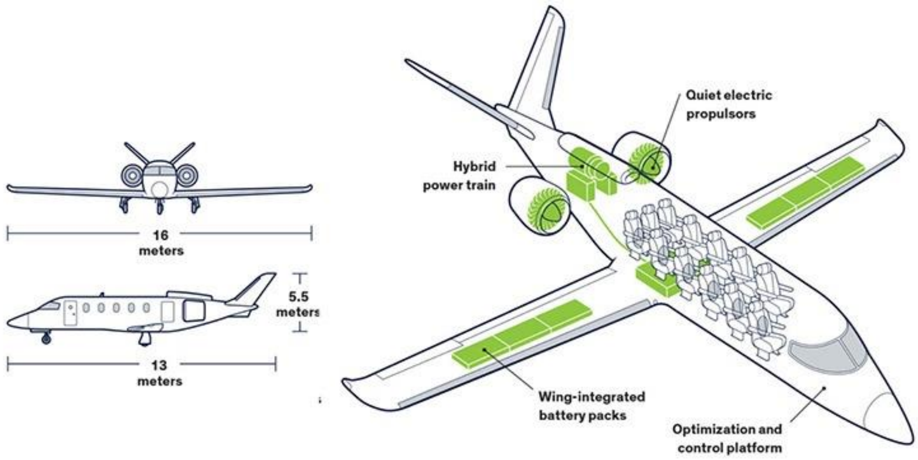


Figure 4: Hybrid-electric powertrain in the aircraft model of Zunum Aero (Courtesy of Zunum Aero)

Currently, there are many developments towards electric propulsion indicating an imminent shift in the respective industries. Big names in the industry such as Boeing and NASA are increasingly spending large amounts of their budgets on electric aviation research and development and new start-ups in the field such as Eviation, Ampaire, Zunum and Magnix attract the interest of big investors aiming to be part of this ongoing development (Downing, 2019; Nanalyze, 2019). Hybrid electric powertrains are already widespread in cruise ships and likely to become a standard in the aviation industry. Particularly with regards to environmental protection regulations, hybrid electrical aircraft will become necessary for the commercial aviation industry to be able to meet emission targets. Accordingly, the aviation and maritime industry constitute a very promising market for the industrial application of the Rutherford cable, opening up a major market opportunity.

2.5. HIGH- AND LOW-LEVEL RADIOACTIVE WASTE MANAGEMENT

Due to its radiation resistance, the CTD-101k epoxy resin used for the impregnation of the superconducting magnets could be applicable for radioactive waste management. With the industry expected to grow by 16.7% annually and surpass a value of 5,627 Billion USD by 2024, it is a promising application field for the technology (Transparency Market Research [TMR], 2016). The industry distinguishes between high, low and intermediate level radioactive waste (HLW, ILW, LLW). High-level radioactive waste stems from nuclear reactors and include particularly spent nuclear fuels. Low-level radioactive waste, which mostly stems from contaminated equipment in hospitals such as the radiology department and other industrial sources, makes up 90% of the volume of radioactive waste and less than 2% of the radioactivity in radioactive waste (Brzobohaty, Habernig, Moravec, Pably, Schürz, Kretzschmar and Quach, 2019). It is typically disposed of in near-surface repositories, meaning, the waste containers are buried at a depths of ten meters (World Nuclear Association, 2018). The containers in which radioactive waste is deposed in the ground represent one of the most crucial parts in an overall multi-barrier system, including an engineered barrier system in a geological disposal facility (King, Sanderson and Watson, 2017).

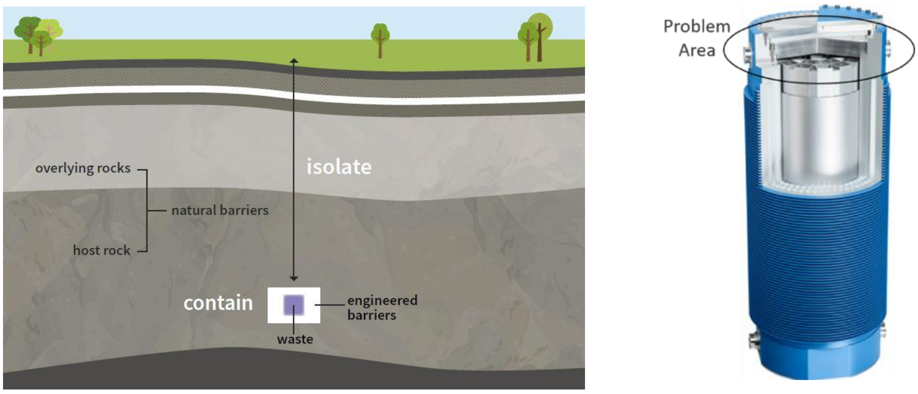


Figure 5: Barriers of geological disposal facility & radioactive waste container (Courtesy of Radioactive Waste Management)

