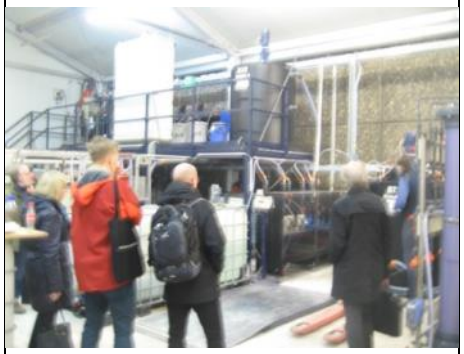
ESPP – DPP – NNP phosphorus recovery technology catalogue http://www.phosphorusplatform.eu/p-recovery-technology-inventory

NOTE: this document aims to provide an indicative overview, not technical information to support decision making. It is accurate to the best of our knowledge, but further information and updates should be sought from the indicated contacts. Inclusion in this document does not constitute any endorsement of technology(ies) by the nutrient platforms, nor validation of intellectual property nor commercial claims.

Process & contact	*Input materials*	*Output products*	*Process description*	*Operating status*	*Photos*
Sewage P-recovery: full scale plants operating or under permitting/construction					
Fertiliser industry – E.g. ICL ***Member ESPP, DPP, NNP*** http://icl-group-sustainability.com/reports/producing-fertilizers-with-recycled-phosphate/ Contact (ICL): anthony.zanelli@icl-group.com	Input: sewage sludge incineration ash, from sewage works using biological and/or chemical P-removal; animal by-product ash (Cat 2, 3); recovered phosphate salts.	Standards mineral fertilisers. Fertiliser production plant must have operating permit authorising to process waste.	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	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 Fertiberia Spain (MBM ash at lab scale)	

Process & contact	Input materials	Output products	Process description	Operating status	Photos
			proposed.		
Ash2Phos (EasyMining) ***Member ESPP, DPP*** http://easymining.se/ Contact: Jan.svard@ragnsells.com	Input: sewage sludge incineration ash, from sewage works using biological and/or chemical P-removal.	- Calcium phosphate, can be converted into – superphosphate, - di-calcium phosphate (DCP), - mono-ammonium phosphate (MAP). Product can also be used as raw material for NPK fertilizers - Ferric chloride as a coagulant for wastewater treatment - Aluminium hydroxide as a raw material for coagulants and other industrial applications - Feed phosphates (subject to legal provisions)	Sewage sludge ash is dissolved in hydrochloric acid (ambient temperature, no pressure). The residue of ash which is not dissolved in acid consists mainly of inorganic silicates, and after separation and washing can be used e.g. in the cement or concrete industries. Phosphorus, iron and aluminium compounds are separated from the acid leachate and from each other by specific dissolution and precipitation reactions, in processes characterized by internal recirculation of chemicals. The remaining acid solution is neutralized and treated to remove heavy metals.	Pilots in Sweden: Uppsala, 50 kg ash/day ash and Helsingborg, 600 kg/day ash. Full scale plants: - 30 000 t/y ash, Helsingborg, Sweden (permit application ongoing), with Kemira - 60 000 t/y ash planned, Bitterfeld-Wolfen, near Berlin	

