Occasional publication No. 5

Agri-Food and Biosciences Institute

Global Research Unit
AFBI Hillsborough

5

An evaluation of manure treatment systems designed to improve nutrient management

A report to the expert group on alternative use of manures

E.G.A. Forbes, D.L. Easson, V.B. Woods and Z. McKervey

December 2005

AFBI Hillsborough, Large Park, Hillsborough, Co. Down, Northern Ireland BT26 6DR
Tel: +44 28 9268 2484 email: vanessa.woods@afbini.gov.uk

Acknowledgements

The authors acknowledge the very valuable contribution made by Dr Peter Frost at various stages in the preparation of this report, and in particular his contribution to the section on anaerobic digestion (AD).

Foreword

This report has been prepared as a reference document to inform those involved in discussion of the implementation of the Nitrates Directive in Northern Ireland and those seeking to take action to comply with its requirements. The technologies relevant to manure and nutrient management are constantly evolving and therefore it is possible that this report may be updated from time to time to take account of new developments. The most recent version of this report can be accessed from the website of the Agri-Food Biosciences Institute.

Statement

Reference to a company, trade name or product does not constitute an endorsement of that company, trade name or product, nor does the omission of a company, trade name or product imply any criticism. Every effort has been made to ensure that the information provided is accurate, but if any errors or significant omissions have been made the GRU will be happy to correct these at the earliest opportunity.

Revised May 2006

Table of Contents

Executive Summary

The EU Nitrates Directive, and the associated proposed Action Plan for Northern Ireland, has brought into sharp focus for livestock producers and the associated industries continuing up the food chain, that society requires them to act responsibly towards the environment in the way they handle manure. The Action Programme proposals have therefore put into specific regulations the requirements considered appropriate for Northern Ireland, and in this report an evaluation is made of the technologies, which could be employed to aid the industry in compliance with these requirements.

The agricultural industry in Northern Ireland has been aware for some time of the issues relating to the excess of phosphate inputs into agriculture over outputs in farm produce and stock. Reduction in the amounts of P fertiliser applied by farmers to the land could play a significant role in addressing the imbalance. The livestock sectors have already taken significant steps to reduce the phosphate content of animal feeds and the review of this topic did not reveal any significant additional steps that could be taken to improve the situation in the short term. If new sources of low phosphate feed components could be found, more use could be made of low phytate cereal varieties, or of increased phytase to allow more efficient utilisation of phytate P in rations.

While the original Action Programme included the proposal that individual farms would be required to achieve a P excess of less than 10 kg/ha by 2010 and 6 kg/ha by 2012, it was announced by Agriculture Minister Jeff Rooker on 7th July 2005, that a revised programme to be submitted to the European Commission in September 2005, would include “the need for a phosphorous balance at individual farm level will not be a requirement at this stage, but may be introduced in 2007 if a review does not show significant progress towards a reduction in the amount of phosphorous used and the introduction of commercial applications. The overall objective is to achieve a farm P balance by 2015”. Another key element of the revised programme is “the proposed closed period for the spreading of organic manure will be from 29 October to 31 January, though this is not agreed with the Commission at this stage”.

Nevertheless, in this report, manure treatment systems are reviewed with regard to their ability to partition N and P, to reduce BOD and COD and to ease the issue of manure storage for the required over-winter periods. It is recognised that many pig farms in particular have insufficient spread-lands in relation to the 170 kg N/ha limit, let alone any P balance requirement and that the development of slurry processing facilities either on-farm or centralised that also allows nutrients to be partitioned into usable and transportable products, generate renewable energy, and results in environmentally benign outputs could be vital if livestock industries are to remain viable.

The conclusions drawn from reviewing the technologies and considering them in the light of the Nitrates Directive Action Plan are:

1. A wide range of technologies are available for manure handling and processing, some of which could have significant benefits for livestock producers having to comply with the requirements of the Nitrates Directive Action Plan.
2. Mechanical separation methods based on sieves, belt and screw presses generally achieve a 20% to 25% reduction of liquid volume, which may be of value if manure storage is an issue.
3. These separators generally partition P or N in proportion to liquid and fibre fractions and are therefore of some value when there is a requirement to export excess nutrients from a farm.
4. The decanting centrifuge, geo-textile tubes and settling basins are technologies, which, to date, have not been used in Northern Ireland for manure processing. These technologies have the potential to partition a higher proportion of P and (to a lesser extent) N in the separated solid fraction than in the liquid fraction.
5. The use of chemical additives, particularly polymer flocculants, is a well-established industrial technique, for precipitating solids and minerals in waste streams.
6. When used with polymer flocculants and associated additives, decanting centrifuges and geo-textile tubes can achieve very high levels of partitioning of P and to a lesser extent total N.
7. Decanting centrifuges can achieve high throughput of manure, but have a high capital cost.
8. Static and mobile decanting centrifuge units could have potential in Northern Ireland.
9. Geo-textile tubes achieve good solids and nutrient separation at low capital outlay and could have potential in Northern Ireland.
10. Settling basins may be less appropriate for Northern Ireland for climatic reasons, and because there could be more odour.
11. Polymers could possibly be used with other mechanical separators, but little work seems to have been conducted on this.
12. In settling basins the addition of alum can significantly increase the precipitation of P.
13. The addition of magnesium salts to liquid manure or separated slurry liquor will result in most P being precipitated as Struvite, which can be collected, dried, and used as a fertiliser.
14. Anaerobic digestion is a mature technology which could be part of centralised or on-farm manure processing systems.
15. Sustainable and economically viable establishment of Anaerobic Digestion plants is dependent on bringing together a wide range of factors into business plans.
16. AD plants in themselves do not deal with the issue of excess nutrients. The P and N present in the manure and other material entering the AD plant will be found in the digestate produced by the plant.
17. When associated or coupled with other technologies such as centrifugal separation, AD has potential to facilitate nutrient re-distribution.
18. Key issues for AD plants are - the prices obtained for electricity and heat, the gate fees obtained, the markets developed for the digestate end products, and the enlisting of public support and planning approval.

19. Similar issues surround other types of ‘Turnkey’ manure processing plants.
20. The specific details of any legislation will have a significant bearing on which types of systems are most likely to be economically viable.
21. Water coming from processing facilities will have been derived from manure, but must be able to be used for, irrigation, washing, discharge or even as potable water if it reaches the appropriate analytical standards.
22. If there is a requirement for individual farms to achieve a phosphate balance as originally envisaged in the Nitrates Directive Action Programme, then continuing efforts to reduce the P and N intake in animal diets may enable further improvements to be made, although it is recognised that the industry has already gone a long way, particularly with the reduction of P in animal diets.

1 Introduction

1.1 Background

The Nitrates Directive, issued in 1991 by the EU, requires all member states to monitor the quality of their fresh surface water and ground water, ensuring that nitrate concentrations do not exceed 50 mg/l. Areas reaching or exceeding this limit are classed as nitrate vulnerable zones (NVZ). Prior to 2002, Northern Ireland had designated several areas as NVZ, but following a consultation paper prepared by DARDNI and DoE (The Scientific Report), the decision was made to declare a policy of 'Total Territory' in which all of Northern Ireland is subject to the restrictions on levels of nitrates as opposed to specific areas only. In February 2005, DOE and DARD issued for consultation a Nitrates Directive proposed Action Programme (NDAP). (http://www.dardni.gov.uk/consultations/con05004.htm). The Programme outlines the proposed implementation of the Nitrates Directive.

The NDAP also includes proposals to limit the excess amounts of phosphate currently being applied to agricultural land in Northern Ireland.

In the light of the discussions taking place in the Agri-Food industry on the implications of the proposed action plan, DARD convened an Expert Group (EGUAM) with representatives from across the industry and appropriate government departments in order to review actions which the industry could take to comply with the requirements of the proposed action plan. The DARD Global Research Unit was asked to provide technical and scientific input to EGUAM and to provide this report summarising the technically feasible options, which could be adopted to assist the industry to comply with the directive.

This report could not aspire to be either totally comprehensive or to cover all areas in depth. For most of the technologies mentioned in this report, there is a wide range of technical and scientific literature. Our aim has been to try to include all the technologies, which could play a part in Northern Ireland, to summarise the key information about them, and to discuss their relevance to the current needs of the livestock industry in Northern Ireland. The authors are grateful to all the experts and commercial companies who have provided information, opinions and expertise, which have contributed to this report.

1.2 Livestock Excreta

The total volume of excreta produced by housed livestock in Northern Ireland has been estimated as almost 10 million tonnes per annum. The largest volume, 88% is from cattle with pigs and poultry adding 7% and 5% respectively (Frost, 2005). The estimated nutrient content of animal manures produced in Northern Ireland is summarised in Table 1 (Frost, 2005).

These excreta are stored as slurries and are composed mainly of water, with a relatively small proportion of dry matter (DM). One tonne of cattle or pig slurry will contain between 2% and 10% (20 to 100 kg) of solid materials.

Tables 2 to 8 show past and current Northern Ireland farm animal numbers, manure output, and nutrient balances.

Table 1 Plant nutrients contained in manures produced by housed livestock in District Council areas of Northern Ireland

District Council	Total undiluted manure volume tonnes (m^3)/year	Total N tonnes/year	Total P_2O_5 tonnes/year	Total K_2O tonnes/year
Antrim	353,991	1,749	1,102	1,684
Ards	336,602	1,372	769	1,492
Armagh	661,178	3,224	2,015	2,982
Ballymena	541,357	3,506	2,407	2,995
Ballymoney	379,860	2,026	1,295	1,862
Banbridge	106,752	1,896	1,152	1,902
Belfast	13,884	50	28	56
Carrickfergus	27,917	104	57	116
Castlereagh	60,796	231	123	267
Coleraine	372,365	1,826	1,139	1,788
Cookstown	603,829	3,064	1,932	2,730
Craigavon	243,010	1,224	771	1,145
Derry	140,517	517	288	576
Down	402,008	1,628	947	1,668
Dungannon	738,431	5,174	3,643	4,135
Fermanagh	951,817	3,810	2,229	4,046
Larne	205,896	786	442	868
Limavady	198,053	758	433	827
Lisburn	350,206	1,801	1,141	1,663
Magherafelt	415,089	1,784	1,060	1,737
Moyle	192,106	818	489	836
Newry +Mourne	634,228	2,687	1,592	2,723
Newtownabbey	122,999	546	326	526
North Down	43,715	166	88	196
Omagh	764,503	3,256	1,928	3,274
Strabane	525,923	2,141	1,223	2,197
NI Total	**9,687,030**	**46,142**	**28,618**	**44,287**
Council Average		1,775	1,101	1,703
Maximum		5,174	3,643	4,135
Minimum		50	28	56
Standard deviation		1,285	853	1,150

(Frost, 2005)

Farm Data

Table 2 Northern Ireland cattle numbers

	1981	2002	2004
Dairy cattle	327,167	356,386	350,750
Total cattle	1,544,553	1,644,486	1,677,563

(Department of Agriculture and Rural Development for Northern Ireland, 2004)

Table 3 Daily Excreta Output of Cattle

	Body weight (kg)	Undiluted excreta (l/day)	DM (%)	Diluted excreta (l/day)	DM (%)
Dairy cow	650	64	10	107	6
Suckler cow	500	32	10	53	6

(Department of Agriculture and Rural Development for Northern Ireland Code of Good Agricultural Practice for the Prevention of Pollution of Water, 2003)

Table 4 Northern Ireland Pig herd Numbers

	1981	2002	2004
Sows in pig	46,000	26,441	25,433
Total pigs	729,462	387,714	424,058

(Department of Agriculture and Rural Development for Northern Ireland Farm statistical survey, 2004)

Table 5 Daily excreta output of pigs

	Body weight (kg)	Undiluted excreta (l/day)	DM (%)	Diluted excreta (l/day)	DM (%)
Sow + litter	130-225	10.9	6	16.4	4
Grower	18-35	2.7	10	6.8	4
Finisher	35-105	4.5	10	11.3	4

(Department of Agriculture and Rural Development for Northern Ireland Code of Good Agricultural Practice for the Prevention of Pollution of Water, 2003)

Table 6 Housed livestock typical yearly manure output and nutrient content

Housed animal	Typical excreta output (tonnes/year)	Nitrogen (kg/year)	Phosphorus (kg/year)
Dairy cow	19.3	91*	23
Sow + litter	3.6	19.5	7.2
Laying hens (1000)	4.0	607	53

(Department of Agriculture and Rural Development for Northern Ireland Code of Good Agricultural Practice for the Prevention of Pollution of Water, 2003).
*Yan *et al*. (2005)

The high nutrient value and organic content of manures and slurries highlights that they remain an essential component of Northern Ireland farming systems. Table 7 shows the monetary value of Northern Ireland slurry nutrients.

This monetary benefit is offset by the high phosphate content and the surplus P levels in Northern Ireland farming, resulting from high application rates of P fertilisers to crops during the latter half of the 20th century. Currently, the average phosphorus balance per farm in Northern Ireland is 14.3 kg P/ha/year. Table 8 shows this disparity in farm nutrients.

Another important waste stream is that from the food production industry. This includes wastes from slaughterhouses and dairy processors, secondary producers of value added food products and returns of spoiled and excess products from shops, supermarkets and the catering industry. On the information available, Frost, (2005) suggested this could be in the order of 150,000 tonnes per annum in Northern Ireland.

Table 7 Fertiliser Values of Slurry Nutrients in Northern Ireland

Slurry Nutrients	Nutrient monetary values (£ million)
13,000 tonnes available N	6.4
13,000 tonnes available P	4.3
35,000 tonnes available K_2O	9.5
Total fertiliser value	20.2

Bailey (2004)

Table 8 Northern Ireland Farm Nutrient Balance

		Phosphate ('000 tonnes)		Potash ('000 tonnes)
Fertiliser input		21		26
Slurry input		13		35
Total input		34		61
Total crop requirement		25		66
	Surplus	+9,000	Deficit	-5,000

Bailey (2004)

2 Reducing Nutrient Inputs

2.1 Reducing Phosphorus Inputs

2.1.1 Methods to reduce the P content of pig and poultry rations and their impact on compliance with the Nitrates Directive Action Plan

Phosphorus is an essential component of animal diets. Most of the P in pig and poultry diets is, however, derived from grain and grain products and in these feedstuffs 60% to 80% of the P is in the form of phytate, which is largely unavailable to monogastric animals as they lack the phytase enzyme in their digestive tract. Pig and poultry manure therefore tends to contain high proportions of P in both soluble and insoluble forms representing 60% to 70% of the P in the feed. The total P content of pig and poultry rations tends to be between 0.5 and 0.7% (fresh), and depending on the range of ingredients in the feed, a proportion of the P may be in the form of added inorganic P supplementation (commonly dicalcium phosphate). van Heugten (2003) showed that the digestibility of dicalcium phosphate in pigs is approximately 70%, which is significantly higher than the digestibility of phytate P (<40%) (Whittemore, 1993).

In the light of the worldwide recognition of the problem of both N and P pollution arising from pig production, many studies and reviews have been conducted investigating the effects of reducing the amount of N and P in pig rations (Murphy, 2004; Magowan *et al*., 2004; Selle *et al*., 2003; Sutton *et al*., 2005). The principal techniques of reducing N and P excretion were summarised by Murphy (2004) and are presented in Table 10. Similarly, Mateos *et al*. (2005) estimated the reduction of N and P excretion by broilers through dietary manipulation strategies (Table 11). As for the pig industry, the poultry industry within Northern Ireland has already adopted these strategies to reduce excretion and maximise efficiency.

Table 9 Typical N and P balance on Dutch Pig Farms (Murphy, 2004)

	Growing pigs		**Sows & litters**		**Starter pigs**	
	N	**P**	**N**	**P**	**N**	**P**
Dietary levels (%)	16.70*	0.52	15.7*	0.59	18.40*	0.67
Intake (kg/pig)	6.36	1.23	27.57	6.53	0.94	0.21
Excretion (kg/pig)	4.48	0.83	22.5	5.5	0.56	0.13
Retention (kg/pig)	1.88	0.40	5.07	1.03	0.38	0.08
Efficiency of retention (%)	29.5	32.5	18.4	15.8	40.5	39.4

*Crude protein = N X 6.25

Table 10 Potential impact of nutritional strategies on excretion of N* and P and their adoption in Northern Ireland

Strategy	**Reduction in Nutrient Excretion**	**Adoption in Northern Ireland**
Improve feed efficiency	3% for every 0.1 unit in improvement in feed conversion efficiency	Reflection of overall management and adoption of best practices
Minimize feed wastage	1.5% for all nutrients for every 1% reduction	Largely adopted
Match nutrient requirements	6-15% for N and P	Already being practiced
Phase feeding	5-10% for N and P	Already being practiced
Split-sex feeding	5-8% for N	Not widely practiced
Phytase	2-5% for N; 20-50% for P	Already used where possible
Formulate on nutrient availability	10% for N and P	Already practiced
Replace protein with amino acids	9% for N for every 1% reduction in crude protein content of diet	Already practiced*
Highly digestible feed ingredients	5% for N and P	Already practiced
Pellet the ration	5% for N and P	Already practiced
700–1000 micron particle size	5% for N and P	Not known
Enzymes: cellulases, xylanases, etc.	5% for N and P for appropriate diet	Already practiced
Growth promoting feed additives	5% for all nutrients	Naturally occurring additives used
Low-phytate grain	25-50% for P	Not currently available – a local study is proposed

Based on Murphy (2004) and Personal Communication, Dr Violet Beattie (2005)

* It is difficult to formulate low CP diets with available ingredients. In addition, only a few of the essential amino acids are synthetically produced, therefore diets could potentially be limiting in essential amino acids

Table 11 Potential impact of poultry nutritional strategies on excretion of nitrogen* and phosphorus and their adoption in Northern Ireland (Mateos *et al*., 2005)

Strategy	Reduction in Nutrient Excretion	Adoption in Northern Ireland
Phase feeding	10-15% for N and P	Already practiced
Reduce safety margins	10-20% for N and P	Already practiced
Highly digestible ingredients	5% for N and P	Already practiced
Reduce feed wastage	2-8% for N and P	Already practiced
Synthetic amino acids	20-25% for N	Already practiced*
Formulate on digestible amino acids	2-5% for N and P	Already practiced
Carbohydrates	2-5% for N and 0-2% for P	Already practiced
Phytase	1-3% for N and 25-40% for P	Already practiced
Growth promoters and additives	2-5% for N and P	Already practiced

* It is difficult to formulate low Crude Protein diets with available ingredients. In addition, only a few of the essential amino acids are synthetically produced, therefore diets could potentially be limiting in essential amino acids.

2.1.2 Feeding management

By improving the management of feeding through minimising wastage, matching nutrients to the animal requirements at each stage of growth and feeding separate sex groups, reductions in P excretion are possible. Where these practices are already widely adopted and feed efficiency is maximised, there may be little opportunity to achieve reductions in P excretion by these techniques. Much research has been performed examining feeding management in Northern Ireland (O'Connell *et al*., 2002) and it is likely that a large proportion of the industry in Northern Ireland is already operating efficient systems. However, the industry in Northern Ireland should not be complacent and where possible, should take more advantage of the opportunity to reduce P intake through phase feeding, single sex feeding, minimising wastage and improving overall animal performance. Furthermore, a recent study by Magowan *et al*. (2004) has shown that there are significant differences in the performance of pigs between farms and research should therefore continue to investigate the factors affecting performance within and between pig farms.

Where pigs can be brought to bacon weight in a shorter time, then both slurry volume and excreted P will be reduced and this emphasises the importance of the quality of overall management and maintaining efficiency.

2.1.3 Ration formulation

Compared with the figures in Table 9 from the Dutch pig industry, Northern Ireland is currently working at lower P contents of approximately 0.6% (fresh) for starter pigs up to 15 kg, 0.55% up to 40 kg and 0.45% for finisher pigs between 40 kg and 110 kg (Personal Communication, Violet Beattie, 2005). As the finisher pig consumes about 210 kg feed out of the lifetime intake of 270 kg, most pig feed going onto Northern Ireland pig farms is already at the lower end of the P content scale. There may, however, be scope for further slight reductions, as in parts of the USA, P contents as low as 0.40% are recommended for finishing pigs (Spears, 1996). However, pigs in the USA have a higher intake capacity and therefore consume more of the 0.4% P ration, which results in the same or even higher levels of excretion.

Local consultation has indicated that all the P in finisher rations comes directly from the natural ingredients and no dicalcium phosphate is added. In addition, it is difficult to source suitable alternative feed components with low P contents which would allow lower P rations to be generated (Personal Communication, Elizabeth McCann ARINI).

Reducing the P further could also decrease bone strength, which could result in an increased incidence of broken limbs, which is the first indicator of P deficiency in the diet. McCann *et al*. (2004) reported that grower and finisher diets containing 0.45 and 0.4% P respectively resulted in reductions in bone strength in pigs.

The situation is similar for poultry rations, with N and P levels of Northern Ireland diets being in line with or lower than those in Europe (0.5-0.7% (fresh) total P depending on the type of diet). The major danger of further reducing the P levels in poultry rations is the risk of lowering bone strength and increasing broken bones during processing, which results in more downgrades and adversely affects welfare (Chen and Moran, 1995; Gordon and Rowland, 1997).

In studies with laying hens, Um and Paik (1999) reported that offering hens maize-based diets with no inorganic P resulted in similar performance to diets with supplemental inorganic P. However, there is a probability that welfare and egg-shell strength would be reduced with this practice and therefore more research is required in this area before firm conclusions can be made.

2.1.4 Phytate P and phytase

In starter and weaner pig and all poultry rations used in Northern Ireland the enzyme phytase is added in order to increase the availability of P and reduce the need to add dicalcium phosphate to the ration. By increasing the efficiency of digestion of phytate P, the addition of phytase also reduces the excretion of P, although it may increase the proportion of soluble P excreted (McCann *et al*., 2004).

However, in pig finisher rations to which no dicalcium phosphate is added, there is no value in adding phytase, as there is currently no way of further reducing the total P content of the feed through the use of phytase.

2.1.5 Low phytate cereals

A possibility for the future is, however, the use of low phytate cereals, particularly barley, which is a major component (up to 50%) of pig finisher rations. In Canada and the USA, research has been conducted in recent years into breeding de-hulled and naked barley varieties, with 50% less phytate P (Murphy, 2003). Similar work has also taken place with maize and soya. However, within the UK no research has yet been undertaken with low phytate cereals and there is a need for a thorough investigation of how sources of low phytate cereals, or even low total P cereals, can be sourced locally.

Hull-less barley has been used as a feed in the USA since the 1920’s and has a potential role in the reduction of P levels in manure, since the absence of an outer inedible hull renders the grain more digestible for monogastrics. Production of hull less varieties has decreased due to a failure in marketing, the need for a separation system and competition with other cheaper grains.

However, it is from this low P base that researchers in Saskatchewan are now developing their low phytate lines. Work has also been conducted on the use of degermed and dehulled corn as a potential feed source. As with hull less grains, dehulling and degerming the cereal improves the digestibility and decreases the excretion of nutrients in the manure. Van Heughten *et al*. (2003) at North Carolina University demonstrated that by processing corn to remove the fibre, P levels in the manure were reduced by 15%.

Improvements in the availability of dietary phosphorus could enable the P content of diets to be reduced by a further 0.1%, this could potentially decrease P excretion by 8.3% (Kornegay and Verstegen, 2001). For a 300-sow birth to bacon unit, this could represent a reduction of over 500 kg P excretion per year, contributing to a reduced P surplus on pig farms.

2.2 Nitrogen Input Reduction

Implementation of the EU Nitrates Directive (91/676/EEC) required both the DoE and DARDNI to produce an Action Programme to reduce and prevent water pollution as a result of agricultural practices. One of the major pollutants to natural waterways is N, of which 100,000 tonnes is applied to agricultural land annually in Northern Ireland. Nitrogen application is largely in the form of inorganic chemical fertiliser such as urea and calcium ammonium nitrate, and organic manures particularly slurry.

Under the Action Programme various proposals for the use of chemical fertiliser include the following:

- Definition of soil and weather conditions for spread of fertiliser
- Recommended rates of application- technical standard RB209
- Fertiliser management
- Record keeping of fertiliser application and balance

Similarly with the use of organic nitrogen fertiliser, the following guidelines have been recommended:

- Spreading of slurry only within a designated period – closed period 29th October – 31st January
- Spreading of farmyard manure and dirty water dependent on weather and soil conditions
- Record keeping of balance of N application on land

In France, some research has been conducted to investigate the practice of using green fertilisers to reduce the N pollution problem in local waterways due to agricultural practices (Newsletter of the European Press (EEP), 2003). Farmers in the Alsace region in conjunction with the water authority and the Chamber of Agriculture, have planted green manure crops from the autumn through to the spring. Two main crops are planted, mustard and phacelia (tansy), which absorb N during their growth and restore it to the soil when later cultivated into the ground. It is estimated that the use of these crops can reduce nitrate levels in local ground water by one third. A research project has been established in the Rhine-Meuse region including an area of 30 sites with local farmers being offered grants to grow these crops.

2.2.1 Nitrogen in feed

Levels of N can be reduced by adopting changes to both diet regimes such as phase feeding and nutrient balance. Protein is one of the most expensive components of animal diets so by incorporating the required levels of amino acids, the efficiency of N utilisation can be improved. It has been demonstrated that N excretion can be reduced by 15% with a reduction in the protein content of a diet from 16% to 14%. One of the main methods of attaining the correct level of N in the diet is by the addition of synthetic amino acids, e.g. lysine. The subsequent reduction in N excretion also helps to lower ammonia production and odour emissions from pig units.

2.2.2 Nitrification inhibitors

Loss of N from agricultural production systems is a major factor within the EU Nitrates Directive. Nitrification inhibitors delay the conversion of ammonia to nitrate and thus help to control the release of nitrate to water systems. The role of these inhibitors has been examined in New Zealand and the Global Research Unit, DARDNI, has prepared a report detailing this research (McKervey *et al*., 2005).

The effectiveness of a number of products in reducing nitrate leaching from grassland have been evaluated, namely dicyandiamide (DCD - marketed in liquid form as Eco-N and in granular form as N-care) and dimethylpyrazole-phosphate (DMPP - marketed as Entec), Wissemeier *et al*. (2002). There are both advantages and disadvantages to the use of nitrification inhibitors, although they effectively reduce nitrate leaching they can be expensive and may have a toxic effect on some plants and their effectiveness reduces with time.

Research into nitrification inhibitors in New Zealand is mainly performed using DCD. However, these studies have been mainly on an experimental scale and not farm-scale. Internationally, other studies have indicated that the use of DMPP may be more appropriate as it is reported to react better in lighter soils, have greater plant compatibility and remain more effective after heavy rainfall.

Although the use of nitrification inhibitors will not provide an answer to the problem of nitrate leaching, they may be incorporated as a useful tool in conjunction with the adoption of good management practices. In particular, an investigation into the use of DMPP could be of value to agriculture in Northern Ireland.

Patterson *et al*. (2004) examined methods of improving the efficiency of utilisation of N in dairy cow diets. Data demonstrated that reducing the concentration of dietary protein reduced the excretion of N by 26 kg/cow across a typical lactation.

Several products are available commercially but as yet there has been limited widespread use with perhaps one of the limiting factors being their cost.

3 Slurry treatment technologies

3.1 Introduction

The Nitrates Directive Action Programme proposes that dairy and beef farms should normally have manure storage for a minimum of 22 weeks and pig and poultry farms for a minimum of 26 weeks. The original stricture that the application of organic manure to land could only take place between 1 February and 30 September in any year, according to rules relating to land condition, quantities and method of application, has been re-considered and a proposal for a closed period from 29 October to 31 January, has been put to the Commission. As the manure storage requirement under these proposals is significantly greater than most Northern Ireland farms currently have, there is a need to consider technologies which could allow manure to be handled without requiring additional manure storage facilities to be built, or would require less capital expenditure than additional new slurry tanks.

It is also recognised that the restriction on the quantity of organic manure which can be applied to land to 170 kg N/ha/year and the possible requirement to achieve a phosphorus balance will result in many farmers having to either process their manure on-farm to separate and extract nutrients into an exportable form, or export the manure off their farm. Exported manure may be utilised by spreading on other farmland within the permitted nutrient levels, or processed centrally to allow the nutrients to be extracted or utilised in compliance with the regulations, and to enable other economic value to be obtained from the manure in terms of energy, fertiliser, fibrous materials, etc.

The purpose of this section of the report is to review the technologies which can be used to achieve the purposes described above. Due regard has also to be given to other regulations which either apply now or are pending, including the Water Framework Directive, the Agricultural Waste Management Regulations and the Integrated Pollution Prevention Control (IPPC regulations).

While the Nitrates Directive Action Plan includes regulation of both farm yard manure (FYM) and slurry, the majority of the issues relevant to farms specifically relate to slurry handling and it is this aspect that is principally covered by this report. However, reference is made to energy generation through anaerobic digestion, gasification or incineration, which could include higher DM source materials such as FYM, or poultry litter.

