ESPP SCOPE Newsletter n°153 – March 2025

5th European Sustainable Phosphorus Conference (ESPC5)

LLEIDA 8 - 10 October 2024 ESPC5 European Sustainable Phosphorus Conference

Conference web page: https://phosphorusplatform.eu/espc5

220 participants in Lleida, Spain, and 30 further participants online, joined the 5th European Sustainable Phosphorus Conference. With over 100 presentations as well as nearly 30 posters, the conference covered all aspects of phosphorus sustainability, with an emphasis on links between climate change and phosphorus management, phosphorus in the Mediterranean region and nutrient recycling from manure digestates.

Lleida is at the heart of Spain's main livestock region, surrounded by intensive pig production and rich agriculture, producing particularly fruit, from figs to apples.

Participants were welcomed to Lleida by **Pilar Bosch of the Lleida City Council** and enjoyed a guided city visit, including giant dolls and human pyramids.

This SCOPE Newsletter summarises the plenary presentations and conclusions of the parallel sessions. All presentation slides and posters, and book of abstracts are publicly online on the ESPP website https://www.phosphorusplatform.eu/espc5

After this successful ESPC5, candidatures are open to organise the sixth European Sustainable Phosphorus event in 2026: [contact ESPP](#).

ESPC5's success was thanks to the team at [BETA Technology Center, University of Vic, Spain](#), the conference organiser: Laia Llenas, Cèlia Guixé, Nagore Guerra, Sergio Ponsá, Albert Palou, Paula Pérez, Ricard Carreras, Jordi Pous, Carla Febrer, Anna Bagó, Lorenzo Proia, Sergio Martínez, Meritxell Uroz, Rosa Vilaplana, Laura Díaz, Berta Singla, Ignacio García-Berro, M. Carme Casas, Jonathan Ovejero, Ana Robles, Jorge Senán, Lidia Paredes, Miguel Martínez, and to Daniel Frank, the conference moderator.

Thanks also to the parallel session rapporteurs for their input to this summary document:, Nagore Guerra, Laia Llenas Argelaguet, Miguel Martinez, Jordi Pous, Veronica Santoro, Chris Thornton.

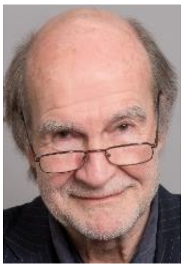
Parallel session moderators: Ricard Carreras, Daniel Frank, Laia Llenas Argelaguet, Sergio Ponsá, Nagore Guerra.

Summaries of previous European Sustainable Phosphorus Conferences

- ***ESPC4**, Vienna 2022: [SCOPE Newsletter n°143](#)*
- ***ESPC3**, Helsinki 2018: [SCOPE Newsletter n°127](#)*
- ***ESPC2**, Berlin 2015: [SCOPE Newsletter n°111](#)*
- ***ESPC1**, Brussels 2013: [SCOPE Newsletter n°092](#)*

ESPP: 10 years and onwards



Chris Thornton, ESPP (European Sustainable Phosphorus Platform), Kimo Van Dijk, Wageningen University and Research, Antoine Hoxha, Fertilisers Europe and **Ludwig Herman, Proman,** summarised ESPP's history and some anecdotes from ten years of action.

The first phosphorus recycling "workshop" was organised in 1998 by the phosphate industry (see Driver, Lijmbach & Stéen 1999 [DOI](#) and Environmental Technology Special Issue [vol.20, issue n°7](#)) The phosphorus recycling movement survived a predicted submersion in Noordwijkerhout, several metres below sea level in The Netherlands in 2001 ([SCOPE Newsletter n°41](#)). In 2009, Dana Cordell published her "Peak Phosphorus" [paper](#): controversial, but seminal in awaking interest in the importance of phosphorus as a critical resource, and coinciding with the peak in phosphate prices (see Figure 1), linked to the Arab Spring, food prices and other factors (see papers by Mew in [SCOPE Newsletter n°128](#)). In 2010, the first global Sustainable Phosphorus Summit (SPS) was organised in [Linköping](#) (the [8th SPS](#) will take place in Ghana 30th September – 3rd October 2025). In 2013, the first European Sustainable Phosphorus Conference (see [SCOPE Newsletter n°92](#)) was organised in Brussels by the Netherlands Government and the recently launched Netherlands Nutrient Platform, leading to the establishment of ESPP in 2014.

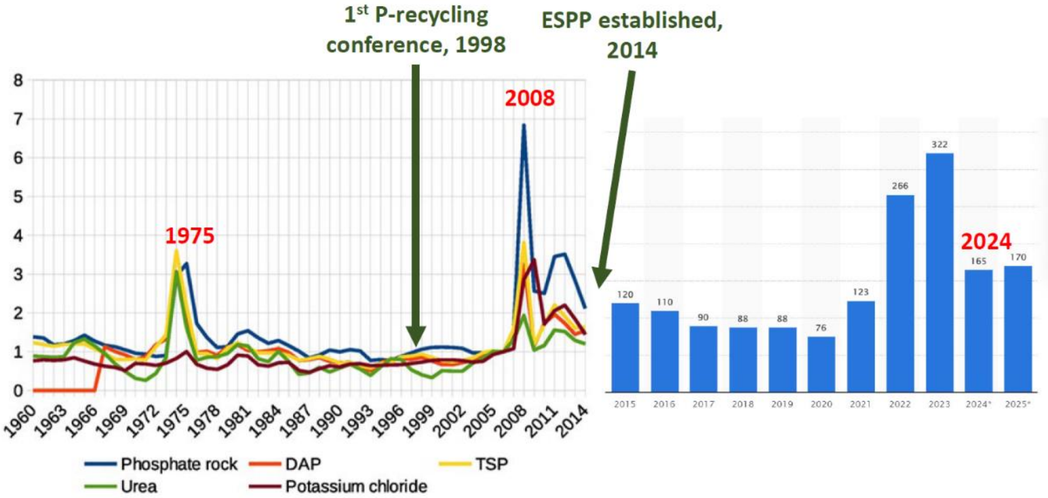


Figure 1: the price of phosphate rock. Sources: lefthand graph = Khabarov& Obersteinerin Frontiers 2017 (see SCOPE Newsletter n°128) , right hand graph = Statista. The graphs have been distorted to try to fit them together.

Thanks are particularly due to ESPP's Presidents since its establishment, **Arnoud Passenier, Netherlands Government** (2014-2016), **Ludwig Hermann, Proman** (2016-2022) and **Robert Van Spingelen, Ostara** (2022-) and to all the members of the ESPP Board over these ten years.

Figure 2: (left to right) ESPP's Presidents Arnoud Passenier, Netherlands Government (2014-2016), Ludwig Hermann, Proman (2016-2022) and Robert Van Spingelen, Ostara (2022-today).

EU policy achievements over ESPP's ten years

Since ESPP's establishment, ten years ago, significant policy advances have been made in Europe:

- *July 2013*: European Commission COM/2013/0517 "Consultative Communication on the Sustainable Use of Phosphorus";
- *2014*: "Phosphate Rock" added to EU Critical Raw Materials list COM(2014)297;
- *2016:* Switzerland, VVEA (waste act), Art 15, makes phosphorus recycling obligatory by 2026 from sewage sludge incineration ash* and meat and bone meal ash
  ** Switzerland banned land use of sewage biosolids in 2006*
- *2017:* Germany, AbfKlärV (sewage sludge regulation): phosphorus recycling from sewage becomes obligatory by 2029/2032 for all WWTPs > 100 000 p.e./50 000 p.e., if sewage sludge P > 2% of dry matter;
- *2019:* EU Green Deal COM(2019)640 "reward farmers for improved environmental and climate performance, including managing and storing carbon in the soil, and improved nutrient management to improve water quality and reduce emissions";
- *2020*: Farm-to-Fork Strategy COM(2020)381 & Biodiversity Strategy COM(2020)380, both fix 2030 targets for nutrients: reduce nutrient losses by at least –50% while ensuring no deterioration on soil fertility, resulting in a reduction in fertiliser use by at least –20%;
- *2019*: EU Fertilising Products Regulation (FPR) Consolidated regulation: (EU) 2019/1009 + (EU) 2022/973 (CMC11);
- *2021, 2022, 2023*: FPR 'Strubias' & other amendments: precipitated phosphates, ash-based materials, biochars, recovered ammonia salts, post-processed digestates (EU 2023/1605) 'End-Points' for certain animal by-products (for some, integration into FPR still pending);
- *2023*: struvite authorised in Organic Farming (EU) 2023/121;
- *2023*: P-recovery from sewage included into EU 'Taxonomy' (EU) 2023/2486;
- *2023*: proposed EU Soil Health Directive COM(2023)416 proposes maximum soil Olsen P levels;
- *2024*: finalised text of EU Urban Waste Water Treatment Directive (UWWTD) - published in OJ, 27th November 2024 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202403019
  - tighter P and N discharge limits
  - "combined reuse and recycling rates" for phosphorus from sewage and sludge to be fixed within 3 years from Directive entry into force
  - feasibility study on N reuse and recovery will be engaged (by 2033);
- *2024*: Austria, AVV Abfallverbrennungsverordnung phosphorus recycling becomes obligatory by 2033 for

WWTP > 20 000 p.e. from sewage (> 60% recovery of wwtp inflow) or sludge ash (> 80% recovery);

- *2014 – today*: Research funding of 90 Horizon 2020 projects, 26 Horizon Europe projects and 40 LIFE projects relevant to nutrients (total of around 750 million € EU funding).

Robert van Spingelen, ESPP President, outlined key directions for nutrients today. Innovation and public policy drivers are key to respond to the challenges of environmental impacts of phosphorus (eutrophication) and resource depletion. Several nutrient recycling technologies are now under implementation full scale, and other innovative technologies are under development.

ESPP sees essential **challenges for nutrient stewardship** for the coming decade as:

- Climate change: intensifies nutrient losses from soil, worsens eutrophication, impacts crop nutrient use.
- Phosphorus in 'strategic' industries: battery electrolytes, solar photovoltaic, and digital technologies.
- Non-thermal routes to P_4.
- Fertiliser, biostimulant and crop innovation, to reduce nutrient losses and improve crop nutrient use efficiency.
- Furthering progress to sustainable, energy-efficient processes for recovering and recycling phosphorus from waste streams.
- Innovation towards P-recovery from sewage sludge without combustion to ash.
- Global: towards a United Nations Environment Assembly (UNEA) resolution on phosphorus.
- Transfer of experience, from P-recovery from wastewater to other sectors such as agriculture, digestate, municipal solid waste, food industry, and aquaculture.
- Circular nutrients for non-food biomass: use of recycled nutrients to feed algae, microbial protein …. and recovery of nutrients from these processes.

