Information sheet

Review: Technologies to optimise the value of digestate (2020)

Technology	Short description	Prior Status[1]	Current Status	Examples	Stage[2]
WRAP "Optimising the value of digestate and digestion systems" short list					
Neo Energy (organic based fertiliser)	Uses excess heat together with electricity from a combined heat and power system to dry the digestate to a granular form. (WRAP, 2015)	The process has been commercialised in certain markets (U.S.) with granules being marketed to golf courses as a high value material offering a range of benefits. The interest around Neo Energy is not the technology itself rather the innovative marketing surrounding the product.	Difficult to determine the success of Neo Energy in the U.S and there is no immediate evidence to suggest that such a product has been marketed successfully in the UK. Digestate pelleting lines have been set up by organisations in the UK. However, although the technology appears available at larger scale there is still little evidence of up-scaling or successful case studies.	PRM Waste Systems UK Kesir Dorset – Green machines	**Commercial**
Hydrothermal Carbonisation (HTC)	Takes wet/dry biomass and applies heat and pressure to convert it into dry, black powder (biocoal/biochar). This reduces the weight of the digestate and adds value to both the digestate and feedstock.	The process was deemed very close to market by the work covered in the original WRAP report. However, there were concerns over the interaction between water within the digestate and heat and pressure required during the process.	No studies had been found to suggest HTC had undergone a Cost-Benefit Analysis. However, organisations were identified who offered such technology (Antaco, TerraNova Energy). The Incover EU project also aimed to validate and demonstrate HTC technology to produce bio-coal. The project determined the process has a technology readiness level (TRL) of	Incover Project EU TerraNova Energy Antaco	**Commercial**

[1] Based on an assessment of technologies in the 2015 WRAP Report: Optimising the value of digestate and digestion systems

[2] Assessment based on the limited review undertaken. Deemed either pre-commercial or commercial.

			9/9. Suggesting that it is ready for market.		
Carboxylate Platform	Fermentative anaerobes are used to synthesise a wide range of carboxyl compounds. Carboxylate platform fermentations produce small-chain carboxylic acids which convert to ethanol, gasoline, jet fuel or industrial chemicals and can also produce acetate, butyrate, lactate, succinate and butanol (Cope et al. 2014).	The technology is well established although information on yield when using mixed cultures is unknown. The high value of the products (butanol and lactate in particular) and the relative simplicity, mean that it is the option that has the highest potential to add value to the feedstock.	Appears to still be laboratory stage but studies (Llamas et al., 2020; Placido and Zhang, 2018; Xiong et al., 2015) show that digestate has potential. Also demonstrates proof of concept for use of nanofiltration membrane bioreactors to recover carboxylic acids produced from digestate.	Unknown	**Pre-Commercial**
PHA Production	PHAs are polyesters that are produced by fermentative microorganisms during anaerobic digestion (AD). They are a precursor for a range of bioplastics.	Work on digestate liquor suggested it is an ideal growth media for Polyhydroxyalkanoates (PHA)-accumulating bacteria (Passanha et al. 2013). The process itself was believed to be technically complex and mainly of interest to larger AD sites.	Economic threats hamper the broad market penetration of PHAs which are more expensive if compared to the well-established, large-scale manufacturing of petrol-based plastics (Koller, 2017). The Incover EU Project used photobioreactors to cultivate microalgae in wastewater which could then be used in the production of biopolymers and bioenergy. The project suggested the technology had a TRL of 6-7. The same project also utilised High Rate Alage Pond Systems in PHA production. The process uses treated wastewater and had a TRL of 7. In addition, Valentino et al., 2019 conducted a pilot which showed the	Incover Project EU Bio-on – The world's first industrial plant to produce PHAs. However, not believed to be using digestate as a feedstock.	**Pre-commercial**