3.2 Passive Separation Methods

3.2.1 Settling basin

Allowing manure to pass slowly through a settling pond prior to storage of the liquid in lagoons or tanks allows sedimentation of a proportion of the solids. Settling basins should be between 0.5 to 1 metre deep, long, wide and free draining, and with a flow velocity of less than 30 cm per second. The hydraulic retention time should be 20 to 30 minutes (Article by Saqib Mukhtar, John M. Sweeten and Brent W. Auvermann, Accessed 24 May 2006). (http://www.p2pays.org/ref/12/11691.pdf). Solids remaining in the basins are left to dry out before being removed.

Settling basins can remove over 50% of total solids and up to 40% of the P, making the remaining liquid more balanced as an agricultural fertiliser. The addition of a precipitating agent such as alum (aluminium sulphate) can increase the proportion precipitated to over 70% of solids and 75% of P (Worley, 2005). Not all studies have found alum to be beneficial (Navaratnasamy *et al*., 2004). Sedimentation basins can separate a greater proportion of solids than some mechanical systems at a lower capital cost, but require a greater land area. Basins can also have a high maintenance requirement as they have to be cleaned out regularly and the wet sediment can be more difficult to utilise effectively. If not regularly cleaned out basins become clogged and inefficient, resulting in increasing odour problems.

Usage: Commercial use on pig farms
Number/location of those in operation: Mostly in North America and Australia
Manufacturer(s): NA
Capital Cost: Depends on design
Running Cost: NA
Throughput: Depends on design
Published data:
Navaratnasany *et al*. (2004) found that compared with reverse osmosis, ozonation and sand filtration, natural settling was the most suitable method to separate the liquid fraction of pig manure.

3.2.2 Weeping walls (Figure 1)

Weeping walls are above ground structures, which are 2-3 metres high and built on a concrete base. The wall can be constructed with vertical or horizontal gaps through which the liquid passes slowly to a storage tank via channels. Weeping wall systems can handle wet FYM, but not liquid slurry, and are therefore not equivalent to the other separation methods covered in this report. Solids dry out as the liquid fraction of the slurry is removed and these solids can be land spread. The liquid fraction that is separated using this method can be spread by a slurry tanker or by irrigation. Weeping walls are designed for wet manures and are not suitable for slurries and as they are generally uncovered and collect rainfall (www.distance.ktu.it/agripo/4-farmwaste.pdf).

Figure 1 Weeping wall
(http://www.lscprecast.com/agricultural/manuretanks.html)
Usage: Commercial use on-farm

Number/location of those in operation: Several in Northern Ireland
Manufacturer(s): Pre-cast concrete suppliers
Published data:

- 60% of total solids retained within the walls (The Milk Lines, 2004).
- Undiluted drainage from weeping wall stores may contain 2 kg N/m^3 (DEFRA, 2001)
- The concentration of organic N was not different between influent and effluent samples analysed from dairy cow manure (Meyer *et al*., 2004).
- Undiluted drainage from weeping wall stores may contain 0.5 kg phosphate/m^3 (DEFRA, 2001).
- Run-off from weeping wall stores will have a high biochemical oxygen demand (BOD) and high nutrient content (DEFRA, 2001).

Other relevant data: Bioplex Ltd. in Hampshire developed a patented low cost conversion of weeping walls linked to an Anaerobic Digestion system, which will allow for the production of on-site energy (http://www.bioplexltd.com/news.shtml).

3.2.3 Geo-textile tube (Figure 2)

A Geo-textile tube is a large porous tube made from a heavy-duty woven textile that can be used to separate manure. Ten Cate Mirafi geotextile tubes (Geotubes) have been used in America as filtering devices to remove solids from animal waste lagoons (Worley *et al*., 2005). The Geo-textile tube holds a large proportion of the solids and allows the liquid to return to the lagoon or tank. Worley *et al*. (2005) reported that the solid waste could be stored for at least one year in the tube. These authors also report that the tubes are available commercially with a maximum circumference of 18 m and any length. The height to which the tube can be filled is dependant on its volume capacity. Additional waste can be pumped into the Geo-textile tube as it dewaters and this process continues until the tube is filled with solids.

The addition of flocculants to the slurry binds the solids together, so that liquid drains through the tube. Geo-textile tubes are not re-usable. The tube material is a burnable, non-polluting polypropylene material (www.geotube.com).

Optional components

Geo-textile tube can be set up to prevent solids from entering a lagoon. Specialist pumps and hosing are necessary for flailing operations (www.geotube.com).

Usage: Experimental on-farm systems and on-farm use in Cyprus.
Number/location of those in operation: Widely used in marine and civil engineering works.
Manufacturer(s): Miratech. Inc. 360 Mount Olive Road, Commerce, GA 30529 Telephone: 706 335 3400, Fax: 706 335 3405 www.tcnicolon.comhttp://www.geotubes. com. Ten Cate Grass Group (holding), P.O. Box 9, 7440 AA Nijverdal (NL). www.tencate.nl.

Continuous flow or batch process: Usually batch but can be continuous flow

Use of additives/flocculants: Conditioners and flocculants are added inline to the slurry as it is pumped into the bag, binding solids and retaining P.
Throughput range: Size of Geotube is selected to meet the needs of the farm.
Capital cost: Approximately €4.85 (£3.30) per m^3 of cattle slurry at 5% DM. As this is based on the DM content the cost will increase in proportion to the total amount of solids finally retained in the Geotube.
Running cost: The cost of pumping the manure is likely to be greater than the cost of the Geotube itself.
Published Data:

- In trials the Geotube retained ~75% of total N (95% organic N – Total Kjeldahl Nitrogen (TKN) of total material entering tube was ~800 ppm), but most of the ammonia N is in the liquid leaving the tube.
- ~50% of P was retained in the Geo-textile tube (Worley *et al.*, 2005), http://www.geotubes.com/geotubes_in_use/inuse_index.html.
- 93% solids can be retained.
- Performance of the Geo-textile tube can be enhanced with the use of additives.

Other relevant data: Answers to frequently asked questions available at (http://www.geotube.com/faq/faq_index.html)

Figure 2 Geotube (Worley *et al*., 2005)

3.3 Mechanical Separators

3.3.1 Screen separators

Screen separation of livestock manure involves the use of a screen with pores of a specific size, which limit the size of solid particles allowed through. Bicudo (2001) reported that screen separators usually achieve maximum performance with manure that has a solid content of less than 5%. There are several types of screen separator available, namely the stationery inclined screen, vibrating screen, rotating screen and the in-channel flighted conveyor screen.

3.3.1.1 Stationary Inclined screen (Figures 3 and 4)

The stationary inclined screen is reported to be the most common screen used for manure separation (FSA Environmental, 2000). This screen is often referred to as a stationary run down screen or static screen. Liquid manure is pumped along the top edge of an inclined screen and the manure passes down over the screen by gravity. Larger solids pass over the screen and down to a storage area, while the liquid and finer particles pass through the screen and can be directed to an anaerobic lagoon or to storage (Kruger *et al*., 1995). A pump is required to move the liquid manure to the top of the screen. One problem with this screen is the accumulation of slime, which can block the openings once it builds up. As a consequence, frequent cleaning is required (Fleming, 1986).

Figure 3 Stationary Inclined Screen (FSA Environmental, 2000)

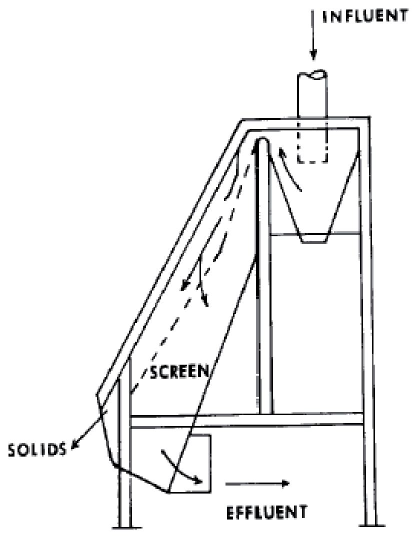


Figure 4 Stationary Inclined Screen diagram (Shutt *et al*., 1975)

3.3.1.2 Vibrating screen (Figure 5)

With a vibrating screen the manure to be separated is poured onto a horizontal screen that vibrates rapidly, where the solids move to the side and the liquid passes through. Kruger *et al*. (1995) reported that vibrating screens have greater maintenance and power requirements than stationary inclined screens, due to the moving parts. Furthermore, such motion can reduce but not prevent clogging caused by slime build up (Article by Saqib Mukhtar, John M. Sweeten and Brent W. Auvermann, Accessed 24 May 2006). (http://www.p2pays.org/ref/12/11691.pdf); Fulhage and Pfost, 1993). Slurries with more than 8% solids may clog a vibrating screen separator (http://muextension.missouri.edu/explore/envqual/wq0323.htm).

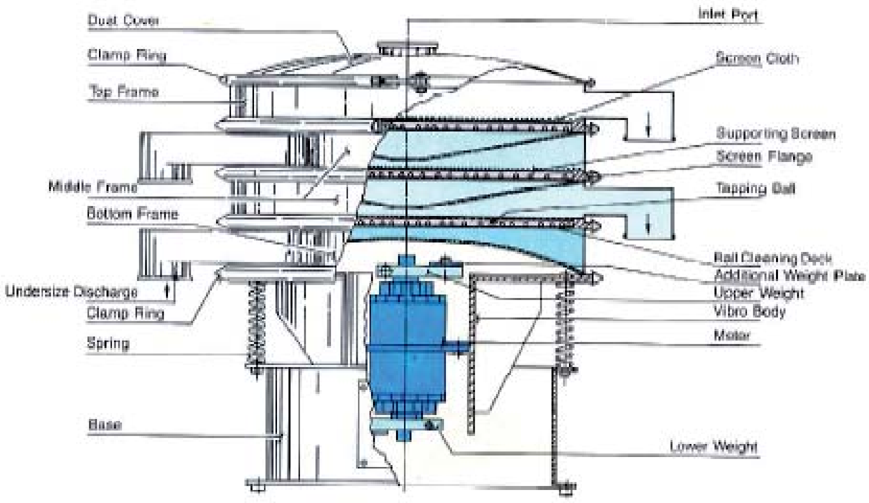


Figure 5 Vibrating Screen Separator (Watts *et al.*, 2002)

3.3.1.3 Rotating screen (Figure 6)
This system consists of liquid passing through a continuously rotating cylindrical screen, with the liquid collected in a tank and the solids remain on the screen (Zhang and Westerman, 1997). Solids that remain on the screen can be removed with a scraper.

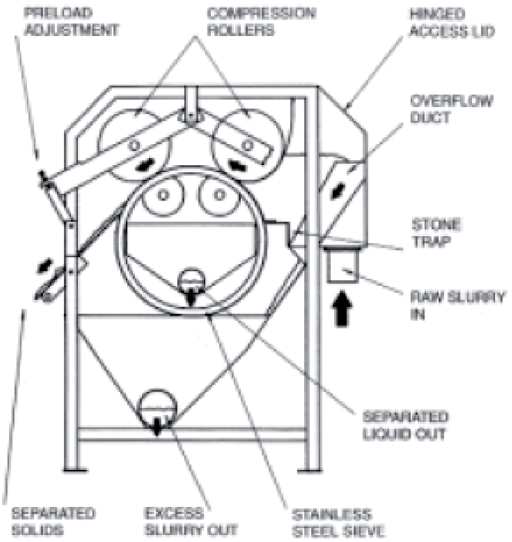


Figure 6 "Carier" Rotating Screen Separator – Diagram and photograph www.lintonagindustrial.co.uk

3.3.1.4 In-channel flighted conveyor screen/drag conveyor (Figure 7)
This consists of an inclined screen with horizontal bars called flighted conveyors, which drag the liquid manure across the screen. The liquid then drains through the screen and the solids remaining are dropped on a collection pad (Article by Saqib Mukhtar, John M. Sweeten and Brent W. Auvermann, Accessed 24 May 2006). (http://www.p2pays.org/ref/12/11691.pdf). It can be placed directly in an open manure channel, therefore removing the need for a pump. Due to the presence of moving parts as with the vibrating screen, these bear a greater operating and maintenance cost than stationary screens (Article by Saqib Mukhtar, John M. Sweeten and Brent W. Auvermann, Accessed 24 May 2006). (http://www.p2pays.org/ref/12/11691.pdf). Maintenance is required due to exposure of parts to corrosive materials.

Figure 7 In-channel flighted conveyor screen (Watts *et al.*, 2002)

Usage: Commercial on-farm. Can also form part of centralised processing systems
Number/location of those in operation: Widely used. At least 17 locally manufactured rotary screen separators are in use in Northern Ireland.
Manufacturer(s): Brome Agri Sales Ltd., 2389 Route 202, Dunham, Quebec, J0E 1M0, Canada. Telephone: (450) 266 5323.
LintonAg Industrial (Rotating Screen), 4C Hallstown Road, Upper Ballinderry, BT28 2NE. www.lintonagindustrial.co.uk
Throughput range: Screens: 30-60 tonnes/hour
Capital cost: Locally manufactured rotary screen separator approximately £20,000
Running cost: Screen separator at least £0.69/pig (Vanotti *et al*., 2002) but variable depending on whether chemicals (polyacrilamyde) are used to remove suspended solids (Funk and Polakow, 2004).

Published data
Data presented in Table 12 details the separation efficiency pig slurry using a screen with and without the addition of flocculant. Table 13 demonstrates the separation efficiency of three types of separator, with varying screen sizes processing pig slurry.

Table 12 Efficiency of separation methods naturally and with flocculant

	Separation Efficiency (% of solids removed)	
Wastewater constituent	**Screen**	**Plus flocculant**
TSS	15.4	89.5
VSS	15.0	89.2
COD	8.0	64.6
N (organic)	13.2	80.0
P (organic)	10.6	85.2

FSA Environmental (2002)

Table 13 Nutrient and COD Separation efficiency (%) of three types of separator processing pig slurry

Screen type	Screen size (mm)	Separation efficiency (% of nutrients removed)		
		Total N	COD	Total P
Stationary screen	1.0	3-6	0-32	2-12
Vibrating screen	0.104	33-51	48-59	34-59
Rotating screen	0.8	5-11	2-19	3-9

Sheffield *et al*. (2000)

3.3.2 Press separators

Pressing involves the application of mechanical pressure to promote the separation of slurry. Dewatering and compression of the solid to produce stackable fibre achieve this. There are three main types of device, namely roller, belt and screw presses. Roller press comprises of two concave screens and a number of rollers. Manure is initially deposited onto the first screen and subsequently moved on to be squeezed by the rollers, leaving solids on the screen and liquid passing through.

3.3.2.1 Brushed screen/roller (Figure 8)

A brushed screen/roller uses the mechanism of the roller press, where the manure is dropped onto the first screen and moved on across the further screens using brushes, with the manure being squeezed by rollers. A rotating brush is used to keep the screen clean. The squeezed out solids are then brushed out of the separator, after which they are moved and stored.

Figure 8 Brushed screen/roller (NC Engineering)

3.3.2.2 Perforated pressure roller separator (Figure 9)
The perforated pressure roller separator (Figure 9) consists of a two-stage double roller separator, where liquid is force-fed into the first set of rollers and solids are fed into a second set of rollers to be removed by a mechanical conveyor.

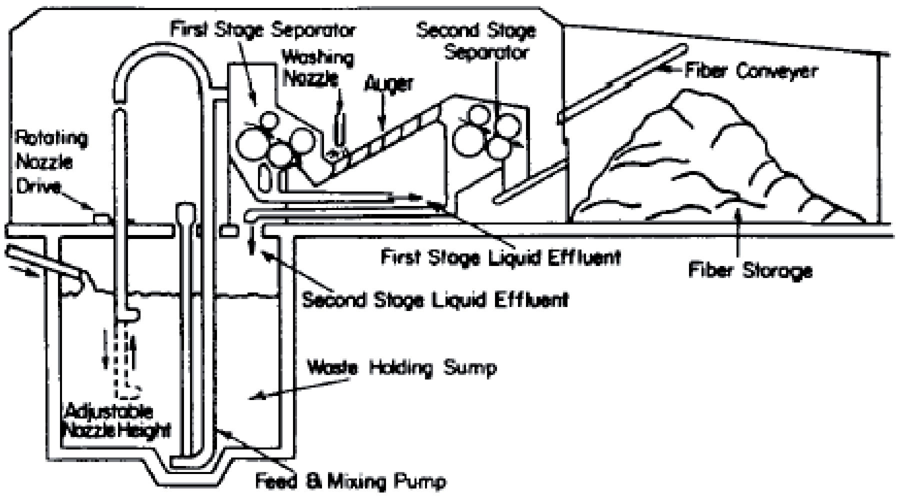


Figure 9 Perforated pressure roller separator (Rorick *et al*., 1980)

3.3.2.3 Belt press (Figure 10)
A belt of flat, woven fabric runs horizontally between two rollers, with the liquid being fed between them and solids are transported along the belt and deposited in a collection so that excess liquid is removed into a collection tank. In general, the belt requires a polymer to be added to condition it, so that an even coat of sludge is formed on the surface of the belt (Watts *et al.*, 2002). Kruger *et al*. (1995) reported a total solid content of the solid material from the belt press of 20-30%. Belt presses require a high level of supervision (FSA Environmental, 2002). Data for the capital and operating costs are given in Table 14. A Bioclere belt press is shown in Figure 10.

Table 14 Capital and operating costs for a belt press

Item	**Units**	**200 sow Low-flush**	**200 sow high-flush**	**2000 sow low-flush**	**2000 sow high-flush**
Total effluent	m l/year	9	25	85	250
Solids	t/year	270	290	2,800	2,940
Capital costs	£	41,054	41,054	61,792	64,798
Operating costs	£/year	2,415	4,260	10,986	15,785

(FSA Environmental, 2002)

Figure 10 Bioclere Belt press http://www.bioclere.co.uk/index.html

3.3.2.4 Screw press (Figure 11)
A screw press consists of a cylindrical screen and a screw type conveyor in the centre, which forces the solids through a tube to be discharged later. When the conveyor presses the solids against a screen, the moisture is removed. Applying different pressure to the screw can control the moisture content of the solids. The efficiency with which screw presses work is dependant on the screen size, the solid content of the wastewater and the rate at which the wastewater is delivered. Watts *et al*. (2002) reported that a total solid content of 5% is required to maximise the performance of a screw press. Data for the capital and operating costs are given in Table 15.

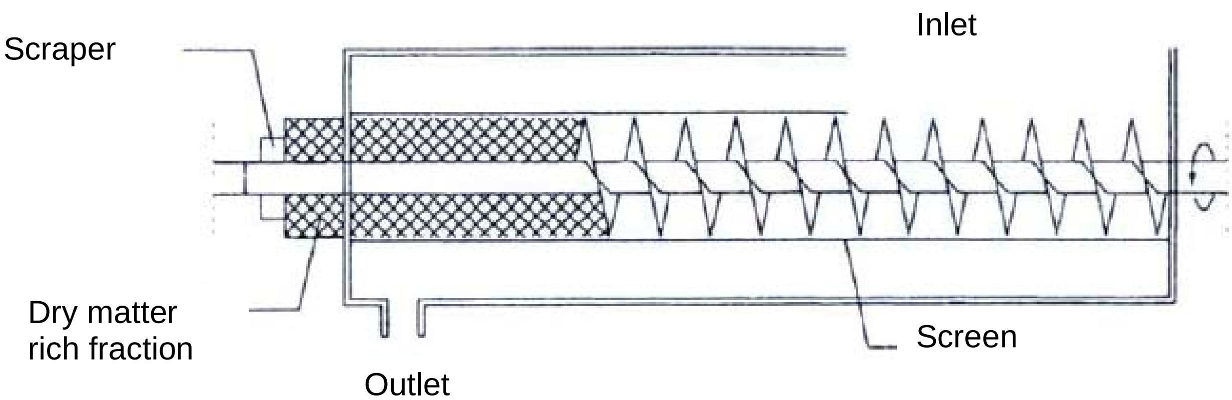


Figure 11 Screw press (Watts *et al.*, 2002)

Usage: Commercial on-farm
Typical application: Part of system and stand alone
Throughput range: Effluents at 530-2725 l/hour
Published data:
A comparison of two presses, namely the Vincent screw press and FAN system press are given at
http://www.fsaconsulting.net/pdfs/Case%20Study%207%20%20Screw%20Press.pdf
% Separation (Screw Press): Range of values from Oechner *et al*. (1995), quoted by Burton and Turner (2003), with a range of screen sizes, pressing resistances and vibration treatments were given as 24-57%, 8-24% and 14-37% for DM, N and P respectively.
Other relevant data: Efficiency of separation dependant on concentration of effluent, recommended total solid concentration of 5% or greater. Flocculants can be used to improve separation efficiency. Screw press can be used as part of a more advanced manure treatment system such as the 'Agri-Clean', which also includes pre-thickening, air flotation clarification and polymer coagulation and flocculation.

Ability to meet standards for "dirty water" discharge into watercourses etc.
'Agri-Clean' using Agri screw press and polymer system complies with the Federal Clean Air and Water Act, Ohio, USA. Patent pending: 60/347,425. (www.presstechnology.com/agriclean_all.cfm).

Table 15 Capital and operating costs of a screw press

Item	Unit	200 sow low flush	200 sow high flush	2000 sow low flush	2000 sow high flush
Total effluent	ml/yr	9	25	85	250
Solids	tonnes/year	270	290	2,800	2,940
Solids removal	%/year	20.5	10.3	20.6	10.3
Capital cost	£	24,284	24,284	45,136	61,792
Total operating cost	£/year	1,274	1,809	6,134	9,923

(FSA Environmental, 2002b)

3.3.2.5 Filter press
Filter presses include vacuum filters and chamber filters with cloth to assist solid removal.

Vacuum filter - slow revolving drum divided into sections that move through the liquid to be treated. A cloth is fitted over the drum and rollers and the

vacuum forces the liquid through the cloth, with solids being deposited on the cloth for future collection.
Chamber filter - manure is separated and fed into filtration chambers, which are configured as plates, which are forced against one another to remove the liquid.

A report by Ford and Fleming (2002) discussed the use of a filter chamber press as outlined by Pieters *et al*. (1999), in which pig manure of 1.5-2% DM was separated to remove solids. Separation of the influent resulted in the removal of 55% total solids, 77% suspended solids, 31% total N, 42% total P and 31% K. Costs for filter press not available.

Manufacturers/suppliers of presses: -

Belt: Tema Engineers Pty. Ltd, PO Box 4335 Milpera DC, NSW 1891. Telephone 02 9792 3555; Fax 02 9792 3134 www.temaengineers.com.au

Bioclere Technology International, Bioclere house, Moons Hill, Frensham, Surrey GU10 3AW. Phone 01252792666; Fax 01252794068
http://www.bioclere.co.uk/index.html

Roller: Accent Manufacturing Inc., 602-30731 Simpson Road, Abbotsford British Columbia, Canada, V2T 677. Telephone: 604 850 7799; Fax: 604 850 7909
www.accentmanufacturing.com

Roller belt press: NC Engineering, Killybawn Road, Hamiltonsbawn, Richill, Co Armagh BT61 9SF. Telephone 028 38871970; Fax 028 38870362 www.nc-engineering.com

Rotating screen: Linton Agindustrial, 4 Hallstown Road, Upper Ballinderry, Lisburn, Co Antrim BT20 2NE, Northern Ireland. Phone 02892 621317; Fax 02892 622933
http://www.lintonagindustrial.co.uk/

Screw: Press Technology and Manufacturing Inc., 1315 Lagonda Avenue, Springfield, OH 45503. Telephone: 937-327-0755; Fax: 937-327-0756
www.presstechnology.com

3.3.3 Cyclonic and centrifugal separators

3.3.3.1 Hydrocyclone (Figure 12)

A cyclone can be described as a conical apparatus with no moving parts that sits in a vertical position, with the apex close to the ground. Liquid is introduced in the top of the cyclone at an angle, with acceleration and swirling allowing the solids to settle at the bottom of the cyclone and out through an exit point by gravity. The liquid and fine particles remaining in the liquid, swirl up to the top of the cyclone and exit the system through a pipe. Olson (2000) stated that the efficiency of hydrocyclones is dependant on the angle and the length of the basal cone used, in that a decreasing cone diameter creates an increased centrifugal force, which assists with the recovery of the more fine particles. Cyclones are capable of removing 80-90% of solids and have the ability to remove additional solids that cannot be removed by other separation technologies (Watts *et al.*, 2002). Kruger *et al*. (1995) reported that cyclones are cheap and versatile but they need booster pumps that are capable of supplying the influent at a minimum pressure of 30 pounds per square inch (Article by Saqib Mukhtar, John M. Sweeten and Brent W. Auvermann, Accessed 24 May 2006). (http://www.p2pays.org/ref/12/11691.pdf).

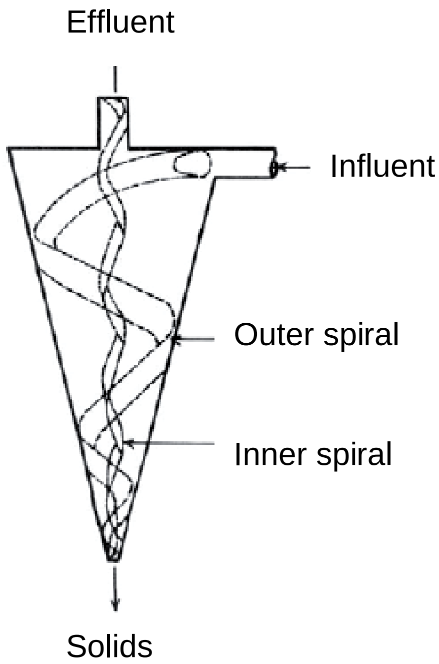


Figure 12 Hydrocyclone (Watts *et al.*, 2002)

3.3.3.2 Centrifuge (Figure 13)

Centrifugation involves the application of centrifugal force to separate solids and liquids on the inside wall of the rotating cylinder. Sheffield *et al.* (2000) reported that centrifuges work best with slurries containing 5-8% solids and are not as efficient when the solids content is lower than this. There are two main types of separator, namely centrisieves and decanters. The centrisieve has an inclined revolving drum lined with a filter cloth that retains the solids and allows the liquid to filter through. Decanters have an auger, which rotates at a higher speed than the cylinder in which it is contained and moves the solids to a conical point for collection. Kruger *et al*. (1995) reported that centrifuges have a high capital and operating cost and this is their main disadvantage. These authors also reported that centrifugal separation of slurries leaves a dry solid that is easily handled with minimal odour.

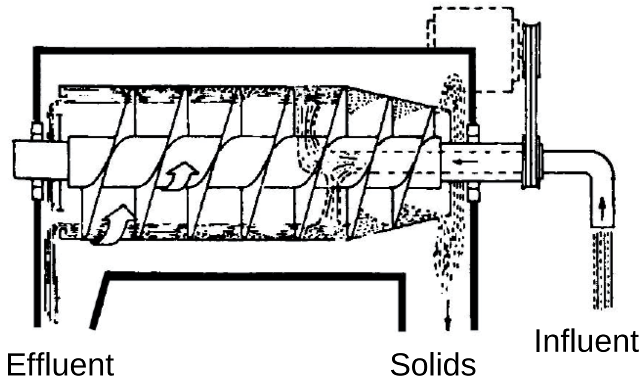


Figure 13 Solid bowl centrifuge (Watts *et al.*, 2002)

3.3.3.3 Decanting centrifuge

Solid bowl centrifuges use the force developed under fast rotation to separate the liquid from the solid fraction. Decanter or scroll centrifuges differ from the earlier basket centrifuges in adding a helical screw conveyor, capable of continuously discharging the separated solids from the bowl (Albertson *et al*., 1991). The conveyor rotates at a slightly higher or lower speed than the bowl, conveying the solids from the stationary zone where the wastewater enters, to the dewatering beach where the solids are discharged. The scroll pushes the collected solids along the bowl wall and up the dewatering beach, located at the tapered end of the bowl. The liquid flows around and through the conveyor, over an adjustable weir towards the liquid discharge end.

Decanter centrifuge models can rotate in counter-current, or continuous concurrent mode. Those with a concurrent design typically operate at lower speeds, depending on the machine size and separated solids properties. The solids content of the separated solids are determined by the length of the dewatering beach, and the differential between the speed of the bowl and conveyor (Albertson *et al*., 1991). By controlling the differential speed, optimum solids residence time in the centrifuge and the desired water content of the separated solids can be obtained. Newer models control the speed of the bowl as a function of the conveyor torque, with eddy current brakes also used.

The best performance is achieved when the flow rate and solids concentration of the influent are standardised. Several decanting centrifuge manufacturers offer mobile slurry processing plants. These are mounted on trailer units that can be transported from farm to farm. Pederson (2004) also reported the mobile decanting unit to be the cheapest solution for the typical Danish pig farmer.

Where a high percentage of solids and nutrient separation is required polymer can be added to flocculate the colloidal material.

Usage: Commercial use in a wide range of applications in addition to agriculture. Can process a wide range of materials eg; agri-food waste, pig slurry, cattle slurry, slaughterhouse wastes.
Number/location of those in operation: Widely used in North America and Europe. Mobile decanting centrifuges are used in Denmark on pig farms. ~250 in non-farm use in Ireland.
Manufacturer(s): Pieralisi, Alfa Laval, Westfalia manufacture decanting centrifuges.
Use of additives/flocculants: Polymers may be used to enhance nutrient separation.
Throughput range: Wide range depending on model. Typical range 5-30 m^3. Can process 50-100,000 m^3 slurry/year (Pederson, 2004).
Capital cost: Typically £80,000-£100,000
Running cost: Including polymer, labour and electricity, £4/tonne for small scale but falling to below £1/tonne for larger scale centrifuges (Jacobsen and Hjort-Gregersen, 2003).

