LIFE Project Number

LIFE13-ENV-IT-001238

FINAL Report

Covering the project activities from 01/06/2014 to 30/11/2018

Reporting Date

<28/02/2019>

LIFE+ PROJECT NAME or Acronym

<K12>

Project Data

Project location	Italy
Project start date:	01/06/2014
Project end date:	30/11/2017> **Extension date:** 30/11/2018
Total Project duration (in months)	54 months (including **Extension of 12 months**)
Total budget	€ 3.975,622
Total eligible budget	€ 3.975,622
EU contribution:	€ 1.941,310
(%) of total costs	48.83
(%) of eligible costs	48.83

Beneficiary Data

Name Beneficiary	Dow Italia s.r.l.
Contact person	Mr Vanni Parenti
Postal address	Via Francesco Albani, 65, 20148, Milano
Visit address	Via Carpi, 29, 42015, Correggio, Reggio Emilia
Telephone	+39-0522-6451, direct n° +39-0522-645829
Fax	
E-mail	vparenti@dow.com
Project Website	http://www.dow.com/en-us/k-12

This document reports the activities and the results obtained within the LIFE13 ENV/IT/001238 K-12 project by Dow Italia, Afros S.p.A. and Whirlpool EMEA. It summarizes the work done from June 2014 and to 30th November 2018 aiming to demonstrate the feasibility and efficiency of an innovative polyurethane technology solution able to hugely impact the thermal insulation of domestic refrigerator market in comparison to current best available technologies in use. In particular the project objective is the reduction of energy consumption of household refrigeration appliances up to 20% vs. the best in class domestic refrigerators sold in Europe, by using a fully carbon dioxide (CO_2) blown foam fully matching Eco-design and F-gas regulations.
The household sector is one of the largest users of electrical energy in the European economic area, consuming 29.7% of total electrical energy. The total household final energy consumption in 2010 was about 840 TWh/yr, of which 14.5% was related to cold appliances consumption as refrigerators and freezers (Energy Efficiency Status Report 2012). Refrigerator's heat loss, so energy consumption, takes place mainly through the walls of the appliances, as well as through the door gasket used to enable the door opening while limiting the heat losses. The polyurethane (PU) foam thermal conductivity is one of the key elements contributing to control and reduce heat loss: the lower the material thermal conductivity, the lower the heat loss, thus the better the refrigerator's energy consumption rank meaning better energy label class.
Nowadays, current polyurethane (PU) insulation technology for such appliances uses cyclo-pentane blown polyurethane foam with thermal conductivity ranging from 18–20 mW/m.K depending on the type of formulation employed. Cyclo-pentane is a hydrocarbon with Zero Ozone Depletion (ODP) and negligible Global Warming Potential (GWP) impacts. Carbon dioxide (CO_2) is known as the lowest GWP Green House Gas (GHG) being the most environmental friendly blowing agent for polyurethane foams. Nevertheless having poor thermal conductivity it is significantly worse than cyclo-pentane in terms of insulation performance. For this reason cyclo-pentane is the blowing agent of choice in use today, thus the baseline reference for the project. The most efficient polyurethane rigid foam in use today to insulate domestic appliances show a thermal conductivity of 18-20 mW/m.K depending on the type of injection technology and formulation employed. Today's insulating technology employing fully CO_2 PU blown foam would offer a foam thermal conductivity of 24-26 mW/m.K, thus already 20% worse than baseline.
The LIFE13 ENV/IT/001238 K-12 project target is to demonstrate that is possible to close this gap by using fully CO_2 blown foam with a novel breakthrough insulation technology which would offer not only to match, but to further gain energy efficiency with respect to today's baseline. This gain could be up to 20%.

Dow did work on the K12 idea at micro-laboratory-scale. Based on the experiences and results of the laboratory phase, Dow Italia, Afros and Whirlpool EMEA believed that it was possible to upscale the K12 technology demonstrating new refrigerator manufacturing process from lab to full industrial scale thus leading to LIFE13 ENV/IT/001238 K-12 project definition.

