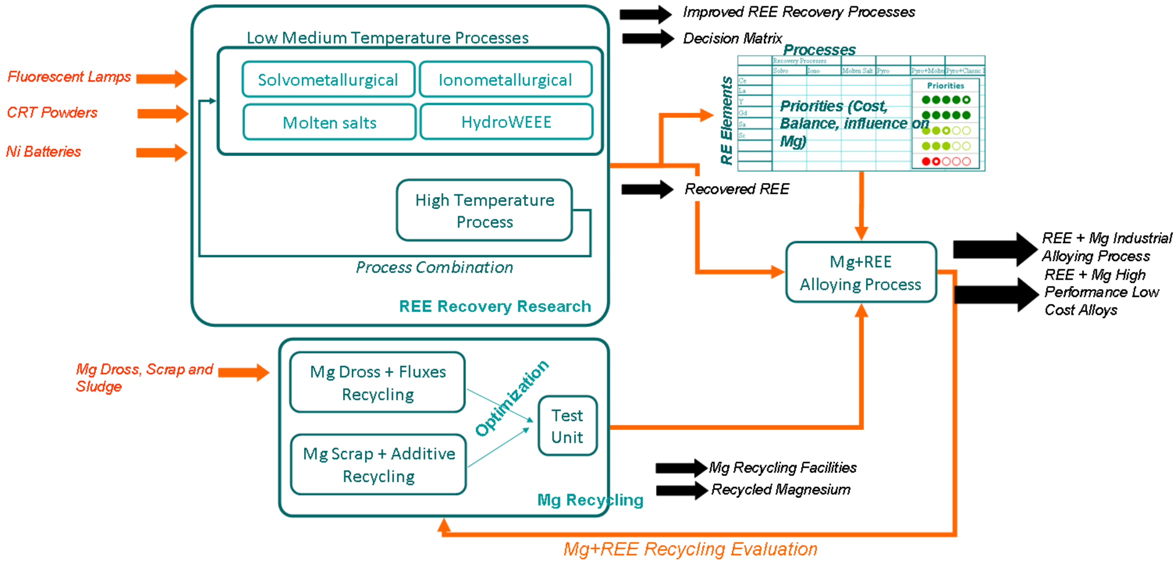
REMAGHIC is focused on contributing to Europe's rare earth recovery and magnesium recycling technologies, improving the efficiencies of these processes and advancing the technology readiness levels for a new generation of industrial processes that will produce new low cost competitive alloys for a wide variety of sectors across Europe's manufacturing value chain.

The project motivation lies on the fact that magnesium alloys can offer a significant weight reduction when compared to aluminium alloys. Weight reduction is a cross sectorial key design driver, if a superior energy absorption and vibratory behaviour is added, magnesium is promising candidate for future application if some of its drawbacks are overcome, such as its cost, manufacturability problems, corrosion and creep behaviour and low allowable service temperature. Addition of rare-earth elements (REE) improves the performance of Mg alloys significantly, though a price increase has to be taken into account. REMAGHIC believes that by investing in recovery and recycling technologies, a new alloying process can be developed to yield low cost Mg+REE alloys. In order to do this, REE that are usually stockpiled (Ce, La) in favour of the most demanded ones (Nd, Dy) will be considered as attractive candidates to lower the price. This list of REE will be completed by other promising candidates found in the literature (Y, Gd, Sm). The project will contribute to reducing the dependency of the supply of critical elements (REE and Mg) on sources exterior to the EU and to solving the REE Balance Problem.

REMAGHIC will contribute to the penetration of magnesium alloys in important sectors for the European industry (Transport, Energy, Biomedicine); it will foster the work done by Tier1s, and promote the interest of different OEMs on future generations of light structural components of competitive performance (that of primary Mg+REE alloys), low cost (that of primary Mg) and weight reduction (30%).This will encourage further improvements in these technologies thanks to finding new markets and applications that will foster the recovery of different REE.

Even though there are many Mg+REE alloys in the market, none of these is obtained from fully recovered/recycled raw materials. The development of an alloying processes that takes into account a different variety of recovered REE (which are expected to come in different forms), and includes recycled Mg (assessing its quality meets the same standards as a primary Mg) is totally unprecedented and will have a multifaceted impact, improving efficiency and competitiveness, promoting sustainable manufacturing, contributing to reduce the manufacturing processes environmental impact, strategically sheltering Europe from supply shortages and enabling better societal life quality.