For the different types of waste, different containers are needed to ensure the safety for the environment. The containers are designed to be stored in specific facilities that shield radiation. However, in Germany, due to stricter legal requirements, the industry is in need for novel designs of the containers, since the current design does not fulfil the new regulations anymore (Kretzschmar, Mehner, Hausberger, Ledermüller, Mayrhofer, Schreiber and Gutleber, 2019). Furthermore, nuclear waste management experts point out that the containers in use are not completely leak-tight, resulting in a higher danger of environmental contamination, particularly with regards to the surrounding groundwater (Kretzschmar et al., 2019). Since the epoxy resin is resistant to radioactivity, the material could be employed to improve the sealing of these containers. While the properties of the epoxy in general make this material well-suited for permanently sealing off the containers, further research still has to be done for example with regards to the application process Kretzschmar et al., 2019).

During interviews conducted to verify the epoxy as suitable material to seal radioactive waste containers, several industry-related companies such as GNS (Manufacturer of radioactive waste container) and NAGRA (Operator of repositories for nuclear waste) showed interest in learning more about the possible usage of epoxy resin. The radioactive waste management industry is dominated by a few key players such as Areva SA, Bechtel Corporation and Veolia Environmental Services (Transparency Market Research [TMR], 2016). The amount of HLW increases approximately by 12.000 tons each year and with more than half of the operating reactors in the world being older than 30 years, decommissioning activities will increase in the near future (World Nuclear Association, 2018). Consequently, most of the running nuclear facilities will have reached their end of life within the next decades, resulting in a growth of demand in disposal. The disposal of HLW is expected to have a huge impact on the development of this industry and will become a challenging task (IAEA Nuclear Energy Series, 2018).

2.6. IN-OVO SEXING IN POULTRY INDUSTRY

One particularly interesting and entirely novel application field for NMR spectroscopy is the early determination of the sex of unhatched chicks in the poultry industry. In this industry, male chicks are considered a by-product since they cannot lay eggs and are unsuitable for consumption. As a consequence, out of the 14 Billion chicks hatched for 21 days in special machineries annually, 7 Billion male chicks are disposed of by electrocution, gassing or grinding immediately after hatching (Krautwald-Junghanns, Cramer, Fischer, Förster, Galli, Kremer, Mapesa, Meissner, Preisinger, Preusse and Schnabel, 2017). Currently, hatcheries are looking into more practical solutions attempting to reduce costs and avoid bad publicity about these morally reprehensible practices negatively affecting their businesses.

Spectroscopic methods have shown to accurately determine the sex of the chick in-ovo at an early stage whilst being non-invasive. These methods rely on different features such as genetic information about the sex in blood vessels which are already developed within the third day of incubation, or the measurement of hormone levels (Krautwald-Junghanns et al., 2017). While these methods could enable the entire industry to increase the effectivity of their incubation machineries up to 50%, fertilized, non-hatched eggs could then be sold to pet food producers or used in immunomedical research for egg-based vaccines such as Influenza shots (Matthews, 2019; Centers for Disease Control and Prevention, 2018).

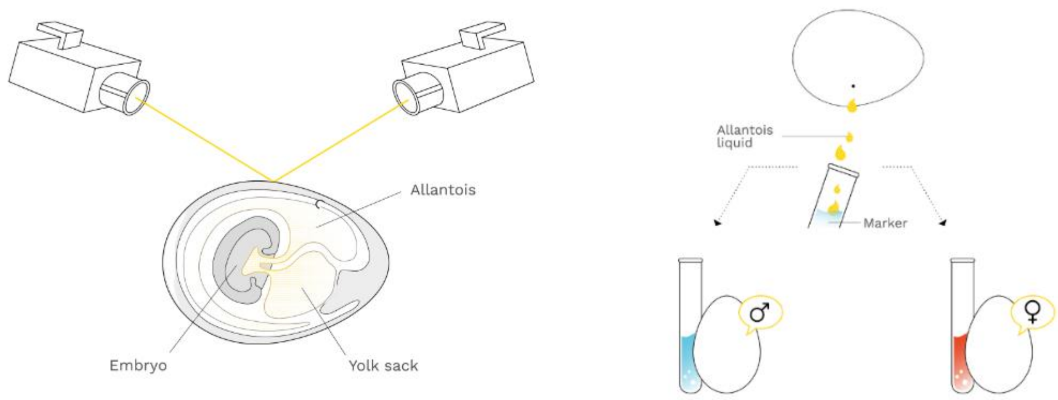


Figure 6: Endocrinological gender identification using the Seleggt method (Courtesy of Seleggt)

