European Sustainable Phosphorus Platform

SCOPE NEWSLETTER

ESPP SCOPE Newsletter special issue on BIOCHARS:

Perspectives for pyrolysis of sewage sludges

This SCOPE Newsletter summarises the first Swedish Conference on Sewage Sludge Biochar (Malmö 11-12 October 2022) and considers the opportunities and challenges for development of pyrolysis as possible routes for sewage sludge valorisation.

Contents

1st Swedish Conference on Sewage Sludge Biochar

This conference was organised in Malmö, 11-12 October 2022, as part of the Testbed Ellinge project, and included a site visit to the AquaGreen pilot test workshop at DTU/Risø near Roskilde, Denmark and to a full-scale AquaGreen integrated sludge drying and pyrolysis installation at Fårevejle (Denmark) municipal wastewater treatment works.

The Testbed Ellinge will include testing a 1 t/day input sludge, 18-30% dry matter (DM) AquaGreen pyrolysis pilot at Ellinge municipal wastewater treatment works, municipality of Eslöv, Sweden, planned for Spring 2023. The project is led by VA SYD, a regional water and wastewater operator based in Malmö.

The conference brought together over 120 participants from 14 countries, including the following pyrolysis / biochar technology suppliers:

- AquaGreen *
- Boston Group
- Carbofex *
- C-Green
- Earth Biochar
- Pyreg *
- Scanship (Vow ASA) *
- Suez *
- Terrafix
- WAI Environmental Solutions

** = member of EBI (European Biochar Industry Consortium).*

The conference was organised by Sweden Water Research (a joint company of three Swedish water companies (NSVA, Sydvatten and VA SYD), as part of the Ellinge Testbed project. Moderation was by **David Gustavsson, of VA SYD and Sweden Water Research**.

Henrik Aspegren, CEO, Sweden Water Research outlined challenges for agricultural use of (digested) sewage sludge in Sweden and potential benefits of biochars.

Sweden's sewage sludge quality has improved considerably with the REVAQ certification (see below and ”Slamspridning på åkermark”). A **Sweden Government report in 2020 concluded that agricultural use of sludge should continue to be allowed with quality control conditions.**

However, water companies are looking for possible alternatives, and pyrolysis could be promising, because biochar soil application can increase soil carbon, crop productivity and drought resistance.

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Site visit sewage sludge pyrolysis

Conference participants were able to visit AquaGreen's technology testing hall at **DTU (Denmark Technical University) at Risø near Roskilde,** Denmark, and the **AquaGreen integrated steam drying and pyrolysis unit at Fårevejle wastewater treatment** works, Denmark.

The Risø test site visit saw:

- Pilot **AquaGreen steam dryer**. A small scale unit, 20 kW electricity input, and in operation since 2017 at Nordlaks, Norway, drying aquaculture sludge, and now at AquaGreen's site at Risø.
- Pilot **AquaGreen pyrolysis** unit
- Pilot **AquaGreen carbon activator**, to test conversion of biochar to activated carbon, using steam at 550°C to open the structure
- Pilot **pyrolysis gas cracker**

Stiesdal SkyClean also have gasification technology research and testing on this site.

At Fårevejle participants visited the **AquaGreen integrated sewage sludge pyrolysis installation** (design capacity 4000 t/y sewage sludge, 22-25% DM). *Photo above.*

The steam drying and pyrolysis installation was operating during the visit, but the automated biochar output system (to transport containers) was not operating as it was undergoing modification. The unit showed limited odour in the building, coming from the sludge transport belts upstream of the unit, which are covered but not hermetically.

The process is continuous and fully automated, enabling distant monitoring and control. Optimization of control parameters is expected to happen continuously.

The AquaGreen process is **energy efficient, due to proprietary integrated steam drying of the sewage sludge** (input c. 22% – 25% DM) using a triple continuous screw dryer, heated by offgas from burning the pyrolysis gas. A **patented input system ensures that no oxygen enters the steam dryer with the sewage sludge**, so ensuring efficient drying, low corrosion and effective pyrolysis.

The pyrolysis process is operated to minimise condensate (oil) production, and the oil is not condensed but burnt directly with the offgas. A specially designed ceramic gas burner (CTI-Risø) with offgas scrubber ensures **low atmospheric emissions** (NO_x < limit values). Energy is mainly used to heat the sludge dryer (so generating steam), with excess energy recovered at 80°C by steam condensation for district heating (estimated 2000 kWh heat per year for the 4000 t/y sludge input at Fårevejle).

The unit at Fårevejle is expected to bring c. 1 500 tCO_2-e carbon credits (1 000 – 1 500 for district heating, 400 for carbon sequestered in the biochar), as well as reducing methane and N_2O emissions and emissions from sewage sludge transport to fields (saving some 2 000 tCO_2e).

Pyrolysis technologies

Henning Schmidt-Petersen and Christian Wieth, AquaGreen, presented the company's development of an **integrated sewage sludge drying and pyrolysis process (650°C).**

The process was tested initially with a container scale continuous-operation pilot, capacity 100 kg/h sewage sludge input, tested for a total of around 2 000 hours.