Process & contact	*Input materials*	*Output products*	*Process description*	*Operating status*	*Photos*
TetraPhos (Remondis) ***Member of DPP*** www.phosphorusplatform.eu/Scope129 Contact; industrie@remondis-aqua.de	Input: sewage sludge incineration ash, from sewage works using biological and/or chemical P-removal.	- phosphoric acid - gypsum - iron and aluminium salts - mineral ash residues	1) ash is leached using phosphoric acid, so solubilising phosphorus and calcium but not most of the iron or heavy metals 2) addition of sulphide to precipitate heavy metals and maximise the proportion of these which stay in the leached ash (solid fraction) 3) solid-liquid separation 4) from the liquid fraction (enriched phosphoric acid), calcium is precipitated as gypsum, by addition of sulphuric acid, and the gypsum is separated out by vacuum belt filter and water washing. 5) the resulting phosphoric acid is partially returned back to leaching process. The additional acid production is purified by ion-exchanger and optionally nano-filtration membrane 6) the resulting purified phosphoric acid is then concentrated (preferably using secondary heat, e.g. from a sludge incinerator) 7) regeneration of the ion-exchange resin produces (using hydrochloric acid) produces a metal salt solution, which can be potentially recycled to sewage works for phosphorus removal.	Pilot plant: Elverlingsen, Germany, 50 kg/h ash (photo) Full scale plant: Hamburg, Germany (Under construction) Throughput: 20,000 t/y ash	 
EuPhore https://www.euphore.de Contact: siegfried.klose@euphore.de frank.zepke@euphore.de marianne.klose@euphore.de	Dewatered sewage sludge. Phosphorus rich biomass.	Phosphate-containing ash which can meet German and EU fertilisers regulation specifications, depending on input ash quality.	The EuPhoRe process uses a specifically-designed rotary kiln incinerator. Flue gas, either from e.g. solid waste incineration, or from the EuPhoRe process itself, is used to dry sewage sludge, and to ensure reducing conditions in part of the reactor. The kiln operates with different zones, reducing and oxidation, up to 1000°C (ensuring destruction of organic contaminants). Alkali- and/or earth-alkali chlorides are added to ensure reduction of part of the	Pilot plant: Dinslaken Germany (Emschergenossenschaft): 100 kg dewatered sludge/hour wet weight input (photo) Existing full scale plants using similar kilns (but not for P-recovery) are operating in Switzerland at Offtringen (30 000 t/y) and Uvrier (15 000 t/y). Two full-scale plant are under construction in Germany at	

Process & contact	Input materials	Output products	Process description	Operating status	Photos
			metals content and removal (as chlorides) into the gas phase. Heavy metals are stripped from the flue gas to a waste stream. All other minerals, including iron and aluminium, remain in the ash.	Offenbach (100 kt/y) and Mannheim (135 kt/y). Several other plants are planned in Europe.	
TerraNova (HTC) ***Member of DPP*** https://terranova-energy.com/umweltschutz/ Contact: erkan.yalcin@terranova-energy.com	Input: raw or digested sludge after dewatering, from wwtps operating biological and/or chemical P-removal	Mg/Ca-P salt	1) continuous hydrothermal hydrolysis carbonization process at 175°C, 20-25 bars. 2) Acid treatment of hydrolysed sludge to dissolve P. 3) Mechanical separation into low-P solid "coal" and P-rich liquid filtrate. 4) Phosphate precipitation from the liquid to produce a Ca/Mg phosphate salt.	Full scale plant operating on dewatered sewage sludge in China (since 2016) input capacity 2 t/h Demonstration plant at Ruhrverband/Duisburg Germany, input capacity 250 kg/h.	
Kubota Kubota Surface Melting Furnace (KSMF) www.phosphorusplatform.eu/Scope125 contact: hiroyuki.hara@kubota.com	Input: dried sewage sludge or sludge incineration ash, from sewage works with biological and/or chemical P-removal	P-containing slag.	Thermal treatment with core temperature 1300°C. Iron oxide is added to retain phosphorus in the solid slag whereas part of the heavy metals, copper and zinc are volatilised and removed. Calcium hydroxide is added to improve phosphorus plant availability in the slag. 90% of input P is in slag. The slag shows 95% P-solubility in 2% citric acid and, in pot trials at soil pH 5.5, 97% fertiliser efficiency relative to commercial phosphorus fertilisers.	30+ full-scale furnaces in operation in Japan, including 11 treating sewage sludge (1 – 10m diameter)	

