Summary of the 3rd IWA Resource Recovery Conference (IWARR 2019)

Venice 8-12 September 2019

https://www.iwarr2019.org

This third IWA Resource Recovery Conference (IWARR 2019), in Venice, September 2019, co-organised with the Horizon2020 SMART-Plant project, brought together over **360 participants from 43 countries**. Around 350 abstracts were submitted to the conference, leading to over 200 presentations in three parallel sessions over three days, 120 posters, and a further fifty or so presentations in pre- and post-conference workshops.

This SCOPE Newsletter special edition presents some of the **conference and workshop conclusions**, and summarises a **selection of the papers and posters** relevant to nutrient recovery and recycling.

Conference conclusions

Conclusions were drawn from the conference by **Ana Soares, Cranfield University, UK** and **IWA RRfW** cluster (IWA Resource Recovery from Water cluster):

- Significant **progress** is being made in recent years into resource recovery from wastewater.
- In Europe, **EU research and innovation funding** is playing an instrumental and leading role in this progress, especially by supporting validation and demonstration in real operating conditions.
- Research has moved beyond energy recover to **recovery of a range of resources**. Nutrient and materials recovery offer important potential, but in many regions the most important resource to recover and recycle is water itself.
- There are significant opportunities but major challenges in **developing countries** which do not already have centralised infrastructure.
- This IWA Conference remains **scientific**, but showed increasing interest from companies, both SMEs and large groups, and a number of examples of progress from research towards scale-up and implementation.
- There is a need to **engage with stakeholders and product value chains**. Platforms present at the Conference can enable this.

From recovery to market

The post-conference workshops linked to IWARR 2019 included the **joint working meeting on implementation of resource recovery research organised by Horizon 2020** projects **SMART-Plant**, **nextGen**, **Hydrousa** and **Project-O** and the European Commission **EASME**. This built on case studies from the pre-conference workshop on recovery implementation (see below).

The conclusions of this workshop will be published more fully by the projects.

The following challenges were emphasised:

- **Long term and consistent political support.**
- **Networking** and collaboration between science, operators, stakeholders and end-users of products.
- **Shared competence**, e.g. benchmarking, knowledge exchange …
- Addressing **regulatory barriers**. A particular example underlined was the divergent End-of-Waste status for the same material under different EU national authorities.
- Communications to obtain **public acceptance** of and positive support for recycled products.
- Further funding of **large demonstration projects** in Horizon Europe.

*IWA (International Water Association) organises two series of conferences on resource recovery and nutrient recycling. The first IWA Resource Recovery (**IWARR**) Conference series started in Ghent in 2015 (see SCOPE Newsletter n°118), whereas IWA Nutrient Removal and Recovery Conferences (**IWANRR**) have been taking place for some time (see e.g. Harbin, 2012, SCOPE Newsletter n°89). Earlier conferences specifically targeting on nutrient recycling include those organised in e.g. Vancouver 2009 (SCOPE 74), Noordwijkerhout 2001 (SCOPE 41).*

IWARR 2019, September 2019 Venice https://www.iwarr2019.org

IWANRR, 8-12 June 2020 (Espoo, Finland) https://iwa-nrr.org/ *- that is the week before ESPC4* www.phosphorusplatform.eu/ESPC4

Members of the European Sustainable Phosphorus Platform

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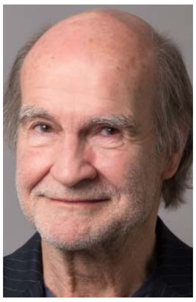
Workshop on implementation

A pre-conference workshop on implementation of resource recovery was organised by **Ludwig Hermann (ESPP), Ilje Pikaar (University of Queensland)** and **Olaf van der Kolk (AquaMinerals)**. This showed, with case studies, the importance of developing a product adapted to market and user needs.

Rob van Springelen, Ostara, indicated that **reliable, high quality recovered struvite today has a high market demand**. The challenge for Ostara, as a producer, is to ensure adequate and reliable supply for contracts with fertiliser wholesalers.

Olaf van der Kolk, AquaMinerals, presented **calcite recovery in the Netherlands drinking water industry**. Modifications in the water treatment technology (using calcite seed instead of sand) has enabled to produce a pure, high quality calcite product, and to find markets in animal feed, industry and cosmetics. He underlined the interest of developing several different markets to avoid dependence on one customer.

He noted the difficulties of moving research to market in the water sector which is structured by very large operators and public investment. There is a need to **clarify the definition of "circular economy"** and interactions with energy and greenhouse gas emissions.



Ludwig Hermann, European Sustainable Phosphorus Platform (ESPP), addressed the questions related to the need of innovative value chains to generate demand for and revenues from wastewater-based recycled products within a regulatory framework which is gradually getting more supportive for sustainable solutions in a circular economy.

The presentation of **Martijn Olde Weghuis, Vitens**, (indisposed) showed that Vitens has the strategy to, **not only generate attractive revenues with its byproducts, but also create an impact on its own environment.** Vitens' waste-streams are upcycled to products that have a positive impact on soil-health and biodiversity, thereby protecting precious groundwater sources and closing the loop. Examples of such applications were shown: Ferreau® (**iron fertilizer**), HumVi™ (**fulvic acid based soil improver**) and **slow-release lime pellets**.

