Final publishable summary report

1.1 An executive summary

FP7 SORBENT project ("Soil remediation technique for in situ cleaning of soils contaminated with heavy hydrocarbon mixtures", Grant Agreement No.: 232533) focuses on heavy heterogeneous soil formations contaminated with mixtures of heavy hydrocarbons and aims to develop and provide the soil remediation market with the cost-effective and highly efficient soil remediation technique applied in-situ to remove fresh and historical oil contamination.

Achievements:

The RTD activities at the first project year were dedicated for development of the separate elements of SORBENT soil remediation technique.

For the development of an environmentally friendly *SORBENT system*, a new extremely cost-efficient natural sorbent material was developed to be used with a specific bio-surfactant at the beginning of the treatment, which acts as an activating agent for separation of the migration fraction of oil, preparing the soil for application of the *SORBENT bacterial preparation*, that consists of five highly effective hydrocarbon degrading strains, selected during the project. Series of experiments were carried out to ensure maximum viability and efficiency of this preparation on various types of soil, contaminated with different kinds of oil pollutants. Applied after the first step treatment of the contaminated soil, the preparation greatly accelerates the biodegradation, preparing the area for the *SORBENT phyto-remediation* process, which involves usage of plants and growth activators, selected through series of experiments and tests, to ensure its viability in different types of soil against different oil pollutants. Applied in order to finalise the treatment of contaminated soil, these plants further mitigates pollutant concentration, gradually completing the remediation process.

The RTD activities at the second project year were dedicated for further development and integration of the technique elements. Multiple experiments and investigations were carried out during the development and testing activities: SORBENT bacterial preparation activity and productivity has been investigated, most suitable plant species for phyto-remediation have been determined, and long term stability experiments of the entire technique were concluded. Demonstration and validation was carried out by preparation of technique application guidance, estimation of eco-efficiency (by an environmental study) and validation of the technique performance (by an external SME). For the evaluation of achieved results, a survey was carried out and a business case validation was conducted as well, both of which revealed that the elements of SORBENT integrated technique meets users expectations and the whole technique should be quite competitive in today's market. Finally, referring to all the work done, Partners jointly prepared a set of recommendations as to how the SORBENT technique could be improved to ensure effective up-scaling.

After the achievement of final results, SORBENT project will provide a cost-effective and highly efficient in situ soil remediation technique for the market and an invaluable working tool to authorities across EU and beyond. The functionalities and cost-effectiveness of the technique will be fundamental for entering the new markets while the environmental friendly approach will provide an added value for facilitating solution for serious ecological problems caused by both oil contamination issues and an abundant supply of pulp and paper mill industrial waste to be recycled.

Further information can be found at http://www.sorbent.lt. The full publishable summary is in the file attached.

1.2 A summary description of project context and objectives

Through the EU, thousands of sites have been contaminated by previous industrial use, former military sites, storage bases of oil products, landfills and other sources of pollution. A huge amount of contaminated sites have been identified and require clean up; moreover, despite of different cleaning measures applied, area of contaminated land is constantly increasing as a result of inadequate practices and accidents. The European Commission has acknowledged that soil pollution in the EU is a major issue and currently soil remediation is one of the top priorities of EU environment policy.

FP7 SORBENT project ("Soil remediation technique for in situ cleaning of soils contaminated with heavy hydrocarbon mixtures", Grant Agreement No.: 232533) focuses on heavy heterogeneous soil formations contaminated with mixtures of heavy hydrocarbons and aims to develop and provide the soil remediation market with the cost-effective and highly efficient soil remediation technique applied in-situ to remove fresh and historical oil contamination. The proposed technique will be applicable to all types of oil (including crude and heavy oil) in different soil profiles and convenient to use in areas difficult to approach. This would be achieved by developing three separate technique elements based on different bioremediation solutions tailored to meet the specific needs of soil remediation practice and further combining them into an integrated technique. The overall three-step treatment or selective treatment elements will be designed to be applied on a specific site in order to reach the environmental goals in the most cost-efficient way. The different options for remediation actions will be selected taking into account current use of the soil and approved future use.

Hence, the overall objective of the SORBENT project is **the development of a novel cost-efficient soil remediation technique** applied in-situ to sites heavily contaminated by oil pollutants effectively combining different soil remediation techniques for bringing a site back to the acceptable environmental standards. Technique will be applicable:

- In high contaminant concentrations;
- In heavy hydrocarbon mixtures;
- In low-permeability or high heterogeneous soil formations, and
- In low temperatures.

The functionality of the developed technique will be validated on different types of oil and pollutant concentrations in different soil profile media by SME partners in 3 different EU Countries.

This overall objective is divided into **a set of scientific, technological and non-technological objectives** targeted to overcome four fundamental obstacles of existing technologies:

- Insufficient technology reliability in high contaminant concentrations – high contaminant concentrations affect the viability of microorganisms, suppressing biodegradation processes in most of these cases.
- Low effectiveness for heavy hydrocarbons mixtures.
- Short lifecycle of microorganisms especially in low temperatures.
- Technology dependence on soil profile. Cleanup goals may not be achieved if the soil matrix prohibits contaminant-microorganism contact.

Therefore, the main *scientific objectives* of SORBENT project are:

- To optimize the development of a new cost-efficient sorbent from pulp and paper mill waste short fibers.
- To enhance the oil migration fraction separation process by optimizing the biosynthesis of the most suitable microbial cells producing bio-surfactants for further embedding into the sorbent.
- To select 5 most active biodegrading microbial strains capable to degrade petroleum hydrocarbons, crude and heavy oil.

The main *technological objectives* of SORBENT project are:

- To develop sorbent system for first-step treatment to reduce contaminant concentration to an acceptable level for starting up the biodegradation process.
- To optimize the biodegradation process for second-step treatment.
- To simulate the phytoremediation processes for final treatment.
- To develop the novel soil remediation technique with the following technology performance:

Technology performance attribute	Value
Contaminant concentration profile	Any oil products, including heavy hydrocarbon mixtures
Maximum contaminant concentration before cleaning	350 g/kg
Minimum achievable concentrations in vadose zone soil	1–5 g/kg (low pollution level: 0.05–15 g/kg)
Surface temperature	-5°C–+35°C
The overall cleanup time required	6–18 months
Applicability	All areas and soil structures
Cost savings	25%
Secondary emissions	None
Residuals	None

- To test and validate the novel technique.

Non-technical objectives of the project are:

- To perform an environmental impact study on newly developed technique.
- To perform a business case validation for assessment of prospects of SORBENT technique and to develop the exploitation strategy.