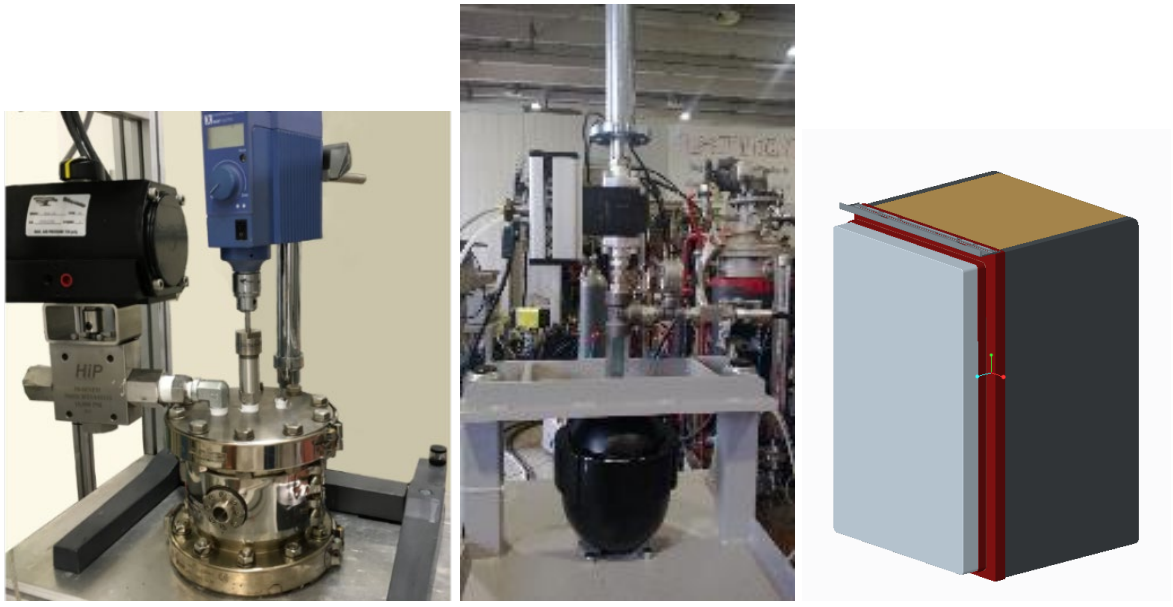
The project outputs included the following and represented the main path followed during project execution:

- Development of the K12 polyurethane foam technology at laboratory level through batch foaming experiments at Dow, to be validated at K12 pilot plant at Afros facility. A great and prolonged effort has been profuse by Dow to explore all the possible parameters in order to achieve the right foam performance. Laboratory foamed prototypes were realized

in collaboration with Institute of Composite and Bio-Polymer Materials (ICBP) at their small reactor in Naples, Italy.

- Design, realization, installation and set up the K12 pilot plant at Afros facility to demonstrate the feasibility of scaling up this novel insulation technology at semi-industrial level. Two hundred 2D square foam prototypes were produced at pilot plant with four different polyurethane formulations; over 60 foam prototypes were produced with a 3L reactor mold to understand the effect of CO_2 degassing process with several different polyurethane formulations
- Design and realization of the refrigerator's door and cabinet models and structures which can adopt and fulfil the K12 technology requirements. 4 K12 door were produced for testing; 2 refrigerators were built with panels molded in the K12 door mold. Studies on redesigning the cooling circuit to adapt to K12 requirements and on thermal design of the structure have been realized.
- Planning, development and upgrade the dissemination activities to promote the K12 project results and outcomes to contribute the European Community energy legislations upgrade, also including the future leverage, applicability and reproducibility of demonstrated technology within the thermal insulation market segments globally other than household appliances.

The pictures below show some equipment installed at the partners facility both at laboratory (Dow Italia) and pilot plant scale (Afros). IN addition the design of refrigerator undercount prototype is there.



All the technical efforts to reach the K12 targets included the production of a wide range of prototypes samples starting from lab sample going to simple geometry panels in the pilot plant to end with K12 refrigerator door and assembled small K12 cabinet. All those samples were deeply studied with internal standard tests and at external laboratories such ICBP, FIW, and UNIBO when ad hoc capabilities were needed. The main data obtained were used by Whirlpool to run simulation on actual behaviour of K12 foam and to highlight the potential of K12 technology. Figure below illustrates as examples some prototypes from lab and pilot plant.