The reasons why this project is important for society are technical, environmental and strategic:

- The technical reasons include fostering recycling activitities to support Europe's circular economy, producing high performance low cost alloys based on secondary raw materials, and recover rare earths, which have been identified as critical material due to their high supply risk and high economic importance.
- This is the main factor behind the environmental reasons, REE recovery processes provide important benefits with respect to air emissions, groundwater protection, acidification, eutrophication, and climate protection. These environmental benefits in turn will impact will impact the society's health, preventing early deaths and improving the life quality, especially around manufacturing facilities and in urban centres.
- The strategic reasons cover the strengthening of Europe's Industrial Competitiveness with competitive high added value materials (new magnesium alloys) and sheltering Europe from its dependency of exterior sources

The aim of the REMAGHIC project is to contribute to Europe's rare-earth recovery and magnesium recycling technologies, improving the efficiencies of these processes and advancing the technology readiness levels for a new generation of industrial processes that will produce new low cost competitive alloys for a wide variety of sectors across Europe's manufacturing value chain
Specifically, this aim can be translated to the following main objective, which is to develop a new efficient recovery process that joins the recovery from magnesium dross and scrap to the recycling of high volume low content industrial waste residues to produce new low cost Mg + REE alloys that will be the base for new applications in the transport, energy and biomedical industries thanks to their improved mechanical performance with lower weight.

This new process will have to integrate and combine several existing technologies with new research, in order to find the best processing routes to recover magnesium, to recover its rare-earth alloying elements and to work with rare-earth alloyed magnesium applications. In order to achieve this, the following scientific and technical objectives have been defined: increase the rare-earth recovery processes efficiencies and the TRL level to 6, focusing in less demanded rare-earth elements; improve magnesium recycling rates; develop and characterize new magnesium alloys that meet the upcoming demands in the transport and biomedical sectors; increase sustainability of Europe's manufacturing processes, improving the environmental impact and lower the dependency of exterior sources, sheltering Europe from supply shortages.

1.1 Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far

Besides Project Management and Dissemination Work Packages, the main work packages that have been producing results during this period are WP1, WP2 and WP3.
The first task in WP1 was devoted to evaluate different waste streams and the rare earths that could be obtained from the. The first step in this evaluation process was to characterize the input waste materials by analysing their main composition and identifying and quantifying the REE content, with focus on Y, Ce and La, but also analysing the total REE concentration in the waste fraction.
The three classes of industrial waste streams initially considered were: E-waste residues, Metallurgical slag and Phosphogypsum. The latter two belonging to a larger category called "by-products".
The objectives of the analysis were (1) to characterize the input waste materials by analyzing the main chemical composition, with focus on the REE, and (2) to identify the most promising waste streams for further study in the REMAGHIC project. Relight provided the research partners with industrial waste recovered from electronic components. Fraunhofer organized and pre-treated nickel metal hydride batteries (NiMH batteries) batteries and provided the dried and sieved electrode powder to the partners. ITRB evaluated other industrial waste like phosphogypsum and metallurgical slags. An industrial waste material was selected and Tecnalia carried out the analyses and gathered information on the homogeneity/heterogeneity of the waste material. The outcome was a waste classification according to the concentration of the most interesting REE for the project (Y, Ce, La), taking into account the information about the presence of other REE. The most interesting REE-containing waste streams were found to be: fluorescent lamp phosphors, cathode ray tubes (CRT) phosphors and NiMH batteries. The selected materials were collected and sent to the research partners for evaluation of different recovery techniques within the other WP1 tasks.
The second task in WP1 was devoted to the Balance Problem, which is the balance between the demand by the economic markets and the natural abundance of the rare-earth elements (REEs) in ores, and it is a major issue for REE suppliers. The ideal situation is a perfect match between the demand and production of REEs, so that there are no surpluses of any of the REEs. The Balance Problem implicates that the rare-earth industry has to find new applications for REEs that are available in excess, or to search for substitutions for REEs that have limited availability and that are high in demand. This task has studied the trends in applications of the different REEs. It is shown that magnesium and aluminium alloys offer an excellent opportunity to mitigate the Balance Problem. This has been illustrated for the REEs recycled from fluorescent lamp phosphor waste, CRT and NiMH batteries. During this task five REEs