			feasibility of using the organic fraction of municipal solid waste as a feedstock for PHA production.		
Extractive Phosphorus Recovery	During AD, hydrolysis takes place and organic matter, ammonia, phosphate, potassium, magnesium, calcium, and sulphur are released to the bulk liquid. Organic matter is mainly converted into methane while both ammonia and phosphate are not consumed during the process (Campos et al., 2019). Phosphorus can be extracted through several different mechanisms (e.g. struvite precipitation).	As a result of the small quantities of phosphorus (P) present in feedstock, P recovery from digestate derived from food waste cannot generally be justified on economic grounds. It has become more operationally successful at sewage treatment works where P levels are higher and where precipitated struvite can cause operational problems .	There appears to be little evidence of scaling up but current practice with P extraction from digestate? is unsustainable. Both Switzerland and Germany for example have introduced legislation requiring the recycling of P. However, although technologies exist, lack of incentives impedes their implementation (Ohtake and Tsuneda, 2019). However, Further studies have shown the feasibility of obtaining recycled phosphate from digestate (Zhao et al., 2017). There is also a viable case study at the Amsterdam West Wastewater Treatment Plant whose operating costs were reduced by 500,000 EUR/year after installation of a struvite crystallizer (Campos et al., 2019).	NuReSys Crystal Green	**Commercial**
Waste Biorefinery Platform	Biorefinery plants accept a range of feedstocks and can incorporate both biological and thermal degradation routes, and usually involve nutrient recovery streams. (WRAP, 2015) They integrate a range of processes and each stream is converted into a co-	The large tonnages biorefinery plants must accept will require multiple waste inputs and the scale makes it more likely that it will succeed financially.	The biorefinery concept has taken its shape in the last decade but has many miles to go before an established system can prosper. Some of the future directions for anaerobic biorefineries could be the integration of different biorefinery platforms where the wastes from these platforms are to be used for the producing biogas. There is also a	EU SYSTEMIC PROJECT There is an upcoming EU H2020 project titled "Valorise the organic fraction of municipal solid waste through integrated biorefinery at commercial level"	**Commercial**

	product stream rather than a waste stream.		need to conduct a comprehensive techno-economic analysis of anaerobic biorefinery by considering the local conditions (Sawatdeenarunat et al., 2016).		
WRAP "Optimising the value of digestate and digestion systems" long list					
Microbial electrosynthesis	This process uses microorganisms to convert the chemical energy stored in biodegradable materials to direct electric current and chemicals. (WRAP, 2015)	The technology is a long way from a commercial scale and at this stage there are some concerns that when applied to digestate or feed stock it will simply provide an expensive and complex route for the carboxylate platform.	A review paper by Sadhukhan et al. (2016) suggests that challenges with scale and yield need to be resolved. This was reiterated in the more recent review by Kong et al. (2020). There have been some technical methodological developments, but these are very much at laboratory experiment stage.	-	**Pre-commercial**
Micro algal growth	Microalgae can be used to recycle nutrients in digestate (Uggetti *et al.* 2014). The resultant microalgae crops are high in protein and can be used as a feed source for livestock or aquaculture industries (Yaakob *et al.* 2014).	Microalgae require specialised Anaerobic Baffled Reactors (ABR) to grow. Technology unlikely to be competitive soon and research costs of ABR development are huge.	Recent review by Stiles et al. (2018) says it's still a long way off being market-ready. One of the challenges is the removal of potentially toxic elements that inhibit microalgal growth such as Cu as it is highly toxic to photosynthetic organisms. However, digestate is a product that could quickly be made available to the microalgae industry, but would require standardizing digestates, which can be costly and time-consuming. Perspectives in process innovation and less restrictive regulatory frameworks make it possible to demonstrate soon, the	Silkina *et al.* (2017) successfully isolated algae from the TATA Steel plant in Port Talbot, UK and tested its bioremediation capacity. The culture was mixed with diluted effluent from AD. After 5 days of cultivation in a 600L photobioreactor 99% of the total P and N were successfully removed from the waste stream. Phycover project	**Pre-commercial**