At the end of the project refrigerators door and small cabinet proto-types realized by Whirlpool were successfully foamed at the novel Afros pilot plant equipment with the newly Dow developed chemistry giving really satifactory results:
The main results achieved with LIFE13 ENV/IT/001238 K-12 are the following:

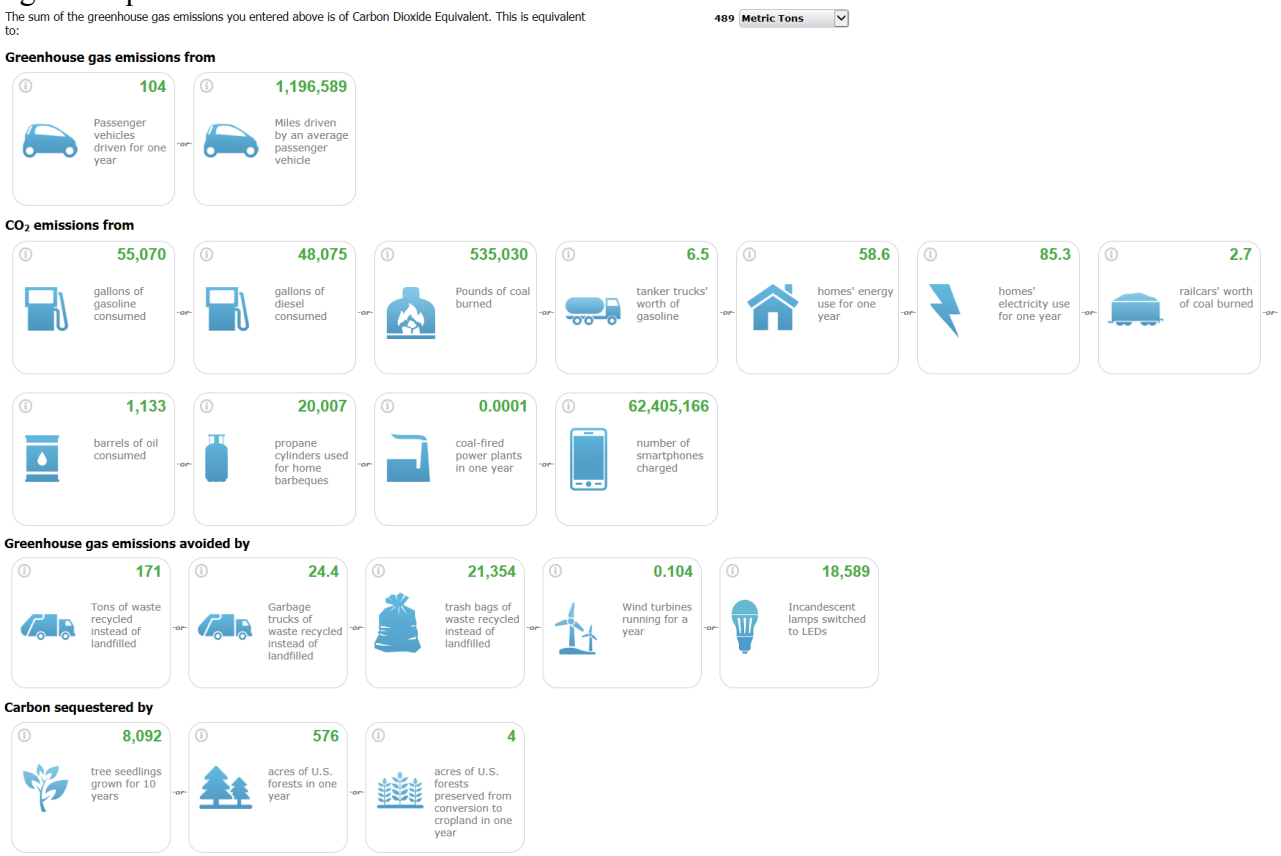
- K12 technology demonstrated the same energy efficiency of today's best in class cyclo-pentane blown foam by using fully CO_2 blown foam, measured by Reverse Heat Leakage (RHL) test The K12 foam thermal insulation is significantly improved vs. any typical CO_2 blown foam.
- K12 PU system demonstrated per kg of foam inputs, to have generally similar or lower (15-30%) burdens than the conventional system, measured by Life Cycle Assessment (LCA).