The poultry industry is the biggest meat industry worldwide with more than 117 Million tons of meat consumed annually (38.8% of the entire meat market) and is estimated to reach 129 Million tons per year by 2021. In 2012, the EU poultry industry had an output of 12.9 Million tons and the total production value was estimated at 24.6 Billion Euro (Van Horne & Bondt, 2013). With frequently emerging lawsuits against the unethical practice and chick culling increasingly gaining media attention, the external pressure for change in the industry is growing. A shift in the industry is noticeable, with more and more start-ups developing innovative alternatives such as the Seleggt method and methods to adapt the female to male ratio of eggs (Seleggt, 2017). Many of the methods developed by companies however are invasive, making the eggs useless for further exploitation, which is where NMR spectroscopy has a strong advantage. Not only is the industry itself highly interested in finding alternative solutions. In 2019, the Foundation for Food and Agriculture Research (FFAR) initiated the start of the open competition “Egg-Tech Price” to fund innovative solutions for non-invasive sex determination to prevent the practice of chick culling in hatcheries, offering up to $6 Million funding for ideas submitted to a two-phase open call until winter 2021 (FFAR, 2019).

2.7. METAL RECYCLING

The furnace used to thermally treat Rutherford cables for superconducting magnets has advantages compared to furnaces in other industries: It can reach high temperatures up to 900 °C precisely within an accuracy range of +/- 3 °C (Kretzschmar et al., 2019). In comparison, furnaces used in the steel industry have a range of +/- 10 °C. The heating system generates a homogenous diffusion of heat with internal fans and permits fast temperature changes at a rate of 50 K per hour. The furnace minimizes the shrinking of metals due to corrosion (oxidation) by leveraging the protective properties of argon, a noble gas. This way, the process becomes more efficient and less material is lost, which is important for valuable and expensive materials (Brzobohaty et al., 2019).

Figure 7: Furnace for thermal treatment of magnets (Courtesy of Friedrich Lackner/CERN)

These properties are particularly relevant for the metal recycling industry. Currently, scrap metal recycling is a lengthy multi-step process, which involves several machines and ovens (Brzobohaty et al., 2019). Consequently, the recycling process is time-consuming and cost inefficient. Adopting the above-mentioned furnace can reduce the number of steps by combining the splitting up and melting of several metals. Specifically, the technology allows the separation of metals with different melting points, such as the separation of aluminium, which has a melting point of 660 °C, from lead with a melting point of 327 °C in one step (All Metals & Forge Group, 2017; Kretzschmar et al., 2019).

According to interviews conducted with industry experts, the furnace is particularly attractive for the aluminium recycling industry (Brzobohaty et al., 2019). Currently, 60 Million tons of aluminium are used annually and the consumption is predicted to increase by 18% until 2023 (Analytical Credit Rating Agency, 2019). The global demand for this valuable metal is primarily driven by industries such as construction, aviation and automotive, where it has replaced steel due to its high strength to weight ratio (Brzobohaty et al., 2019). The metal is highly recyclable, with around 75% of all aluminium manufactured, dating as far back as 125 years, still being in use today (Nappi, 2013). The metal is infinitely recyclable without degredation and its recycling process is considered to be a closed-looped, implying that no new material has to be introduced along the way (Horton, 2008). Furthermore, the re-melting process of aluminum is much less costly and energy-intensive, using only 5% of the energy needed for the production of new aluminum (Aluminum Association, 2011).

The current recycling process exhibits some challenges such as possible contamination (Devaney, n.d.). Impurities in the metal have an impact on its properties and can weaken the metal, rendering it unusable for specific industrial purposes. However, by using the particular furnace for the process, the aluminum could be separated from contaminating metals such as lead and tin, which are primarily responsible for its contamination (Devaney, n.d.). Furthermore, during the melting process, a waste by-product called dross develops due to the oxidation of the metal. Around 8 - 10% of the melt produced by a normal furnace is dross, which consists of 50 ro 60% of aluminium. With argon as a protective gas, the furnace could help to reduce the development of dross, consequently diminishing the loss of aluminum during the recycling process.

The aluminum recycling industry is steadily growing: While primary aluminum production decreased by 8.5% within five years, the amount of recycled aluminum increased by 21.6% within the same timeframe until 2015. In Europe alone, this secondary aluminum production is operated by more than 300 aluminum recycling plants (Bureau of International Recycling, 2016).