			safety of such an approach and its economic and societal interest.[3]	AlgEN EU Project AlgaeBioGas EU Project	
Microwave hydrolysis	A pre-treatment process that is applied to dewatered municipal waste sludge. A method that may replace conventional heating in the pre-anaerobic digestion stage.	There were concerns over the process not releasing adequate fermentable organic material to cover the energy costs of the process itself.	A recent study by Akgul et al., 2017 concluded that Microwave hydrolysis and ultrasonication are not feasible for industrial applications for single-stage and temperature phased AD.	-	**Pre-commercial**
Macro algae (Lemnoideae)	The process involves growing macroalgae on digestate to produce methane. Macroalgae grows rapidly on the surface of waters that have a high N and P concentration.	The large land bank required and restricted periods over which the technology can be utilised are likely to make this an unattractive option.	Review paper (Kumar et al. 2016) states that: "currently the energy requirement and cost of biofuels production from algae is not competitive with fossil fuel-based sources of energy. Technological challenges have not been overcome to make the biofuel production process energetically and commercially viable." Economic analysis (Soleymani and Rosentrater, 2017) of bioenergy production from macroalgae was determined not to be economically feasible in the USA.	-	**Pre-commercial**
Community by Design	Setting up mini AD plants across cities which could provide enough methane to run restaurant kitchens/cafés etc. Staff and volunteers would collect food waste from local sources using	The community by design project was initially a small scale demonstration project designed as a proof of concept for further roll out once demonstrated.	Unknown	http://communitybydesign.co.uk/	**Unknown**

[3] https://anr.fr/Project-ANR-14-CE04-0011

	bikes. The project integrates advanced fermentation, hydrogen generation and bioplastics production.	There were however concerns over the economics of producing PHAs and hydrogen on such small scales and bioplastic production at small scale has not been sucessful			
Electro-dewatering	This is a pre-treatment process that may replace the conventional thermal drying that occurs prior to AD. Its key benefit is that it decreases the water content of the feedstock making the final product cheaper to transport.	There were a lot of attractions to this technology, but it carried a high risk of failure if properties of the digestate turned out to be unfavourable for a charged-based separation.	Environmental and economic analysis case study in Milan from a small wastewater treatment plant (Zhang et al. 2019). Results suggest that it is environmentally and economically feasible to implement electro-dewatering of the sludge if it is then incinerated.	Dorset – Green Machines – have an electric-only version of the Arnold Evaporator.	**Pre-commercial**
Pyrolysis	Organic feedstock is thermally degraded in the absence of air/oxygen. It produces end-products of a solid (charcoal), liquid (tar and other organics) and gas (H_2, CO_2 and CO). These are all of interest as they are possible alternative sources of energy generation from organic wastes.	Food waste and digestate are poor feedstocks for pyrolysis. Their water content is too high, and they contain too much ash. There are other, more appropriate heat and pressure-based systems for this applicable.	A study by Hung et al., 2017 suggested that biochars produced from solid digestate were not suitable for use as solid fuel in the industrial sector but could serve as a biofertilizer. A study by Breunig et al., 2019 highlighted that digestate and biochar can be land applied to sequester carbon and improve net primary productivity, but the achievable scale is tied to the expected growth in bioenergy production and land available for application.	https://www.oxfordbiochar.org/ - Biochar created from Wood Dorset – Green machines	**Pre-commercial**
Proman Management	Straightforward digestion processes that involve plug flow digestion followed by mineral fertiliser production.	This option presents a flow sheet of established technical options for which little	Unknown	-	**Unknown**