- at the end of the refrigerator's life time, any appliance must be collected and dismantled to remove by aspiration and condensation both refrigerant and blowing agent GHGs, with a costly process for the community. Moreover, some part of these gases are released to the atmosphere increasing the greenhouse effect. On the contrary K12 CO_2 blown foams do not need this process making the K12 refrigerators easier and less costly to recycle.
- K12 PU technology has high replicability in the cold chain market as demonstrated by the many 3D items produced during the life of the project. Thus insulated panels for cold store, refrigerated transportation and thermal insulated boxes could be produced by using this technology without any loss of energy efficiency vs. today's insulating technology in use.

Figure below shows a door prototype and the new equipment able to manage the carbon dioxide as unique blowing agent.

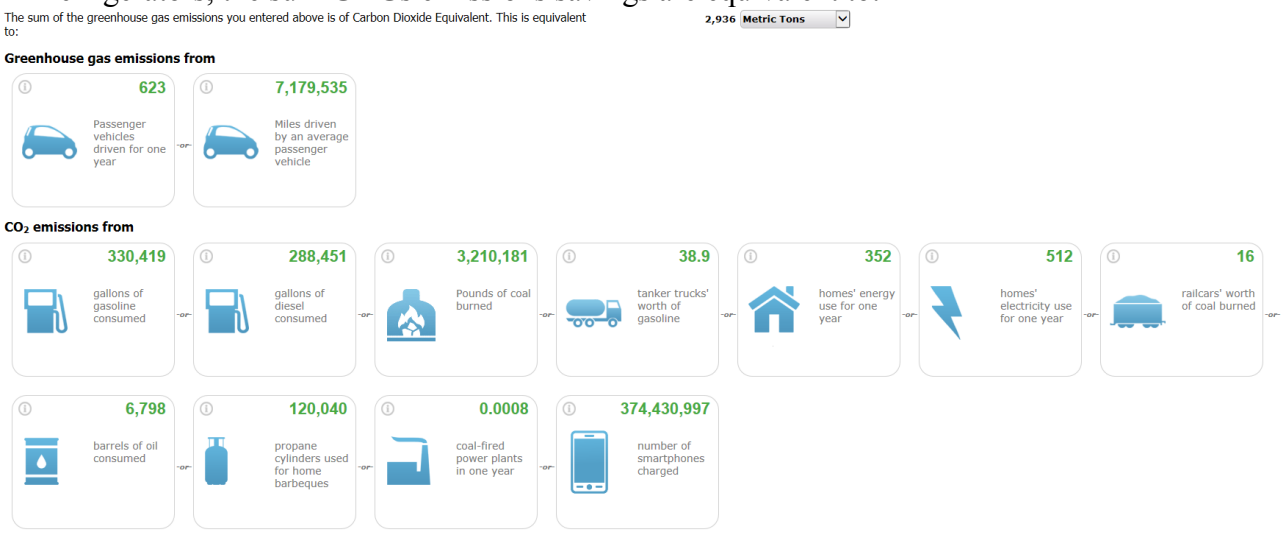
An important expected results for such innovative K12 technology is the demonstration that the same energy efficiency of today's refrigerators is achievable by using fully CO_2 blown polyurethane foam leading to an impactful CO_2eq for Kg of foam savings. Thus giving an insight into how the novel K12 technology can upgrade the environmental footprint of the household appliance industry and update/enhance the European Union environmental policy and legislation, suggesting to include the integration of the environmental impact into other policies (e.g. GWP>15 vs. today's limit of 150).
Furthermore Eco-design and appliances Energy Labelling are nowadays under review within the European community: it has been announced a new energy label regulation to be in place by year-end 2019 that would imply and average 20% improvement on each classes which will be redistributed between class A (best energy consumption) to class G (worst energy consumption). In such a scenario, innovation is critical to match these requirements, and this is valid for the PU insulation foam as well as for the equipment to process it and for the final

