LIFE 09 ENV/IT/000185

MDPATC

NEW ECO-PROCESS OF SUPERFICIAL TREATMENT
OF THE METALLIC WIRE PRODUCTS

TECHNICAL REPORT

LIFE Project Number

< LIFE09 ENV/IT/000185>

TECHNICAL FINAL Report

LIFE+ PROJECT NAME

<MDPATC>

Project Data

Project location	Calestano (PR), via Baganza n. 6, CAP 43030 – Italy
Project start date:	01/11/2010
Project end date:	31/10/2013
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Total eligible budget	€ 2.246.465
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(%) of total costs	45,16
(%) of eligible costs	50

Beneficiary Data

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1. Introduction

– Description of background, problem and objectives

The project is based on the assumption that currently the production of wire rod by-products causes a high environmental impact due to manufacturing practices that have not been able to renew themselves over time to meet the new environmental challenges and, therefore, they continue to entail the use of large amounts of water and acids. To date, to protect the wire rod by-products from corrosion, a zinc coating is applied through hot dipping, which results in a very thick coating to compensate the fragility of the interface layer as a reaction with the iron-based substrate, and to take into account the progressive loss of the layer. The process, therefore, leads to the production of different types of pollutant emissions and waste in general: in the EU alone 3.2 million cubic meters of water and 95,000 tons of hydrochloric and sulphuric acid are used in the production of metal wires alone and 24000 tons of scrap metal is produced from wire cuttings. In addition, acid pickling is still the most widely used process to descale and de-oxidise the wire rod, and it is carried out at temperatures of about 80° C; this leads to the generation of hazardous vapours, which require special treatments, and to the production of acid sludge as final product of these processes. Furthermore, pickling entails iron oxides in solution, such as Fe ions, and the acid solution requires a constant regeneration, with the formation of slurry of acids rich in iron oxides. Last, but not least, water is used in all production stages, as a solvent, detergent or for cooling.

Trafileria e Zincheria Cavatorta spa has developed the project MDPATC to make the production of wire rod by-products more environmentally friendly.
The project is based on 3 fundamental elements that can significantly reduce the environmental impact of the treatment:

- Mechanical descaling;
- Microwave plasma treatment;
- Dip-coating (Zn-Al-Mg).

The descaling allows to mechanically, rather than chemically, clean the wire rod and separate the abraded particles from the abrasive one, which in this way can be recovered. The implementation of this system allows the complete elimination of the use of acids, of the generation of hazardous vapours and acid sludge. Mechanical descaling is carried out by duly selected prismatic metal fragments (and recovered from previous processes) capable of cleaning up to 95% of the treated surface.
The microwave plasma treatment is used to complete the cleaning process of the surface of the wire rod and to prepare it for the following actions. In the case of iron-based alloys, in addition to cleaning, the system is able to simultaneously perform

heat treatments. This system contributes to the total elimination of the use of water and sludge.
Finally, the new composition of the zinc bath allows to lower the temperatures of the final wire treatment and to reduce the amount zinc necessary, which leads to a reduced thickness of zinc necessary to confer corrosion resistance properties; in addition the production of zinc ash will be reduced thanks to the protective action of Al.

The tests carried out on the wire rod by-products in the pilot plant, comprising such instruments, showed the following results:

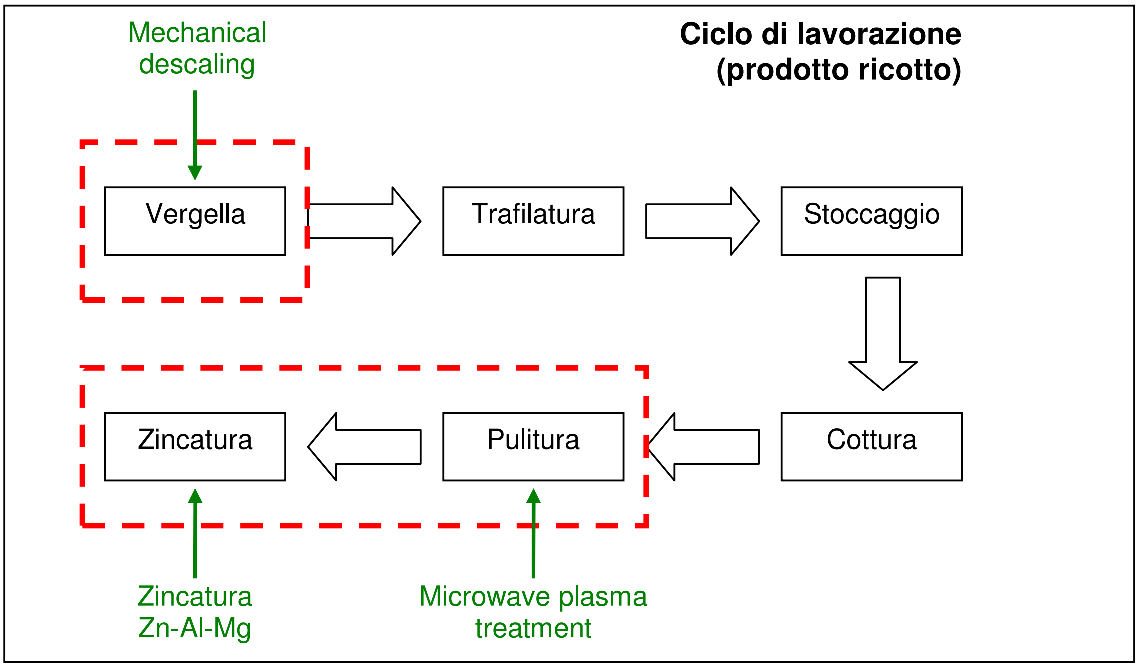
- Reduction of electricity consumptions;
- Elimination of water consumption (-100%);
- Elimination of acid consumption (-100%);
- Elimination of acid waste production (-100%);
- Reduction of harmful emissions from the galvanizing bath and the acid tanks;
- Reduction of zinc consumption;
- Improvement of the working environment.

