PYROlysis based process to convert small WWTP sewage sludge into useful bioCHAR

**Final Report Summary - PYROCHAR (PYROlysis based process to convert small WWTP sewage sludge into useful bioCHAR)**

**Executive Summary:**
The PYROCHAR project brings together five SMEs and three research institutions to address the increasingly pressing issue of sewage sludge disposal in Europe. PYROCHAR will provide small municipalities and their waste water treatment plants (WWTPs) with an economically and environmentally sound solution for the treatment and disposal of their sewage sludge.

The implementation of the European Directives for the treatment of wastewater (e.g. 86/278/EEC, 91/271/EEC) has improved the general quality and management of the wastewaters across the member states but has also generated a complex problem in the management and disposal of the increasing

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sewage sludge: according to the recent estimates, more than 10 million tons of dried sludge is produced yearly within the 26 member states.

More than 60% of the WWTPs in Europe service small municipalities. For these plants, the established sludge treatment and disposal options, developed specifically for large treatment plants, are too complex and expensive to provide on-site practical solutions.

Because of this, small WWTPs face a number of challenges presented by sewage sludge:
• Compliance with the latest EU directives for wastewater treatment and sewage sludge management.
• The costs of sludge treatment, storage and transport to composting/incineration facilities, farming or to larger WWTPs for further treatment(s) are high.
• New technological solutions and those in development are focused on medium to large scale WWTPs. The adaptation of these to small scale plants requires investment and investigation that are simply not prioritised.
• There is a high level of public mistrust of sewage sludge and its reuse, which widespread fears about adverse effects on the environment and human health.

The PYROCHAR technology will thermo-chemically treat sewage sludge, converting it to biochar (biomass-derived charcoal) and syngas (synthesis gas) in a system with low operation and maintenance costs and compliant with EU regulations. The PYROCHAR technology’s re-use of energy and resources will offer the perfect solution for small municipalities in the €2 billion European marketplace of sewage sludge management.

Project Context and Objectives:
The implementation of the European Directives for the treatment of water and wastewater has improved the general quality and management of the waters across the member states, but has also created challenges for the cost-effective management and disposal of the increasing sewage sludge. According to the recent estimates, more than 10 million tons of dried sludge is produced yearly within the 26 member states. Several routes for sludge management exist and are applied successfully for the large wastewater treatment plants (WWTPs). However, such routes are too complex and expensive for the small municipalities in rural areas and their WWTPs – less than 10,000 p.e. (Population Equivalent) – which represents in Europe more than 60% of the WWTPs.

The original methods for sludge management were: landfill, sea disposal, agriculture recycling and incineration. However, since 1998, the EU legislation has banned sea disposal of sewage sludge. In parallel, even though 35% to 45% of the sludge in Europe is still deposited, deposits in landfills have been drastically restricted and will be phased out in the near future. With incineration being the most expensive and restrictive way of disposal, agricultural use, driven by the Sewage Sludge Directive (86/278/EEC), has become the main outlet for municipal sludge – used as fertilizer –. The European legislation defines the necessary treatments of the sludge and regulating its reuse to prevent harmful effects.

In addition to the EU regulations, numerous European countries have implemented more drastic measures (or are on the verge to) for its agricultural reuse: The Netherlands and Flanders have banned almost all use of sludge in agriculture, Denmark has implemented stricter regulations with lower limits for heavy metals and other contaminants, and France, Finland, Hungary, Luxembourg, the Netherlands, Sweden,
Metals and other contaminants, and France, Finland, Hungary, Luxembourg, the Netherlands, Sweden, Flanders, and part of Austria have introduced limitations in terms of maximum annual concentration of heavy metals. To take into account these recent national legislations, the European Commission (DG Environment) is currently assessing the need to revise the Sewage Sludge Directive from 1986, with the first rounds of public consultations dating from 2010. The expected revision of this directive will be more stringent, requiring further sludge treatments, taking into account the latest researches on the impacts of heavy metals and pathogens contained in the sludge, and driving growth in recycling and waste-to-energy (WtE) systems.

In parallel, the latest EU environmental Directives (2008/105/EC) and (2006/118/EC) keep increasing the level of wastewater treatments in the Water Framework Directive, which is expected to in turn increase the sludge production, while limiting its reuse – in this case to avoid the contamination of surface water and groundwater.

Furthermore, when sludge is used in agriculture, food producers are facing legal limitations as crops produced with sludge are not suitable for “eco-labeling”. This is threatening the use of sludge, as organically grown food is getting more popular and consumers are willing to pay a premium price for foods that they consider to be not contaminated (as sludge is generally perceived as potentially harmful waste by the population). This eco-market has a current growth of 25% in Europe, and is forecasted to reach 20% share of the food market in Germany.

The solution and objective of the PYROCHAR project is to develop a compact system to treat and dispose of the sewage sludge produced in small municipalities and their WWTPs (<10,000 p.e.). The PYROCHAR system will dry the dewatered sludge and then use a slow pyrolysis technology to thermo-chemically reduce the dried sludge’s volume by 90% and convert it into char and gas by-products: Synthetic Gas and Biochar containing a limited amount of heavy metals suitable as filter, sequestrator or fertilizer.