Circular City workshop

A pre-conference workshop organised by the EU 'COST' (Horizon2020) action Circular City (2018-2022) presented work underway and discussed factors favouring or hindering nature-based solutions (NBS) and the circular economy in cities.

This COST network engages some **360 persons in 39 countries**. This COST network engages some **360 persons in 39 countries**. As a first main outcome, all Working Groups have produced a review paper that will be published in IWAP open access Blue-Green System journal (end 2019/early 2020),. The 'Resource Recovery' WG paper will present state-of-the art in the field of recovery of resources from urban and industrial wastewaters and solid wastes and gaseous effluents.

Discussions at the workshop in Venice identified a number of barriers to implementation of NBS and circular economy in cities: obstacles to **changing public behaviour** and habits, including lack of understanding; **regulatory barriers and lack of regulatory support**, and again lack of understanding within local authorities; and the **need for full scale demonstrations and local case studies** ("living labs").

However, **examples in operation already show that implementation of NBS in cities is possible** where political will is combined with expert support, subsidies, stimulating and flexible regulations and a multi-criteria approach to suggested solutions.

The conference organising team:

Conference keynotes and context

Diane d'Arras, IWA President, opening the conference, underlined the progress already made in resource recovery R&D and the need to include Circular Economy in utilities' contracts with regulators, in order to move forward implementation. She emphasised that the water treatment industry functions in the long term. Extension of infrastructure service life to 50 years and beyond is essential for economic sustainability. Design for the future is very challenging, but **resource recovery and energy efficiency are clearly strong, long-term drivers**.

Mark Van Loosdrecht (TU Delft) and **Willy Verstraete (Ghent University),** noted key challenges to uptake of resource recovery from wastewater:

- need to integrate into **existing infrastructure** and to integrate with water and heat recovery;
- logistics (many **decentralised producing sites** each with limited quantities);
- need for **policy action on economic pricing of externalities** to make circularity viable;
- addressing **contaminants**
- and the critical question of **consumer acceptance**.

Future wastewater treatment will **move away from breaking down organic matter to its valorisation**, including in biogas (upgraded to methane), capturing in flocculation, algae production or other routes.

Paul Callaghan, BlueTech Research, presented the trailer (3 minutes) of the upcoming **Brave Blue World documentary** movie (release planned late 2019), presenting success stories in sustainable water technologies "into a new future for water". The movie emphasises the need to move technologies to implementation, with examples from across the world, including Ostara struvite phosphate recovery in Chicago and All-Gas, Chiclana, Spain (in the INCOVER project), converting algae grown with wastewater to biomethane for transport.

The Brave Blue World has an **open call for stories in water sustainability**, and will share further examples via their website https://www.braveblue.world/share-your-story

Sewage sludge challenges in Italy

Andrea Guerrini, ARERA Italy and WAREG (European association of national water regulators www.wareg.org) underlined the need to develop economic tools to accompany resource recovery implementation.

Water operators should be enabled to pass on costs to consumers for resource recovery and for investments in efficiency, should be financially rewarded for quality and penalised for non-compliance with regulations. For example, sewage sludge use on farmland or recycling should benefit from incentives, and sludge landfilling should be financially penalised. Existing economic tools, such as energy savings certificates or feed in tariffs for bio-methane or electricity should be made more secure. In Italy, quality targets for operator investments in water management have increased since 2017 from 50 to 70€/person/year.

Andrea Lanuzza, Gruppo CAP, Italy, presented the operator's strategy for resource recovery and reuse. Gruppo CAP, covering the region around (but not including Milan) operates 63 wwtps and treating nearly 2.5 million p.e. Sustainability objectives for 2033 include reducing network drinking water losses from 24% to 15% and reducing CO_2 emissions by -40%. **Currently over one quarter of sewage sludge is marketed to agriculture as fertiliser (**mostly after composting), however sludge disposal is becoming more difficult, with costs having risen from 75 €/t.DM to 115 €/t.DM today. Sludge content is generally around 2.1% P/DM. Gruppo CAP aims to develop struvite recovery (objective 130 t/y of struvite), to continue to valorise around one quarter of sewage sludge in agriculture, and to create a centralised sludge incineration site (62 000 t/y wet weight dewatered sewage sludge, plus 3 000 t/y dried sewage sludge, plus municipal green wastes) with possibly phosphorus recovery from the incineration ash (around 8 000 t ash/year) as well as district heating (as well as biomethane from anaerobic digestion upstream of incineration).

Baltic Bonus RETURN

Karina Barquet, Stockholm Environment Institute, summarised conclusions of the Baltic BONUS RETURN project assessing **what is needed to accelerate transition towards a circular phosphorus economy**. The assessment is based on a literature search and analysis (600 reports and publications) and interviews with ten experts. The project identified a number of barriers and opportunities for phosphorus recycling, including: manure supply-demand mismatch, lock-in to existing waste water technologies, some technologies now at commercial implementation level, need for knowledge transfer, importance of farmer ease of use of recycled products and of social acceptability, inadequate policy steering (despite phosphorus being on EU Critical Raw Materials List and targeted actions such as the new EU Fertilising Products Regulation), need to account environmental externalities into economics and prices.