Key **policy objectives** for ESPP for the new European Commission (2024-2029) are:

- Revised UWWTD (Urban Waste Water Treatment Directive): definition of phosphorus "reuse & recycling rates";
- Announced new EU Circular Economy Act: create market demand for secondary materials;
- Common Agricultural Policy: integrate the Green Deal targets to reduce nutrient losses by 50% and fertiliser use by 20%;
- Addition of P_4 to the EU list of "Strategic" Raw Materials (for electronics, green energies);
- EU Fertilising Products Regulation: authorisation of Category 1 Animal By-Product ash;
- Organic Farming: authorisation of further recycled nutrient products;
- EU 'Taxonomy': add P-recovery from manure, agri-food streams, etc and N-recovery.

ESPP aims to continue to drive these changes by promoting and communicating research and development, advocating for policy and regulations, sharing knowledge and stakeholder engagement.

Public Policy

Green Deal and new EU Commission

Bertrand Vallet, European Commission, DG Research & Innovation, underlined the Green Deal target to reduce nutrient losses by -50% by 2030. Significant EU funding has been invested in nutrient-related projects under Horizon 2020, with further funding under Horizon Europe, and ongoing through the Circular Bio-based Europe Joint Undertaking (CBE-JU).

Outcomes of Horizon 2020 nutrient projects indicate the need to better understand P and N flows at the regional levels and to define action thresholds, difficulties to move from demonstration to market uptake, the importance of changing behavioural attitudes (farmers, consumers) and challenges to implementation of EU nutrient policies in Member States.

Ursula von der Leyen's Mission Letters to the new European Commission announce implementation of the Green Deal, an update to the EU Bioeconomy Strategy, with a focus on scale-up of biomass production, a new Circular Economy Act, to include measures to create market demand for secondary materials and a single market for waste, especially for critical raw materials (phosphate rock is confirmed on the EU Critical Raw Material List by the EU Critical Raw Materials Act 2024).

EU Common Agricultural Policy

Stephanos Kirkagaslis, European Commission, DG Agriculture, started by underling the importance of nutrients and their key role for food security within a growing population.

The Green Deal includes the target to reduce nutrient losses by –50% by 2030 (Farm-to-Fork and Biodiversity strategies), the aim to create market demand for secondary materials (Circular Economy Action Plan). Russia's illegal and unjustified invasion of Ukraine led to soaring fertiliser prices, and Phosphate Rock is confirmed as a Critical Raw Material in the EU Critical Raw Materials Act 2024, which calls on Member States to engage actions for recycling.

The Common Agricultural Policy (CAP) 2023-2027 includes ten objectives, which are the bases on which Member States define CAP Strategic Plans (CSPs). One of the objectives is (SO5) "*foster sustainable development, efficient management of natural resources and reducing chemical dependency*". The CAP also specifies that Member States must provide farm advisory services to farmers, including a Farm Sustainability Tool (FaST) for nutrients, that is any digital application providing at least the balance of nutrients at field scale, legal requirements on nutrients, soil data and administrative data relevant for nutrient management. The CAP can fund actions on nutrient management, if included by Member States in CSPs, by the following tools: Eco-Schemes, Sectoral Interventions, Interventions for Rural Development, such Agri-Environmental and Climate Commitments, while the CAP Network supports dissemination and knowledge exchange activities (demonstration projects). Mr Kirkagaslis presented a number of examples of Member States including in their CSPs support for fertiliser use optimisation and/or their replacement with organic fertilisers, actions on soil organic content or on soil conservation in their CSPs, and examples of EIP-Agri Operational Groups on nutrient management funded under the CAP Network.

The "Strategic Dialogue" report, which will inform the new European Commission's agriculture policy, includes in recommendation (7) Enhancing Sustainable Farming Practices: Integrated Nutrient Management, the development of nutrient recovery technologies and reducing external inputs (including mineral fertilisers).

Revised EU Urban Waste Water Treatment Directive

Michel Sponar, European Commission, DG Environment, summarised the revised Urban Waste Water Treatment Directive (UWWTD). The final text was agreed in April 2024 and validated by Parliament (no comments, so not submitted to re-vote) and Council in November 2024. NOTE: It has now been published in the Official Journal on the 27th November 2024, see ESPP eNews n° 93.

Assessment of the existing 1991 UWWTD concludes that it is effective, with clear impacts in improving sewage collection and treatment, and so water quality. This success is because the Directive is simple (clear requirements) and operates by carrot and stick (EU regional development funding to support investments, infringement procedures), and that benefits are much higher than costs.

The revised Directive particularly addresses identified outstanding problems: pollution by micropollutants, nitrogen and phosphorus, storm overflows, treatment of wastewater from small agglomerations and non-connected households, improved governance and coherence with other legislation, as well as fixing the objective of energy neutrality for wastewater systems. Analysis suggests that total EU costs of the changes will be 3.8 billion €/year compared to benefits of 6.6 billion €/year.

The revised Directive introduces stricter N and P discharge limits and nutrient removal in all sewage works > 150 000 p.e. Nutrient recovery is encouraged and minimum reuse and recycling rates for phosphorus must be defined within three years from publication, taking into account the waste hierarchy (priority should be reduction at source), health and environment and national markets. Fertigation is taken into account. Reuse is considered to mean valorisation of treated sewage sludge to agriculture.

Veronica Santoro, European Sustainable Phosphorus Platform, summarised ESPP's proposals for UWWTD phosphorus 'reuse and recycling' targets and for market pull for recycled nutrients . These were developed at stakeholder workshops with some 200 participants (SCOPE Newsletter n°151).

ESPP proposes that:

- P reuse & recovery targets should keep technologies and sludge management routes open;
- Targets should be ambitious but feasible, with rates to increase over time;
- Recycling should generate market-ready products;
- Recycling targets should be set as a % of sewage works inflow (taking into account any recycling upstream), with an additional specific rate from ash where sludge is combusted;
- Rates should be fixed as a national overall total (the same for each Member State), to allow optimisation between sewage works and catchments;
- Sewage sludge valorisation to farmland should be subject to monitoring, traceability, and producer-responsibility, and should ensure safety with an EU-validated (national or EU) quality certification scheme covering nutrient content and plant availability, contaminants, application limited to crop nutrient needs.

ESPP proposals for "market pull" for the uptake of recycled nutrients:

- Policies should incentivise recovery of nutrient products of quality and corresponding to user needs and specifications;
- Integrate nutrient recycling in the CAP revision (GAEC standards, Eco-schemes, monitoring through the FaST tool, …);

- Tie farm carbon credits to nutrient balance and application of nutrients that match crop needs/in a form crops can absorb;
- Include nutrients into agriculture-ETS (Emission Trading Systems);
- Extend the existing CBAM (Carbon Border Adjustment Mechanism) on fertilisers to cover P;
- Study a progressive quota of recycled nutrients in EU fertilising products;
- Admit further recycled nutrient products as inputs to Organic Farming;
- Introduce definitions of "recycled nutrient" and "bio-based nutrient" into the EU Fertilising Products Regulation;
- Extend P reuse and recycling targets beyond municipal wastewaters to other secondary nutrient streams;
- Continue actions to address regulatory obstacles to nutrient recycling (e.g. waste regulation, Nitrates Directive, …), develop an EU Integrated Nutrient Management Action Plan, revise the Sewage Sludge Directive.

ESPP's proposals are published here and open for further input and comment.

Francesco Fatone, Università Politecnica delle Marche, Italy, discussed implementation of the Urban Waste Water Treatment Directive (UWWTD) and sludge management in Italy. Italy has still not yet implemented the 1991 UWWTD requirements, and faces infringement procedures: referral to the European Court of Justice (March 2024) for failure to adequately collect and treat wastewater from nearly 180 agglomerations, inadequate wastewater collection in 36 agglomerations, failure to adequately treat sewage in 130, failure to respect nutrient removal obligations for 12 agglomerations in sensitive areas. Plus failure to adequately monitor waste water treatment plant discharges for 165 agglomerations. A further maybe 2-3 billion € investment is needed. On top of this Italy will now face the tighter obligations of the revised UWWTD. A move away from sludge valorisation to agriculture to sludge mono-incineration would require additional millions of € of investment.

Phosphorus levels in sewage sludge in Italy are generally < 2% P/dry-matter. Sludge from sewage works > 2 000 p.e. is often transported to larger sewage works for processing (regional sewage sludge hubs).

Studies suggest that optimal sewage sludge management strategies, including the aim of phosphorus reuse or recovery, will differ between regions. This will depend on sewage sludge quality, regional agricultural fertiliser demand (competition with manure), water demand (possible fertigation). In some cases, higher quality sludges could go (after anaerobic digestion to produce methane) to composting then agricultural use, whereas more contaminated sludge could go to incineration. Besides cost efficiency, the main driver in sludge processing route choices is energy optimisation, which is even more relevant to achieve the target of energy neutrality of the EU Directive 2024/3019.

Nutrient platforms in action

National platforms in Europe

Jorn Baan Hofman, Netherlands Nutrient Platform, summarised a decade of actions. The Platform was established in 2011, motivated by concerns about geopolitical supply dependence for phosphorus. The platform is independent from Government and aims to engage with stakeholders to identify bottlenecks in regulation, research and industry. Key actions include addressing issues around 'waste' status of secondary nutrient materials, initiative R&D projects and helping supporting members with legislation. The Platform today has around 25 members with a wide representativity of the value chain, completed by active dialogue with NGOs, farmers and consumer organisations. Nutrients are a part of the Netherlands Government "Circular Netherlands 2050" strategy.

Challenges are particularly acute in The Netherlands, with its very high concentration of livestock, population, food production and food processing. Closing the nutrient cycle is part of the solution. In this context, the Netherlands Nutrient Platform is positive and is looking forward for further cooperation with its members and the value chain, with the aim of developing solutions which will also be applicable in other countries with less pressing constraints.

Tabea Knickel, German Phosphorus Platform (DPP), updated on implementation of the 2017 German P-recovery regulation (Sewage Sludge Ordinance AbfKlärV). The deadline is 2029/2032 (depending on sewage works size) but many operators have not yet planned implementation. Obstacles are difficulties in selecting which P-recovery technology to adopt, and different funding mechanisms between different German regions. Only sewage works < 50 000 p.e. will be able to continue to use sewage sludge on land (see summary of the German P-recovery regulation in SCOPE Newsletter n°129). Larger sewage works which have not implemented P-recovery by the deadline will have to put sewage sludge incineration ash into temporary storage for P-recovery later, whereas there are doubts about the feasibility of such storage and later retrieval. Further developments of sewage sludge incineration capacity are needed. An update on German sludge incineration and P-recovery capacities is here: RWTH Aachen University's Refoplan project, EvKK. Germany is also updating is national fertilisers regulation to include recycled products.

Elin Kusoffsky, Research Institutes of Sweden (RiSE), presented the Swedish Nutrient Platform, established in year 2019, and with today 29 members. The Platform addresses nutrients in sewage only and provides information exchange with a newsletter, meetings and webinars. Currently nearly half of Sweden's sewage is valorised in agriculture, the remainder being mostly used in other applications, such as soil production. An EasyMining Ash2Phos P-recovery plant is under construction and sludge pyrolysis to biochar is a technique raising big interest (see SCOPE Newsletter 144).