Main project achievements:

The RTD activities at the first project year were dedicated for development of the three following elements of SORBENT soil remediation technique:

1. SORBENT system;
2. SORBENT bacterial preparation, and
3. SORBENT phyto-remediation process.

The treatment with these core elements is based on different bioremediation solutions: SORBENT system involves natural attenuation and bio washing, SORBENT bacterial preparation will be used for enhanced biodegradation and phytoremediation process is targeted for the final cleaning by using selected plants.

For the development of *SORBENT system*, at the initial stage of the investigations the new extremely cost-efficient natural sorbent material from pulp and paper mill short waste short fibres was developed. The new approach of bio-surfactant use applied to integrated SORBENT system development lead to use specific bio-surfactant as activating agent for separation of the migration fraction of oil at the very beginning of the oil remediation action. The sorbent material and the specific bio-surfactant constitute the core of the SORBENT system with the following envisaged performance: after filling the contaminated site with SORBENT system, the sorbent will bind migration fraction of oil thus preventing contamination of surrounding soil matrix and microbial strains will start to produce bio-surfactant, which will begin to separate non- migration fraction of oil (which is strongly tied to soil) from soil binding it by sorbent. Both sorbent and bio-surfactant are environmentally friendly thus there is no risk it would cause secondary contamination. This presents unique and novel way of reducing pollutant concentrations to required level for starting the enhanced bioremediation process.

For the second step of SORBENT soil remediation process, five highly effective hydrocarbon degrading strains for *SORBENT bacterial preparation* were selected. Series of experiments were carried out in order to ensure maximum viability and efficiency of this preparation in highly contaminated environment of various soil profiles at various temperature ranges as well as during the storage and transportation. As a result, bacterial preparation was developed suitable for very efficient treating of various types of soil, contaminated with different kinds of oil pollutants. Applied after the first step treatment of the contaminated soil, the preparation will accelerate the biodegradation greatly, preparing the area for a third and final step of SORBENT technique.

For the final step of SORBENT soil remediation process suitable plants and growth activators were selected through series of experiments and tests undertaken to ensure the plants viability in different types of soil contaminated with various oil pollutants. Applied in order to finalise the treatment of contaminated soil, these plants will further mitigate pollutant concentration, gradually bringing the soil to acceptable conditions, thus completing the remediation process.

The RTD activities at the second project year were dedicated for further development and integration of aforementioned SORBENT integrated technique elements. Specific objectives set out for the second year were oriented towards development and testing of the technique components, then demonstration and validation of the results and finally evaluation from technical and economical points with preparations for up-scaling of the entire solution.

Multiple experiments and investigations were carried out during the development and testing activities – SORBENT bacterial preparation activity and productivity in different soil and temperature profiles has been investigated, optimal dosage estimates have been defined and control algorithms finalized. Phyto-remediation stage of the technique has been researched in-depth as well – most suitable plant species have been determined, ensuring optimal performance of the technique in different soil and weather conditions. Approaching the end of the project long term stability experiments of the entire technique were concluded too, enabling research teams to proceed to the results validation phase.

Demonstration and validation of the SORBENT technique was carried out by preparing technique application guidance, estimating eco-efficiency and validating the performance of the technique. The guidance describes storage and transportation requirements as well as detailed application guides, together with technical details and useful tips by developers. Concerning eco-efficiency, an environmental impact study has been prepared, comparing the environmental impact caused by the application of the SORBENT technique against projected gains and effects. Results of the study were very encouraging, indicating excellent environmental performance of the technique and its elements. Performance cost calculations for laboratory and pilot scale production have also resulted in very positive indicators, showing high cost-efficiency and remarkable performance. To test these results and to determine whether the technique meets the

needs of future customers, a validation of functionality was carried out by an external SME, resulting, once again, in very positive conclusions.

For the evaluation of the achieved results, a questionnaire was designed according to the functionalities of all three stages of SORBENT integrated technique, which revealed that both external and internal respondents were satisfied with the results and agreed that it have met their expectations. A business case validation was conducted as well, encompassing socio-economic impact, potential stakeholder markets and calculations of interest and system costs. Finally, referring to all the work done, Partners jointly prepared a set of recommendations as to how the SORBENT technique could be improved to ensure effective up-scaling.

After the achievement of final results, SORBENT project will provide a cost-effective and highly efficient in situ soil remediation technique for high-growth soil remediation market and an invaluable working tool to authorities across EU and beyond. SORBENT project bestows an incentive to companies and organizations of both Public and Private sectors to drive active promotion and usage of proposed in situ remediation method for the treatment of the contaminated sites. The functionalities and cost-effectiveness of the technique will be fundamental for entering the new markets while the environmental friendly approach will provide an added value for facilitating solutions for serious ecological problems caused by both oil contamination issues and an abundant supply of pulp and paper mill industrial waste to be recycled.

Project consortium

The SORBENT consortium has been created on the basis of existing supply chains and combines *know-how* on ecological biotechnology, environmental research and research on soil and soil structures. The proposed consortium aims to create a non-competitive supply network in EU which would allow the SME partners to use the developed technique to secure a competitive advantage in EU and worldwide markets.

1.3 A description of the main S&T results and foregrounds

1.3.1 Project background

Various human activities have already resulted in more than 3.5 million sites across EU being contaminated with oil and the soil contaminated by oil pollutants represents more than a half of overall affected sites. Many of those sites are rendering otherwise valuable soil unusable. A clear need exists to remediate these sites through effective solutions at a viable cost to society. Preferably, in-situ techniques are applied to decontaminate such sites, because the alternatives – ex-situ treatment or containment – are too expensive or socially poor solution. However, the high contaminant concentrations especially in case of heavy hydrocarbon mixtures and the low soil permeability are limiting the application of available in-situ techniques. These techniques can only be enhanced by combining several soil remediation technologies and improving the performance of existing techniques.

Therefore, a consortium of seven research and business partners has been formed by several SMEs to solve this significant environmental problem. The consortium combines know-how on ecological biotechnology, environmental research and research on soil and soil structures, as well as experience in environmental engineering, phyto-remediation services, manufacturing and distribution of bioremediation agents. Three research organizations and four SMEs representing non-competitive supply chain compose the consortium to achieve the ambitious research and economic goals. Scientific investigations have been performed by Lithuanian, Spanish and Estonian research institutions which resulted in a unique integration of know-how on biologically active compounds, environmental and soil remediation technologies, whereas SMEs represent the

worldwide experience of Lithuania, Spain, Poland and United Kingdom in high value bioremediation market.

The growing need for remediation of soil contaminated by oil pollutants, acquaintance with existing technological solutions and market awareness led the SME consortium to propose the idea of SORBENT project. The project has been partially financed by Research for the Benefit of SMEs scheme of 7th Framework Programme – the main financial tool through which the European Union supports research and development activities. *The SORBENT idea is based on the systematic approach for enhancing the soil remediation process by employing different remediation techniques into integrated soil remediation solution.* The available knowledge and a high potential of investigations have resulted into integrated SORBENT soil remediation technique capable to contribute to a reduction of quite remarkable range of both economic and social problems caused by oil contamination.

