Existing Nutrient Recovery Facilities

1.1. Existing Nutrient Recovery Facilities

Here, you can access a report of the current status (19/10/22) of Nutrient Recovery Technologies in the European Union Member States. Emphasis has been given to the new additions reported in publicly accessible inventories of the nutrient recovery routes.

Tracking the industries that practice material and resources recovery from their waste and Waste Water at a national and regional level registered to the Industrial Reporting Database as potential candidates for the application of Nutrient Recovery technologies can lead to mapping of the current status in the EU matrix.

In 2019, Nutrient Recovery processes focused on recovery of P or N separately (Perera, Englehardt, & Dvorak, 2019). Currently, Nutrient Recovery technologies involve the recovery of both P and N and there are cases in which micronutrients are also recovered from the input streams.

Earlier than 29.01.2021 registrations of mature N and P recovery technologies can be found in the Research and Innovation page of the European Commission Participant Portal (European Commision, 2021).

- Full scale Nutrient recovery plants operating or under permitting/construction, Nutrient Recovery technologies at TRL 6+ or at R&D scale were presented according to the latest version (accessible to the public 9/6/2022) of the European Sustainable Phosphorus Platform (ESPP) (Phosphorus Platform, 2022)) report on Nutrient Recovery technologies with the assistance of the German Phosphorus platform (DPP) (Deutsche Phosphor Plattform, 2022) and the Netherlands Nutrient Platform (NPP) (Nutrient Platform NL, 2022).

- The 'Recovered products' column in, Table 1 and Table 2, refers to all currently available candidates as economically prime important nutrient resource-based products derived from Nutrient Recovery Practices in Bio-based input streams and how they can be associated with fertilisation practices.

Table 1: 2022 additions of nutrient – recovery technologies in the EU, in the catalogue of phosphorus recovery technologies updated on 9/6/2022.

	Bio-based Input streams	Recovered Products	Nutrient Recovery Technology	Current operating status
Fertiliser industry (e.g. ICL, Borealis)	sewage sludge, incineration ash, from sewage works using biological and/or chemical P-removal; animal by product ash (Cat 2, 3); recovered phosphate salts	Standard mineral fertilisers	Recovered materials are mixed into the phosphate rock or phosphoric acid based fertiliser production process, either during acid attack of rock, or after this stage where product still has residual acidity (acidulation), so ensuring plant availability of P in ashes. Contaminants in ash are diluted in final product. This is legal under EU regulation on condition that the ash is not classified as "Hazardous". Final fertiliser product is covered by EU Fertilising Products Regulation 'STRUBIAS' annexes as proposed. Recovery rate (P in final product / P in input ash): c. 100% Iron and aluminium in input ash are transferred into final product Heavy metals are not removed.	ICL tested full scale and industrial installations now operation at ICL Netherlands (inaugurated March 2019, photo) and Germany (several hundred tonnes ash and struvite processed to date). Production from 100% ashes (without mixing with phosphate rock) is planned. Use of ash in fertiliser production has also been tested at by Borealis, Austria and by Fertiberia Spain (MBM ash at lab scale
PAKU (Endev)	Dewatered sewage sludge or dewatered sewage sludge digestate.	Ash with low contaminant levels suitable for fertiliser use: - Organic contaminants in sewage sludge are eliminated by incineration. - Heavy metal levels in the fertiliser ash (indicative averages mg/kg DM): As 7; Cd 1.1; Cr 170; Cu 400; Hg	Sludge disposal (incineration) with heat and nutrients recovery. Dewatered sludge is thermally dried to >95% DM content, using secondary energy from a PAKU incineration unit. In a specific process, heat is transferred using hot sand. PAKU ensures incineration at 850°C without additional fuels. Thermal drying condensate undergoes nitrogen	Full-scale plant operating since early 2021 in Rovaniemi (Finland), located adjacent to the WWTP of Rovaniemi city. Capacity 10 000 tonnes sludge (25% DM) per year