Several technologies were looked at in more detail: Helsinki **HSY Ravita** (see below), **EasyMining** (see below), **BioPhree** (proprietary phosphorus adsorbents with regeneration, see ESSP eNews n°29 *), **Palopuron Symbioosi** (agroecological symbiosis, University of Helsinki) and TerraNova. **TerraNovaUltra** is a continuous hydrothermal hydrolysis carbonization process at 175°C, 20-25 bars, where most of the phosphorus ends in the liquid fraction not the hydrochar. Full scale plants Full scale plants are already operating (to date without phosphorus recovery), in Jining, China 14.000 t/y dewatered sewage sludge, generating a solid fuel for energy production.

** The development of BioPhree is not impacted by the dissolution of the US license holder Green Water Solution The BioPhree technology continues to be developed by the proprietor, Aquacare, The Netherlands.*

Operator resource recovery strategies

Bruno Tisserand, Veolia, presented the company's "**Ecosystem**" approach to link cities and regions, water cycle management and agriculture. The objective is a paradigm shift towards resource recovery, including water reuse, recovery of mineral nutrients (N, P, K) and return of organic carbon to soil.

Key factors to move forward are the engagement of both R&D and plant operators in developing **Circular Economy approaches for water, waste and energy activities**, in dialogue with agriculture and farmers; developing **recycled products which ensure quality** and correspond to users' needs and market demand; and reduction and control of pollutants at source to **improve sewage sludge quality**.

Veolia is engaging resources not only in nutrient recovery R&D (P-REX, Phos4You, PhosForce, Nutrient Upcycling Alliance NUA with Yara – EIT Raw Materials) but also in implementation (**Phosphorus Roadmap**), including in wwtp design – build and operation, P-recovery technology benchmarking, in organic and mineral fertilising product development and in field testing and support for farmers.

Bart Saerens, Aquafin, Flanders, outlined the operator's strategy to develop nutrient recovery. Aquafin treats water for 5.5 million p.e. at 300 wwtps. Aquafin has successfully tested struvite recovery (see SCOPE Newsletter n°116) with a full scale pilot plant (8 m^3/h). The struvite was sold and used in agriculture, and the process improved sludge dewatering (+2% DS). However, struvite recovery only functions in biological nutrient removal wwtps.

Aquafin has fixed an objective of 2/3 of sewage sludge to go to mono-incineration (not mixed with municipal solid or industrial waste) with **phosphorus recovery by 2030**, and is currently looking at technologies available.

Aquafin also intends to test **ammonia recovery**, looking at both air stripping and membrane + vacuum stripping. Use of sewage nitrogen to produce bacterial protein is also a potential route.

Potassium recovery seems more difficult, because most potassium is present in the water discharge stream, at dilute concentrations.

Laura Rossi, Helsinki Region Environmental Services Authority (HSY), Finland, summarised the phosphorus removal and resource recovery strategy and new technology developments underway. The objective is to develop a phosphorus recovery route (**RAVITA**), applicable in combination with chemical P-removal (to achieve low discharge consents), and adapted to small sewage works. HSY is developing its own processes (see also SCOPE Newsleter n°127):

- **tertiary post-precipitation of phosphorus**, solids separation (rotating disc filter) and sludge dewatering, to achieve **low P discharge (0.2 mgP/l).** A pilot plant is (1 000 pe) is operated since 2018 at Viikinmäki, Helsinki, sewage works.
- Acid treatment of this tertiary sludge (high in iron or aluminium from chemical P-removal) using phosphoric acid, then **separation of the phosphoric acid (for phosphorus recycling)** and of the iron/aluminium chemicals (recycling as coagulants to the sewage works), by continuous solvent - solvent extraction. A pilot plant (1 000 pe) will start operation at Viikinmäki in 2020.
- **nitrogen recovery**, by ammonia stripping and reaction with phosphoric acid to produce ammonium phosphate fertiliser (project stage)
- **pyrolysis of the secondary (biological) sewage sludge**, at 450 – 800°C, after drying. Lab scale trials show that pharmaceuticals and organic contaminants are mostly non detectable in the biochar. A current (2018-2020) project with Natural Resource Institute Finland and Gasum Oy takes the process into pilot-scale, will assess the quality of the sludge-derived biochar in more detail and study possible end-uses. Results from the research will be used to design a full scale sludge pyrolysis plant (55 000 p.e., 3 000 t/y sludge DM input), to be launched in 2020.

EU funding of water resource recovery R&D

Evdokia Achilleos, European Commission - EASME (Executive Agency for Small and Medium-sized Enterprises) underlined the high quality of scientific content presented at this IWARR 2019 Conference. She underlined the support of the European Union in this area, with major **19 water resource recovery projects funded under Horizon 2020 SC5** (including 86 demonstration plants and business models) and around **30 projects under LIFE** (with the next LIFE Water call expected Spring 2020).

She noted that resource recovery in the water sector leads to sustainability, supports Circular Economy objectives and contributes to environmental protection and climate action. It is now at a critical point because there are significant research advancements and proof of viability of new solutions, a need to tackle major challenges for the environment and climate, and there is political will at European level.

Research needs to progress towards demonstrating proof of sustainability and of industrial and economic feasibility, and to support social acceptance.