To reach a sound solution it has been expected that the PYROCHAR solution to reach the following objectives:
- A compact system adapted to small plant with a drying capacity of 80-90kg/h and pyrolysis capacity 30kg/h.
- Sludge reduction (95% in volume, 90% in mass) Drying process – reduction of 75% Volume/75% mass
  Pyrolysis process – reduction of 90% Volume/ 70% masse
- Reuse the energy needed to produce heat for the drier and electricity for the system with a heat generation of 5% of the necessary heat for the drier (3-5kWth) and the electricity generation up to 40% of the total electrical needs (20kWel)
- Advanced control system to monitor the performance of the process and maintain its sustainability, by keeping the syngas quality and calorific value above 6 MJ/m3 (LHV)
- Recovery of wastewater from the process (from 60 to 70% of water recovery, depending to the feedstock and its water content)
- Heat recovery from the generated biochar, to heat up the air coming to the gas engine (CHP) and improve the combustion efficiency (by up to 10%)
- Hot gas clean-up technology to clean the pyrolysis syngas from its impurity and increase its calorific value before going to the gas engine (more than 75% efficiency in tars/particles removal, achieving < 30mg/Nm3 and 10% increase in hydrogen content)
The PYROCHAR solution delivers a compact system to treat and dispose of the sewage sludge produced in small municipalities and their WWTPs (<10,000 p.e.). The PYROCHAR system dries the dewatered sludge and then use a slow pyrolysis technology to thermo-chemically convert the dried sludge into useful solid and gas by-products namely synthetic gas and biochar. Downstream, a hot gas clean-up unit followed by a combined heat & power (CHP) unit such a gas turbine/engine to convert the synthetic gas (syngas) in energy (heat and electricity) for the system. In addition, the by-product of small municipalities’ sewage sludge pyrolysis (biochar) contains a limited amount of heavy metals as compared to sludge from big industries. This makes it perfect for homologations and reuse – for example, in land spreading.

Project Results:

STATE OF THE ART

Small municipalities are widespread in Europe, as 25% of the population lives in rural areas. This configuration is particularly true in Central and Eastern Europe (CEE) where 91.4% of the settlements have less than 2,000 inhabitants, representing 20% of the CEE population. However, the focus being primarily on the implementation of the Water Framework Directive by 2015 on the larger municipalities, the villages and small municipalities are less of a priority and are ignored.

Distances with the closest larger cities or centralized WWTPs being important, small communities cannot be directly connected to their collecting systems via piping networks. With limited infrastructure, labour and financial means, current available solutions were based on septic tanks, activated sludge, aerated ponds/lagoons and damping the generated untreated sludge in landfills or using as liquid fertilizers. With the implementation of the sludge legislations and without facility to treat their sludge, they will need to outsource its treatment and disposal to private companies and bigger and centralized plants (incineration, composting...).

Hence, as confirmed by BIBO experience in wastewater treatment, they need decentralized WWTPs to treat wastewaters and manage the generated sludge locally.

All the existing routes for sludge management have been questioned in recent years. Consumer and nature protection associations have voiced concerns about the use of municipal sewage sludge and its nutrients (nitrate, phosphorous potassium) for crops, as it contains as well pathogenic microbes, heavy metals and other toxic substances. On the other hand, the incineration of sludge, through its emission – especially carbon monoxide, dioxins and furans–, is always a concern for air pollution. Moreover, people living close to WWTPs complain frequently against unpleasant odors generated by the sludge, especially for open treatments (lagoons, stabilization ponds, aerobic reactors...). The transportation of the sludge is often seen as a nuisance in the cities.

Hence, there is a clear need to develop novel WWTPs for small municipalities, allowing both safe environmental disposal and the reuse of solid by-products by waste-to-energy systems.

Currently there are only two possible routes for Municipal waste management:

a) Outsourcing: centralized plants are expensive (dependence on prices/fees and schedule) and generate extra costs for storage and transportation.

b) On site: The usual available technologies on-site are aeration methods (ponds, lagoons, etc) but they demand large areas, generate odor issue and do not solve the disposal of the sludge, which is rarely managed locally.

"WWT Best Practices" defined by the EU requires the sludge to be treated in a range of expensive and
WTW Best Practices defined by the EU requires the sludge to be treated in a range of expensive and complex processes: thickening/dewatering, anaerobic digestion, drying, lime treatment, heating, incineration, composting, agricultural use, transport, and storage. WWT is inappropriate to small plants producing less than 200t DM/year, due to the size effect (high Capital and Operation costs), the limited labor and technology available on-site.

Alternative processes – such as wet oxidation, pyrolysis/gasification – have been developed in several units in Europe and worldwide, and seem promising. However, at the current state, this has been done mostly for larger scale with frequent technical problems and low industrial success.

THE SOLUTION

The PYROCHAR process has been developed by a consortium formed by SMEs, universities and research centres, that have developed an affordable adaptive and energy efficient process to convert the municipal sewage sludge into useful charcoal from pyrolysis treatment (or biochar) and synthetic gas (or syngas) which is converted into electricity via a gas engine. The system dries the dewatered sludge and then uses pyrolysis technology to convert it into char and gas by-products.