The revised Urban Waste Water Treatment Directive will pose significant challenges in Sweden. The tighter nitrogen removal requirements will be difficult to achieve in a cold climate. The current absence of sewage sludge mono-incineration will make phosphorus recycling targets difficult.

Laia Llenas Argelaguet, BETA Technological Center, University of Vic, Spain, presented the project for a Catalan Nutrient Platform. Catalonia faces important nutrient challenges, in particular from manure, with a large regional nutrient excess whilst 40% of the region is classified Nitrate Vulnerable Area. Catalonia generates around 100 000 t/y of nitrogen, mainly in manure but also in sewage sludge and municipal organic wastes. The proposed nutrient platform will work with existing industry sector clusters including Circular Economy and Agri-Food Industry Sustainability, and within the Catalonia Bioeconomy Strategy and Biogas Plan. Aims are to bring together all stakeholders, promote societal awareness, develop markets for bio-based fertilisers, develop joint projects and make Catalonia a reference region for nutrient sustainability. The Catalonia Nutrient Platform kicked-off on 17th December 2024, with the objective of defining strategy, establishing a legal entity and launching the platform within two years.

Beyond Europe

Matt Scholz. The Sustainable Phosphorus Alliance (SPA), USA, is a membership funded organisation, established in 2016 and with today 12 members. SPA was closely involved in obtaining federal research funding for STEPS, the Science and Technologies for Phosphorus Sustainability Research Centre (5 million $ funding x five years). STEPS research integrates disciplines from across the physical, life, social, and economic sciences.

Just as in Europe, eutrophication remains a major environmental issue in the USA. 42% of rivers (by length, 2019) and 50% of lakes (2022) in the USA are in poor condition for phosphorus levels. A significant aspect is methane climate emissions. A Global Methane Budget (Saunois et al., 2024, DOI) estimates that anthropogenic eutrophication contributes 5 – 8 % of global methane emissions, so a significant climate impact.

Significant regulatory developments underway include possible restrictions on phosphorus and nitrogen discharges from large meat processing factories – expected 2025, farm funding for conservation actions (including nutrient management), and Supreme Court rulings which may weaken phosphorus regulations (e.g., WOTUS, that may impact which waters are protected from pollution under the US Clean Water Act). Concerns about PFAS in sewage sludge are leading to bans or restrictions on use in agriculture in some States.

Cristina Cardenete, Secretariat of the Union for the Mediterranean, presented the Union's actions for sustainable development. The Union for the Mediterranean is an intergovernmental organisation bringing together 43 countries to promote dialogue and cooperation in the Euro-Mediterranean region.

Important for phosphorus stewardship are the Union for the Mediterranean Ministerial Declarations on Sustainable Blue Economy (November 2015 and February 2021) and on Environment and Climate Action (May 2014 and October 2021). Through the declaration, the ministers agreed on a common agenda to strengthen efforts in the Euro-Mediterranean region to urgently tackle the multiple climate and environmental challenges it faces. The Agenda was named "Towards 2030: Agenda for a Greener Med - Contributing to Achieving the Environmental SDGs in the Mediterranean" (2030GreenerMed). This Agenda provides a regional structured framework that, based on the coordination of existing and future programmes and projects, creates political and operational convergence around the three priority axes of cooperation, as agreed by the 42 Union for the Mediterranean countries, including accelerating the transition towards a green, circular and inclusive economy as a stable basis for sustainable growth. The 2030GreenerMed agenda is owned, steered and developed by countries together with partner organisations. The Secretariat of the Union for the Mediterranean supports with the coordination and puts in place the appropriate collaboration tools. Its Thematic Axis 2 includes KA2.1 pollution prevention and reduction, KA2.4 chemical pollution, KA2.5 soil quality, KA2.6 air pollution and a range of actions on ecosystems and biodiversity under Thematic Axis 3. Supported actions include the promotion of joint agendas and roadmap for implementation among the 43 Union for the Mediterranean/Euro-Med countries; setting up of key multi-stakeholders partnerships at Mediterranean level;

policy/technical dialogue and knowledge exchange meetings/webinars; mobilisation and convergence of technical and financial resources around these themes; activation of dedicated technical assistances; contribution to national pathways for food system transformation within a wider circular, green and blue transition.

Ning Liu, United Nations Environment Programme (UNEP). The United Nations Environment Assembly (UNEA) has adopted two resolutions on sustainable nitrogen management (2019, 2022).

The 2019 resolution established a UNEP Working Group on Nitrogen. Today 95 countries have nominated focal points to this Working Group and six meetings have taken place (online or in person). The group has screened data on existing national nitrogen policies and defined the framework for voluntary national action plans. This covers leadership, monitoring, codes for good practice, action plans, wastewater discharge and combustion emissions standards, public investment programmes, research and science, awareness and capacity building.

The 2022 UNEA resolution mentions phosphorus, expressing "*concern that excessive levels of nutrients, in particular reactive nitrogen and phosphorus, have a significant impact on species composition in terrestrial, freshwater and coastal ecosystems* …". The UNEP Executive Director's Report to UNEA6 (February 2024) identifies six areas for action, three of which are relevant for phosphorus: implementing the Kunming-Montreal Global Biodiversity Framework (this includes the objective to reduce nutrient losses by -50% by 2030), sustainable minerals use and "*advancing cooperation concerning nutrients, especially phosphorus*".

The Global Partnership for Nutrient Management (GPNM), which is hosted by UNEP, plans to re-establish a Phosphorus Task Force, to particularly address phosphorus use efficiency and consequent impacts of phosphorus losses on biodiversity (working with the UN Biodiversity Convention), recovery of phosphorus from waste streams, links to improving wastewater treatment (working with the UNEP World Water Quality Alliance WWQA) and lack of information and monitoring on phosphorus flows.

Stakeholders

Farmers

Ramon Armengol (Copa-Cogeca), Eduard Cau (Unión de Uniones) and Àlex Bayo (Alcarràs Bioproductors) (left to right in the picture) outlined the positions of farmers concerning nutrient recycling.

At the EU level, Copa-Cogeca has concerns that cadmium limits for mineral fertilisers could limit availability, and so

increase cost. Amendment of the Nitrates Directive is needed to enable nutrient recycling from manure, when the recycled nutrients have the same properties as mineral fertilisers. Authorisation of further recycled phosphorus materials in Organic Farming is needed. A strategic objective is to increase production of bio-based fertilisers from farm wastes.

In Catalonia, agriculture faces phosphorus application limits under the Nitrates Directive Regional Action Programme and the challenge of dealing with phosphorus in livestock manure. At the same time, food prices must not increase. Nutrients in manure are not in the right form for optimal use, nor at the right time (manure is produced 12 months per year) and need transporting to areas where nutrients are needed. The Catalonia Biogas Plan underlines the importance to manage manure digestates. The long-term vision is 100% processing to enable storage, transport and improved nutrient use as fertiliser.

Alcarràs Bioproductors is working to reduce groundwater pollution and nutrient losses and on production of biogas from manure, with processing of manure digestate to stable compost and recovered inorganic phosphate and ammonia fertilisers.

Frank Willem Oudshoorn, Innovation Centre for Organic Farming, Denmark, summarised the current status of recycled nutrients in Organic Farming in Europe. The average yield of Organic Farming is 30–35% lower than conventional farming due to diseases, pests, weeds and lack of nutrient supply. A doubling of organic area in the EU will increase the urge to find available nutrients (ICOEL, 2024 Knowledge synthesis).

Phosphate fertilisers currently authorised in EU Organic Farming include struvite from wastewater (since 2021), manure (but not from intensive livestock), biochars from plant materials (low in phosphorus), digestates and composts from e.g. domestic or food wastes (again, intensive livestock manure is excluded), bone meal as well as phosphate rock and certain phosphate slags. The challenge with most of these materials is that the phosphorus is not rapidly available for crops. Trials show that even if crops can uptake phosphorus over the growing season, lack of available P at the spring growth period leads to lower yields. Struvite and bone meal on the other hand, of the authorised materials, can provide P as needed for this spring growth, even in dry weather.

The EU Green Deal (Farm to Fork) target to double Organic Farming will necessitate recycled phosphorus sources in regions without significant manure resources. Organic Farming therefore needs transportable, recycled P materials. Options include struvite and bone meal, dried food waste digestate. Organic Farming will need other recycled products from sewage, food waste, abattoirs and food processing. These should be refined products, to limit contaminants. A significant potential is recycled nutrient materials from digestates. The EU Organic Farming scientific committee, EGTOP, has published an Opinion to define what materials should be allowed from digestates: possible limits to nitrogen levels and a better regulation of the use of conventional animal products to replace the wording "factory farming origin" (see eNews n° 93).

Environmental NGO

Sara Johansson, European Environmental Bureau (EEB). EEB represents over 185 environmental citizens' organisations in 41 European countries, including a growing number of networks. Despite major actions and progress over the last thirty years, still today in Europe 81% of marine waters and more than one third of rivers, lakes and coastal waters are reported to be eutrophic. The resulting costs to society are some 22 billion €/year.

The EU's phosphorus flows surpass planetary boundaries by a factor of two and a third of phosphorus applied to land is lost in soil erosion. At the same time, the EU is dependent on imports of fertilisers, exposing farmers to volatile market prices. Following Russia's attack on Ukraine, the cost of EU fertiliser imports from Russia doubled to 2 billion € per year (from 2020 to 2021).

Analysis by the European Commission's JRC (Joint Research Centre, 2023, DOI and ESPP eNews n°76) suggests that existing EU policies will only reduce phosphorus losses by 17%, and that a 60% reduction in fertiliser use is needed to respect ecological boundaries. Recycling could replace only around a quarter of mineral fertiliser needs.

Currently around 70% of EU's farmland is used to produce livestock or feed for livestock, which is highly inefficient in terms of nutrient losses compared to farming for direct human consumption. The EEB underlines the need to transition to agroecological farming, cut food waste and shift to sustainable, more plant-based diets in order to achieve the necessary reduction in fertiliser use.

EEB calls on the European Commission to deliver the promised "Integrated Nutrient Management Action Plan" to achieve the Green Deal target of reducing nutrient losses by 50% by 2030, to enforce the Water Framework Directive and Nitrates Directive to protect water quality from eutrophication and to review and strengthen the CAP in line with the objectives of the Farm-to-Fork Strategy.

Fertiliser Industry

Antoine Hoxha, Fertilizers Europe, agrees that losses related to fertiliser application must be reduced, both organic (including manure) and mineral and that the agri-food system needs to become more circular, whereas today recycling is mainly only on-farm. Today around twice as much phosphorus is applied to soils in organic materials than mineral fertilisers and around 60% of P in organic wastes is recycled or returned to the field.

Fertilisers Europe calls to develop upcycling to ensure that organic wastes are converted to controlled quality products, enabling higher nutrient use efficiency. To achieve this, barriers must be addressed: market fragmentation (quantities/ logistics), negative user perceptions and costs.