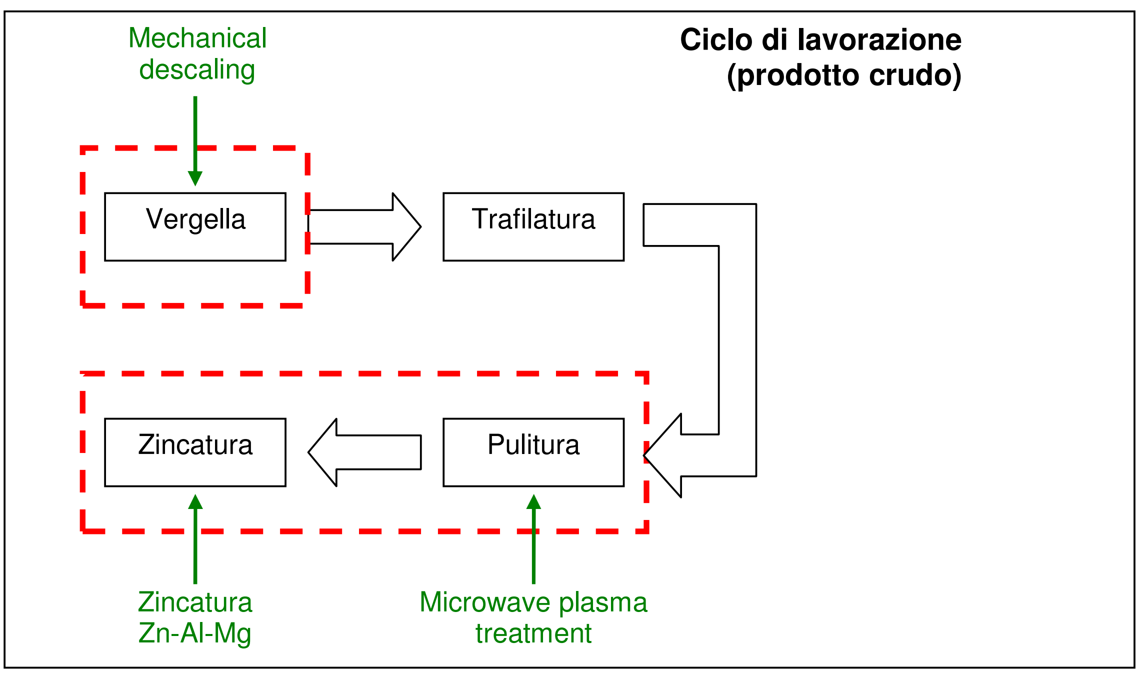
– Expected longer term results

The project does not have a geographical horizon limited only to Italy but is open to all of Europe. The company's objective is to transfer the technology to other foreign companies so that the benefits obtained can be extended to a greater number of firms in order to further increase the environmental benefits, such as the reduction in the consumption of water or acids and in harmful emissions into the atmosphere.
For this purpose Trafileria Cavatorta organized several meetings with its sellers, also abroad, to ensure that they were properly and thoroughly informed about the project and were able to inform their key customers abroad. The dissemination material created was sent to abroad to the Trafileria e Zincheria Cavatorta subsidiaries to obtain the support of the relating sales representatives.
Trafileria e Zincheria Cavatorta is trying to establish relationships with companies in the sector in order to favour the transfer of the technology. Given the complexity of the system developed, the adoption of the line by another firm can only occur through close collaboration with the project coordinator, which is necessary to define the processing parameters and the supply of the microwave plasma system.
Trafileria e Zincheria Cavatorta would industrialise, in the near future, the pilot plant made with the Life project. The feedback from the company's contacts have confirmed the expected positive evaluations, therefore, staff believes that the introduction of the new technology as a final replacement for the whole production line of the wire rod by-products is not only possible but also achievable.

2. Technical part

The MDPATC project aims to tackle the environmental problem entailed with the production of zinc - coated drawn wire, by acting on three specific phases of the production cycle, that is: wire rod drawing, cleaning of the drawn wire and the final galvanizing process, as shown in the production flow chart below:





In particular, the cleaning process for the drawn wire involves the removal, prior to the drawing operation, of the lamination scales and the calamine that form on the surface of the wire rod during the siderurgical process, together with the layer of oxides and impurities that form during the storage phase. This phase have been accomplished through a *mechanical descaling system*, by which impurities are removed from the rod surface by grit blasting, thus eliminating the use of acids or other hazardous substances. Moreover, it will be possible to use other kinds of abrasive material, even manufacturing waste (i.e.: cuttings and scrap deriving from the production of screws or when imparting the proper geometry to nails).

Lastly, a continuous-cycle system for recovering and separating waste produced during the descaling process shall allow for three distinct flows of recyclable waste: fine iron oxide dust, that can be used as pigments, prismatic or sharp-edged metal particles that can be reused as abrasive elements during the descaling process and metal particles that have lost their prismatic properties, therefore smaller and with rounded edges, which can be reused in the micro - blasting process or subject again to fusion.

Prior to the zinc-coating phase, depending on whether it is an annealed product (that is, subject to annealing after the drawing process), or raw (zinc- coated after drawing, but without annealing), the wire rod must undergo a cleaning process (descaling, degreasing and fluxing) according to the case. The presence of iron oxide or residual drawing soap on the surface may compromise the integrity and uniformity of the zinc coating and cause it to merge with the steel surface layer. The cleaning phase is accomplished by dipping the wire in a bath of hydrochloric acid (a corrosive, irritant substance) and/or ammonium chloride (also known as sal ammoniac, highly toxic) and zinc chloride (the product of reaction between zinc and hydrochloric acid, highly corrosive and hazardous to the environment). Such process will be replaced by a *microwave - induced plasma treatment* which shall also serve the function of activating the surface for the subsequent zinc-coating phase.

The actual zinc-coating phase is accomplished by means of an innovative Zn-*Al-Mg tertiary coating system*, bonded with small percentages of other substances (tin and rare earth metals) to reduce the quantity of zinc required for coating, while increasing corrosion resistance to the finished product.

To prove the feasibility and applicability of the foregoing processes, Trafileria e Zincheria Cavatorta S.p.A. has developed a demonstrative pilot line that is able to treat up to 1,000 Kg/h (4,000 ton/per year) of wire rod, while achieving the following environmental benefits:

- reduced energy consumption during the descaling and hot–dip galvanizing process;
- total elimination of water consumption;
- total elimination of the use of hazardous substances (hydrochloric acid, ammonium chloride and zinc chloride) ;
- total elimination of hazardous waste production;

- total elimination of toxic emissions- derived from the use of acid substances- into the atmosphere;
- reduced noxious vapour emissions deriving from galvanizing processes and from the production of zinc waste;
- recovery and reutilization of metal waste produced during the descaling phase;.
- improvement of the working environment.