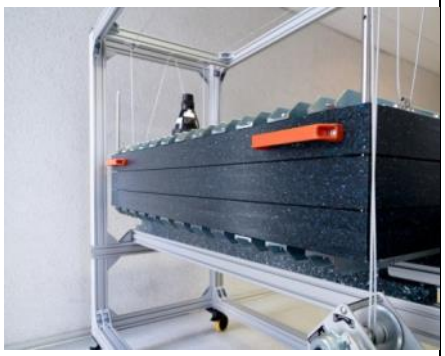
Process & contact	*Input materials*	*Output products*	*Process description*	*Operating status*	*Photos*
PHOS4Green (Glatt) https://www.phos4green-glatt.com/innovation-78.html Contact: jan.kirchhof@glatt.com	Sewage sludge incineration ash	P or NPK fertilisers	Ash is reacted with phosphoric acid to render 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.	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. Photo above: A full-scale plant (30 000 t/y ash) is under commissioning at Haldensleben (Germany) with Seraplant. Photo below: Glatt experience in fertiliser granulation	 
Metawater alkaline ash leaching http://www.metawater.co.jp/eng/product/plant/sewer/rin_collection/	Sewage sludge incineration ash, from sewage works using chemical or biological P-removal.	Calcium phosphate (hydroxyapatite) for use as fertiliser or in fertiliser production. Registered as a fertiliser in Japan (2009) and demonstrated in plant tests.	1) Dilute sodium hydroxide is used to leach sewage sludge incineration ash (90 minutes, 50-70°C) 2) After filtration, calcium phosphate is precipitated from the leachate, then separated (sedimentation) then dried. 3) Leaching of P in the ash is limited to around 30% in order to minimise leaching of heavy metals. 4) The remaining ash is treated with poly-ferric sulphate solution to immobilise remaining metals. This residual ash now has a slightly higher mass than initially (30% humidity) and is used as a construction material or soil amendment.	Two full-scale plants operating in Japan: Gifu, since 2010, 5 t/day ash (taking ash from two mono-incinerators treating sewage sludge from four wwtps, total 380 000 inhabitants), and Tottori, since 2014, 2t/day ash (taking ash from one mono-incinerator treating sludge from total 90 000 inhabitants). Photo: Gifu plant, from "Phosphorus Recovery and Recycling", ed. Otake & Tsuneda, Springer; 2019	
Struvite enhanced: biological ***Members of ESPP / DPP*** WASSTRIP Waste Activated Sludge Stripping To Recover	Only applicable to wwtps operating biological P removal, usually with sludge digestion (AD).	Struvite as above.	Sludge return streams or sidestreams 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	Ostara WAASTRIP (Crystal Green) is operating at 12 wwtps worldwide, recovering 45 – 50% of wwtp inflow P. Phosphogreen at Aarhus Åby, 70 000 p.e. since 2013: 45-50%	

Process & contact	*Input materials*	*Output products*	*Process description*	*Operating status*	*Photos*
Internal Phosphate (Ostara) https://ostara.com/nutrient-management-solutions/ Phosphogreen (Suez) see above. Phosforce (Veolia)			inflow P as struvite. This rate can be further increased to 45 – 50 % by processes which hydrolyse sewage sludge to render the phosphorus soluble (e.g. Cambi or IRSTEA, see below)	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.	
Struvite enhanced: acid (MSE-mobile) ***Member of DPP*** https://www.mse-mobile.de/Dienstleistung/PhosphorRecycling/ contact: r.turek@mse-mobile.de	Sewage sludge before dewatering, from sewage works using chemical or biological P-removal.	Struvite Phosphorus-depleted dewatered sewage sludge (filter cake)	1) Sulphuric acid is added to sewage sludge, to dissolve phosphorus 2) Solid/liquid separation by filter press 3) The phosphorus depleted filter cake contains <2%P/DM 4) The acid liquor is treated with citric acid (to complex and remove metal ions) then neutralised with sodium hydroxide and magnesium oxide is added to precipitate struvite 40-60 % of P in the inflow sewage sludge is recovered in the struvite.	One mobile (two containers) pilot-scale installation has been operated since 2016 at 7 sewage works. Capacity 50 t/day inflow sewage sludge (wet weight before dewatering).	
Sludge lysis Cambi, Pondus, Haarslev, LysoTherm (Eliquo Stulz), Exelys (Veolia), Bio Thelys (Veolia) …	Aqueous sewage liquors or sewage sludge	***NOTE: lysis is not itself a nutrient recovery process*** but breaks down organic matter and dissolves phosphorus, so making P available for struvite or other precipitation processes.	Example: Cambi thermal hydrolysis operates typically at 150-170°C, 6 bars, 20-40 minutes. Breakdown of volatile solids improves methane production from anaerobic digesters and reduces required digester residence time, as well as releasing phosphorus into solution (ortho-phosphate).	55 full-scale Cambi plants operating across the world www.cambi.com - contact kine.svensson@cambi.com	