An industrial scale pilot is now under commissioning at **Fårevejle municipal wastewater treatment works, Denmark**, 50 000 p.e. - ***details in "Site visit" above***. This unit has an input capacity of c. 4 000 t/y sewage sludge and will produce c. 400 t/y of biochar. This unit has now been operated for testing since April 2022, and optimisation of automatisation and control is now finalised. (*Photo*).

A second full-scale unit also treating around 4000 t/y sewage sludge is installed at **Søndersø wastewater treatment works, Denmark**, and is currently being commissioned (*photo*).

A third AquaGreen installation is under construction and will be installed at **Ellinge wastewater treatment plant**, **Eslöv, Sweden**.

Biochar produced from sewage sludge contains 5 - 6 % P_{-total} and 2 - 3 % N_{-total}.

Photo: Conference site visit introduction, AquaGreen offices.

Tests performed by Eurofins and Force Technologies have shown **removal of PFAS (perfluoroalkyl chemicals), PAH (poly aromatic hydrocarbons), pharmaceuticals and pesticides**. PFAS was reduced from 52 µg/kg-$PFAS^4$ in incoming sludge to non-detectable in the biochar, offgas scrubber water and condensate from the dryer. PAH in biochars produced is c. 0.2 mg/kg (an order of magnitude lower than the 6 $mgPAH_{16}$/kg limit in the EU Fertilising Products Regulation CMC14).

Photos: AquaGreen integrated sewage sludge drying and pyrolysis installations at (above) Fårevejle and (below) Søndersø wastewater treatment works, Denmark.

Marcel Rensmann and Helmut Gruber, Pyreg, explained that the company is supplying pyrolysis installations since 2009 with today **over 50 commercial installations operational worldwide, of which 7 treat sewage sludge.**

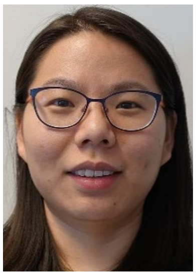
Pyreg is market leader for pyrolysis units, with an estimated 40% of the world market.

Pyreg's process is **carbon credit certified**. The pyrolysis reactor is operated at 500 – 800 °C, depending on the biomass input, and is heated by burning pyrolysis offgas. Some oxygen is allowed into the pyrolysis reactor to foster exothermal reaction (generate heat).

Operation is generally net-energy zero (no external energy input required) when pyrolysing digested sewage sludge dried to at least 80% DM. The 1500 tDM/y Pyreg installation treating sewage sludge at Lorsbach, near Frankfurt, Germany (*photos below*), uses an ELIQUO-Stulz sludge drier to take digested sludge at c. 23% DM to 80% DM, with a low specific energy consumption of c. 0.8 kWh/kg H_2O evaporation.

Photos below: Pyreg

Photo below: Pyreg



Steinar Danielsen and Ran Tao, [WAI Environmental Solutions AS](https://). The company has a first **pilot pyrolysis installation at Tønsberg, Norway, since 2017 (20 kg/h)**. WAI is currently building a full-scale pyrolysis unit, intended to input 40 000 t/y (increasing to 100 000 t/y in a second phase) of dry woody materials (sawmill by-products and demolition wood) in Haslestad, Norway.

In a Norway-China collaboration research project, WAI has built and is operating, in Yixing, Jiangsu Province, a rotary kiln pyrolysis demonstration plant (500 kg/h), *photo below*, able to treat sewage sludge, food waste, woody biomass and other organic materials.

WAI participates in the **RenCARBio project**, a 4-year research project funded by the Norwegian Research Council and led by Aquateam COWI. This project includes sewage sludge anaerobic digestion, pyrolysis, plant-growth experiments with the resulting biochar and life cycle assessment.

Pål Jahre Nilsen, Scanship (VOW ASA), explained that the company is market leader for on-ship waste and wastewater treatment for cruise ships. A 10 000 passenger cruise ship generates 50 000 p.e. wastewater.

Scanship has developed microwave-assisted pyrolysis (at 700 – 800 °C), which can be much more compact and have a power intensity up to thousand times higher than conventional kilns. Installations have been sold, are under installation on cruise ships, and will be in operation at sea late 2023.

A commercially sold 5 t/h hybrid rotary kiln pyrolysis reactor is under construction and will be in operation onland in 2023.

VOW has currently one customer working with pyrolysis of sewage sludge, and sees a large potential for on-land application of their technology.

Gudny Flatabo, Scanship, presented simulation results on **inputting pyrolysis gases and oils from digested sludge pyrolysis into an anaerobic digester** (*photo pilot tests below)*. The objective is to convert hydrogen and carbon monoxide from pyrolysis gas to methane so that it can contribute to biomethane production at biogas plants.