More in detail, the SORBENT project is focused on heavy and heterogeneous soil formations contaminated with heavy hydrocarbons mixtures and intended to develop and provide the soil remediation market with a cost-effective and highly efficient soil remediation technique applied in-situ to remove historical oil contamination as well as accidentally or intentionally deposited oil. The developed SORBENT integrated technique is applicable to all types of oil (including crude and heavy oil) in different soil profiles and convenient to use in areas difficult to approach. This has been achieved by developing three separate technique elements based on different bioremediation solutions tailored to meet the specific needs of soil remediation practice and further combining them into an integrated technique. The overall three-step treatment or selective treatment elements are designed to be applied on a specific site in order to reach the environmental goals in the most cost-efficient way.

1.3.2 Progress of the project

The SORBENT project has been structured into three phases and broken down into eight individual work packages (WP), consisting of a number of tasks to be carried out by the teams formed within the consortium.

The SORBENT consortium began by defining detailed requirements and specifications for separate elements of SORBENT soil remediation technique and for SORBENT integrated technique itself. These requirements are being based on the knowledge and experience of SME participants and existing know-how of RTD performers. The investigations in the **Initial Research Phase** covering mainly tasks of WP 2 have resulted into the set of new scientific knowledge, generated by performing the following RTD activities:

- The highly effective sorbent material on the basis of pulp and paper mill waste short fibers was developed and tested;
- Then, the optimization of the oil migration fraction separation process was performed;
- Finally, five most active biodegrading microbial strains for bacterial preparation development were selected and the ability of these strains to biodegrade the oil hydrocarbons pollutants was measured.

Next, during the **Technology Development Phase** of the project, separate elements of SORBENT soil remediation technique as well as the integrated technique itself were developed. This phase covered activities of WP 3, WP 4 and WP 5, where the following objectives were achieved:

- SORBENT system for the first-step treatments was developed and tested;

- Bacterial preparation for the second-step treatment was developed and tested;
- Phyto-remediation process for the final treatment was designed;
- Integrated technique and its elements were tested in the field conditions;
- The integrated technique was developed, demonstrated and validated, and
- Technique application guidance and environmental impact study were prepared.

The final **Innovation Phase** of the project was targeted to ensure that the achievements of the project results are made known to the public and the targeted potential clients. This phase covered activities of WP 6 and WP 7, where the following objectives were achieved:

- Internal and external validation by users was performed;
- Business case validation is completed, and
- Dissemination measures are implemented and exploitation strategy is prepared.

During the scientific part of the project, most of the tasks were carried out by RTD performers, but SME partners had a great influence on directing the RTD performers to meet the needs of SME partners to develop and provide for soil remediation market with a cost-effective and highly efficient in-situ soil remediation technique.

The partners of consortium have been working closely constantly keeping in touch for consulting and brainstorming during the meetings, etc. The expectations of SME partners were justified as RTD performers achieved significant scientific results by generating new knowledge and added high value for the project innovativeness on the benefit of SMEs.

Finally, the SORBENT integrated technique has been developed, consisting of three elements:

1) **SORBENT system**;
2) **SORBENT bacterial preparation**;
3) **SORBENT phyto-remediation**.

The aforementioned project results are briefly introduced in the following subsections of this document.

1.3.3 Main S&T results

SORBENT system

SORBENT system (Fig. 1) is a newly designed organic system consisting of (1) sorbent material developed from paper mill wastes short fibers, (2) biosurfactant, (3) microbial cells producing biosurfactant, and enriched with (4) nutrients: nitrogen and phosphorus.

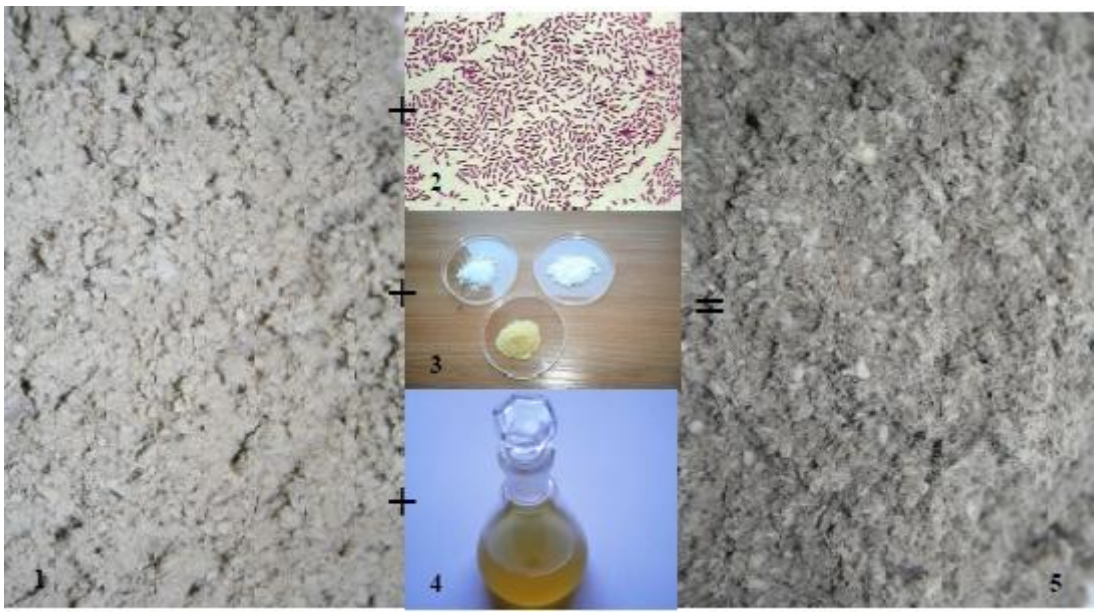

Fig. 1 SORBENT system and its components

The optimum composition of the SORBENT system (Fig. 1) for all types of soil has been defined as follows:

- Biosurfactant producer (*Arthrobacter* sp N3 strain): **at least 10^7 CFU/g**;
- Biosurfactant: **3%**;
- Nitrogen: **0.5%**;
- Phosphorous: **0.2%**;
- Moisture: **7–10%;**
- SORBENT material: **86.3–89.3%**.