Study data
Table 16 summaries the results from a decanting centrifuge trial with aerated pig slurry in Northern Ireland.

Table 16 Partitioning of DM, TP, and TN between cake and supernatant from a decanting centrifuge-with and without chemical treatments.

% In each fraction		**Raw slurry**	**Separated material**	**Total P**	**Total N**
Untreated	Liquid	92	37	15	79
	Solid	8	63	85	21
Polymer	Liquid	92	27	9	62
	Solid	8	73	91	38
Polymer + conditioner	Liquid	72	10	0	35
	Solid	28	90	100	65

Without the use of additives, the centrifuge separated 63% of the total DM, 85% of TP and 21% of the TN into the solid fraction, which comprised 8% of the total volume (Table 16). The addition of polymer increased the solid content to 73% of the total DM, 91% of the TP and 38% of the TN. These values were increased further with the use of polymer and conditioner, to 90% of the total DM, 100% of the P and 65% of the total N.

With the addition of coagulant average total solid removal rates of about 60% can be achieved, although removal rates exceeding 80% are possible. However, the cost of adding the coagulant may not justify the improved performance.

Other Data
With polymer at 120 ppm:
31% N removal with Alfa Laval 518 Centrifuge
75% P removal with Alfa Laval 518 Centrifuge
(http://www.agf.gov.bc.ca/resmgmt/publist/300series/382340-1.pdf)
BOD: Influent BOD_5 and COD of pig manure reduced by 18% and 52% after decanter centrifuge (Glerum *et al*., 1971).
32% removal of 5-day BOD with Alfa Laval 518 Centrifuge, with 30 ppm polymer

3.4 Advanced Methods of Slurry Separation

Separated slurry may be further refined to treat the separates and remove an even greater proportion of nutrients. Several methods for achieving a high level of nutrient removal from the liquid component are available including (1) reverse osmosis (2) activated membrane technology or (3) evaporation.

3.4.1 Reverse osmosis

Reverse osmosis uses a membrane filtering system removing bacteria and nutrients to produce a clear water. Reverse osmosis is applied after previous stages of separation including initial filtering and ammonia stripping. Salts are concentrated in a reverse osmosis unit fitted with spiral wound water membranes, the process being carried out at 35-40°C. It can be used to separate the liquid fraction from manure and further use it as a source of drinking water for livestock.

Slurry can contain up to 95% water and 5% solids. The solids consist of total suspended solids (TSS) and total dissolved solids (TDS), both of which need to be removed in order to reuse the liquid fraction as drinking water. Reverse osmosis is an effective method of removing total dissolved solids by membrane filtration, with most systems having the potential to remove up to 90% of TDS (Cheremisinoff, 1995). However, membranes used in the process are prone to fouling up by organic matter (Zhao *et al*., 2000) and although the water produced is clear and meets chemical standards for animal drinking quality, the volume produced can be as low as 4% at a level of 345-414 kPa applied pressure (Navaratnasamy *et al*., 2004).

Canadian researchers at the University of Guelph (Morris *et al*., 2003) examined the potential of reverse osmosis to separate and clean the water from pig slurry for use as a source of drinking water for pigs. The quality of the water was assessed along with the growth performance and health of the pigs that were drinking it. Data demonstrated that the water quality was acceptable to pigs and no effect on performance or health was noted.

3.4.1.1 Activated membrane technology

A variation on reverse osmosis is the use of an activated membrane in which both electrical charging and vibration are used to increase the performance.

An example of this is the Vibratory Shear Enhanced Process (VSEP) system (http://www.vsep.com).

Biorek is a system which incorporates the process of reverse osmosis and products include P and K concentrate and clean water (Figure 14). The operation is performed at 32 bar pressure and a temperature of 35-40°C.

Usage: Commercial use as part of turnkey plants.
Examples of systems in operation for manure treatment:
Sandager Slovgaard-14,600 tonnes/year pig slurry; Eldendorp, Holland; Lathen, Germany; Hashimato, Japan

Manufacturer(s):
Bioscan Engineering A/S, Tagtaekkervej 5, DK 5230 Odense, Denmark.
e-mail bno@bioscan.dk.

New Logic Research, Inc. 1295 67th Street, Emeryville, CA 94608-1120 Phone: +1-510-655-7305; Fax: +1-510-655-7307 e-mail: info@vsep.com.

Throughput range: Typical plant handles 40 m^3/day (Norddahl and Rohold, 2000)
Capital cost: NA.
Running cost: Bioscan system net cost approximately £4.50 /m^3 with a daily input of 41 m^3/day. (Norddahl and Rohold, 2000).
Nutrient Separation: Norddahl and Rohold (2000) quote that 80% of P and K is extracted by reverse osmosis carried out at an operating pressure of 32 bar and a temperature ranging from 35 to 40°C.

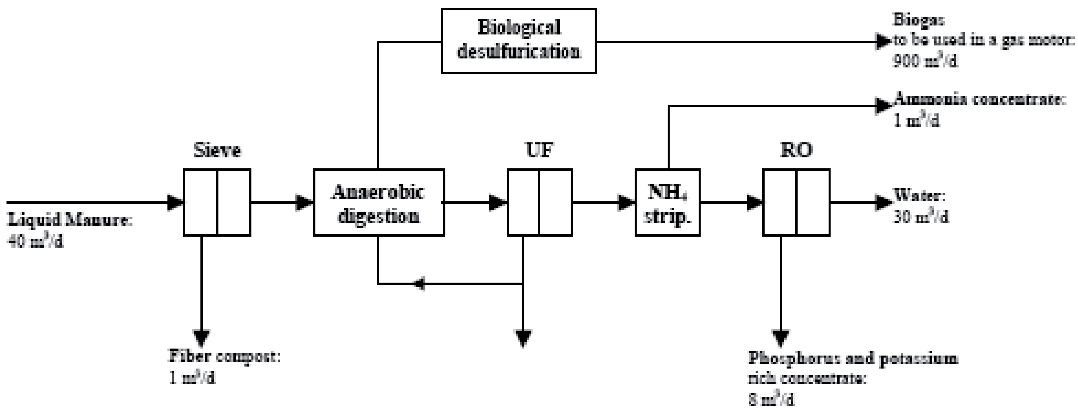


Figure 14 Overall mass balance for the Biorek process (Reproduced from Norddahl and Rehold, 1998) (Sieve: removal of particles >1 mm, UF = Ultrafiltration (40 kDa), RO = Reverse Osmosis)

3.4.2 Evaporation

Evaporation involves the use of thermal separation technology to concentrate or separate liquid solutions, suspensions and emulsions. Evaporation can also be used to separate the volatile components of a liquid. Evaporation alone is not capable of reducing the nutrient load, but it does increase the transportability of manure. There are a number of evaporation technologies available namely, falling film, forced circulation, plate, circulation, fluidised bed, rising film and stirrer.

3.4.2.1 Falling film evaporator (Figure 15)

The falling film evaporator consists of a shell and tube heat exchanger in a vertical position, with a centrifugal separator as shown in Figure 15. The liquid influent is supplied at the top of the heating tube and flows down the inside walls (by gravity) as a thin film, which boils as a consequence of the external heating of the tubes. A vapour is then formed and a centrifugal separator at the bottom of the vessel separates the film and vapour. There is a requirement for wetting the film-heating surface as deposits accumulate if this is not conducted. The longer the heating tube, the greater the wetting rate that is required. The remaining evaporator technologies mentioned work on a similar principle to the falling film evaporator.

Evaporation has been linked to operating biogas plants with excess heat being applied to the manure separation, one such system being the Septec by a Danish company Bjorn Elts. The products include a 6% highly concentrate liquid manure with NPK, 15% solids and 79% clear water with max 200 mg N/l.

Usage: Commercial use as part of turnkey plants (eg Xergi and LRZ).

Manufacturer(s): GEA Weigand is a German company that uses evaporation technology

(http://www.geapen.nl/ndk_website/PdivExhibition/CMSResources.nsf/filenames/680%20Evaporation%20Technology.pdf/$file/680%20Evaporation%20Technology.pdf)

INCRO, C/Serrano 27, 28001 Madrid, Telephone: 34 91 435 08 20; Fax: 34 91 435 7921
http://www.incro.es/pages/vaporizacioningles.htm

Septec by a Danish company Bjorn Elts
http://www.bjornkjaer.dk

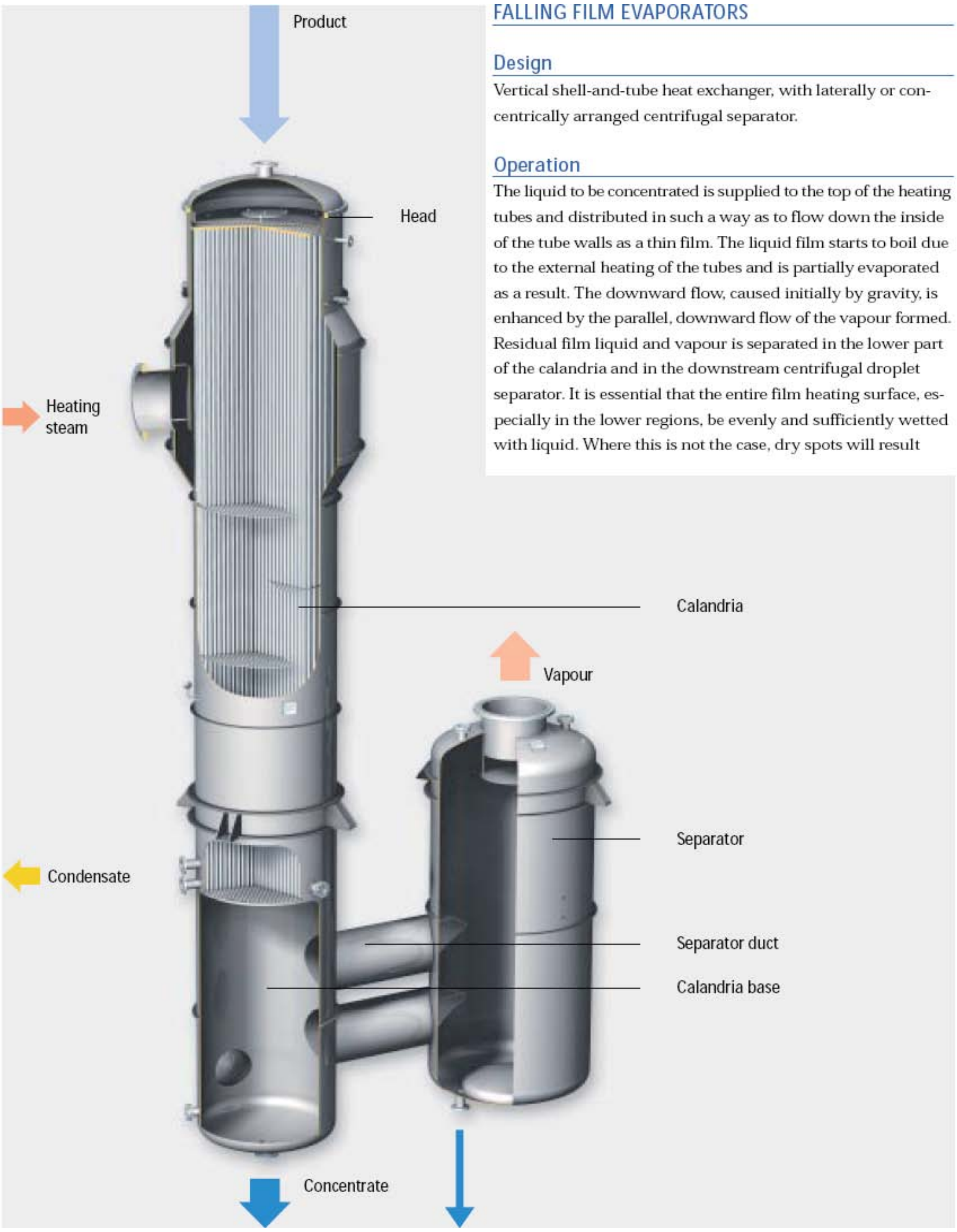


Figure 15 Falling Film Evaporator (GEA Wiegand, Germany)

3.5 Chemicals for Solid and Nutrient Separation

Chemical treatment of manure can assist in partitioning nutrients. Solids can also be separated using chemicals known as coagulants and flocculants. Processes involved in chemically separating the liquid and solid fractions of manure and reduce P levels include flocculation, coagulation and precipitation. Coagulants and Flocculants are a normal part of municipal wastewater treatments systems.

3.5.1 Coagulants

Albertson *et al*. (1991) reported that the use of lime or ferric chloride as coagulants might increase the total solids content of separated sludge by 20-25%. Polymers and precipitation agents can also be used for this purpose. Commonly used coagulants include metal salts such as aluminium sulphate or Alum (Al_2SO_4), ferric sulphate (Fe_2SO_4), ferric chloride ($FeCl_3$) and calcium carbonate ($CaCO_3$) and cationic polymers. Worley (2005) found that alum increased precipitation of total solids from 58% to 72% and P from 38% to 78% in a pig manure settling basin system, leaving the liquid fraction with a nutrient balance more suitable for crop application.

3.5.2 Flocculants

Rushton *et al*. (2000) described flocculation as a process whereby molecular bridges are formed between particles. Flocculants are used to precipitate nutrients from slurry by increasing particle size through aggregation. However, precipitation can produce a large number of fine particles with electrostatic charges that create repulsive forces that can prevent aggregation. This can result in the need for the addition of coagulants such as metal salts to overcome the repulsive forces produced between particles. (http://www.frtr.gov/matrix2/section4/4-50.html).

Cationic polymers such as polyacrylamides (PAM) have largely been adopted by other industries such as food processing and wastewaters, with their application in agriculture being more limited as they require a more dilute waste stream and high cost is a limiting factor.

Bragg (2003) demonstrated that flocculation is a useful method of reducing P in manure from 80 to 20 mg/l and that the process can be enhanced by using precipitation chemicals such as ammonium hydroxide at < 3 mg/l to achieve a >95% reduction.

Usage: Used widely in many different systems to enhance separation of solids and minerals, particularly P.
Separation of nutrients: Vanotti *et al*. (2002) evaluated the use of polymers to separate solids from flushed swine manure. Flocculation enhanced the separation of nutrients such as P (92%) and N (85%) following initial screen separation.
Running cost:
Costs/m^3 of screened effluent: Ferric chloride 400 mg = £1; Polymer 25 mg = £1.20

Treating swine manure of 2.5% TS was estimated to have a cost of $1.27 (0.71 p) per finished pig (Vanotti *et al*., 2002).

3.5.3 Optimised struvite precipitation

The addition of a magnesium source to manures or separated manure liquor will result in the formation of a crystalline precipitate containing struvite (magnesium ammonium phosphate hexahydrate, $MgNH_4PO_4 \cdot 6H_2O$).

Phosphorus reductions greater than 90% can be achieved where struvite precipitation is maximized. The optimum conditions for struvite formation are: -

- The presence of P, ammonium and magnesium. In manure, magnesium is the limiting factor and it can be added in the form of magnesium hydroxide, oxide or chloride. Magnesium chloride is the commonly used form
- pH value between 7 and 11. Above pH 11, ammonium becomes unavailable
- Low content of organic solids. Struvite precipitation is therefore most effective in separated manure liquor

In a review of phosphate recovery from animal manures, Greaves *et al*. (1999), found that there are effective biological and crystallisation methods used in the treatment of sewage, which should be adaptable to manures. Economic viability of these technologies would be unlikely but changes in legislation regarding P loading to the environment would require consideration of these as a slurry management option.

Burns and Moody (2002) treated 140 m^3 of pig slurry with 2 m^3 of magnesium chloride and achieved a 90% reduction in the P content. A high pH was maintained by mechanical stirring prior to land application. However, Burns and Moody (2002) had not been able to go as far as demonstrating commercial use of struvite precipitation at farm-scale.

Although Burton and Turner (2003) concluded that the cost of the chemical additives were greater than the fertiliser value of the precipitated struvite, Burns and Moody (2002) proposed that struvite precipitation was an ideal way of extracting P in a form which could easily be transported to where its P and N fertiliser value could be utilised. The process would then leave the liquid fraction with a nutrient balance more suitable for application to meet crop nutrient needs.

Levlin and Hultman (2003) studied the recovery of phosphate in working wastewater treatment plants by the Pho-strip process, which precipitates phosphorous by addition of lime, producing calcium phosphate and the precipitation of struvite, which can be achieved by several combinations of precipitation. Results from these plants show phosphate recovery (as calcium phosphate or struvite) can reach 60–65%, levels that would comply with the Swedish Environmental Protection Agency requirement of 60% P recovery by 2015.

In the USA, investigations of laboratory and field scale experiments into the precipitation of soluble phosphorous (SP) from liquid swine manure, has been undertaken by the Biosystems Engineering and Environmental Science department at the University of Tennessee. In one experiment a magnesium chloride ($Mg Cl_2$) solution (64%) was added to pig slurry in holding ponds to force the precipitation of struvite. SP reductions of 76 and 90%, respectively, were observed in the laboratory and field experiments. Analysis of recovered precipitate by X-ray diffraction, confirmed the struvite precipitation. Examination of the molar N:P:Mg ratio suggested the presence of other compounds in the precipitate.

http://notes.utk.edu/bio/unistudy.nsf/0/2bfe2582cb0a3ee885256f330050733f?OpenDocument.

An experiment applying aluminium chloride (Al Cl_3) to bind SP in pig slurry in holding ponds affected the formation of aluminium phosphate in the slurry. The SP was reduced in the ponds, though the efficiency of Al Cl_3 in reducing SP was better in high SP than low SP ponds, at 48% and 6% efficiency respectively. http://notes.utk.edu/bio/unistudy.nsf/0/1e9287c37bf3496585256f330050577b?OpenDocument.

3.6 Review of Slurry Separation and Nutrient Partitioning Technologies

Reducing the total volume of slurry is an established practice on farms, with possible benefits of reduced storage requirement and easier handling of the solid and liquid fractions. In Northern Ireland, slurry separation is already practiced on some farms, and includes use of locally manufactured units. However, most manure is applied to farmland as untreated manure and the primary concern has been to 'dispose of' the manure in an acceptable manner, with only secondary consideration to the efficient utilisation of N, P and K by crops.

With the advent of the Nitrates Directive, livestock units are required to comply with a number of regulations regarding waste storage capacity. In some cases these requirements include the need to export a significant proportion of the manure and nutrients to other farms or to manure processing facilities. This export of nutrients particularly N, can help these farms to comply with nutrient application limits. Application of excess quantities of manure to farmland will result in the manure being considered as a 'waste' under the terms of the Waste Management Directive, rather than a beneficial resource, and require the farm to be licensed for waste disposal.

In relation to these issues, the liquid portion resulting from slurry separation could provide a number of advantages, which are summarised by Burton and Turner (2003) as being: -

- Improved penetration into the soil following spreading, with a reduction in odour and ammonia emissions. It might be reasonably expected that there will be less manure entrained on herbage and consequently reduced hygienic hazards during subsequent grazing
- Easier handling enabling better spreading accuracy for an even distribution of nutrients and better utilisation by plants
- Nutrient reduction in slurries (relevant where there are problems of surplus).
- Separation can be expected to reduce overall organic load in terms of COD and to achieve reduction in non-soluble components in the manure. In this way it cannot be expected to greatly affect the ammoniacal nitrogen concentration
- Reducing the solid content of slurries to obtain a dilute phase
- Improving the homogeneity of liquid phase (no sediment or floating layers)

- Reducing required storage volumes for slurries
- Reducing energy requirement for pumping and mixing

- Avoiding blockages during further handling
- Manure preparation for biological treatment

Advantages of solids
- Solid fraction posing less environmental hazard as nutrients are less mobile on the farm
- Solid material more readily transported off farm
- Material more suitable for additional treatment e.g. composting of solids, nutrient extraction from liquid

Disadvantages of separation noted by Burton and Turner (2003) were: -
- Storage, handling and spreading techniques for both liquid and solid phases are required
- Investments in machinery have to be made
- Farm labour input and training is required

3.6.1 Separation technologies
The principal technologies available for the separation of slurry were reviewed by Burton and Turner (2003) and have been described briefly in Section 4 of this report. Most of the passive or mechanical technologies screen out or filter 40%-60% of solid particles in the slurry and deposit them as bulk and stackable residues. The original volume of slurry is reduced by between 20% and 30%. Table 17 summarises separation efficiencies of some separation techniques.

Table 17 Comparison of separation efficiencies

	Volume Reduction	DM	N	P	K
Settling pond (no additives)	-	58	18	38	6
Settling pond (with alum at 0.4%)	-	72	25	75	9
Geotube (including use of polymer)	-	90	50	90	-
Belt press	29	56	32	29	27
Sieve drum	10-25	20-62	10-25	10-26	17
Screw press	5-25	20-65	5-28	7-33	5-18
*Decanter centrifuge	13-29	54-68	20-40	52-78	5-20
Decanter centrifuge with polymer	25	80	50	95+	-
Centrifuge decanter	8	63	21	85	-
Decanter + polymer	8	73	38	91	-
Westfalia decanter + polymer + conditioner	28	90	65	100	-

(* Burton and Turner, 2003; Frost, 2005; FSA Australia, 2000; Worley, 2005)

- For the sieve, belt press and screw press based techniques, the partition of N and P is approximately in proportion to the weight. There is limited benefit from these methods for exporting nutrients compared with transporting raw slurry. These methods will also have little effect on the BOD value
- Without the use of additives, the settling pond and to a greater extent the decanter centrifuge, were able to partition higher proportions of P in the solid fraction
- With the use of additives, the settling pond, decanter centrifuge and the Geo-textile tube system were able to partition a high proportion of P and for the centrifuge and Geo-textile tube, N in the solid fraction
- Polymers and chemical treatment could be used with other mechanical separators to improve the partitioning of nutrients in the solid fraction

3.6.2 Mechanical separators

A substantial quantity of scientific and engineering information is available regarding the performance of the various separator types on the market at present. Ford and Fleming (2002) produced an in depth review of a wide range of separator technologies and reported that they generally fall within three categories namely, screens, presses and centrifuges. Separators could also include a combination of any or all of these three basic categories. The DM content of separated solids obtained from various separation devices are shown in Figure 16.

Ford and Fleming (2002) cite high capital cost and increased management requirement as major drawbacks of separation, while ease of handling and transport of separated fractions, odour reduction and reduced pollution potential to surface waters are benefits gained. Burton and Turner (2003) referred to similar work and reached similar conclusions.

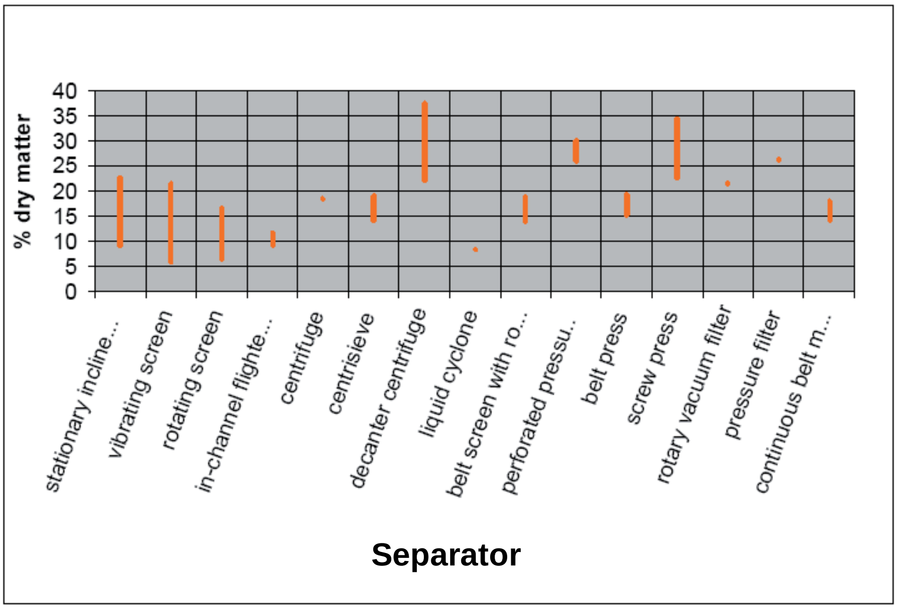


Figure 16 Dry matter content of separated solids fraction using different separation devices (Ford and Fleming, 2002)

3.6.3 General performance and efficiency

The performance of a separation system are defined in terms of the following according to Burton and Turner (2003): -

- Throughput
- Volume reduction
- Partitioning of nutrients (mainly P and N)
- DM content of solid fraction
- BOD of liquid faction
- Energy consumption
- Capital and running costs

The principal factors affecting the performance are likely to be: -

- Type of separator
- Sieve mesh size (or centrifugal force)
- Manure type
- Additives (polymers, flocculants, conditioners etc)
- TS content of raw manure

Burton and Turner (2003) quoted the work of Oechsner (1995) regarding the performance of a screw press auger separator, with a range of sieve sizes, with and without vibration and with high and low pressing resistance.

Finer sieves tend to: -

- Reduce the throughput
- Reduce the DM content of the solids
- Increase the proportion of nutrients in the solid fraction (N and P)

The use of vibration and increased pressure tends to: -

- Reduce the moisture content of the solids
- Reduce the N content of solids

Frost and Stevens (1991) studied the performance of a flat belt separator at a range of sieve sizes and with cattle slurry having a range of DM contents (Figure 17). The authors reported that reducing mesh size and increasing slurry DM content increased the proportion of total DM ending up in the solid fraction, but at the expense of throughput. Reducing the mesh size from 2.0 to 0.4 mm reduced the throughput by 45%. Diluting the slurry from 100 g to 60 g DM/l doubled the production of separated liquid, but only increased solids separation by 20%. It was concluded that this would be of little benefit as a means of improving separator efficiency.

Frost and Stevens (1991) also reported that separation through a 0.4 mm sieve reduced ammonia volatilisation by 50% and increased grass DM yield by 29%-36% when the separated liquid was applied instead of the whole slurry.

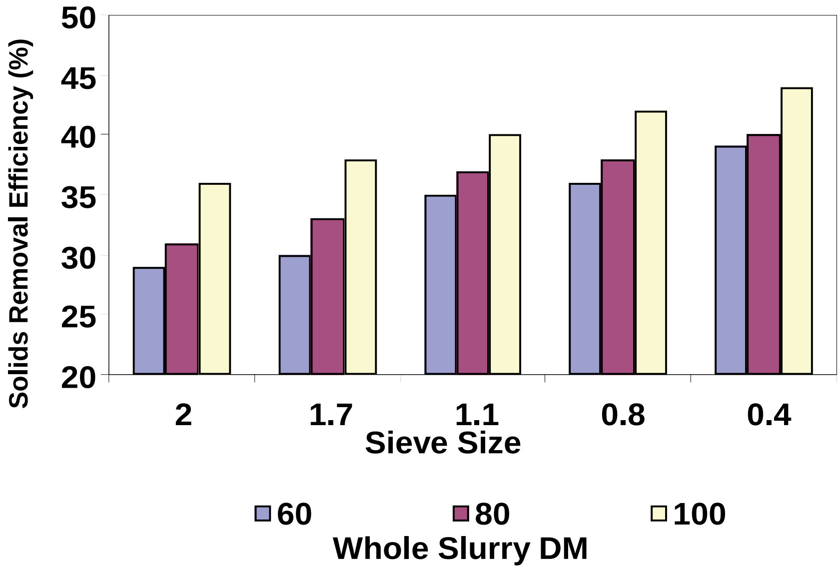


Figure 17 Effect of mesh size (mm) and DM content of manure on solid separation efficiency of a flat belt separator (Frost and Stevens, 1991)

More recently, the on-farm performance of a rotary screen separator (Carier) was evaluated by Wallace (2004) at CAFRE, Greenmount Campus Dairy Unit. Use of the separator reduced the slurry volume by approximately 26% (Table 18). The N and K content of the separated fractions were similar to those of the original raw slurry (Table 19), but the analysis of the fractions indicated some partitioning of P and sulphur in the solid fraction, although this had only a small effect on the content of these nutrients in the liquid fraction. Where the reduction in volume of material to be stored in tanks would mean a lower financial investment, the analysis of Wallace (2004) indicated that there could be a positive return from the use of a separator (Table 20).