Also, should be rolled out improved fertiliser application (4 R's: right fertiliser, right quantity, right time, right place) and adapted fertiliser products (controlled nutrient release, micronutrient formulations …). This requires support through policy and funding (CAP) to address higher costs and uptake barriers for farmers.

Cristian Terrones, ICL, presented agronomic trial results for Puraloop, ICL's recycled phosphorus fertiliser. The acidification-based process used to treat sewage sludge ashes yields a granular fertiliser with 38% total P_2O_5 (50% water-soluble and 50% NAC-soluble), plus Ca (10.5% CaO), K (2.0% K_2O), and S (5.8% SO_3). Heavy metals are below EU limits. Replicated pot trials with cabbage (Israel), maize (Italy and Germany), pepper (Italy) and ryegrass (Germany) showed comparable fresh biomass, yield, and P uptake to triple super phosphate (TSP). A replicated field trial on winter flax showed that the Puraloop treated plots had higher yields as compared to TSP treated plots, however the differences were not statistically significant. These results show that this recycled fertiliser can be used to replace fully water soluble phosphorus fertilisers. Additionally, with a slow-release P fraction, Puraloop can offer beneficial residual effects compared to conventional phosphorus fertilisers.

Cinta Cazador, FERTIBERIA, Spain, summarised outcomes from the B-Ferst project. The project identified over 150 EU biowaste sources and developed a logistics model to assess their suitability for fertiliser production. Key innovations from the project include the production of recycled fertilisers, biostimulants, and biodegradable coatings, a demonstration plant producing 500 kg/h of dicalcium phosphate via acid leaching from sewage sludge incineration ash, and a coating plant (1 ton/h of fertiliser). Field trials in Spain, Italy, Portugal, and Poland validated the agronomic effectiveness of NPK fertilisers with biobased nutrients, showing equal or better performance compared to conventional fertilisers. Results indicate that a rational fertilisation with mineral and biobased fertilisers improved soil biodiversity, promoted rhizosphere Plant Growth-Promoting Rizhobacteria (PGPR) attraction, and reduced carbon footprint for biobased fertilisers.

Climate change and nutrients

Antonio Delgado, University of Sevilla, Spain, summarised expected impacts of climate change on nutrient management. Extreme heat, droughts and precipitation events (floods) will increase soil nutrient mobilisation and soil erosion, and so nutrient losses. Losses in crop productivity due to such events will also increase potential for nutrient losses. The Mediterranean region will particularly suffer from these challenges. This will exacerbate existing pressures on nutrient use in agriculture: inefficiencies in crop uptake and in the food system, EU import reliance on phosphate rock and natural gas for nitrogen fertiliser production, eutrophication and water quality problems, as well as water scarcity. Changes in agricultural practice will be needed to address these challenges including: increasing organic matter in soil, crop rotations and crop soil cover, no-till (which can increase crop productivity under water scarcity and can increase phosphorus availability), improving fertiliser application, recycled fertilisers, … A key aspect is soil health, in particular soil organic content and microbial activity.

Iris Zohar, Tel-Hai College, Israel, explained how extreme heat events impact soil phosphorus. Dryer, hotter soil increases P sorption, so reducing P plant availability, but also increases soil biological activity, so increasing P availability. Repeated heatwave events can thus lead to unstable nutrient conditions in soils, possibly with increased crop plant uptake when root systems are well developed and active, but also increased risk of losses to surface and ground waters with rains.

Golnaz Ezzati, Agricultural Catchments Programme Teagasc, Ireland, presented the use of empirical modelling on the impacts of the climate change and extreme hydrological events on surface-water phosphorus concentrations in six hydrologically-diverse agricultural catchments in Ireland. Very high temporal resolution data (10-min) starting from 2010 were modelled to understand climatic condition(s) that would lead to increases in P concentrations in the catchments' outlets. Then projected climate change scenarios with two different emission pathways were used to investigate the possibility of experiencing P-loss events (due to similar climatic conditions) until turn of the century. The results showed that while there would be step-wise intensifying changes in temperature and rainfall toward end of the century with different monthly trends in different landscapes, climate change impa cts were highly catchment specific. The sensitivity of catchments toward extreme weather events were defined by their characteristics such as soil texture/type, drainage status, farming practices, slope, climate, etc. Hence, efficient climate-smart adaptation/mitigation measures are needed to be catchment specific.

Nutrient recycling technologies

Sido Altenburg, EasyMining, presented the AQUA2N process, recovering over 95% of ammonium nitrogen from sludge liquor or reject water streams (see ESPP Technology Catalogue). The process itself has no nitrous oxide (N_2O) emissions and 15-30% of the total nitrogen load on wwtp can be removed and recovered by this technology. This can reduce total sewage works nitrous oxide (N_2O) emissions by the same percentage, because of reduced ammonia in return flows to nitrification – denitrification and this creates also extra capacity for the wwtp. The process involves two steps: first, magnesium and phosphate are dosed to precipitate struvite; second, struvite is dissolved by adding sulphuric acid, producing ammonium sulphate solution. Magnesium and phosphate are recycled for reuse in the initial step. A 4 m^3/h demonstration pilot has been tested on reject water. A portable pilot is now available for feasibility testing for potential users and the process is now available for commercial full-scale installation.

Vitor Correia, European Federation of Geologists, outlined the EU-funded FIC Fighters project to develop an industrial process to process phosphogypsum from historic "stacks" in Europe. The project is currently starting and has no results to date, but is based on research published here. Its aim is to convert the phosphogypsum to sodium sulphate for use as a filler in detergents, in paper production or in cement, to recover rare earth metals, phosphorus and boron and to capture carbon.

Two chemical routes will be tested:

- attack the phosphogypsum with sodium hydroxide rich aluminium processing wastes, generating katoites (calcium aluminium silicates) and sodium sulphate. The katoite will be then be reacted with CO_2 to produce aluminium trihydroxide (ATH) and calcium carbonate.

- React the phosphogypsum with ammonia and carbon dioxide, then with acid mine wastes, generating ammonium sulphate and precipitated calcium carbonate, with the aim of separating rare earth metals and phosphorus.

Challenges are that the phosphogypsum is very variable in different stacks, is radioactive (but below EU limits), recovery of rare earths is expected to be difficult, and that the processes will not be economic by the output products. Economic feasibility will depend on a remediation gate fee or value of land recovered.

Eugenio Marin, FCC Aqualia S.A., presented the actions of the Deep Purple and B-Ferts projects in phosphorus recovery. In the DEEP PURPLE project, Aqualia developed and patented the ANPHORA® technology. An ANPHORA® demonstrative plant was constructed at the Linares WWTP (Jaén, Spain) with a maximum treatment capacity of 350 m³/d (1.500 p.e.). The demonstrative plant utilizes purple phototrophic bacteria (PPB) to treat urban wastewater and generate phototrophic biomass. PPB use infrared solar radiation as an energy source, metabolizing and accumulating high-value biopolymers intracellularly, such as polyphosphates. Phototrophic biomass rich in polyphosphate has been used as a raw material in fertilizer formulation and has shown excellent results in agronomic trials. Aqualia is also a partner in the B-Ferst project (see Cinta Cazador presentation above), where the struvite precipitation process from sewage sludge dehydration liquor has been tested at the Jerez de la Frontera WWTP (Cadiz, Spain). Aqualia, in collaboration with the University of Santiago de Compostela, has patented this technology. Additionally, the product obtained has been registered by Aqualia under the name Aquavite®. The Aquavite® production plant has a maximum capacity of 200 m³/d, making it the second largest in Spain, with the potential to produce 22 tonnes of Aquavite® annually.

Jesper Højer, Clean Matter, Denmark, presented their electrolysis-based process for P recovery from sewage sludge incineration ash, without chemical addition and without waste products or emissions. The technology can release up to 85% of phosphorus from ash, recovered as phosphoric acid or calcium phosphate. Heavy metals are isolated in the cathode compartment and may be further valorised to specific industries. The process is currently TRL 5 and aiming for TRL 6 with a pilot plant for 1 t/day SSA in 2025 and production plant in 2026.

Joachim Clemens and Christien Oeppert, SF-Soepenberg www.iphos.eu, **Germany,** presented the iPhos® process, a phosphorus recovery technology developed to meet Germany's P-recovery obligation, which requires (for larger sewage works) phosphorus recycling if sewage sludge contains over 2% P/DM. The iPhos® process involves five treatment steps to release P from iron-phosphorus compounds in sludge: (1) reduction by a chemical process with addition of sulfide, (2) acidification to pH 4, (3) separative precipitation of heavy metals, (4) flocculation (polymer dosing) and dewatering, (5) struvite precipitation from dewatering liquor and struvite settling. The system recovers P as struvite from most forms of P but not from aluminium-phosphorus compounds. After successful lab tests in 2022, iPhos ® was operated continuously for three months in 2023 at Gifhorn sewage works, Germany, treating sludge equivalent to 5 000 p.e. and reducing phosphorus in sludge from 3.8 %P/DM to a defined target of 1.8%P/DM. In fact, reduction to 1.1 %P/DM was achieved with 16 hours total process residence time. Soepenberg is now constructing a mobile test unit with capacity to treat thickened sludge for 20 000 p.e. for testing onsite at sewage works from 2025.

Outi Grönfors, Kemira, presented the ViviMag® process, which recovers iron phosphate from sewage sludge, as vivianite (iron(II)phosphate), using magnetic separation technology. To date, a 1 m^3/h automatic continuous operation pilot has been tested at three sewage works in The Netherlands, Germany and Denmark, with continuous operation for up to eleven months, showing demonstrated separation of up to 80% of P in sewage sludge as vivianite. The separated vivianite has approx. 29 % DM/wet weight and approx. 7% total carbon/DM, see ESPP Technology Catalogue. Currently, efforts are underway to scale up the technology. The ViviMag® process is scalable, characterised by low capital expenditure (capex) and adapted to decentralised implementation.

Vishal Zende, Prayon, presented pilot scale trial of recovery of phosphoric acid from incinerated Category 1 Meat and Bone Meal ash (MBM-ash), within the EU Reflow project. According to EFPRA estimation, around 1 million t/y of Cat1 animal by-products are disposed of by incineration in Europe, as required by the Animal By-Products Regulation. This is estimated to generate 250 – 300 000 t/y of ash, containing around 15 000 tP/y of phosphorus. Phosphoric acid is recovered by attacking the ash with sulphuric acid in a two-step process, followed by filtration to remove insoluble calcium sulphate (gypsum). In trials, phosphoric acid containing 28-30% P_2O_5 was produced, containing some silica, and very low levels of iron, aluminium, heavy metals (more than 10x lower than EU Fertilising Products Regulation limits, and around 5x lower for copper). The acid could be concentrated to a P_2O_5 content of 54% without decantation issues. The generated gypsum is nearly white and also has low iron, aluminium, fluorine and heavy metal levels. A European Food Safety Agency assessment of the safety of Cat.1 ash is currently underway (see ESPP eNews n°90) which may open the way for authorisation of phosphates recovered from such ash in fertilisers and other applications.