Looking beyond Europe

Xia Huang, Tsinghua University, China summarised the situation of municipal wastewater treatment and resource recovery today in China. 2/3 of China's 650 cities face water shortages and only a fifth of surface waters are at quality levels IV – VI. The number of sewage works has increased from 600 in 2003, to nearly 6 000 today. Main technologies operating are **biological nutrient removal**: AAO (anaerobic – anoxic – aerobic), oxidation ditch, sequential batch reactor.

Currently around 10% of urban wastewater is reused, with an objective of 20% water reuse by 2020 in water-scarce cities. Water reuse quality specifications are in place since 2005 for aquifer recharge, irrigation and other uses.

Phosphorus is identified by China as a Critical Raw Material. Phosphorus discharge limits for sewage works can be low, for example 0.2 – 0.3 mgP/l in Beijing. However, **at present, around 63% of sewage sludge goes to landfill**, 2% to incineration and only around 14% is recycling to compost / agriculture. Specifications are however in place for technical phosphorus recovery (**Technical Regulation on Metal Phosphates from Waste Water Treatment Plants**). An Airprex struvite plant is operating since 2016 at Jinnan, Tianjin (800 t struvite / year).

Obstacles to the development of phosphorus recycling include the absence of a legal obligation, the need to implement sewage sludge anaerobic digestion more widely, dilute levels of phosphorus in sewage sludge and high levels of iron.

Miriam Otoo, International Water Institute, USA, presented opportunities for resource recovery (nutrient, energy and water) from wastewater in developing countries. She emphasised understanding of viable institutional linkages and business models that can incentivise private sector engagement in sanitation service delivery.

See "Resource Recovery from Waste. Business Models for Energy, Nutrient and Water Reuse in Low- and Middle-income Countries", 2018 *http://www.iwmi.cgiar.org/Publications/Books/PDF/resource-recovery-from-waste.pdf*

Phosphorus recovery technologies

Adsorbents

Solvei Jensen, Aarhus University (presentation) and **Chiara Esposito, University of Florence** (poster) showed results of tests looking at a number of different materials for phosphorus adsorption from treated wastewater. This work, within the Horizon 2020 **INCOVER** project, aims to identify materials for implementation in small sewage works, for example in reed bed substrates, to achieve reliable low phosphorus discharges. Eight different materials were screened in lab experiments. Good performance was in particular achieved by the cat litter material Catsan (which contains sand, lime and other minerals). A problem was that materials dissolved over time, and this was successfully addressed by using coatings permeable to phosphorus. After two years of testing (7 l/day, 6 mgP/l) the material was not phosphorus saturated and was continuing to remove phosphorus. Full scale testing is underway at Almeria and Barcelona sewage works, using treated wastewater (12 mgP/l) showing 90% P-removal. Pot trials with maize show that the media after P adsorption are effective slow-release fertilisers. This work will be taken to demonstration scale in the new **LIFE INTEXT** project 2019-2023, led by AQUALIA with participation of Aarhus University and AIMEN.

Juan Antonio Alvarez, AIMEN Technology Centre, presented further work in the **INCOVER** project, with three full scale case studies testing integration of a number of innovative technologies for anaerobic sludge digestion, nutrient removal and resource recovery. These include, in Barcelona and in Chiclana, Spain, combinations of PBR (photo-bio-reactor), anaerobic digestion of the algae produced, production of a bio-fertiliser or N and P recovery by evaporation; in Almeria, Spain, N and P recovery in adsorbing media in constructed wetlands; and in Leipzig / Bad Königshofen, Germany, hydrothermal carbonisation HTC (producing biochar). Key results are related to the **integration of technologies, sensing and monitoring systems**.

Céline Vaneeckhaute, Université Laval, Canada, presented a P-recovery technology based on "nano-enhanced" **adsorption resins containing $FeOH_2$** (Purolite FerrIX A33e). This has been tested at pilot scale (11 m^3/day) at Holland Marsh in Ontario and an optimised configuration will now be further tested at Québec City municipal wwtp (photo below), operated as a tertiary treatment system on sewage works discharge. The concept is to install the phosphorus adsorption columns in sewage works, and to operate centralised resin generation. Tests suggest that low phosphorus discharge limits of <0.1 mg total P/l could be achieved. Phosphorus is recovered in the resin regeneration process as an NPK liquid fertiliser solution with up to 150 mgP/l concentration. Work is currently underway to address the problem of competing ions (e.g. sulphates) in the adsorption resin. *Photo below.*

Asya Drenkova-Tuhtan, University of Stuttgart / Tallinn University of Technology, presented 200 litre reactor scale tests of iron (Fe_3O_4) containing composite particles (5-25 µm) for phosphorus adsorption. The materials can be suspended in wastewater, magnetised and demagnetised on demand, so enabling removal in a low-cost continuous magnetic drum separator. Phosphorus is selectively adsorbed from the wastewater onto the particles, then released and concentrated using sodium hydroxide, and the regenerated particles are then be reused. Testing in municipal wwtp effluent spiked to 10 mgP/l showed **reduction of soluble phosphorus to below the detection limit**, consistently over 30 cycles, and 90% recovery of removed phosphorus (release in regeneration, then struvite precipitation). The system does not target particulate phosphorus, but in these tests total phosphorus was <.0.05 mgP/l after treatment.