Table 18 Output from slurry separator running for eight hours

Volume of slurry pumped from cattle house to separator	100,620 litres
Volume of slurry after separation	74,790 litres
Reduction in volume	25.6%

(Wallace, 2004)

Table 19 Analysis of slurry components

	% DM	% N	% P	% K	% S
Slurry	7.2	0.37	0.064	0.369	0.047
Separated liquid	4.9	0.36	0.058	0.353	0.041
Separated solids	21.8	0.42	0.097	0.352	0.097

(Wallace, 2004)

Table 20 Estimated benefits and separator costs, based on a 10 year depreciation period

Costs saved	£	Extra costs	£
25% slurry storage 320 m^3 @ £65/m^3	2080	Separator £27,500	2750
1450 kg available N @ £0.54/kg	783	Running costs 150 hours @ £2/hour	300
330 kg available P @ £0.74/kg	244		
3600 kg available K @ £0.27/kg	972		
Total costs saved	4079	Total extra costs	3050
Extra profit	1029		

(Wallace, 2004)

3.6.4 Performance of the decanting centrifuge

Where partitioning of the nutrients is a primary objective, along with a high throughput, only the decanting centrifuge is capable of combining these in a unit. This unit can either be installed on-farm or set up as a mobile system that can move from farm to farm. The decanting centrifuge is a well-established and working technology, used in a wide range of industries. A number of studies have been performed regarding its use to treat animal manures and a small trial has also recently been carried out in Northern Ireland.

Compared with the screw press and other mechanical systems which can only separate out solids of 0.1 mm or greater, the decanting centrifuge can retain all particles greater than 0.02 mm (Moller *et al*., 2002). The use of a polymer to coagulate colloidal suspensions can improve the performance of the centrifuge further.

Centrifuges produce solids that are readily handled and have minimal odour (Kruger *et al*., 1995). One manufacturer claims an average total solids (TS) content of 28.3%, with a range of 25-35% (Fulhage and Pfost, 1993). Kruger *et al*. (1995) claims an average TS content of 35%.

Hahne *et al*. (1996) examined the performance of a decanter centrifuge for separating solids from piggery effluent. They used influent containing 7% TS and an inflow rate of 1.2-2.7 m^3/hour. The authors reported that the centrifuge removed 54-60% of TS, 20-30% of N and 70-78% of P_2O_5. The TS concentration of the solids removed was 20-30%.

The performance of a single centrifuge in Western Australia was examined by Payne (1990). The device was reported to have removed 37% of TS from the influent. The solids produced had a TS concentration of 35.4%, and were sufficiently dry for easy handling.

Horizontal centrifuges seem to work significantly more effectively than vertical centrifuges. Average TS removal rates of approximately 35-45% can be expected, although removal rates of up to 60% TS are achievable. The TS content of the solids removed is typically 20-35%.

With the addition of coagulant, mean TS removal rates of approximately 60% can be achieved, although removal rates exceeding 80% are possible. However, the cost of adding the coagulant may not justify the improved performance. Centrifuges have a high capital and operating cost.

3.6.5 Northern Ireland trial with a decanting centrifuge

A trial was undertaken on a Northern Ireland farm with a mobile decanting centrifuge separating cattle slurry, aerated and non-aerated pig slurry. Limited results were obtained with the non-aerated pig slurry and the cattle slurry, due to low initial DM contents in the raw material (0.8%-1.9% DM). However, work with the higher DM, aerated pig slurry (2.4% to 5.8%) yielded a full set of data (Frost, 2005).

3.6.5.1 Equipment and additives

The trial was conducted with a Westfalia mobile rig on loan from Dungannon Meats Ltd. In order to precipitate soluble P from the slurry, a polymer or polymer plus chemical conditioner were included (Table 21). During the trial, a Westfalia appointed chemist made the choice of polymer.

Table 21 Rates of addition of polymer and conditioner

	Addition Rate	Approximate Cost £/m^3
Polymer	0.65 kg/m^3	1.17
Polymer + Conditioner	0.30 kg/m^3	1.24

Without the use of additives, the centrifuge separated 63% of the total DM, 85% of TP and 21% of the TN into the solid fraction, which comprised 8% of the total weight (Table 16). The addition of polymer increased the separation efficiency to 73% of the total DM, 91% of the TP and 38% of the TN. These values were increased further with the use of polymer and conditioner, to 90% of the total DM, 100% of the P and 65% of the total N. Although a full set of data could not be attained from the other slurries, data obtained showed the same trends.

In terms of nutrient separation the performance of the decanting centrifuge in this one-off Northern Ireland trial exceeded the figures published from other trials and showed that as a means of partitioning P and N into the separated solids, centrifugation can achieve a very high degree of efficiency. Even without the use of additives it was capable of achieving more partitioning than other mechanical separators. However, in terms of slurry nutrient volume reduction, centrifugation would be less effective if polymer and conditioner were not used.

3.6.6 Other methods of slurry separation

Although not widely used in the British Isles, settling ponds and the more recently developed technology of Geo-textile tubes have the potential to achieve partitioning of a high proportion of total P and up to half of total N into the solid fractions, particularly if additives are used (polymers for the Geo-textile tube and alum for the settling pond). The Geo-textile tube does not reduce the liquid storage any more than other separation methods. The advantages of settling ponds and Geo-textile tubes in terms of the liquid fraction will be similar to those found from mechanical separation (low odour, easier handling, better nutrient balance, more efficient utilisation) and the principal issue then becomes how the solid fraction is utilised. The Geo-textile tube is likely to leave a solid fraction that is easier to handle and drier than from sedimentation ponds, particularly in our climate, where there is likely to be little natural evaporation. The solid material would be suitable for composting or other processes, which would allow it to be marketed for soil amendment. However, precisely how this P-rich fibrous material could be used would be an important aspect of the overall system.

While the centrifuge has a very high throughput potential, the Geo-textile tube is slower when dewatering manure. Geo-textile tubes can be set up as a batch process, for example to contain the contents of one slurry tank, or as a trickle flow system when the manure is constantly added to the Geo-textile tube until it is full. The capital cost of Geotubes are relatively low at less than £3.30/m^3 of slurry, with a DM content of approximately 5%.

Compared with settling ponds and the Geo-textile tube, weeping walls are a relatively crude system which only address the issues of solid/liquid separation for wet farmyard manure and not for liquid slurry, leaving a liquid fraction that is high in BOD, COD and nutrient content.

While polymers and flocculants can be used to improve the performance of physical separation techniques, they can also be used on their own or with other chemicals to achieve separation. In Denmark, some manure handling systems are based principally on the use of chemical flocculation and precipitation.

4 Alternative manure utilisation systems and energy generation

4.1 Manure Utilisation

4.1.1 Composting

Composting is the aerobic biological decomposition of plant residue, food waste and manures under controlled conditions to form compost. Decomposition of manure and other organic substrates occurs in a thermophilic environment, with a temperature of 40-65°C (Buckley, 2003). The most common methods of composting are (1) Windrow and (2) In-vessel composting. The former method involves the mixing and piling up of organic material into long rows. These rows are monitored to optimise decomposition. In-vessel composting involves the use of a controlled environment, where optimal conditions for decomposition are maintained. These two composting technologies can be used independently or in combination. The key factors for composting are nutrient balance, moisture content, temperature and aeration. Turning the material to be composted introduces more oxygen, which accelerates decomposition.

Composting of solids extracted from manures is a potential method of dealing with surplus manures and separated solids. Many companies offering advanced or improved technologies for producing compost have been identified. However, a profitable market for compost products has yet to be developed. Although compost is a biologically de-activated material, it is not always acceptable to many potential users because of the knowledge of associated risks from animal wastes. These factors combine to reduce the feasibility of composting as a practical option in manure utilisation at this time.

Compost operation in Ireland - Number/location of those in operation:
16 facilities in Republic of Ireland (Boland, 2004)
4 facilities in Northern Ireland (Boland, 2004)
Several new facilities planned (Boland, 2004)
A map of composting locations in Ireland can be found at The Composting Association (http://www.compost.org)

Celtic Composting systems
Mr Craig H Benton
Celtic Composting Systems Ltd
Gearagh Road
Ballinacurra
Midleton
Co Cork
Republic of Ireland
Tel: +353 21 462 1721

Accelerated Compost Ltd
Mr Simon Webb
Accelerated Compost Ltd
The Heliport
Lyncastle Road
Appleton
Warrington
Cheshire WA4 4SN
Tel: 0870 240 7313

Type of material handled and any limitations: Almost any organic material but with an ideal ratio of 25:1-30:1 Carbon/N ratio (Buckley, 2003). An excess of a

certain material or allowing the compost get too wet or too dry can create problems.
Continuous flow or batch process: Continuous or batch
Use of additives: Calcium carbonate. As bacteria breakdown compost, the pH drops, making the compost more acidic and hence killing some of the bacteria and slowing down the rate of composting. Calcium carbonate can buffer the system to alleviate this problem.
Typical system: On farm or centralised or stand alone or part of system
Throughput range: Farm scale: 28.5 l/day/m^2 (Fleming and McAlpine, 1999) Ontario, Canada. Small to Medium scale: >100 lb-several tonnes/day based on four different in-vessel technologies used in New York (Regenstein *et al*., 1999)

Capital cost: $300-$100,000+(£167-£55,700+) Based on four different in-vessel technologies used in New York (Regenstein *et al*., 1999)
Running cost: Home made in-vessel system (Emerson, 2004) - Estimated operations and maintenance total ~$1,475 (£821)/year or $28 (£15.60)/tonne

Bioganix Ltd (UK) built and operate first UK in-vessel composter, processing >8000 tonnes/year. Output products (including heat/energy): Compost and low-grade heat.
http://www.bioganix.co.uk/

Pilot plant data: Changes in nutrient (N) values of separated slurry after composting: (From an experimental composting plant at Modena, Italy (Bonazzi and Piccinini, 1997))

Material for composting	Nitrogen (%)
Solid Fraction separated from cattle slurry	12
Solid Fraction separated from pig slurry	25
Solid Fraction separated from poultry manure	54
Solid Fraction separated from sewage sludge from animal manure	37

4.1.2 Pelletising (Figure 18)

One possible option of transforming slurry/manure to fertiliser is the process of pelletising the dried cake extract. This greatly reduces volume as the cake is compacted at high temperature and pressure to produce sterilised pellets that can be used as an organic fertiliser for soil enrichment and plant nourishment. There may also be some potential as a fuel source for certain types of combustion technology. Producing high quality pellets requires relatively high cost equipment and is affected greatly by the moisture content of the raw material. Markets are not yet established in this country. A North American company, AgriRecycle, have developed pelletising technology for processing poultry litter into organic fertiliser. They offer a complete turnkey plant, with a capacity to process 120,000 tonnes/year costing ~£4.5m to £5.7m. This is a very sizeable operation requiring a 40 acre site, taking some 6-9 months until commissioning. Plants can be bought and operated on a profit sharing basis or bought outright and the company buy and mark*et* all the fertiliser produced. Figure 18 demonstrates an AgriRecycle pellet making machine and a plant in the USA.

4.1.3 Fertiliser production

Many treatment systems claim to offer nutrient removal to the degree of producing a baggable and saleable fertiliser product. Calcium phosphate, struvite (Magnesium ammonium phosphate) and basic N, P and K fertilisers are cited by various companies as possible or definite by- or end products from the systems they install.

Figure 18 Pelletising equipment and Plant (http://www.agrirecycle.com/) (Accessed September 2005)

Some of the European biogas companies do have working methods for the capture of nutrients to produce N, P and K fertilisers, principally as calcium phosphate. These products are claimed to be marketable in European farming, though it has not been possible to ascertain the uptake or the selling cost of these. The German biogas plant manufacturer Landhandels-und Recycling-Zentrum GmbH* (LRZ)–Neukirchen provide turnkey plants, which produce an end product organic compound N, P, K, S, Ca and Mg fertiliser, bagged and marketed as BIONAT. The process recovering the fertiliser occurs at the end stage of anaerobic digestion and the diagram shown in Figure 19 shows this is a bio-filtration technique.

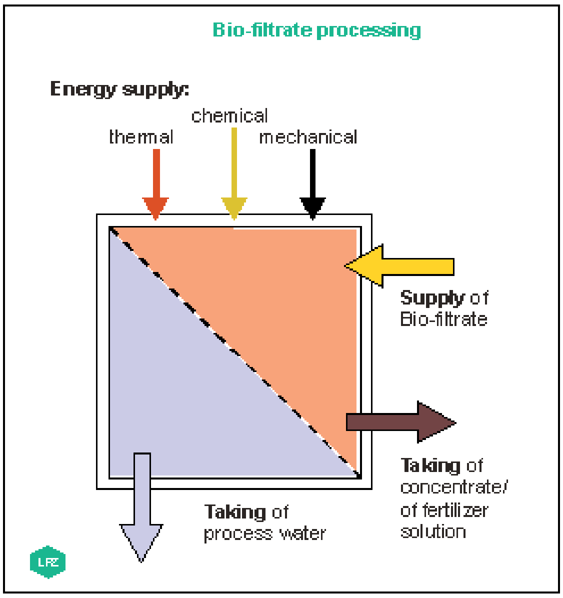


Figure 19 LRZ fertiliser production flow diagram
http://www.lrz-neukirchen.de/englisch/haupt-en.html (Accessed September 2005)

As the need to remove P from Northern Ireland farms is essential, the production of P-rich fertiliser is of limited direct benefit to Northern Ireland farms. This product would therefore have to be exported either as a fertiliser/soil additive or as a chemical industrial feedstock. Inquiries indicate that the first option is not realistic as no such market was identified. To export as a chemical feedstock would only be economically feasible with large volumes of material, which would have to meet stringent chemical quality and safety requirements.

Some of the methods suggested for obtaining the nutrients from the manures are still not proven. The BHP Cookstown report suggests that precipitation of struvite (Mg, NH_4O_3 and P) could be easily incorporated into their proposed treatment systems and several other suppliers also mention this as a method for precipitating nutrients. However, clear evidence for this being an easily incorporated technology has not been found. There are some scientific trials that do show a high degree of success, but these are only from laboratory or small-scale trials. The BHP systems report on a solution for the Cookstown waste stream includes an article by Çelen and Türker (2001) who conducted laboratory scale experiments to recover ammonia as struvite from anaerobic digestate. Results indicated that adding magnesium chloride ($MgCl_2$) and phosphoric acid produced a very fast reaction time and resulted in ammonia recovery of over 85% (after a purification process) as white struvite crystals.

4.2 Energy Generation

4.2.1 Anaerobic digestion (AD)

A number of relevant reports relating to AD are listed in the reference list at the end of this section. These reports are a useful reference source for further details on AD and are made use of in the following summary.

General background

Anaerobic digestion of organic wastes is a proven, well-tried and tested technology that is used throughout the world to convert organic matter to biogas in the absence of oxygen. AD can be carried out on-farm or in larger centralised AD plants.

During digestion, 30-60% of the digestible solids are converted into biogas that is then burned to generate heat and/or electricity. When used for heat only, the biogas is burned in a modified gas boiler to provide process heat to the digester and heat for export. Alternatively, the biogas can be used to fuel engines for vehicles, other machinery and electricity generators. When used to generate electricity, a combined heat and power (CHP) system is often used. Heat from the CHP unit can be used to maintain the digester temperature and supply energy for other purposes. Some CHP plants are used to supply heat to buildings and electricity to the grid.

The following is a transcript of a useful summary prepared by British Biogen (http://www.r-p-a.org.uk/content/images/articles/adgpg.pdf) (Accessed 7 October, 2005)

What is Anaerobic Digestion?

Anaerobic digesters produce conditions that encourage the natural breakdown of organic matter by bacteria in the absence of air. Anaerobic digestion (AD) provides an efficient and effective method for converting residues from livestock farming and food processing into useful products.

Feedstocks include animal slurry (from cattle, pigs and chickens) and residues from food processing industries. Other organic materials can also be digested.

The initial reasons for developing an AD plant will vary but are likely to include one or more of the following:

- A wish to manage food processing residues and farm slurries more effectively, including control of odour
- A wish to utilise biogas to offset farm or factory energy costs
- A wish to sell electricity off-site (through the grid or other local user)
- A wish to utilise or sell fibre and liquor as soil conditioner and liquid fertiliser

  Whatever the initial reasons, for a scheme to be successful it must utilise all the products of AD.

What does the process involve?

The feedstocks are placed into a digester (a warmed sealed airless container). The materials ferment and are converted into a gas and a solid called the digestate, which in turn can be separated out into fibre and liquor.

The AD plant could be a small on-farm facility run by a farmer using only the slurry produced on the farm and using all the resulting products on the farm. Alternatively, it could be a larger scale development known as a Centralised Anaerobic Digester (CAD), taking feedstock from local farmers and food processors and marketing the products on a larger scale. The process is the same whatever the scale but the safe running of the digester and marketing of products is more complex for a CAD scheme.

What are the benefits of Anaerobic Digestion?
Anaerobic Digestion has a number of potential and actual benefits: -

Reducing emission of greenhouse gases
Methane is the main constituent of the biogas and is a major greenhouse gas. By burning the gas as a source of heat and/or electricity, the amount of methane lost to the atmosphere is likely to be reduced. Equally, by using this renewable source of energy it could displace the need to use energy from fossil fuels such as coal and oil.

Reducing odour
AD can reduce the odour from farm slurries and food residues by up to 80%.

Reducing land and water pollution
Land and water pollution can be reduced through efficient waste management. Badly managed disposal of animal slurries can lead to land and ground water pollution. AD can reduce the risk of pollution by stabilising and allowing more control of residues.

Nutrient recycling
The nutrients available in the liquor and fibre can be used as part of an overall fertiliser programme and reduces the need for inorganic fertilisers.

Effective waste management
Anaerobic Digestion can be regarded as part of an integrated waste management plan. The process stabilises slurries, making them easier to handle and reducing odour. New legislation is placing increased pressures on the safe handling of waste. Properly managed AD schemes will help farmers meet these pressures.

What are the problems with Anaerobic Digestion?

Costs
AD has significant operating and capital costs. It is likely to be most viable for those people who can utilise all the products effectively.

Control of dangerous emissions
Some of the trace gases found in the biogas are toxic and dangerous to human health (hydrogen sulphide and ammonia). This means the gas must be cleaned and only dealt with by trained operators.

Traffic
If a CAD plant is being developed it will involve transporting feedstock to and from the site. Consideration needs to be given to the impact on local communities and the overall distance it will be viable to transport residues.

Animal health
There may be some risk of animal disease transmission between farms in CAD schemes, through cross contamination from vehicle movements between farms and the centralised site. Strict quality control measures are needed.

Careful planning, design and operating will reduce the problems and maximise the benefits of AD. Good Practice Guidelines have been produced in partnership by a wide range of organisations which have an interest in AD including the AD industry, farmers, planners, electricity companies and environmental groups. They explain in detail all the issues that must be considered in any AD scheme (British Biogen http://www.r-p-a.org.uk/content/images/articles/adgpg.pdf accessed 7 October, 2005)

Anaerobic Digestion plants can also include additional processes such as: -

- Sterilisation of feedstock
- Separation of fibrous solids from digestate, which after further processing, can give a value added product such as compost or pellets
- Fertiliser production
- Production of clear effluent to meet standards for discharge to water systems
- Co-digestion of animal manures with a proportion of fats or oils to enhance gas quality and production

General process description
For optimum AD in temperate climates, heating of the digester is normally required. Products of AD are biogas [mixture of methane (60-80%), carbon dioxide (20-40%) plus low levels of hydrogen sulphide (0-3%), ammonia and nitrogen (0-5%)] and digestate (liquid). Digestate is typically spread on agricultural land and is a source of plant nutrients. Typically, 40-60% of organic matter is converted to biogas with a typical calorific value of 17-25 MJ/m^3 (20 MJ/m^3 at 70% methane content). Biogas can be utilised by combustion in modified gas boilers to produce heat or in a combined heat and power unit to produce electricity and heat. Biogas can also be used as a vehicle fuel. Feedstock digestion times (retention time in the digester) for optimum production of biogas depend on type of feedstock and temperature of digestion.

The two main types of AD system are as follows (http://www.adnett.org/) (Accessed 21 February 2005): -

Mesophilic: - The digester is heated to 25-35°C and the feedstock residence time is typically 15-30 days. Mesophilic digestion tends to be more robust and tolerant than the thermophilic process, but gas production is less, larger digestion tanks are required and sanitation, if required, is a separate process stage

Thermophilic: - The digester is heated to 49-60°C and the residence time is typically 12-14 days. Thermophilic digestion systems, compared with mesophilic systems, offer higher methane production, faster throughput, better pathogen and virus 'kill' though they require more expensive technology, greater energy input and a higher degree of operation and monitoring

Most agricultural biogas plants are operated at mesophilic temperatures whilst large-scale CAD systems often use thermophilic temperatures (http://websrv5.sdu.dk/bio/Bioexell/Down/Bioexell_manual.pdf) (Accessed 24 May 2006).

To ensure good levels of gas production, it is important to maintain a carbon to nitrogen ratio of 20-30:1 in the AD. A high C:N results in lower gas production whilst a low C:N results in NH_3 build up and high pH (>8.5), sufficient to kill the bacteria (methanogens).

Digester designs include continuously stirred tank reactors (CSTR) and plug-flow systems (Mahoney *et al*., 2002). Plug-flow and CSTR digesters have been used for on-farm systems whilst CAD plants commonly use CSTR systems (Mahoney *et al*., 2002).

On-farm AD systems have an environmental advantage over CAD systems in terms of transport costs. However, it is claimed that to be economic the minimum size of farm unit with a cost of $800,000 Cdn (£400,000) is 150 kW. (Norman Dunn, http://www.betterfarming.com/2005/bf-nov05/europe.htm) (Accessed 24 May 2006). This size and cost of plant is limiting the current uptake by farmers and has promoted a swing towards centralisation. In Austria, a one-megawatt capacity CAD fuelled entirely by corn silage, whole crop cereals and grass delivered by 60 local farmers has been built. A further 15 plants are expected to be up and running in Austria by mid-2006. In Germany, a CAD is being completed to supply electricity for 8,500 households. For this plant, surrounding farmers have been contracted to deliver 2,000 tonnes of whole crop silage per day.

Role of Anaerobic Digestion Systems

Anaerobic digestion is practiced for two reasons (1) the generation of renewable energy and (2) the rendering of hazardous and polluting organic material into innocuous and marketable by-products. Anaerobic digestion does not, however, dispose of nutrients such as N and P, but the products of AD containing these nutrients may be more easily utilised as fertilisers or further treated for the export of the nutrients to other markets.

Table 22 Typical gas yields from different AD feedstocks (Kottner, 2004).

	DM %	Organic matter % in DM	Biogas yield m³/t substrate	Methane content %
Dairy cow slurry	8	85	20	55
Fattening cattle slurry	10	85	34	55
Pig slurry	5	85	18	60
Chicken manure	25	75	93	65
Vegetable residues	6	87	35	56
Rape seed cake	91	93	612	63
Canteen residues – high fat	18	90	108	68
Canteen residues low fat	12	90	108	68
Whole crop silage	40	94	195	53
Grass silage	35	89	183	54

Renewable energy
Suitable substrates for AD are farmyard manures and liquid slurry from all farm animals. The results of rumen digestion, the composition of nutrients and the carbon structure make cattle slurry particularly suitable while pig slurry tends to be lower in DM content but higher in energy and nutrients. High DM manures (horse, poultry) and manures with a high straw content will need the addition of liquid substrates and will require additional mixing. The high ammonia content of poultry manure also requires the addition of carbon sources (straw, grain, fat) for effective digestion.

Co-digestion of animal manures with other waste streams such as food waste, offal or biomass from set-aside and the utilisation of these streams can help to generate a more balanced and higher yielding substrate while improving the financial viability through the derivation of gate fees.

Typical biogas yields from various feedstocks are summarised in Table 22.

One m^3 of biogas contains 5-7 kWh of total energy. Combined heat and power (CHP) plants will generate approximately 30% of this as electricity and 30% as utilisable heat, although more efficient plants are available. Combined heat and power units can range in size from 15 kW to 1 MW. An annual production of 2,500 m^3 biogas, equivalent to the manure from 5 to 6 Livestock Units, is required to supply 1 kW installed capacity.

Production of marketable by-products

- *Reduction of pathogenic organisms and viable weeds*. Mesophilic systems with temperatures of 35 to 45°C will reduce pathogens by a factor of log 2 to log 3 (95%), and virtually eliminate common pathogens (Wright *et al.*, 2001). Thermophilic AD systems come closer to pasteurisation and will be able to achieve a log 3 - log 4 reduction (99.99%). Organisms that are more resistant may require additional treatments such as composting. However, the introduction of co-fermentation waste streams, the transportation of waste from one farm to another and the centralised processing of waste from a number of farms and other sources can cause particular biosecurity hazards

- *Odour reduction*. In a biogas plant, most of the odorous fatty acids are decomposed into methane and carbon dioxide, which are odourless. On the other hand odour annoyance can arise in connection with the handling and transport of manure to the biogas plant. The AD process reduces the odour potential of manure and other waste streams by 80% or more. In the USA, odour reduction has been the principal driving force behind the adoption of AD plants on pig farms
- *Nutrients*. Essential plant nutrients (N, P and K) present in the feedstock largely remain in the digestate. However, whilst total N is not altered, digestate generally contains 25% more inorganic N and has a higher pH than the feedstock slurry. Without further treatment, the digestate can be used as an agricultural fertiliser. Digestate from anaerobic digestion is often separated with the distribution of nutrients between liquid and fibre being in proportion to the respective volumes. The separated liquid may be used as a fertiliser, frequently on the farm of origin and the bulky fibrous component can be composted or used as an organic soil conditioner.

Anaerobic Digestion in some European Countries (Bioexell, 2005)

Austria
In Austria the number of agricultural plants has increased from 119 (2003), 171 (2004), to 191 (2005). A further 23 plants are being planned. The Austrian Agricultural Chamber (2003) expects 175 new biogas plants, each about 300 kW electrical power, by 2009. The main driver for this increase has been supporting Bioenergy legislation (Ökostromgesetz BGBl. I Nr. 149/2002) that has given rise to favourable economics. Energy crop digestion plants receive guaranteed fixed electricity tariffs (for 13 years), ranging between €0.165 (<100 kW), €0.145 (100-500 kW), €0.125 (500-1,000 kW) and €0.123 (>1,000 kW) electrical power. In order to receive these tariffs, only energy crops and selected agricultural by-products (e.g. crop residues, straw, residual feed, manure, stomach contents) are allowed.

Denmark
Whilst Denmark leads Europe on AD issues, uncertain electricity sale prices has led to a period of stagnation in AD development. More recently, the Danish Parliament has targeted an increase in the biogas sector from the existing 3 PJ per year up to 8 PJ per year. By offering a price guarantee for the electricity produced on biogas of €0.079 for new plants, it is expected that about 20 new biogas plants will be established. This price guarantee will be reduced to €0.053 after ten years. Reaching the 8 PJ target will depend on positive acceptance by

the local communities and finding the most suitable locations for the biogas plants. Examples form Denmark of a small on-farm and a centralised AD plant are shown in figures 20 and 21.

Interest in slurry separation has increased due to a change in law that allows farmers who separate slurry to increase their number of livestock units without having to increase spread land. Whilst separation can be independent of AD, trials have shown that it is easier to separate digested slurry in a decanter centrifuge than untreated slurry. Several separator companies (Dansk Biogas, Green Farm Energy, Bioscan) have AD as an integral part of their treatment plant concept. If separation prior to digestion is used, the volume of the biomass that is transported to the AD is reduced, thus increasing the capacity of the biogas plant. At least one plant is working with this concept at present.

Germany
In Germany, the Renewable Energy Sources Act (EEG) 2000 and 2004 requires electricity grid operators not only to pay a specified price for electricity, but also to give priority to the purchase of electricity from solar energy, hydropower, wind power, geothermal power and biomass. The price offered for the electricity produced is based on production costs. Investors are guaranteed fixed rates for their electricity sales for a 20-year period. This guarantee is an important factor when securing finance for projects. There has been a considerable increase in the number of on-farm AD plants in recent years with over 2,500 currently in operation. The Federal Government aims to double the share of renewables in the national energy supply to 4.2% and the share in gross electricity consumption to 12.5% by 2010. Currently the share of electricity from biogas is less then 3%. The price support for electricity derived from bioenergy has been fixed to ensure that the real costs of production are covered. Because production costs of different bioenergy technologies differ widely, support rates are varied accordingly. For new plants, the price support for electricity is lowered by 1.5% each year starting in 2005. The base compensation fee for biogas plants varies from €0.084 - €0.115 per kW electric depending on size of the plant. This mechanism should ensure a mix of renewable energies and lowering of production costs through improvements in technology.

Greece
In Greece, there is significant potential for AD. However to date there has been limited uptake. Legislation and forthcoming deregulation of energy markets will help ensure future developments [e.g. Law 2244/1994 "Regulation of power generation issues from renewable energy sources and conventional fuels and other provisions; Law 2773/1999 for the liberalisation of the electricity market; Law 2941/2001 "Simplification of procedures for establishing companies, licensing Renewable Energy Sources plants; Law 3017/2002 “Ratification of the Kyoto Protocol to the Framework-convention on climate change”; Law 3175/2003 "Exploitation of geothermal potential, district heating and other provisions") financial instruments (The Operational Programme “Competitiveness” (OPC), National Development Law 2601/98)].

Ireland
In Ireland, there is considerable potential for AD. Despite this potential, development of AD is at very early stages. Four on-farm AD plants have been commissioned in the past 10 years, ranging in size from 72-1,350 m^3. In addition, there are 10 sewage treatment plants in operation. Government policy objectives relating to the Nitrates Directive, renewable energy, global warming and slurry storage are seen as significant factors in increasing the role of AD in Ireland. Under the most recent round of the Irish Alternative Energy Requirement (AERVI) competition, 9 AD plants were awarded contracts. Six of these plants are scheduled for commissioning in 2005.