Process & contact	*Input materials*	*Output products*	*Process description*	*Operating status*	*Photos*
Pyreg (pyrolysis) ***Member of DPP*** https://www.pyreg.de/ Contact: info@pyreg.de	Sewage sludge (minimum calorific value 10 MJ/kg, that is around 80% DS). Biomass materials.	Pyreg biochar (from sewage sludge) registered as a fertiliser in Sweden (PYREGphos). However, sewage sludge biochar not included in current EU Fertilising Products Regulation STRUBIAS proposals	Twin screw carbonisation reactor operated at 500 – 800 °C. This temperature results in a biochar with labile organic carbon content < 1%.	Nearly 30 full scale units in operation today (1000 – 4000 t/y input), of which 4 using sewage sludge: - Unkel, Germany (1200 t DS/y, since 2015) - Homburg, Germany (1200 t DS/y, since 2016) - Redwood, California (1200 t DS/y, since 2016) - Hammenhög, Sweden (1200 t DS/y, since 2016)	
Sewage P-recovery: (TRL 6+)					
Phos4Life (ZAR – Técnicas Reunidas) ***Member of ESPP*** http://www.phosphorusplatform.eu/Scope119 Técnicas Reunidas www.tecnicasreunidas.es Contact: agalindoc@trsa.es ZAR Foundation Contact: stefan.schlumberger@kebag.ch	Input: sewage sludge incineration ash, from sewage works using biological and/or chemical P-removal.	Technical grade phosphoric acid. Silica filter cake to cement/concrete industries Heavy metal concentrate. Fe-III-chloride solution as a coagulant for wastewater treatment	1) Leaching of ash in sulphuric acid to dissolve phosphorus, solid/liquid separation by filtration. 2) Separation of iron, aluminium and heavy metals by solvent extraction 3) Concentration of dilute acid to technical grade phosphoric acid by evaporation	Pilot tests carried out at Tecnicas Reunidas in Madrid Spain. Full scale (30,000 t/y ash) implementation planned in Solothurn, Switzerland	

Process & contact	*Input materials*	*Output products*	*Process description*	*Operating status*	*Photos*
RAVITA (Helsinki HSY) Helsinki Region Environmental Services www.ravita.fi Contact: Laura.Rossi@hsy.fi	Chemical post-precipitation, then P-recovery from the resulting P-rich sludge. Also, nitrogen recovery from sewage sludge dewatering liquor.	Phosphoric acid Recovery of iron/aluminium chemicals for use as coagulants in wwtp P-removal. Ammonium phosphate.	1) Tertiary post-precipitation, using iron or aluminium coagulants, then separation by e.g. disc filters, to generate a P-rich sludge. This can be installed in smaller wwtps, then the sludge transported to central processing. Heavy metals are low in this post-precipitation, so facilitating recovery. 2) Dissolution of this sludge in phosphoric acid. 3) Continuous solvent-solvent extraction to separate iron and aluminium salts in solution (can be recycled as coagulants) and phosphoric acid 4) Combination with nitrogen recovery (ammonia stripping from secondary sludge dewatering liquors) to produce ammonium phosphate.	Post-precipitation: 1 000 p.e. pilot for tertiary P-removal operating since 2017 (achieving 0.4 mgP/l wwtp discharge). P-recovery: 1 000 p.e. pilot under construction, start-up 2020.	
Extraphos (Prayon)	Input: digested sewage sludge	Calcium phosphate	1) Liquefied CO_2 (standard gas product) is used to partially dissolve phosphorus in liquid sludge to soluble form (ambient temperature, operating pressure c. 10 bars). 2) solid/liquid separation 3) the liquid fraction is used for P-recovery, by pressure release and some lime addition, resulting in calcium phosphate precipitation Iron, aluminium, heavy metals and organic carbon remain mainly in the solid fraction. Tests of contaminant removal using acid acidulation are underway	Process initially developed by Budenheim with a mobile pilot plant: 1 m^3 volume. Technology now owned by Prayon.	