Besides the environmental benefits listed above, the following technical-economical benefits have been achieved:
- reduced zinc consumption;
- enhanced level of finished product quality.

3. Technical progress

The execution of the project involved the following technical macro-actions:
- Study, design and fine-tuning of the mechanical descaling system including waste recovery and recycling;
- Study, design and fine-tuning of a pre-treatment system and surface activation by means of microwave – induced plasma;
- Study, design and fine-tuning of a coating system with the utilization of a Zn-Al-Mg bath.

Mechanical descaling and scale milling

This action, which was regularly implemented upon start-up of the project, aimed at accomplishing mechanical descaling of the wire rod with continuous – cycle separation and recycling of the waste produced from such operation.

The activities carried out resulted in the creation of the first prototype of the descaling system that includes a device intended for the collection and separation of waste and abrasive elements by means of a combined cyclone and sieving system

After consulting with the Department of Materials and Environment Engineering of the University of Modena and Reggio Emilia, it was ascertained that cleaning the wire rod before the drawing phase (thus, prior to the mechanical descaling process), could influence the subsequent delicate plasma treatment phase. In fact, the drawn wire must bear minimum qualitative properties in order to achieve effective results while keeping in line with the processing time.

The descaling machine that was developed (see Photo 1) features three turbines positioned at 120° with respect to the wire rod to enable the abrasive element to strike the wire rod surface in a uniform manner.

The turbines are fed with the desired amount of abrasive elements that pass through a piping system; the abrasive elements are contained in a hopper, placed above the turbines, from where the abrasive elements are blasted against the wire surface.
The abrasive elements used for blasting the wire rod surface are recovered through a suction system and reintroduced into the hopper through a bucket elevator.
The combined cyclone and sieving system separates the iron oxide from the abrasive material.

Photo 1: Mechanical descaling system

The first results of the experimental activity were encouraging. In fact, the calamine and iron oxides were removed successfully from the wire rod surface, which, amongst the other things, bears strong cleaning properties that are most likely to produce positive results in the future.
The next step was to combine the use of steel abrasives with waste from the company's own production cycle processing, for example waste from cutting of lattice or the production of nails: this, however, was only possible for a part of the waste, or for that which was extremely small, comparable to that of the abrasives, which otherwise could damage both the plant and the wire rod to be descaled.
Optimisation of the phase of separation between the iron oxides which had detached from the wire rod during the descaling phase and the recovery

abrasives was therefore focussed on, thus overcoming the problems stemming from the presence of excessively high amounts of iron oxide in the hopper containing the abrasive material.
Separation of the abrasive material that could still be used from the material that has lost its abrasive capacity, ensuring excellent results of descaling, constant in use, and the possibility of recovering the material when it is no longer suitable for shot-blasting was finally discussed.
The activity was thus successfully concluded.

<u>Activities carried out</u>

- definition of a list of possible consultants to be involved in the current technical phase of the project;
- effectuation of the first lab tests aimed at achieving the best suitable conditions for wire rod descaling;
- development of the first version of the mechanical descaling system;
- starting of the first mechanical descaling tests;
- study on the wire rod surfaces and impact of the process parameters obtained through the first collisions;
- creation of the first system for waste-abrasive material separation by means of a combined cyclone and sieving system;
- starting of the first test on waste - abrasive material separation;
- final design of the mechanical descaling plant components;
- implementation of changes to the mechanical descaling system and the system of separation of waste and abrasive material;
- final tests and fine-tuning of the mechanical descaling system.

<u>Results obtained</u>

All the results foreseen were achieved; in particular, the mechanical descaling system, capable of treating 1000 kg/h of wire rod, obtaining a surface cleaning of over 95%, was developed.
In addition to this, it is important to emphasize that, with regard to the waste of the processing phase (iron oxides), contacts were established with other companies that are experimenting with the use of this product within innovative projects. More particularly, contacts were established with Ceramica Fondovalle, beneficiary of a LIFE project (LIFE10 ENV/IT/419 “Waste3”) that intends to experiment with the use of iron oxides deriving from descaling as a raw material for execution of their project, as well as with Ceramiche Gardenia Orchidea, interested in experimenting with the use of the same iron oxides in the mixture of their innovative products.
With regard to the grit now exhausted, thus no longer reusable for the descaling phase, this had also been tested by Ceramiche Gardenia Orchidea. However, given the rounded shape of the exhausted grit, the small size of the same and the results of the trial under way at Metallurgica Abruzzese, in the coming months experiments will be performed on the use of such waste in

wire cleaning micro-peening plants such as to create synergies between the present LIFE project and that under way at the other company of the Cavatorta group (LIFE09 ENV/IT/174 "Ultra Crash Treatment").

Problems encountered

During the development of this phase, no problems or difficulties that may affect the execution of the actions have been encountered.
Particular attention has however been paid to the cleaning requirements of the drawn wire, which will influence the next plasma treatment phase, the effective separation between abrasive material and waste (iron oxide detached from the wire rod), as well as between abrasive material that is still reusable and abrasive material that is no longer reusable because it has lost its abrasive capacity.

Microwave plasma treatment

After consulting with the Department of Materials and Environment Engineering (University of Modena and Reggio Emilia), who assisted Zincheria Cavatorta S.p.A. during the design and development phases of the new system, it was deduced that, in order to attain optimal plasma treatment results that remain constant over time, the incoming wire must bear specific properties (mostly in terms of cleaning and surface deformation), also attributable to the wire rod cleaning phase.
In this respect, the numerical simulation phase, with the implementation of the following activities, was undertaken:

- definition of equivalent permittivity of plasma base;
- numerical simulation and optimization of a microwave applicator for plasma generation;
- numerical simulation of “choke” systems to prevent microwave leakage from the microwave enclosure

The simulation phase was supported by an experimental phase carried out at the Department of the University of Modena and Reggio Emilia, mainly focused on checking and assessing potential microwave leakage. A further experimental phase foresees the use of wire samples of different type and diameter, realized by Trafileria and Zincheria Cavatorta, for drawing the rod cleaned with the new prototype for the mechanical descaling system, which made it possible to carry on with the project activity and subsequent realization of the microwave-induced plasma source.

The experimental activity carried out on the first plasma torch prototype (see photo 2), as well as that carried out on the second larger prototype (see picture 3) has highlighted the difficulty in obtaining homogeneous treatment due to the small size of the torch, which then interacts solely with the wire portion to which it is directly exposed.