Italy
Over 100 AD plants for livestock slurries were in operation in 2003. Most of these plants are in the north and treat pig slurry. In 1999 there were 5 CAD plants treating a range of substrates (cattle slurry, pig slurry, sewage sludge and agri-industrial waste). An approximate further 120 AD plants used to treat urban waste were in use in 2,000.

United Kingdom
In the UK there were approximately 1,000 AD plants operating in 2004, mainly in the water treatment industry. At least 60 plants were digesting/co-digesting slurry and food waste/industrial residues. Approximately 29 on-farm AD systems were in operation and one CAD system for animal manures and industrial waste. Current regulations, directives and legislation (Landfill Directive, Animal By-products, Nitrates Directive and Renewables Obligation) have created a refreshed interest in AD as a means of helping towards pollution avoidance, sustainable nutrient management and renewable energy production. At least 10 new plants have been built in the last 3 years. Within the UK, a number of issues are being considered e.g. regulation and classification of digestate; plant economics; plant reliability and political and interdepartmental awareness.

Figure 20 Danish centralised Anaerobic Digestion plant (Seth Madsen, 2004)

The Hodsager plant is one of the smallest centralised plants. Its treatment capacity amounts to only 40-45 m³ biomass on a daily basis. The plant also include a wood chip burning facility.

Figure 21 A small Danish on-farm biogas unit (Hjort-Gregerson 1999)

4.2.2 Gasification

Under controlled conditions, characterised by low oxygen supply and high temperatures, most biomass materials can be converted into a gaseous fuel known as producer gas, which consists of carbon monoxide, hydrogen, carbon dioxide, methane and N. This thermo-chemical conversion of solid biomass into gaseous fuel is called biomass gasification. The producer gas so produced has low a calorific value (1000-1200 kcal/Nm^3), but can be burned with a high efficiency and a good degree of control without emitting smoke. Each kilogram of air-dry biomass (10% moisture content) yields about 2.5 Nm^3 of producer gas. In energy terms, the conversion efficiency of the gasification process is in the range of 60%-70%. Figure 22 shows a basic gasification flow schematic.

- Gasification systems are not generally considered to be a reliable technology at present
- However, rapid developments are taking place
- Test unit in USA for gasification of pig manure
- Low emissions
- Energy output in form of hot water and electricity generation
- High quality nutrient rich ash can be used as feed or fertiliser
- Can be medium or large scale

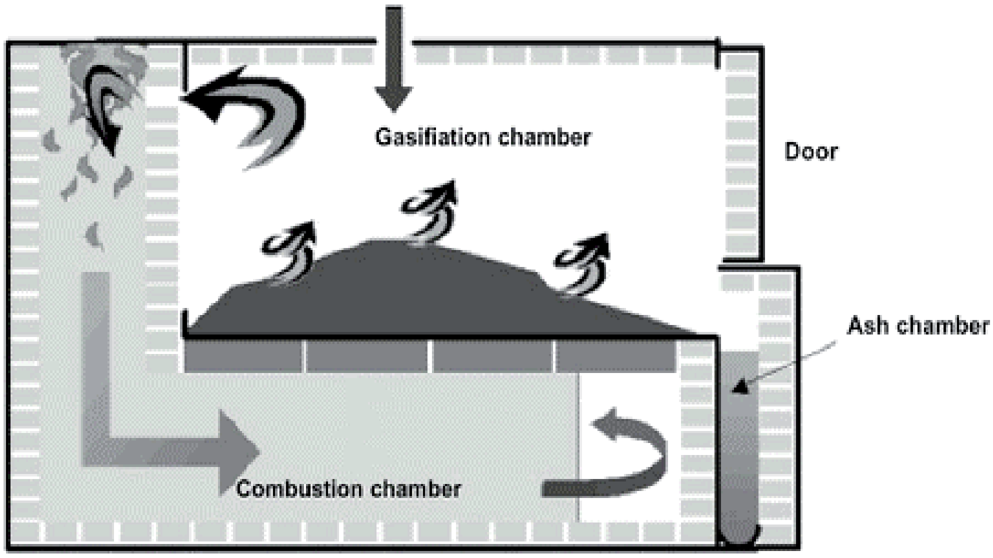


Figure 22 Basic gasification flow chart

Advantages of a small-scale decentralised, farm-based gasification plant over a large-scale centralised combustion plant are summarised by Buffinga and Knoef (2005) as being: -

- Avoidance of transporting manure with the logistic advantages of avoidance of transhipment, smell nuisance of ammonia and danger for infection
- Higher attainable energy efficiencies of a gas engine compared to a steam cycle
- Cleaner technology because of the lower temperatures less pollutants appears which can be removed more easily. By incorporating a novel thermal catalytic tar cracker all ammonia is converted to inert gases
- Cheaper gas cleaning since the gas volume to be cleaned is 3 times less
- Less risk of slag formation due to melting of the minerals in the ash
- Applicable at farm level
- Permits are easier to obtain since MER and participation procedures are not required
- Less financial risks because centralised disposal requires long-term contracts from farmers to supply the manure as well as long-term contracts for the delivery of heat and electricity to the grid
- A renewable feedstock is used as fuel for green energy production, which has a positive impact on the CO_2 emission
- High cost for farmers of centralised manure conversion (increasing disposal costs, sampling costs for MINAS (minerals accounting system), necessary investment in drying equipment to 60% DM with its associated costs

Home Farm Technologies are a Canadian company that have developed an alternative fuel gasification system, the ENERGY REACTOR, that can co-fire animal slurry solids mixed with other biomass materials.
This gasifier system (linked to the ENVIRO-REACTOR described in Section 5) partially combusts the fuel at 1600°F to 2200°F, to form carbon monoxide gas

which powers a generator. Company literature describes the energy reactor as a potential design that eliminates hazardous emissions and is fully automated, allowing 24/7 running, thus producing a constant supply of energy and heat. Figure 23 is a schematic of a complete enviro-reactor/energy-reactor system.

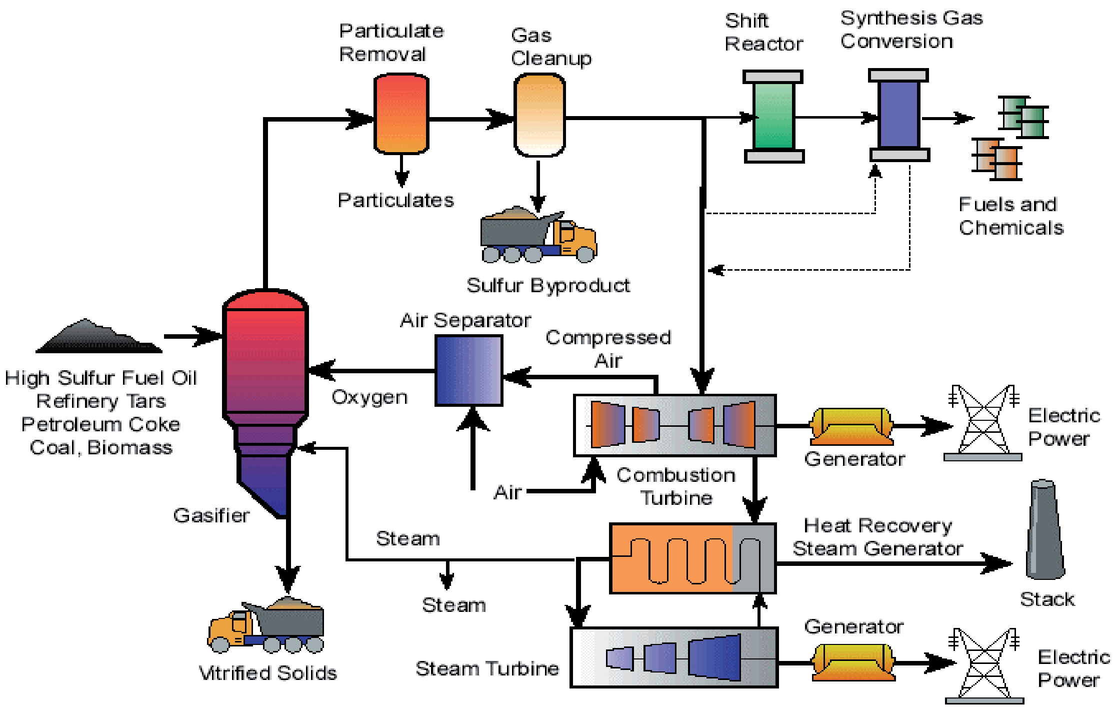


Figure 23 EnviroReactor-Energy reactor slurry cake/biomass processing schematic (http://www.homefarmstech.com/energyreactor/) (Accessed 24 May 2006)

To achieve a 1 MW (24 hour) output requires 21 tonnes of pig manure cake or woodchips, with an energy conversion (biomass to carbon monoxide gas) of 95%-100% and an overall energy efficiency of 85%-90%. Plants less than 1 MW are not considered economically feasible and the system is described as applicable to large industrial facilities.

However, the company have found that North American fossil fuel and electricity prices might now limit the viability of their schemes to plants over 5 MW (~65-75 Mbtu/hr), (Personal Communication, Andy Butler, Engineer, Home Farm Technologies, 2005).

Skøtt (2005) described the advances of the gasification of fuels that are difficult to manage, such as straw and livestock manure. A company in Denmark, Danish Fluid Bed Technology, have successfully gasified these wastes and scaled up from a 50 kW test plant to a 500 kW plant and hope to progress to 5-10 MW capacity. The researchers see potential for gasification of separated manure solids and even AD biogas plant digestate. The ash residues from the gasifier would have potential value as a saleable fertiliser product.

The following web link contains Gasification information sites: -
http://www.crest.org/articles/static/1/1011975339_7.html

4.2.3 Incineration

Dried cake derived from pig and cattle slurries has potential as a low calorific combustion fuel. The Green Circle company (see Section 5) in particular, consider this as an essential feature of their proposed Eco-Park treatment processes.

Dried pig and cattle slurry cake collected from a decanting centrifuge (approximately 25%) separated solid tested at ARINI were found after oven drying to have calorific values ranging from 15.3–19 MJ/kg DM for pig cake and 12.5–18.6 MJ/kg DM for beef cattle cake. These values are of a similar range to those given for willow woodchip.

The UK has three poultry manure incinerators, one of which is the largest biomass fuelled power station in Europe with a throughput of 400,000 tonnes of manure each year. There is concern over toxic emissions. The ash is used as PK fertiliser.

An example of an incineration plant is the Westfield plant at Fife in Scotland that processes poultry litter to produce electricity and fertiliser is shown in Figure 24. The project is a EU demonstration incineration plant built by Abengoa SA of Spain and cost £22 million to design and construct. The plant is the first in the world to utilise a fluidised bed combustor to incinerate poultry litter. Throughput for the plant is 115,000 tonnes/year to produce 10 MW of electricity and phosphate and phosphate rich fertiliser, without producing waste. Grampian foods are the major contract supplier from its meat production division. The plant has a central location for the Scottish poultry industry and is served by an excellent road infrastructure.

Figure 24 Westfield Incineration plant, Fife, Scotland

5 Complete 'turnkey' systems for manure processing

Turnkey plants provide combined processes for the treatment and utilisation of manures, slurries and other farm and related food processing and production waste streams.

Turnkey plants offer a strategic solution for dealing with manure/slurry disposal problems. Professional design, manufacturing, installation and commissioning are combined to leave a facility that will deal adequately with the volumes and types of waste streams that are present. These plants will fully comply with planning, technical, health and safety and environmental legislative requirements, with training and back up for operating staff. There are numerous European and several UK companies offering their particular technologies as solutions for farm and allied animal processing and food producers.

Some companies offer AD facilities exclusively, while others offer complete treatment plants incorporating separation, nutrient and heavy metal removal, pathogen reduction, solid fraction processing (pelletising or composting), fertiliser production, energy conversion (thermal and electrical) and advanced water purification systems. Modules or add-on treatment components are also available from some suppliers and these can often be added to existing facilities to improve efficiency and performance. Treatment plants and systems are also available as farm scale (capable of treating several thousand tonnes of slurry and waste per year) to large industrial scale plants, with processing capacities of 500,000 tonnes per year.

Hjort-Gregerson (1999) lays out the case for centralised biogas plants and the benefits that accrue to both farmers and the wider community. Positive factors listed include: -

- Utilisation of manure
- Sustainable processes
- Food-waste recycling
- Pathogen eradication
- Energy production
- Greenhouse gas reduction

Turn-key plant providers The following descriptions are examples of some suppliers and providers of different types of turn-key treatment plants.

5.1 Xergi- Danish Turn-key Biogas Plant Suppliers

Xergi plants incorporate the latest technology to treat combined waste flows, recovering energy and nutrients for export and financial recovery. Of particular interest is the production of a saleable liquid fertiliser compound, derived from the treatment system and dischargeable water fraction, which meets Danish water quality standards.

Xergi plants range in size from a standardised farm biogas unit, capable of processing approximately 15,000 m^3/year of manure/slurry with additional organic material to boost the energy content of the gas, to large centralised plants capable of treating >300,000 tonnes per year. These plants comprise the following: -

- Homogenisation unit
- Pressurised heat sterilisation of category II animal and household wastes
- AD tank
- Separate post-digestion storage (gas + digestate)
- Biological gas cleaning
- CHP unit (gas engine + boiler)
- Fully automated (control + monitoring systems)

Xergi also offer plants that can include numerous treatment processes for different feedstocks. This enables maximisation of outputs and can allow the system to be set up to deal with multiple feedstocks, which can vary from manure/organic (energy crops) to manure and slaughterhouse waste.

Particular attention is afforded to nutrient separation, which occurs after the AD phase. Degassed biomass (digestate) is passed through a decanting centrifuge to separate the solids/liquids, partitioning >80% P and approximately 25% N in the fibre fraction. The remaining 80% N (90% of which is NH_4-N) and the 20% P is suitable as a liquid fertiliser. A further stage process, an evaporation unit, can be incorporated to produce a liquid fertiliser that is 10-20 times more concentrated than the original influent from the separator. This is described as of a lower strength, but comparable with artificial fertilisers. The water fraction discharged from the evaporator has nutrient contents below Danish drinking water limits, with a small COD (organic acid) and can be spread on land.

The company are currently (since April 2005) building a manure/maize silage powered biogas plant in Germany with a projected throughput of over 300,000 tonnes/year. The working process of the Xergi plant is demonstrated in Figure 25.

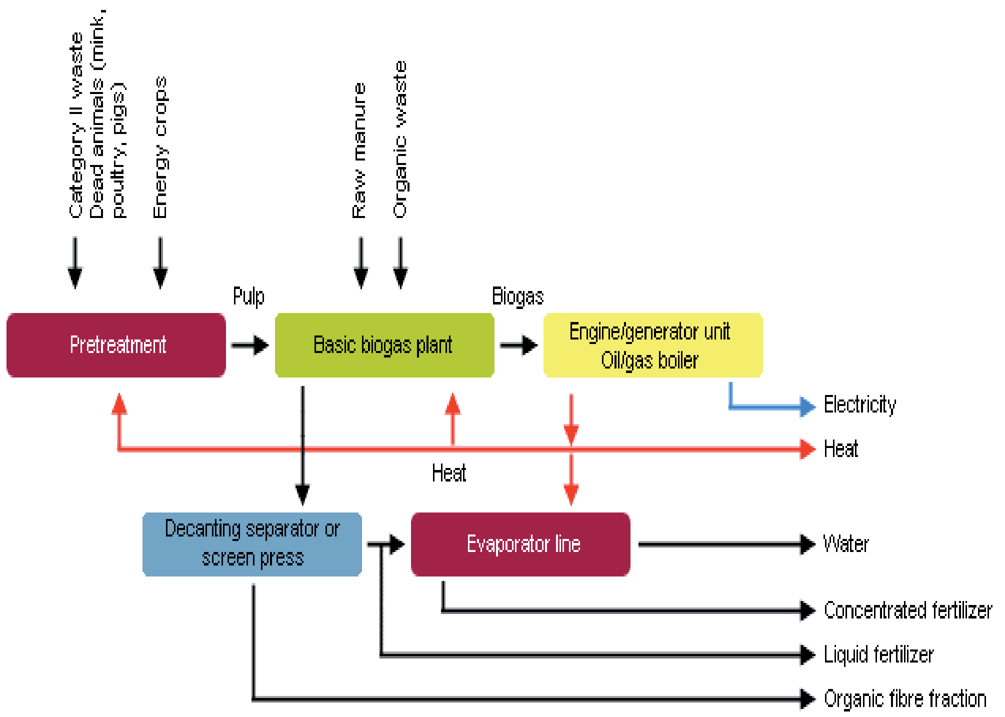


Figure 25 Xergi process flowdiagram (http://ww.xergi.com/)

5.2 Hese Umwelt GmbH

Turnkey biogas plant suppliers; a German company manufacturing and supplying slurry, manure, farm and food produced organic waste treatment.

5.2.1 Description of process

The Hese Umwelt system is heat pasteurised and undergoes a solid/liquid separation phase. The solid fraction passes to an AD and gas (methane) is drawn off to run electricity generators.

5.2.2 Output characteristics

The post-separation liquid fraction contains approximately 1% or less nitrate and as it is pre-pasteurised this can be classed as dirty water and can be used for land irrigation. The solid fraction (~20%) can be bagged as compost or pelletised as a crop fertiliser or if there is no market, burned as an energy source. The digestate liquid undergoes filtration and reverse osmosis to remove >99% of P, which can be bagged and sold as a calcium phosphate fertiliser. Odour problems are claimed to be virtually eradicated in the Hese Umwelt system.

The biogas facilities Hese Umwelt provide normally have a capacity of up to 100,000 m^3/year and are intended as local facilities for farms within a ten mile radius of the plant. They are designed to handle animal manures/slurries and a proportion (~15%) of crop and animal wastes. Plants are equipped with two generators to allow for continuous gas and electricity production during maintenance periods. Hese Umwelt offer fully automated, low maintenance turnkey plants.

5.2.3 Relative economics

Running costs are stated to be approximately 2-2.5 €/m^3 (£1.40-£1.70/m^3), with an installation cost of approximately 6 € (£4.10)/m^3. At this cost, (which was given as a rough estimate) a plant processing 100,000 m^3/year would cost £410,000 to establish.

Since 2001, the German Government has required power companies to buy "renewable" energy (which includes that from biogas) at a 0.12-0.18 € premium. This has allowed the development and installation of HESE type systems as economic options for agricultural waste stream treatment. It was also claimed that centralised schemes are more easily monitored and are run more professionally, compared to small farm systems and are therefore much preferred by authorities.

An example of a Hese Umwelt plant is at Johannesburg, Papenburg, Northern Germany. This is described as an extension of an existing plant, with new components of:-

	Capacity
• 2 disinfection tanks	Each 60 m^3
• 1 buffer tank	22 m^3
• 1 digestion tank	1500 m^3
• CHPP	626 kWe – 863 kWt
• Gas treatment & compression	
• PLC control	

The plant feedstocks are manure, fat and oil wastes with an annual capacity of 40,000 t/year and 911 kWe + 1299 kWt installed power by 2002.

A newly commissioned Hese Umwelt biogas plant in Leicester, England, is now operational and takes approximately 60,000 tonnes/year of agricultural and municipal organic waste. Figure 26 shows a Hese Umwelt Biogas plant.

Figure 26 Hese Umwelt Biogas plant http://www.hese-umwelt.de

5.3 Green Circle

Eco-Park concept, where a centralised service driven, combined waste treatment and energy generation facility is located in an industrial vicinity.

Green Circle presented a proposal for a custom designed Eco-Park development based on agricultural and municipal waste treatment and disposal. Eco Parks are designed to be commercially service driven integrated facilities that generate energy and fuel, recover nutrients and produce organic fertilisers as by-products. The company have stated that they have already established the following sources of capital funding:-

- Interreg III grants for fertiliser production
- Invest Northern Ireland grant for demonstration technology plant processing 50,000 tonnes of waste per annum
- Application to the EU for organic fertiliser permit

Green circle expressed a preference for deliverable waste in the form of a dry cake (25% DM) as opposed to a liquid waste, with the application of a gate fee. However, the cost of gate fees may be offset by previous on-farm separation. The process involves the use of following technologies: -

- Homogenisation and sterilisation of waste
- Anaerobic digestion and biogas production
- Production of organic fertiliser
- Gasification for combined heat and power
- Production of dried organic material as a solid fuel
- Production of dischargeable water

The company suggested the potential for the supply and production of organic fertiliser to the Middle Eastern market.

5.4 BHP Systems

Turnkey plant providers - A description of several schemes they have been involved in as process design engineers, especially in the chemical aspect of waste treatment systems:

Silverhill Foods

Scheme designed to treat 70,000 tonnes of slurry/year at approximately 3% solids with slurry de-watering, followed by high rate anaerobic digestion of the liquid fraction. This produces gas for a combined heat and power unit (CHP). The factory utilises electrical power and heat is used to dry and (de-water) sludge and any liquids remaining are polished by aerobic digestion before discharge. BHP was unable to clarify how the final liquid could be discharged to a river system under current legislation.

S.A. Foods

Approximately 80 tonnes of wet waste/week and 900 m^3 of washing and processing water. Scheme was designed to reduce solid waste disposal costs in excess of £360,000/year and wastewater discharge fees in excess of £240,000/year.

Stevensons Pork, Cullybackey

A combined heat and power system designed to deal with wastewater consisting of: -

1. BHP Micro-DAF solid removal unit
2. Twin M60 module to reduce COD by up to 85%
3. Biogas burner

The BHP representatives have stated that they design digestion systems that work better than crude farm digesters, which they claim are inefficient and unreliable, principally because high operating temperatures have to be maintained and ammonia levels greater than 3 g/l stop methane production. BHP systems control/reduce ammonia levels by oxygenation or accretion with zeolite. They also use digestion bacteria that operate at lower temperatures (approximately 38^{O}C) and convert digestate to gas in less than an hour compared to a 12-hour period in a normal system.

BHP systems also claimed to be designed to handle very different substrates without modification or homogenisation, a very unusual feature compared to most digesters. The BHP representatives stated that many options are available for N and P removal but that component is determined by what the client is willing to pay to meet a required standard.

A flow diagram of proposed BHP solution for Cookstown waste stream with a yearly volume of 154,000 tonnes of slurry animal and food wastes is demonstrated in Figure 27.

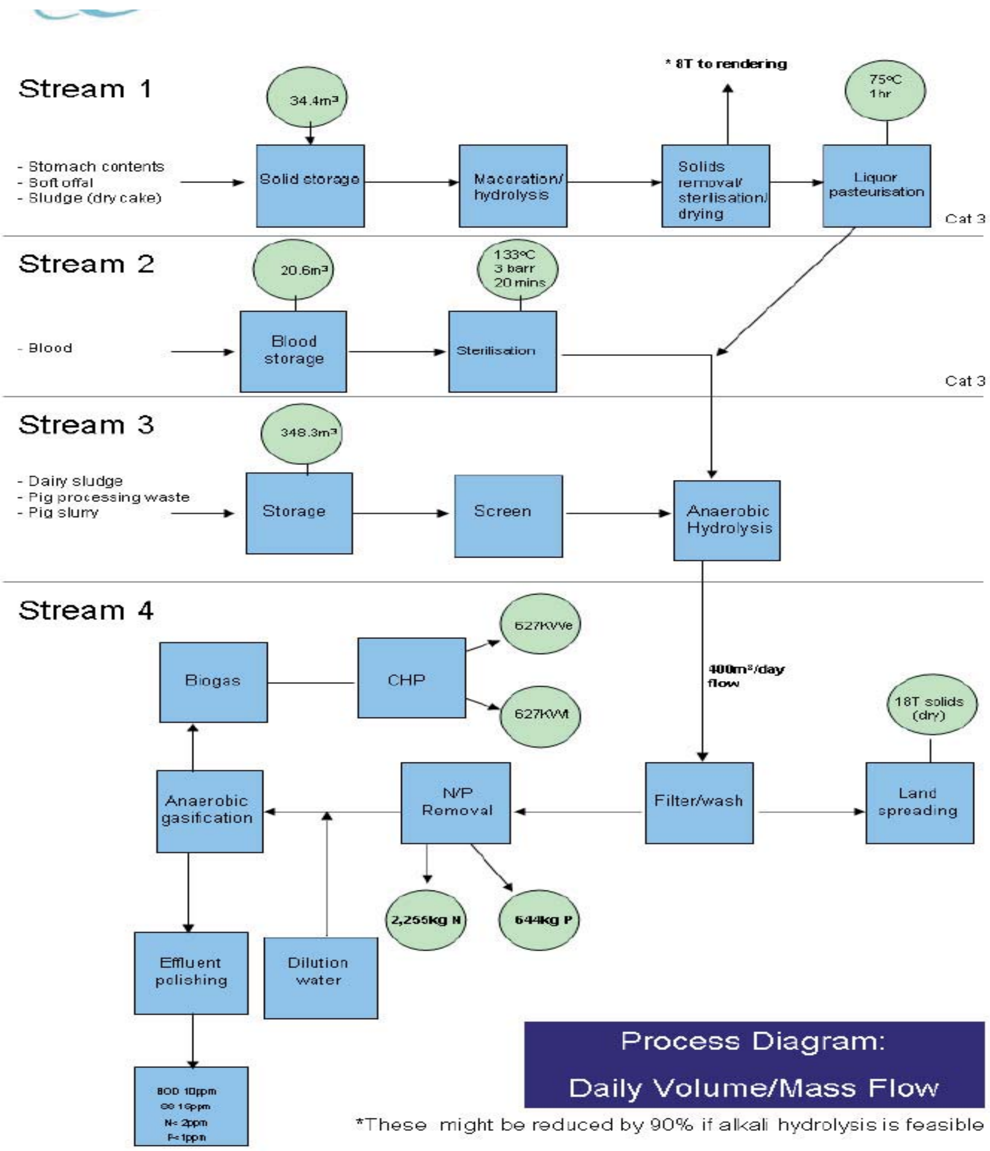


Figure 27 BHP flow diagram for Cookstown waste-stream
http://www.bhp-systems.co.uk/

5.5 Greenfinch Ltd.

An English company that specialise in provision of Anaerobic digestion facilities with 20 years experience in sewage processing, the company is currently involved in an experimental agricultural/ municipal waste AD scheme in Shropshire. They have also been involved with the Scottish Executive in supplying and installing seven AD plants on Scottish farms, to assess the impact such plants might have on reducing nutrient enrichment and pollution of water, caused by manure and slurry. Information supplied by Greenfinch indicates that these plants can process 5000 t/yr of bio-waste through a system of: -

- Homogenisation of feedstock
- Pasteurisation (1 hour @ 70°C)
- Anaerobic digestion

Outputs from the system (processing 5000 tonnes/year) include: -

- 500 tonnes solid biofertiliser
- 3600 tonnes liquid fertiliser
- 900 tonnes biogas
- 1,400 MW hours/year surplus electricity
- 2,000 MW hours surplus heat

A schematic of a farm scale biogas plant by Greenfinch, typical of similar sized facilities installed at several UK locations is shown in Figure 28.

Figure 28 Schematic of Greenfinch plant http://www.greenfinch.co.uk/ Greenfinch Ltd. (2005). Business Park, Coder Road, Ludlow, Shropshire, SY8 1XE. Tel; 01584 877687.

5.6 Landhandels-und Recycling Zentrum (LRZ)

This is a German company who design, assemble and operate large biogas plants, which are designed to run continuously (and remotely, if desired). Described in company literature as an “all eating universal plant”, the treatment modules include waste sanitation, an anaerobic reactor, heavy metal remover, filter press and bio-filtrate treatment, biogas conditioning and block type thermal power station. End products include heat and power and an organic N, P, K, Mg, S, Ca compound fertiliser, which is marketed as BIONAT. Low BOD water is also produced as an end product. Reactors can be supplied with volume capacities ranging from 300–6000 m^3, and biogas output are listed as 1.1 m^3/kg organic DM. Schematic illustrations of some of the LRZ plant processes are demonstrated in Figures 29–30.

