PROJECT PERIODIC REPORT

Grant Agreement number: 310312

Project acronym: RECYVAL-NANO

Project title: Development of recovery processes for recycling of valuable components from FPDs (In, Y, Nd) for the production of high added value NPs

Funding Scheme: Collaborative Project

Date of latest version of Annex I against which the assessment will be made: 2012-10-09

Periodic report: **1st** ☐ **2nd** ☐ **3rd** ☑

Period covered: **from** 1 December 2015 **to** 30 November 2016

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[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement .

[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

3.1 Publishable summary

- **A summary description of project context and objectives,**

Waste Electrical and Electronic Equipment is increasing drastically in the current decades. WEEE contains considerable quantities of valuable components used in high-tech applications that currently are not recycled. Europe needs to improve and develop Recovery, Recycling and Reuse of critical materials in order to avoid the dependency on imports, high prices and risk of supply imposed by countries owning mineral reserves.

The FP7 EU funded RECYVAL-NANO project has been working in the development of recycling processes for recovery and reuse of critical metals. More in detail, the focus of the project were the recovery of indium, yttrium and neodymium metals from Flat Panels Displays (FPD), one of the most growing waste sources. One significant aspect of the project objectives is that it was not only focused to the recovery of the critical metals, but also to obtain from the recycling process metallorganic precursors for direct reuse in the production of high added value nanoparticles, more specifically ITO, Y2O3:Eu3+ and Nd-Fe-B nanoparticles.

The objectives of the project included an integral study of the recycling process, starting with logistic issues of the waste collection, optimising mechanical sorting technologies and developing innovative ones for the recovery and concentration of smaller fractions containing indium, yttrium and neodymium, developing solvent extraction routes based on tailored chemical extraction agents able to extract a 95 % of the key metal in a metallorganic extracted solutions, and using these extracted solutions as precursors in the direct production of advanced nanoparticles.

RECYVAL-NANO objectives included the validation of the recycling techniques developed through the construction, optimisation and demonstration of full pilot lines for mechanical recycling of FPDs and hydrometallurgical metal recovery processes. Finally, in order to demonstrate the superior performance application of nanoparticles produced, the objectives of the project have been focused to apply these materials in final products such as indium in transparent conductors, yttrium in LEDs and neodymium in permanent magnets, completing the entire cycle of the project.

- **A description of the work performed since the beginning of the project and the main results achieved so far,**

The ultimate objective of RECYVAL-NANO has been to further develop recycling processes of FPDs in order to extract critical metals of high added value applications. In this way, the objectives of the project were divided in three major groups, were each of them is described in the following paragraphs.

First major objective of the project was related with the optimisation and development of mechanical processes for the concentration of target fractions including the critical metals contained in FPDs. COOLREC, set the starting point of the project based on their current process. In order to increase the recovery and purity of the fractions of interest, COOLREC

developed some significant modifications in the pre-disassembly process of the FPD-line giving to the identification of target fractions and conclusions for further processing. The following work and results were derived:

- Manually disassembly of the LCD module including indium was viable in the process. Coolrec and MOS worked in shredding and spinner systems for the reduction of size while maximising the separation of indium coated glass.

- TUDelft worked in Magnetic Density Separation (MDS), separating a cleaned glass fraction coming from the FPD line, however the process was not able to concentrate metals of interest in the glass.

- Neodymium metal was not present. Main reason of the diluted presence in FPD wastes was that magnets from loudspeakers are still majoritarian based on ferrite.

The second major activity of the project was the development and assessment of hydrometallurgical processes. On one hand, solvent strategies were applied by TWI in order to revalue current PET polymer which now is discarded in the recycling process. In addition, Chalmers University focused in indium and yttrium refining from two different fractions, indium glass from LCD modules and a mixed powder containing many different metals, among them yttrium. Two solvent extraction routes were developed, one for each fraction obtaining purities larger than 90 %. In addition, demonstration of the indium solvent extraction process was made at pilot scale (5 L/h) by MEAB. Finally, an additional versatile process was depicted including selective precipitation steps in order to avoid larger initial dilutions needed for the solvent extraction and able to treat WEEE wastes in a general sense with significant amounts of Au/Ag/Y/In/Ln.