Biogas and digestate

Lucile Sever, European Biogas Association, noted that EU biogases production is currently around 6% of total EU natural gas consumption. Production of biomethane has doubled in the last four years but the European Commission considers that an 8x increase is possible by 2030. A significant part of this potential is from manure and will result in nutrient-rich digestate. Digestate can be processed to quality organic fertiliser, and enables stable carbon input to soil: tests show that nearly 90% of carbon in the solid fraction of digestate is still present in soil one and a half years after application.

Today only around 15% of digestates are upgraded, whereas this will widely be necessary with manure digestates to enable storage and transport to regions where fertilisers are needed and to enable optimal application and improve nutrient use efficiency.

To enable this, policy support is needed including:

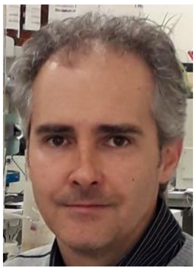
- Implementation of the Waste Framework Directive requirement for separate collection of biowaste;
- Validation of alternative anaerobic digestion processing profiles for animal by-products;
- CAP funding support for farmers processing digestates;
- Coherent national End-of-Waste for digestates in Member States;
- Acceptance of conventional farm manure digestate in Organic Farming;
- EU Integrated Nutrient Management Action Plan;
- Policies for nutrient resilience.

Ricard Carreras, BETA Technology Center, University of Vic, Spain, outlined the Catalonia Biogas Plan, in the context of EU policies and the Spanish biogas roadmap, and of Catalonia policies on waste, bioeconomy and agriculture. Today only around 3% of Catalonia's manure is digested (0.4 out of nearly 15 million tonnes/year of manure and slurry). The objective is to increase this by 10x by 2030 (12 new manure biogas plants per year).

However, the regulatory complexity poses obstacles to this development, with the accumulation of Catalonia, Spanish and EU rules. Particular obstacles identified are:

- Exclusion of sewage sludge from digestates with Spanish fertiliser status (copied from the EU Fertilising Products Regulation), leading to cost and logistic difficulties, because digesters cannot mix inputs;
- Exclusion of manure digestate, where manure is from conventional farms, from use in Organic Farming;
- No regulatory framework for water reuse of waters from digestate processing (important in Spain's dry climate);
- Need for investment support, e.g. under CAP;
- Questions around ammonia emissions, capture and recycling.

Lidia Paredes, BETA Technology Center, University of Vic, Spain, presented studies within the EU Reflow project on use of an anaerobic membrane bioreactor and freeze concentration to recover nutrients from cheese whey. Tests were carried out in a pilot operated continuously for 16 months. Cheese whey has 50 – 120 g/l COD, 0.2 – 2.7 gN/l, 0.1 – 0.6 gP_{total}/l and 4 – 30 g/l of lactose. 200 million litres/year are generated worldwide. The process used a 30 nm ultrafiltration module and an agitated, propylene glycol-cooled freeze-concentration installation. At -10°C, a nutrient concentrate containing 7.5% organic carbon and 0.9% P (2.2% P_2O_5) was obtained (minimum for a liquid organic P fertiliser under the EU Fertilising Products Regulation: 1% P_2O_5). 85 – 90 % of the whey nutrients were in the concentrate, the remainder in the liquid discharge.



Giuseppe Moscatelli, Research Center on Animal Production - CRPA, Italy, presented pilot trials of pig slurry digestate treatment (200 l/h pilot, operated at Colombaro pig farm, Modena, Italy). This is an EIP-Agri Operational Group project (http://struvite.crpa.it/) and it is one of the 12 OGs engaged in the European project Nutri-Know. The treatment consists of a solid-liquid separation by screw press. The liquid fraction is then slightly acidified in order to increase the mineral phosphorus form and after microfiltered at 40 micron to partially remove suspended solids and organic matter that hinders the struvite formation. In a final reactor, magnesium solution and a base are added to promote the struvite crystals development and precipitation. The surnatant digestate after treatment was depleted in nitrogen (-20%) and phosphorus (-73%) compared to the input digestate. Methane and ammonia emissions from the storage of the treated surnatant fraction were 86% and 42%, respectively, lower than the emissions from the untreated digestate. Soil application of the treated digestate led to 19% reduction in the N emissions (as sum of N-ammonia and N-nitrous oxide) as compared to untreated digestate.

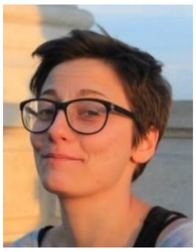
Managing phosphorus in soils

Several EU-funded projects have demonstrated good agronomic performance of waste-derived/bio-based fertilisers with various crops and soil conditions. However, speakers noted that more field trials are necessary, as most of the studies presented were conducted in pots, and results may vary when trials are transitioned to field conditions. Most organic wastes however require processing to improve their fertiliser efficacy, given their low nutrient concentration and limited plant availability, and this can lead to higher production costs compared to conventional fertilisers. Regulatory uncertainties also affect product development and field trials, underscoring the need for close collaboration with policy makers and with industry to facilitate change.

Soil phosphorus losses

Elise Van Eynde, European Commission Joint Research Centre (JRC), summarised JRC work on phosphorus management, based on soil Olsen P levels and P application rates. The LUCAS dataset has over 20 000 soil Olsen P data points. The proposed directive on soil monitoring and resilience (COM/2023/416) proposes a threshold between 30 and 50 mg kg^{-1} Olsen-P for healthy soil. Around half of Europe's soils have soil P levels considered to be high (Olsen P > 40 mg kg^{-1}). Using this limit of high soil P concentration leads to the conclusion that average P-application in these regions with high soil P should be reduced by –14 kgP/ha/y, that is –20% total EU P inputs and –40% EU mineral fertiliser inputs.

Beata Jurga, Poland State Research Institute *(text not validated speaker)*, discussed links between soil erosion and phosphorus losses. A European Commission JRC study suggests that over three-quarters of EU soil have higher than 'acceptable' soil erosion. Poland has generally low soil phosphorus and shows an average soil loss of 1.4 t/ha/year and an average phosphorus loss of 0.2 kgP/ha/year. Investigation show that soil P levels are often not correlated to soil P losses. Mountainous areas for example show high soil erosion and important soil phosphorus deficits.

Alessandro Scibona, Po river management authority, and **Monia Magri, University of Parma, Italy,** presented the challenges of nutrient management and how climate change will impact soil phosphorus losses in the intensive agriculture Po river basin, Italy.

Wastewater treatment plants, in particular serving Milan and Turin, have been upgraded and today remove nearly 75% of total phosphorus inflow. This is however insufficient, resulting in nearly 3 000 tP/y discharge into the Po river, and EU Urban Waste Water Treatment Directive infringement procedures are underway (under the current UWWTD, that is before tightening of requirements under the now-revised Directive revision, see ESPP eNews n°93). The basin also has widespread agricultural phosphorus excesses (input > crop offtake by 5 – 50 kgP/ha/y) and largely no crop cover in winter: 80% of agricultural land is maize and 65% uses flood irrigation. Around 2/3 of P inputs to the basin's agriculture are in animal feed, 1/3 in fertilisers.

Target phosphorus loads to the river have been defined based on diatom algae, macrobenthos and pollution level from macrodescriptors index, under EU Water Framework Directive quality status obligations, and current P loads are around 25 – 50% above targets.

A study of the Chiese sub-basin showed manure inputs of phosphorus around 5x higher than offtake in crops. Phosphorus load in the river at baseflow is estimated to be only around 1% of the agricultural excess whereas estimated load during the ten rainiest days is around 1.5%, mainly as particulate phosphorus. The considerable difference between river-analysed phosphorus loads and soil phosphorus surpluses is unexplained. Analysis showed lower losses from grassland than from irrigated crops. Conclusions are that phosphorus losses can be expected to increase with climate change, as this will lead to more frequent high rainfall events and that P losses are strongly influenced by agricultural practices and land use.

Trials underway show that restoration of vegetation in secondary drainage canals can contribute to nutrient removal or retention. The Po basin has some 4 000 km of such canals. Allowing phragmites (reeds) development in around a quarter of canals could be sufficient to achieve Water Framework Directive "good status". Phragmites can enable over 90% nitrogen removal, by microbes on roots and stems. They also retain phosphorus, by slowing water movement allowing deposition in sediments, and by storage, mainly in microbes and only partly in the phragmites plants themselves. This will only be effective for reducing phosphorus loads if the phragmites and sediment can be removed (without nutrient losses), transported and used elsewhere as fertiliser.

Phosphorus measurement

Morten Kjærulff Sørensen, NanoNord A/S www.nanonord.com **and Aarhus University, Denmark,** described the Tveskaeg mobile NMR (Nuclear Magnetic Resonance) sensor technology, designed for on-farm applications and fertiliser processing sites, including slurry spreaders (see photo). The technology is adapted from widely used medical MR scanners and is today commercially available for slurry measurements and at the pre-commercial test unit development phase for feed and soil measurements. The sensor has no sensitive components in contact with samples and operates without the need for cleaning of optical windows. Using unique isotope frequencies, the NMR allows on-site quantification of elements, including phosphorus, either in batch samples or on flows. It measures total phosphorus in slurries, feeds and soils, total nitrogen and ammoniacal nitrogen in slurries, aluminium and sodium in soils, and several other parameters in solid or liquid substrates. After digestion, it can also measure protein content of animal feeds (based on total N). Accuracy has been demonstrated by laboratory rig-testing (see e.g. Jensen et al. 2021 LINK, Sørensen et al. 2022 LINK, and Sørensen et al. 2024 LINK). The sensor is applicable across sectors like food, wastewater, biogas, and more, and it accurately documents agricultural nutrients on-site.


Francesca Degan and Alexia Crézé, Arvalis, France, presented a study on bread wheat varieties, focusing on tolerance to phosphorus deficiency to identify high-performing varieties. Four trials over four years in central and southern France evaluated 199 varieties under two treatments: high P (2x recommended rate) and zero P. They developed early-stage indicators and phenotypic traits to assess P deficiency tolerance and studied genetic factors influencing this tolerance. Key indicators were grain P yield, P Use Efficiency (PUE), and a P deficiency sensitivity index, which were significantly impacted by the variety and the P management. Vegetation indices, especially the red edge chlorophyll index, correlated strongly with grain yield, aiding P-efficient genotype identification. Seventeen genomic regions related to P deficiency tolerance were identified, with genomic prediction models showing interesting accuracy for PUE prediction.

ESPP members

Jean-Christophe Ades. Kemira's vision is to optimise the full water cycle including drinking water, municipal and industrial wastewater. Iron and aluminium salt coagulants can enable 90% or higher phosphorus removal in sewage works and contribute to lower carbon footprint, improved biogas production and better sewage sludge dewatering. The ViviMag® patented technology, owned by Kemira enables magnetic recovery of iron phosphate in the form of vivianite with several promising valorisation routes.