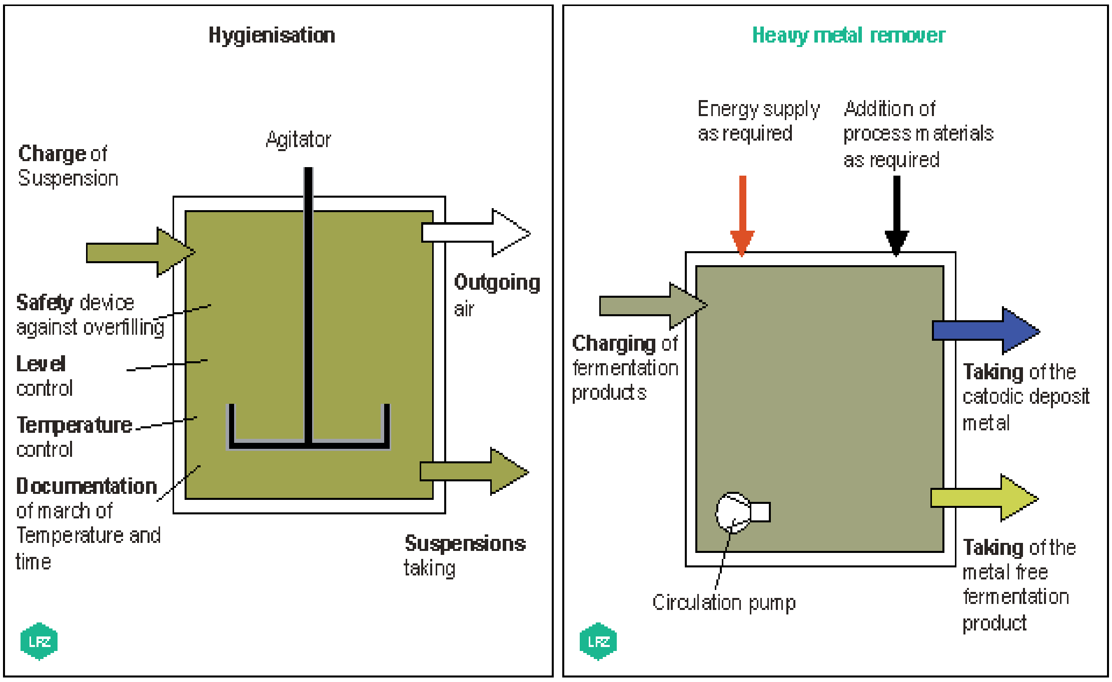


Figure 29 Schematic of LRZ hygienisation and heavy metal removal processes Landhandels-und Recycling

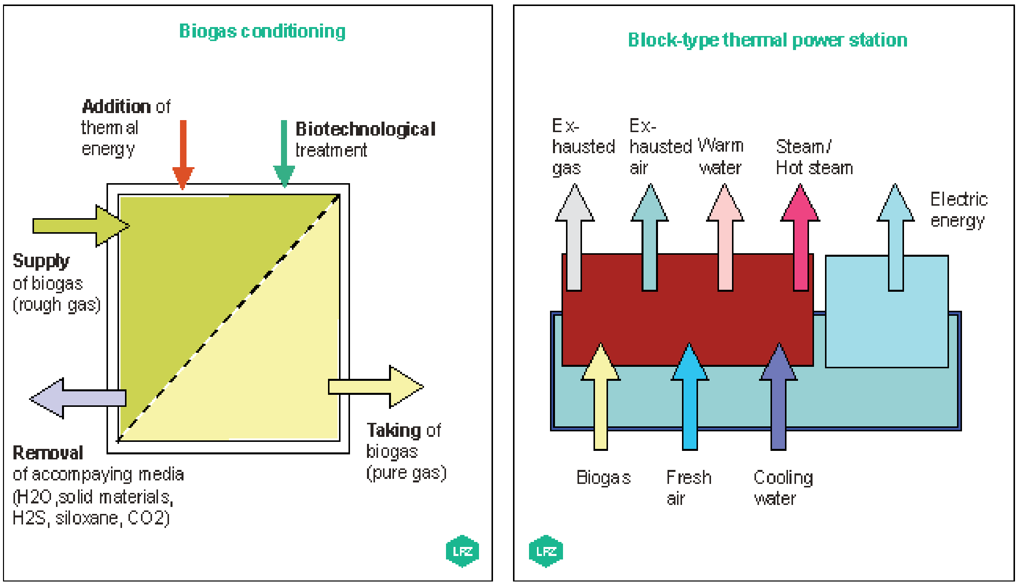


Figure 30 Schematics of LRZ Biogas conditioning and CHP processes. Landhandels-und Recycling Zentrum (LRZ), http://www.lrz-neukirchen.de/englisch/haupt-en.html

5.7 Biogas NORD

A German company that manufactures and supplies slurry treatment plants (farm scale and centralised) with technology based on their flow storage method.

Raw slurry is heat sanitised before being passed through two (and possibly a third) fermentation tanks. These are cylindrical, upright vessels made of reinforced concrete and incorporating heating pipes within both the walls and floor, with insulated, non-corroding trapezoid panels fixed to the exterior. The second tank is covered with a gas retaining membrane that is covered by a second, weather protective membrane.

Hydrogen sulphide is removed from the biogas in a desulphurisation unit and gas flows to a gas-powered generator. Power is utilised within the plant and exported for income. A schematic representation of the Biogas Nord technology is presented in Figure 31.

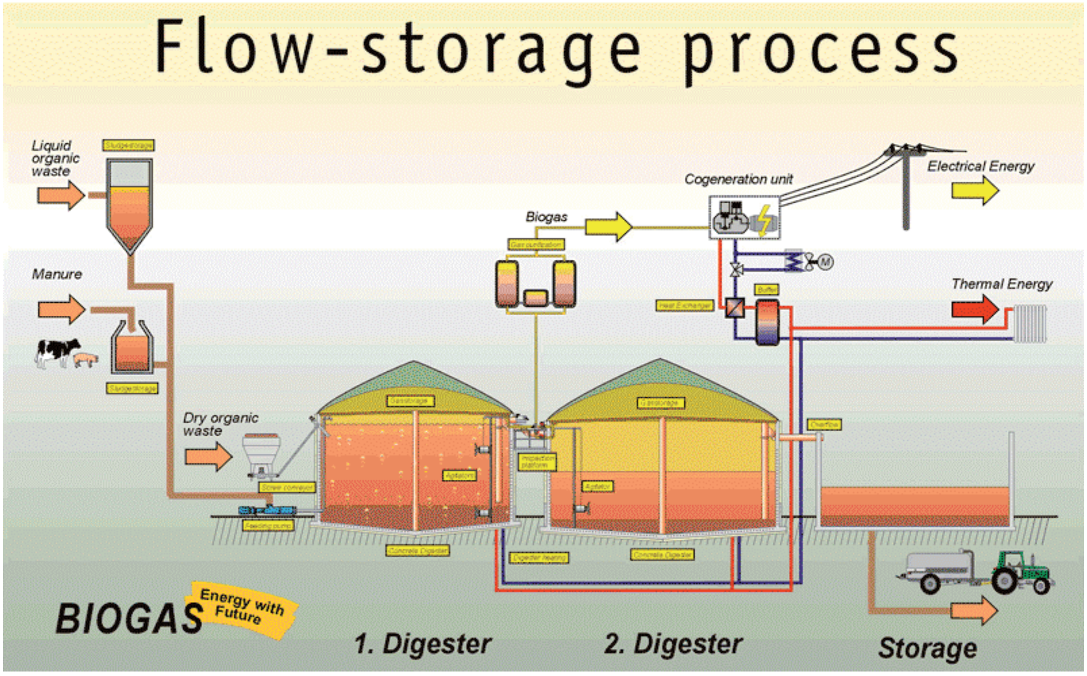


Figure 31 Biogas Nord flow chart http://www.biogas-nord.de/docs/home.html

5.8 Selco-Ecopurin

Turnkey slurry treatment technology

The technology employed by Selco uses a novel combination of chemicals, screens, membranes and filters to effect a very high level of solid removal, with further enhanced methods available to remove nutrients from the liquid fraction. Martinez-Almela and Marza (2005) described the Selco system (Figure 32) using polyacrilamyde (PAM) polymer to enhance solids removal from liquid manure. Firstly the polymer is mixed with water and added to the wastewater/slurry. Following this a self-cleaning rotating screen with 0.8 mm openings, separates the flocculated solids. Further dewatering occurs in a filter press before a final separation of residual solids is effected in a dissolved air flotation tank.

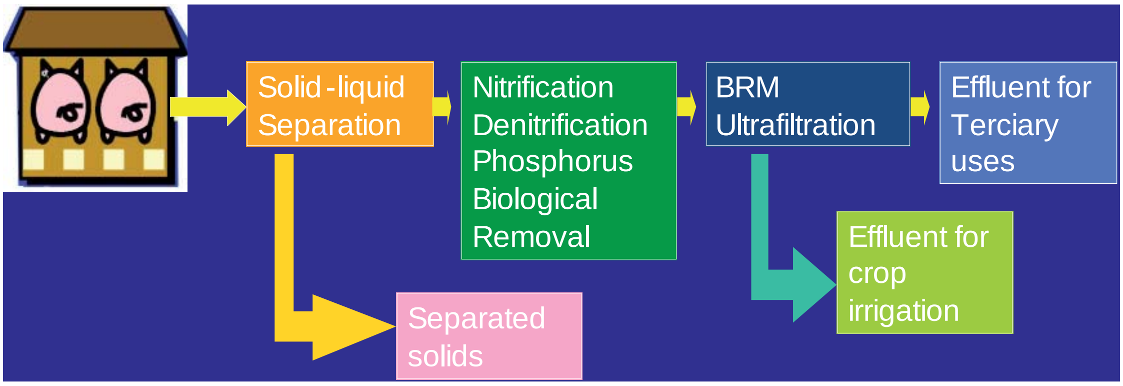


Figure 32 Selco-Ecopurin system (Martinez-Almela and Marza, 2005) These slurry processing modules are available separately or as complete plants, with capacities ranging from 2 m^3 to >10 m^3/hour.

Selco also offer a mobile version of this plant that can be drawn from farm to farm on a flatbed lorry trailer. This unit has a throughput capacity of 2-7 m^3/hour. Capital cost is currently £153,050 and running costs are quoted as £0.95/m^3, (Personal Communication, Miriam Lorenzo Navarro, Selco). A photograph of a Selco mobile unit is shown in Figure 33.

Figure 33 Selco-Ecopurin mobile option (http://www.selco.net)

Advanced treatments of separated liquid to remove soluble N and P are available as add-ons to the main process. Nitrification-denitrification using polymer immobilised nitrifying bacteria (PINBT) and membrane bioreactors can result in 97-99% N removal efficiency. Soluble P can be removed by any of three different systems. The first option is a piston flow, biological P and N elimination two-phase anoxic reactor (run parallel). The second system requires the addition of organic aluminium or iron salts (Al, Fe) to the liquid to precipitate the P as orthophosphate. Option three is a United Sates Department of Agriculture-Agricultural Research Service (USDA-ARS) protocol (Figure 34) using hydrated lime and polymers to precipitate P as calcium phosphate (Vanotti *et al*., 2005).

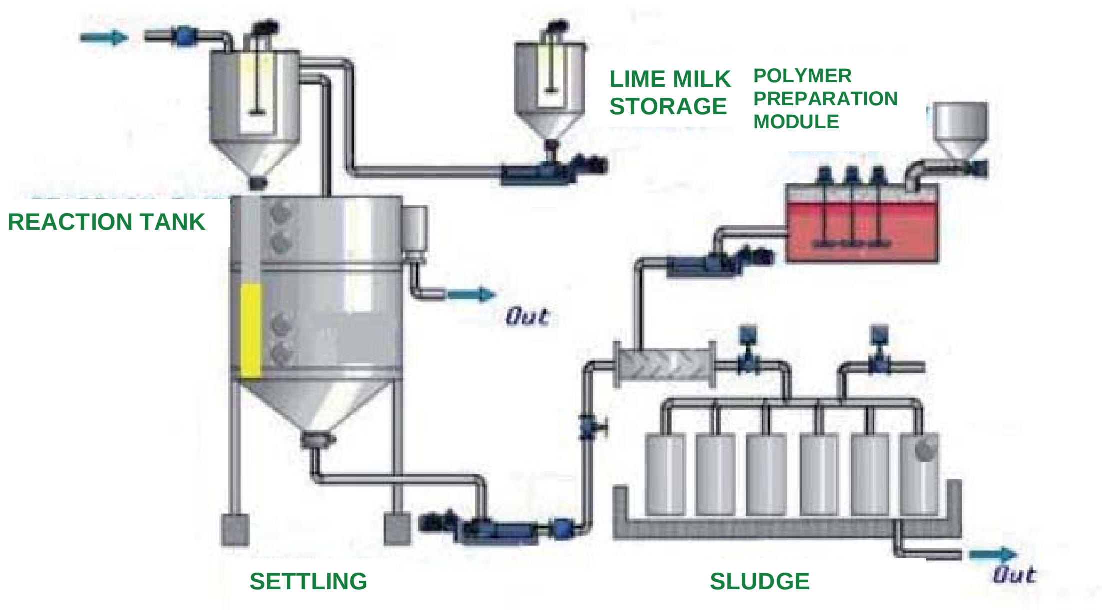


Figure 34 USDA-ARS Phosphate precipitation method (http://www.selco.net)

5.9 Tao™ Systems

Tao™ systems, Korea offer a pig slurry processing turnkey plant with a system that utilises phototropic bacteria in what is described as an auto thermal, thermophilic, aerobic digester (in contrast with most other digesters which are anaerobic) that does not produce Biogas. Operating at 50-60°C, these effect pathogen destruction and odour elimination and have a very short hydraulic resonance time (HRT) of only 4 days (whereas anaerobic HRT is ~20-40 days). A schematic diagram of the system is shown in Figure 35.

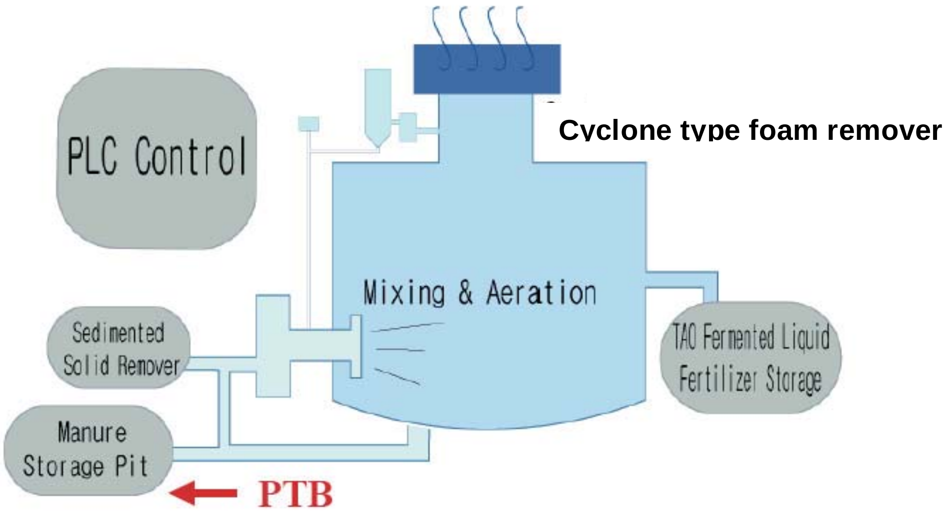


Figure 35 Tao™ System

The TAO™ plants have a range of capacities from 3-9 tonnes/day (for 600-1800 pigs). Biogas is not produced and the by-products from the plant are a concentrated liquid fertiliser and a dry organic humus, suitable as a soil conditioner. Over 100 TAO plants have been installed and a collage of some is shown in Figure 36.

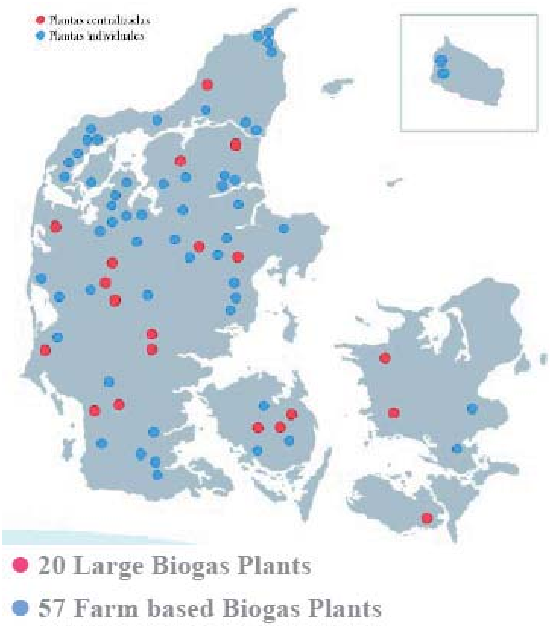
Figure 36 TAO™ systems in operation

***NOTE:** During revision of this document (25 May 2006), the web link for TAO^{TM} systems had become unavailable. However, a reference document describing the system is available (Myung-Gyu Lee and Gi-Cheol Cha, 2003).*

5.10 Review of on-farm, centralised biogas & manure processing plants

A number of companies can provide partial or complete manure processing systems. Some companies provide service that includes from feasibility studies, planning application, design, installation and commissioning of 'turn-key' plants. Manure processing plants can have throughput capacities ranging from 5,000-500,000 tonnes of manure/wastes per year (Table 18). Smaller units may be suitable for on-farm situations, while large units are normally centralised and process manure and organic wastes from a range of sources.

By 2002, there were over 20 large centralised biogas plants in operation in Denmark processing 1.48 million m^3/year. Location and types of materials and volumes processed in these 20 large plants and 57 farm-scale plants processing 300,00 m^3/year are shown in the map of Denmark and accompanying text (Figure 37).



m^3 biomass processed in large plants (2002)

	m^3 (million)
Animal manure	1.105
Organic waste	0.375
Total	1.480
Farm plants	0.300
Combined Total	1.780

Figure 37 Biogas plants in operation in Denmark in 2002 (Seth Madsen, 2004)

Hjort-Gregerson (1999) shows that incentivised schemes, subsidised with direct or indirect government funding are essential to ensure their economic viability (Table 23) and conclude that this is evident in Denmark, where over 20 large centralised plants are now operating and this trend is also evident in other European countries. A cost comparison with other waste disposal technologies is given in Table 24.

Table 23 Costs and revenues per m³ biomass treated

	DKK*/m³ biomass treated	
	No investment grants	**20% investment grants**
Transport		
- Operating costs	16	16
- Capital costs	4	3
AD biogas production		
- Operating costs	21	21
- Capital costs	26	21
Energy sales	60	60
Gate fees (receiving organic waste)	6	6
Profit	-1	5

*DKK- Danish Kroner Hjort-Gregerson (1999)

Table 24 Waste disposal costs in different technologies in Denmark

	Incineration	**Composting**	**Centralised Biogas plant**
	DKK/tonne	**DKK/tonne**	**DKK/m³***
Treatment costs	200-300	300-400	50-60
Waste deposit tax (1998)	210/260**	-	-

Hjort-Gregerson (1999)

*Note that treatment costs are per m³, which is almost but not quite equal to a per tonne unit; ** Depending on whether it is utilised for combined heat and power production or just for heat

5.10.1 Capital costs and operating costs

Seth Madsen (2004) demonstrated that throughput capacity was relevant for establishment costs of large centralised biogas plants in Denmark (Figures 38 and 39). Capital costs increase with plant size while operating costs decrease. Various suppliers have quoted possible capital and operating costs for establishment of a centralised plant in Northern Ireland (Table 25).

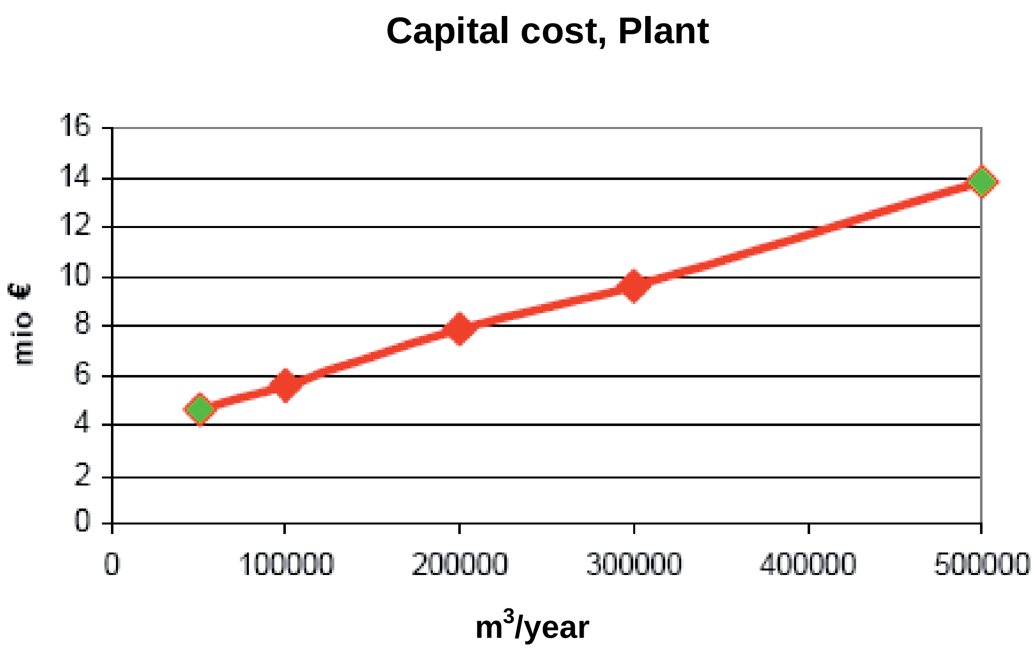


Figure 38 Capital cost vs plant capacity (Seth Madsen, 2004)

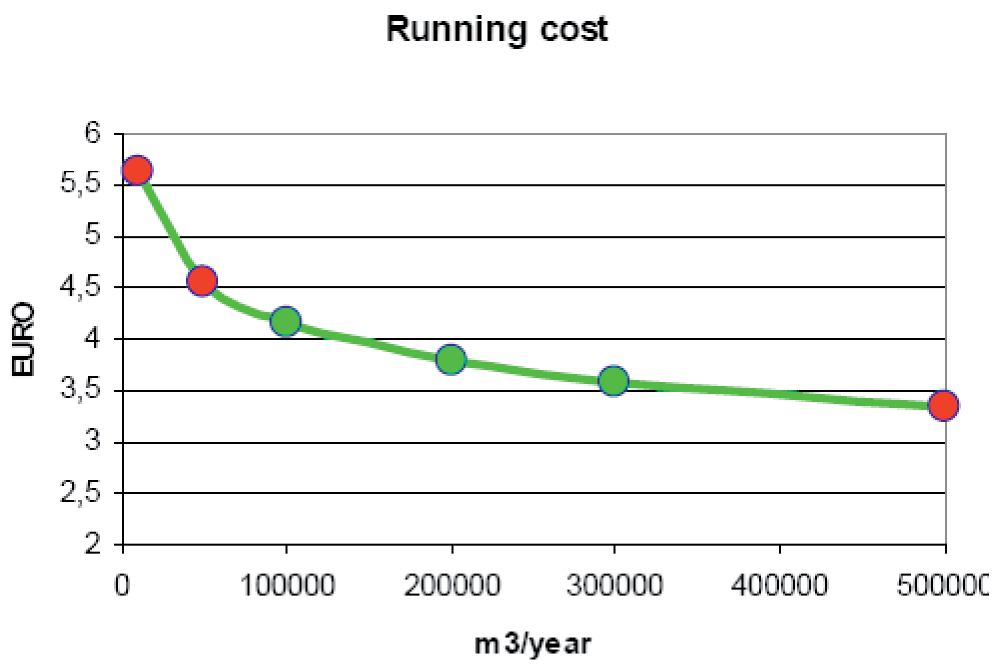


Figure 39 Running costs vs plant capacity (Seth Madsen, 2004)

Table 25 Possible capital and operating costs for provision of turnkey combined heat and power (CHP) biogas plant providers

Supplier	Plant capacity ('000 tonne/year)	Capital cost (£ million)	Operating cost (£/tonne)
Hese-Umwelt	60	1.5-2	2.0
BHP Systems	150	2.5-3	2.0
Selco-Ecopurin	100	1.2	1.4-2.0
Xergi	50–500	1.2-4	N/A
Krieg & Fisher	5-100	N/A	N/A
Biogas Nord	5-50	N/A	N/A

N/A=Not Available

While Denmark may lead the field in large centralised biogas plant operations, other countries have ventured into the technology. Nordberg and Edström (2002) reported on seven plants in Sweden that run successfully on a combination of manure (slurry) and slaughterhouse waste (one plant also utilises restaurant waste). An example is the Linkoping Biogas AP Company, a joint venture between a wastewater treatment company and two agricultural partners, Swedish Meats and LRF (Swedish Farmers Association). Some €8.7 million was invested, which included a government subsidy of 11.5% (~€1.7 million). Originally, the feedstock was mostly animal manure (~51% in 1998) but by 2001 low risk animal by-products formed 72% of this and other higher energy wastes such as food and animal processing wastes reduced the slurry intake to <6%. The high-energy wastes are used to produce higher volumes and calorific value of gas and the output is refined to provide vehicle fuel for 64 city buses and 125 other vehicles, which includes the municipal refuse fleet. Table 26 shows the relative methane conversion values of the waste factors used in the plant.

Table 26 Methane yield from various materials

Waste Fraction	Methane yield m^3/tonne
Animal by-products (pasteurised)	225
Slaughterhouse waste mixture	160
Sorted household waste	130
Animal by-products (non-pasteurised)	56
Manure	13

Nordberg (2003)

This method of utilising the gas output is viewed in Sweden as offering a higher net income than electricity generation. Also recently launched in the Linkoping area was Sweden's first train to run on biogas. The following web link provides updated information on the Linkoping Biogas schemes, http://www.energie-cites.org/db/linkoping_113_en.pdf

The Netherlands had 55 biogas plants by 2004, 45 of these for municipal sludge and 8 processing slurry/manure, with 7 on-farm plants and one large plant with a capacity of 22,000 tonnes/year. A new plant designed to handle 10,000 tonnes/year of category II and III animal waste is under construction. The digestate from this plant will be used for composting. Another 80 plants (of varying size) are planned for manure and organic waste processing (http://www.novaenergie.ch/iea-bioenergy-task37/Dokumente/07%20Biogas%20in%20The%20Netherlands.pdf). Dutch attempts to deal with the excessive manure problems in the intensive agricultural sector are described by the Van Ruiten Advicebureau B. V. (1998) as having begun in the early 1980's, when the government encouraged the establishment of large processing facilities to remove 25 million kg P_2O_5 (~6 million tonnes of pig manure) from the farms. However, many of these plants failed, including the Promest factory, which was capable of processing 500,000 tonnes per annum. The reasons for these failures were given as:-

- High cost compared to land spreading
- Insufficient sector support
- End product market problems
- EU prohibition of subsidies and long distance haulage
- Poor plant location
- Licensing problems

Subsequently, this cooled attitudes in the Netherlands towards large centralised plants and the tendency latterly has been to consider farm level solutions for manure problems.

Germany has also witnessed a surge in interest and development of Turnkey Biogas plants. These however are mostly small-scale, on-farm turnkey plants that are farmer operated and often supplied from local companies, who tailor the plants to the needs of each individual farm. Regulation ensures construction, performance, and operating standards and adherence to health and safety legislation. In a study of opportunities for nutrient recovery from animal manures, Morgenrath (2000) concluded that small-scale on-farm plants offer a partial solution to the manure problem and technological advances in management and operational systems make it easier for farmers to consider installing turnkey plants. Kottner (2001) reported that over 1250 plants were installed and running in Germany and that the passing of energy laws guaranteeing renewable electricity price advantages for 20 years and 30% building subsidy underpinned this.

5.10.2 Other types of turnkey plants

Other types of turnkey plants have also been developed in different countries and these often incorporate new technologies or modifications of existing ones, which accentuate performance and efficiency. Selco–Ecopurin and Tao Systems (described earlier in Section 5) are basically separation and nutrient partitioning processes designed to function efficiently without energy utilisation as an end result (though Selco do offer the option of AD as a “bolt on” addition). These are both described as part-biological systems as the Selco-Ecopurin treatment process employs Bioreactor Membranes (BRM) and nitrification/denitrification phases, while the TAO™ system uses phototropic bacteria (PTB) for their autothermal thermophilic anaerobic digestion module. The fibre and liquid fractions are useable end products that can be further refined if required for specific end use. Both these companies have significant numbers of operating plants (Section 5 refers) which would indicate that where they are in use they can meet specified performance criteria.

Installation costs are difficult to access accurately, but figures provided by Selco seem to indicate that for the hypothetical 50 m^3/day plant, costs for each individual module would be as shown in Table 27.

Table 27 Cost of individual modules of Selco system

System component	Cost (€)	Cost (£)
Solid/liquid (5 m^3/hour)	226,808	154,759
Nutrient reduction (2 m^3/hour)	185,254	126,124
P-removal	26,222	17,72
Anaerobic digestion	297,467	202,480
Composting	734,840	504,220

Costs quoted in the TAO™ website are $120,000 for the largest plant with operating and management costs of ~$19,000 per annum. Depending on the market price for the liquid fertiliser, there is potential for the plants to operate at a profit, as the data in Table 28 show.

Table 28 Potential fertiliser income and profitability of TAO™ plants

Fertiliser (1900 tonnes/year) sale price	Income from fertiliser sales ($)	Profit after O&M costs ($18,990) deducted
$5/tonne	9,500	-9490
$19/tonne	36,100	17,110

(TAO™ Systems)

6 Novel technology solutions

In this section, technologies that are under development but not yet in commercial use for the treatment of animal manures are reviewed. Some of these technologies may be in commercial use in other industries, but not yet in Agriculture.

6.1 EnviroReactor

EnviroReactor is a patented slurry separation system developed by Homefarms Technologies, Inc. Canada. The system is described as an in line flocculation of organic residues in the slurry, which is pre-treated with a Homefarm Catalyst™, a proprietary chemical formulation that is injected in controlled doses to the reactor with flocculation occurring immediately.