To reach an economically and environmentally sound solution, this new system includes the following features:

- High energy efficiency. The Drying and pyrolysis are energy consuming processes. To reduce the energy consumption to a minimum, all the energy contained into the sludge is recovered and reused. First, the pyrolysis syngas is burned into a gas engine to generate heat and electricity for the system. Secondly, the waste heat from the gas engine is reused to offset a part of the hot gas requirements of the dryer.
- Catalytic hot gas clean-up: Integration of a catalytic technology into the downstream hot syngas clean-up may allow to both, clean the syngas from its impurities and improve its carbon efficiency by reforming the tars to create more syngas.
- Flexible control system: This new control optimizes the energy efficiency and performances of the process by monitoring all the key parameters. Moreover, the process control ensures the sustainability of the PYROCHAR process, limiting the need for human supervision.
- Reusable and high value biochar: By using sewage sludge from small municipalities, the produced biochar will then contain a limited and acceptable amount of heavy metals, allowing its homologations in the EU countries and its reuse.

The Pyrochar is a compact solution that is able to treat and dispose the sewage sludge produced in small municipalities and their Waste Water Treatment Plants.

WORK PACKAGE DESCRIPTION AND SPECIFIC ACHIEVEMENTS

WP1. CHARACTERIZATION OF SEWAGE SLUDGE AND ITS PYROLYSIS BY-PRODUCTS

The applicability of the solid biochar product of the (energy) optimised pyrolysis process to three areas of potential marketability was investigated and explicated in the work carried out in this task. The three areas of interest are applications for energy production, applications for environmental protection/remediation and agricultural applications.

The energetic applications of the optimized PYROCHAR biochar are limited by its relatively low calorific value and high ash content. Ash content, calorific value, surface chemical composition, particle morphology and ashing and fouling propensity of the biochar were found all to be largely independent of particle size and hence size selection is not an efficient strategy by which to improve this biochar’s performance in thermal applications. Both calorific value and ash content were found to be improved by ash stripping: 50% ash removal and >25% calorific value increase resulted from simple acid stripping. For commercial scale operations, however, it may be necessary to develop more cost-effective froth flotation strategies for ash removal.
Strategies for ash removal.

The potential for using a two-stage pyrolysis-gasification strategy in order to improve the characteristics of the produced syngas was theoretically investigated. This strategy may prove useful in the event of the produced syngas presenting problems for downstream catalysts and/or the gas turbine technology. This process has the advantage of converting sewage volatiles before gasification, thereby increasing the H2 yield and reducing the condensable component of the produced syngas.

The optimized PYROCHAR biochar was found to have good metal adsorption characteristics at low metal concentration, being able to remove in excess of 90% of Cu2+ ions from solution at an aqueous concentration of 5 ppm. This removal efficiency falls to less than 20% as concentration rises to 500 ppm. However, smaller particle size fractions were shown to be capable of improved high-concentration removal efficiencies. Therefore, particle size restructuring is sufficient to access these elevated capacities. Activated carbon with a ten-fold enhanced cation exchange capacity was produced by pyrolytic KOH activation of the biochar and there is real potential to explore the market opportunities of such a material.

The agronomic properties of the optimized biochar were investigated and found to be of interest, particularly the phosphate content of the material which is well above the minimum EU standard for phosphate fertilizer. There are also potential fertilizer values to be exploited in the nitrogen and calcium content of the material, depending on the exact nature of the feedstock sewage treatment sludge. There is, however, some concern with respect to agricultural application relating to the heavy metal content of the material, and this issue is likely to need further explication if agronomic applications become part of the exploitation plan.

WP2: DESIGN/DIMENSIONING OF THE CLEAN-UP AND CHP UNITS

The first real tests of the novel catalyst from Teesside on the breakdown of tars were carried out using the syngas derived from the pyrolysis of sewage sludge in the Biogreen® unit. A section of the syngas outlet pipe was fitted with wire grids so that 1 kg of the best performing catalyst from Task 2.3 could be added to test the effect on the removal of tars from the syngas in an environment representative of that experienced by the catalytic filter in the PYROCHAR prototype. The preliminary results showed a reduction in the tar fraction of just over 45%, an increase in the total gas fraction of the pyrolysis products of 5% and increases in the CO, CH4 and H2 content of the syngas. This led to an increase in the calorific value of the syngas compared with the control with no filter of 12%. The performance of the catalyst in the final PYROCHAR system is expected to be better as particle deposition on the catalyst surface was a problem during these tests. A simple fabric filter was used to remove dust particles from the gas stream but this was seen to have limited effectiveness.

Comparative tests had previously been undertaken with the same experimental setup with a commercial catalyst (nickel oxide on aluminium) from Johnson-Mattey. The fraction of syngas, calorific value and composition was very similar with and without the catalyst; indicating that the catalyst formulated by Teesside was significantly superior to the commercial catalyst for the decomposition of tars from the syngas produced in PYROCHAR.

The results from the preliminary tests with the Teesside catalyst were used to estimate the mass of catalyst needed in the hot gas clean-up unit. It was calculated that a total mass of 2 kg of catalyst should be sufficient. Design calculations were also carried out on the catalytic filter bed to ensure that the flow was turbulent.