Process & contact	Input materials	Output products	Process description	Operating status	Photos
ViViMAG (WETSUS) ***Member of ESPP*** https://www.wetsus.nl/vivimag Contact: leon.korving@wetsus.nl	Input: sewage sludge digestate, before dewatering, from wwtp using iron salts for chemical P removal	Product: vivianite. Can be used as an iron fertiliser. Or possibility to process to PK fertiliser and iron coagulants for use in wwtps)	Precipitation of iron phosphate in the form of vivianite, by reducing iron(III) to iron(II) in anaerobic conditions (digester), then recovery of the vivianite by magnetic separation. Vivianite can be used as an Fe fertilizer to treat Fe-chlorosis of for instance olive treas. Optional extraction of P from vivianite to liquid PK fertiliser and recycle iron as coagulant to wwtp	Continuous 1 m^3/h pilot for magnetic separation of vivianite tested at Nieuwveer wwtp, NL	
AshDec (Outotec) ***Member of ESPP*** https://www.outotec.com/products/energy-production/sludge-incineration-plant/ Contact: tanja.schaaf@outotec.com	All ashes with P-content >7%	Modified Rhenania Phosphate (Calcium-Sodium-Phosphate) P_{nac} solubility >80%; granular material with P_2O_5 content of 15-20% (depending on input-ash); no organic matter; product is blendable with all other fertilising products.	Ash is mixed with a sodium carrier (Na_2CO_3, $NaHCO_3$ or Na_2SO_4) 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). Some heavy metals are removed (Cd, Hg, Pb) and captured in a baghouse filter from where they can be separated from the fertilising product as a small waste stream (3% of input material).	Pilot plant (300 kg/h) operational for several years, continuous production campaigns to produce up to several hundred tons in a row.	
Kemira iron/aluminium phosphate ***Member of ESPP*** www.kemira.com Contact Outi.gronfors@kemira.com	Upgrading of existing sewage treatment works	Iron or aluminium phosphate	1) Optimisation of primary and secondary (biological) treatment by polymer dosing with control algorithms giving increased biogas production 2) Tertiary P-removal with iron and/or aluminium coagulants, control algorithms, separation by settling and/or centrifugation to produce a P-rich sludge, <10% C-org, containing >50% of wwtp incoming P. Can be installed at smaller wwtps and recovered material treated at centralized treatment process. 3) Optionally further processing of the P-rich sludge, by drying, granulation, or separation of P and Fe or Al to produce phosphoric acid, phosphate salt and Fe or Al coagulant for water treatment	Tested at full scale at two wwtps (63,000 pe and 130,000 pe) for 1-7 months, and at pilot scale at three wwtps for 2-3 months. Iron phosphate granules have been tested as fertiliser in pot trials with rye grass. Photos: NPK fertilizer granules including iron phosphate (left). Recovered aluminum phosphate pellets (right). Pilot set up for P-rich sludge separation in tertiary unit (bottom).	

Process & contact	*Input materials*	*Output products*	*Process description*	*Operating status*	*Photos*
ePhos (Fraunhofer IGB) ***Member of ESPP*** https://www.igb.fraunhofer.de/en/research/water-technologies/nutrient-recovery/phosphorus-recovery.html Contact: siegfried.egner@igb.fraunhofer.de	Sewage sludge dewatering liquor	Struvite or K-struvite (magnesium ammonium phosphate)	Electrochemical struvite precipitation, using sacrificial magnesium anode and no chemical inputs	Full-scale installation 2017 OVIVO (USA) ????	
Other nutrient recovery TR6+					
Hitachi Zosen https://www.hitachizosen.co.jp/english/products/products006.html Contact: ueda_k@hitachizosen.co.jp	Manure, solid/liquid separated and dried to 60% DM.	Stabilised and sanitised biochar, rich in phosphorus and can be used as organic fertiliser and/or soil improver	Manure is pyrolyzed at 400-500°C under oxygen-limiting conditions in the reactor. The reactor is kept at a slight negative pressure to prevent leakage of pyrolysis gas. Energy efficient pyrolysis can be operated without requiring energy input if input is drier than 60%DM / 40% water	Pilot scale plants operating in Japan on manure (capacity 720 kg/day, operating since 2012) Planned : Demonstration plant (5 t/day) and full scale plant (18 t/day)	
AguaDB Website: ???????? Contact: Mike Waite mike.waite@aguadb.com	Nutrient recovery from drinking water treatment. Adaptation possible for tertiary N-removal in sewage plants.	Solution of nitrate with K, S, Ca and Mg for local fertigation.	Ion-exchange is today widely used to remove nitrates from drinking water, but uses salt for regeneration. This generates a phytotoxic sodium nitrate brine, which has to be disposed. The Agua DB process uses water quality potash (KCl) for regeneration, instead of salt, in significantly lower quantities, so generating liquors rich in sulphate, nitrate and potassium, which can be used for fertigation in local agriculture. These can partially replace synthetic fertilisers and reduce use of potash by farmers, so reducing salination (Cl input) to	A three months pilot project with Affinity Water (a UK drinking water company supplying 3.6 million people), showed effective nitrate removal down to 5 mgN/l. The resulting fertigation solution was demonstrated to be effective for use in hydroponics.	