Scanship/VOW ASA bought ETIA Technologies in 2019 and has integrated ETIA's **Biogreen** heated spiral screw system into their portfolio (*see photo*). This technology is widely implemented in the specialty sector of spice sterilisation (Safesteril® with over 100 units installed worldwide) and can also be used for pyrolysis. VOW ASA also bought the company C.H. **Evensen** in 2022, specialists in high temperature equipment

Scanship's **Oda Kjørlaug Svennevik** wrote her PhD thesis, published in 2019, on dewatering of sludge. Scanship has in pilot testing reached up to **50% DM after dewatering.**

Below : Biogreen industrial unit (Scanship VOW)

Christoph Gareis, HSY (Helsinki Region Environmental Services) is operating a 3 600 t/y treatment capacity pyrolysis unit since 2021 (*photo*), after research with Luke and Gasum. Approximately 20% by weight of wood is added as a support material. The unit has a drying device, pyrolysis drum, gas burner and exhaust air and flue gas cleaning systems.

The products from the HSY pyrolysis unit (*photo* above) are sewage sludge biochar and pyrolysis gas, which is used to supply heat to the unit. Various operating temperatures and retention times were tested in a one-year program, over 170 organic contaminants were tested in input sludge and in biochar, and the biochar was tested in various applications.

Conclusions from operation were that the unit operated reliably and largely energy self-sufficient (with 20% wood added to input), generation of pyrolysis oil could be prevented and that cost and quality objectives were achieved. A pyrolysis temperature of at least 500°C and a retention time of approx. 40 minutes seem appropriate and sufficient. An upscale of the system is possible, but implementation is not currently planned.

In Finland it is currently possible to use sludge char as an additive in biowaste composting. Approval as a fertilizer has been applied for.

Nadav Ziv, Earth Biochar Ltd, Israel (Compostor.co), produce the CompoChar product, a biochar from sewage sludge compost mixed with wood chips. The current installation takes around 500 kg/day input (70 – 85 % DM), for continuous pyrolysis at 550°C - 700°C. A larger installation is under construction (10 000 t/y biochar output, *photo below*).

This sewage sludge derived biochar is authorised in Israel, no longer subject to water-sewage regulations, and is used and marketed as a greenhouse growing media. It combines optimal water retention and a nutrient reservoir which buffers deficiencies.

The CompoChar allows growing with minimal to no extra fertilisation. Inoculation of pro-biotics into the biochar to improve crop fungal resistance is being tested.

Photos below: plants grown on CompoChar

Jessica Deane, Welsh Water, Sion Brackenbury, Terrafix, and Alex Wilcox Brooke, Severn Wye Energy Agency presented tests of a **200 kg/h pilot pyrolysis unit at Port Talbot municipal sewage works** (*photo below*). The unit has a pyrolysis unit (800°C, c. 2 minutes), an offgas burner (producing heat) and an offgas scrubber.

Under these conditions, **microplastics and cadmium were removed from the biochar, and detectable PFAS was reduced by nearly 95%.**

For Welsh Water, pyrolysis of sewage sludge may offer a solution to reduce pressure on land application of sludge resulting from Nitrate Vulnerable Zone limits, reduce transport of sludge and contribute to the company's 2050 carbon net zero objective.

A challenge is that the energy content of the sewage sludge after digestion is only around 4 MJ/tDM, whereas at least 10 MJ/tDM is estimated as necessary to enable self-sustaining pyrolysis. Other biomass such as wood chips must therefore be pyrolysed with the sewage sludge.

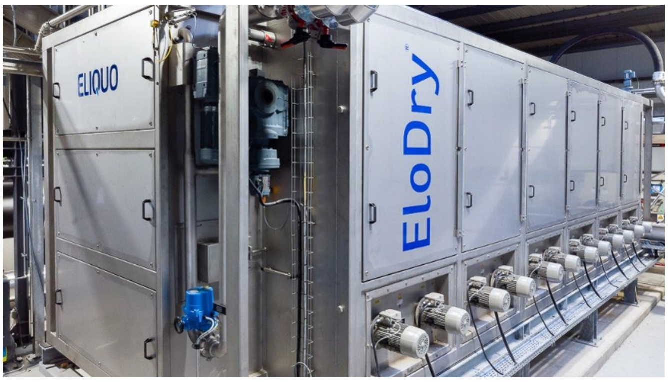
Photo: Terrafix pilot, Port Talbot wwtp, Welsh Water

Joyce Dou, Beston Group (online from China). 3 stage process: drying 150°C, pyrolysis 300°C, carbonisation 600°C. Product aims for markets as a barbecue coal or activated carbon. Over twenty **full-scale installations (10 – 30 t/day input) are operating today in China and worldwide,** treating wastes such as tyres, oils, plastics. A unit is now developed to treating up to 40 000 t/y wet weight sewage sludge or manure.


Maria Dittmann and Elke Sellering, ELIQUO, presented the **Elodry** sewage sludge heated belt drier, today operational in five full-scale sludge carbonisation plants worldwide, including treating sludge for the 300 000 p.e. Loganholme sewage works (Australia, Queensland). *Photo below.*

The belt drier here dries to at least 90 % DM for input to the pyrolysis unit (pyrolysis at approx. 600 °C, technology supplied by Pyrocal). **The sewage sludge biochar produced is authorised as a fertiliser in Australia**.

Energy consumption in the heated belt drier upstream of pyrolysis can be reduced if the dry matter content of the input sludge is increased. Centrifuges or filter presses can achieve up to 26% DM with digested sewage sludge, compared to maybe 22% with undigested sludge. Use of **LYSOTHERM** (see below) can enable nearly 30% DM to be reached.