The technology was developed in cooperation with Fraunhofer Institute for Silicate Research (ISC), Germany. Further information can be found in the following publications: https://doi.org/10.1016/j.watres.2016.11.039 and https://doi.org/10.1016/j.watres.2018.08.067

Masanobu Takashima, Fukui University of Technology, Japan, presented lab scale tests of nutrient recovery from high-solid thermophilic anaerobic digestion, using municipal sewage sludge from a works not operating P-removal. **Porous iron hydroxide was tested as a P-adsorbent**, using acid for regeneration. Around 70% removal of soluble phosphorus was achieved from the digested sludge, and around 50% of the sludge phosphorus was recovered after regeneration.

Laura Delgado-González, IRSTEA/Syntea, France, presented tests underway of **use of apatite as a filter material**, for wwtp final effluent polishing, applicable to smaller wwtps. Apatite is the main constituent of natural phosphate rock. Perhaps surprisingly, it is proven to be effective as in removing soluble phosphorus from effluents. Apatite does this by adsorption and precipitation of calcium phosphate (in effect, "more apatite"), so that the spent apatite material could potentially be recycled as a fertiliser. Multiple pilot-scale filter beds (20 cm depth filter beds), fed with synthetic wastewater and with sewage works effluent (treated wastewater), have been tested with a range of different apatite materials and different operating conditions for up to 6 months operation. Modelling work is underway (using HP1: Hydrus-PHREEQC).

Sludge hydrolysis

Cristina Monea, University of Stuttgart, Germany, presented the '**Stuttgart process'**, see e.g. SCOPE Newsletter n°89 from 2012. Tertiary sludge (from a post-precipitation process) is dissolved in acid to release phosphorus into solution, so that it can then be recovered as struvite. Results presented show that a pH of below 3 must be achieve to release 80-90% of phosphorus in sludges where wwtps are using aluminium for phosphorus removal, and pH 1.5 is necessary where the wwtp is using iron for P-removal.

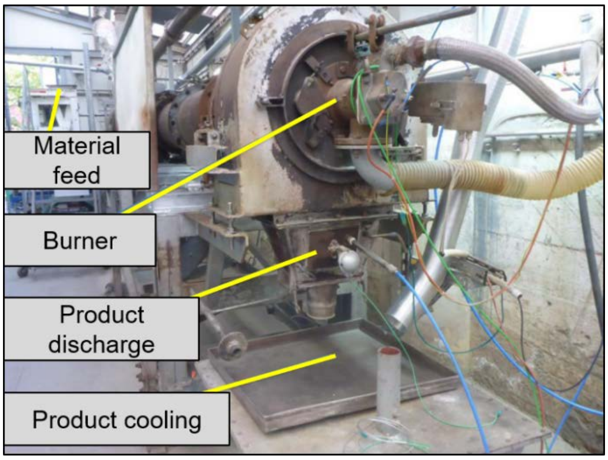
Srdana Kolakovic, New Lisbon University, presented the **PhosForce** project (Veolia) testing **bioacidification to solubilise phosphorus in digested sewage sludge**, in order to then enable struvite recovery (Struvia, Veolia). A 150 litre pilot has been operated continuously for several months at Frielas, Portugal and at Schönebeck, Germany, showing 65 – 75% phosphorus solubilisation in both iron P-removal and biological P-removal sludges.

Neslihan Semerci, Marmara University, Turkey, presented **lab scale tests and 1 m^3 pilot tests of solubilisation of sewage sludge** (from Atakoy wwtp, operating enhanced biological P-removal EBPR) during fermentation for several days at alkaline pH followed by struvite recovery. Higher pH led to higher phosphorus release and higher volatile fatty acid production. One day of fermentation at pH 8 achieved 15% release of phosphorus to soluble PO_4, increasing to 40% at pH 10. Struvite was successfully precipitated in a stirred batch reactor at pH 8.5

Thermal and ash processes

Julian Ulbrich, Outotec, presented an update on the **AshDec** process to recover phosphorus from sewage sludge incineration ash (see SCOPE Newsletter n°78). This has now been tested at pilot scale (at IBU-tec testing facility, Weimar, *photo below*), with a 20 – 50 kg/h ash input rotary kiln, operated continuously for up to ten days.

Operation at around 850°C with addition of sodium carbonate (Na_2CO_3) was shown to be **reliable and stable, generating a product with around 9%P content, 80-95% NAC soluble** (neutral ammonium citrate, a test of plant phosphorus availability). Concentrations of lead and cadmium were significantly reduced, but less so arsenic, copper and zinc. Pot trials with spinach show fertiliser performance comparable to triple super phosphate (TSP). A proposed full scale installation is now pending funding (RePhoR, Bavaria, Germany).



Yariv Cohen, EasyMining, Sweden, presented the **Ash2Phos** process. Sewage sludge ash is dissolved in hydrochloric acid (ambient temperature, no pressure). The residue of ash which is not dissolved in acid consists mainly of inorganic silicates, and after separation and washing can be used e.g. in the cement or concrete industries. **Phosphorus, iron and aluminium compounds are separated from the acid leachate** and from each other by specific dissolution and precipitation reactions, in processes characterised by internal recirculation of chemicals. The main chemical consumed in this process is lime. The remaining acid solution is neutralised and treated to remove heavy metals.

