Summary of Nutrient Management Technology Options in the Context of Hullcar

A part of the Hullcar Situation Review
Nutrient Management Practices - Technical Report

September 2017 **File No. 631.700-5**

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EXECUTIVE SUMMARY

Innovative methods and technologies that optimize nutrients are being analyzed for incorporation into agricultural waste management with the intent of reducing over application and/or leaching of nutrients. The technologies being considered are able to either stabilize the land applied manures in such a way to reduce nutrient leaching or to recover a portion of the nutrients from manures that are typically land applied, which allows for excess nutrients to be exported. The Ministry of Agriculture, along with other agencies have looked into waste management practices to reduce nutrient leaching and runoff from land applied manures that are suitable and economically feasible for the agricultural sector in B.C.. This report summarizes the findings from various sources to help identify and assess potential nutrient reduction options.

This review focuses on dairy manure, beef feedlot manures and considers poultry litter where applicable. When considering feasible and suitable technologies it is important to consider the composition of the waste stream as the moisture content plays a large role in the feasibility for farm operations. For example, liquid dairy manure has very high moisture content which limits several technologies from being considered such as heating processes that would require large amounts of energy to be used. For a discussion of dairy manure handling systems and the water content generated in each system, see *Summary of Manure Handling Systems in the Context of Hullcar* report.

The technologies considered in this report will be commercially available technology or close to commercially available and must be feasible within the waste management practices on B.C. farms based on scale and farm wastes. Commercialized technologies are those that have gone through R&D, innovation and demonstration, and have been purchased by farms, the technology has been proven under ‘real world’ conditions and thus installation and operation is less risky.

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1. TECHNOLOGY REVIEW

Nutrient Recovery technologies have been investigated in B.C. as a means to reduce overall nutrient loading but have focused on Phosphorus (P) removal from manures to allow export of excess nutrients. The ratio of P to N in animal manures is higher than that taken up by crops, which can result in excess P when manure is applied at rates to supply plant N requirements. While the reduction techniques investigated focus on P they tend to have a benefit of N removal as well, but to a more limited extent. Specific N removal technologies have not been investigated in B.C. extensively.

The technologies considered in this report are waste to energy technologies, composting, manure injection, and nutrient recovery technologies; Table 1 gives a summary of the findings.

It was found that:

- Anaerobic digestion (AD), composting and manure injection technologies are not considered nutrient recovery technologies (NRTs). They do assist in manure upgrading and improved nutrient management if implemented with a proper Nutrient Management Plan (NMP).
- In order to increase biogas productivity AD operations in B.C. import additional nitrogen sources for optimal operation. On its own, AD is often a net-importer of nitrogen based feedstock onto a farm operation.
- The AD process converts the nitrogen to a form that is able to be more readily converted to nitrate in soil.
- AD or composting can produce a feedstock which is better suited for nutrient recovery by an NRT
- NRTs vary considerably in their process, cost, application and nutrient recovery capabilities.
- NRTs can concentrate nutrients into a soil amendment product or fertilizer, and can also make transport more economically viable compared to the untreated manures, particularly if the untreated manure is a liquid.
- The majority of NRTs are designed for liquid manure (dairy manure) or AD digestate and not solid manure (beef manure and poultry litter).
- Most NRTs are focused on P recovery and are not specifically designed to remove nitrogen.
- Biological NRTs, centrifuges, flocculation and ultrafiltration technologies appear to be the most technically feasible, cost –effective and best suited for B.C. farm practices. These technologies could be examined further for operation or site specific feasibility.
- Biological NRTs provide the most direct option for nitrogen removal.
- A site-specific analysis would need to be done to determine the viability of NRTs; however, it is likely that many technologies are not financially viable based on current B.C. market and regulatory conditions. Markets for end-products are emerging and value is unknown; ultimately, the nutrient rich end-product would need to be exported to a destination that requires the nutrient to have a positive impact.
- One way to reduce the cost and thereby improve economic feasibility for any of the technologies considered is to use economies of scale and for several farms to take part. Although, only some of the technologies that were investigated are suitable as mobile units.

Table (1): Manure nutrient management technologies

Technologies	Costs*	Nitrogen Removal (%)	Commercial Success (Scale)	Waste Management Practice Considerations
Anaerobic Digesters	***Capital Cost:*** $1.5M - $8 M	Not applicable N removal from including an NRT after AD system	3 successful AD units in B.C. Small scale not feasible	For liquid manures, not suitable for Beef feedlots or poultry operations
Gasification or Pyrolysis	***Capital Cost:*** $29 M - $49 M ***Operating Costs:*** $0.8 M - $1.7M/yr	100%**	Not for agriculture Large scale	For solid manures Not suitable for liquid manures
Composting	***Capital Cost:*** $8.5K - $5.5 M (dependant on farm size and complexity) ***Operating Costs:*** $1.8 K - $96 K /yr	Not applicable Reduced N mobilization	Common practice on Farms	Can be used for solid manures or separated solids from liquid manures
Solid Liquid manure separation and bedding recovery technology	***Capital Cost:*** $155K - $238K ***Operating Costs:*** $11K - $26K /yr ***Savings:*** $36K-$40K /yr	0% N removal P removal: <20%	Commercially available technology	Mainly used as a first process step in other NRTs or as bedding recovery option P removal is much greater then N removal
Centrifuges	***Capital Cost[1]:*** $100K - $ 300K ***Operating Cost[2]:*** $19K - $21K	25% - 50% P removal: ~50%	Widely used throughout EU and US.	Typically designed for P removal, could be investigated on site by site basis for N removal.
Drying and pelletizing	***Capital Costs:*** Up to $300,000K ***Operating Costs:***	20% And up to 90% if wash water is used	Hundreds of commercial units in Europe May not be feasible without onsite	For liquid manures, beef feedlots or poultry operations. not be feasible for sites without access to