This treated liquid flows to a wedgewire screen separator, with solids passing to a dewaterer and liquids passing to a filtering unit. The solids can be used for composting or land spreading or to a Homefarms Gasifier unit (described in section 4) and the effluent water is used for barn flushing or land spreading.

The Homefarm Catalyst™ is described as a 100% natural product, which enhances the performance of normal decomposing microorganisms, reducing emissions and odours. The EnviroReactor is capable of a throughput of 20,000 gallons (US) of slurry in 3 hours and can run 24 hours non-stop, processing approximately 170,000 gallons (~643,450 l). No information was available for any nutrient partitioning effect with this system, but processed solids (70% moisture) from a test site (Green Acres farm with a 660 farrow to finish pig unit) have listed fertiliser values of 0.52: 0.37: 015, N:P:K.
http://www.homefarmstech.com/enviroreactor/

6.2 Poultry Litter Charring

Poultry manure can be converted into granules and powder that are capable of absorbing pollutants, such as metals from wastewaters and excess nutrients for agricultural effluents. Lima and Marshall, from the Southern Regional Research Centre (SRRC), New Orleans, Louisiana, have developed a process of charring and activating poultry litter by using steam to induce porosity. After initial work, they discovered that a less costly method would involve simply charring the litter to 700°C and that would lend the material a negative charge, enabling it to attract the positive ions from metals such as zinc and cadmium. The researchers concluded that P is the element present in the litter that has the capacity for absorption of the metal ions. The only other components capable of similar results are synthetic ion-exchange resins, which are expensive compared to poultry litter. This process could have potential for use in the carbon-manufacturing industry and Lima and Marshall have applied for a patent for their project and also hope to attract commercial partners.
(http://www.ars.usda.gov/is/AR/archive/jul05/char0705.htm)

6.3 Conversion of biomass to active char

Biomass Energy Services and Technology (BEST) Pty Ltd., an Australian company that have developed a low temperature thermal “torrefaction” process for converting a range of green-waste, cotton trash and chicken litter to an active char. During trial runs the feedstock materials were mixed and stirred by a paddle mechanism and heated in a drum by LPG and volatile gases reacting from the process, to 400 and 600°C with a controlled heating rate for 2 hours.

Results indicated that the char produced during the process had high NPK content, useful trace elements, and a high carbon content. The company claim that trials by specialist fertiliser and potting mix manufacturers found that char applied with standard fertiliser produced significant improvements in yields. It was also reported that char, chemical fertiliser and organic matter combinations increased sorghum yield from 0.3 t**onnes**/ha to 1.2 t/ha. A prototype 300 kg/**hour** demonstration processing unit has been built and operated and a skid mounted (portable) unit is available. Costs quoted for a 1/tonne/**hour** unit are $Aus 500,000 (£210,500). Figure 40 gives a schematic illustration of the Biomass Energy Services and Technology (BEST) char production system. Figure 41 provides a photograph of a BEST portable unit.

Contact:
Biomass Energy Services and Technology (BEST) Pty Ltd, 5 Kenneth Avenue, Saratoga, NSW 2251, Australia.
Tel; 00 61 2 4340 4911 Fax 00 61 24340 4878
Email: joseph@biomass.com.au

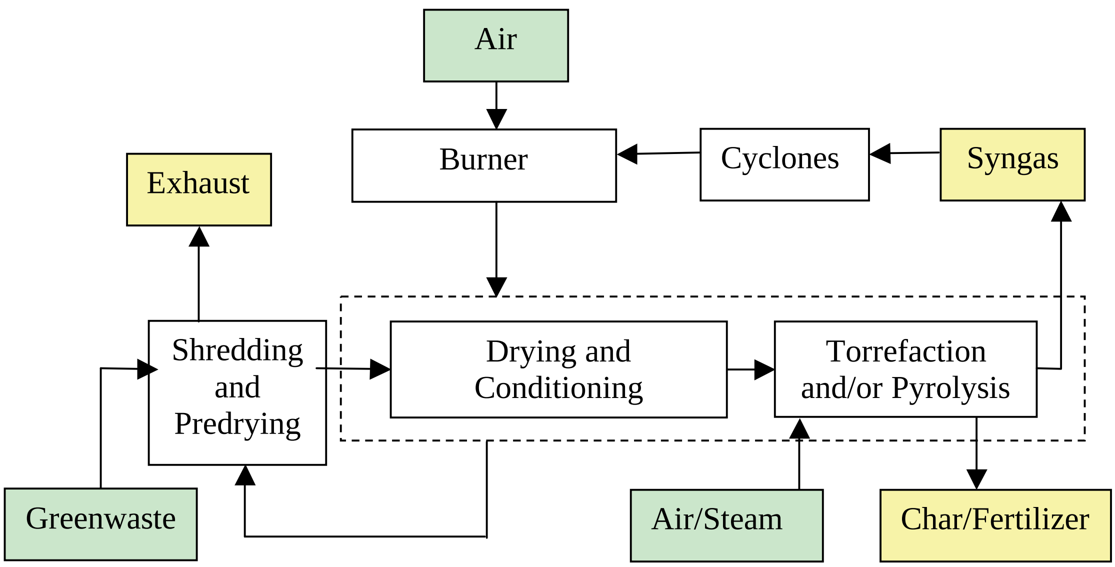


Figure 40 Schematic illustration of BEST process

Figure 41 BEST portable unit installed on a farm in northern North West Australia

Vermiculture

6.4. Nutrient Management Technologies Ltd.

This is a Canadian company that has developed a pig slurry processing technology, the Philmar Treatment System (PTS). This is a three-stage process that includes: -

- Separation of liquids and solids
- Enzymatic removal of pathogens
- Conversion of solids to organic fertiliser by digester worms

The PTS has been operating on an Ontario 98 acre, 2000 sow weaner farm for several years and is claimed to have saved 65% of total costs in that time. The plant consists of a bioreactor, typically 24x8x6 feet, with 3 to 5 separate compartments of aerobic and anaerobic environments. Each has a Bio-cord, which provides a microbe-growing medium but does not interfere with slurry flow and the recirculating air pumps oxygen in the aerobic compartments. After separation, the solid waste fraction is channelled into an organic vermi digester, containing millions of worms that digest the material and excrete castings termed “Vermi-compost”, this is described as an odourless, sanitised, soil loam, excellent as a fertiliser. The liquid fraction is directed to a reactor, to which bacteria are added. These destroy the pathogens, break down any remaining solids and reduce BOD and COD levels that, after several days, this water is clean enough to be used for flushing and washing animal pens.

Exact costs for the plant (consisting of anti-corrosion painted steel and plywood/plastic laminate panels) are not available, but are estimated to range from $60,000 to $250,000 Canadian dollars (£29,000/£120,871) depending on farm size. http://www.nutrientmtl.com/

6.5 Biological nutrient removal - Annamox bacteria

The Anammox process (anaerobic ammonium oxidation) is a method of converting ammonium and nitrite to N gas by the action of planctomycete bacteria such as *Brocadia anammocidans*. The basic reaction is as follows:

$NH_4^+ + NO_2^- = N_2 + 2H_2O$

The process was developed in the 1990's at the Delft University of Technology, and subsequently used by Paques, a company specialising in the purification of wastewater systems and further commercialised by ZHEW, with the installation of an anammox reactor in a plant at Rotterdam. (www.environmental-center.com/articles/article1144 /article1144htm)

This method of N removal from wastewater reduces the amount of carbon by 100% and the amount of oxygen by 50%, leading in a reduction of up to 90% in operational costs and 100% in CO_2 emissions as compared to normal methods of N removal. (www.anammox.com/application.html)

Vanotti *et al.* (2005) enhanced the process with the addition of polymers (polyvinyl chloride) as carrier beads to immobilise and enrich the growth of the bacteria. They have been successful in applying this technology to the treatment of agricultural wastewater, such as pig effluent and removed up to 500 g N/m^3/ day.

6.6 USA Super Soil Systems USA, Inc.

This system includes solids separation at 97% efficiency, N removal using nitrification and denitrification technology, and soluble P removal. The solids are composted and used as organic fertiliser. The liquid is treated to reduce pathogens, nitrogen and phosphorus. The liquid is then recycled back to the houses as flush water. By reducing the pathogens, N, and P in the recycled water, it provides enhanced animal health and a reduced threat to the environment. The excess water from the liquid treatment can be stored in a tank above ground or existing lagoons and utilised for irrigation purposes. Excess water has been treated to ammonia and P concentrations of less than 10 mg/l and BOD at less than 30 mg/l.

The benefits of the system are the elimination of odours, pathogen reduction in flush water, excess water, healthier animals, and solids that can be marketed as organic fertiliser.

Contact Information:
Lewis M. Fetterman, Chairman and CEO
Super Soil Systems. USA, P.O. Box 306 Hickory Grove Road, Clinton, NC 28328
Phone: 910-592-3735. Fax: 910-590-0040

6.7 Supercritical Water Oxidation (SCWO)

Supercritical Water Oxidation (SCWO), also known as Hydrothermal Oxidation, is described as a high efficiency, thermal oxidation process capable of treating a wide range of hazardous and non-hazardous wastes and to be ideal for treating aqueous wastes. The system works by combining dilute organic waste with oxidiser in a sealed vessel and elevating temperature and pressures to >550°C and >221 bar respectively for a 10–15 seconds period. This is sufficient to homogenise the reactants allowing what is described as destruction and removal efficiencies (DRE) of 99.99%. This is a complex chemical process involving elemental gas/liquid phases and nitrates and ammonia can be destroyed/altered by the addition of reducing or oxidising agents. Figure 42 shows a typical SCWO process flow diagram.

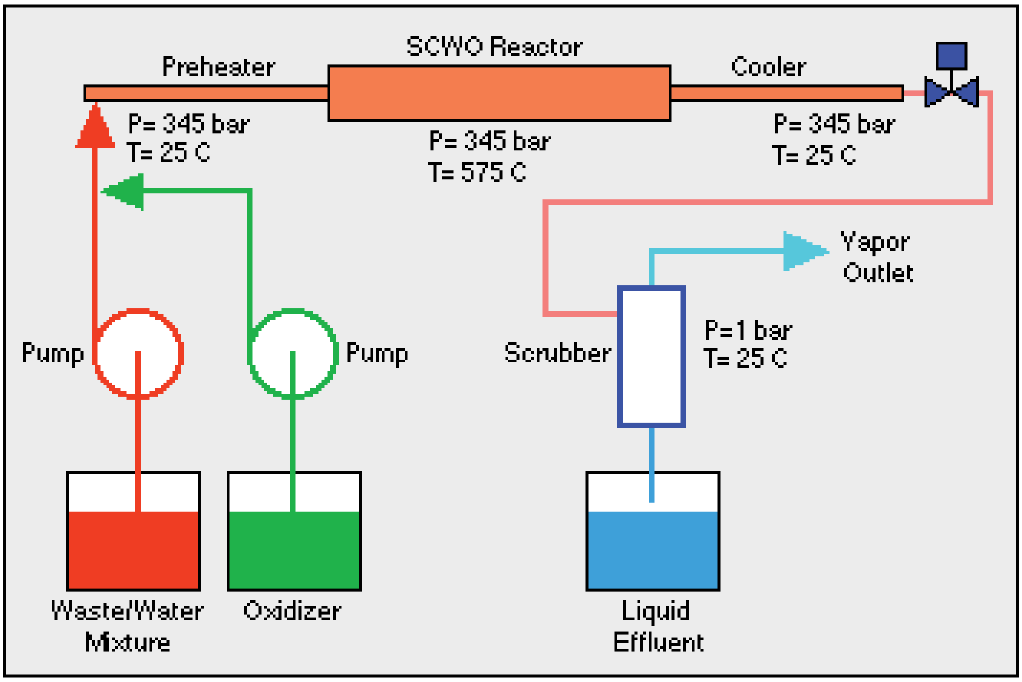


Figure 42 Supercritical Water Oxidation (SCWO) process

After completion of the DRE, cooling and depressurisation of the reaction vessel, the effluent is separated into liquid and gaseous phases. Excess heat from the process can be re-cycled and the processing of raw biomass slurry has the potential to allow development of power generation.
http://www.turbosynthesis.com/

Abeln *et al*. (2001) studied the performance of two bench scale SCWO's under laboratory conditions and concluded that amongst many other findings, results showed: -

- Complete destruction of toxic organic materials
- Oxidation produced carbon dioxide and water
- No nitrogen oxides
- Hetero-atoms were mineralised
- SWCO can be applied to real waste effluents

6.8 Environmentally Superior Technologies

The United States Department of Agriculture (USDA), in an attempt to define and establish an experimental environmentally superior technology (EST) for swine waste treatment, (Vanotti *et al*., 2004), recently undertook EST research. The aim of this work is to develop systems that eliminate the requirement for anaerobic storage lagoons on pig farms (Williams, 2004). After some 100 projects were submitted for scrutiny, 18 were short-listed and eventually two new technologies were chosen for development. Three process modules were incorporated to provide a complete slurry treatment as follows:-

1. Selco-Ecopurin solid/liquid separation module
2. Biogreen N removal module (Hitachi, Japan)
3. Phosphorus Separation module (USDA Agricultural Research Station)

The EST included a biological ammonia-N removal phase, which consisted of a reaction tank containing 12 m^3 of nitrifying bacteria encapsulated in polymer gel pellets, which are permeable to oxygen and ammonia and therefore allow the bacteria to perform nitrification. The pellets form the basis of the Biogreen process, developed by Hitachi Plant Engineering and Construction Company, Tokyo, Japan. Vanotti *et al*. (2005) concluded that results verified the effectiveness of the combined technologies used for the EST.

The EST was established in a large pig-finishing farm (4,400 pigs) in North Carolina by Super Soil Systems, USA. Results from this work are very positive, with very high solid and nutrient removal rates as shown in Table 29. Odour compounds were reduced by 98% and pathogen indicators were reduced to non-detectable levels.

The report concluded that the demonstration of this combination of alternative technologies verifies their consistent performance and that they fully meet the stringent requirements of an EST. On this basis, further innovation and development of these technologies for slurry treatment is to be undertaken.

Table 29 Nutrient, solids and BOD removal efficiency of EST system.

	Removal Rate %
Total Suspended Solids (TSS)	98
Biological Oxygen Demand (BOD)	99
Total Kjeldahl Nitrogen (TKN)	98
Ammonium Nitrate (NH_3)	98
Phosphorus (P)	95

Vanotti *et al* (2005)

6.9 Other new or experimental alternative systems reviewed

Use of dairy manure to produce fibres for production of horticultural pots-USA
http://cris.csrees.usda.gov/cgi-bin/starfinder/0?path=fastlink1.txt&id=anon&pass=&search=AN=0190603&format=WEBFMT7

Growth of plants (Triticale) with high P uptake – INRA- France
http://www.innovations-report.de/html/berichte/agrar_forstwissenschaften/bericht-26609

Use of charred chicken manure to produce pellets to absorb metals from wastewater-USA
http://www.ars.usda.gov/is/AR/archive/jul05/char0705.htm

Use of electrically charged bark and Zeolite to absorb nutrient from manure – NZ
http://www.agscience.org.nz/ag%20science10%20v5.pdf

Use of bacteria and fungi to treat slurry – France
http://www.esemag.com/0502/slurry.html

Air dry slurry – Belgium
http://www.thepigsite.com/LatestNews/Default.asp?AREA=LatestNews&Display=7977

Use of dairy manure water as a fertilizer- USA
http://www.news.ucanr.org/storyshow.cfm?story=435&printver=yes

Use of black soldier fly larvae to digest swine manure – USA
http://nespal.cpes.peachnet.edu/sustain/ibs_conf.pdf

Use of slurry bags- 5 months storage – The Netherlands- Harper-Adams UK
http://www.nfucountryside.org.uk/newssearch-1252.htm

7 Discussion and Conclusions

The EU Nitrates Directive and the associated proposed Action Plan for Northern Ireland, has brought into sharp focus for livestock producers and the associated industries continuing up the food chain, that society requires them to act responsibly towards the environment in the way they handle manure. The Action Plan proposals have therefore put into specific regulations, the requirements considered to be appropriate for Northern Ireland, and in this report an evaluation is made of the technologies, which could be employed to aid the industry in compliance with these requirements.

While the original Action Programme included the proposal that individual farms would be required to achieve a P balance of less than 10 kg/ha by 2010 and 6 kg/ha by 2012, it appears at the time of writing of this report that this proposal will not be in the final Action Programme. Nevertheless in this report manure treatment systems are reviewed with regard to their ability to partition N and P, to reduce BOD and COD and to ease the issue of manure storage for the required over-winter periods. It is recognised that many farms, particularly pig farms, have insufficient spread-lands to comply with the 170 kg N/ha limit, let alone any P balance requirement. The development of slurry processing facilities either on-farm or centralised, that allow nutrients to be partitioned into usable and transportable products, generate renewable energy and result in non-polluting outputs could be vital to the livestock industries.

The principal issues are: -

- The requirement to have additional manure storage capacity on farms
- The requirement to export manure in excess of the 170 kg N/ha limit off farm
- The requirement to apply total nutrients (including those in manure) to meet crop requirements and not in excess
- The possible requirement to achieve a closer P balance on livestock units
- The definitions of ‘manure’ and ‘dirty water’

7.1 Slurry Separation to Reduce Liquid Storage Requirement

While this report does not consider methods of manure storage *per se*, it does consider manure separation techniques, which could have a significant bearing on liquid volumes stored. A number of farms in Northern Ireland are already employing slurry separation techniques, such as weeping walls, rotary screen, and screw or belt press separators. The weeping wall is perhaps the crudest of these systems, which will leave a relatively wet solid fraction retaining about 60% of the TS and producing a liquid effluent, which remains high in P, N and BOD.

The performance of mechanical separators can vary substantially depending on the specific design, the nature of the manure, and the settings adopted. Total solids separation can range from 40%-80%, but there is unlikely to be significant differential partitioning of nutrients between the liquid and solid fractions. A high proportion of soluble N (ammonia) will remain in the liquid fraction, but the ratio of total N and P will remain much as it was in the raw manure. Approximately 20%-

25% of the original weight will be retained in the solids and this will have a DM content between 20%-30%.

The introduction of a mechanical separation system into an existing farm system may not reduce the overall storage requirement for manure. Storage for the same weight of manure will still be required, albeit as three materials (raw manure, separated solids, separated liquid) rather than one. Nevertheless, there can be significant benefits achieved from the use of a separator, because the liquid fraction will flow more easily and can be utilised more efficiently as a fertiliser. Without further treatment, however, there will still be an excess of P in this fraction when applied to meet crop N needs, if the soil is at index 2+, 3 or above. This is particularly so for pig slurry. As the separated solid fraction is normally stackable, storage may be simpler and this fraction could also be suitable for composting or transportation to a centralised processing facility.

7.2 Nutrient Partitioning

Where there is a specific requirement to export excess N or P off a farm, then a number of options can be considered. Partitioning a higher proportion of P and N in the solid fraction can be achieved through: -

- Passing the manure through a sedimentation pond (with or without additives to encourage sedimentation)
- The use of a decanting centrifuge
- Chemical flocculation and precipitation
- The use of polymer to flocculate solids in conjunction with: -
    - Decanting centrifuge
    - Some mechanical separators
    - Geo-textile tube filter fabric containers

Alternatively P can be precipitated from the separated liquid, or raw manure by the addition of magnesium salts, resulting in the formation of insoluble ‘Struvite’ which can be removed from the system. Calcium salts can also be used to generate precipitation.

In all cases the extraction of P results in the remaining liquid having a nutrient balance which is closer to crop requirements and for which application to supply the recommended amount of N would be unlikely to result in excess application of P.

Each of the options has a number of advantages and disadvantages: -

- Sedimentation ponds leave a nutrient rich wet sludge, which must be removed from time to time and disposed of appropriately. This could mean transportation and associated costs. If mixed with a drier substrate, the nutrient-rich sludge could possibly be composted to form a nutrient rich marketable material. Otherwise, the sedimentation pond system should require little other maintenance and could be of potential for some livestock units

- The decanting centrifuge is more expensive to install than other mechanical separators, and has high running costs. Where polymer and/or chemicals are added, this further increases the cost. The advantages of decanting centrifuges are their potential for very high throughputs and their effectiveness at separating out both P and N, particularly if polymer is used. In parts of Europe with a high pig population such as Denmark and Northern Italy, mobile decanting centrifuges are used to treat the manure on farms
- In contrast with the decanting centrifuge, the 'Geo-textile tube' system has a low capital outlay and when used in conjunction with polymer flocculants, can achieve a similar degree of nutrient partitioning. The filtration process may be relatively slow, but the system, which is already marketed in USA and Europe for a range of industrial applications, could be of particular interest in Northern Ireland. The system can be scaled to an appropriate size for each unit. The fixed and operating costs of the Geotube per m^3 of slurry treated could be less than those for mechanical separation
- The decanting centrifuge and Geo-textile tube can also achieve up to 50% partitioning of total N in the solid fraction and this could be of particular importance for pig units where exporting of N is of as much importance as P. Where little or no land for land spreading is available, separation can be followed up by further filtration and cleaning of the liquid (e.g. by reverse osmosis) to achieve close to potable water standards as in the more sophisticated 'turnkey' systems

7.3 Energy Production and Turnkey Systems

Anaerobic Digestion is a well-established and mature technology, which is widely used in many other countries as a source of renewable energy at both farm scale and centralised level. Animal manures often form a large proportion of the material being digested. In many cases organic waste streams from other industries are co-digested with farm slurries in order to attract gate fees and provide increased biogas production. This co-digestion helps economic viability of AD plants.

A major contributory factor to the success of AD in different countries has been financial incentives for the industry. For example in Germany there is relatively high compensation paid to the producer of 'green' electricity combined with the favourable attitude of the public to such schemes. Compensation of up to 21.5 eurocents/kWh can be obtained. In Denmark, capital grants of up to 20% have been paid. A review of AD and centralised manure processing facilities in the Netherlands has shown that there can be many reasons for plants failing to be financially viable (Van Reuten, 1998) which, in their report, were summarised as:-

- Insufficient sector support (from farmers)
- High running costs
- End product market problems
- Long distance haulage issues
- Poor location
- Licensing problems with the authorities

The review of AD in Section 4 has shown that at a technical level, AD plants in Northern Ireland to handle animal manures and (as was proposed for the plant at Fivemiletown), a number of other waste streams, could have potential. The study undertaken by Frost (2005) indicates that except for Belfast, Castlereagh, Carrickfergus and North Down, there is sufficient slurry produced from housed livestock to support at least one 100,000 tonnes/year CAD plant in each district council area. Feedstock supply and accessibility will determine CAD plant numbers and location. It is suggested by Frost (2005) that there is potential for at least 5 CAD systems in Northern Ireland with a combined power output of 6 MW electric and 5 MW heat (1.2 MW_e plus I MW_h per plant).

These findings support an earlier report by Power (2003), which considered potential energy production from renewable sources in Northern Ireland including farm slurry and agri-wastes. The report indicated that (assuming 20% of total agri-wastes are available) Northern Ireland agri-wastes could contribute ~5 MWe (with chicken litter providing 5.8 MWe separately). The report also stressed the importance of location and guarantee of feedstock supply as critical to feasibility.

Anaerobic digestion does not remove N and P from slurry but results in a digestate that has less odour and has less BOD than the original input slurry**.** In addition, the nutrients in the digestate can be more readily utilised as fertiliser or separated to produce a liquid and a fibrous solid. The separated fibre could be composted or pelleted. However, the market for this type of product has yet to be developed fully. In addition, CAD systems could play a very significant role in collection and redistribution of plant nutrients in slurry that would assist in compliance with the Nitrates Directive and any further P requirements.

Anaerobic digestion plants could therefore play a valuable role in Northern Ireland in the initial handling of raw manure and waste streams from other industries, where the value of the outputs (gas, electricity, heat, liquid, solids) can be maximised, reliable streams of digestible material can be obtained locally, the business case is carefully researched and prepared, the locating is optimal in terms of both haulage distances and public acceptability and all issues of licensing and planning are resolved. Another major consideration is that relating to dealing with category III animal slaughter and food processing wastes. Guidance on disposal and treatment of these wastes is available on the DEFRA website http://www.defra.gov.uk/animalh/by-prods/default.htm

A range of types of Turnkey plants, which may or may not include AD, have been identified in this report and are basically subject to the same constraints as AD plants. While the systems vary technically and in the precise nature of the outputs, it is the preparation of a realistic business case, which will establish whether any proposed plan is likely to be economically viable and sustainable.

In most EU countries, government support schemes for renewable energy and related environmental projects have played a significant role in the initial development of AD and manure processing plants. Hjort-Gregerson (1999) has shown that without some government support, such schemes struggle for financial viability.

FIB Bioenergy Research (2004) carries a report, which states that Danish industries would receive DDK 14M (£1,286,445) for environmental purposes over the next 4 years. This money is derived from CO_2 taxes. Projects will be established in 4 main areas, chemical waste, water environment and water industry and funds will be available for projects that fall under the heading "Development of New Technologies for Treatment of Manure and Reduction of Odour Nuisances".

When relatively dry animal manures (poultry and separated solids from pig and cattle manure) are produced, then the options of gasification or other forms of combustion are possible. While there is a substantial quantity of literature on gasification systems showing that they have relatively low emissions compared with other forms of combustion, a question remains regarding their ability to run continuously and reliably. Gasification cannot therefore be recommended in this report as a mature technology. The poultry industries in North America and UK already have substantial plants for generation of green electricity from poultry litter using combustion technology. The principal concern is with emissions from such plants.

Recent experience in Northern Ireland with the Fivemiletown project has indicated the importance of public attitudes to CAD plant development. It may be in Northern Ireland's interest that a study is undertaken to assess how public attitudes in countries such as Denmark and Germany have been influenced by the widespread development of centralised and on-farm manure processing plants.

Tijmensen and Van den Broek (2004) restate some advantages of AD biogas plants as:-

- An economically attractive investment
- Easily operated and can be safely installed
- Produce renewable energy
- Reduce CO_2 emissions
- Reduce methane emissions
- Improve fertiliser value of manure

The authors contend that while Denmark and Germany have successful biogas industries, the UK and some other EU countries, particularly Ireland, lag behind. Clear regulations and financial attractiveness are critical to market penetration of the biogas industry in these countries.

Conclusions

1. A wide range of technologies are available for manure handling and processing some of which could have significant benefits for livestock producers having to comply with the requirements of the Nitrates Directive Action Programme.

2. Mechanical separation methods based on sieves, belt and screw presses generally achieve a 20% to 25% reduction of liquid volume, which may be of value if manure storage is an issue.

3. These separators generally partition P or N in proportion to liquid and fibre fractions and are therefore of some value when there is a requirement to export excess nutrients from a farm.

4. The decanting centrifuge, geo-textile tubes and settling basins are technologies, which have not been used in Northern Ireland for manure processing. These technologies have the potential to partition a higher proportion of P and (to a lesser extent) N in the separated solid fraction than in the liquid fraction.

5. The use of chemical additives, particularly polymer flocculants, is a well-established industrial technique, for precipitating solids and minerals in waste streams.

6. When used with polymer flocculants and associated additives, decanting centrifuges and geo-textile tubes can achieve very high levels of partitioning of P and to a lesser extent total N.

7. Decanting centrifuges can achieve high throughputs of slurry, but have a high capital cost and require more power than some other separators.

8. Static and Mobile decanting centrifuge units could have potential in Northern Ireland.

9. Geo-textile tubes achieve good solids and nutrient separation at low capital outlay and could have potential in Northern Ireland.

10. Settling basins may be less appropriate for Northern Ireland for climatic reasons, and because there could be more odour.

11. Polymers could possibly be used with other mechanical separators, but little work seems to have been conducted on this.

12. In settling basins the addition of alum can significantly increase the precipitation of P.

13. The addition of magnesium salts to liquid manure or separated slurry liquor will result in most P being precipitated as Struvite, which can be collected, dried, and used as a fertiliser.

14. Anaerobic digestion is a mature technology which could stand alone or be part of centralised or on-farm manure processing systems.

15. Sustainable and economically viable establishment of Anaerobic Digestion plants is dependent on bringing together a wide range of factors into business plans.

16. AD plants in themselves do not deal with the issue of excess nutrients. The P and N present in the manure and other material entering the AD plant will be found in the digestate produced by the plant.

17. When associated or coupled with other technologies such as centrifugal separation, AD has potential to facilitate nutrient re-distribution.

18. Key issues for AD plants are - the prices obtained for electricity and heat, the gate fees obtained, the markets developed for the digestate end products, and the enlisting of public support and planning approval.

19. Similar issues surround other types of ‘Turnkey’ manure processing plants.

20. The specific details of any legislation will have a significant bearing on which types of systems are most likely to be economically viable.

21. Water coming from processing facilities will have been derived from manure, but should be able to be used for, irrigation, washing, discharge or even as potable water if it reaches the appropriate analytical standards.

22. If there is a requirement for individual farms to achieve a phosphate balance as originally envisaged in the Nitrates Development Action Programme, then continuing efforts to reduce the P and N intake in animal diets may enable further improvements to be made, although it is recognised that the industry has already gone a long way, particularly with the reduction of P in animal diets.