The Ash2Phos process generates three products: **pure calcium phosphate** (e.g. typically <0.1 mg/kg cadmium), **ferric chloride** and **aluminium hydroxide**. The latter two can be used for production of coagulants for use in waste water treatment, which creates a closed loop. The intermediate calcium phosphate can be processed into NPK fertilisers, ammonium phosphates, superphosphates, as well as into feed phosphates.

Pilot trails for process optimization are conducted in EasyMining's R&D centre in Uppsala. A **30 – 45 000 t-ash/year plant is planned for 2022 in Sweden and a 60 000 t-ash/year plant is planned for 2023 – 2024 in Germany**.

Anna Hämäläinen, Tampere University, Finland, presented **lab scale (2 litre Parr batch reactor) tests** of **HTC (hydro thermal carbonisation)** of 25% DM sewage sludge digestate. Nutrient mass balances, operating at 210°C, showed 60-70% of input total phosphorus and nitrogen in the hydrochar (rather than the liquid or gas fractions), but slightly lower % at higher temperature (230°C). 1 litre of sewage sludge was converted to around 400g solid hydrochar and around 600g liquid fraction. Work is now ongoing on plant availability of the nutrients in the hydrochar and on fate of contaminants in the process.

Maurizio Volpe, Unikore-Unitn, Italy, presented lab scale (2 litre batch reactor) tests of **HTC (hydro thermal carbonisation)** of sewage sludge, and the industrial scale CarboREM project underway.

The lab tests used digested sludge from Trento Nord wwtp Italy (3.1 %P/DM). The HTC process was operated at 190-210°C, then hydrochar was separated from the liquid fraction using filter paper, followed by acid leaching to release phosphorus, then finally sodium hydroxide solution was added to increase pH to 9 and so

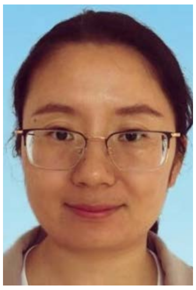
precipitate phosphates. **Around 55 – 70% of total P in the sewage sludge was recovered in the phosphate precipitate**, with a higher proportion at lower HTC operating temperatures. The **acid leaching also reduces heavy metal content of the hydrochar**, taking lead, cadmium and nickel below detection limits, so that the hydrochar could be used as a soil amendment (conform to Italy's fertilising product regulation).

The **CarboREM** unit (*above photo*) is a 1 m^3 transportable HTC continuous reactor, with oil boiler heat recirculating system, designed to treat digested, centrifuged sewage sludge. A CarboREM HTC plant will be assembled in Mezzocorona (TN) and will be operative at the end of October 2019

Dines Thornberg, Biofos, Copenhagen, explained that this is the largest wastewater treatment operator in Denmark, with three wwtps (Lynetten, Avedøre and Damhusåen, operating Bio-Denipho nutrient removal) treating 1.8 million p.e. Biofos produces **8 000 t/y of mono-incinerated sludge ash, and has a further 280 000 t in separate landfill**. The operator's resource recovery strategy targets energy (including biogas), carbon, nitrogen (development of Anamox process) and phosphorus recovery for recycling. A cooperation agreement has been signed with EasyMining (see above).

Also, Biofos is testing with Veolia, at 10 litre lab scale, a **membrane electrodialysis process** with the objective of producing phosphoric acid from acid-dissolved sewage sludge incineration ash. Work is underway to improve the reactor design and reduce ash wear on the membrane with the objective of now developing a container-scale unit.

See results of lab tests: "Electrodialytic Separation of Phosphorus and Heavy Metals from Two Types of Sewage Sludge Ash", L. Ottosen et al. 2014 https://doi.org/10.1080/01496395.2014.904347 and "Phosphorous recovery from sewage sludge ash suspended in waterin a two-compartment electrodialytic cell", L. Ottosen et al., 2016 http://dx.doi.org/10.1016/j.wasman.2016.02.015



Tingting Qian, Nanyang Technological University, Singapore, presented results of **lab scale tests assessing the fertiliser value and impacts on soil micro-organisms of biochar produced from sewage sludge**. The biochar was produced from non-digested EBPR (enhanced biological phosphorus removal) wwtp sludge, in a lab scale pyrolysis unit at 400°C or 700°C. The biochar showed high phosphorus content (16 -19% P/DM), with good plant availability within 2 days. Much of the phosphorus in 700°C biochar was present as polyphosphate, which can be adsorbed onto surface-negative bacteria, then metabolised. Tests suggested that free radicals present in the 400°C biochar may inhibit bacteria metabolism, so that the 700°C biochar is a more effective phosphorus fertiliser.

Marek Holba, Asio Tech, Czech Republic, presented ongoing testing of different materials (biochar, sand, slag) surface modified with iron oxides and oxohydroxides, as adsorbents for phosphorus removal. Following successful lab scale tests, pilot trials are now underway testing the materials for tertiary treatment of the effluent of two municipal wwtps.