It was decided at the medium stage of the project that the gas turbines produced by TURGUC would be inappropriate for use as a CHP in the PYROCHAR project. TURGUC were currently developing a small gas turbine for an Unmanned Air Vehicle (UAV) but this would be much smaller than the requirements of the CHP in PYROCHAR and worked with liquid fuels. Modification of this unit to fulfil the PYROCHAR
the CHP in PYROCHAR and worked with liquid fuels. Modification of this unit to fulfill the PYROCHAR objectives would have been extremely difficult. The decision was therefore taken to use a commercial CHP unit.

Unfortunately, commercial gas turbine CHP units are designed to work with natural gas and have restrictions on the amount of CO (5% maximum) and H2 (1% maximum) in the fuel that may be used. The syngas composition at the preferred pyrolysis conditions from Task 1.4 contained 35% of CO and 27.5% of H2. Various options were investigated to solve this problem including removing the CO and H2 from the syngas using membrane filtration, though it was decided that this would be very difficult due to the high quantities of these gases and would also significantly reduce the calorific value of the syngas (and therefore the overall efficiency of the system). It was therefore decided that the only practical solution was to change the type of CHP unit. Three different options for the CHP unit for PYROCHAR were presented to the consortium.

Different options were studied, along with their respective advantages and disadvantages (including cost and time needed for construction). The SME partners were asked to vote on their preferred solution and the reciprocating IC engine was chosen (primarily for the cost, efficiency and the time needed to construct the system). It should be noted that the PYROCHAR system should still achieve the technological objectives for the efficiency of the overall system despite the change in the CHP from a gas turbine to a reciprocating IC engine.

The IC engine system chosen was a commercial 30kW natural aspirated diesel generator from Fiat (F32 AM1A). The maximum electrical power output from the system was actually greater than that required for PYROCHAR but this gave a margin of safety to the CHP system as it would only ever be run at part load during the development of the PYROCHAR prototype.

WP3: DEVELOPMENT OF THE HEAT RECOVERY SYSTEMS

The Simulink® model of the complete PYROCHAR prototype system was constructed to examine the energy balance of the overall process. A Simulink® model of each individual unit in the prototype (dryer, pyrolysis unit, hot gas clean-up and heat exchanger, CHP unit) was constructed and connected to form the Simulink model.

- Dryer
The dryer model developed in Task 3.1 was modified to function in steady-state to reduce total model run time following the most recent information from Enviro-Pharm on the dryer calculated hot gas heat requirements.

- Pyrolysis system
This was modelled as a look-up table based on the results contained in deliverable D1.2. The input variables were the spiral temperature, residence time, type of sludge and the feed rate. The outputs were the different fractions of the pyrolysis by-products, the calorific value of the syngas and the electrical consumption in the spiral.

- Hot gas clean-up unit and syngas cooler
It was assumed that the cooling of the hot syngas in the clean-up unit was very small so that the temperature of the syngas was maintained and that the proportion of the different pyrolysis syngas products changed due to tar decomposition in proportion to the achieved in WP2.

- CHP unit
The model of the CHP unit (Fiat F32 AM1A) was constructed using data provided by the manufacturer and assuming a lower electrical efficiency of the diesel generator when run with dual fuel (syngas and

and assuming a lower electrical efficiency of the diesel generator when run with dual fuel (syngas and diesel) as opposed to just diesel. The model assumed that energy production only came from syngas and that a very small proportion of diesel is necessary to ignite the gas and maintain stable combustion and this has no effect on the overall energy balance.

A number of different scenarios where run using the developed model examining the effect of increasing the dry solids content at inlet to the dryer and the electrical efficiency of the CHP unit. It should be noted that in all scenarios modelled the technological objectives of the project related to the overall energy balance (5% of the heat for the dryer and up to 40% of the electrical needs of the system would be met. This was despite the change in the type of CHP unit used.

WP4: DESIGN OF THE MONITORING SYSTEM FOR PROCESS ENHANCEMENT

The main process to control the Pyrochar have been designed to manage the energy balance of the whole system maintaining the level of performance of each subsystem (dryer, pyrolysis, cleanup and CHP) according to the setup input configuration of the operator and the parameters measured during the process. The most critical parameter to control is the syngas input pressure of the CHP which is generated by the blower controlled by the control system through its motor. This has been solved by using an automatic controls loop using a pressure sensor at the output of the pyrolysis process which govern the gas intake in the CHP through a gas blower control.

Two main energy optimization strategies have been implemented in the system. The first one consist in the cascade activation of the process where the subsystems are initialized sequentially at the beginning of the Pyrochar process operation and then also finalized sequentially when the system determines that the sludge have been consumed.

The second one consist in maintaining the appropriate levels of performance and a continuous gas flow rate between the pyrolysis and the CHP using the sensor system that has been implemented.

The main control system P&ID has been designed in order to, not to control each subsystem individually but, to monitor the performance and react in case of unbalanced conditions. The control strategy approach resides in maintaining the gasification performance of the pyrolysis which is proportionally influenced by the dryer performance, which is influenced by the flue gas of the CHP and thus the energy and equilibrium in the rest of the system.