2.8. FOOD QUALITY CONTROL

Standard sorting machines in the food industry work with high-frequency cameras that take pictures of vegetables and fruits in different angles. This approach however limits the quality evaluation to external characteristics such as size, color, curvature and visible damages, disregarding potential internal physiological defects. According to industry experts from companies such as VOG, Microtec and Greefa, this is an important concern in the food quality industry and thus, some companies currently employ infrared and UV technology to detect internal defects (Kofler et al., 2017). However, these technologies are not able to conduct a structural analysis of organic material, determining for example the maturity of the produce, which is an important predictor for shelf life expectancy and storage conditions (Marcone, Wang, Albabish, Nie, Somnarain & Hill, 2013). In addition to limited conclusiveness about total product quality, many technologies are invasive (thus destroying the fruit or vegetable), time-consuming or too superficial to analyze the fruit core. Nuclear magnetic resonance (NMR) spectroscopy can overcome these challenges by analyzing the chemical composition of the products and detecting parasites, impurities or diseases based on compositional and structural properties (Marcone et al., 2013; Brzobohaty et al., 2019). Research shows that magnetic resonance technologies can rapidly distinguish between vegetables with and without fungal infections and can be used for the quality analysis of fresh fruit and vegetables (FFV), as well as herbs, drinks, meat and carbohydrates (Marcone et al., 2013). Furthermore, the technology is able to investigate aromatic and bioactive compounds, spoilage as well as adulteration, i.e. covertly adding cheaper or poor-quality ingredients (Marcone et al., 2013). While having the advantage of being non-invasive, NMR can also reduce the need for space in food quality control since NMR-based technologies are more compact than standard fruit sorting and grading machinery, with some sorting machines being nearly as large as a football field (Brzobohaty et al., 2019).

In recent years, the food sorting market has exhibited steady growth, with the average growth rate of 7.24% per year (technavio, 2017). Factors contributing to the development are higher consumer expectations as well as the demand for higher quality standards within the industry (Brzobohaty et al., 2019). Furthermore, control mechanisms such as take-back-agreements between retailers and suppliers further increase the pressure to deliver high quality goods. With its non-invasive properties, NMR-based technology can ensure the quality of organic produce throughout the entire food supply chain and would enable producers to diversify their prices with regards to the quality of the product. In 2008, FFV waste of US retail stores due to low quality was estimated at around 43 Billion USD (retail price) (Mattsson, Williams & Berghel, 2018). With 29-34% of the total waste, it is also considered to be the main contributor to retail store waste (Mattsson et al., 2018). As an example, 30% of all avocados shipped to Europe are disposed of upon arrival (Kofler et al., 2017). Since food waste due to spoilage and contamination incurs the most economic costs at the end of the supply chain, an employment of NMR early in the value chain would economically be the most effective option.

Figure 8: Bruker's NMR-based food screener for wine quality analysis (Bruker HTS is beneficiary in this project and Bruker Biospin, the application development branch of Bruker is partner in this project. More information about this product family can be found at www.bruker.com/bruker/food-screener)

One particularly interesting market is the vanilla bean market, which is expected to grow 4.7% per year until 2027 (New Food Magazine, 2019). A first-grade vanilla bean is priced at around 500 USD per kilogram but unfavorable weather conditions as well as early harvesting are reasons for diminishing quality (Gelski, 2019). The current grading process of vanilla beans is done manually: The beans are usually sorted into four categories based on size and color (Medina, Rodríguez, Garcia, Rosado, García & Robles, 2009). However, the difference in quality is primarily based on the moisture content, with grade A vanilla beans (black vanilla) having at least 10% more moisture than grade B beans (brown vanilla) (Hoffman, Harmon, Ford, Zapf, Weber, King, Grypa, Philander, Gonzalez & Lentz, 2005). Due to increasing demand for high quality vanilla beans and suppliers progressively striving to ensure high quality, the vanilla bean industry appears to be a very promising market for NMR-based grading technology.

Figure 9: Manual vanilla conditioning (three-month long process) for quality management. It is the essential step to determine the yield of high-quality vanilla and ultimately the price of the product