The final major activity carried out during the project was the assessment and development of alternative final applications of indium and yttrium based on the use of nanoparticles starting from recycled solutions. For this purpose, the synthesis and upscaling of nanoparticles was developed during the project based on Flame Spray Pyrolysis technology by Lurederra and TECNAN. One important limitation during the project was the lack of enough quantities of recycled materials for development of these final applications. However, during the project, nanoparticles were produced starting from commercial precursors and simulated recycled ones produced by ABCRlabs where promising results were found in terms of performance. The following interesting conclusions were obtained:

- ITO nanoparticles were used to produce non-sintered targets at lower pressures which were used by PQL for producing conductive films by sputtering showing promising results in terms of resistivity and transparency (~95%).

- Characterisation of the luminescent efficiency of the produced Y2O3:Eu+3 nanophosphor revealed that the synthesised nanometric material present a higher performance even at ten times lower concentrations than micrometric materials. These results were extrapolated to LEDs applications together with EXKAL partner were high efficient nanobased phosphors could represent a competitive advantage.

Finally, in order to assess the real impact of the results, economical and environmental assessments have been made giving indications for the future development and exploitation of the project results.

- **The expected final results and their potential impact and use (including the socio-economic impact and the wider societal implications of the project so far),**

The most important results of the project are the assessment and validation of what recycling routes could be implemented in current Flat Panel Displays recycling lines in order to recover critical metals. Most important results obtained gives a potential positive impact for the recovery of Indium from FPD as different aspects analyzed in the project like the amount of material that is available in the waste, the compositions, the continuity of the waste as well as prices volatility in the market of Indium support this idea together with the technical and economical results obtained in the recycling processes.

Around the world, 30 to 50 million tons of electronic devices are discarded every year. That volume of e-waste is expected to increase by an impressive three to five percent per year as consumers demand more and more "smart" products. One of the e-wastes which a larger growing rate are the FPD which although are recycled in order to recover larger fractions other valuable metals present like indium are not still recovered. Europe is import dependent on these critical metals and therefore is subject to supply shortage periods. Recycling strategies such as the one in RECYVAL-NANO project represents a potential solution in order to overcome the Europe dependence of other countries in the supply of critical materials, therefore enabling the European market to promote the creation of new companies in not only the recycling, but also in the transformation of raw materials to manufacture electronic systems and devices and the research of new materials and improved applications, therefore improving the industrial competences of European markets.

During the project, the assessment of indium, yttrium and neodymium metals was made, however only in the case of indium there is a potential impact in order to extrapolate the results obtained to a final viable industrial process. Indium fractions is disassembled from glassplates of FPDs. Taking into account that these glassplates are currently a waste which ends in landfills and therefore which has to be managed and suppose a cost for the recycling process, an important impact for the recycling industries like Coolrec is that they could offer a new valuable product where Indium can be recovered out of the glass rich fraction.

Although the clearest impact of the project is based on the recovery of indium, one of the chemical routes developed for extraction has been designed to be suitable for complex mixtures of electronic wastes where a variety of metals are present and could be recovered by selecting the required steps of the route. In this way, other increasing technologies of e-waste could be target of recycling by means of the processes developed in the project. For example, smartphones, tablets and other popular electronic products contain precious materials, including gold, copper, palladium, silver and more. The developments of the project open the typologies of e-wastes to be treated and therefore the potential economic incomes.

Finally the results of the project have bring also potential impacts due to the innovative applications developed with indium and yttrium metals based on ITO nanoparticles and Y2O3:Eu+3 nanoparticles.

To summarise the expected potential impacts of the RECYVAL-NANO project results are the increase of European recycling business for the recovery of indium, involving higher recovery rates in current FPDs recycling companies and generating new business of metal chemical extraction, to provide a viable source of indium metal for Europe minimising dependency of other countries, increasing recycling of wastes, FPD and depicted fractions reducing the consume of resources and reducing environmental consequence derived of landfill and increase understanding of nanomaterials, providing improvements in TCOs and nanophosphors, therefore increasing competitiveness of nanotechnology in Europe for nanomaterials manufacturing companies and research based companies.

- **The address of the project public website, if applicable**

http://www.recyval-nano.eu/

- **Further information and interest on results**

The RECYVAL-NANO consortium is interested in making available to third parties these technologies developed under the project in several ways.

a) Sale of Know How: The relevant Recyval partners make process technology available under licence

b) Joint research: The relevant Recyval partners will contribute Recyval Foreground to new research projects on terms to be agreed.

c) Sale of equipment: The relevant Recyval partners supply equipment and know-how under licence.

Third parties interested in any of the above should in first instance contact to:

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giving information on their areas of interest