Silvester Bombeeck, SNB - Slibverwerking Noord-Brabant and **Marissa de Boer, Susphos**. SNB operates Europe's largest sewage sludge mono-incinerator at Moerdijk, The Netherlands (> 90 000 t-sludge-DM/year, producing around 40 000 t-ash/y). A full-scale plant to process all the output ash is being planned using the SUSPHOS process: acid is reacted with the ash (similar to existing industry Single Super Phosphate type processes) then a proprietary inorganic solvent is used to extract phosphoric acid from the resulting wet solid, without transferring contaminants (iron, heavy metals). Phosphate chemicals can be reacted and separated from the solvent (e.g. calcium phosphates or ammonium phosphates) or the solvent can be evaporated giving an acid mixture. The solvent is recycled back into the process. The process thus operates without an aqueous phase, so avoiding energy-intensive phosphoric acid concentration. This is not the same as the widespread industrial 'solvent extraction' process where solvents are used to extract contaminants from merchant-grade ("green") phosphoric acid. The process has to date been tested for two years at 25 kg/day showing industry-quality of recovered phosphate products (see ESPP Technology Catalogue).

Mohamed Takhim. TTBS - Takhim for Technology and Business Services has developed the Rubiphos process to recover phosphorus from sewage sludge incineration ash. A mobile 100 kg/day (12.5 kg/h) pilot has been tested for over 200 hours during 3 weeks with HVC, Dordrecht, The Netherlands, and is available for onsite testing at ash production sites. The process attacks the ash with acid, using selective acid digestion then membrane separation to achieve > 90% P-recovery, > 95% heavy metal removal and separation of potassium and magnesium salts. See ESPP Technology Catalogue.

Elena Rojo. Veolia supplies drinking water to over 110 million people worldwide, treats wastewater for over 90 million, manages domestic solid waste for 46 million and manages nearly 50 000 thermal energy installations. Veolia is engaged in the Horizon2020 R&D project WALNUT to produce bio-based fertilisers from municipal and industrial wastewaters.

Juliette Cassart. Biomasa Peninsular, Spain, offers solutions for biowaste recycling, including engineering, consulting and innovation. BIOMASA is, and has been, involved in several EU-funded projects (e.g., Urbiofin, Sustainext, Life EBP, Waste4Soil) in which it focusses on the development of bio-based fertilising products. BIOMASA identifies as challenges to improving nutrient sustainability: extensification of livestock production, low input agriculture, separate collection of municipal solid organic fraction (biowastes), simplification of the legal framework, development and scale-up of economically viable recovery and recycling technologies.

Kimo Van Dijk, Wageningen Environmental Research, discussed visions for nutrient circularity. The 1980's Biosphere2 project, Arizona, showed that nutrient cycling was a limiting factor. Society's nutrient use has high leakage with significant losses of phosphorus to surface waters. The Netherlands aims to become self-sufficient in nutrients, but manure recycling is insufficient and nutrients from wastewater, food waste and agri-food industry by-products will also be needed, but these pose issues of contaminants.

Dario Frascari. University of Bologna is testing an adsorption – desorption process, using calcium hydrates, to concentrate phosphorus prior to precipitation of calcium phosphates. To date, the process has been tested using both clarified digested sludge and the effluent of a municipal wastewater treatment plant in a 50 litres/day pilot up to 7 regeneration cycles, achieving 70 – 85% P-recovery.

Rajan Choudhary, University College Dublin. The SINFERT project is testing a process to produce certain organophosphorus chemicals from sewage sludge incineration ashes, viviante or other non-organic materials, using a proprietary deoxychlorination (DOC) promoter and catalyst. This would enable production of triorganophosphates (e.g. triethylphosphate) or triorganophosphines and triorganophosphine oxides that can otherwise only be accessed via thermal-route P_4. Laboratory scale-up from 1g to 100g scale is underway. See ESPP Technology Catalogue.

Andrea Salimbeni, Re-Cord, University of Florence, Italy, has recently patented, at EU level, a new process to extract phosphorus from sludge, based on integrating slow pyrolysis and chemical leaching. He is currently developing a new version of the process to recover phosphorus from sewage sludge by slow pyrolysis, followed by 2-stage selective leaching using organic acids, which could enable to separately recover phosphorus and iron/aluminium salts. Re-Cord is also working on other biochar processes and on an innovative route to P_4 based on high-performance steel furnaces. Record consider that fiscal incentives for nutrient recycling should be implemented to drive uptake, applying the 'polluter pays' principle to raw materials consumption.

Kasper Reitzel, University of Southern Denmark. The RecaP Marie Curie network has trained fifteen young interdisciplinary phosphorus experts, generating numerous publications, training events, conference participations and already one patent. These students are now completing their PhDs and are ready to professionally take on the global phosphorus sustainability challenge.

Manan Sawhney. NuReSys has developed and refined its IPM (Integrated Phosphate Management) process over the years, enabling the recovery of phosphorus in the form of struvite from both digestate and centrate. The technology is highly scalable, handling flows from as low as 1 m³/hour to 340 m³/hour and higher. The recovered product, Bio-Stru, serves as a valuable raw material for fertilisers and is accredited as a complete fertiliser by AFNOR. With multiple full-scale installations across Europe and the US, Nuresys continues to expand its global footprint, having launched a new entity in India earlier this year and planning to open in Brasil before the end of 2024. Nuresys has also participated in several EU Horizon projects, including ValueWaste, Circular Agronomics, FerPlay, and BioSolutions, demonstrating its commitment to sustainable innovation and circular economy principles.

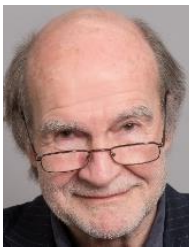
Leonardus Vergütz presented **OCP Group**'s vision of innovation, sustainability and nutrient stewardship. Over 40% of the world's agricultural land has inadequate phosphorus for optimal crop yields, especially in Southern and tropical regions. In Europe also, nearly 30% of farmland has low phosphorus, especially in Southern Europe. Phosphorus is key to sustaining soil health which in turn is critical to feeding the world's growing population and to enhancing soil carbon sequestration to combat climate change.

One example is Nigeria. Phosphorus flow data shows that the country annually exports nearly 15x more phosphorus in crops than it imports in fertilisers, despite soils already poor in phosphorus. This is aggravating low yields, soil degradation and deforestation.

OCP is actively engaged in improving fertiliser use in Africa. Soil mapping has already been completed of 50 million hectares and more is underway, with the aim of optimising fertiliser application, delivering customised fertilisers with the appropriate nutrient and micronutrient balance, and so improving crop yields and farmers' incomes at the same time as protecting the environment.

In its own operations, as leading custodian of phosphate rock reserves worldwide, OCP is investing 13 billion € to move to using only renewable water sources (no ground extraction) and all green energy (carbon neutral in all three scopes by 2040) and to improve circularity, with the aim of obtaining one third more phosphorus from mined ore.

Nicolas Willaume. ICL is a global leader in fertilisers, including biodegradable controlled release (coated) fertilisers, fertigation, fertilisers for Organic Farming, phosphorus, potash, poly halite fertilisers, and phosphorus in industrial applications such as flame retardants and batteries. Innovation is based on R&D and collaboration with agri-food start-ups. ICL has 500 agronomist staff, and is now producing recycled phosphate fertiliser, Puraloop (see Cristian Terrones, ICL, above), from sewage sludge incineration ash (see SCOPE Newsletter n°151)



Ludwig Hermann. Proman is addressing the planetary challenge of phosphorus sustainability by working on economic solutions, business models and research towards valorising nutrients in waste streams and delivering improved nutrient 'services' to crops, soils and farmers.

Hubert Halleux. For **Prayon**, the circular economy is a company priority. Prayon is a phosphoric acid producer, a technology developer and provider and a commercial partner to the phosphate industry, so can act for recycling both in its own processes and for customer secondary residues, as well as proposing recycling and upcycling technologies to the market.

Helmut Gerber. Pyreg is a leading technology provider and plant operator for biochars. Biochar is recognised as a carbon storage solution by the IPCC (International Panel on Climate Change) and the EU. Pyrolysis of sewage sludge can eliminate contaminants (microplastics, pharmaceuticals, PFAS). Sewage sludge biochar is accepted as fertilising product in several countries and work is underway to propose its inclusion into the EU Fertilising Products Regulation.

Pär Larshans, Ragn-Sells, underlined the need to address the nutrient challenges of planetary boundaries, eutrophication and phosphorus: a non-renewable and limited resource. The EU is now moving towards nutrient recycling, and Ragn-Sells aims to now make these developments global. The first full scale plants for phosphorus recovery from sewage sludge incineration ash are now coming online in Europe. This technology should be rolled out to big cities across the world. Ragn-Sells is actively promoting nutrient recycling in forums such as the United Nations GPNM (Global Partnership on Nutrient Management), COP29 and the World Trade Organisation. An important obstacle is to move global standards and trade agreements on recycled materials from an 'origin' based approach to 'quality' based: if a material is safe and of high quality, then it should not matter whether it is produced from virgin raw materials or from wastes.

Yariv Cohen. EasyMining, part of the Ragn-Sells group, offers solutions for phosphorus, nitrogen and potassium recovery. A first full-scale Ash2Phos plant, under construction with Gelsenwasser in Schkopau, Germany, will treat 30 000 t/y of ash (3.5 million p.e.) recovering phosphorus, iron (for use as coagulant in water treatment) and aluminium (for zeolite production). The recovered calcium phosphate has received a positive Opinion from EGTOP for use in Organic Farming.

Felix Bein. Wien Energie is the largest regional energy utilities provider in Austria and ensures that the city's residents enjoy uninterrupted access to electricity, power, heating, cooling, electromobility and telecommunications. Wien Energie also process sewage sludge from Vienna's water treatment facility in its incineration plants. Austria adopted in 2024 a legal obligation of P-recovery from sewage by 2033. Wien Energie has two initiatives in the field of phosphorus recovery, on the one hand by supplying sewage sludge incineration ash in a cooperation with the City of Vienna to LAT's nearby factory for fertiliser production, and on the other hand by evaluating further possibilities/collaborations for P-recovery.

Research

Phosphorus recycling

Darren Oatley-Radcliffe, Swansea University, Wales, discussed the circularity potential of algae, due to their fast growth and ability to thrive without competing for terrestrial resources. Algae can naturally control pollution and are versatile in their application, including in food, feed, cosmetics, and fertilisers. Focusing on nutrient recovery from digestates, pre-conditioning methods for algae are critical as well as adjusting to strict nitrogen/phosphorus ratios, while the use of nanofiltration membranes seems promising to recover phosphates while filtering out nitrates. Other innovative approaches include the use of tubular polymeric membranes and submersible LED lighting systems to enhance algae growth and product yield, particularly for high-value products like proteins and pigments.

Juan Baeza, Autonomous University of Barcelona, Spain, presented an overview of various sewage works/sludge P-recovery routes, based on theoretical studies and his experimental studies on biological P removal WWTPs. He concluded up to 90% or more of phosphorus can be recovered when sewage sludge is mono-incinerated (P-recover from ash) and over 50% by currently operational in-works P-recovery routes (sludge stream fermentation to release additional soluble P, then phosphate precipitation, e.g. as struvite).

