PHYTO2ENERGY NEWSLETTER #4

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SOIL -ENERGY NEXUS: COMBINING PHYTOREMEDIATION AND ENERGY CROPS PRODUCTION.
A SUMMARY OF THE PHYTO2ENERGY APPROACH

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EDITORIAL

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Welcome to the last issue of the Phyto2Energy newsletter .

Our project has been a long, four-year journey that allowed our 26 fellows from 3 commercial and 3 research organizations gain new experiences in scientific, cultural, practical and finally human dimensions. The works implemented jointly by the fellows brought a number of interested research advancements that are not only valid as scientific results but maybe further explored in commercial activities of the commercial partners and in a business offers of the research units participating in the project. First of all, thanks to the work of IETU and VITA34 fellows we gained a lot of new knowledge concerning the use of energy crops for phytoextraction and phytostabilisation purposes. The field trials carried out at the experimental sites in Poland and Germany allowed us to gain new knowledge relevant for planning phytoremediation driven energy crops production as a concept for managing heavy metal contaminated soils. That includes a better understanding on what stimulates and what hinders the biomass growth and heavy metals uptake, which among the four tested plant species are good for producing uncontaminated biomass on soils with heavy metal content and which are suitable to remove the contamination. We also confirmed that the Phyto2Energy approach is an option for long rather than short runners. Taking account of the best availabilities of the plants, one should take about a 20 year perspective when planning to combine site remediation with an economically viable production of biomass. On the other hand however we propose a nature based solution dedicated to economic and environmental restoration of sites that are idle anyway. The microbiological studies carried out by PrioBiotics, HMGU and IETU lead us to the composition of a prototype formula based on 3 isolated and characterized Pseudomonas Putida bacterial strains stimulating the growth of biomass. Unfortunately, during the course of our project some recent scientific communications concerning the risks potentially associated with these strains made our field experiments with the application of the formula impossible. To compensate this ProBiotics and IETU focused on identifying a method for preserving the bacterial strains. These works were accomplished with results demonstrating liophilisation as a promising method for preserving the bioformula also in view of its production in the future. Additionally, based on the field trials and mcrobiological works a theoretical framework of system for monitoring soil quality in support of the

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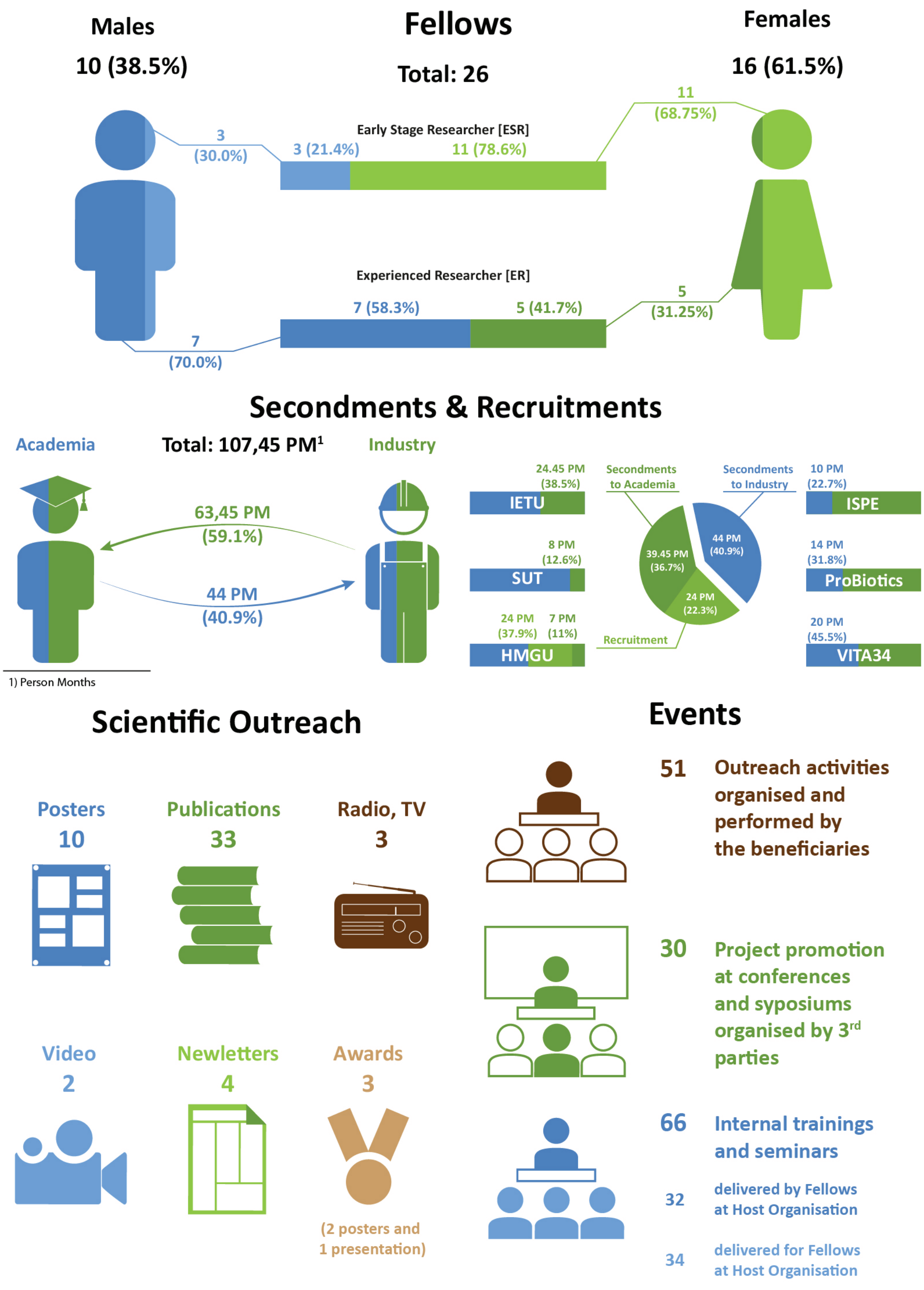