SORBENT system (hereinafter – SS) has many significant advantages:

- Enables to lessen or localize spread of oil hydrocarbons in case of accidents, extreme situations or their liquidation.
- Can be used effectively in both large and small areas of oil contamination in any soil type.
- Can absorb contamination caused by all oil products in case of relatively small accidental spillage.
- If the initial concentrations of heavy oil hydrocarbons are very high (350 g/kg and more) SS can be used as fast and effective tool to reduce the contaminants concentration (*for the first-step treatment* in cases requiring immediate response) until the concentration level becomes acceptable for the bioremediation.
- When SS is mixed with contaminated soil, hydrocarbons pass to the inner SS structure and are caught there, therefore less oil hydrocarbons contamination is left in the soil.
- It can be effectively used in temperatures ranging from 4 to 40 ºC.

- Not only has the immediate sorption activity, but a sorption capacity in most of the cases even higher than required 2.5 g oil/g sorbent as well, reaching up to more than 3 g oil/g sorbent.

- Is biodegradable including all of its components, and as such does not cause any secondary environmental pollution, allows to achieve closed ecological cycle and therefore can be even considered as helpful for the environment.

- Is very helpful for the soil quality and plants augmentation because it enhances roots aeration in soil and accelerates microorganisms activity thus plants can better assimilate nutriment.

- Is stable in dry environment for at least 12 months.

- Transportation does not require to employ any specific safety measures, as the material does not have any hazardous components that could possibly harm the environment.

SORBENT bacterial preparation

SORBENT bacterial preparation is a mixture of microbial cells, consisting of Arthrobacter sp N3 and NJ5 strains, targeted for the decontamination of hydrocarbon polluted environment.

Fig. 2 SORBENT bacterial preparation

The main advantages of the SORBENT bacterial preparation (hereinafter – SBP) are listed below:

- Strains of SBP deployed in soil contaminated with heavy oil hydrocarbons use it as a source of carbon and energy to sustain themselves.

- Both strains of SBP not only tolerate hydrocarbon mixtures in soil at concentrations higher than 10%, but also degrades the hydrocarbons effectively at these conditions.

- Strains of SBP are capable of surviving in soil contaminated by hydrocarbon mixtures but does not propagate in uncontaminated soil.;

- SBP survive in fluctuating temperature (ranging from -20º to +35 ºC) and repeated cycles of freezing and thawing.

- SBP is able to degrade oil hydrocarbons the best at temperature +25 ± 5 °C.

- SBP is able to degrade various types of hydrocarbons (normal, branched, aromatic and etc.) in different soil profile media; and not only crude oil heavy fraction and its heavy products but also light fraction which can migrate rapidly through soil.

- SBP is able to degrade oil hydrocarbons efficiently in presence of biosurfactant developed for SORBENT system (applicable in the first step treatment).

- SBP scales well with the different level of contaminant concentration: for the low initial concentrations of oil hydrocarbons (10–20 g/kg), the hydrocarbons degradation rate is 0.10–0.14 g·hydrocarbon/day, and for the high initial concentrations of oil hydrocarbons (100–300 g/kg) the hydrocarbons degradation rate is 0.61–0.70 g·hydrocarbon/day.

- The increase of initial hydrocarbon concentration in most cases accelerates the already present biodegradation process (started by the SBP) as well.

- After the 1st step treatment with SORBENT system, SBP can be used from 220 g/kg of oil concentration, which is the optimum value required to achieve contaminant concentration levels innocuous enough for microbial strains hydrocarbon degraders to start up the biodegradation processes.

SORBENT phyto-remediation

SORBENT phyto-remediation process was found to be the most effective with two plant species: *Phleum pretense* (timothy) and *Lolium perenne* (ryegrass).


a)


b)

Fig. 3 *Phleum pretense* (timothy – a)) and *Lolium perenne* (ryegrass – b)) plants

SORBENT integrated technique

SORBENT integrated technique stages should be carried out one after another to achieve the most efficient polluted soil treatment:

- 1st step treatment with SORBENT system;

- 2nd step treatment with SORBENT bacterial preparation, and

- 3rd step treatment with plants.

However, in some cases stages of SORBENT integrated technique can be used independently to solve the contamination problems depending on initial concentration, location, etc. In any case, SORBENT integrated technique allows reducing very high oil pollution concentrations to acceptable levels, in accordance to environmental standards.

I stage – SORBENT system can be applied for soil treatment when initial oil concentrations are up to 350 g/kg. It reduces the oil concentration to 220–170 g/kg during 7–10 days. Then, the second step of SORBENT integrated technique can be applied.

II stage – SORBENT bacterial preparation can be applied for soil treatment when residual oil concentration is 220–170 g/kg. It reduces the oil concentration to 50–20 g/kg during 6–9 months. Then, the third step of SORBENT integrated technique can be applied.

III stage – SORBENT phyto-remediation can be applied for soil treatment when residual oil concentration is around 20 g/kg. It reduces the oil concentration to 5–1 g/kg (environmental standard) during 3–6 months.