Alberto Bouzas, University of València, Spain, presented the RECREATE project, Spain, (PID2020-114315RB-C22). A pilot scale (2 m^3/day) AnMBR (anaerobic membrane bioreactor) is being tested at sewage treatment plant at Conca del Carraixet municipal sewage works. Biogas is produced by the AnMBR unit and sludge digestion. After dewatering, the solid fraction of digested sludge is treated by HTC to produce hydrochar. The dewatering liquor is membrane purified, then the permeate is treated in an electrodialysis cell with cationic and anionic exchange membranes, to generate a concentrated stream in ammonia (0.6 gN/L) and phosphate (0.08 gP/L) and discharge water conform to nutrient discharge limits.

Simone Martinoli, University of Applied Sciences and Arts Northwestern Switzerland FHNW *(text not validated speaker)*, presented the process being researched to recover phosphorus from sewage sludge incineration ashes, with Erzo ARA, (waste water treatment operator Oftringen and area, Switzerland). The process, currently at the 5 – 10 litre batch laboratory test phase, involves attacking the ash with sulphuric acid, filtration, sulfide precipitation, then using ion exchange and hydrochloric acid to purify the resulting phosphoric acid. Up to 90% of phosphorus in the ash has been recovered in acid, yielding 0.6% phosphoric acid. Current work aims to improve the heavy metal removal to achieve contaminant levels specified by Switzerland's fertilisers regulations.

Samantha Gangapersad, McGill University, Canada, presented laboratory studies (batch tests, several day residence time) into using elemental sulphur to drive reduction reactions in sewage sludge to release phosphorus from iron phosphate and other compounds (see also Soepenberg iPhos® process above). Results show that longer residence times and higher temperatures improve sulphur-reduction P release. Calcium containing concrete wastes were also tested in the laboratory for precipitation of the released phosphorus.

Guozhu Ye, Swerim AB, discussed the PHIGO project, which uses a thermal metallurgical approach, operating at about 1400°C. In the process, $Ca_3(PO_4)_2$ and K_2O in the fly-ash generated from biomass incineration was reduced by carbon to P(g) and K(g) and recovered as potassium phosphate, KPO_4. SiO_2 was also added to get a Ca_2SiO_4 based product which was aimed for valorisation as a construction material. The main resulting product is a pure, white coloured KPO_4 powder without heavy metals. The KPO_4 product was under evaluation for fertiliser uses in pot trials. The use of the obtained Ca_2SiO_4 based product as construction material was also under evaluation. After testing in lab scale (batches of about 500 grammes), the process is currently being upscaled to 5 – 10 kg batch scale. Testing with 14 different sewage sludge and chicken manure ashes have been investigated to prove the PHIGO concept.

Alice Boarino, University of Turin, Italy, presented lab studies (beaker scale, batch) of struvite precipitation from the digestate liquid fraction derived from the anaerobic digestion of organic fraction of municipal solid waste and dairy manure. Three different additives and hydrocavitation (pressurisation then pressure release, resulting in bubble generation and implosion) were tested to increase the soluble fraction of phosphorus (accessible for struvite precipitation): a commercial enzyme mix (UltrasweepC4), phosphatase, phytase. Lab results suggested that these could enable c. 40% increase in digester methane production and c. 45% increase in soluble phosphorus.

Kea Purwing, University of Hohenheim, presented the NuTriSep digestate treatment process developed with Geltz https://geltz.de/. The digestate is acidified (currently using sulphuric acid dosing) then solid-liquid separated. The liquid fraction undergoes a first filtration step (to remove solid particles), then sodium hydroxide is added, enabling precipitation of phosphate salts. This is followed by ammonia stripping and recovery of ammonium sulphate solution (c. 10 % NH_4-N). Tests are underway to replace sulphuric acid addition by use of carbon dioxide at 5-10 bars, to reduce chemical consumption. The process has to date been tested at 100 litre batch scale.

Marzena Kwapinska, Dairy Processing Technology Center, Limerick University, Ireland, presented tests of HTC (hydrothermal carbonisation) of dairy product processing sludge. Ireland produced 9 billion litres of milk, and 150 000 tonnes of such sludge (wet weight). These sludges have c. 20% solids content (similar to sewage sludge after filter press or centrifuge) and contain phosphorus, nitrogen, other nutrients and organic carbon, and also iron or aluminium used in P-removal in the dairy water treatment, but do not contain Cd, Cr, Cu, Hg, Ni, Zn. They can be directly used in agriculture as fertilising products. This however poses problems of storage until the fertiliser use season (methane and ammonia losses), transport (supply exceeds crop needs around large dairy product factories) and farmers reluctance to accept such sludges. HTC was tested using four different dairy sludges, in a 8 litre lab batch reactor, at 180 - 200ºC. Hydrochar and an HTC liquid were obtained as the main products of the process, with relatively easy solid-liquid separation, and 10-20% of output as solid, most of the remainder as liquid (very low gas production). Over 95% of the P was recovered in the hydrochar. The generated hydrochar solid fraction contained 7 – 14% phosphorus, but did not meet the EU Fertilising Products Regulation (FPR) CMC14 specifications for “pyrolysis and gasification materials” because the H/C_{org} ratio is too high (> 0.7). This ratio is included in the FPR because it is the recognised indicator that organic materials are largely pyrolysed. The solid hydrochar fraction was tested in maize pot trials where it showed depending on process conditions either positive or negative effect on plant growth compared to control (dried sludge). NAC-solubility of the phosphorus was c. 60 – 80%, so probably not sufficiently rapidly available for maize seedlings (NAC = neutral ammonium citrate). Further work is being carried out to identify routes to valorise the liquid HTC fraction.

Recovery of P_4 or organo-phosphates

Andrea Kotze, University of Stellenbosch and **InsPyro,** and **Lukas Pohl, University of Stuttgart, Germany,** presented the FlashPhos project, which aims to develop a process to recover white phosphorus (P_4) from sewage sludge and other organic materials. See ESPP Technology Catalogue. To date, the drying and grinding characteristics of sewage sludge, as well as its thermal decomposition and reaction mechanisms at elevated temperatures have been systematically studied, including its behaviour in mixtures with various additives. The design and digital simulation of the reactors and the associated processes have been successfully finalized. Furthermore, potential sites for implementation have been analysed through digital mapping techniques.

Eric Franke, TU Bergakademie Freiberg, Germany, presented laboratory research (grammes scale) release of elemental phosphorus (P_4) from different dried sewage sludges under heat without oxygen (PhosCOOR project). Sludge pyrolysis is largely completed at 550°C and P_4 release is seen to start at 970°C – 1050°C for different sludges. The release of P_4 is considered to be by carbon present in the sewage sludge acting as a reducing agent (no P_4 was released when sludge ash was tested, unless reducing agents such as hydrogen or carbon monoxide were added). Phosphorus recovery rates (as P_4) of 75% - 95% were achieved in the laboratory conditions. Iron content in sludge reduced the P_4 release rate whereas aluminium content facilitated P release. Adding hydrogen did not increase the P_4 release rate. For further details see https://doi.org/10.1016/j.jclepro.2025.144687

Recovered fertiliser pot trials

Nieves Núnez-Romero, University of Seville, Spain, presented a pot trial study evaluating 14 waste-derived fertilisers as alternatives to mineral P fertilisers using wheat and two sandy soils with varying clay content. Tested fertilisers (50 mg P/kg) included recovered vivianite, struvite, sewage sludge, various composts, olive pomace, digestate, vermicomposts, fish meal, and commercial products. Controls with diammonium phosphate as well as an unfertilised control were used. Results showed comparable total biomass and grain yield between most fertilisers and mineral fertilisation, with vivianite and vermicompost yielding the highest. Total P uptake was similar for several fertilisers and, comparing all treatments, the agronomic replacement value varied between 70 and 120%.

Berta Singla, BETA Technological Centre, University of Vic, Spain, presented ryegrass pot-trials of bio-based fertilisers (BBFs) derived from pig slurry for ryegrass cultivation (Fertimanure project). At the Spanish pilot plant, pig slurry (manure) solid fraction undergoes biodrying to produce a P-rich amendment and, after thermal treatment, phosphoric acid. The liquid fraction is processed through membranes and freeze concentration to produce two liquids with a concentration of 0.4 - 0.5% N. In the pot trials, BBFs (biodried solid fraction, phosphoric acid, and liquids fractions) achieved comparable or higher dry matter yield and P uptake than those with mineral fertiliser (TSP), due to BBFs' slow mineralisation. Notably, certain BBFs, (especially the N liquids obtained from membrane filtration) outperformed TSP, delivering significantly better results in yield and P uptake than the positive control TSP.

Sophie Schönfeld, Fraunhofer UMSICHT, Germany, presented findings from a 30 kg/h pilot pyrolysis plant treating cattle manure as part of the Fertimanure project. Using the Thermo-Catalytic Reforming (TCR®) process—an intermediate pyrolysis method combined with post-catalytic reforming—the resulting biochar was characterised by 13 g/kg P and 67 g/kg of K. The biochar meets the limits of the European Biochar Certificate (EBC) standards. The limits for polyaromatic carbohydrogens (PAH) listed within these standards remain below the safety thresholds for the 16 EPA PAHs, the 8 EFSA PAHs, and PCBs. Maize pot trials in low-P soil showed that biochar achieved comparable dry biomass and P uptake to full mineral fertilisation but was less effective for K uptake. Ryegrass trials demonstrated that biochar, used as the sole P source, supported biomass, P, and N uptake equivalent to mineral fertilisers, highlighting its potential as a sustainable nutrient source. The biochar provides gradual P availability, matching plant needs over time. Further assessment is ongoing to evaluate compliance with EU FPR criteria, particularly regarding P-solubility requirements.

Ana Robles, BETA Technological Centre, University of Vic, Spain, presented a ryegrass pot trial of five different hydrochars derived from raw pig manure, compared to TSP and digestates with different percentages of pig manure (10%, 40%, or 100%) (in collaboration with ICL group). Hydrochars were produced from different feedstocks (manure or digestates with different percentages of pig manure) and at different hydrothermal carbonisation (HTC) conditions, with retention times (3h or 6h) and temperatures (180 °C or 210°C). Hydrochars derived from pig manure showed higher phytotoxicity than those derived from digestates. Results showed no significant difference in P uptake between TSP and two digestate-based hydrochars, but raw manure-derived hydrochars did not significantly improve plant performance over control.

Systems approaches

Kimo van Dijk, Wageningen University & Research, highlighted the importance of nutrient recycling in various sectors, focusing on case studies in wastewater treatment, agriculture, and horticulture that are being studied in the KNAP Public-Private Partnership project. He discussed how residual flows, such as phosphorus and nitrogen from wastewater and black water, can be transformed into fertilisers. He also emphasised the development of legal guidelines and quality systems for assessing the potential of recycled nutrients, as well as the challenges faced in scaling these processes. His work aims to create a circular economy by engaging stakeholders across the value chain and testing products to ensure they meet market and environmental standards.

