PROJECT FINAL REPORT

Final Publishable Summary Report

Grant Agreement number: 601616

Project acronym: **GRABGAS**

Project title: ***Green roofs that clean SME industrial gas containing low and variable concentrations of Volatile Organic Compounds.***

Funding Scheme: FP7-SME-2013-1

Date of latest version of Annex I against which the assessment will be made: 2014-02-04

Final report: **1st □ 2nd X□ 3rd X 4th □**

Period covered: **from 01/5/2015 to 30/04/2016**

Name, title and organisation of the scientific representative of the project's coordinator[1]:

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[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the grant agreement

Declaration by the scientific representative of the project coordinator[1]

I, as scientific representative of the coordinator1 of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;
- The project (tick as appropriate):

  ☐ has fully achieved its objectives and technical goals for the period;

  ☒ has achieved most of its objectives and technical goals for the period with relatively minor deviations[2];

  ☐ has failed to achieve critical objectives and/or is not at all on schedule[3].

- The public website is up to date, if applicable.
- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 6) and if applicable with the certificate on financial statement.
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 5 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator: **Stephanie Saulgeot**

Date: 16 / 06 / 2016

Signature of scientific representative of the Coordinator: 

[2] If either of these boxes is ticked, the report should reflect these and any remedial actions taken.

[3] If either of these boxes is ticked, the report should reflect these and any remedial actions taken.

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1. Executive Summary

Cost-effectiveness for controlling emissions of Volatile Organic Compounds (VOC) in industrial waste gas depends on the characteristics of the gas emitted. SMEs affected by VOC emission Directive 99/13/EC (wood, printing, surface cleaning, dry cleaning, leather, vehicle refinishing) generate low and variable concentrations of several different VOCs in small volumes of waste air. This profile of VOC emissions will be the focus of the new Industrial Emission Directive 2010/75/EU, but it shows the most techno-economic problems for VOC control.

GRABGAS project aims to get an improved waste gas cleaning technology in to efficiently controlling emissions of volatile organic compounds in industrial waste of SMEs, by means of and adequate integration of some key techniques:

1.- GRABGAS will use rhizodegradation to treat small volumes of industrial waste air (1,000 m3/h) with low and variable concentrations (30-300 mgC/m3) of several different VOCs with a removal efficiency of >93% to comply with directive emission limit values (20mgC/m3).

2.- Rhizodegradation uses plant roots, microorganisms and soil to biologically degrade VOC into CO2 and H2O. It can simultaneously degrade several VOC in very low concentrations or even when they are temporarily absent. GRABGAS will adapt to changing concentration of different pollutants, as well as to weekend and short holiday interruptions without losing removal efficiency.

3.- To make VOC mixtures more biodegradable, a solar photocatalytic pre-treatment using doped-TiO2 will be applied before rhizodegradation.

4.- To support plant growth and solar photocatalysis with sunlight, GRABGAS will be installed on industries' roofs, following European green roof standards. Optimal air flow through the rhizofilter will be achieved by a substrate allowing root growth, high active surface for bacterial growth, permeability for air and VOC storage capacity. It will keep the internal temperature and moisture within constant ranges by appropriate sealing, insulation and drainage.

GRABGAS technology also has an impact in the EU society reducing the VOC emissions from SMEs in order to meet with the different European Regulations such as the VOC Solvent Emission Directive (SED, 1999/13/EC) and the Emission Directive (IED, 2010/75/EU)

2. Summary description of project context and objectives.

According to the European Thematic Strategy on Air Pollution, the main air pollutants causing the most damage and costs are SO2, NH3, particulate matter PM2.5, NOx and Volatile Organic Compounds (VOCs). VOCs are carbon-based chemicals that evaporate very easily and are extensively used in the EU as solvents in industrial activities like varnishing/painting, printing or cleaning. NOx emissions are produced in combustion processes, for example when VOCs are burnt before release to the environment as an end-of-pipe solution for VOC control. VOCs, together with NOX and sunlight, generate toxic ozone (O3) at ground level. The total ozone damage to crops and human health is estimated by the EC to cost the astonishing figure of 15€ billion each year. Unfortunately, according to the European Environment Agency (EEA), 11 countries of the EU-27 exceeded their maximum global emissions (National Emission Ceilings) in 2011. Spain and Portugal exceeded their joint ceilings by more than 10%. Thus, a good way to achieve the needed reduction of VOC and NOx emissions is helping eco-industries to provide with SMEs that emit pollutants with cheap and efficient solutions for VOC emission control.

New VOC legislation will target SMEs emitting low and variable VOC concentrations.