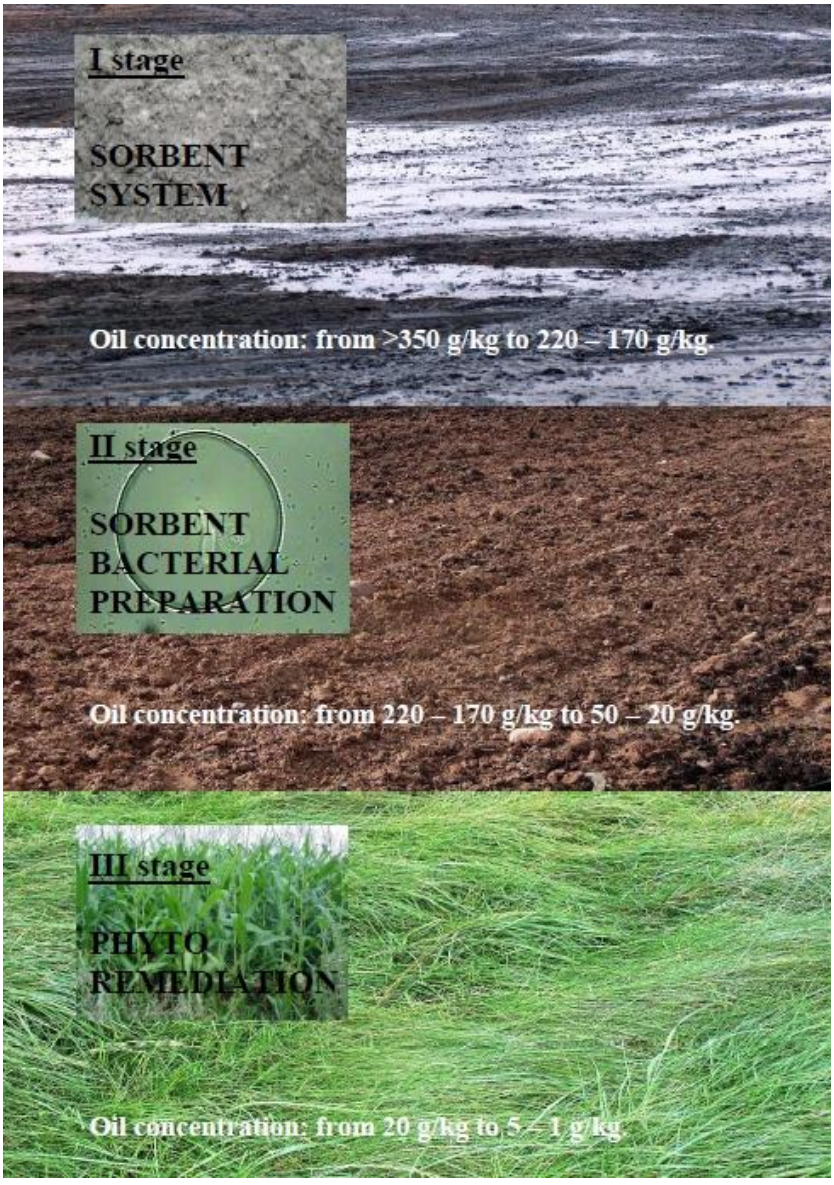

Fig. 4 III steps of SORBENT integrated technique

The following advantages of the technique could be emphasized:

- *Fast and effective reduction of the contaminant concentration*: first-step treatment in cases requiring immediate response.

- *Secondary pollution elimination*: both the applied bio-surfactants and SBP do not contaminate the environment and can be easily degraded.

- *Sufficient shelf-life:* stabilization of the microbial cells producing bio-surfactant and microbial cells hydrocarbon degraders permits a shelf-life of one year or more so the material can be available and ready for use immediately when needed.

- *User-friendliness:* the selected microbial strains are easy proliferating and inoculated in the contaminated site demonstrates an excellent degradation rate of different kinds of oil in different soil profiles.

- *High competitiveness*, standing out in comparatively small investments needed, low maintenance costs and environmentally friendly approach.

The SORBENT integrated technique meets the market demands and addresses the following market needs:

- In-situ soil remediation approach.

- High efficiency in high concentrations and with heavy hydrocarbons mixtures.

- Expanded applicability (easy to use in all areas, including sites difficult to approach due to its effectiveness and easy performance).

- Cost-effectiveness (all: SORBENT system, SORBENT bacterial preparation and SORBENT phyto-remediation process are cost-efficient).

- Comparatively short overall remedial clean up time.

- Minimal environmental and social impacts.

In particular, application of the SORBENT technique enables to achieve very low soil pollution level (no more than 1–5 g/kg) both in sandy soils and in low-permeability or highly heterogeneous soil formations.

1.3.4 Evaluation of project results

Approaching the end of the Project, its results were evaluated from technical and economical point of view by a survey, encompassing opinions of both internal and external users of SORBENT integrated technique and its separate elements, and a business case validation. Furthermore, a set of recommendations for further improvements was prepared, in order to help up-scale the technique for commercialisation and define potential points for future development. Brief conclusions of evaluation and list of the recommendations are both presented in the subsections below.

Evaluation questionnaire

The scope of the survey encompassed five EU countries: Lithuania, Estonia, Spain, Poland and UK. A grand total of 70 respondents participated in evaluation of project results, which can be considered as representative amount of answers for the analysis of the results. External respondents mostly represented SMEs (44%), 24% were from research institutions, 15% respectively were from governmental and non-governmental public organizations, and finally 2% represented large companies. Most of the respondents were working in the field of environmental protection and had at least some knowledge about soil decontamination technologies and products.

In general, both external and internal customers were satisfied with the achieved project results as most of the functionalities and advantages of SORBENT integrated technique and its elements were evaluated positively. What is more, as much as 75% of internal customers agreed that the results of the Project SORBENT have met their expectations which were set at the beginning of the project as the functionalities of SORBENT Integrated technique and its all three steps.

The environmental friendliness was chosen as the main functionality of the SORBENT integrated technique and its elements, establishing that the main unique selling point for SORBENT integrated technique is it environmental friendliness and functionality. Furthermore, based on the analysis results, "effectiveness" and "easy to use" can be used as additional selling points which distinguish it from other soil bioremediation technologies. It's worth mentioning, that in all cases the internal respondents, who had participated in the development of SORBENT project results and acquired a deeper understanding about its novelty and advantages, had given SORBENT Integrated technique, SORBENT system and SORBENT bacterial preparation higher evaluation scores than the external respondents.

Business case validation:

- As described in Section 3 of Deliverable D6.2, the international market for the remediation sector is estimated to be in the range €21–25 billion. The application of bioremediation and phytoremediation cleanup technologies is rapidly expanding and, according to an estimate, worldwide demand for these biological technologies is thought to be valued in the region of €1.06 billion per annum.

- Annual estimated expenditures of land contamination, according to European Environmental Agency is €2.1 billion.

- There are two main factors that impact on the cost-effectiveness of remediation technologies:

    - The impact of waste legislation and regulation;

    - The designated land-use of a remediated site.

- It is strongly suggested that decisions on the most appropriate risk management options for a particular site needs to be considered in a holistic manner and these key factors are:

    - Driving forces to remediate and goals for the remediation objectives;

    - Risk management;

    - Sustainable development;

    - Stakeholders' views;

    - Cost effectiveness;

    - Technical feasibility.

- The principal stakeholders in remediation are generally considered to be the "problem owners" (usually the polluter or site owner), and also all those with an interest in the land, its redevelopment, and the environmental, social and financial impacts of any necessary risk management works. It is worth noting at this point that for some stakeholders, the end conditions of the site are likely to be significantly more important than the actual process used to arrive at that condition.

- 5 patents that are relatively similar to SORBENT technology were selected. Most of them (4) were know already before submission of the proposal and none of them have serious impact to SORBET technology and its potential success in the market.

- It was suggested that market penetration should start from new EU member states, proceeding to Russia, Ukraine, Central Asia, Middle East and the rest of the world.

- Next actions for beneficiaries of SORBENT project were suggested and as they don't need very specific knowledge neither strong time-commitment, it is believed that SMEs can carry these out themselves.

- It can be stated that SORBENT Integrated technique or its separate stages that have been developed during the Project can be applied on any specific site in order to reach the environmental goals in the most cost-efficient way. At the moment, the SORBENT technique can be considered rather cost-effective which would be the main buying driver to compete with conventional techniques. According to market data and assumptions based on them, the consortium will gain €3.8 M in net profit during the first five years after the project. Over a 10 year period, the total net profit will be €25.84 M. The internal rate of return (IRR) of the project is 35% over a five year period and 57% over a ten year period.