Photos: Eliquo sludge dryers at (above) Loganholme, Australia and (below) Lorsbach, Germany.

ELIQUO also offer other technologies relevant to enhance the energy balance of sewage sludge drying and of pyrolysis plants. This includes **LYSOTHERM**, a thermal sludge lysis process which can enhance VSR (volatile solids reduction) in the digester and dewaterability of the sludge to reduce the energy demand for drying. **ELOVAC** (*photo below)* is a combined vacuum dewatering and phosphate precipitation process which also enhances the dewaterability of digested sludge (see SCOPE Newsletter n°134).

Photos: Eliquo (above) LysoTherm, Amersfoort, The Netherlands and (below) ELOVAC.

Research

Eliminating contaminants in pyrolysis

Linus Ekmann Burgman, Linköping University, discussed sewage sludge use in agriculture in Sweden. After a crisis in food industry perception in the 1990's, related to concerns about public opinion on contaminants, the % of Sweden's sewage sludge going to land fell to around 5% in 2002. The **REVAQ voluntary sludge quality certification system, combined with active stakeholder dialogue engaging farmers, food industry and retailers organisations**, has enabled the % going to land to climb back to around 40% today (see ESPP SCOPE Newsletter n°123).

Pelin Kocatürk Schumacher, Norwegian University of Life Sciences, presented **lab studies of fate of PFAS in sewage sludge** in AD and pyrolysis. Levels are reduced by around one third in anaerobic digestion of sludge (mesophilic 38 – 42 °C, c. 12 days residence time). PFAS were detectable in 300°C biochar from digested sewage sludge, but not in 500°C and 700°C biochars. Further investigation is needed to verify whether PFAS degradation products remain in these biochars.

Lab trials show that sewage sludge biochar can be effective in removing phosphate from aquaculture wastewater, with removal being mainly related to iron and aluminium content. The biochar was also effective in removing pharmaceuticals and personal care chemicals from treated grey water.

Erlend Sørmo, Norwegian Geotechnical Institute, presented testing of a 2.5 kg/h pyrolysis pilot unit (Biogreen), operated at 500 – 800 °C. Analysis of 56 PFAS cogeners enabled establishment of an approximate mass balance. Standard analysis methods did not detect PFAS in biochars, but improved methods found 0 – 3.4 mgPFAS/t in biochars. PFAS were also detected in offgases.

Overall, **98% PFAS "elimination" was shown for pyrolysis temperatures > 500°C**, but further investigation is needed to establish the fate of the "eliminated" PFAS: in pyrolysis oil? or broken down to substances such as perfluoroalkanes?

Longer chain PFAS molecules were more resistant to elimination. These will be banned in the EU in 2023 (C9-C14 PFAS, EU OJ 5/8/2021) but long-chain PFAS may also be present as an impurity in production of shorter-chain PFAS (such as PFOA, PFHx). The EU has also announced the principle of a general ban of all PFAS (except for "essential uses") as part of the Green Deal Chemicals Strategy, but the horizon and conditions remain to be defined (see ESPP eNews n°49).

Naemieh Vali, Swedish Centre for Resource ReCovery, University of Borås, presented lab tests and thermodynamics equilibrium calculation modelling (TEC) of pyrolysis of dried sewage sludges (batch, 800g input) at 500 – 900 °C, looking at removal of heavy metals. Around 650°C is recommended to reduce heavy metals. More than 95% of the phosphorus remains in the biochar. **Cadmium and arsenic are largely removed (volatilised) in pyrolysis at this temperature, lead and zinc are significantly reduced, but copper is not**. Levels of copper, zinc, and cadmium were well below the limits of the Swedish regulations for farmland application. Treatment of pyrolysis gas burner offgas must therefore ensure that volatilised heavy metals are not emitted to the atmosphere.

Below photo: lab tests, Swedish Centre for Resource ReCovery, University of Borås

Helmut Gerber, Pyreg, summarised knowledge on contaminant removal in pyrolysis. Meyer, Glaser et al. 2014 (DOI) showed 99% elimination of PAH (poly aromatic hydrocarbons) from high-PAH input materials. The German environment agency UBA (2019 here) concluded that **pharmaceuticals were non-detectable in sewage sludge biochar** from Pyreg's full-scale plant operating in Unkel, Germany (pyrolysis at 500°C). He noted that temperatures of 600°C or higher are in some cases necessary to eliminate cadmium in sludge, but result in lower plant availability of phosphorus.

A recent study (summarised below) shows that sewage sludge biochar (from a wwtp using chemical P-removal) shows 90% P-fertiliser effectiveness compared to mineral fertiliser TSP (grass, 160 days).

Lab and pilot pyrolysis trials and LCAs

Gunnar Thelin, Ekobalans. Ekobalans develops sewage sludge valorisation solutions, using different company's pyrolysis and other technologies. Mr. Thelin considers that cadmium levels in sewage sludge in Sweden can be an obstacle to sewage sludge use in agriculture (average 0.9 mgCd/kgDM in Swedish sewage sludge*), despite considerable reductions over recent decades.