Most large enterprises comply with emissions since 2007 because environmental regulations have historically focused on them: as a starting point. However, the real problem is diffuse SME emission: large number of sources emitting low concentrations. According to the 2010 EC report "SMEs and the environment", Small and Medium enterprises are responsible for 64% of the European environmental impact, including NOx and VOCs. As a response, EC environmental legislation in 2013 will start focusing on small companies. Therefore, the eco-industries need to develop new VOC control solutions that fit the chemical composition of VOC emission and the economies of these SMEs.

● The recent Industrial Emission Directive (IED, 2010/75/EU) for gas emission control will be transposed into Member States' legislation by January 2013 and it will mainly focus on two most urgent problems23:

- Limitations in SME compliance and insufficient implementation of Best Available Techniques (BAT): BATs are the most effective and economically feasible solutions. According to the EC Reference Documents on BAT for industrial waste gas control, biological treatment of VOC emissions is BAT. In the EC words, "The objectives set in the Thematic Strategy on Air Pollution will not materialise unless emission reduction is achieved by BAT".

● The VOC Solvent Emission Directive (SED, 1999/13/EC) affects 20 industrial sectors that use VOC solvents in manufacturing process. Industries have to comply with Emission Limit Values (ELV: 20-100 mg VOCs/m3 waste gas). According to the last available 2010 analysis of SED implementation, the future goals are:

- Making small SMEs comply with ELVs by requiring more periodic measurements. Small VOC installations normally don't have end-of-pipe measures, but they exceed ELVs for some periods as a result of their fluctuating production processes. The EU-27 Member States are now enforcing more periodic measurements on small installations: SMEs will need to install VOC control equipment to comply from now on. But today's technologies aren't completely suitable for SMEs because they've been historically design for large enterprises.

- Giving emission permits based on the implementation of BAT in order to allow industrial operation. There is thus a strong need to promote solutions for SMEs and based on BAT so that they can get a permit to operate.

- Some EU countries like Germany have suggested making ELVs more stringent. This is in line with the EC "Future of Manufacturing in Europe 2015-20202", that predicts stricter environmental regulations.

Economic limitations for SMEs to comply with VOC regulations.

Reducing SME impact by enforcing compliance is a challenge due to the small size of their economies:

- SMEs lack in-house expertise to deal with environmental administration (reporting, training, data gathering) necessary for the expected frequent measurement of VOC emissions. According to a study for five VOC emitting sectors in three of our target countries, SMEs need to allocate an average of 6 full time person-month, equivalent to 19,000 € a year. It is necessary develop a technology with low annual operating costs to alleviate the inevitable reporting burdens and maintain competitiveness.
- SMEs have a more difficult and costly access to financial investments to comply with environmental regulations. Based on EC data, the capital investments in VOC control equipment can be as high as 67,000 €. When dividing this cost by their small production volume or number of employees it's clear that SMEs bear higher costs than large enterprises. The EC Expert Group calculated that where a big company spends 1€ per employee, a medium-sized enterprise spends 4€ and small business up to 10€. Therefore it is absolutely necessary that the new VOC control solutions needed by SMEs have low capital costs. Otherwise compliance will be hindered, there will be a risk of penalties and sanctions, and environmental protection and derived benefits won't be achieved.

Biological VOC treatment (microorganisms degrading VOCs rather than physico-chemical methods like combustion or adsorption) is a very good solution: it has the lowest capital and operational costs.

The profile of the affected VOC-emitting SMEs

Of the 20 sectors using organic solvents in their manufacturing process, wood coating companies is the perfect example of the new SMEs affected by the Solvent Emission Directive. Other sectors are printing; surface cleaning; coating of metals, plastics, textiles or paper; dry-cleaning of clothes; and leather treatment. Coating of wooden surfaces (Activity 10 in SED) is the varnishing/painting of wooden pieces, and its industry has the following characteristics:

- There are around 1,200 installations in the EU27. Around 86% have less than 10 workers.
- In wood coating activities, different paints/varnishes with different solvent compositions are applied on wood. Classic solvent-based paints and varnishes contain acetone, methylethylketone, ethyl acetate, toluene, butyl acetate, cyclohexanone and butyl glycol. Therefore a mixture of VOCs is emitted by SMEs.
- Different pieces and kinds of furniture are coated every day/week in different amounts, while on weekends there's normally no activity. Therefore VOC concentrations emitted change with time.
- When solvents dry out in rooms, VOCs mix with air, which dilutes their concentration to lower levels before the waste gas is pumped out of the facility. Also, the partial substitution of solvents by low-VOC products is increasing in the EU2740. Therefore VOC emissions have low concentrations (30-300 mg carbon/normal m3 but still > ELVs).
- According to the latest report, only 18% of the 53,000 SED-registered installations use a reduction scheme, which is the replacement, in the production process, of traditional solvent based products by low-solvent option. These products contain water (partially or fully) as a solvent instead of VOCs. This has two direct implications:

- End-of-pipe equipment, treating VOCs just before release to the environment, is still the option most used.
- Water evaporated from low-solvent products will also be present in waste gas together with VOCs.