The full control system has been implemented. The main controller has been designed with a Human machine Interface (HMI) where an operator is able to change the parameters of each subsystem and it relationship with the rest of them in such a way to the operator could select the best production configuration.

WP5: MECHANICAL DESIGN AND SYSTEM ASSEMBLY STUDIES

Simulations were undertaken by INSP using Computational Fluid Dynamics (CFD) of the flow and mixing in the diffusion step of the ENVIRO-PHARM three-step dryer with the objective of optimizing the design of this part of the drying process. The simulations were focused on the diffusion step as this was an innovative step introduced by ENVIRO-PHARM to improve the efficiency of the overall drying process.

The original three-step dryer from Enviro-Pharm was reduced to a single step as the lower maximum dry sludge feed rate of 20 kg/h required in the PYROCHAR prototype could be supplied by a single stage with an inlet feed rate of 100 kg/h of dewatered sludge. The development of the burner was carried out using a propane-butane gas burner to provide the necessary hot exhaust gases. These were mixed with excess air provided by an external fan to provide the hot flue gases that would be used to dry the sludge.

Recirculation of the waste air containing the steam evaporated from the sludge was carried out and this was fed to a heat recovery system to optimize the efficiency of the dryer.

Furthermore the study continued simulating the rest of the system. The optimization of the pyrolysis unit
Furthermore the study continued simulating the rest of the system. The optimization of the pyrolysis unit was carried out by Messag who included a number of optimizations compared with the original Biogreen® pyrolysis unit.

Materials. The high maximum spiral temperature (800°C) to be used in PYROCHAR placed extra strain on the material used in the pyrolysis unit. A design study was presented in deliverable D1.2 on the stainless steel to be used in the spiral to avoid high temperature creep and other mechanical problems. An Inconel alloy 625 was used in the optimized unit. Other improvements to the materials used in the construction of the PYROCHAR pyrolysis unit were made to improve the resistance to high temperature. The spiral section diameter was allowed to vary to change the temperature profile at the spiral surface and optimize the heat transfer from the spiral to the dry sludge. This optimization was carried out based on thermal calculations from Messag.

Design calculations were carried out to estimate the required area of the cooling screw for the biochar cooling storage assuming that the biochar was originally at a maximum temperature of 800°C. The biochar was cooled by an external cooling jacket through which water flowed and water was also sprayed directly onto the biochar to reduce the risk of fire. A screw type conveyor was used to transport the biochar to the storage location.

Finally Messag carried out a detailed design study on the assembly of the overall PYROCHAR prototype system using the drawings of the new drier from Enviro-Pharm and the hot gas clean-up system and the CHP from Hydro in addition to their own drawings of the new pyrolysis unit (along with their respective control systems). The objective of the study was to design the connections between the different subsystems of the PYROCHAR system and to therefore fit it in a 40 foot container for ease of transport to potential customer sites and trade fairs, etc. Due to the height of the hot gas system this currently cannot fit into the container, and will be modified in the future but the rest of the system has been designed to fit in the so called “containerized prototype”.

WP6: PROTOTYPING, INTEGRATION AND VALIDATION

Apart from the dryer and pyrolysis unit which have been discussed in Task 5.1 the PYROCHAR system consisted of the hot gas system, which could be further divided into the (1) hot gas cleaning section and (2) the power section.

The hot gas system consisted of:
- A filter using a commercial ceramic candle. This was designed to remove 99% of all particles between 1 and 10 microns (from the manufacturer’s data). The particles in the syngas flow stream were mainly char and ash.
- The catalytic filter. Which was constructed in three sections that could all be filled with catalyst to contain the 2 kg of filter media from Teesside and any other future filter media developed. The cross-section of the filled sections was kept small to maintain turbulent flow. The catalytic filter was designed to remove tars.
- A heat exchanger, which has been previously described in Task 3.2. In addition to cooling the syngas so that it was at an acceptable temperature for the inlet of the CHP unit. The heat exchanger would also removing any remaining tars that had not been broken down by the catalytic filter.

The power section consisted of a:
- A syngas pumping system to maintain a constant flow rate of syngas at the inlet of the CHP and more importantly maintain the pressure at exit of the pyrolysis unit slightly below atmospheric pressure to avoid potentially dangerous gas leaks from the pyrolysis unit.
- A reciprocating diesel engine which has been previously described in Task 2.4. The intake manifold of the engine was modified to accept a mixture of syngas and air and the diesel consumption was measured using scales to determine the percentage of syngas burnt.
Using scales to determine the percentage of syngas burnt.

The integration and testing of the control system with the first PYROCHAR prototype was carried out by Inspiralia with support from ETIA and HydroItalia. After the pressure and temperature sensors were integrated into the hot gas system and connected to the control system, preliminary tests were carried out to ensure that they functioned correctly and for instance the chosen range of the sensors was appropriate for the range of pressures and temperatures at that particular location.

Once this first modification of the control system had been carried out a test was undertaken running the whole PYROCHAR system but using the manual overrides to control the pressure at the exit of the Biogreen® pyrolysis unit (by modified the syngas pump speed) and opening and close the valves to allow the syngas to be burnt directly or fed to the reciprocating engine. Minor modifications were then carried out to the control system to allow the automatic control of the PYROCHAR process. It should be noted that in these tests the PYROCHAR control system did not directly control the Biogreen® unit. The decision not to fully integrate the pyrolysis unit control system was taken by ETIA for commercial reasons, though the PYROCHAR control system has been designed to be able to control the Biogreen® as well.