ESPP note: this cadmium level is lower than the EU Fertilising Products Regulation limits: 0.9 vs 1.5 mgCd/kgDM for organic fertilisers, or 15 vs. 60 mgCd/kgP$_2$O$_5$ for inorganic fertiliser.

Ekobalans has carried out **pilot pyrolysis tests with batches of 100 – 500 kg dried digested and non-digested sludge**. These suggest that high temperatures are needed vaporise cadmium in pyrolysis (e.g. 750°C, 15 mins.). In these tests, heat energy from pyrolysis of dried, digested sewage sludge (from burning of pyrolysis gas and tar) was inadequate to ensure stable pyrolysis at this temperature. Possible solutions proposed by Ekobalans are electrical heating or mixing of sludge with high-energy substrates such as wood chips.

Jaroslav Moško, UCT Prague, presented laboratory tests of pyrolysis at 400°C – 800°C of anaerobically digested sewage sludge (operating chemical P-removal). **Higher pyrolysis temperatures led to higher ash contents, increased porosity and higher sulphide content** of the biochar (from sulphates in the sludge). The sulphides may facilitate heavy metal immobilization.

Tong Han, KTH (Sweden Royal Institute of Technology) presented laboratory pyrolysis tests at 550°C. **Co-pyrolysis of sewage sludge with willow wood resulted in higher carbon and nitrogen stability in the biochar** (up to 0.69 and to 0.68 respectively, for accelerated oxidization testing using 5% H_2O_2 for 48 hours). Treatment of the biochar with hydrogen peroxide (H_2O_2) at 80°C also improved carbon stability.

Maja Karolina Rydgård, University of Copenhagen, Ferticycle project, presented a **Life Cycle Analysis** (LCA) comparing storage of sewage sludge (anaerobically digested sewage sludge as received from the wastewater treatment plant, storage for 6-12 months which is current management practice before field application of sludge in Sweden) and pyrolysis of sewage sludge. The LCA includes the field application of the materials. It was concluded that key contributions to the lower climate impact of the pyrolysis were the avoided emissions of CO_2, N_2O and CH_4 during sludge storage, and higher sequestration of carbon in soil with biochar as compared to sewage sludge.

Lisa Zakrisson, Swedish University of Agricultural Sciences (SLU), Rest till Bäst project, presented further **Life Cycle Analysis** (LCA) work, underlining that different choices of parameters lead to widely varying conclusions. Water content of sewage sludge input to pyrolysis and duration of carbon sequestration in biochars both strongly impact conclusions.

Ruben Sakrabani, Cranfield University UK, presented analysis of different hydrochar and pyrochar materials. Conclusions are that **lower pyrolysis temperatures produce biochars with higher levels of organic carbon**, beneficial for plants and for soil health.

Biochars as phosphorus fertilisers?

Claes Johansson, Lantmännen, a Swedish farmers' organisation, underlined the need for reliable recycled nutrient products which are recognised as safe, that is no risk of contaminants. Today, digested sewage sludge is excluded from use in grain production where grain is intended for human food use (e.g. bread, pasta) and **sewage sludge biochar could be acceptable if proven contaminant-free**.

Farmers are prepared to pay for the nutrient content of biochars (phosphorus), and fertiliser prices are now high. However, **the economic value of the organic carbon soil improvement from biochar remains to be demonstrated** because unrealistically high application tonnages would be needed to really impact soil carbon levels.

Josephine Kooij, University of Copenhagen, presented laboratory studies of phosphorus extractability (Hedley extraction) from biochars produced at 400°C and 600°C from digested sewage sludges from wastewater treatment plant using iron for chemical P-removal (Biofos, Copenhagen) and from a facility using biological P-removal (Gardeby, Denmark).

Pyrolysis significantly reduced water and bicarbonate extractable phosphorus for both sewage sludges. Differences in P lability were attributed to differences in speciation, observed using liquid state NMR and SEM-EDX. Work is underway to understand how these products impact agronomic efficiency and P leaching propensity.

Clara Sophie Kopp, University of Copenhagen (FertiCycle Marie Curie project) presented laboratory trials adding acid (sulphuric acid) or alkali (sodium hydroxide) to sewage sludge biochars. See also slides presented at ESPC4/PERM Vienna June 2022 here.

Four different sludge biochars were compared coming from differently treated sewage sludges (all digested, three with chemical P removal with Fe or Al and one from biological P-removal, pyrolysis at 600-700 °C). **Maize and wheat pot trials showed plant growth with untreated biochar no higher than with no P fertiliser**. Both sulphuric acid and NaOH treatment of the biochar increased the extractable P, but the highest shoot biomass was achieved with the NaOH treatment for all four biochars. Sulphuric acid increased metal mobility in the biochar, posing questions about risks of possible metal contaminants, whereas sodium hydroxide reduced the mobility of the metals. Further work is needed to assess whether these treatments impact the stability of the organic carbon in the biochar.

Hessen report on recycled P materials as fertilisers

A report on phosphate solubility and fertiliser effectiveness trials of recycled materials by the **Hessen State Testing Institute**, with logistic support from the German Phosphorus Platform, is published by the Hessen State Environment Ministry (HMUKLV).