GRABGAS project is aiming to get an improved waste gas cleaning technology for treating those exhausted gases from SMEs. In order to get this, GRABGAS project has defined several scientific and technological objectives.

Scientific objectives:

1. To understand the role of doping agents in the absorption of visible light by TiO2.
2. To study the pattern of photolytic breakdown of VOCs.
3. To select plant species suitable for rhizodegradation on green roofs.
4. To understand the activity of bacteria, plant roots and substrate in VOC rhizodegradation.
5. To comprehend the role of substrate components in VOC rhizodegradation.

Technological objectives:

1. To develop a solar photocatalytic VOC pre-treatment of industrial waste gas of target SME industries.
2. To develop an extensive green roof with VOC rhizodegrading capacity.
3. To develop a control system for operation in outdoor environment. In order to overcome these problems, the SMEs have selected 3 RTD organisations (ACCIONA, WELIENCE, INSP) with wide experience in the fields required to improve existing technology. ACCIONA has been contacted because their research group of Biotechnology and Environment has extensive experience in the study of soil compositions and the degradation of NOx, CO and organic compounds by the "soluble fraction" of the soil. WELIENCE has been contacted because research group in their Agro-Environment department is focused since 1994 on the biodegradation of organics by microbes in soil and hot spots such as the rhizosphere. INSPIRALIA has been contacted because has achieved successful results with doped-TiO2 catalysts based on the accumulated knowledge on solar photocatalysis of their Materials group. The group of Electronics develops intelligent control logic for a low-cost operation of industrial processes, while the Simulation group excels in using Finite Element Analysis and Computer Fluid Dynamics to simulate and understand multi-physical behaviour.

3. Description of main S & T results/foregrounds

The actual developments obtained for each result after the execution of the GRABGAS project have been:

1. To develop a lab scale photoreactor based on solar doped TiO2 for VOCs abatement.
2. To study the degradation of VOCs contained in gas exhaust: molecule characterization of intermediate molecules.
3. To characterize the main factor that governs the photodegradation of VOCs in in ideal conditions.
4. To develop and construct a suitable pilot plant/demo solar photoreactor for VOC degradation contained in an industrial environment. The reactor has an efficiency of about 69% in the degradation of VOCs such as ethyl acetate, acetone, toluene and xylene.
5. To develop suitable mathematical models which simulate the air flow, drop pressure, temperature on a rhizofilter prototype at pilot plant scale.
6. To design and build a suitable control system for controlling and real measuring on line of rhizofilter variables such as residence time, temperature distribution, total concentration, air flow, drop pressure, etc. on designed rhizofilter.

7. The main system architecture will be based on a micro-PLC controller with an interface between the humidity and temperature of the rhizofilter.
8. A substrate mixture was designed and physicochemical characterized and water behaviour of the substrate was characterized.
9. Tests with the biofilter operating in continuous were performed for the substrate. The design and installation of the lab-scale biofilter was performed.
10. Tests with substrate with toluene as a synthetic contaminant flow showed a removal efficiency up to 80-100%.
11. Degradation tests with the biofilter operating under various irregularities were performed with substrate 7A. These irregularities include discontinuity tests, sudden increase in inlet concentration and influence of temperature under continuous operation.
12. The prototype rhizofilter and the operational definition of the system is defined. The rhizofilter, including the irrigation and distribution system, and also the monitoring system, was installed at ACCIONA's facilities.
13. Tests with the prototype rhizofilter with toluene as a synthetic contaminant flow showed a removal efficiency up to 60%.
14. Tests with the prototype rhizofilter with acetone as a synthetic contaminant flow showed a removal efficiency up to 80%.
15. Tests with the prototype rhizofilter with ethyl acetate as a synthetic contaminant flow showed a removal efficiency up to 80-90%.
16. Tests with the prototype rhizofilter with cyclohexane as a synthetic contaminant flow showed a removal efficiency up to 80-90%.
17. A literature review on plants helping the biodegradation was done. Best candidates were selected. Biodegradability with radiolabeled VOCs assay was designed and to study the time needed for the VOC to be degraded.
18. - The intrinsic permeability of two of the substrates was calculated using the results of the measurements of pressure drop at different flow rates. The intrinsic permeability value was calculated to be of the order 10-9 m2.
19.- Finally, GRABGAS technology consists of:

Integrated solution process for specific degradation of VOCs emitted by SMEs of mentioned industries´ sector by:

a) Coupling a using rhizodegradation (substrate + plant roots + bacteria) with a mild solar VOC pre-treatment to achieve a reliable >93% removal efficiently for low and variable concentrations (30-300 mg/m3) of VOC mixtures in industrial waste gas emitted by SMEs (<1000 m3/h).
b) Our end-of-pipe technology will be installed as a green roof on top of SME buildings to improve their thermal insulation and thus reduce heating/cooling costs. On roofs, sunlight will also sustain GRABGAS plan growth and photocatalysis at <40,000 € capital costs and <5,000 operating costs.

4 Potential impact and main dissemination activities and exploitation results.

European SME Eco-industries provide diverse services, like air pollution control. The most recent EC 2008 data[i] show that the European air pollution eco-industry moves 20,000 employees, has a turnover of 7€ billion and grows at 3% per year. According to the European Thematic Strategy on Air Pollution[ii], the main air pollutants causing the most damage and costs are SO_2, NH_3, particulate matter PM2.5, NOx and Volatile Organic Compounds (VOCs). VOCs are carbon-based chemicals that evaporate very easily and are extensively used in the EU as solvents in industrial activities like varnishing/painting, printing or cleaning. NOx emissions are produced in combustion processes, for example when VOCs are burnt before release to the environment as an end-of-pipe solution for VOC control. VOCs, together with NO_X and sunlight, generate toxic ozone (O_3) at ground level. The total ozone damage to crops and human health is estimated by the EC to cost the astonishing figure of 15€ billion[iii,iv] each year. Unfortunately, according to the European Environment Agency (EEA), 11 countries of the EU-27 exceeded their maximum global emissions (National Emission Ceilings) in 2011. Spain and Portugal (two of the target markets of GRABGAS) exceeded their joint ceilings by more than 10%. Thus, a good way to achieve the needed reduction of VOC and NOx emissions is helping eco-industries like us to provide with SMEs that emit pollutants with cheap and efficient e solutions for VOC emission control.

Most large enterprises comply with emissions since 2007 because environmental regulations have historically focused on them: as a starting point, it was easier to control a few sources releasing large amounts of VOCs. However, the real problem is diffuse SME emission: large number of sources emitting low concentrations. According to the 2010 EC report “SMEs and the environment”, Small and Medium enterprises are responsible for 64% of the European environmental impact, including NOx and VOCs. As a response, EC environmental legislation in 2013 will start focusing on small companies. Therefore, the eco-industries like us need to develop new VOC control solutions that fit the chemical composition of VOC emission and the economies of these SMEs.

The final target of GRABGAS dissemination is the VOC emitting target industries identified in the DOW and also in Deliverable 8.2 (Interim Exploitation plan).
As a first dissemination target, GRABGAS Partners propose to firstly take advantage of existing dissemination paths: clusters, professional associations, journalists and media. The following have been identified as they are already acting in the field of our target these industries.

- clusters and associations of companies marketing depollution solutions
- “Interprofessionals” in the field of depollution
- We need to reach, among others, the governments and relevant stakeholders (University Rectors, Deans, Directors of the National Science and Technology Institutions, Foundations, etc.), the Industry and Service sectors, and the wider science community.
- Specialized technological journalists (specialised media) will be reached at the end of the project.

Dissemination at Professional trade fairs and Congress

GRABGAS partners have already disseminated the project at:

- **POLLUTEC Show** (International Exhibition of Environmental Equipment, Technology and Services for Industry and Local Authorities) in Lyon in December 2014. Partners involved: WELIENCE and LE PRIEURE.
- **Energy Decentral** (International trade fair for innovative energy supply) in Hanover (Germany) from 11st to 14th November 2014. Partner involved: UGN.
- **EUROCOAT Exhibition** in Paris (Fr) 22-25th March 2016. Partners involved : COLORIS and LE PRIEURE

Some of Professional Trade Fairs and Scientific Congress have given rise to GRABGAS **presentation**:

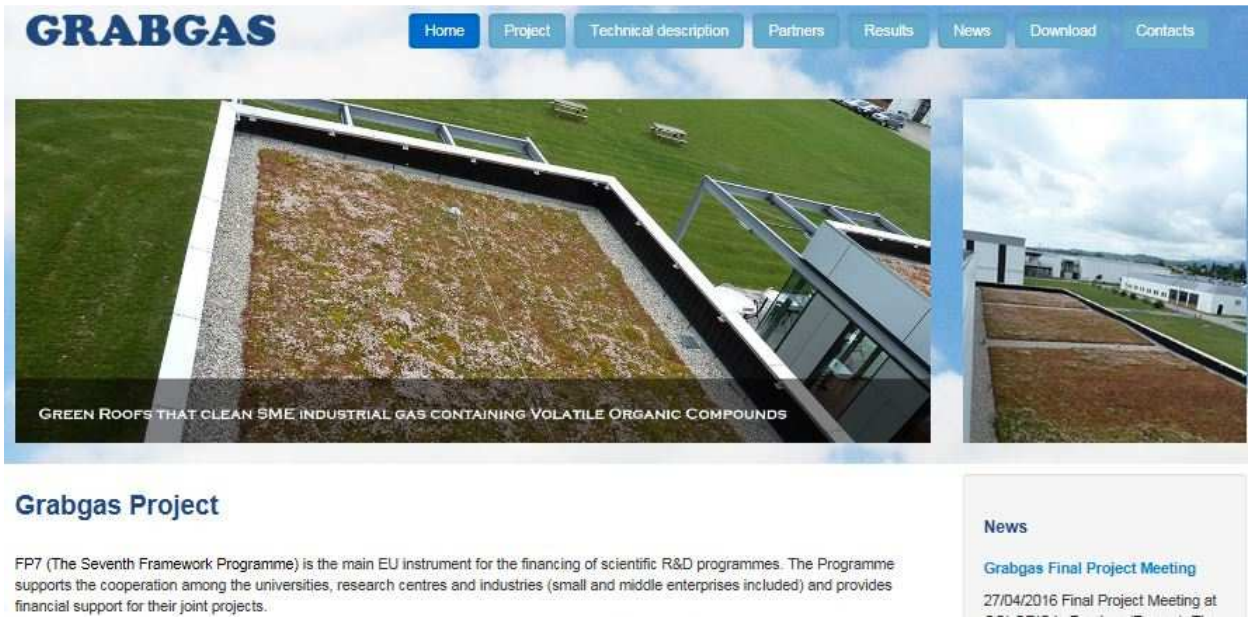
- UGN had a presentation at **the 2nd exchange of experience in air cleaning conference** (2. Erfahrungsaustausch Abluftreinigung) on 9th April 2015 in Chemnitz (Germany) at the Saxony Textile Research Institute (Sächsisches Textilforschungsinstitiut e.V.).
- ACCIONA had a presentation of test lab results at the **III International Conference on Odour Management in Environment** in Bilbao (Sp) on 23rd Nov 2015.
- SATT Grand Est had a presentation of the process and first results at the **ABBEM Congress** in Agrinio (Gr) 28th Jan 2016.
- COLORIS and LE PRIEURE had a presentation of process and first results at **EUROCOAT Conferences** in Paris 22th March 2016.

Other events have been visited: ATMOS'FAIR (http://www.atmosfair.fr/) in Lyon (France), ACHEMA in Frankfurt (Ge) and IFAT in Munich (Ge), in June 2015 in order to :

- Enlarge our professional network,
- Be closer to the sector activity,
- Know more about needs, trends, innovative technologies and processes and actors panel.

5. Address of project public website and relevant contact details :

http://www.grabgas.eu/



6. Consortium Members

List of participants:

Beneficiary Number *	Beneficiary name	Beneficiary short name	Beneficiary type	Country
1 (Coordinator)	LE PRIEURE Végétal-I.D.	LEPRIEURE	SME	FR
2	AGRIFUTUR s.r.l.	AGF	SME	IT
3	UGN-Umwelttechnik GmbH	UGN	SME	DE
4	Coloris	Coloris	SME	FR
5	Tecnologías Avanzadas Inspiralia, S.L.	INSP	RTD	ES
6	SATT GRAND EST SAS	WELIENCE	RTD	FR
7	ACCIONA Infraestructuras S.A.	ACCIONA	RTD	ES

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[i] Study on the Competitiveness of the EU eco-industry Within the Framework Contract of Sectorial Competitiveness studies – ENTR/06/054 Final Report – Part 1
[ii] http://europa.eu/legislation_summaries/environment/air_pollution/l28159_en.htm
[iii] http://www.eea.europa.eu/publications/2599XXX/page008.html
[iv] European Environment Agency, Ozone and health, Environmental impacts http://www.eea.europa.eu/maps/ozone/impacts