Finally, tests of the PYROCHAR system were carried out by ETIA. The tests were carried out at a dry sludge feeding rate of about 5 kg/h to avoid potential blockage problems in the hot gas system with higher feed rates. The system was able to run continuously for a number of hours with all the syngas produced from pyrolysis consumed in the CHP unit. An electrical load was provided by a 14kW heater and measurements of diesel consumption were carried out to determine the percentage of electricity generated from the syngas. Calculations showed that 4kW of electrical energy were generated directly from the syngas with the generator having an overall electrical efficiency of 28%. Further tests to increase the sludge feeding rate and therefore the percentage of the electrical input derived from syngas will be carried out by ETIA.

Potential Impact:

DISSEMINATION OF THE KNOWLEDGE

PYROCHAR aims at designing and developing an innovative process, based on pyrolysis, to address the sludge management problem of the small European municipalities, direct consequences of better water and wastewater treatment policies.

The PYROCHAR process will allow small WWTPs to treat the sludge on-site, decreasing its total dewatered volume by more than 95% and hence decreasing also in more than 50% its O&M cost. Thanks to an advanced control strategy and an efficient reuse of the calorific power of the sludge to fuel the system (heat and electricity), the PYROCHAR system will be highly energy efficient. Finally, the useful nutrients such as nitrate, phosphorus or potassium, will not be lost but trapped in stable by-products, the biochar, with an economic value for the end users.

In order to ensure the efficient launch and successful commercialization of the PYROCHAR technology, the Consortium partners are developing throughout the project lifetime a thorough Dissemination Plan, organizing all the activities to be carried out to generate the awareness about the project and promote its progress and results, reaching a maximum impact amongst the targeted audience:

- Municipalities
- Wastewater/water utilities and their associated Small Wastewater Treatment Plants (WWTPs)
- Maintenance/installation companies working with/for WWTPs
- Research and Investigation Institutes
- Public
The secondary target audience will be the other potential End Users, mainly from the biomass and the industrial sectors (plastics, wood, tyres...) that could be interested by an innovative, efficient and eco-friendly sludge management method providing high value by-products.

In this respect, the Dissemination Plan is focusing on two main directions:
- Towards the awareness and notification of the PYROCHAR project progress and results in the scientific community and the industrial sectors (sewage sludge management);
- Towards the marketing and promotion activities, in order to enhance the commercial potential of the system.

It is noteworthy to add that clear communication channels between the project partners themselves as well as with the wider community have played a crucial role in the project so far and will carry on after to ensure a successful exploitation.

Overall Dissemination Strategy

As previously stated, the main purposes of the dissemination activities is to raise awareness and promote the project in order to make PYROCHAR successful and sustainable. During the course of the project this has been carried out by using several communication and dissemination materials, but also through direct information on conferences and trade fairs. The information is also being provided to the general public through media coverage (e.g. project website).

As leader of the Work Package 7 “Dissemination, IPR and Exploitation Management”, the Dissemination Manager Lorenzo Amadori (HYDRO) has been working with the project Coordinator Olivier Lepez (ETIA) on the overall Dissemination strategy, being always in close contact with the rest of the SME partners and RTD performers. HYDRO and ETIA have been coordinating and supervising the different Dissemination actions, making good use of the inputs provided by all the partners. They are in charge of the Dissemination Plan, describing all the planned activities, and its update during the project lifetime.

All the members of the consortium are actively contributing to the Dissemination according to their capabilities and own means, whether it is by giving presentations, participating in conferences/trade fairs, publishing articles, networking or similar activities. In this regard, the Internal Dissemination (within the Consortium) have been very important to ensure that all the partners had a good knowledge of all research, technical, industrial and economic aspects related to the PYROCHAR technology and its progress.

The PYROCHAR Dissemination has been structured as follows:
- Internal communication
  The project is being supported with a regular and efficient use of all the communication means (phonecall, emails, technical/project meetings), ensuring a smooth and continuous data sharing throughout the project.
- PYROCHAR project website http://pyrochar.eu/
  The main section (i.e. Public section) is the front face of the project. It provides information to the public via the description and organisation of the project, the presentation of the partners and the description of the technical and research activities and progress.
  A private section has been created by the partners and WP leaders to upload reports, deliverables and other significant documents. This platform allows a quick and safe data sharing within the Consortium.
  Note: The website is updated regularly, ensuring availability of latest news and presence in search engines.
- Presence on partners’ website (SME/RTD)
  The partners have created links between their own website and the project website, along with several
The partners have created links between their own website and the project website, along with several announcements of PYROCHAR progress and events on their web pages.

- Presence/Participation in international events, conferences & trade fairs
Attendance to international trade shows and events is primordial to present and show PYROCHAR progress and ensure the interest of the targeted End Users (via direct contact with them). Focus on the participating countries and other countries with potential European and International markets.