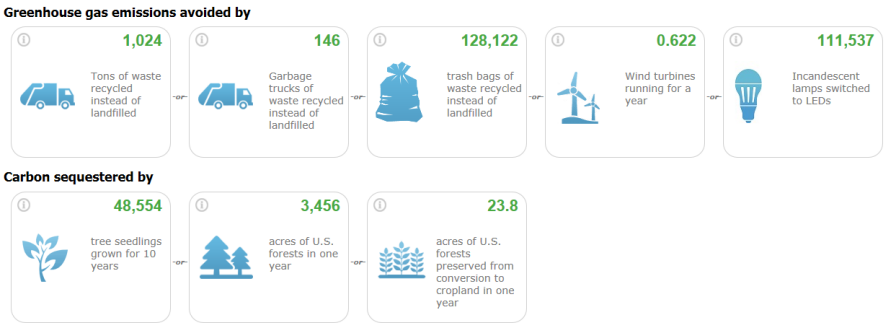
refrigerator to launch in the market. As impact of the novel K12 technology penetration in the European market for high-end household refrigerators only, it is estimated that a portion of the A+++ models produced today would be enhanced in terms of efficiency and/or sustainability footprint. As example, equivalency results shows that if 5% of A+++ refrigerators produced today would adopt the K12 door only, the sum GHGs emissions savings are equivalent to:



Source: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Similarly, if 5% of A+++ refrigerators produced today would be replaced by K12 refrigerators, the sum GHGs emissions savings are equivalent to:





In terms of potential for other markets replication, the novel K12 insulation technology demonstrated within the LIFE13 ENV/IT/001238 K12 project can be applied to any discontinuous PU injection process, thus could be applied and leveraged to the following market segments, among others:

- Commercial and professional refrigeration appliances
- Water Heaters
- Refrigerated transportation
- Cold store panels
- Thermal boxes

The use of Afros equipment for CO_2 sorption into polyol side can be leveraged also to other market segment, as example in flexible foam where the use of CO_2 is already used to gain in precise foam properties but being difficult to be efficiently processed.

For what concern the innovation, the novelty of K12 project it is clearly evident: such breakthrough technology lead Dow to patent the PU chemistry and physic of the novel K12 PU foaming process. Afros has patented the system to mix and dose carbon dioxide in high quantity in the polyol side.

In addition K12 represents innovation also into the field of new eco-friendly blowing agent: it is possible to improve the domestic refrigerator's energy efficiency by using carbon dioxide instead of typical organic Blowing Agents (BAs) such us Hydrocarbons (HCs) or even halogenated BAs of the newest BA generation such as Hydro-Chloro-Fluoro-Olefins (HCFOs) and Hydro-Fluoro-Olefins (HFOs) which show very low Global Warming Potential (GWP), however molecules containing halogens into a olefin structure.

Furthermore all the scientific publication on international scientific journal of polymer science (See the list of publications) demonstrate the scientific value of K12 technology that enhance the use of carbon dioxide to generate polymer microcellular properties to polyurethane and not only to thermoplastics polymer as it was before. The importance of polymer with microcellular structure is well documented and known from various industrial aspects.

The project partners have been fully committed to disseminate results of the project, demonstrating the LIFE K-12 technology as one of the best-performing technology available on the European and global market and showing the next competitive level for eco-design of CO_2 blown foams for the Cold Appliance sector, in the spirit of art. 15 of Directive 2005/32/EC regarding the Eco-design of Energy using Products. On May 18th, 2017, K12 Mid Term Conference took place in the Cannon Sandretto Plastics Museum of Pont Canavese, near Turin, Italy. The aim of the Mid Term conference was to reveal Project first achievements and to disseminate LIFE Program information. On November 6th 2018, K12 Final Conference took place in the international fair of ECOMONDO in Rimini, Italy. The

aim of the Final Conference was to reveal the final results of the project which uses CO_2 as blowing agent for an innovative polyurethane insulation foam and discuss in view of their impact on environment, social community and industrial sustainability.
Technical and scientific results were disseminated through publications on scientific journals such as "Fluid Phase Equilibria" and through the participation to international conferences such as "12th International Symposium of Supercritical Fluids".
Web site was created and update (https://www.dow.com/en-us/k-12).