- The net present value (NPV) of the project is €1.401.255 over five years and €10.986.647 over ten years.

- In conclusion, as the net present value of the project is significantly positive and IRR is relatively high, it is beneficial to continue with the project and commercialise the SORBENT technique.

Recommendations for further improvements:

- Additional to technical developments, strong focus on Business Model(s) development and Open Innovation approach is recommended.

- To identify ways to improve bacterial preparation. For example using other preparation form (i.e. dry preparation) which might be more attractive for end-users of SIT and also should reduce costs of the preparation and storage.

- To further investigate ways to extend shelf life of sorbent system and bacterial preparation in order to provide flexibility and therefore cost-reduction in manufacturing and storage.

- To widen the selection species plants for phytoremediation stage. That would make SIT suitable being used in more various environmental conditions and soils and therefore widens geographical area where SIT can be sold and used, like Middle-East, Africa or North Siberia where different kinds of plants are more common.

1.4 The potential impact

Long decades of various industrial and military activities have resulted in more than 3.5 millions sites across EU being contaminated mostly by oil pollutants and thereby rendered otherwise valuable soil unusable for agricultural activities and unfit for habitation. According to recent estimates, soil contamination urgently requiring cleanup is present at approximately 250,000 sites in the EU member countries and if current trends continue, the number of sites needing remediation is expected to increase by 50% by 2025.

Preferably, in-situ techniques are applied to decontaminate such sites, because the alternatives – ex-situ treatment or containment – are too expensive or socially poor solution. Unfortunately, the high contaminant concentrations especially in cases of pollution by heavy hydrocarbon mixtures together with the low soil permeability are limiting the applications of available in-situ techniques.

During the project, SORBENT consortium has developed a cost-effective and highly efficient soil remediation technique applied in-situ to treat accidentally or intentionally deposited oil as well as historical oil contamination. The technique is applicable to all types of oil (including crude and heavy oil) in different soil profiles and convenient for the use in areas difficult to approach.

1.4.1 Economical impact

The economical impact of the project has been calculated according to the following market data:

- An soil remediation market value in EU in 2006 was €5.16 billion.
- Annual market growth is 0.5–1.5% of GDP, i.e. 3% with expected of EU GPD growth about 1% for EU27 (EUROSTAT data).
- The 53.4% of the contaminated soil in EU countries is affected by oil pollutants.
- The 30% of oil pollutants are heavy hydrocarbons mixtures.
- Initial production set-up and marketing costs are estimated to reach no more €50000 (almost no new investment is needed and all main raw materials are industrial waste, furthermore, the production machinery are available for small-to-medium scale production at contractors facilities).

On the basis of the above the following assumptions have been made:

- Total soil remediation market in EU in 2012, the first after-project year, could amount to €6.16 billion (calculating from the year 2006 as the base year with 3% annual growth).
- The soil contaminated by oil pollutants market sector in 2012 could amount to €3.2 billion EUR.
- The soil contaminated with heavy hydrocarbons mixtures market sub-sector in 2012 could amount to €0.96 billion.
- The target is to achieve 5% market penetration in 10 years.
- In order to arrive to realistic estimates, the price strategy was based on macroeconomic methodology and was based on earning not less than 15% net profit from the remediation services provided/technique sold, accordingly.

Profit predictions are difficult as not all target market research has been completed. Furthermore, evolving economic conditions in different markets as well as the development of environmental regulations will have an important impact on market acceptance and uptake. In addition, monitoring competitors will be crucial in determining the correct marketing strategy. At the moment, the SORBENT technique can be considered rather cost-effective which would be the main buying driver to compete with conventional techniques.

Nevertheless, in order to assess the feasibility of a project, forecast of income and net profit are essential. According to market data and assumptions based on them the consortium will gain €3.8 M in net profit during the first five years after the project. Over a 10 year period, the total net profit will be €25.84 M. The internal rate of return (IRR) of the project is 35% over a five year period and 57% over a ten year period.

In conclusion, as the net present value of the project is significantly positive and IRR is relatively high, it is beneficial to continue with the project and commercialise the SORBENT technique.

1.4.2 Social impact

Successfully implemented SORBENT project contributes to the following Community objectives.

Contribution to ENVIRONMENTAL protection:

- The Kyoto Protocol highlights that soil acts as a major carbon storage, which must be protected and increased where possible. Carbon sequestration in agricultural soils by some land management practices can contribute to mitigating climate change. The European Climate Change Programme (ECCP) Working Group on Sinks Related to Agricultural Soils estimated this potential at equivalent to 1.5 to 1.7% of the EU's anthropogenic CO2 emissions during the first commitment period under the Kyoto Protocol.

- The Convention on Biological Diversity identifies soil biodiversity as an area requiring specific attention; therefore an International Initiative for the Conservation and Sustainable Use of Soil Biodiversity has been established.

- Contaminated soil itself can impact the environment in various ways, including:

    - Subsequent contamination: contaminated soil that is not (or not properly) remediated has the potential to migrate from the impacted area significantly and possibly contaminate surrounding soils, surface waters and even ground water;

    - Irreversible environmental damage;

    - Human health: hazardous chemicals may enter food chains;

    - Land use: the contaminated land is not longer in use as an asset and becomes a long-term treat to surrounding environment.

Direct contribution to SOCIAL sector:

Soil remediation sector employment level in 2004 was equal to 60.966, accounting for 2% of total eco-industry employment in the EU-25. The employment has doubled in 2010 in Eastern Europe that had a strong growth market (Poland, Hungary and Czech Republic are among the most dynamic markets). The employment effect will also be higher in countries where authorities invest money in cleaning up soil pollution, creating jobs in the private sector thus.

Contribution to POLICY objectives:

In September 2006, the European Commission adopted the comprehensive Thematic Strategy for Soil Protection, acknowledging that soil is under increasing threat from a wide range of human activities, which are undermining its long-term availability, viability and the contamination being the rapidly developing key issues.

The area of contaminated land is increasing despite of various cleaning measures taken. This is considered to be a result of soil contamination currently being produced by inadequate practices and various accidents. The main consequences of soil contamination consists of risk to human health, most prominent to people living on or nearby a contaminated site, contamination of surface water and groundwater, risk of ecotoxicity for the flora and fauna, causing loss of biodiversity and biological activity, limitations of contaminated land use and etc.

Keeping in mind that as much as 53.4% of the contaminated soil in EU countries is affected by oil pollutants, it is evident, that SORBENT project addresses these concerns directly and successful implementation of the project results can be expected to have a significant impact on the situation.