were considered as very critical (Nd, Eu, Tb, Dy, Y), but it is forecast that on the medium -term only neodymium will remain a critical.
During this year the work on Task 1.3 was kicked off as well. In this task the treatment of the residues with different processes takes place. These processes include solvo metallurgical and iono metallurgical methods, molten salt process, HydroWEEE process and high temperature processes, as well as different combinations between processes that might be found more efficient depending on the waste streams.
WP2 is focused on the magnesium recycling methodologies. The first task of this work package has been dedicated to analyze the dross and sludge and the scrap resulting from Grupo Antolin magnesium process, in order to later optimize the process. Making use of compositional analysis as well as other techniques like SEE the quality of the composition of the scrap material has been evaluated, the presence of critical elements like Ni and Cu has been followed, the possible use of fluxes has been tested, and the scum composition has been studied.
With the information obtained in the previous task, the most adequate technique for recycling is being developed in task 2.1. There are several routes or techniques in order to obtain the maximum quantity of magnesium metal from the waste, but not only quantity it is important, the quality (final composition, and inclusion content) will be crucial in order to finally achieve the desired efficiency for the global process.
Finally, WP5 is devoted to the LCA analysis of the REE recycling processes (Task 5.1) and to the Mg recycling process (Task 5.2), with a final analysis of the Mg+REE alloy overall process (Task 5.3). During this first year data collection sheets have been compiled and distributed to the project partners. The first phase of both LCA, goal and scope definition, has been covered, and life cycle inventories are currently ongoing.

1.2 Progress beyond the state of the art and expected potential impact (including the socio-economic impact and the wider societal implications of the project so far)

In the REMAGHIC project in depth knowledge and technologies will be achieved from the current situation of the state-of-the-art. The processes improved thanks to the project development will yield new alloys that are expected to meet different sectors (automotive, aeronautics, biomedicine) demands, constituting the new raw material for future high performance weight reducing applications. The REMAGHIC innovation potential can be summarized as follows:
Related to REE supplier chain, keeping the REE markets in balance is of strategic importance, not only to secure the supply of all REE required for technological and other applications, but also to avoid dramatic price shocks for critical REEs. Different solutions have been proposed to solve the Balance Problem, diversification of REE resources, recycling or recovering processes, substitution or reduced use of the main demanded REE , and develop new high volume applications. With the REMAGHIC proposal 4 of these 5 solutions will be taken into account. **Related to the recovery processes for rare earth elements**, new processes will be evaluated introducing innovative solvents and using current developments with different industrials wastes than those for which these processes were initially developed.
REMAGHIC intends to evaluate, improve and update existing recovery processes, focusing on increasing their TRL and on finding different REE than those these

processes were developed for, in order to find new uses in Magnesium alloys for these elements. This will encourage further improvements in these technologies thanks to finding new markets and applications that will increase the demand of those REE that are currently stockpiled in favour of obtaining enough Nd or Dy to meet other markets demands.

For the recycling process of magnesium, increasing the efficiency of the process and its technology readiness level will be the main innovation. New stirring systems remain the best option to get the expected result.

In the case of dross and sludge, with the use of fluxes a proper stirring technique is necessary to get a correct distribution between the metal and non-metal components. Even when only scrap is being melting the existence on convection movements for the metal (forced or non-forced) create an homogeny distribution of temperatures which improve the energy requirements of the process that can result in a reduction in sludge formation.

Finally, the most important innovation will come through the alloying processes: even though there are many Mg+REE alloys in the market, none of them is obtained from fully recovered/recycled raw materials. The development of an alloying processes that takes into account a different variety of recovered REE (which are expected to come in different forms), and includes recycled Mg (assessing its quality meets the same standards as a primary Mg) is totally unprecedented, and as the Market Innovation will demonstrate, will have an important impact on the European Manufacturing Industry.

Regarding the market innovation, there are currently some applications in the automotive, aeronautics and energy markets that use Mg+REE alloys, however these applications are found only in elite vehicles, general aviation small aircrafts and wind turbines under research. The same happens in the biomedical market, though magnesium is predicted to be poised for growth and substitution of titanium, and mentioned in many research initiatives, it has not reached massive figures in production volumes.

This project will contribute to the penetration of magnesium alloys in important sectors for the European industry; it will foster the work done by Tier1s, and promote the interest of different OEMs on future generations of light structural components.

The project’s business plan has estimated an important production of parts per year for Grupo Antolín, as representative of the Tier1 industry, and includes the interest and collaboration of important End Users (OEMs) that have helped define the project Use Cases and will ensure the developed alloys will be useful and will impact their product portfolio.