Priscila de Morais Lima, Research Institutes of Sweden (RISE), introduced the CiNURGi project (https://interreg-baltic.eu/project/cinurgi/), which aims to tackle eutrophication in the Baltic Sea by developing standards for nutrient recycling, improving policy frameworks, and creating business opportunities. The project fosters collaboration between stakeholders, such as farmers and fertiliser producers, to promote the use of organic fertilisers. She emphasised the importance of demonstrating the effectiveness of these products through field trials and surveys, as well as exploring synergies between nutrient management strategies in the Baltic and Mediterranean regions.

Julia Santolin, University of Antwerp, Belgium, discussed actor's choices shaping the adoption of nutrient recovery technologies in the food processing sector, focusing on leverage points for effective interventions and technological attributes influencing the decision-making process. Mandatory implementation ranked highest among technological attributes, followed by relative advantage, and trialability. She emphasized the importance of policy-makers setting stricter regulations that push the adoption of nutrient recovery technologies, and allowing currently restricted recovery practices. To improve the business case, policy-makers can offer governmental incentives and facilitate centralized treatment for companies in the same sector and geographical proximity. Technology developers could also intervene by designing low-maintenance systems that require minimal operator involvement, reducing the OpEx. To increase adoption rates through trialability, technology developers should offer the option to test a technology before implementation, while policy-makers could support pilot programs to enable gradual implementation.

Marc Sonveaux, Prayon, presented the company's integrated approach to phosphorus stewardship and P-recovery, including recycling P containing by-products from customers into Prayon's production processes, distributing Prayon and other available recycling technologies to customers, developing Prayon processes to recover P from waste streams. Some wastes and by-products can be recycled through Prayon's production processes to purified phosphoric acid. Where there are legal restrictions (e.g. not for use in food applications) or technical incompatibility, other wastes and by-products can be recycled into Prayon's fertiliser production processes. And thirdly, Prayon is developing a specific process to recover phosphorus from sewage sludge incineration ash as technical grade phosphoric acid: Prayon Ecophos LooP Process PELP. This process has been industrial pilot tested (5 t/day). The ash is attacked with phosphoric acid, then ion exchange is use to recover purified phosphoric acid and to separate aluminium and iron salt solutions. Prayon's production sites in Belgium (Engis and Puurs) produce around 300 000 t P_2O_5 (phosphoric acid and salts) per year. See ESPP Technology Catalogue.

Modelling

Sofia Jaray, CEIT-Basque Research and Technology Alliance (BRTA), focused on how PWM modelling can enhance resource recovery at wastewater treatment plants, helping them transform into "water resource recovery factories." These models simulate operational scenarios, optimise phosphorus recovery, and address influent variations and climate change impacts. In a case study performed in Madrid at Sur WWTP, modelling helped to select technology and strategies for phosphorus recovery through struvite precipitation, demonstrating practical benefits. Based on the study results the technology was implemented at real-scale in plant, after sludge dewatering. The methodology presented is flexible, new transformations and components can be included for a better understanding of resource recovery technologies.

Sofia Högstrand, Lund University, Sweden, presented modelling of impacts of a hypothetical shift from chemical precipitation (CP) to enhanced biological phosphorus removal (EBPR) in wastewater treatment plants in Sweden. The model indicated trade-offs between the configurations, such as increased direct methane emissions for EBPR and higher heavy metal emissions for CP. The results suggested that implementation of EBPR could decrease chemical usage and heavy metal emissions, but increase electricity consumption and possibly also greenhouse gas emissions. To meet stringent phosphorus limits, some amount of precipitation chemical is likely to be necessary also for the EBPR. However, in the case of a long-term, national shortage of these chemicals, EBPR decreases the risk of eutrophication in sensitive recipients compared to CP. More info at https://doi.org/10.1016/j.jclepro.2024.144047

Lobna Amin, Aalto University, Finland, presented modelling of iron phosphorus compound forms in one sewage works in which iron salts are dosed for P-removal (Viikinmäki, Finland). Modelling suggests that up to 85% of inorganic phosphates can be in the form of vivianite (iron(II) phosphate) in sludge streams upstream of anaerobic digestion and 100% downstream of the sludge digesters. These numbers are if iron is dosed at 2.5 – 3 x molar ratio compared to phosphorus. % of vivianite measured in samples (taken when the sewage works full-scale operation was compared to the simulation results, and the iron reduction rate used in the model was assessed based on our laboratory experiments). The presence of sulfur in the sludge competes with phosphates on iron, and therefore reducing the availability of iron for forming vivianite.

Muhammad Rubel, University of Coimbra (*text not validated speaker*), presented a life cycle analysis of use of animal bone biochar in a hypothetical system where this biochar is used to remove nutrients from dairy processing waste digestate liquid fraction then returned to the pyrolysis unit before then being composted with manure compost to produce a fertilising product (in the Horizon2020 R&D project WALNUT). The conclusions of the life cycle analysis show to depend principally on the allocation of environmental emissions to the cow bones: the bones show high LCA impacts if considered as a part of livestock production but could also be considered as having zero LCA impact because cows are reared for meat not for bones. Input data was based on inputs from a TRL6 pilot and estimates from the company selling the animal bone char technology (Refertil ABC, rebranded for subsequent EU-funded projects as 3R-Biophosphate).

Projects starting

Laura Diaz, BETA Technological Center, University of Vic, Spain, presented the Nutribudget project, which started in September 2022. With the objective of optimising nutrient flows and reduce pollution without compromising food production in agriculture, the Horizon Europe project NutriBudget will develop and implement an integrated nutrient management platform, called Nutriplatform, as a decision-support tool for farmers, advisors, policy makers and regional authorities. The Nutriplatform will be grounded on knowledge from existing and new field-tested agronomic measures to mitigate nutrient losses from agriculture combined with cutting-edge models on nutrient budgets, data standards and indicators. Thus, a wide range of mitigation measures to shrink nutrient losses from agricultural-farming systems are being tested in 5 pilot regions: Boreal (Finland), Atlantic (Belgium), Mediterranean (Spain), Continental + nutrient surplus (Italy), and Continental – nutrient deficient (Switzerland). In the Mediterranean pilot, BETA-UVIC is responsible of testing 5 mitigation measures: precision fertilization; use of upgraded manure products as organic fertilisers (BBFs); zeolites for soil ammonia emission mitigation; use of duckweed grown in pig slurry effluent as green manure; and perennial cereal forage crop (*Thinopyrum intermedium*) to reduce soil nutrient losses.

Lorenzo Proia, BETA Technological Center, University of Vic, Vasileios Takavakoglou and Vassilis Aschonitis, ELGO-DIMITRA, Soil and Water Resources Institute, Greece (left to right in the picture), and **Monia Magri, University of Parma, Italy** presented the SECURE project, which is addressing nutrient pollution along the landscape-river-sea continuum in the Mediterranean region by demonstrating and upscaling innovative solutions to prevent, reduce and remediate nutrients excess in six demo regions distributed in Italy, Greece and Spain.

Federico Battista, Università di Verona, introduced the LIFE DIMITRA project, which focuses on developing two demonstration plants for the valorisation of anaerobic digestate using distinct technological approaches. The first plant, located in the Thiva region (Greece), will process 50 tons per day of digestate derived from an anaerobic digestion facility treating organic fraction municipal solid waste (OFMSW). The primary goal is to produce ammonium sulphate through a series of treatments, including solid-liquid separation and low-temperature evaporation. The second plant, situated in the Veneto region (Italy), will handle 20 tons per day of agricultural digestate from a full-scale anaerobic digestion plant. This facility will utilize advanced sequential processing methods—combining solid-liquid separation, ultrafiltration, and reverse osmosis—to recover, fractionate, and concentrate different N, P and K compounds. Both demonstration plants are expected to commence operations in early 2025.

Site visits

ESPC5 participants had the opportunity to attend two technical visits to companies implementing nutrient recovery and the circular economy within the Lleida region.

Fertiebro

This fertiliser production facility specialises in three core areas: liquid fertilisers, deficiency correctors and blending of solid fertilisers. The site was taken over from a local operator three years ago by Fertinago (Tervalis Group) and is undergoing upgrade and considerable expansion. Current production is around 70 000 tn/y up from 2 000 t/y two years ago.

Fertinagro's business is centred on circularity. The company has no phosphate mine and no Haber Bosch nitrogen production and 35 - 40% of inputs used are secondary materials, including agri-food by-products and industrial by-products.

The Fertiebro site benefits from the regional agri-food context, taking in locally generated secondary materials and delivering liquid fertiliser for fertigation to local farmers and distributers, as well as providing sulphuric acid to local farmers for slurry acidification (to reduce ammonia emissions, so improving manure nitrogen use efficiency).

In order to ensure regulatory certainty, the site works only with materials with by-product status and does not take in wastes.

During the visit, attendees observed the entire production process, from the reception of raw materials sourced, including a range of organic secondary materials, to the final fertilisers.

The Horizon Europe Novafert project was presented, where Fertiebro and Fertinagro serve as a are partners for development and testing of innovative bio-based fertiliser technologies and nutrient recovery solutions.

Bioenergia de Almenar

The plant processes by anaerobic digestion some 150 000 t/year (wet weight) of input materials,, of which around 60 000 t/y pig slurry from 150 local farms. The remainder is organic waste from agrifood industries. Input comes from a distance of up to c. 60 km. The biogas produced is burned in three cogeneration motors (43 MW electricity output per day), with residual heat used to warm the digesters, and for evaporation / concentration of digestate onsite.

The plant has four primary and four secondary digesters, each of 2 700 m^3 capacity. Total residence time is around 50 days at 37 – 42°C.

Input materials are chopped into small particles, then go to the digesters. The digestate goes to solid-liquid separation (with polymer dosing). The liquid fraction is treated with a combination of membranes (ultrafiltration and reverse osmosis), heat evaporation at 80 bars and ammonium stripping-scrubbing. The ammonia solution goes back to the liquid concentrate.

Outputs are a solid organic fertiliser (obtained by composting of the solid fraction of the digestate), a nutrient-rich liquid fertiliser (approx. 3 % N) and clean water which is reused within the plant (in particular for cleaning the ultrafiltration and reverse osmosis membranes). The aim is to function with zero discharge water.

At present, the solid digestate fraction is classified as "fertiliser" under Spanish regulations, but this is expected to change as Spain may align national regulation with the EU Fertilising Products Regulation (FPR), in which case the solid fraction will not be classed as fertiliser (because of intake of industrial sludge in the digesters). The liquid concentrate is currently spread under waste regulations.

Moreover, the digesters do not achieve Animal By-Product specified conditions, so the outputs of the plant remain subject to ABP regulation. This also excludes from the FPR criteria

During the visit, participants saw reception and storage of input materials and visited the digesters and the plant control room.

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