Ricardo Gori, Florence University, Italy, explained that agricultural application of sewage sludge is no longer possible in the Tuscany region since 2016, following a court decision (application of law 99/92). A solution is thus needed for the region's 110 000 t/y wet weight (expected to increase to 130 000 t/y) sewage sludge, which is currently exported to other Italian regions and abroad. In the **SLUDGE4.0 project** (co-funded by Tuscany region), 300 ml laboratory scale tests of HTC (180-220°C, 30-240 mins.) were carried out on sewage sludge (before anaerobic digestion, 5% DM) from San Colombano wwtp, Florence. This wwtp has very dilute inflow. It uses modified Ludzack-Ettinger process (BOD and N-removal) plus chemical P-removal. Conclusions are that the sewage work sludge residence time in the wwtp (MCRT) significantly impacts the HTC process, and methane production from anaerobic digestion of the HTC liquor. Ammonia removal from the HTC liquor is necessary if this recirculated to the wwtp. A **centralised HTC plant is now planned in Tuscany** (capacity 80 000 t/y wet weight sludge).

Phosphate precipitation

Saba Daneshgar, University of Pavia, Italy, presented tests of **struvite precipitation from pure mineral solution** (simulating aerobic bio-P mixed liquor, without organics) in a 200 litre continuous-flow reactor. 60% (at pH 8.5) – 90% (at pH 9) soluble phosphorus removal was achieved, but a tendency to precipitate amorphous calcium phosphate (instead of struvite) was seen. Conclusions are that struvite precipitation was not very efficient in this aerobic liquor (possibly due to low ammonia levels), but use of lime to precipitate amorphous calcium phosphate could achieve 75% soluble P removal at pH 8.5.

Carolina Gonzalez, Universidad de Antioquia, Colombia, presented **batch beaker struvite precipitation experiments from sewage sludge centrate** (after anaerobic digestion, Yorkshire Water UK Esholt wwtp), with 3 hour reaction time at pH 8 – 10 and temperature 25 – 40°C. Results show >90% soluble P-removal, but ammonia losses at high pH or high temperature. The optimum pH and temperature to obtain large struvite particles were pH9 and 20°C.

Wokke Wijdeveld,, WETSUS, The Netherlands, presented pilot scale (1 m^3/h continuous) recovery of phosphorus from sludge digestate (before dewatering) by magnetic separation (**ViviMag** process, see ESPP eNews n°26). Vivianite, $Fe_3(PO_4)_2*8H_2O$, can be the prevalent phosphate form in digestate, if enough iron is present, because anaerobic conditions reduce iron(III) to iron(II). The **TRL7 pilot** VPHGMS (Vertical ring Pulsating High Gradient Magnetic Separator) was tested at Nieuwveer wwtp, The Netherlands for 9 months, and bench-scale tests were carried out with sludge from four other wwtps in The Netherlands, Finland and Germany. Around 80% vivianite separation was achieved, corresponding to around 40% of total P in the digestate. Increased iron dosing can increase these rates. **The resulting product was 70% pure vivianite**, containing also organics and other iron compounds. Vivianite has possible industrial applications as an iron fertiliser or in lithium potassium batteries.

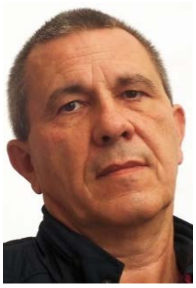
Tests are underway to extract the phosphorus from the vivianite as potassium phosphate and to recover iron salts which can be recycled to wwtps for use in chemical P-removal. As well as possible phosphorus recovery, ViviMag can reduce sewage sludge production by 10-15%.

Recycling nutrients via algae growth

Lucia Rigamonti and **Elena Ficara, Politecnico di Milano**, presented production of micro-algae as a sidestream process in wwtps. A **6 m^2 surface area pilot algae raceway** has been tested for four months at Bresso wwtp, near Milan (Gruppo CAP), **fed with sludge digestate centrate and with anaerobic digester offgas** (via a contact column), producing (during this summer period) 4 – 10 g algal dry mass/m^2/day. The algal biomass produced showed heavy metals below the limits of the (outdated) EU sludge directive 86/278. Atmospheric losses of NO_x and CO_2 were reduced by the offgas contact column, whereas the raceway led to ammonia emissions (could probably be reduced by pH control). Energy consumption of the algae system would be more than offset by reduced energy consumption for wwtp aeration (removal / oxidation of carbon and nitrogen in centrate returned to wwtp). Around two thirds of the centrate soluble phosphorus was removed in the algal system (c. 6 mgP-PO_4/l inflow).

Darja Istenič, University of Ljubljana, Slovenia, presented results of demonstration scale testing of different green technologies for waste water treatment (Ajdovščina wwtp, Slovenia, effluent after primary treatment only): evapotranspirative willow tree plantation (27 m^3, since 2016) and high rate algal pond (batch, 3 m^3, since spring 2019). Both systems were considered to achieve waste water treatment objectives.

The **algal pond** was operated at 2 m^2/p.e. footprint, generating c. 25 kg DM algal biomass/p.e. per year (350g P, 1650 gN), which could be used to produce fertilisers. *ESPP comment: this is around 1gP/p.e./day recovered in the algae, that is probably very approximately half the phosphorus in domestic wastewater*. Lower loading rates might increase the transfer of P from wastewater to biomass due to longer retention times. The **willow tree plantation** operated with zero discharge, meaning that all inflow waste water was used for tree growth and evapotranspiration. Nutrients are stored in wood biomass and soil. It was operated at around 42 m^2/p.e. footprint, generating c. 130 kg of woodchips/p.e. per year, containing 130 gP and 7.2 gN / p.e. / year).