Process & contact	Input materials	Output products	Process description	Operating status	Photos
			farmland.		
Agro America (VP Hobe) ***Member of NNP*** www.agroamerica.nl Contact: h.willems@vp-systems.nl	Liquid or dry pig manure	Biochar	Pig manure is solid-liquid separated by belt-press, most P remains in solid fraction. Liquid fraction is spread locally to fields. Solid fraction is dried then pyrolysed (with heat energy recycling)	250 000 t/y ww pig manure installation operating 5 days/week since 2015 on farm at Holland, Holland near Horst-Venlo Operation 24/7 is planned.	
GENIAAL (Nijhuis) ***Member of NNP*** https://www.nijhuisindustries.com/de/solutions/digesters/nijhuis-geniaal/ Contact: thijs.wolbrink@nijhuisindustries.com	Liquid manure digestate	N-K fertiliser solution, used by farmers locally (1 - 1,5% N and 1 -1,5 % K2O). P-rich organic fertiliser. Clean water.	1) solid/liquid separation by decanter, without polymer use 2) clarification of the liquid fraction by flotation technology 3) two-stage membrane filtration to produce N-K fertiliser solution and purified water 5) the solid fraction is phosphorus-containing organic fertiliser (1.3 – 2.6 % P DW) Also RePeat and AECO-NPR technologies (please add web links for each one)	Full scale plant operating since 2019 at Groot Zevert Digestion, Beltrum, The Netherlands (100 000 t/y manure wet weight)	
BioEcoSim (Suez) ***Member of ESPP*** Contact: Kai.Bastuck@suez.com	Liquid manure or liquid digestate, with dry matter content of at least 35%	Recovery of precipitated phosphate salts, ammonium sulphate, organic soil amendment (biochar)	• mineral acids are used to dissolve nutrients into liquid fraction • solid-liquid separation • optionally: superheated steam drying, then pyrolysis • phosphate precipitation from liquor • gas permeable membrane ammonia stripping • palletisation of solid biochar	Process developed by Fraunhofer IGB and transferred to Suez. A 1.2 t/day pig manure pilot was operated by Fraunhofer IGB 2017-2018 at Kupferzell, Germany. A pilot plant (10 000 t/y) is operating since July 2019 in Zorbau, Germany.	

Process & contact	Input materials	Output products	Process description	Operating status	Photos
				Industrial scale in preparation.	
N2-Applied ***Member of ESPP*** www.n2.no Contact: henk.aarts@n2.no	Manure slurry, biogas digestate (any inputs)	Combines N in manure with N fixed from air to produce a stabilised, ammonium nitrate based, liquid fertiliser product.	Using renewable electricity and air, a plasma reactor fixes nitrogen by generating nitrogen oxides, which react with ammonia in manure or digestate to form ammonium nitrate, so lowering pH and stabilising the nitrogen, reducing ammonia and greenhouse gas emissions during storage and field application. After solid/liquid separation the liquid fraction of manure or digestate can be managed as a liquid nitrogen fertiliser and most of the phosphorus will remain in the solid fraction.	Several mobile trailer pilot units up to 500 l/day tested on farms in UK, Norway, Sweden, Finland, Denmark and South Africa, on fresh cow and pig manure and on a variety of biogas digestates (varying in feedstock). Pilot runs have included 24/7 for periods of months. Planned scale up to 5-15 m^3 (tonnes) liquid per day in 2020.	
Technologies at R&D scale					
CarboREM www.carborem.com Contact: info@carborem.com	Digested dewatered sewage sludge (10-15% DS)	Precipitated phosphate salts	1) HTC (hydrothermal carbonisation) at c. 200°C 2) filter separation of hydrochar, containing 55-70% of total P 3) dissolution in acid 4) addition of alkali for phosphate salt precipitation	Pilot installed in 2019 at Ecoopera sewage sludge plant installed in 2019 and located at Ecoopera Sewage sludge plant, Mezzocorona (TN) Italy, capacity: 1.4 t/h sewage sludge	
RecoPhos thermal (Italmatch) ***Member ESPP*** Contact: c.michelotti@italmatch.com Patent acquired, initially from	Input: sewage sludge incineration ash, from sewage works using biological and/or chemical P-removal.	White phosphorus (elemental phosphorus P4), Critical Raw Material for electronics and organo-phosphorus chemical industry	Electrical induction heated InduCarb reactor, heats ash with coke or graphite to 1500°C. P4 (elemental P) is released in gas form, which can be reacted to PCl_3 (chemical vector for industrial organic phosphorus chemistry) or to high purity phosphoric acid (electronics grade).	10 kg/h input pilot was tested at Leoben, Austria in 2015 (EU FP7 project)	Recophos Project by Italmatch Chemicals