			recovery (ammonia stripping) and energy recovery. The ash from incineration is separated into a fertiliser fraction and a by-product fraction (	
PHOS4Green (Glatt)	Sewage sludge incineration ash	P or NPK fertilisers	Ash is reacted with phosphoric acid to render the P-content of the ash more plant available. Other elements can be added in this suspension (N, K, Mg, S, trace elements). The resulting material is then granulated to produce fertiliser pellets. Heavy metals, iron, aluminium, silica and other minerals present in the sewage sludge remain in the final product. Recovery rate (P in final product / P in input ash): c. 100% Iron and aluminium in input ash are transferred into final product Heavy metals are not removed.	Lab and pilot scale plants tested in Glatt's Technology Center in Weimar. Pilot of up to 30 kg/h input ash operated continuously for a number of multi-day trials for different input materials. A full-scale plant (30 000 t/y ash) was commissioned June 2021 at Haldensleben (Germany) with Seraplant
Renewable Nutrients (Quick Wash ©)	Solid or liquid waste streams: - sewage sludge digestates, - food processing wastes.	The final product is a stackable solid, typically c. 20% dry matter (can be dried to c. 90% dry matter), consisting of a mixture of amorphous calcium phosphate with organics (10 - 40 % dry matter organic carbon), and containing also organic nitrogen and minerals such as calcium, sulphur, magnesium. P-content of the final product: c. 0.25 – 0.55 % dry matter P for recovery from manures, digestates, wastewater or e.g.	The QuickWash process consists of: 1) Solubilisation of phosphorus using acid at pH 3-5 (e.g. citric acid or hydrochloric acid). 2) Solid is then separated from the acid liquid by settling. 3) Precipitation of calcium phosphate from the acid solution by increasing to pH 8-10 by lime dosing. 4) Recovery by settling. Anionic polyacrylamide polymer (at c. 7 mg/l) is dosed to enhance settling and	Over 20 pilot installations have been constructed and tested at sites including municipal wastewater treatment works, farms and industrial sites, treating up to c. 0.5 million litres/day (c. 1 500 t/y output product). 1.5 million litres/day installations are under planning in the UK and USA.

		>6% for recovery from P-rich industrial stream. The amorphous calcium phosphate has high P fertiliser effectiveness* **. Data on NAC solubility (required for labelling as a "Mineral" fertiliser under the EU Regulation 2019/1009) are not provided. Contaminants will depend on the input stream treated. Typical levels of copper and zinc are 100 – 300 mg/kg dry matter.	recovery of the precipitated calcium phosphate. Recovery of P from input material is generally > 95%. This process enables recovery of a relatively pure amorphous calcium phosphate, but in operations today this is recovered along with organics, in order to provide organic carbon and other nutrients to farmers.	
TetraPhos (Remondis)	- sewage sludge incineration ash, from sewage works using biological and/or chemical P-removal	- phosphoric acid - gypsum - iron and aluminium salts - mineral ash residues	- Ash leaching - Heavy metals precipitation - Solid-liquid separation - Gypsum precipitation - ion-exchange and optionally nano-filtration	Full scale plant: Hamburg, Germany (commissioning underway 2022) Throughput: 20,000 t/y ash. Further full scale plants are in project phase in Kiel, (Germany), Lünen (Germany) and Moerdijk (The Netherlands).
RAVITA (Helsinki HSY) TRL 6+	- P-rich sludge from chemical post-precipitation (P-recovery)	- Phosphoric acid - Iron/aluminium chemicals for use as coagulants in WWTP P-removal.	- tertiary post precipitation - Sludge dissolution -solvent-solvent extraction	Post-precipitation: 1 000 p.e. pilot for tertiary P-removal operating since 2017 (achieving 0.4