- PYROCHAR publications
Publication activities (such as announcements, articles, papers) will be aimed into two directions: Articles in local or international industrial/general magazines (about wastewater/water/sludge managements, environment solutions) and vulgarization media to popularize PYROCHAR technology and make it known to the End Users;

- Promotion & Dissemination materials
After the Official Press release for the project start in November 2013, the 1st Poster has just been designed and released. The 2nd Poster have been designed for the dissemination activities showing the updates of the project along with a promotional video made during the 2nd Period.

- Dissemination via partners’ networks
The Consortium, and in particular the SME partners, will use their own network (suppliers, clients, partners, associations where they are members, End Users...) to promote the PYROCHAR project.

- Communication with environmental and agricultural associations/organizations
Environmental and agricultural associations are very influential with municipalities during the buying decision process – the first one for the environmental and health concerns, the second one for the accepted agricultural reuse of the sludge. The partners will contact the main associations (EUREAU, ADEME, OFWAT, DWA, COPA, COGECIA) in order to support the uptake of PYROCHAR new technology.

- Promotional Video
A promotional video has a length of 1.5min and it has been developed for both, the general and specialized audience showing the main advantages of the PYROCHAR project.
The video has been made in an animated sequence that follows a script that has been approved by the consortium. Special care has been taken to the visual aspect of the system as the colors and visual aesthetics follows the same line as the ones used for the rest of the Pyrochar dissemination material as the website and the different promotional posters designed by the consortium.
The video will be available in the Pyrochars website and other public domains like Youtube.

THE MARKET NEEDS ADDRESSED IN PYROCHAR

PYROCHAR objective is to develop a compact Waste Water Treatment (WWT) plant which will solve the sludge management problem of small municipalities, direct consequences of better water and wastewater treatment policies. The main concern of the European municipalities is treating and disposing of their sewage sludge at an affordable cost, which is getting more difficult due to lack of infrastructures and stringent EU and national regulations, making the treatment of sludge compulsory and limiting the existing outlets – landfill, incineration, and agricultural reuse.

PYROCHAR is addressing those problems by decentralizing the management of the sludge directly within the small WWTPs with an initial investment of 400k€. Clear commercial advantages will be that the sludge
Clear commercial advantages will be that the sludge will be treated on-site, decreasing its total dewatered volume by more than 95% and hence decreasing also in more than 50% its O&M cost. Thanks to an advanced control strategy and an efficient reuse of the calorific power of the sludge to fuel the system (heat and electricity), the local high energy craving from the pyrolysis will be balanced by an efficient reuse of its by-products energy, making the whole system energy efficient and independent, perfectly adapted to the End Users such as small municipalities. Finally, contrary to current incineration solutions, the useful nutrients such as nitrate, phosphorus or potassium, are not lost but trapped in stable by-products, the biochar, with an economic value for the end users.

European Small Municipalities needs (up to 10,000 p.e.)
- Comply with Directives 91/271/ECC and 86/278/ECC
- Sludge load: up to 200 tons of dry matter/year
- Average costs: 400-650€/t of dry matter yearly

PYROCHAR impact:
- EU Directives Compliance
- Initial investment: 400k€ / O&M costs: 20k€/year
- Capacity: >200t of dry matter/year of sludge
- Biochar sale: up to 500€/ton
- Water recovery: up to 1500€ of savings/year

PRIMARY MARKET
The sludge treatment equipment market in Europe reached $1.85 billion in 2003 with 6.6% growth for the 2000-2010 period. Within this market, the novel solutions are well received, representing a 9% share in 2010. The services for sludge disposal market reached up to $2.9 billion in 2002, $3.5 billion by 2009. As the PYROCHAR solution treats and disposes of the sludge, our targeted market includes both treatment and disposal markets, i.e. the sludge management market, which represented 2€ billion in 2006. As the growth of the Western Europe WW treatment technology is forecasted for the years to come at more than 3% – the one for the Central and Eastern Europe is even higher – and the growth for the disposing market has been more than 2.5% for the period 2002-2009, the growth for the whole sludge management market can be assumed to be at least at 2.5% for the next 10 years. Hence an estimated primary market of 2.26€ billion in 2011.

SPILLOVER MARKETS
The direct secondary market for PYROCHAR process is the industrial sludge management for small industries. This market has similar needs, especially concerning the EU and national sludge regulations. In addition to this first one, the other markets to consider are the municipal and industrial solid waste management for small plants, given the pyrolysis technology can treat a variety of feedstock other than sewage sludge (plastics, wood, tyres, etc.). However, each new feedstock will require a preliminary study to optimize the pyrolysis settings (calibration) and to control the performance of the clean-up unit – using the knowledge derived from the PYROCHAR project, these tasks could be done by the SMEs as product adaptation.

ECONOMIC OPPORTUNITIES FOR THE SME CONSORTIUM
NEW MARKETS PENETRATION
PYROCHAR will enable our SME consortium to obtain market share in a niche market: the sludge management for small plants. This market still underestimated and without efficient solutions, has a sustainable growth due to EU environmental regulatory compliance and represents more than 50,000
Sustainable growth due to EU environmental regulatory compliance and represents more than 50,000 small plants. After 5 years of exploitation of the PYROCHAR system, we expect a turnover of about 160M€, with a market penetration of 1.77%. This is without counting on the spill-over markets – such as industrial sludge and waste management for small plants – in which the proposed system will be perfectly adapted to.