Nine recycled materials from sewage are studied: Pyreg sewage sludge biochar (from works using iron for chemical P-removal ???), struvite x2, sewage sludge incineration ash x2, SePura - Outotec calcined phosphate, calcium phosphate recovered from biochar, superphosphate from phosphoric acid extracted from ash.

Only the two sewage sludge ashes showed NAC P-solubility (neutral ammonium citrate / total phosphorus) significantly below the 80% limit specified for declaring phosphorus as a nutrient of the EU Fertilising Products Regulation, Annex III – PFC 1, 4(b). However, **the sewage sludge biochar was also very slightly below this 80% solubility limit** (table p10).

Five month rye grass pot trials (160 days) were carried out with the test material mixed initially into a zero-P soil substrate. The two ashes, calcined phosphate and sewage sludge biochar all showed P-uptake and rye grass dry matter production significantly below mineral P fertiliser TSP (page 14). **The sewage sludge biochar showed biomass production around 10% lower and P-uptake around 25% lower than with mineral P fertiliser**.

"P-Düngewirksamkeit von Klärschlamm-Rezyklaten. Abschlussbericht." F. Jacobi et al., 6/10/2022, 40 pages https://umwelt.hessen.de/nachhaltigkeit-und-ressourcenschutz/phosphorrueckgewinnung

Biochars as pollutant adsorbents

Christoph Thomsen, Flensburg University Germany, presented operational trials **using 1 m^3 containers of biochar as filter adsorbents to treat manure digestate liquor and manure storage run-off on-farm**, at his parents' cattle farm. The $1m^3$ container filter systems are easily moved using farm equipment, installable by the farmer, use simple equipment (hosepipe connections, timer) and can be used in duplicate in parallel or in series. Filters were trialled with miscanthus fibre, wood chips and with sewage sludge biochar or wood biochar. Both types of biochars had been pyrolyzed at approximately 700 °C.

The filter blocks (*photo* above) showed, over six months, reliable removal of around one third of COD, one third of total P and half of total N and ammonia, probably as a combined result of biological activity and adsorption, but after this time P reduction diminished.

Including biochar in the filter blocks ensured that the container material did not become smelly and was readily handleable enabling field spreading at times of year when crops need nutrients.

Further work is underway to combine this system with a reed-bed for further purification.

Ida Sylwan, Mälardalen University, Sweden, summarised lab tests of heavy metal adsorption using biochar produced from sewage sludge at temperature 550°C. The biochar was effective in removing copper, cadmium, zinc, lead, nickel, chromium, mercury and silver from solutions in water. When tested in municipal wastewater mainly cadmium adsorption occurred.

Regulation and standards

Christian Wurzer, University of Edinburgh, Great Britain, underlined the current **absence of standard methods for analysis of organic contaminants in biochars**. Methods used in other organic substrates may not give accurate results because contaminants are bound into recalcitrant organic carbon in biochars. "Not detectable" may thus not mean not present.

ESPP comment: a large number of EU testing standards are being developed to support the new EU Fertilising Products Regulation (FPR), see links below. However, standards will only be developed for testing of parameters which are specified in the EU FPR. Biochar stakeholders should therefore input to the European Commission on standards needed to support the FPR CMC14 "Pyrolysis and gasification materials" or for analysis of FPR Annex I (PFC) parameters for which existing test methods may not be appropriate for biochars. See: European Commission mandate to CEN-CENELEC for development of standards to support the EU Fertilising products Regulation C(2020)612 M/564 and amendments HERE and proposed standards for development for STRUBIAS materials (including CMC14 Pyrolysis and gasification materials) HERE.

Chris Thornton, ESPP (European Sustainable Phosphorus Platform), presented the current status and ongoing developments in the regulatory status of biochars as fertilisers.

The new EU Fertilising Products Regulation 2019/1009 (FPR) which entered into application summer 2022, introduces "optional harmonisation". This means that waste-derived biochars can be used as fertilising products by one (or more) of the following routes:

- CE-Mark (EU) fertilising product, under the FPR
- "National" fertiliser, under national regulations
- Under waste regulation, with traceability and producer responsibility

Biochars are now included in the EU FPR, as CMC14 (Component Material Category) titled "Pyrolysis and Gasification Materials".

However, to date, all biochars derived from Animal By-Products (including manures) or from sewage sludge are excluded.

Certain ABP-derived biochars may become included, if the DG SANTE proposals currently open to public consultation (to 24th October 2022) are adopted: biochars made from composts or digestates where the composting or anaerobic digestion respects the existing ABP "standard" processing requirements, and/or if the pyrolysis or gasification itself respects the ABP "standard" processing requirements for sanitisation of manures (>=70°C for >=60 minutes, inter alia).

Biochars from sewage sludge are today excluded from CMC14 after discussion in the STRUBIAS expert group (in which ESPP participated), because the European Commission (JRC) concluded that there was insufficient evidence of elimination of pharmaceuticals, microplastics and other organic contaminants, and of their possible breakdown products. See detail in JRC STRUBIAS report, pages 137-138 here.