8 References

Abeln, J., Kluth, M., Petrich, G. and Schmieder, H. 2001. Supercritical Water Oxidation (SCWO): A process for the treatment of industrial waste effluents. *High Pressure Research*, **20:** 537–547.

Albertson, O., Burris, B., Reed, S., Semon, J., Smith Jr., J.E. and Wallace, A. 1991. Dewatering Municipal Wastewater Sludges. Pollution Technology Review Number 202. Noyes Data Corporation, Park Ridge, New Jersey USA.

Bailey, J. 2004. Slurry - a valuable resource. In 'Slurry - it's value and potential - a DARD/UFU partnership event', April 2004, Greenmount Campus, College of Agriculture, Food and Rural Enterprise.

BHP Systems 2005. Preliminary report on a least cost economic solution for the processing of agri-industrial organic waste streams within a seven mile radius of Cookstown, Co. Tyrone. Project No. 5400.01, May 2005.

Bicudo, J.R. 2001. Frequently Asked Questions about Solid-Liquid Separation. University of Minnesota, Bio-systems and Agricultural Engineering Extension Program. http://www.bae.umn.edu/extens/faq/sol_liqfaq.html.

Boland, C. 2004. Ireland - Now. Current status of composting and prospects for the future. Cré Seminar, Tullamore, May 6th 2004. http://www.compostireland.ie/docs/conallboland_seminar060504.pdf (Accessed 24 May 2006).

Bonazzi, G. and Piccinini, S. 1997. Manure surplus processing at the farm level and in coordinated groups of farms. Environmentally friendly management of farm animal waste International Workshop, 25-29 November, Sapporo, Japan.

Bragg, A. 2003. Reducing Phosphorus in Dairy Effluent Wastewater through Flocculation and Precipitation. Report, Texas Water Resources Institute**,** http://twri.tamu.edu/reports.php?view_year=2003.

Buckley, K.E. 2003. Composting hog manure – Is it right for your farm? Swine seminar, Brandon Research Centre, Brandon, Manitoba, January 29-30, 2003. http://www.gov.mb.ca/agriculture/livestock/pork/swine/pdf/bab14s04.pdff

Buffinga, G.J. and Knoef, H.A.M. 2005. Implementation and demonstration of an embedded small scale poultry manure CHP process. Report of BTG biomass technology group. BV. Netherlands, 2005.

Burns, R.T., Moody, B. 2002. Phosphorus Recovery from animal manures using Optimised Struvite Precipitation. *Proceedings of Coagulants and Flocculants: Global Market and Technical Opportunities for Water Treatment Chemicals, Chicago, Illinois.*

Burton, C.H. and Turner, C. 2003. Manure Management: *Treatment Strategies for Sustainable Agriculture, 2nd Ed.* (C.H. Burton and C. Turner, eds.), Wrest Park, Bedford, UK: Silsoe Research Institute.

Celen, I. and Turker, M. 2001. Recovery of ammonia as struvite from anaerobic digester effluents. *Environmental Technology*, **22 (11):** 1263-72.

Chen, X. and Moran, E.T. 1995. The withdrawal feed of broilers. *Journal of Applied Poultry Research*, **4:** 69-82.

Cheremisinoff, P.N. 1995. Handbook of water and wastewater treatment technology, New York, NY: M. Dekkar.

Department of Agriculture and Rural Development for Northern Ireland (DARD) 2003. Code of Good Agricultural Practice for the Prevention of Pollution of Water. 108 pp.

Department of Agriculture and Rural Development for Northern Ireland (DARD) 2004. Farm statistical data survey 1981-2004. http://www.dardni.gov.uk/econs/statdata.htm.

Department of Agriculture and Rural Development for Northern Ireland (DARD) 2005. Nitrates Directive Consultation Paper. Proposed action programme measures for the protection of Northern Ireland's waters. Department of Agriculture and Rural Development and Department of the Environment. Belfast, 66 pp.

Department of Agriculture and Rural Development for Northern Ireland (DARD) 2005b. Nitrates directive progress and 60% grant aid announced. Department of Agriculture and Rural Development, Press release 141/05. 7 July 2005. http://www.dardni.gov.uk/pr2005/pr050141.htm.

Department of Environment, Food and Rural Affairs (DEFRA) 2001. Opportunities for saving money by reducing waste on your farm. A manual for farmers and growers, 97 pp. Crown Copyright 2001. www.defra.gov.uk/environment/waste/topics/agwaste /reduce-waste.pdf

Emerson, D. 2004. Scavenging the way to biosolids composting in coalville. *Journal of Composting and Organics Recycling*, *Biocycle*, **45 (10):** 45. October 2004. www.jgpress.com/archives/_free/000280.htmll

FiB Bioenergy Research 2004. CO_2 taxes can be used for the development of manure technologies. *FiB Bioenergy Research* **1 (4):** October 2004. p. 7.

Fleming, R. 1986. Solids-Liquid Separation of Manure. Ontario Ministry of Agriculture and Food. Factsheet No. 86-032.

Fleming, R. and MacAlpine, M. 1999. Development of a farm-scale system to compost liquid pig manure. *The Composting Council of Canada 9th Annual Composting Conference,* November 1999, Toronto, Ontario.

Ford, M. and Fleming, R. 2002. Mechanical Solid-Liquid separation of livestock manure. Literature Review. University of Guelph, Ontario. 55 pp. http://www.ridgetownc.on.ca/research/documents/fleming_separator.pdf

Frost, J.P. 2005. Opportunities for Anaerobic Digester CHP systems to Treat Municipal and Farm Wastes. http://www.dardni.gov.uk/consultations/con05026a.htm.

Frost, J.P. and Stevens, R.J. 1991. Slurry utilisation. *64th Annual Report of the Agricultural Research Institute of Northern Ireland*, pp. 20–30.

FSA Environmental 2000. Alternative systems for piggery effluent treatment. A report prepared for the Environmental Protection Agency and the Rural city of Murray Bridge by FSA Environmental, Queensland, ISBN 1 876562 23 4. November 2000. 137 pp.

FSA Environmental 2002. Low cost alternatives for reducing odour generation. Case study 10. Decanting Centrifuge. Australia Pork Limited, Canberra, Australia. http://www.fsaconsulting.net/pdfs/Case%20Study%208%20-%20Belt%20Press.pdf.

FSA Environmental 2002b. Case study 7-Screw Press. 20 pp. http://www.fsaconsulting.net/pdfs/Case% 20Study%207%20-%20Screw%20Press.pdf.

Fulhage, C.D and Pfost, D.L. 1993. Mechanical solid/liquid separation for dairy waste. University of Missouri webpage. http://muextension.missouri.edu/xplor/envqual/wq0323.htm.

Funk, T.L. and Polakow, J. 2004. Manure liquid-solid separation factors that determine system choice. 17 March 2004. http://www.traill.uiuc.edu/sowm/paperDisplay?ContentID=6524.

Glerum, J.C., Klomp, G. and Poelma, H.R. 1971. The Separation of Solid and Liquid Pig Slurry. *Proceedings of the 1st International Symposium on Livestock Wastes, 345 - Columbus, Ohio*, 19-22 April: *American Society of Agricultural Engineers*.

Gordon, R.W. and Rowland, D.A. 1997. Performance of commercial laying hens fed various phosphorus levels, with and without supplemental phytase. *Poultry Science*, **76:** 1172-1177.

Greaves, J., Hobbs, P., Chadwick, D. and Haygarth, P. 1999. Prospects for the Recovery of Phosphorus from Animal Manures: A Review. *Environmental Technology*. **20 (7):** 697-708.

Hahne, J., Beck, J. and Oechsner, H. 1996. Management of Livestock Manure in Germany – A brief overview. *Animal Manures and Environment in Europe*, pp. 11-22.

Hjort-Gregerson, K. 1999. Centralised Biogas Plants - Integrated energy production, waste treatment and nutrient redistribution facilities. *Danish Institute of Agricultural and Fisheries Economics,* October 1999.

Jacobsen, B.H. and Hjort-Gregersen, K. 2003. An economic and environmental analysis of slurry separation. *Proceedings of the 14th* International Farm Management *Congress, Perth, Australia,* May 2003. 12 pp. http://www.ifmaonline.org/pdf/congress/Jaconsen%20HjortGregerson.pdf.

Kornegay, E.T. and Verstegen, M.W.A. 2001. Swine nutrition and environmental pollution and odour control. *Swine Nutrition, 2nd ed*. pp. 609-630.

Kottner, M. 2001. Biogas in agriculture and industry potentials, Present use and perspectives. *Renewable Energy World* **4 (4):** 132-143.

Kottner, M. 2004. The role of biogas in German farm business development. Transactions of 'Biogas in Society' Conference, Northern Ireland. 8 pp.

Kruger I.R., Taylor, G. and Ferrier, M. 1995. Effluent at Work. Australian Pig Housing Series. New South Wales Agriculture, Tamworth NSW Australia.

Levlin, E. and Hultman, B. 2003. Phosphorus recovery from phosphate rich side streams in wastewater treatment plants. *Proceedings of a Polish-Swedish seminar,* March 23-25, 2003, Report No 10, Joint Polish-Swedish reports, TRITA.LWR Report 3004. pp. 47-56.

Magowan, E., McCann, M.E.E., Beattie, V.E., McCracken, K.J., Bradford, R., Mayne, C.S., Smyth, S. and Gordon, F.G. 2004. Variation in Growth Performance. *Proceedings of the Northern Ireland Pig Event held at the Agricultural Research Institute of Northern Ireland*, 3 November 2004, *Occasional Publication No. 35*, pp. 16-17.

Mahoney, T., O'Flaherty, V. and Colleran, E. 2002. Feasibility study for centralised anaerobic digestion for treatment of various wastes and wastewaters in sensitive catchment areas. Final Project Report, Environmental Protection Agency, Johnstown Castle Estate, County Wexford, Ireland. ISBN 1084095-087-0.

Martinez-Almela, J. and Marza, J.B. 2005. Selco-Ecopurin pig slurry treatment system. *Bioresource Technology,* **96 (2)**.

Mateos, G.G., Serrano, M.P. and Garcia, R.L. 2005. Methodologies to reduce N and P in poultry manure through nutrition. *Proceedings of EC Workshop: N and P in Livestock Manure, Brussels*, 14 February 2005.

McCann, M.E.E., McCracken, K.J., Beattie, V.E., Magowan, E., Smyth, S., Bradford, R. and Henry, W. 2005. Investigations into phosphorous requirements of growing/finishing pigs and the use of phytase. *Agricultural Research Institute of Northern Ireland. Advances in Pig Research. 24th June 2004*. *Occasional Publication No 33*. pp. 15-64.

McKervey, Z., Woods, V.B., Easson, D.L. and Forbes, E.G.A. (2005). Opportunities to reduce nitrate leaching from grazed grassland. A summary of research finding in New Zealand (www.afsni.gov.uk/gru).

Meyer, D., Harner, J.P., Tooman, E.E. and Collar, C. 2004. Evaluation of weeping wall efficiency of solid liquid separation. *Applied Engineering in Agriculture*, **20:** 349-354.

Moller, H.B., Sommer, S.G. and Ahring, B.K. 2002. Separation efficiency and particle size distribution in relation to manure type and storage conditions. *Bioresource Technology*, **85 (2):** 89-96.

Morgenroth, E. 2000. Opportunities for nutrient recovery in handling animal residues. In: *Proceedings of the Animal Residuals Management Conference, Kansas City, Missouri*, November 12-14, 2000, *Water Environment Federation, Alexandria, Virginia*.

Morris, J., Fleming, R. and MacAlpine, M. 2003. Separated drinking water from liquid manure for swine. Prepared for Ontario Pork, Project number 03/07. Ridgetown College, University of Guelph, Ontario. 16 pp.

Murphy, J. 2003. Low-Phytate Barley Loosens Phytate's Grip on Phosphorus. *Ministry of Agriculture, Food and Rural Affairs*, Ontario, Canada. http://www.omafra.gov .on.ca/english/livestock/swine/facts/info_n_phytate.htm.

Murphy, J. 2004. Nutritional Strategies To Decrease Nutrients. In: Swine Manure Factsheet. *Ministry of Agriculture, Food and Rural Affairs*, Ontario, Canada. http://www.omafra.gov.on.ca/english/livestock/swine/facts/04-035.htm.

Myung-Gyu Lee and Gi-Cheol Cha 2003. Valuable organic liquid fertilizer manufacturing through the TAOTM process for swine manure treatment. *The American Society of Agricultural and Biological Engineers (ASAE), Annual Meeting 2003.* Las Vegas, NV July 27-30, 2003.

Navaratnasamy, M., Feddes, J.J.R. and Leonard, J.J. 2004. Reusing liquid manure as a possible source of drinking water for pigs. *Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, Alberta, Canada,* **46:** 627-632.

Newsletter of the European Press (EEP) 2003. Green fertilisers to save ground water. July 18, 2003, Issue 49. (www.eep.org/newsletters/newsletter180903.htm).

Nordberg, A. (2003). Treatment of animal waste in co-digestion biogas plants in Sweden. Presented at The future of Biogas in Europe II, Esbjerg, Denmark, 2-4 Oct 2003.

Nordberg, A. and Edström, M. 2002. Waste management in Northern Europe : experiences from the LINKOPING Biogas plant. Presented at workshop : *Impact of Waste Management Legislation on Biogas Technology*. IFA-Tullin, America, 2002.

Norddahl, B. and Rohold, L. 2000. The BIOREK® concept for the conversion of organic effluent to energy, concentrated fertiliser and potable water. 4 pp. http://www.bioscan.dk/The_BIOREK_Concept_May_2000.pdf.

O'Connell, N.E., Beattie, V.E. and Weatherup, R.N. 2002. Influence of feeder type on the performance and behaviour of weaned pigs. *Livestock Production Science*, **74 (1):**13-17.

Oechsner, H., Beck, J., Förschler, J., Käck, M. and Siemers, V. 1995. Feststoffabtrennung aus Flűssigmist mit Preßsschneckenseparatoren. Agratechnische Berichte, Nr. 25, Institut fűr Agrartechnik und Landesanstalt fűr landw. Maschinen-und Bauwesen, Universität Hohenheim, Germany.

Olson, T. 2000. Hydrocyclone design for fine separations at high capacities. 2000 Annual AICHE Meeting. *Symposium on Recent Advances in Cyclones and Hydrocyclones, Los Angeles*, 12-17 November 2000.

Power, P.B. 2003. A study into the economic renewable energy resource in Northern Ireland and the ability of the electricity network to accommodate renewable generation up to 2010. A report prepared by PB Power, 30th June 2003. http://www.detini.gov.uk/cgi-bin/downutildoc?id=73.

Patterson, D.P., Yan, T. and Hameleers, A. 2004. Nutritional strategies to improve the efficiency of utilisation of dietary nitrogen in milk production. In: Nitrogen, Phosphorus and Methane – Improving nutrient use in milk production. *Occasional Publication No. 34, Agricultural Research Institute of Northern Ireland, pp. 25-37.*

Payne, R.W. 1990. 'On-farm performance of pig effluent treatment systems in use in Western Australia'. *Final Report to the Research Advisory Committee Western Australia. Pig Industry Compensation Fund, Department of Agriculture, Western Australia*.

Pedersen, P. 2004. Point-source pig manure management processes in Denmark. *The National Committee for Pig Production and Danish Meat and Bacon Council*. 17 March 2004. http://www.traill.uiuc.edu/sowm/paperDisplay.cfm?ContentID=65255.

Pieters, J.G., Neukermans, G.G.J. and Colanbeen, M.B.A. 1999. Farm-scale Membrane Filtration of sow slurry. *Journal of Agricultural Engineering Research*, **73:** 403-409

Regenstein, J.M., Kay, P., Turci, P. and Outerbridge, T. 1999. Small to medium scale composting of food wastes in New York City. *Final Report prepared by Cornell University and City Green, Inc.* 65 pp. http://compost.css.cornell.edu/NYC Composting.pdf.

Rorick, M.B., Warburton, D.J., Spahr, S.L. and Day, D.L. 1980. Performance of a perforated pressure roller solid/liquid separator on dairy manure. *Proceedings of the 4th International Symposium on Livestock Wastes*, 426-429. Am`arillo, Texas, 15-17 April: American Society of Agricultural Engineers.

Rushton, A., Ward, A.S. and Holdich, R.G. 2000. Solid-liquid filtration and separation technology. Second Edition, WILEY-VCH.

Selle, P.H., Walker, A.R. and Bryden, W. L. 2003. Total and phytate-phosphorus contents and phytase activity of Australian-sourced feed ingredients for pigs and poultry. *Australian Journal of Experimental Agriculture*, **43 (5):** 475-479.

Seth Madsen, A. 2004. Large Biogas Plants in Denmark – technology and operation experience. NIRAS presentation. www.sag\25\305.50\praesentationer\Biogas-bergen_drt_310504.

Sheffield, R., Barker, J. and Rashash, D. 2000. Solids separation of animal manure. *North Carolina State University*. http://www.bae.ncsu.edu/programs/extension/manure/technologies/solids.pdf.

Shutt, J.W., White, R.K., Taiganides, E.P. and Mote, C.R. 1975. Evaluation of solids separation devices. *Proceedings of the 3rd International Symposium on Livestock Wastes,* 463-467. Urbana-Champaign, Illinois, 21-24 April: *American Society of Agricultural Engineers*.

Skøtt, T. 2005. From straw to gas. FiB Bioenergy Research. **2 (7):** 1. http://www.biopress.dk/PDF/FiB%20nr.%2007-2005%20-%20UK.pdf.

Spears, J.W. 1996. Optimising mineral levels and sources for farm animals. In: *Nutrient Management of Food Animal to Enhance and Protect the Environment*, Kornegay, E.T. (Ed.), CRC Press, Boca Raton, FL. pp. 259-276.

Sutton, A.L., Radcliffe, J.S. and Joern, B.C. 2004. Overview of Phosphorus Issues in Swine Feeding. Swine Odour Waste Management Papers 3-Nutrition. 17 March 2004. 15 pp. http://www.traill.uiuc.edu/sowm/paperDisplay?ContentID=6509.

The Milk Lines 2004. Evaluation of the efficiency of weeping wall solid liquid separation. **1 (2)** July 2004. http://cetulare.ucdavis.edu/pub/Milk704.pdf.

Tijmensen, M. and Van den Broek, R. 2004. Clean Power from Farm Waste, International Experiences with anaerobic digestion of farm manure. *Renewable Energy World.* 1 March 2004. (Accessed 4 October 2005). http://www.earthscan.co.uk/news/article/mps/UAN/307/v/3/sp/.

Um, J.S. and Paik, I.K. 1999. Effects of microbial phytase supplementation on egg production, egg shell quality, and mineral retention of laying hens fed different levels of phosphorus. *Poultry Science*, **78:** 683-691.

Van Heugten, E. 2003. Selected phosphorus research presented at the 2003 Animal Science Meetings. *Swine News. North Carolina Cooperative Extension Service*, College of Agriculture and Life Sciences. **26 (8)** September 2003. 4 pp. http://mark.asci.ncsu.edu/Swine_News/2003/Sep03.pdf.

Van Heugten, E., Funderburke, D.W. and Dorton, K.L. 2003. Growth performance, nutrient digestibility, and fecal microflora in weanling pigs fed live yeast. *Journal of Animal Science*. **81 (4):** 1004-1012.

Van Ruiten Advicebureau B.V. 1998. Phosphate recovery from animals manure. The possibilities in the Netherlands. Van Ruiten Adviesbureau/Projectbureau BMA, for Centre Européen d'Etudes des Polyphosphates (CEEP), (November 1998). 36 pp. http://www.nhm.ac.uk/research-curation/departments/mineralogy/research-groups/phosphate-recovery/VanRuiten.pdf.

Vanotti, M., Furukawa, K., Garcia-Gonzalez, M. and Szogi, A. 2005. Nitrogen removal with the Anaerobic Ammonia Oxidation (Anammox) process using polymer gel biomass carrier seeded with swine effluent. *Proceedings of the American Society of Agricultural Engineers Annual International meeting.* July 17-20 2005. Tampa, Florida.

Vanotti, M.B., Rashash, D.M.C. and Hunt, P.G. 2002. Solid-liquid separation of flushed swine manure with PAM: Effect of wastewater strength. *Transactions of the American Society of Agricultural Engineers.* **45 (6):** 1959-1969.

Vanotti, M.B., Szogi, A.A., Hunt, P.D., Ellison, A.Q., Millner, P.D. and Humenik, F.J. 2004. Development of environmentally superior technology in North Carolina: The Super soil project. *Symposium of the State of the Science of Animal Manure and Waste Management, January 5-7, 2005,* San Antonio, Texas. 6 pp. www.cals.ncsu.edu/waste_mgt/natlcenter/sanantonio/Vanotti.pdf.

Wallace, G. 2004. Separation of Slurry. In 'Slurry its value and potential'. A DARD/UFU Partnership Event. Greenmount Campus. College of Agriculture, Food and Rural Enterprise. Department of Agriculture and Rural Development, Northern Ireland, pp. 26–30.

Watts, P.J., Tucker, R.W., Pittaway, P. and McGahan, E.J. 2002. Low cost alternatives for reducing odour generation. Milestone 5 Report Project 1629 Part A – Literature Review and Recommendations, 86 pp.

Whittemore, C.T. 1993. The Science and Practice of Pig Production. Published by Longman Group, UK.

Williams, C.M. 2004. Development of Environmentally Superior Technologies. Phase I Report for Technology Determination per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers. North Carolina State University. 26 July 2004. http://www.cals.ncsu.edu/waste_mgt/smithfield_projects/phase1report04/phase1report.htm (Accessed 25 May 2006)

Wissemeier, A.H., Weigelt, W. and Haehndel, R. 2002. Environmental aspects and plant compatibility of ammonium containing fertilizers with the new nitrification inhibitor DMPP (ENTEC). *XXVIth International Horticultural Congress, Toronto*, pp. 1220-1240. www.cshs.ca/annual_meeting/scientific2002/Syposium So2.pdf.

Worley, J. 2005. Manure Solids Separators. Biological and Agricultural Engineering Department, College of Agricultural and Environmental Sciences, Cooperative Extension Service, University of Georgia, 5 pp. http://www.engr.uga.edu/service/extension/agp2/resources/publication/H-M/Manure%20Solids%20Separato46.pdf (Accessed 25 May 2006)

Worley, J.W., Bass, T.M. and Vendrell, P.F. 2005. Performance of Geotextile Tubes with and without chemical amendments to dewater dairy lagoon solids. *Proceedings of the Animal Manure and Waste Management Symposium, San Antonio, Texas*, 5-7 January 2005.

Wright, P.E., Inglis, S.F., Stehman, S.M. and Bonhotal, J. 2001. Reduction of selected pathogens in anaerobic digestion. *5th Annual NYSERDA Innovations in Agriculture Conference*. 11 pp. http://www.manuremanagement.cornell.edu/docs/ReductionofSelectedPathogensinAD%20-%20received%20Mar'04,%20edited%203-17-04.pdf (Accessed 25 May 2006)

Yan, T., Patterson, D.C., Agnew, R.E., Frost, J.P., Keady, T.W.J., Binnie, R.C. and Mayne, C.S. 2005. Reducing organic nitrogen outputs from dairy cows and beef cattle in Nitrate Vulnerable Zones. End of project report to AgriSearch. 2005. *Agricultural Research Institute of Northern Ireland*, 68 pp.

Zhang, R.H. and Westerman, P.W. 1997. Solid-Liquid Separation of Annual Manure for odour. Control and Nutrient Management. *Transactions of the American Society of Agricultural Engineers.* **13 (3):** 385-393.

Zhao, Y.Y., Wu, K.F., Wang, Z., Zhao, L. and Lee, S. 2000. Fouling and cleaning of membranes – A literature review. *Journal of Environmental Science*, **2 (2):** 241-250.

All internet sites referenced in this document were accessed between April 2005 and May 2006

9 Appendices

Appendix 1 Approaches by different countries to manure & nutrient management issues

The Netherlands

- Reductions in production - encourage older producers to retire
- Programs for manure injection at spreading and covering storage facilities to reduce ammonia
- Restricted period for slurry spreading
- MINAS - (Mineral Accounting System) - A record of all minerals in and out and remaining on the farm
- Livestock density 2.5 LU/ha (livestock unit)
- Levy if nutrient levels are exceeded €2.3/kg N (2003)
- Producers reducing liquid fraction of manure
- Phytase additives in feed
- Compensation for farmers to reduce production - £14.70 for each kg P reduced
- On-farm Biogas plants

Denmark

- Set nitrate level in groundwater at 25 mg/l
- Livestock density more restrictive 170 kg N/ha or 1.7 LU/ha
- Harmonisation - nutrient/area balance
- Distribute excess manure to arable farms
- All farms exceeding 10 hectares must produce compulsory fertiliser and crop rotation plans
- Use of biogas plants - seems successful due to government assistance
- Cover for liquid manure tanks – straw often used
- Storage capacity for 9 months

Germany

- Regulations vary according to the Bundesland, resulting in differing limits for livestock density ranging from 160-340 kg N/ha
- Closed period for manure spreading
- Government grants for farms with livestock densities lower than 2 LU/ha
- Mineral balance accounting systems
- Fertilization plans - restrict amount applied according to crop requirements
- Up to 1600 biogas plants by 2001

Switzerland (Non-EU State)

- Generally smaller farm size compared with other EU countries
- Government subsidies reduce the need for expansion of production
- Similar legislation as other EU states, even though not a member
- Greater restrictions in mountainous regions
- From 2005, livestock units restricted to 2.5 LU/ha
- From 2002, introduction of mineral accounting system in order to receive government subsidies
- Phytase and amino acid production being considered

- Different management techniques adopted in each canton
- Sowing of spring cereals rather than winter
- Restricting farming beside river plains

France
- Fertilizer application - similar restriction of application as in other EU states
- Requirement for manure storage facilities
- Limit of 170 kg/ha for N produced
- Plan for application of manure, recordings dates etc
- Creation of ZAC (complimentary action zones) - ground cover in winter
- Compensation to farmers for cost involved in ZAC's – 2001–2006 to reduce livestock numbers

Ireland
- Closed period for spreading of manure
- Requirement for storage capacity for manure for 16-20 weeks
- Limit of 170 kg/ha for N produced - seeking to extend this to 250 kg/ha for latest submission to EU commission on March 22nd 2005
- Proposal by Environmental Protection Agency (Dr John Curtis) for establishment of 40 biogas plants to deal with 132 tonnes of agricultural waste produced annually

Canada
Differing restrictions depending on province

Alberta
- Intensive livestock operation is defined as 300 animals at a density of 43 animals/acre (housed animals)
- An animal unit is defined as the number of animals excreting 73 kg N/year
- Storage capacity for 9 months
- Slurry cannot be spread on frozen ground
- Application for any new or expanding facilities exceeding 300 animal units
- Soil sampling for N and P
- Manure cannot be applied at a rate exceeding 176 lbs or approximately 79 kg mineral N
- Records of manure application

Saskatchewan
- Animal unit similar to Alberta
- Intensive livestock unit equal to 300 or more animals

Manitoba
- Intensive livestock unit of 400 or more animals
- Animal unit defined as animal that excretes up to 75 kg mineral N

- 320 sows
- 200 dairy cows
- 332 beef cattle
- 40,000 laying hens

Quebec

- 250 days manure storage
- Intensive livestock operation equivalent to more than 75 livestock units
- Covered storage facilities from 1998
- No spreading of manure on frozen ground
- Farmers to prepare agri-environmental plans
- Restrictions on use of P fertilizer
- Record keeping of mineral inputs and outputs
- Penalties for failure to comply with regulations

USA

Restrictions vary according to individual state legislation

Wisconsin

- Closed period for spreading of liquid + solid manure
- Storage requirements
- Reduced application rates of fertilizer – organic and inorganic
- Recording of nutrient application and farm inspections

North Carolina

- $15 million research program
- Development of Environmentally Superior Technology (EST)

Environmental performance reviews for each individual EU state can be viewed on the OECD (Organisation for Economic Co- operation and Development) website www.oecd.org

Several European countries receive funding from Interreg, a program supported by the European Regional Development Fund (ERDF) involved in funding cross border research into environmental issues such as nitrate levels in drinking water.

Examples include: -

- Wetlands research between Wales and Ireland – 2nd February 2005
- Nitrates project – Klettgau region Switzerland
- Atlantic area project – France - Green dairy monitoring dairy waste from 9 research stations from Oct 2003-2006

New Biogas laboratory established in Hohenhiem, Germany, December 2004.

Finnie Council, Dumfries and Galloway are investing £79K in waste management-August 2004

Guidelines for monitoring under the Nitrates directive are currently in draft form, and outline the monitoring of agriculture and water quality emphasises the influence of factors such as soil type, geology of rock, climate and location on water quality. Education of farmers, type of farmers and existence of farm successor also play a role (European Environment Agency) 21-22 February 2005. http://www.omafra.gov.on.ca/english/agops/otherregs4.htm.

Department of
Agriculture and
Rural Development
www.dardni.gov.uk

This study was funded through
the DARD Vision Project

AFBI Headquarters, Newforge Lane, Belfast, Northern Ireland BT9 5PX
Tel: +44 28 9025 5690
email: info@afbini.gov.uk
www.afbini.gov.uk