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phytremediation driven energy crops production has been worked out. While production of the biomass is one thing, its use for energy production is a gasification process is another. The studies carried out by SUT, ISPE and IETU showed that despite the fact that gasification of the biomass can deliver many more environmental gains compared to combustion, it is not that easy to convert the contaminated biomass into energy in a safe way. The studies on the properties of the biomass as feedstock for gasification in a small installation showed that the material needs some pre-treatment like peletisation, refraction or addition of some common minerals such as halloysite to improve the gas parameters. Also areas for the improvement of a small capacity mobile gasification installation to better fit the needs of the biomass have been identified. The cost benefit analysis performed for the gasification lead to a conclusion that the process seems to deliver best economic benefits if the gas obtained after gasification process of HMC biomass is used to obtain the combined electricity and heat energy only if the installed electrical power greater than 50 kWel. For smaller installed capacity, the impact of labor cost are quite large and practically eliminates any profits.

Where plants can make a change

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The over three growing seasons of field experiments with energy crops – *Miscanthus* x *giganteus*, *Sida hermaphrodita*, *Spartina pectinata* and *Panicum virgatum* on arable land (Bytom, Poland) and former sewage sludge deposit site (Leipzig, Germany) allowed to verify the initial hypothesis, that combining energy crop production on heavy metal contaminated land with phytoremediation of soil is a promising approach. It also allowed to draw some conclusions about the potential of the selected energy crop species to cumulate heavy metals.

All of tested plant species demonstrated the ability to grow and develop in a heavy metal contaminated environment, even at sites with difficult soil conditions like the former sewage sludge deposit site in Germany. The studies proved that the wo main factors which determine the biomass production are: soil conditions, especially soil structure and organic matter content. Also soil characteristics is the key step in making an initial assessment on the feasibility of using energy crops for phytoextraction and/or phytostabilisation. For example, if the soil contains high organic matter content, like in the case of the Leipzig site, phytoextration of heavy metals will be very limited due to low bioavailability of heavy metals in soil solution as typically more metals are bound with the organic matter.

The influence of heavy metals on the biomass yield seems not to be primary. Both sites were contaminated with lead, cadmium and zinc at comparable levels. About twice lower biomass yield found at the Leipzig site was mainly due to soil structure. High content of fine soil particles and high level of organic matter made this soil very compacted in the rain periods and dusty in the dry periods. Because of these conditions the plant roots were not able to penetrate the soil and establish a dense root system as in case of typical arable land. Organic matter level caused sorption of nutrients and made them not available for plants. The highest biomass yield was found for *Miscanthus* x *giganteus* and *Spartina pectinata* cultivated at the Bytom site, with the yield of about 20 tons per hectare after the third growing season. *Sida hermaphrodita* yield was strongly dependent on the used type of fertilization, where yields from the plots with NPK and inoculum fertilization were almost twice higher when compared to the control, reaching 15 tons per hectare. Only for *Panicum virgatum* comparable results in biomass yield from each of the sites were found (about 5 tons per ha after the third growing season).