	Operating on manure in agriculturally intensive regions, it requires significant feedstock for viability. N recovery is by stripping and scrubbing as ammonium sulphate and P is recovered by magnesium chloride addition as struvite.	additional investment is needed to fully understand them.			
Boerger Bioselect separator	Digestate flows through the Bioselect vessel through a sealed slotted screen, which separates the outer vessel from an auger chamber. The liquid then filters through the screen to the outer vessel. The liquid phase is discharged whereas the solid particles remain in the filter area where they are conveyed by a rotating auger unit to a post-press channel. It has been applied to digestates treating from 6 to 15% dry solids and achieving up to 35% dewatered fibre.	This is a fully commercial process that is already being utilised at a full-scale and thus needs no funding to take it to marketplace.	No expected change since 2015.	https://www.boerger.com/en_UK/our-company.html	**Commercial**
Advetec biothermic digester	This digester accepts mixed waste streams such that multiple materials can all enter the reactor along with the organic material. The process is an aerobic one and claims to exploit extremophilic bacteria. The	Although the biothermic digester was awarded the Zero Waste award in 2014 from Organics Recycling, it is not clear that this process generates a useful product. Although the organic fraction and water appear to be, removed the	This company seems to be expanding. Still seems to be a modular setup rather than large volumes like in AD plants, but this company is ideal for small to medium-scale volumes.	Advetec – case studies	**Commercial**

	organic fraction is thus aerobically digested, and the inorganics are then removed with the digestate, as clean product for mechanical sorting and sale.	inorganics remain as an ash with the claims that they can be subsequently separated and sold. .	Appears to be commercially viable and operating at medium-full scale. Needs no further funding to take it to marketplace.		
Profi Nutrients BV	This Dutch company offers a range of standard technologies to separate nutrients. They have a simple struvite precipitation option using magnesium hydroxide to separate the P; caustic stripping and acid scrubbing to recover N as ammonium sulphate.	The company has funding from the European Agricultural Fund for Rural Development to trial its process treating co-digested manure in Holland with the aim of separating the nitrogen, potassium and phosphate to leave an organic residue for recycling. Funding is intended to generate a prototype mineral separation plant, for which an appropriate licence will be obtained. There appears to be no additional benefits to be derived from WRAP funding of this work, although it is worth following the outcomes of the project.	Unknown	Profi Nutrients	**Unknown**
Equares Clean Steam Reformer	Farm waste/feedstock is fed into the steam/CO_2 rotary reformer where heat is raised to the point that the waste molecules separate into gases. The resulting hydrogen-rich synthetic gas is fed seamlessly into a solid oxide fuel cell to generate electricity.	The product is scalable starting at 0.5 to 1 tonne of dry feedstock per day. It can be scaled up to 75 dry tons per day. A co-product is a clean carbon-rich phosphorous-potassium fertilizer pellet that can utilised as a fertilizer base.	https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming	-	**Unknown**

		At this stage the process simply appears to be an idea taken from the nuclear industry as not yet tried at a full-scale facility (although Equares consider the process to be at the commercial stage).			
Additional technologies					
Thermal dewatering post-AD	The process of undertaking thermal dewatering after the AD process has occurred.	N/A	A Norwegian study (Svennevik et al. 2019) – found that dewatering after AD increased the dry solids content by 87% on average (from a sample of 32). Samples included a range of biowaste including sewage sludge, sewage and food waste, sludge wine industry, pulp, fish waste.	-	**Pre-commercial**
Solid State Fermentation (SSF)	SSF is the biodegradation of solid organics into value products such as enzymes, biosurfactants or bioplastics.[4]	N/A	Results from the EU DECISIVE Project showed that biopesticide production from digestate using SSF appeared promising. Biopesticides have a high market value.	Biowaste valorisation in a future circular bioeconomy	**Pre-commercial**
Nitrogen Removal / Ammonia Stripping	The process of removing nitrogen, usually in the form of ammonia, from digestate or wastewater.	N/A	Many forms of nitrogen removal are fully commercialised. Dependent on the approach adopted.	AMFER ANITA ANAMMOX BYOFLEX DeAmmon	**Commercial**
Acidification	Lowering the pH of slurry has shown to reduce the levels of ammonia. When the pH drops	N/A	Used predominantly in Denmark, where it was shown that acidified	Why is acidification a success only in Denmark?	**Commercial**