Photo 2: First prototype of microwave plasma torch

Photo 3: Components of the second prototype of microwave plasma torch

To reduce this problem, 4 paths were identified:

1) installation of 3 torches in series, arranged by forming an equilateral triangle 300 mm along the slide direction of the wire. This solution reproduces what currently takes place in the context of mechanical

treatments and of other "line of sight" processes. The simplicity of this solution, however, clashes with the different fluid dynamics of the gas exiting the torch positioned horizontally with respect to those positioned at an angle of 120°. As such, homogeneity is not however perfectly guaranteed

2) rotation of the wire during passage into the area of the torches: the treatment chamber, fitted with 3 torches arranged horizontally, is traversed by the wire such that it performs a rotation of at least 360° around its own axis. This ensures perfect homogeneity of the treatment, but adds a plant design complexity due to the wire rotation systems
3) increase in the size of the torch in order to hit the entire wire. This requires redesigning of the torch and the use of sources of higher power microwaves. For this purpose, it was decided to introduce a transition between a typical mode of the rectangular wave guide and one typical of the coaxial cable (doorknob transition) such as to achieve transmission of the microwaves along a section of truncated line in the vicinity of the area of gas leakage. The use of a double cone cover ensures correct exposure of the wire to the torch and prevents leakage of microwaves
4) Crossing of the torch in an axial and not transverse direction. In this case, the wire moves in a coaxial direction in development of the plasma torch plume and is uniformly hit by the plasma. This solution requires a redesign of the torch so that the nozzle is able to accommodate the wire and so the wire itself does not act as antenna, emitting microwaves into the atmosphere. This solution, though promising, has the disadvantage of requiring a fine adjustment of the torch each time the wire diameter is changed, as well as replacement of the nozzle. It was therefore immediately abandoned at the design phase.

In parallel, the experimental phase was continued using samples of wire of different nature and diameter produced by Trafileria e Zincheria Cavatorta with the clean wire rod drawing with the new mechanical descaling prototype. What in fact emerged from preliminary tests was the best performance of the plasma torch in the presence of surfaces that have already been partially cleaned (mechanical descaling) compared to highly oxidised surfaces (removing only part of the oxides).

Experimentation also included the option of providing a supply of heat to the wire in transit such as to modify its microstructure and carry out, in fact, in-line annealing. This, however, required a sharp slowdown in the speed of feeding of the wire, at least on the prototype used so far. The implementation of this solution in the production field will therefore require the execution in parallel of the heat treatment, as it is in other areas of the plant, where the wires pass in parallel through certain thermal machines or galvanizing baths.

Moreover, depending on the plasma-generating gas being used, the opportunity arose to perform light thermochemical treatments (in particular, surface nitriding, via nitrogen plasma) with the aim of improving the surface hardness of the wires.

<u>Activities carried out</u>

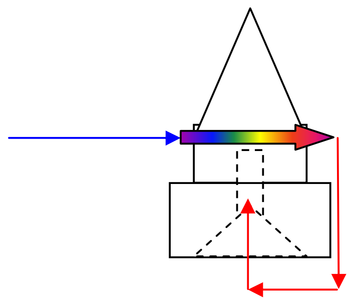
- Contacts, talks and meetings with Prof. Veronesi from the Department of Materials and Environmental Engineering (University of Modena and Reggio Emilia);
- Signing of the collaboration agreement with University of Modena and Reggio Emilia;
- Bibliographical research carried out on plasma treatment for wire rod cleaning;
- Definition of equivalent permittivity of plasma base;
- Numerical simulation and optimization of a microwave applicator for plasma generation;
- Numerical simulation of “choke” systems to prevent microwave leakage from the microwave enclosure
- Experimental tests on plasma torch treatment to assess potential microwave leakage;
- contacts, talks and meetings with Prof. Veronesi from the Department of Materials and Environmental Engineering of the University of Modena and Reggio Emilia for the redesign of the plasma torch with increase of the size of the torch and the installed power;
- numerical simulation of biconical system to prevent the escape of microwaves from large torches.
- numerical simulation of "doorknob" transition between waveguide and coaxial
- Executive drawings of the new torch, with interchangeable components for possible adaptations to specific loading conditions (double wire in transit, coaxial transit of the wire)
- experimental treatment tests with nitrogen plasma torch to verify the effect of heat and thermochemical treatment, including the effect on the adhesion of the protective zinc coating.

<u>Results obtained</u>

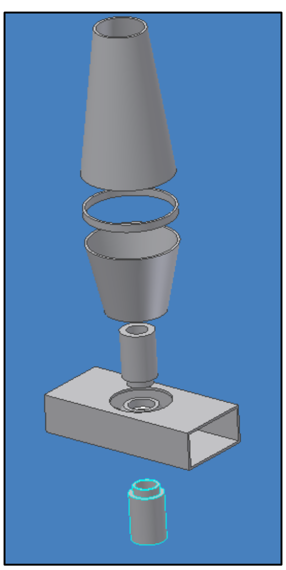
The necessary studies (definition of equivalent permittivity of plasma base, numerical simulation) for the design and development of a microwave – induced plasma treatment were completed, as well as the devices designed to prevent microwave leakage.

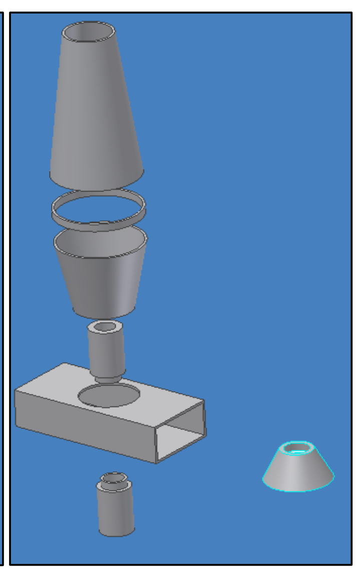
Preliminary tests for the treatment of the drawn wire with microwave-induced plasma were performed on a small laboratory prototype; these tests, which aimed to prove the technical feasibility of the project, provided the results foreseen and resulted in the company starting the design phase of the equipment.