LEGISLATIVE impact:

SORBENT project results conform to the following legislations and official documents by governing bodies related to environment protection and associated technologies development:

- The Thematic Strategy for Soil Protection (one of the 7 instruments of The Sixth Environment Action Programme of the European Community 2002–2012) adopted by European Commission in September 2006 addressed the soil remediation. The specific proposals in the Thematic Strategy:
    - Communication document: provides an assessment of the current state of soil pollution in Europe and reasons why action is needed at the EU level. It mandates member states to identify and implement strategies to minimize the risk of soil contamination;
    - Proposals for Framework Directive: sets common principles for protecting soils across EU (Member states can decide how best to protect their soils within this framework);
    - Impact assessment: contains an analysis of the economic, social and environmental impacts and identifies the ways how the EU policies will be impacted.
- The Environment Liability Directive 2006/21/EC, which aims at preventing environmental damage by forcing industrial polluters to pay prevention and remediation costs. Environmental damage includes contamination of land, which presents a threat to human health. For land contamination, the Directive provides that, as a minimum, 'the relevant contaminants must be removed, controlled, contained or diminished so that the contaminated land, taking account of its current use or approved future use at the time of the damage, no longer poses any significant risk of adversely affecting human health' (Annex II.2). Directive does not apply to historical contamination or to damage prior to its entry into force.
- National law: provides a framework for identification and remediation of contaminated land and defining who is liable for clean-up costs. Some countries use tax systems or incentives to promote the cleanup of contaminated sites. Others have voluntary agreements with the petrochemical and oil industries to fund the remediation of old petrol stations. Historic pollution is particularly difficult to regulate since it is not always easy to identify the polluter. In this case, in most countries, remediation activities are often covered by public funds.

- EU action plan on Environmental Technologies (ETAP). Its objective is to identify promising technologies, barriers to the take-up of these technologies and measures to overcome these barriers.

- Green Paper on market based instruments adopted in March 2007 in order to advance the discussion about using market-based instruments as policy tools in the EU.

Ethical and gender issues

Throughout the duration of the project, there were no known ethical or gender issues and, considering project subject, it is not likely to occur in the future.

Although equality of rights is not directly expressed in project objectives and tasks, equal rights are ensured between all project Partners for both male and female participants, disregarding their social status, religion, race, physical or mental disorder or any other characteristic.

1.4.3 Dissemination activities

The main purpose of dissemination efforts in SORBENT project is to raise awareness of SORBENT in order to maximise its impact and encourage acceptance of its results by the targeted stakeholders. This plan is intended to ensure that the dissemination activities within project SORBENT are closely oriented to the current and future market opportunities and to prepare the target audience including potential users, customers, researches and strategic partners for SORBENT results adoption.

The SORBENT consortium considers the task of dissemination to be of great importance. All partners contribute to dissemination efforts in one form or another, for instance by participating and giving presentations and demonstrations at local and international conferences, internal and customer events, publishing papers, holding press conferences, networking and similar activities and will strive to maximize use of existing dissemination channels for the purpose of project result adoption and successful future commercialization of the project results.

A policy of broad dissemination of project results has been particularly focused on potential customers, remediation practitioners (technology developers, technology vendors, technology users, technology verifiers, and technology investors), funding agencies and authorities making decisions on large-scale soil remediation projects.

The dissemination actions were aimed to:

- Create awareness about the SORBENT project on European and national levels;

- Motivate the partners and any interested parties to collaborate, and

- Attract researchers and environment sector players to use SORBENT results in planning and execution of environmental actions and promote SORBENT results through workshops, panels, seminars and etc.

Dissemination activities were planned in accordance with stage of the development in the project. Although a number of dissemination activities took place during the first 18 months of the project, the most significant dissemination activities took place during the last six months of the project (as soon as technical results were available). Dissemination was done by:

- Project presentation by dissemination the written information;

- Project Web site, and

- Scientific exchange.

1.4.4 Dissemination channels

SORBENT has been promoted through presentation at both academic and industry venues. The consortium organized different meetings and sessions and an integral part of the dissemination activities was also the cooperation with other EU projects, organizations and professionals working in the field of common interest. These dissemination opportunities represent general dissemination channels.

The selection of the appropriate channels accords with both the SORBENT objectives and with the development stage of the project. With respect to character of SORBENT project the following dissemination channels were selected and developed in this dissemination strategy:

- Professional magazines;
- Presenting SORBENT at conferences and workshops;
- Networking, and
- Internet based communication.

Professional Magazines

The publication of SORBENT results and achievements through publication in scientific and technical journals was encouraged. SORBENT project has been disseminated in the following relevant magazines:

Table 1: Magazines publications

Magazine	Description/ Authors	Partners involved
"Nueva Gestión"	SPAIN. Economic and business fortnightly magazine. The article noted the cooperative research between different European SMEs and R&D centres in the project as well as the basis of the project SORBENT and its function in the environment.	LUR
"La Rioja" (Joyas empresariales riojanas)	SPAIN. Daily magazine. Nathalie Beaucourt and Angélica García Description of the project and cooperative research between different European SMEs and R&D centres	CBIO
Chemistry 2011	Aikaitė-Stanaitienė J., Kavaliauskė M., Grigiškis S., Baškys E.V., Čipinytė V. New soil remediation technique for cleaning soils, contaminated with heavy hydrocarbons, 10the international scientific conference „Chemistry 2011", Vilnius, Lithuania. Poster and article in conference proceedings (accepted).	BC
Customer as Change Driving Force.	Kavaliauskė M., Baškys E.V. „The acceptance of customer requested eco-innovations by involved and not involved customers". International scientific conference BMRA 2011 „Customer as Change Driving Force", Kaunas, Lithuania. Presentation in plenary session and article in conference proceedings (accepted).	BC
Science and technology	Article about Biocentras, including information about Sorbent project.	BC

Presenting SORBENT at conferences and workshops

Essential to the promotion of SORBENT is its presence at the regional, national or international events focusing particularly on the above listed field of interests. SORBENT participation at events took two forms in particular. Firstly, representatives of SORBENT presented ongoing work, progress and results reached during the project, while the other form was more formal and consisted of a distribution of SORBENT promotional materials. In most cases both forms were applied at once.

Especial attention was given to environmental sector as it will mainly benefit from the project results developed during the project. The aim is to promote results of SORBENT to relevant commercial organizations in order to influence the market and create opportunities for future exploitation and use of SORBENT results. To achieve this, dissemination activities had been focused on the events (conferences, workshops, trades, exhibitions etc.) that are more environmentally oriented.

Existing resources and links of SORBENT SME partners (GROTA, HIMAL, CBIO, and WB) had been used for promoting SORBENT to the potential future customers of a finished product(s). The SORBENT achievements were also presented to scientific community by the RTD partners (BC and LUR) through presentation given at conferences, workshops, forums of experts and publications in conference papers.