Project partners were also committed to participate to Italian, European and international conferences and exhibitions. More in detail, the participation of K12 consortium has been registered in the following events:

Event name	When
Sustainable Chemistry Workshop	December 2015
Kunststoff2016 Fair	October 2016
Ambiente ed energia: dal progetto al mercato con i contributi Europei	May 2017
"LIFE platform conference on waste management and the circular economy"	June 2016
Poly-Foam conference	April 2017
European Meeting on Supercritical Fluids	April 2017
Conferenza AIMAT, Associazione Italiana di Ingegneria dei Materiali	July 2017
Sustainable Chemistry Workshop	May 2017
K12 Project Mid Term Conference	May 2017
33rd International Conference of the polymer processing society	December 2017
12th International Symposium of Supercritical Fluids	April 2018
LIFE MATHER Project Mid Term Workshop	September 2018
European Conference on Thermally and electrically conductive polymers	October 2018

News about the K12 Project and its results have been published both in sectorial magazines and in scientific journals, as described in detail in the following table.

Journal	Authors	Title	Scope	Publication date
Platinum – Sole24Ore	Dow, Whirlpool, Afros	LIFE+ Project K12, Enhanced Insulation Technology for the Refrigerator of the future	Public sector dissemination	November 2015
Cannon news	Dow, Whirlpool, Afros	Three industry leaders join hands in LIFE + K12 project	Public sector dissemination	March 2016
Cannon news	Afros	Refrigerators, Always a Cool Business!	Public sector dissemination	October 2016 -
Fluid Phase Equilibria	Dow with CNR	Polyether polyol/CO_2 solutions: solubility, mutual diffusivity, specific volume and interfacial tension by a fully experimental procedure	Scientific dissemination	October 2016
Polymer Testing 62	Dow with University of Naples and CNR	A pressure vessel for studying gas foaming of thermosetting polymers: sorption, synthesis and processing	Chemical Industry dissemination	September 2017
Italian LIFE National Contact Point Section Project of the Month	Dow, Whirlpool, Afros	Progetto del mese di dicembre 2017 LIFE+ K12 (LIFE13 ENV/IT/001238) - "Tecnologia innovativa per migliorare l'efficienza energetica dei frigoriferi domestici"	Public sector dissemination	December 2017
Fluid Phase Equilibria	Dow with University of Naples and CNR	Mass Transport and Physical properties of polymeric methylene diphenyl diisocyanate / CO_2 solutions	Chemical Industry dissemination	January 2018
PhD Thesis	Maria Rosa Di Caprio (University of Naples)	Rigid polyurethanes foaming with CO_2 as physical blowing agent	Chemical Academic Dissemination	January 2018

K-12: Project Partner Companies

Dow Italia S.r.l.

Dow Italia was established in Italy in 1960. A key player of the chemical industry in Italy, Dow can count on a solid structure of production plants as well as a Global R&D Center of Polyurethanes in Correggio. Dow combines science and technology knowledge to develop premier materials science solutions that are essential to human progress. Dow has one of the strongest and broadest toolkits in the industry, with robust technology, asset integration, scale and competitive capabilities that enable it to address complex global issues. Dow's market-driven, industry-leading portfolio of advanced materials, industrial intermediates, and plastics businesses deliver a broad range of differentiated technology-based products and solutions for customers in high-growth markets such as packaging, infrastructure, and consumer care. Dow is a subsidiary of DowDuPont (NYSE: DWDP), a holding company comprised of Dow and DuPont with the intent to form three strong, independent, publicly traded companies in agriculture, materials science and specialty sectors. More information can be found at www.dow.com.

The Company connects chemistry and innovation with the sustainability (www.dow.com/sustainability) to help address many of the world's most challenging problems such as the need for clean water, renewable energy generation, energy efficiency, and increasing agricultural productivity. DOW's diversified industry-leading portfolio of specialty chemical, advanced materials, agro-sciences and plastics businesses delivers a broad range of technology-based products (www.dow.com/products) and solutions (www.dowsustainability.com) to customers in approximately 160 countries and in high growth sectors such as building and construction, electronics, water, energy, coatings and agriculture.