Heavy metal uptake by plant species depended on two factors: the natural abilities of species to uptake heavy metals from the soil solution as well as heavy metal bioavailability in the soil. The highest metal uptake by the tested energy crop species were found for plants cultivated on heavy metal contaminated arable land in Poland, where metal bioavailability was significantly higher (especially for cadmium and zinc) compared to the former sewage sludge deposit site in Germany. Among tested plant species, *Spartina pectinata* turned out to be a species with phytostabilization abilities, with low metal uptake to the aboveground part of the plants. *Sida hermaphrodita* seems to be a species accumulating high amount of cadmium and zinc, while *Panicum virgatum* had high concentration of zinc in shoots with low concentration of lead and cadmium. From the practical point of view the experiences from the field experiments provided us with a new knowledge and skills necessary for full scale remediation project planning. Based on the results we are now able to provide consulting to contaminated site owners and engineering companies dealing with remediation concerning determination which plant could be used for extraction purposes (cleanup) and which for stabilization of heavy metal contaminated soil based on future land use.

Based on the measurement results of the plant physiological parameters it could be assumed that the response of plants to the applied fertilization was not only species specific but also highly site specific.

The most important factor for remediation potential of energy crop species is the biomass yield. Even if a plant is not accumulating a high amount of heavy metals, when producing high yield it is able to extract significant amounts of the contaminants. For example *Miscanthus* x *giganteus* was able to extract the highest amounts of cadmium and zinc among all the tested species, while the most efficient zinc removal was found for Spartina pectinata. This fact makes those two species optimal crops for heavy metal contaminated areas. On the one hand - high biomass yield with a relative low heavy metal content, on the other – yield multiply by concentration gives significant removal of the contaminants from the soil.

Monitoring the improvements: soil quality monitoring system

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One of the objectives for the Phyto2Energy project was to identify bacterial species, which could be used as a biological indicator for an improved quality of heavy metal contaminated soils, as a result of the bioremediation process. For that purpose a green house experiment was performed a HMGU to identify bacterial responders towards heavy metals. In the frame of this study soils were spiked with heavy metals. As controls, we used soils where only water had been applied, but also soils which were spiked with ammonium – nitrate to simulate a fertilization. Our aim was to analyze which shifts in the soil microbiome are naturally occurring and which can be specifically dedicated to the presence of the heavy metals. To analyze the influence of the different treatments on soil bacteria, a molecular barcoding approach was chosen. Our data indicated that the overall diversity of bacteria in soil (as indicated by the Shannon index) was not significantly affected. However, shifts in diversity were observed for single bacterial groups. In bulk soil Cyanobacteria were most affected by the application of the heavy metals, whereas some proteobacterial species strongly benefited from the heavy metals and increased. The strong increase in proteobacteria as a result of the heavy metal application was also visible for the microbiome of root endophytes. For the rhizosphere no indicators could be defined, as all species which showed a response towards heavy metals also responded towards the fertilizer application, so for this soil compartment no indicators could be defined. This data needs no to be validated in real field situations in future studies. If the two indicator groups show comparable response pattern also in such studies, they can be applied to monitor the improvement of soil quality in the future at sides where (bio) remediation of heavy metals had been performed. Such indicators are of central importance for stakeholders, regulators and policicans, as the assessment of soil quality itself is highly complex and cannot be assessed by standarized methods so far.

Preserving by freezdrying

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Freeze-drying is a commonly used method to preserve bacteria, in research as well as in industry. Compared with traditional liquid cultures, freeze-dried cultures have many advantages, including their low volume, convenience for transportation and storage, and ease of use. However, freeze-drying can cause many types of damage to cells, including a loss of viability, reduction of metabolic activity, and changes in cell morphology. Phyto2Energy fellows from IERU, HMGU and Probiotics investigated this method as a way for preserving the *Psedomonas Putida* bacteria strains identified for prototype bioformula stimulating the growth of the energy crops.