	- sewage sludge dewatering liquor (N-recovery)	- Ammonium phosphate	- Ammonia stripping from secondary sludge dewatering liquors	mgP/l WWTP discharge). P-recovery: 1 000 p.e. pilot under testing, started in 2020.
Struvite enhanced Phosphogreen (Suez). Phosforce (Veolia) Parforce	Only applicable to WWTP operating biological P removal, usually with sludge digestion (AD).	Struvite, useable directly as a fertiliser. Has added value as a slow-release, low leaching, non root-burning fertiliser. Over 50 studies show that struvite is plant available an effective fertiliser. EU Fertilising Products Regulation criteria for recovered struvite proposed are under finalisation (see the final STRUBIAS report Sept. 2019). Recovered struvite already has End-of-Waste status and EU 2003/2003 fertiliser validation in a number of countries. In bio-P WWTP, struvite precipitation.	Sludge return streams or side streams in the biological treatment process are adapted to optimise soluble orthophosphorus release and to increase P available for struvite precipitation, enabling recovery of 20 – 35 % of sewage works inflow P as struvite. This rate can be further increased to 45 – 50 % by processes which hydrolyse sewage sludge to render the phosphorus soluble (see "Sludge lysis" below)	Ostara WAASTRIP (Crystal Green) is operating at 12 WWTP worldwide, recovering 45 – 50% of WWTP inflow P. Phosphogreen at Aarhus Åby, 70 000 p.e. since 2013: 45-50% recovery of WWTP inflow P is achieved so long as ferric dosing is not required in WWTP operation. NuReSys (Apeldoorn Hybrid Unit): 30% recovery of WWTP inflow P. Veolia Phosphogreen: pilot scale trials at 3 sites, demonstration scale planned

				Parforce: under construction (early 2022) at Wolfsburg, Germany, 150,000 p.e. up to 60 – 70% recovery of WWTP inflow P by struvite precipitation from hydrolysed sludge
ViViMag™ (WETSUS - Kemira)	- sewage sludge digestate, before dewatering, from WWTP using iron salts for chemical P removal	- vivianite (iron(II) phosphate). Can be used as an iron fertiliser. Or possibility to process to PK fertiliser and iron coagulants for use in WWTP)	- Anaerobic digestion for magnetic separation of iron phosphate precipitation by iron (III) reduction to iron (II).	Manual 1 m^3/h pilot for magnetic separation of vivianite tested at Nieuwveer WWTP, NL. Automatic 1 m^3/h pilot currently under construction, with continuous trials planned in Germany, Denmark and the Netherlands starting from summer 2022.
AshDec (Metso Outotec) TRL 6+	- All ashes with P content >7%	- Modified Rhenania Phosphate (Calcium-Sodium-Phosphate) P_{nac} solubility >80%; granular material with P_2O_5 content of 15-25% (depending on the input-ash); no organic matter; product is blendable with all other fertilising products.*	- Ash is mixed with a sodium carrier (Na_2CO_3 or $NaHCO_3$) and heated to about 850-900°C in a rotary kiln to modify the P-compounds to neutral ammonium-citrate soluble $CaNaPO_4$ (Rhenania Phosphate).	Pilot plant (300 kg/h) operational for several years, Leoben, Austria. Continuous operating campaigns produced several hundred tons of product. A full scale plant (30 000 t/y ash input) is planned in Altenstadt (Bavaria), with Enter GmbH and sePura GmbH, in the R-Rhenalia RePhoR project.

CarboREM TRL 6+	- Digested dewatered sewage sludge (10- 15% DS).	- Precipitated phosphate salts.	- hydrothermal carbonisation - solid-liquid separation of hydrochar - dissolution in acid (citric acid or HCl) - addition of alkali (NaOH) for phosphate salt precipitation**	Industrial-scale continuous HTC plant installed in 2019 and located in the wastewater treatment plant of Mezzocorona, Italy. Capacity: 1.4 t/h of wet digested sewage sludge

Table 2: 2022 additions of nutrient – recovery technologies in the EU, in the catalogue of other recovery technologies updated on 9/6/2022.