**BETTER COMPETITIVENESS**

The technological knowledge that the SME consortium will get from the RTDs over the 2 year project will provide them with a leading edge in thermal treatment, process monitoring and energy efficiency. Having a system with centralized control to monitor process performances and its stability will decrease the need for high skilled technicians, facilitating its use in low infrastructure areas. In addition, the position of ETIA and HYDRO will be very competitive on these markets, thanks to the intellectual property rights (IPR) from the hot gas clean-up technology.

**BENEFITS FOR END USERS**

The End Users, the municipalities, will also benefits from PYROCHAR: in addition to addressing their needs in sludge management, the municipalities will save up to 1,2M€ after 20 years of exploitation (388k€ for a 6,000 p.e. municipality, and 1,18M€ for a 10,000 p.e. municipality). Also, they will be eligible for national support schemes – funding, tax supports, certifications – from using CHP equipment and reusing sludge (Waste-to-Energy funding). Moreover, the decentralization of the sludge management to rural areas will provide more activities and job opportunities, as each municipality with a PYROCHAR system will have the possibility to work as small sludge management platform for the neighbor communities.

The budget from the municipalities to manage their sludge varies according to the solution. On average, the current costs in Europe are as follow: 110-160 €/t DM (dry matter) for landspreading (agriculture), 260-350 €/t DM for incineration, 210-250€/t DM for landspreading of composted sludge/use of sludge in land reclamation.

In the case of small plants, the limited sludge production has an important impact on the prices – considering the smaller amounts of sludge to treat and dispose of, in comparison with larger WWTPs – the average price to consider for small WWTPs is estimated around 400-650€/t DM.

The costs above include the amortization of the equipment and infrastructures, the Operation & Maintenance costs and the treatments used. Though these costs are useful to get a general idea of the municipality budget, they do not reflect the reality of the initial investment and the yearly O&M costs. As stated previously in section B1.1 the investment cost for a WWTP including sludge treatments is around 185€/p.e., the sludge management counting for up to 50% of it. Also, the Operation and Maintenance costs for small WWTPs are relatively high, with an average of 15-25€/p.e./year 25-50% being only for the sludge management. This can be translated to O&M costs ranging, on average, from 7000 to 70,000€/year.

For the small municipalities, the costs to consider with the purchase and use of the PYROCHAR system are divided into two categories: the Capital cost – 400,000€ – and the yearly Maintenance and Operation (O&M) cost. The latter will be in the range 15,000-20,000€/year, which means more than 50% decrease in O&M costs, if we consider a 6,000 p.e. plant. Such O&M costs will be reached as our system is energy efficient and highly self-sustainable (a technician from the site will be able to manage the system by itself, the main maintenance tasks being ash/char extraction, cleaning, monitoring sludge feeding and inspection checks). The lifespan of the system has been estimated to 20 years, which the average lifespan of the main units forming the whole system.

**ECONOMIC IMPACT FOR SME PARTICIPANTS**
ECONOMIC IMPACT FOR SME PARTICIPANTS

The market for novel solutions was estimated at 2.26€ billion (2011), at a 2.5% growth for the period 2012-2016. The penetration on the treatment market for new solutions has reached 9%, which means that a reasonable penetration factor for the PYROCHAR system would be from 0.5% to 2.0%. Such factor is due to the initial mistrust of the market towards solutions with limited proven industrial applications; which is the case of pyrolysis systems.

At a price of 400,000 € per unit and based on the advantages to the municipalities (End Users), we consider that 50 systems will be sold in Europe during the first commercialization year after the end of the project, i.e. 2015, with an estimated sales growth of 25% per year during the first years. The launch in the international markets will start after 5 years of exploitation in the EU, so as to minimize the risk and consolidate an original market well known by the consortium.

ENVIRONMENTAL AND SOCIETAL IMPACTS

The main contribution of PYROCHAR will be to provide an eco-friendly solution to the municipal sludge problem. The process will help decrease the amount of sludge while complying with the national regulations and EU directives. In addition, the energy from the sewage sludge will be reuse to fuel the system and its nutrients and carbon will be stored in high value by-products. As the technology is based on a thermal treatment without oxygen, the process will generate low emissions and contribute to achieve Kyoto Protocol requirements. PYROCHAR will provide to the EU an adapted “Best Practice” solution for sludge management to small plants, thing that is currently missing.

The proposed system will address the public and association concerns about sludge reuse and health. Not only will the decrease of transportation and storage improve the daily life of the municipalities, but also the reuse of the sludge via an EU homologated, odourless, pathogen-free and full of nutrients biochar will win over the European public. Biochar from small municipalities – the amount of heavy metals is low in absence of industrial effluents – is the answer to the EU policy promoting recycling and reuse systems. Furthermore, the possibility to use PYROCHAR as a decentralized platform to handle the sewage sludge from nearby communities will create new jobs in the rural areas.: with a forecasted turnover of 24.6M€ of the PYROCHAR system, we estimate at 100-150 the number of job creation in the wastewater and sludge treatment industries and plants (this estimation is based on a turnover of 150-200k€/employee).

List of Websites:
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Related documents

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