In 2011, DOW had annual sales of $60 billion and employed approximately 52,000 people worldwide. The Company's more than 5,000 products are manufactured at 197 sites in 36 countries across the globe. DOW operates in Italy as of 1960. The several legal of TDCC in Italy, with about 760 employees, and an annual turnover of 1.084 million euro in 2011, have production sites located throughout the Country. Italian Head Offices of DOW are based in Milan. http://www.dow.com

AFROS Spa

AFROS is part of (owned by 92%) the CANNON Spa holding (www.cannon.com), an international, independent group providing a range of industries world-wide with dedicated to engineering solutions. The group's main fields of activity are plastics processing technologies (for polyurethane, thermoplastics, composites and thermoforming), equipment for energy efficiency and ecology, aluminum die-casting machines and electronic control systems for industrial processes. With more than 900 people employed in 12 Manufacturing facilities and over 40 branches, the AFROS Group supports over 15.000 customers worldwide.

Since 1962 AFROS has gained a worldwide experience in the engineering and design of dosing, mixing and foaming machines and systems for polyurethanes and installed more than 11.000 metering units all over the World. AFROS metering machines are specifically designed for the PU Industry and can be tailored to suit various production configurations. Moreover, throughout the years, AFROS have developed in-house cutting-edge technologies and related processes for the production of high quality composites (mainly PU and Carbon

Fibre). The main specific competences which will be implied in the present project by AFROS are:

- Epoxy High Pressure mixing and impregnation Injection (ESTRIM);
- New skills in precision airless spraying;
- Vacuum assisted injection system;
- High efficiency, self- cleaning solvent-less Mixing heads;

AFROS through its R&D team and facilities carries out an intense research program for continuously improving its products and technologies, resulting in the development of more than 100 international patents for the PU industry. AFROS has its production facilities and R&D center in: Via Galileo Ferraris, 65. - 21042 Caronno Pertusella (VA), Italy Web site: www.afros.it, www.cannon.com

Whirlpool EMEA S.p.A

Whirlpool Corporation (NYSE:WHR) is the number one major appliance manufacturer in the world, with approximately $21 billion in annual sales, 93,000 employees and 70 manufacturing and technology research centers in 2016. The company markets Whirlpool, KitchenAid, Maytag, Consul, Brastemp, Amana, Bauknecht, Jenn-Air, Indesit, Hotpoint and other major brand names in nearly every country throughout the world. In Europe, Middle East and Africa (EMEA) it has approximately 24,000 employees, a sales presence in more than 30 countries and manufacturing sites in eight countries. Whirlpool EMEA is an operating segment of Whirlpool Corporation. Whirlpool Corp.'s EMEA Headquarters are located in Pero (MI), Italy. Additional information about the company can be found at WhirlpoolCorp.com or find us on Twitter, LinkedIn and Facebook.

Whirlpool R&D S.r.l.

Whirlpool R&D S.r.l. (WHRD) is a newly established Italian subsidiary of Whirlpool Corporation and has its Headquarter in the European Centre of Excellence for Research in Cassinetta of Biandronno (Va). WHRD is also an affiliated company of Whirlpool Europe S.r.l., both having the same parent company; Whirlpool is present in Europe with 14.000 employees, a sales presence in more than 30 countries, manufacturing facilities in 7 countries and a high conception of the power of innovation. Whirlpool's culture embracing values like sustainability, diversity and innovation is continuously seeking for better solutions for enhancing the resource efficiency of its products and innovative more sustainable technologies. WHRD is the heart of research and development in Europe for Whirlpool Corporation and it aims to increase the level of innovation and competitiveness of Whirlpool through activities of technological transfer and collaborative research initiatives at national and international level. WHRD aims to strengthen and extend this wealth of know-how with the new areas of advanced development for all product groups (Refrigeration, Cooking and Washing Machines).WHRD is made up of about 50 specialized researchers engaged in research on materials, product engineering, technologies of storage and preparation of food and advanced electronic, with also a specific team responsible for management of funded research projects.

A central role in WHRD is played by the research center on global food technologies, that is the strategic heart in terms of specialized resources, facilities and laboratories. In Cassinetta, WHRD develops and experiments with new technologies of food preservation and processing, and generally for all the products that Whirlpool sells worldwide (EMEA,NAR, ASIA, LAR regions). http://www.whirlpool.it/