The JRC conclusions specify however that **the exclusion of sewage sludge biochars could be revisited**, if sufficient new data is provided. ESPP suggests that the biochar industry should collate and input new evidence (new = not already referenced in the STRUBIAS report).

ESPP reminds that the FPR specifies (for all for all PFC1 Inorganic, Organo-Mineral and Organic Fertilisers, in Annex III Labelling, part II – 4b) that, "**where phosphorus is a declared nutrient** … declared P content shall consist only of P in the phosphatic form" and at least 40% of total phosphorus shall be water soluble or 75% NAC soluble (neutral ammonium citrate).

ESPP's full slides are available online here, and include also information on biochars in national fertilisers regulations, and biochars in Certified Organic Farming.

Nikolas Hageman, Ithaka Institute, presented the **European Biochar Certificate (EBC),** which is now owned by Carbon Standards International CSi. Around one hundred biochar producers are today certified, representing some two-thirds of EU biochar production. EBC's objectives are the definition of biochar, safety of use, sustainability, conformity with regulatory requirements and transparency through partial disclosure of analyses.

Permitted biomass for biochar production is defined in a positive (limiting) list. EBC guidelines include requirements on energy efficiency and emissions, biochar sampling and analysis. Biochars are certified according to application classes (what applications are allowed, e.g. EBC-Feed for use as animal feed amendment, EBC-Agro for use in agriculture in accordance with EU Fertilising Products Regulation CMC14). The CSi approved certifier q.inspecta will offer EU-fertiliser certification in collaboration with their partner Certrust as an add-on to EBC certification

EBC-C-Sink can certify negative carbon emissions from biochar production, enabling possible access to carbon credits. C-Sink specifies H/C_{-org} in the biochar < 0.4, that is lower than the H/C_{-org} < 0.7 required in EBC and in the EU Fertilising Products Regulation CMC14.

Until Dec 31st, 2022, only plant biomass inputs are permitted. Questions relevant for sewage sludge biochars and for manure biochars are terminology and public acceptance (biochar in German 'Pflanzenkohle' = plant char) and contaminants.

EBC v11 (Jan 2023) is expected to cover manure, sewage sludge, and digestates. These are both proposed to require pyrolysis >=550°C for >= 10 minutes to eliminate a broad range of contaminants.

A new application class **"EBC Fertilizer"** will be introduced for materials containing pyrogenic carbon that are rich in (macro/micro)nutrients. Specifications, including minimum nutrient content requirements and input materials, are work in progress. National annexes to EBC-Fertilizer could set more or less strict requirements for certification for sale on a national market, and are e.g. in preparation for Denmark.

It is reminded that sewage sludge and manure derived biochars are today excluded from biochars under the EU Fertilising Products Regulation CMC14 (may soon be partly authorised for manure under certain conditions), so that such EBC certified biochars cannot obtain the EU fertilisers CE-Mark.

Sewage sludge biochar regulatory status

Biochars produced from sewage sludge are today authorised as fertilisers (under different conditions) in several countries (i.e. pyrolysis, gasification and hydrothermal carbonisation materials), either by national fertiliser regulations, or by authorisation of sewage-derived products from one or more companies.

ESPP wishes to collate information on authorisation elsewhere, where applicable.

Biochars (pyrolysis materials) from sewage sludge are currently excluded from CE-Mark fertilisers (under the EU FPR = Fertilising Products Regulation 2019/1009, Annex 2, CMC 14 "Pyrolysis and gasification materials"). The EU Joint Research Centre (JRC) preparatory study (STRUBIAS) concluded (p137-p138) that there was not sufficient evidence of elimination of organic contaminants in sewage (phthalates, cleaning products, pharmaceuticals, endocrine disruptors) and of their breakdown products.

However, **sewage sludge biochar is today authorised for use in agriculture** in the following countries:

- **Czech Republic.** By Annex 1 of Decree 474/2000 (amendment of October 2021), subject to limits on heavy metals and PAH (20 mg/kg DM PAH_{12} compared to 6 mg/kg DM PAH_{16} in the EU FPR). Biochars from sewage sludge for agricultural use must be approved by regional authorities, and must apply to obtain national End-of-Waste status. A successful registration has been made by KARBO HF s.r.o. for sewage sludge biochar from a PYREG / HST Hydrosystemy installation at Bohuslavice-Trutnov municipal wastewater treatment plant (Product name Karbofert T1).
- **Sweden.** Sewage sludge biochars from two PYREG installations in Germany (Unkel wastewater treatment plant, Bionero) have been successfully registered as fertilising products with the national agency KEMI (Kemikalieinspektion), see registration process roadmap.
- **Italy.** Biochars from sewage sludge are covered by an Italian Standard for "Hydrothermal carbonization" chars (or biocarbons) from municipal sewage or organic industrial sludge published in February 2022. This specifies HTC temperature of 180 – 230°C (the EU FPR CMC14 specifies a minimum temperature of 180°C), limits for ash content, volatiles, nitrogen, heavy metals, and a range for "fixed carbon" of 11 – 34%. The standard does not however confer End-of-Waste status.
- **Denmark.** The Danish Environment Ministry has stated on 22nd June 2022 that pyrolysis of sewage sludge and certain other wastes is an acceptable pre-treatment prior to agricultural application (controlled sanitation of waste). The pyrolysis must take place at minimum 500 °C for 3 minutes. The biochar retains waste status and application is subject to Danish waste to soil regulations and limits, the same as for sewage sludge.
- **Estonia**: The Estonian legislation allows the agricultural use of biochar produced from sewage sludge according to Regulation No. 24/2017, which is based on the Waste Act as well as on the Product Conformity Act. Products derived from sewage sludge and/or biodegradable waste can be applied on agricultural lands, including biochar. Possible uses include certain agricultural and forest applications, landscaping and soil restoration. The regulation excludes e.g. vegetable cultivation in the first year after spreading, grazing animals or animal feed use within two months of spreading.
- **UK:** UKWIR is preparing and will publish soon a report "Converting sewage sludge to biochar - a review of options & feasibility". This will be summarised in ESPP eNews when published.
- **Norway:** biochar products from sewage sludge can be used in agriculture, under the same constraints as for hygienised sewage sludge, that is subject to spreading limitations (heavy metal levels, only certain crops …) and full traceability from sewage works to field.
- **Israel**. The Israel EPA has authorised sludge biochar with a first full composting phase and then pyrolysis (600°C, 20 minutes). The biochar is no longer classified as'Sewage Sludge' according to the Israel Sewage sludge regulations [Water regulations (water pollution prevention) (Sludge use and elimination) 2004].
- **Australia:** sewage sludge biochar is authorised as fertiliser and is no longer considered waste.

The information above is correct to the best of our understanding, but may be incomplete or inaccurate, as understanding different national regulatory frameworks is complex.

ESPP would be happy to receive information concerning other countries where use of sewage sludge biochars or HTC materials in fertilisers is authorised.

The information above was kindly provided by University of Department of Power Engineering (UCT Prague), PYREG, DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH, NIBIO , ELIQUO, Università di Bologna, Earth Biochar Ltd, European Biochar Industry Consortium (EBI) and AquaGreen.

Conclusions

These are ESPP's conclusions from the conference, and these conclusions were not validated by participants in Malmö. However, all speakers have been consulted on these conclusions and either concur, or their differences are indicated below:

- **Pyrolysis temperatures of at least 500°C – 650°C, for sufficient time, are needed to ensure effective elimination (close to 100%) of organic contaminants, such as pharmaceuticals, and also microplastics**. See e.g. review by Buss et al. 2021 in ESPP eNews n°58)
- **Appropriate incineration of pyrolysis gases is also necessary** to avoid possible contaminant emissions in exhaust gases (IED conditions, 850°C)
- These temperatures also seem to ensure **elimination of PFAS**. Further verification on PFAS elimination is needed to ensure that (a) breakdown products are not remaining and (b) the "non detectable" results of analysis are not because PFAS is tightly bound into the biochar.
- These temperatures also ensure **significant removal of heavy metals**: most cadmium ….
- **There is not agreement about what minimum pyrolysis temperatures and times are necessary to eliminate all organic contaminants including PFAS**: 500°C ? 650°C ? 10 minutes ? 20 minutes ? 40 minutes ?
- Different pyrolysis temperatures will modify biochar **properties in soil**: carbon content, specific surface area..
- **The fertiliser value (plant availability) of phosphorus in sewage sludge biochars needs to be clarified**. Higher pyrolysis temperatures tend to reduce P availability, as do probably **iron or aluminium content** of sludge (from chemical P-removal in sewage works).
- Biochars, including sewage sludge biochars, can be **effective as adsorbents** to remove heavy metals, pharmaceuticals and other organic contaminants from wastewaters, and also (especially biochars rich in iron or aluminium) to remove phosphorus. However, such contaminated biochar can no longer be used in agriculture, so regeneration is necessary to remove contaminants: one possible way to do this is to re-pass through the pyrolysis process.
- **Uptake of sewage biochars** by farmers will require ensuring reliable product quality, demonstrating plant availability of nutrients, and convincing farmers and other food industry stakeholders that sewage sludge biochars are free of organic contaminants (POPs, PFAS, pharmaceuticals, microplastics). **Biochar certification can support this.**
- To enable successful implementation in sewage treatment works, it is essential to **convince and to train operating staff**, and to maximise automatisation.
- **Sewage sludge biochars are currently excluded from the EU Fertilising Products Regulation,** and also from national fertilisers in some countries**, but are authorised for agricultural application in a number of countries,** (see above). These regulatory obstacles need to be addressed.
- Companies present at the conference suggested that the **European Biochar Industry Consortium (EBI),** should take the lead in advocacy, dossier preparation and data gathering to **support regulatory authorisation of sewage sludge derived biochars**, in cooperation with ESPP.
- Following exchanges with ESPP, the **European Biochar Industry Consortium (EBI)** is also working with interested companies to prepare a dossier for EFSA (European Food Safety Agency) to request validation of the safety of manure derived biochars, as a preliminary to requesting definition of an 'Animal By Product Regulation End-Point'. This would enable inclusion of manure biochars in CMC14 of the EU Fertilising Products Regulation.

ESPP members