[4] http://www.decisive2020.eu/the-project/solid-state-fermentation/

	ammonia is changed to ammonium which doesn't evaporate.		slurry could improve biogas production (Jacobsen, 2015)	BioCover	
Evaporative systems	The systems consist of a big basin with a protected liner. A layer of sand is used to allow treated material (e.g. wastewater) to spread to trees planted on top. Trees uptake nutrients and dewater any sludge.[5]	N/A	The Incover EU Project demonstrated that a 250m^2 system could be used to treat up to 2800kg of sludge a year. The project suggested the technology had a TRL or 8.	Incover Project EU	**Pre-commercial**
Sludge Treatment Wetland	Wetlands are constructed using specialized filter material then a network of pipes are used to pump sludge/digestate into the wetlands. The digestate is dewatered by evapotranspiration and the digestate is turned into a good soil conditioner with high dry matter.[5]	N/A	The Incover EU Project suggested this technology has a TRL of 9 – ready for market.	Incover Project EU	**Pre-commercial**
Adsorption columns	An environmentally innocuous and degradable material used in an in-line filter that captures phosphorous from wastewater streams.[6]	N/A	The Incover EU Project aimed to validate the technology for it to be taken up by a suitable operator.	Incover Project EU	**Pre-commercial**

[5] https://incover-project.eu/technologies/anaerobic-digestate-valorisation
[6] https://incover-project.eu/technologies/nutrient-recovery

GENIUS and Re-P-eat	Digestate is separated into a solid and a liquid fraction by means of a decanter. The N-rich liquid fraction will be processed into a nitrogen-potassium concentrate and clean water through a combination of DAF and membrane filtration system. Following decanting of digestate. The P-rich solid fraction will be treated with a P-stripper called "Re-P-eat" through a process of acid (H2SO4) and base Ca(OH2) addition. The products of this process will be mineral calcium phosphate (CaP) and a P-poor organic soil conditioner.[7]	N/A	Digestate volume is reduced. Only small volumes of concentrated minerals need to be transported or applied on fields, leading to reduction of digestate transport cost over long distances. During year one of the SYSTEMIC project major progress has been made on the engineering and optimisation of the RePEat process based on experiences gained at the pilot installation and additional laboratory tests. The process has been further optimized based on new insights after market research.	Groot Zevert Vergisting (Beltrum, NL)	**Commercial**
Fertiliser production	CCm Technologies has developed a method of producing fertiliser and soil conditioner through the use of captured carbon dioxide from industrial power generators. The first full-scale fertiliser manufacturing plant has been successfully commissioned at CCm's Technology Centre in Swindon before its deployment to	N/A	CCM are moving slowly from a developmental technology to deployment in the UK water industry with plants established in two water companies. Web quote Transformation of 6,500 tonnes of waste Anaerobic Digestate cake into approx. 13,000 tonnes of high-grade compound fertiliser. Exothermic heat (1.98 GJ (551kWh) of thermal energy per tonne of carbon dioxide; high storage density	CCm Technologies	**commercial**

[7] https://systemicproject.eu/wp-content/uploads/D1.6_Update_factsheets_demonstration_plants.pdf

	Viridor's multi-waste site in Somerset**.**		at 200kWh/m3) from the process will supply Viridor's regulatory pasteurisation step, freeing up valuable bio-gas to be sent to the grid. Capture and utilisation of carbon dioxide being emitted from Viridor's bio-gas generators. 85% reduction in the carbon footprint when compared with traditional fertiliser manufacturing techniques. Application extensions have been developed for the sewage sector allowing for the capture of the waste Phosphorous and Ammonia, currently being discharged into watercourses, to be integrated CCm's upgrading of the bio-solids into fertiliser. This sustainable technology is stand-alone financial viable and is not reliant on government subsidies. The base case internal rates of returns (IRRs) for the process generate between 15-18%. Industry matching fertiliser following years of agricultural trials at the Royal Agricultural University & Velcourt.		

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