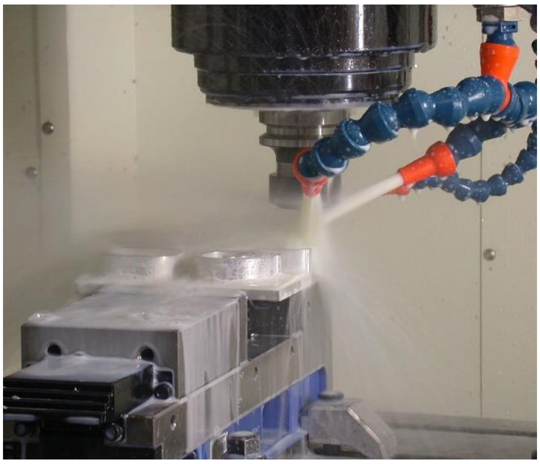
2.9. FILTRATION SYSTEMS

The current state of superconducting magnet technology allows a reliable electromagnetic separation of a plethora of materials, making the technology beneficial for many industries. Economically, the use of machinery based on superconducting magnet has many benefits: Depending on their application, superconductors are able to operate continuously with requiring only limited essential maintenance of less than twelve hours per year (Beharrell, 2015). Furthermore, materials - either a single solid compound or a range of solid compounds - can be separated at low cost in a single stage (Beharrell, 2015). The subsequent paragraphs give an overview over the multitude of application fields for superconducting magnetic separation.

Figure 10: Superconducting magnetic separator in the mineral industry (Courtesy of Imerys)

In industrial manufacturing, filtration assets operating with costly neodymium or ferrite magnets separate metallic impurities out of assembly lines of a production process in order to ensure a high-quality standard. These systems exhibit a high energy consumption and, compared to superconducting magnets, have a low magnetic field, resulting in a low cost-efficiency (Kofler et al., 2017). Experts of the recycling industry refer to an actual energy consumption of 10 KWh per magnet (Kofler et al., 2017). With superconducting magnets, companies can create stronger magnet filtration assets, filtering out even bigger metallic parts without loss of electric current, thus operating much more cost-efficient on a permanent basis (Kofler et al., 2017).

The manufacturing industry, especially automobile manufacturing plants and the heavy machine industry are key users of metalworking fluids (MWF) (Rocker, 2013). This class of fluids, which includes neat cutting oils, water soluble cutting oils and rust preventive oils is used worldwide for the cutting and forming of metals and is expected to exceed a world-wide consumption volume of 3 650 kilotons by 2025 (Research and Markets, 2019). Automotive engine manufacturing plants utilize millions of tons of these fluids, which need to be filtered within a close-cycle process in order to remove contaminants through filtration systems (Beharrell, 2015). These filtration systems are either expensive, require a lot of floor space, prone to clog, or need to be disposed of at a frequent rate (Cimcool, 2001). Substituting these systems by superconducting magnetic separators can help to reduce overall costs, making the process much more convenient and efficient (Beharrell, 2015).



Figures 11 and 12: left: Thin-wall milling of aluminium with cutting fluid (Courtesy of Glenn McKechnie), right: Traditional vacuum-filter system for MWF (Courtesy of Eriez Hydroflow)

The minerals industry is one of the largest customers of magnet-based separation devices. Superconducting technologies are particularly beneficial for the ore mining industry, which will cease to be commercially attractive in the future due to decreasing quantity and quality of mined ore (Beharrell, 2015). Here, the strong electro-magnetic fields of superconducting magnets can be employed to enhance the profitability of the industry. Furthermore, valuable materials such as gold, platinum and uranium can be extracted from mineral waste dumps, which are usually disposed of in the mines (Beharrell, 2015).

Superconducting magnets can be used to improve the environmental friendliness of industrial processes. Filtration systems based on superconductivity can filter out pollutants from industrial wastewater before the water is discharged into natural rivers and lakes (Beharrell, 2015). This is of particular concern in the steel production industry, where the direct disposal of iron and iron oxides, which function as cooling and rinsing agents, represents a crucial natural hazard (Beharrell, 2015).

Further application fields for superconducting filtration systems include the removal of materials such as asbestos from dust samples, very fine particles of precious materials such as gold in rinse water of the plating industry, radioactive particles out of water reactor cooling systems, specific low-molecular-weight materials such as cholesterol from butter and the separation of blood components to treat illnesses such as leukaemia through magnetic tagging of malignant cells (Beharrell, 2015).

3. OUTLOOK

This report focuses on superconducting magnet technologies and application fields outside the research domain. Similar follow-up projects conducted at WU Wien will analyse the impact potentials of superconducting radiofrequency systems and their manufacturing process. Radiofrequency cavities are metallic chambers containing an electromagnetic field that is used to accelerate the particles in the particle accelerator. Similar to the technology which superconducting magnets are based on, the knowledge encompassed in constructing radiofrequency cavities can be beneficial for outside the collider domain. Hence, for the next project we aim to analyse the manufacturing value chain of radiofrequency cavities and to identify key processes that hold valuable knowledge for other industries. For these key processes, innovative application fields will be identified and evaluated with regards to their marketability. Subsequently, a detailed market analysis for selected high-potential application fields will be conducted.

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