Process & contact	*Input materials*	*Output products*	*Process description*	*Operating status*	*Photos*
SGLCarbon					
Flashphos (Uni. Stuttgart, Italmatch) ***Italmatch: Member ESPP*** Project summary on EU CORDIS website. Contact: Matthias Rapf matthias.rapf@iswa.uni-stuttgart.de	Dewatered sewage sludge or other organic wastes containing P.	P_4 white phosphorus	Input materials are dried and ground, then flash gasified at high temperatures with CaO (lime) as reducing agent to produce elemental phosphorus (P_4). The process claims to also produce a cement material and a valorisable iron metal alloy (so recovering iron salts used in wastewater phosphorus removal).. FlashPhos presentation at ESPP's PERM4 meeting, 2nd June 2021. Project summary on EU CORDIS website. University of Stuttgart press release 7th June 2021.	FlashPhos is based on different technologies of project partners will develop and unify to best standards. The process will be integrated into existing industrial infrastructure (cement plants). 12 M€ funding under Horizon 2020 announced June 2021 to construct and test a c. 2 tonnes/day dry matter input pilot plant	
P-roc ***Member of DPP*** Website: https://www.cmm.kit.edu/english/297.php Contact: anke.ehbrecht@kit.edu	Sewage sludge dewatering liquor. Liquid manure.	Highly disordered and microcrystalline phosphate salts (hydroxyapatite, struvite, K-struvite).	Crystallization by means of Calcium-Silicate-Hydrate	Mobile pilot plant: 300 litres/hour.	

Process & contact	*Input materials*	*Output products*	*Process description*	*Operating status*	*Photos*
Parforce ***Member of DPP*** www.parforce-technologie.de Contact: info@parforce-technologie.de	Sewage sludge incineration ash, other ashes, phosphate rock or other secondary materials. Struvite can used as raw material: it is calcined: (prior to step 1) to remove ammonia (which is collected) and eliminate organic matter.	Phosphoric acid	1) Acid digestion using HCl or HNO_3, to generate raw phosphoric acid 2) solid-liquid separation 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 4) membrane electrodialysis to separate metal cations (especially Ca, Mg and heavy metals) to a concentrated salt solution. Calcium chloride / nitrate can be recovered from this solution after heavy metal precipitation. 5) concentration of the remaining phosphoric acid, or struvite can be precipitated from the acid 6) some of the phosphorus passes the electrodialysis membranes. In order to achieve 80% P-recovery, this must be precipitated with lime, after separation of the heavy metals, and the calcium phosphate returned to step (1)	Batch pilot (with continuous electrodialysis, capacity c. 1t/day input material), tested for several different materials in 2018 and 2019 at TU Bergakademie Freiberg, Germany.	
RSR (Green Sentinel) (Recovered Sludge Resources) https://green-sentinel.at/en/recovered-sludge-resources/ Contact: office@green-sentinel.at	Dewatered sewage sludge (after e.g. filter-press or centrifuge)	PecuPhos®: a mixed aqueous solution of minerals, including phosphates with c. 75% water / 25% minerals w/w, which can be used as an input to mineral fertiliser production. The solution is pH 3 and contains: - 1.5 – 4 % P - 2-4 % Ca - 0.5 – 1.5 % K - sulphates, chlorides, etc.	The RSR module uses a special solvent to adjust pH-value and ensure high dewatering of sludge (PecuLeach®) to extract up to 75% of the phosphorus (and of other minerals) from the dewatered sewage sludge into an aqueous solution (PecuPhos®). The solvent is recycled to enrich the aqueous solution with phosphorus and minerals. Optionally, solid phosphate can be precipitated from this solution (as a mixture of brushite, struvite …). Heavy metals are also extracted by the solvent, then precipitated to a separate solid fraction for disposal (c. 60-80% of e.g.	Pilot installations have been tested at 8 kg dewatered sludge input per hour scale for 2 weeks. A first semi-full scale installation is contracted for Wels municipal sewage works, Austria (165 000 p.e., operating chemical P-removal), commissioning planned mid 2022. This will intially treat 2 500 t/y wet weight dewatered sludge input, that is c. 30% of the sewage from the works. Extension to treat 100% of the works' sludge is planned as a second stage.	