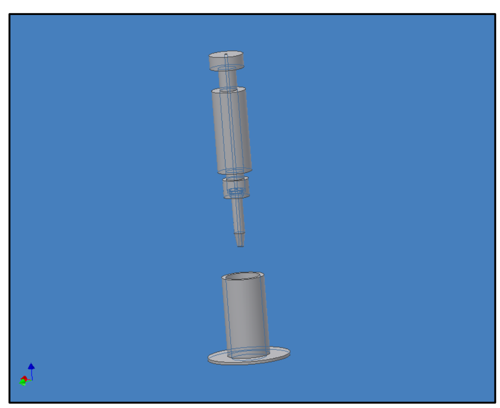
The microwave-induced plasma torch (Annex 6) was redesigned as well as devices to prevent the leakage of microwaves, assuming four different configurations that allow the rapid change of the functional elements (transition, nozzle, chokes) and cooling of the plasma generation area. In particular, to this end, circulation of the plasma-generating gas was used which lightly touches by forced convection the outer part of the plasma torch, before being used as plasma-generating gas that is the torch power. This constructive solution allows the recovery of heat from the torch (which would otherwise be dispersed into the environment), by preheating and expanding the plasma-generating gas, in fact increasing the energy efficiency of the entire system, as shown in the following diagram:



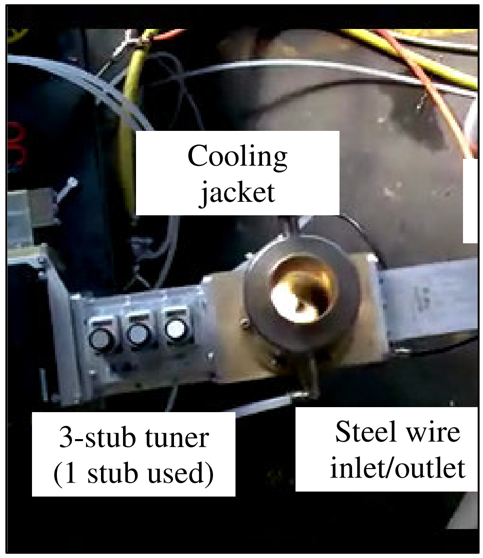
The new geometry of the torch is shown in the figure which also shows an untapered area between the two cones where the entrance and exit of the wire occurs:
The second image also shows the doorknob transition, hollow to allow the flow of gas from the ion input pipe (below) to that of the torch power supply (above). The cooling area (not shown) surrounds the lower cone.
The difference compared to the previous prototype in which the torch had an opening of only 0.5 mm for the passage of gas and a much more compact transition, given the smaller powers involved, is obvious.





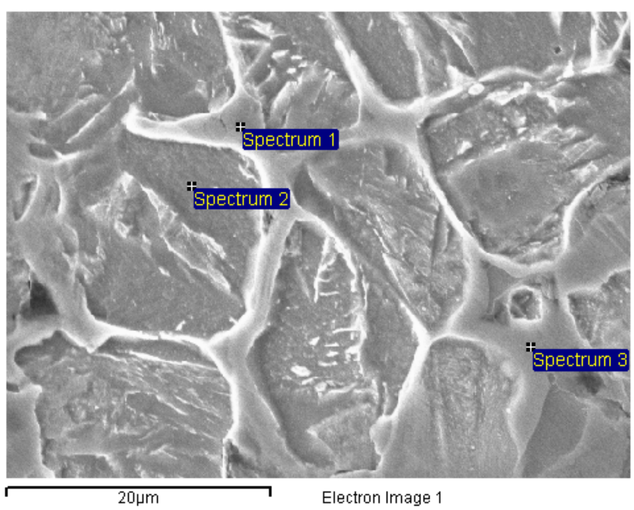


The torch produced and shown in the figure, seen from above, in which the generation area of the plasma and the two impedance matching devices (3-stub tuner and shorting plunger) is visible



With regard to the results of experimental tests carried out on samples of wire and wire rod subjected to mechanical descaling, the following trends are revealed:

- possibility of nitriding the wire: the electron microscope image shows grain edge nitrided areas, which translates into a greater hardness

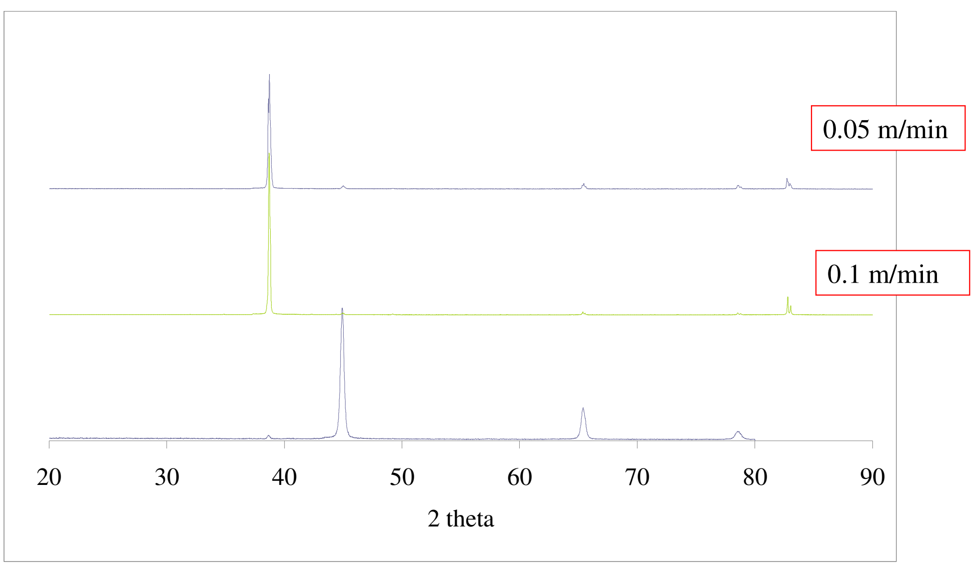


Spectrum	Fe	Ni	Cu
Spectrum 1	93.59		6.41
Spectrum 2	100.00		
Spectrum 3	90.89	9.11	

- better adhesion of the galvanized steel layer, especially in the presence of bath modified with Al: the table shows the value of critical load (for which there is detachment of the zinc or its damage), measured through a scratch test with progressive load, in the case of wire treated or not treated with nitrogen plasma - the critical load is almost doubled.