The aim was to find out such a freeze-drying medium which would prevent damage, improve storage stability, and facilitate rehydration of the bioformula. The following lioprotectat solutions were tested: trehalose, inulin and glycerol. The choice was based on the experiences of ProBiotics. Additionally, to evaluate the efficiency of the applied freeze-drying process the survival rates of the bacterial species during the storage were established. The bacterial survival ratio (BSR) was calculated. After 180 and 360 days the survival rates of the bacteria were 70% and 58%, respectively. In short, the results indicated that freeze drying seems to be a promising method for preserving the bioformula and provided ProBiotics with some guidance on its potential production in the future. At the same time, based on the data from the survival rates investigations, trehalose and inulin seemed to work best as lyoprotectants.

Lyophilization proces

The challenge of gasifying a HM contaminated biomass for energy production

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Phytoremediation has been increasingly used as a more sustainable approach for the remediation of contaminated sites. The costs associated with this remediation method are usually lower than other well-known remediation technologies and some environmental impacts, like atmospheric emissions and waste generation, are inexistent. The biomass produced in phytoremediation could be economically valorized in the form of bioenergy (biogas, biofuels and combustion for energy production and heating), representing an important environmental co-benefit, added to others such as erosion control, improving soil quality.

Wastes such as heavy metal (HMC) contaminated biomass are widely available resources, which could be gasified to produce biofuels and electricity and thus help to cope with fossil fuel depletion and reduction of greenhouse gas emissions. The energy crops phytoremediation process is one of the techniques used for remediation of contaminated areas.

After cleaning soil, contaminated biomass is produced. It should be utilized in the safe way. Among available energy crop conversion technologies, the most suitable seems to be gasification, which gives the possibility of controlling the fate of the extracted HMs. The gasification process of heavy metal contaminated biomass in fixed bed installation has many advantages in comparison to the combustion process. It produces a gaseous fuel, which can be used to produce energy in different types of installations.

Properties of the heavy metal contaminated (HMC) samples of Miscanthus x giganteus, Sida hermaphrodita and Spartina pectinata was presented. The data were collected from an HMC arable area in Bytom, Upper Silesia, Poland and the former sewage sludge deposit site in Leipzig, Saxony, Germany. The study investigated the impact of different treatments on biomass elemental compositions to determine its suitability for energy production. Both sites were treated as follows: (i) Control, no treatment, (ii) treated with NPK, fertilizer applied directly to the soil before planting, (iii) treated with the commercial microbial inoculum.

Two further gasification tests were carried out using a fixed bed and termogravimetry (TG) installation at SUT. Analyses have been initiated to collect data of the end products from the gasification.

Additionally, areas of the possible gasification process operations improvement were identified and tested (SUT, ISPE). Pelletizing of Miscanthus feedstock has been performed. Additionally, halloysite as a catalyst was tested as an additive to the pellets.

The possibility of using energy crops in fuel production on HM contaminated sites was presented. Collected biomass were characterized based on parameters, which determine its utility as a biofuel feedstock where gasification processing is advantageous.

Gasification residues are not waste

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Gasification of the energy crop gives by-products such as ashes and tars. Disposal of this residues is an important point for the closing of the phytoremediation driven energy crop production life cycle. Returning of biomass ashes to the locations where the biomass was harvested can be considered as the best sustainable option. In line with the principles of circular economy, it brings back the nutrients to the original soils and thus closes the mineral cycles.

Heavy metals present in the biomass are retained in the solid residues after gasification process together with sulphur, nitrogen, phosphorous and potassium – elements important from the fertilizers point of view. The results of our project show, that despite the presence of heavy metals in ash after the gasification process, some of it still could be used as a fertilizer, especially on heavy metal contaminated sites. Heavy metals limits for utilization of biomass ashes in agriculture and forestry vary between the EU countries. For example, Finnish limits for Pb, Cd and Zn content in ashes for agriculture/forestry application are 100/150, 1.5/17.5 and 1500/4500 mg kg^{-1} respectively. The highest permissible levels of heavy metals in biomass ashes for forestry application are reported from Sweden, amounting to 300 mg kg^{-1} of Pb, 30 mg kg^{-1} of Cd and 7000 mg kg^{-1} of Zn. Polish Government limits for Pb and Cd content in organic-mineral fertilizers used in agriculture are 140 and 5 mg kg^{-1} respectively. This regulation also states that the contents of P and K in fertilizer cannot be lower than 2%. The obtained results were below the limits set for heavy metals, especially for the ashes derived from gasification of the biomass cultivated at the former sewage sludge dewatering site. The presented idea is not to promote use of such materials as fertilizers in high value arable lands, but to consider them as an option for sites already contaminated where concentration of heavy metals exceeds the limits. Application of such ashes on the one hand will not change the situation dramatically on the field concerning heavy metals content but may help in its restoration due to the recirculation of mineral nutrients.