Process & contact	Input materials	Output products	Process description	Operating status	Photos
		Iron is < 1.3%, Heavy metals are low, e.g. Cd, Hg, Cr < 13ppm, Cu and Zn < 50-500ppm. Organic carbon is < 30ppm PecuPower® = alternative fuel - comparable to pellets (water content < 10%, thermal value 4 800 MWh/t) or PecuGrow® = a refined sludge which can be composted	Hg, Cu, Zn, Fe in dewatered sludge are separated out to this fraction). The remaining organic fraction can be further processed either by drying to produce fuel (PecuPower®) or is processed to compost (PecuGrow®)		

Susphos P-recycling from ashes and precipitates https://vnci.nl/chemie-magazine/actueel/artikel?newsitemid=5861638144 Contact: sales@susphos.com	Tested to date: sewage sludge incineration ash, struvite. Planned: other phosphate-rich materials with low levels of organics, e.g. vivianite.	Phosphoric acid, or mono- or diammonium phosphate (fertilizer or flame retardant quality). Iron / aluminium salts as aqueous solution: can be recycled to sewage works for P-removal. Solid magnesium sulphate salts (if struvite is input), recycled by sewage works for struvite precipitation. Inert mineral material stream (containing sand, gypsum, iron oxides) can be used in the construction industry.	The input materials are attacked with concentrated sulphuric acid. The resulting phosphoric acid is purified using a proprietary organic solvent extraction process, without requiring ion-exchange or membrane filters. The acid has low levels of impurities and concentration >50% P_2O_5 (from ash), because the only water input is in the sulphuric acid. Iron and aluminium are c. 99% removed from the phosphoric acid, and partly recovered for recycling, partly fixed in the insoluble minerals stream. Mono- or diammonium phosphate can be precipitated from the phosphoric acid by reaction with ammonia gas. Heavy metals are largely removed and rendered inert in insoluble calcium minerals: e.g. >95% of Cd, Hg, Cu, Zn …	25 kg/day pilot operated in Leeuwarden (NL) for 8 months for struvite and tests with sewage sludge incineration ash are underway since May 2021. Full scale plant of 50 000 t/y is planned in The Netherlands, with objective of operation in 2023-2024.	
Currently no longer under development					
Ecophos www.phosphorusplatform.eu/Scope127	Input: sewage sludge incineration ash, from sewage works using biological and/or chemical P-removal.	Fertiliser / technical / feed grade phosphoric acid or DCP (Di Calcium Phosphate). Animal feed use subject to legal conditions.	Phosphates present in ash are dissolved using phosphoric acid. Insolubles containing metals go to a waste stream. The acid leachate is purified by ion exchange. Ion exchange resins are regenerated using hydrochloric acid, yielding mostly calcium chloride (which can be discharged to the North Sea) and aluminium chloride which is recycled as a coagulant for sewage treatment.	220 000 t/y output DCP plant operating since November 2017 in Dunkerque France using same process with input material low-grade phosphate rock (photo). 100 000 t/y input ash second line announced at this site for input material sewage sludge incineration ash now not planned following bankruptcy of Ecophos in 2019.