	Plasma treated	**Untreated**
Scratch length	3 mm	3 mm
Indenter	Rockwell, 100 mm radius	Rockwell, 100 mm radius
Scratch speed	1 mm/min	1 mm/min
Critical Load	17.2 ± 1.9N	8.3 ± 0.4N

- option of performing annealing treatments: the following diffractograms, relating to gold wires, used in the testing phase due to their greater thermal conductivity and chemical inertia with respect to ferrous alloys (they are not subject to nitriding, therefore the result obtained is attributable only to heat and not chemical application) show how it was possible, under different conditions (speed of passage of the torch) to remove the preferential orientation due to wire drawing



Problems encountered

The beneficiary coordinator considered it appropriate to continue using the cooperation of Prof. Paul Veronesi of the Department of Materials and Environmental Engineering of the University of Modena and Reggio Emilia, given his renowned and established experience in the field of microwaves and microwave-induced plasma.
In light of the tests conducted, as mentioned in the previous paragraph, the only difficulty can be traced to the geometry of interaction between wire and plasma. The new torch allowed improvement of the homogeneity of treatment, both when the wire transits at right angles to the direction of the torch, horizontal position, and when the torch is in a position rotated through 120°.

Dip coating bath

The action was initiated with a simple experimental phase of galvanizing with Zinc-Aluminium alloy; the first works on the galvanizing line were initiated early, in particular dedicating a tank specially for experimentation of the new alloy. This, on the one hand, was in order not to affect the normal production of the company; on the other hand, in order to limit the necessary operations on the systems in case issues with the introduction of the other alloy components (in particular Magnesium) should arise.
Subsequently tests were started adding Magnesium and rare earth elements to the Zn-Al alloy; these tests were initially carried out in the laboratory to check the most suitable combinations of metals and earth elements; the combinations will then be tested on the line being prepared. Coating with the Zn-Al alloy has given excellent results. The metallographic observation of the wire shows an intermetallic layer of Fe-Zn-Al alloy between the steel wire and the external layer made of a Zn/Al eutectic alloy. Other tests have shown an improvement in corrosion resistance and improved mechanical characteristics compared to pure Zinc.
The tests carried out made it possible to increase the percentage of Al compared to Zn. We have in fact already produced anticorrosion coatings with Galfan alloy (Zn: 95% - Al: 5%), with the last tests we achieved an alloy composition made of 85% Zn and 15% Al, increasing the corrosion resistance of the product and consequently its duration, using less raw materials to obtain the same results.
The study for the design of the final mixture most suitable in terms of composition and percentage of components was then started; Magnesium was added and at the same time, to complete the coating line, Zn-Al-Mg was added to start testing the coating of wire treated with plasma.
From a mechanical point of view, the covering for the bath for the Zn-Al-Mg baths was prepared in order to appropriately control the reactions of the

mixture and guarantee a more pure result on the wire and a less contaminated application.
The ceramic tank for the coating bath is complete of metal containment structure, composed in carbon steel of adequate thickness. The inner lining of the tank is made of refractory material, with two rows of different refractory bricks and a more external insulating bricks, all sealed with special cement mortar. A combustion system ensures the achievement of the ideal temperature, as well as the containment hood and upper crowning, composed of a series of bath sealing elements in particular material and coated in refractory concrete. The combustion chamber is lined with refractory bricks and insulation panels and contains a modulating burner 30-350 °.
The wire input and output stations, to and from the system were also prepared using winding and unwinding systems.
As regards the addition of rare earth elements, tests showed that this activity is not necessary. Just by increasing the percentage of Al in the mixture and by adding Mg, even if only in a small quantity, we have achieved the required results as regards the thickness to the applied, wire resistance and treatment homogeneity.
Once the treatment bath was available, staff carried out a number of tests to identify the optimal process parameters, in particular the temperature of the bath and the length of time of the immersion. To this end, we collaborated with the University of Modena and Reggio Emilia, which was available to support the activities of the coordinator in defining the treatment parameters of different types of wire. Once the action was completed various tests were made to determine the environmental impact of the system: a comparison with conventional systems showed that the new line has a more efficient functionality than the traditional lines, in particular:

- Reduction of electricity consumptions;
- Reduction of harmful emissions from the galvanising bath;
- Reduction in zinc consumption;
- Improvement of the working environment.

The system developed can treat 1000 kg/h of wire.

<u>Activities carried out</u>

- Conclusion of the coating tests of the drawn wire with Zn-Al alloy;
- Tests to define the most suitable Zn-Al-Mg mixture;
- Continuation of the work to construct the line to coat the wire with Zn-Al-Mg alloy, following the various mixtures tested;
- Covering of the dip bath to reduce contamination and control the reaction of the mixture;
- Development of transport systems for the transit of the wire in the coating bath;
- Immersion tests in the final mixture varying the time and temperature.

Results obtained:

Coating with the Zn-Al alloy has given excellent results. The metallographic observation of the wire showed an intermetallic layer of Fe-Zn-Al alloy between the steel wire and the external layer made of a Zn/Al5 eutectic alloy.
The first tests carried out have shown an improvement in corrosion resistance and improved mechanical characteristics compared to pure Zinc.
The work for the development of the coating line with Zn-Al-Mg alloy is progressing as planned. The main result obtained has been the construction of the treatment system, which can treat about 1000 kg/h of wire. As mentioned previously the environmental results obtained have been very positive and have shown an improvement compared to the current treatment systems.