	Bio-based Input streams	Recovered Products	Nutrient RecoveryTechnology	Current operating status
Ash2Salt (EasyMining)	- Fly ash from municipal solid waste incineration (not bottom ash)	- Potassium chloride - Sodium chloride - calcium chloride The salts are of high quality and suitable for industrial use and fertilisers. -Ammonium sulphate (40% solution)	- Ca, S, K dissolution - Sulphates precipitation - Vacuum filtration - The treated brine is upconcentrated by recirculation, then undergoes ammonia removal and recovery (as ammonium sulphate). After removal of ammonia, the brine is evaporated and three different salts are recovered: potassium chloride (solid), sodium chloride (solid) and calcium chloride (solution). The salt separation is based on differences in the solubilities of the salts involved. The clean condensate water can be recycled in the process or be used for other purposes.	A first full scale plant is being built at Ragn-Sells waste management plant, Högbytorp, near Stockholm, Sweden. Planned start-up: late 2022. This plant will have a capacity of 130 000 ton fly ash per year, producing approx 3 500 t/y (dry) potassium chloride, 7 000 t/y (dry) sodium chloride and 32 000 t/y calcium chloride (36% solution).

Project Nitrogen (EasyMining)	- Liquors with a high ammonium concentration, e.g. WWT sludge dewatering liquors.	- Ammonium sulphate ($(NH_4)_2SO_4$). (10-25% solution) Contaminations in the ammonium sulphate are well below fertilizer requirements.	In the first step, the ammonium nitrogen is precipitated with a specific chemical. In the second step, the precipitant is regenerated and sent back to the first step, and acid is used to convert the nitrogen to a form usable either directly in fertilisers or in fertiliser production.	The processes are currently (early 2022) being demonstrated in a continuous demonstration plant of capacity 4 m^3/h inflow. This installation was tested December 2021-March 2022 at RagnSells' waste management plant Högbytorp in Bro, Sweden, and in AprilSeptember 2022 at BIOFOS' municipal wastewater treatment plant Lynetten in Copenhagen, Denmark.
CCm CCm Technologies Carbon Capture and Utilisation TRL 6+	-Digestates of sewage sludge, - food waste - In some cases, also other secondary materials e.g. wood chips, organic fibres, biomass ash - Offgas CO_2	Pelletised organo-mineral fertiliser, containing stabilised N and P. Field tests of the fertiliser product show compatibility of the pellets with existing farm fertiliser equipment: rotating discs up to 36m wide spreading radius), crop performance comparable to commercial mineral fertilisers and positive impacts on soil	Ammonia captured from digestate is used to capture (as carbonate) CO_2 from digester biogas (mixed off-gas or separated CO_2 stream from biomethane). This is then combined with organics in digestate cakes, further stabilising the nitrogen and carbon. The product is then dried and pelletised, to produce a stable organo-mineral fertiliser (OMF). Additionally, CCm are operating a pilot unit Pilot (4 m_3/day) at Yorkshire Water Caldervale site, UK, to remove and recover phosphorus as struvite from Prich sludge dewatering streams, using magnesium and ammonia. The output integrates the phosphorus into the stable organo-mineral fertiliser pellets.	Industrial demonstrator at Kew Technology Sustainable Energy Centre, UK, to produce OMF fertiliser. Output: 500 t/yr. Inputs: biochar, digestate, recovered CO_2 from enhanced thermal conversion technology. Operational in Q1, 2022.

		bioflora, water retention, soil carbon and reduced nutrient runoff	Aim: 75% P reduction from liquors. Startup planned Q2 2022.	Industrial demonstrator is located at Severn Trent Water Minworth site, UK. Output 10 000 t/yr OMF fertiliser pellets. Input capability: sewage sludge, biomass ash, recovered CO_2, recovered ammonia. Operational from 2021. Full scale plant at Walkers potato processing plant (Pepsico, Leicester, UK). Outputs: 12 000 t/yr OMF fertiliser pellets. Inputs: food waste digestate, recovered CO_2. Operation start Q2, 2022.
Parforce	- Sewage sludge incineration ash, - other ashes, - phosphate rock or - other secondary materials - Struvite can be used as raw material after calcining (prior	- Phosphoric acid - By-products or waste streams depending on process design and input material. - % of P in input material recovered in	1) Acid digestion using HCl or HNO3, to generate raw phosphoric acid 2) solid-liquid separation (filtration) 3) if the input material is sewage sludge ashes, then iron and aluminium are extracted (prior to electrodialysis) by either ion exchange or solvent extraction	Batch pilot, capacity 150 - 250 kg ash per batch and semi-continuous acid purification, tested for several different materials in since 2018 at Freiberg University