Robert Reinhardt, Algen (Algal Technology Centre), Slovenia, summarised work on nutrient recycling from wastewater with algae in the Algaebiogas, Saltgae, Water2Return and AlgaeCan projects. Challenges are the footprint required, cost, control of microbial community, harvesting techniques, legislation and developing added-value use for the algal biomass. A 100 m^2 demonstration algal pond has been operated in Ljubljana since 2014, and methanisation of the algal biomass has been tested. Different harvesting techniques have been tested: sedimentation, dissolved air flotation, electro coagulation/flocculation. Algae produced from food industry wastewater have been **successfully tested as animal feed** (piglets), as well as for materials recovery (non-isocyanurate polyurethanes). **Algae from slaughterhouse wastewater treatment** (Matadero del Sur, Spain) have been tested for production of fertilisers and fertilising product biostimulants, showing effectiveness in rye grass pot trials.

Larissa Arashiro, Universitat Politècnica de Catalunya, presented wastewater treatment and resource recovery using microalgae (cyanobacteria) in a photobioreactor (PBR), with results from 2 litre lab tests on real wastewater/sewage sludge. 30 – 60 minutes residence time in the PBR enables **>90% ammonia and over 50% COD removal**. Freeze drying / thawing, ultrasound and centrifugation were used to separate blue pigments. The remaining biomass can be used for methane production, with nutrients remaining in the digestate.

Other R&D

Maria Lopez Abelairas, Idener, Spain, summarised the Horizon2020 **Afterlife** project, looking at innovative technologies to recover resources from food industry wastewaters (cheese production, citrus fruit processing). The objective is to generate products such as biopolymers and VHAs (e.g. polyhydroxyalkanoates PHAs), essential oils, proteins and biogas. It was suggested to also look at recovery of nutrients.

Cristina Cavinato, University Ca' Foscari of Venice, and **Giovanni Battista Gatti, Trento Province**, presented four years full-scale testing of anaerobic co-digestion of sewage sludge with municipal organic wastes (organic fraction of municipal solid waste OFMSW) at Rovereto, and compared the economics for Rovereto and Treviso wwtps. The OFSMW is pressed then sieved to remove impurities such as plastic bags used by households for the waste. Such co-digestion can significantly improve both methane production and feasibility of resource recovery, but does bring some disadvantages (e.g. increase in sand in anaerobic digesters). The treatment of the OFSMW also brings significant revenue to the wwtp with around 60€/t gate fees and Green Certificates.

Kees Roest, KWR, Netherlands, presented the **CoRe Water** project, using membranes with forward and reverse osmosis to treat sewage, recover reuse-quality water, and develop a concentrated stream for energy and nutrient recovery (up to 30x more concentrated than the initial sewage). The process uses several membrane steps using osmotic pressure (pumping only). A 200 l/h pilot has been successfully tested and a 2000 l/h pilot is now under construction. Challenges include ammonia and salt 'leakage' through the membranes and fouling of the forward osmosis membranes.

Florent Chazarenc, IRSTEA, Villeurbanne (Lyon), France, presented studies on performance of bio-sourced flocculants /coagulants (to improve sedimentation and so remove BOD/COD/TSS in wwtps, for chemical P-removal) and interactions with methane production from sludge digestion (Agence de l'Eau Rhône-Méditerranée-Corse **CAPTURE** project). 54 products were tested, including iron salts, petrochemical polymers (polyamine, polydadmac) and bio-sourced products (tannin, starch), in jar tests and 40 litre column tests. Conclusions are that starch-based flocculants are bio-degradable (whereas tannin has low biodegradability) and offer acceptable performance, so improving carbon capture and methane production from sludge. Combination with iron salts enables also phosphorus removal. Full scale tests (3 000 m^3/h) are now underway at the Saint Fons wwtp, Lyon (1 million p.e.).

Attilio Toscano & Stevo Lavrnić, University of Bologna, and **Anna Laura Eusebi, Polytechnic University of Marche** presented the **FIT4REUSE** project (Prima funded, started July 2019). This project aims to improve municipal wastewater treatment and desalination techniques, to enable reuse of water for irrigation or aquifer replenishment. The project will look at both intensive and nature-based solutions (e.g. constructed wetlands), including addressing organic nutrient recovery and contaminant removal. Demonstration sites are planned at wwtps in three Mediterranean countries (Italy, Greece, Tunisia).

Ljiljana Zlatanovic, Delft University of Technology, The Netherlands, and **Olivia Bailey, University of Bath, UK**, presented work monitoring water, COD, total phosphorus and total nitrogen flows in the sewer outflow of a 418 home housing area at Prinseneilend, Amsterdam. Monitoring was continuous 24h/24h for one week without rain. As could be expected, there were strong daily variations in water flow (lower during the night, but also during the day – probably because many residents were out at work or school). Overall, **nutrient concentrations in the sewer were lower than predicted by standard models**.

Previous studies measuring real phosphorus discharges from clearly identified urban "sewerage catchments" include "Per capita phosphorus loading from domestic sewage", G. Alexander, Water Resources, vol. 10, pp 757-764, 1976 and "Identifying human waste contribution of phosphorus loads to domestic wastewater", D. Gilmour, S. Comber et al., 11th International Conference on Urban Drainage, Edinburgh, Scotland, UK, 2008