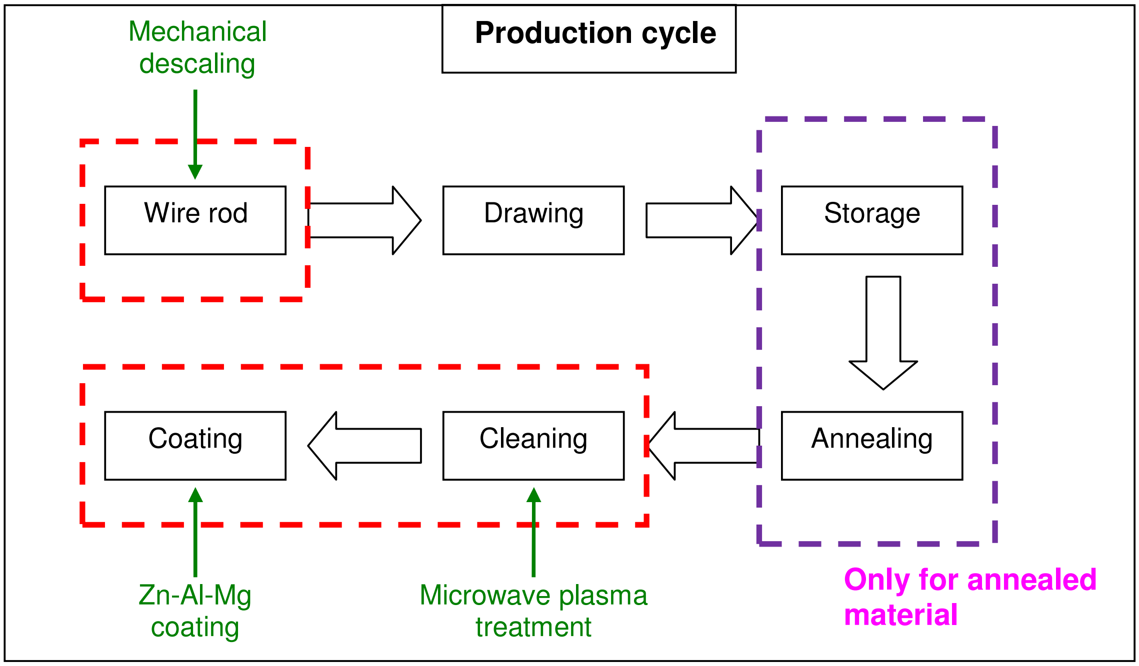
Problems encountered

No problems have been encountered.

Pilot line assembly

The aim of the project was to construct a pilot demo line with a production capacity of about 1000 kg per hour of iron products in the form of drawn wire to be used for experimental activities and to define the mass, energy and environmental balance of the solution proposed, and to be used for the characterisation and final testing of the treated products. The tested materials will then be compared with materials from standard productions.
The components of the pilot line have all already been constructed and a semi-continuous production line has already been used to test the effects of the process variables, in particular of the plasma treatment, on the properties of the materials. The pilot line is called semi-continuous because the main equipment of the innovation (the mechanical descaler of the wire rod that operates by means of blasting) concerns the first processing phase, after which there are other processing phases (drawing and annealing) that are not involved in the project. The plasma treatment system has been installed on the line between the firing phase and the input of the coating bath with Zn-Al-Mg alloy, replacing the pickling phase.

The phases of the process concerned by the new project are highlighted in the following diagram:



Once the system had been entirely assembled various tests were carried out to check the actual production capacity of the system and the quality of the product obtained. The system can treat 1000 Kg/h of wire as foreseen and the output product features excellent characteristics in terms of mechanical and corrosion resistance.
The last technical activity of the project concerned the drafting of a mass and energy balance to assess the environmental impact of the entire system compared to a conventional wire rod treatment system. The study carried out, detailed in annex 12, showed the environmental benefits that can be achieved with the new treatment, in particular in terms of water and acid consumption, energy saving and reduction of harmful emissions. All these factors contribute to create a safer working environment.

<u>Activities carried out</u>

- Design of the pilot line layout;
- Construction of the components of the pilot line for the various process phases;
- Construction of the wire rod winding and unwinding systems upstream and downstream of the treatment system
- Installation of the pilot line and construction of transport systems, connections, safety devices, cabling and connection to auxiliary systems:
- Experimental tests on the temporary line with different wire rods, to test the effects of the process variables on the material properties;
- Mass, energy and environmental balance and evaluation of the results actually achieved and obtained.

Results obtained:

The plant layout has been sized and the space within the plant to implement it has been defined, near a traditional wire treatment line. The various components of the line were sized and developed during the project to be assembled on the line during this action, together with all the accessory equipment necessary for the operation of the system. After having completed this action various characterisation tests were carried out on the products delivered by the system and analyses were performed to assess the environmental impact of the entire system.

Problems encountered

No problems were encountered; the fine tuning of the final system was completed after the date of conclusion of the action but not after the date of conclusion of the project. The coordinator decided to dedicate more time to the fine tuning phase in order to achieve the best possible result.

4. Evaluation of Project Implementation

From a technical point of view no significant problems occurred and the differences compared to what was foreseen in the application, are irrelevant as thy only concerned the extension of certain activities without however affecting the general project timetable.
The 3 core elements of the project (mechanical descaling system, microwave plasma applicator and dip coating bath) have been achieved following the procedures and methods described in the application.
The tests carried out on the assembled system have shown that all the main technical and environmental objectives have been achieved, therefore the coordinator is satisfied with the procedures implemented.
The total cost of the project were in line with many research and development projects previously carried out. The costs mainly concerned the technical activities, the heart of the project, and the dissemination actions, necessary for the diffusion of the technology developed. The budget allocated to the project is not however significant considering the economic and environmental benefits obtainable: first of all a reduced use of Zinc in favour of other substances such as Aluminium and Magnesium will result in cost savings, in the short term, and savings related to the supply of raw materials; secondly all the waste produced by the project will be either recovered during the mechanical descaling stage or used in other processes, thus resulting in lower waste disposal costs.

From the environmental point of view the results are substantial, the adoption of the technology in Europe would lead to:

- A saving of 3.3 million cubic meters of water;
- A saving of 95,000 tonnes of hydrochloric acid and sulphuric acid;
- A saving of 24,000 tons of scrap metal;
- A substantial reduction in the production of acid sludge;
- An improved working environment.

All the results obtained by implementing the project are immediately visible, both the technical and the environmental ones; in detail:

- reduction of electricity consumptions;
- total elimination of water consumption (-100%)
- total elimination of the use of hazardous substances (hydrochloric acid, ammonium chloride, zinc chloride) (-100%);
- total elimination of hazardous waste production (-100%);
- total elimination of harmful emissions into the atmosphere deriving from the use of acids (-100%);
- reduction of harmful vapour emissions from the galvanising baths and from the production of zinc waste;
- exploitation of metal waste produced in the decaling phase;
- improvement of the working environment.

In addition to the above mentioned environmental benefits, the following technical-economic benefits will be achieved:

- reduction in zinc consumption;
- improvement of the quality of the finished product (physical properties).

Not to mention the improvement of working conditions, reduced harmful emissions into the atmosphere and lower energy consumption. The aim of the coordinator is to transfer the technology to anyone that is interested, in particular to companies operating in the metallurgical sector. The pilot line is easily transferable but the support of Trafileria e Zincheria Cavatorta is necessary as some of the system components are not readily available in the market (e.g. the microwave plasma generator, specially created by the University of Modena and Reggio Emilia).