	to step 1) to remove organic contaminants, with ammonia recovery	phosphoric acid: > 80% for sewage sludge incineration ash, higher for other input materials. - Approx. 5 – 35% of iron and 40 – 55% of aluminium in ash are leached by acid in step (1). Iron must then be removed in step (3) to protect the electrodialysis of step (4). - >99% removal of leached heavy metals, copper, zinc can be achieved in the phosphoric acid purification, step (4).	4) membrane electrodialysis to separate metal cations (especially Ca, Mg and heavy metals) to a concentrated solution. 5) concentration of the remaining phosphoric acid 6) the metal Ca, Mg, heavy metals etc solution (separated from the phosphoric acid in step 4) is treated with lime. This precipitates the metals to a waste stream leaving a salt solution which can possibly processed to road salt. In pilot trials, some of the phosphorus passed the electrodialysis membranes. so that a return stream was required. This is resolved in larger scale trials where continuous electrodialysis offers better selectivity.	of Mining and Technology, Germany. An automated demonstration plant is now planned (2022) for Bottrop, Germany, capacity 1 000 t/y ash. Continuous campaigns will test different ash inputs.

For the better interpretation of the information presented in Table 1 and Table 2, some key points are summarised as follows:

- Combining biological, chemical, and physical methods with thermal treatment appears to be the most effective way for the treatment of waste water sludge in terms of phosphorus recovery.
- Accessibility and efficiency of the osmotic membrane bioreactors (OMBR) and the bioelectrochemical systems (BES)-based hybrid systems for Nutrient Recovery can increase by the reduction in their operational costs along with the improvement of their technical feasibility.
- Attention must be paid on the evaluation of the feasibility and the performance (sludge properties, membrane fouling, permeate flux) of OMBR with different WW solutions as feed and the necessity of pre-treatment.
- Integration of membrane technology into current and conventional technologies increases the quantity and the quality of recovered nutrients due to low fouling potential and low energy consumption.
- Further research on the anaerobic OMBR –based hybrid systems should be considered regarding nutrient recovery, given the lower energy consumption when compared to the aerobic ones.
- Microbial Fuel Cells (MFC) have great potential in Nutrient Recovery due to the electricity generation and the high pH zone for chemical precipitation. The combination of MFC with forward osmosis, membrane distillation or electro dialysis favours nutrient enrichment from diluted WW, as well as the quality and the quantity of recovered nutrients.
- Hydrothermal, thermochemical, and adsorption on thermally treated adsorbents are characterised by a high phosphorus recovery rate (over 95%).
- Due to its large volume and relatively low phosphorus content, WW is a resource that requires additional treatment to recover the highest possible amount of phosphorus.
- Pretreatment of WW with combined methods seems to be a possible way to improve phosphorus recovery.
- Regarding N-recovery, mainly struvite precipitation and acid absorption followed by separation by gas stripping or gas permeable membranes can be applied. Electrodialysis, bioelectrochemical processes and Ion Exchange/adsorption can be applied for the concentration of N.
- The combination of enhanced biological phosphorus removal with (electro)chemical struvite precipitation and chemical precipitation alone can be applied for P-recovery in centralised WW treatment plants. The preference towards struvite precipitation is pointed out.
- Regarding low requirements in maintenance and chemicals, ability to adapt on-site and to implement on pre-manufactured WWTP, electrochemical and chemical precipitation as well as ion exchange processes are mostly preferred.
- Nutrient Recovery in algal biomass may be particularly useful for the production of bio-based fertilisers and biostimulants. Further investigation is required for the direct microbiological recovery as a protein source in food.

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1.2. References

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