Costs and benefits of a full scale Phyto2Energy approach field application

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VITA34 AG

Finally, financial aspects have to be taken into account. Therefore, costs for full scale remediation of a 1 ha HMC site are calculated representatively for the species Miscanthus x giganteus (German price level, exemplarily for Miscanthus x gigantheus; sources: Ministry for Environment, Agriculture and Geology of Saxony (www.publications.sachsen.de), Service Center Rural Area (DLR) Eifel (www.dlr-eifel.rlp.de)). The plant species is a permanent crop that can be cultivated for 15 years with moderate requirement for nutrients and soil. Waterlogged soils as well as wind and frost exposed sites should be excluded for MG cultivation. Estimated costs for full scale remediation of a 1 ha HMC site consist of one-off and annual costs. Thereby one-off costs are usually planned for the beginning of the project. One-off costs comprise land preparation as well as cultivation and planting of plants. For land preparation weed control has to be carried out optionally before plowing and plant bed preparation. Therefore about 150 EUR have to be calculated. For planting 1 ha with MG about 10,000 rhizomes have to be purchased with about 20 cent per rhizome. Rhizomes are planted by machine and loss of plants within the first year of about 15% has to be calculated. Lost plants have to be replaced. If necessary weed control has to be done. In sum about 2,850 EUR are estimated, leading to one-off costs of about 3,000 EUR.

Annual costs consist of harvest and transport of biomass (650€) as well as storage of biomass (350€). If the application of the inoculum is desired, additional costs for inoculation amount to 2,330 EUR. For 1 ha a demand of 500 L was calculated. The price for inoculum (EmFarma Plus™ by ProBiotics™ Polska, http://www.probiotics.pl/probio-emy/dla-gleby-i-roslin/emfarma-plus.html) is 4.46 EUR/L. Hence, total annual costs were estimated to 3,330 EUR.

Calculating estimated one-off and annual costs for a period of 10 years about 36,300 EUR have to be invested for remediation of 1 ha HMC land. Not included are costs for leasing agricultural land, if applicable, and costs for project management. The latter comprise all management activities for planning of full scale remediation, monitoring and consulting. Further a return of investment considering the revenues for energy production is not considered. Nevertheless, comparing 36,300 EUR to investment costs for conventional soil remediation techniques like e.g. soil excavation, the cost advantage is clearly on the part of the Phyto2Energy approach. Thus, the Phyto2Energy project provides instructions for a direct and financially beneficial application of research results in the agricultural/industrial sector.

About Costs, profits and environmental gains

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Cost-effective and environmental benefit analysis for gasification of HMC biomass is designed as on open document that was improved, adjusted and completed with the experimental results that will be obtained during the project PYTO2ENERGY lifetime and for this, the knowledge has been exchanged and transferred between all the project partners.

The main objective of this work is to create a methodology and an interactive Excel file. The comparison of the small fixed bed gasification unit with other technologies (fluidised bed gasification, pyrolysis and combustion) was determined.

The analysis gives an identification and quantification of appropriate benefits: environmental benefits, economic profits, social aspects, CO2 reduction, agricultural land saving for food production

The determination of the Cost benefits of HMC biomass gasification is a complex procedure and the results are depend on the following variables: installation scale, investment cost, cost of the capital, price for the fuel (natural gas, biomass, coal, petrol, etc.), type of energy produced (electricity, heat, cold), price for the energy (thermal and electricity), the labor cost, geographical position, subsidies from the UE and national governments for promotion of the Renewable Energy Sources (RES), maintenance cost, environmental aspects, EU legislation aspects.

According to the criteria analyzed, and the best solution for energy recovery for HMC Biomass was small and mobile gasification plants.

The labor market and the energy market are constantly changing in Europe, so with the help of the excel file, the decision to implement a project using HMC Biomass in gasification installation can be made according to specific needs.

Project details

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Phytoremediation driven energy crops production on heavy metal degraded areas as local energy carrier

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Industry-Academia Partnerships and Pathways

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Project consortium

Project co-ordinating unit:

IETU

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