Aware of the importance of the support necessary for the transfer of the technology, the coordinator is fully to meet the needs of the interested parties in the project, by providing also a part of the staff that will be deployed at the premises of the customer interested in the transfer of the technology. Agreements have been made also with the University of Modena and Reggio Emilia for the development of other generators of microwave plasma.

Through these activities, the coordinator hopes to convince other companies to adopt the technology developed.

From a social point of view, the technology developed will improve the working environment of the workers in the metallurgical sector; the working environment will be healthier for the following reasons:

- Water will not be used;
- Less gaseous zinc emissions will be produced;
- The coating bath temperatures will be lower.

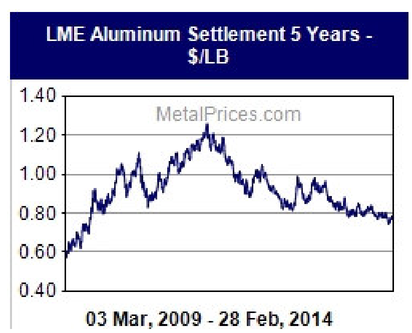
Humid environments, generated by the high presence of water, are the best places for the growth of mould and bacteria. The total elimination of the water will completely eliminate the presence of these potentially dangerous organisms making the workplace safer; furthermore, the presence of water in the case of bare wires can be potentially lethal for workers.

Currently, the coating bath is carried out at an average temperature of 80°C, which determines the production of toxic zinc fumes; the application of the new technology lowers the temperature of treatment leading to a reduction in the production of fumes that are harmful for people.

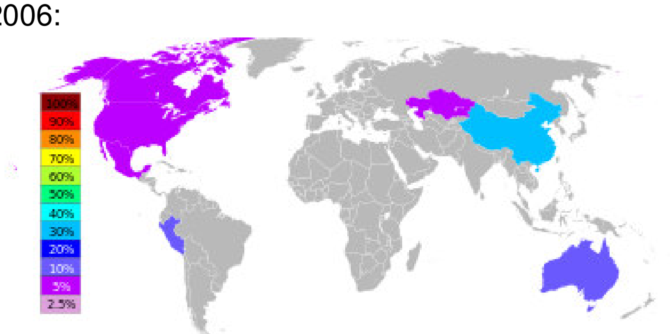
The new treatment proposed, will result in the improvement of working conditions for the workers, preventing possible sources of accidents and diseases.

The main economic benefit that can be obtained is related to the reduction in use of zinc. Zinc has been widely used (and is still very much used) in various fields therefore its cost has increased significantly.

Please find below a comparison between the price trend of zinc and aluminium between 2009 and 2014 (source: metalprices.com):



Please note also that zinc is not produced in Europe therefore it must be imported from other parts of the world, resulting in am additional cost for European users. The picture below shows a breakdown of the areas where zinc was produced in 2006:



The reduction in the use of Zinc, will therefore result in lower production costs for companies and consequently lower purchasing cost of final goods for consumers. This will increase the competitiveness of European companies operating in this sector, making them able to face product competition from emerging markets including India, China and Brazil.
Companies that will adopt the technology developed will provide not only a cheaper product, but also a sustainable product that will lead to additional competitive advantages, especially in the European context where consumers have issues such as quality and sustainability at heart.

5. Transfer of the technology

The environmental benefits mentioned above only concern the case in which the technology in question is only used by manufacturers of metal wires; there are actually some possible spin-offs of the technology that can lead to additional environmental benefits.
The Zn-Al -Mg dip bath can be applied to any type of product subjected to the galvanising process, because the tanks can house products of different shapes. The use of this bath in the processing of other products determines a further reduction in the use of zinc and relevant emissions. Zinc in fact, although it is not a toxic metal, if inhaled in its gaseous state can cause several health problems in humans in addition the lack of availability of zinc in nature means it has a high supply cost.
The transfer of the technology to other processes, will basically lead to lower production costs and improved working conditions for employees of many metallurgical companies.
Trafileria e Zincheria Cavatorta is implementing various marketing activities in order to seek companies suitable for the transfer of the technology developed. The pilot line developed can be easily reproduced somewhere else, however the cooperation of the coordinator is necessary as some components are not readily available in the market. The most difficult system to replicate is the equipment for the production of microwave plasma as it is completely innovative. For this purpose Cavatorta has already made an agreement with the University of Modena and Reggio Emilia for the production of other similar systems if required. The coordinator has also already given instructions to the staff to be completely available in the case of requests to reproduce the system; we have also foreseen the possibility of transferring part of the staff at the premises of the interested company so that the system can be correctly installed properly and the production parameters can be optimised.

If companies will be interested only in the "Zn -Al- Mg coating bath" the staff will provide technical specifications on the composition of the bath and any technical support so that the company concerned may operate almost independently.
Communications concerning the transfer of the technology focus on two fundamental aspects:

- Cost savings related to the procurement of raw materials;
- Creation of a sustainable product.

The two concepts mentioned are of great impact for companies operating in the sector and will attract their attention and then lead to the discussion of more technical issues.
The target potentially includes all metallurgical companies worldwide, accessible through the widespread network of contacts that the company also has abroad. The company will not only target the manufacturers of wires but also all the companies that operate in the metallurgical industry, as the pilot line (or parts of it) can be adapted for the treatment of other metal products. The coating bath does not require additional changes to be used for other metal products, while the microwave plasma generator needs to be sized according to the item to be treated.

6. The LIFE experience

The project embodies many innovative features, all the systems introduced in the pilot line represents a step forward in the state-of-the-art of the sector and the microwave plasma generator represents height of innovation, a device created by combining the company's know-how with that of the university. The financial contribution of the European Union was fundamental to transform the idea of the management of Trafileria e Zincheria Cavatorta into reality. The financial support enabled the company to carry out a research project that otherwise would have been difficult to develop in part for financial reasons and in part because it is not easy to tackle such a challenge when the economic situation is unfavourable.
Given the innovative nature of the system, it was of fundamental importance to be able to count on the European Union, which instilled confidence in the interested parties that listened to the results obtained with disbelief. In the same way, the support of the Life programme played a crucial role when we contacted international firms with which we did not have a direct personal contact.
Being part of the Life program also means being part of a network of European projects aimed at researching sustainable innovation; the coordinator hopes to effectively become part of this network in order to accomplish numerous other networking activities in partnership with companies, even international ones.