A summary of dissemination events where SORBENT has been presented with the brief description of them is included in Plan for use and dissemination of foreground.

Networking

The dissemination activities will be extended by networking activities with other EU funded projects, professionals, working groups of European technology platforms, etc. The networking activities aim at fostering close links and exchanging of technical information, expertise and results. In addition to this, the joint efforts of the projects dealing with related or complementary topics should minimize duplications and maximize the potential to ensure the wide diffusion of projects results to the target audience. The SORBENT partners had informed professional networking community and proactively presented SORBENT at selected events enabling discussion and exchange of experience.

Apart from attendances to conferences, leading tradeshows and meetings, the consortium of SORBENT project is member of different networks and technological platforms which are summarised in the table below. These networks and technological platforms are a very useful way of publishing project results.

Table 2: Networking

Network /Technological Platform	**Description**	**Partners involved**
RICAI	RICAI is an IBERIAN Network in which technological centres and universities are involved. In this network, ideas and subjects are shared and Technology Initiatives are discussed. All the communities of Spain are represented and some other countries as Morocco and Ibero-American countries.	LUR
RETECNA	Navarre Technological Centres Network	LUR
EITB Network	The Innovative companies with technological base (EIBT) are small companies that use the scientific and technological foreground to develop their products or innovative processes. L'Urederra is member of this network and shares the results of its projects with universities and others technological centres	LUR
PLANETA	Spanish technological platform of environmental technologies (PLANETA) is an association of organizations with interests in the environmental technologies sector.	LUR
BIOPLAT	Spanish Biomass Technology platform	LUR
ASEBIO	ASEBIO has been the biotechnology sector platform since 1999, bringing the sector together and representing its members' interests before regional, national and European governments.	CBIO
BIOVAL	BIOVAL is composed of more than 40 biotechnology companies located in the Valencian Region, as well as research and technology centres, universities, and hospitals who's R&D are oriented towards biotechnology.	CBIO

Network /Technological Platform	Description	Partners involved
LITHUANIAN BIOTECHNOLOGY ASSOCIATION	The Government of Lithuania approved the Programme on the Development of High Technologies, identified and approved Priority Areas of Research and Development. Recently the Programme on the Development of Industrial Biotechnology has been launched. Lithuanian members of the Consortium are members of the Association.	BC
LITHUANIAN NATIONAL PLATFORM OF BIOTECHNOLOGY (LNBP)	The LNBP serves as a tool to define the medium-term and long-term RTD objectives of the Lithuanian biotechnology sector and to identify the principal activities necessary for the attainment of such objectives.	BC
UK Environmental Agency	WB as SME in UK is very conscious of policies of Environmental Agency of United Kingdom.	WB

1.4.5 Exploitation of project results

The SORBENT Exploitation approach attempts in depth investigation of the full spectrum of exploitation opportunities – not just product development and commercialization, but involves all the partners independently of their profile and position in supply chain in the exploitation efforts based on their nature and type of activities, as well as their stated individual exploitation perspectives concerning the project results.

Although exploitation evolved in parallel with the technical work, it offers a different view of the project results and supports the partners to think about the results more from a market perspective and identify exactly what they have to offer as well as find and reveal the value of the results for the business and scientific world. Exploitation is not the same process as commercialization hence the exploitable results from European RTD projects such as SORBENT may arise in many forms. As well as technologies which might form the basis for commercial products, such exploitation opportunities could include:

- Developing new services based on the prototypes, methods and tools.
- Creating start-up businesses to commercialize results.
- Protecting results through patents and IPR agreements.
- Inputting to standardization and legislative activities.
- Feeding RTD results and know-how into further research.
- Feeding RTD results and know-how into national or industrial research projects.

The exploitation potential of the project depends mainly on the following critical parameters that are assessed during the project lifetime:

- The project results:
    - The nature of the results (research approaches or concrete prototypes);
    - The degree of innovation (proof of concepts using mature, but risking to be outdated technologies, or forward the state of the art exploiting cutting edge but immature technologies);
    - The quality of the results (results that perform just what they promise, or better than expected (easier and faster for example);

- Their applicability in the market (they might be the perfect results but not applicable to the market).

- The project partners:
  - The nature of each partner's organisation. RTD and SME partners in general have different exploitation goals.
  - The perspectives and the expectations of each partner from the project.
  - The continuous commitment of each partner.

- The market:
  - The maturity and the trends.
  - The movements and the role of the leaders.
  - The "customers" needs.

1.4.6 Overall Exploitation Strategy

Aiming to facilitate the management of the project exploitation activities and taking into consideration the above mentioned issues, the consortium generic exploitation strategy has been prepared.

The main concept of the exploitation strategy is that each partner will define its exploitation plan based on 3 criteria:

- Definition of the exploitation assets / SORBENT results (what is to be exploited?);
- Decision on the exploitation policy for each asset (how are we going to exploit it?);
- Decision on the market schemas (where and in which promotion channels should we implement the exploitation policy of the specific asset?).

The above answers create a set of directions, which will be aggregated into a generic exploitation strategy for each partner.

The use and monitoring of the IPR issues derived from the shared and individual contribution of the partners into the creation of the exploitation assets will ensure that there is a clear understanding and agreement of the ownership of the assets, thus avoiding any potential conflict in the consortium.

1.5 Project public website

The public part of the SORBENT website is one of the means for increasing awareness of the SORBENT project results and the project itself amongst the wider public and for attracting potential users of the SORBENT project results and its applications. The SORBENT web page has been created to inform about the project and its events. The Public area navigation bar has been designed to provide general public audience with basic information such as: project goals and structure, presentation of the project partners, description of the objectives, some news and information on upcoming SORBENT events as well as project partners contact info.

The internal part of the web site is designed for internal use of project members. Its role is to support Project management and coordination – the internal sections are oriented towards aiding in the management and handling of the internal affairs of the Project and comprise essential collaboration information, materials and documents.

The structure of the SORBENT website at **http://www.sorbent.lt** is designed in a clear and consistent way, so that visitors can easily locate all information intended for them. Upon entering the homepage of the Project, users are able to browse the Public area content, while access to Partners area requires entering password in a standard login interface that is located below the subsections list. All subsections of Public area can be accessed by all users. However, all public content within the website is read-only – changes to texts and files therein can be made by administrator only.

Partially due to security concerns and partially due to its simplicity no complex programs or separate web interfaces are used for the maintenance of the website. Notepad++ is used for coding and any standard FTP interface program (i.e.: Windows Explorer) can be used to access and manage the files within. However, access to websites internal structure to make changes from remote machines is restricted – management requires physical access to the server workstation.