	$10 K (excluding heat)		waste heat.	waste heat
Membrane/ultrafiltration NRTs	***Capital Cost:*** $200K - $500K ***Operating Costs:*** $14K- $22K	50-95%	Limited examples of commercial success for manure; it is an emerging technology. designed for larger scale farms	Used on dairy manures, may apply to feedlots but not suitable for poultry. Needs to be investigated in B.C. conditions.
Flocculation	***Capital Cost :*** $210K - $450K ***Operating Cost:*** $16K - $34K	20-50%	Some commercial success with manure, but mixed results; it is an emerging technology.	Suitable for dairy manures and AD digestate; not applicable to beef feedlot manure and solid poultry manure
Struvite	***Capital Cost:*** $175K - $300K ***Operating Costs:*** $15K - $35K	15-20%	No know examples of commercial success for manure.	for P recovery and is not intended for N recovery; Suitable for dairy manures and AD digestate
Biological NRTs	***Capital Costs:*** $100K ***Operating Costs:*** $23K	50%	No known examples of commercial success for manure. Technology is under development	Suitable for poultry manure or AD digestate; may be suitable for Dairy manures.

* Cost estimates were provided by companies; in many cases, they interpolated costs by scaling down their existing systems to fit the small size of typical B.C. farm (i.e., they only sell much larger systems suited for large US farms);
And
Operating costs are expressed on a yearly basis; maintenance costs, which can be considerable, are excluded from operating costs.
**Manure is assumed to be shipped off farm to a centralized facility.

2. WASTE TO ENERGY TECHNOLOGIES:

2.1 Anaerobic Digesters

Anaerobic Digestion (AD) is a process that converts carbon rich material, manure and other organic by-products, such as food processing waste, in the absence of oxygen. This process generates biogas, a mixture of methane and carbon dioxide, and digestate. Biogas is a methane-rich gas that can be combusted to produce renewable heat, renewable heat and energy, or upgraded and injected into the natural gas pipeline. Anaerobic digesters are most likely to be located on dairy farms as the dry matter (DM) content, buffering capacity, and bacteria present in dairy manure make it a great feedstock for the AD process[1].

AD facilities typically utilize manure as the main substrate, but other materials such as food processing waste and crop residues are added to improve the AD process, increase biogas production and to make the unit financially viable. The AD feedstocks will vary from 25% to 49% off-farm sources, and as the off farm % goes up, the number of economically viable sites in B.C. would increase dramatically.[2] But the use of off farm feedstocks results in the importation of additional nutrients onto the farm[3].

The AD process produces a nutrient rich effluent, known as 'digestate', that can be land applied, upgraded and/or sold off-farm as a value added product. The AD process converts organic N into ammonia (NH_3), which results in a greater proportion of readily available mineral N. Although AD changes the form of N and P in dairy manure, these nutrients are not significantly reduced during the AD process and remain in the digestate.

If a surplus of nutrients is identified in the AD nutrient management plan the excess nutrients and/or the digestate will need to be removed from the farm[4] . A nutrient recovery system can be used; however, this will greatly increase the capital expenses of the system.

Another major consideration is the associated hauling and delivery costs as there is an extensive cost for shipping liquid dairy manure (95% water) over long distances. As with dairy manure, digestate has fairly high moisture content and the transportation off-farm could be costly. If the AD facility is located off-farm it is not considered financially feasible to export liquid dairy manure from the farm to the AD unit.

Feedstock considerations:

- The influent to an AD system needs to be homogenized and have a solids content of less than 14%.

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[1] Evaluation of Nutrient Recovery Technologies for Dairy Manure and Digestate http://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/agricultural-land-and-environment/waste-management/manure-management/evaluation_of_nrt_dairy_manure_digestate.pdf
2 British Columbia On-Farm Anaerobic Digestion Benchmark Study
3 British Columbia On-Farm Anaerobic Digestion Benchmark Study
4 Evaluation of Nutrient Recovery Technologies for Dairy Manure and Digestatehttp://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/agricultural-land-and-environment/waste-management/manure-management/evaluation_of_nrt_dairy_manure_digestate.pdf

- AD systems require feeding on a daily basis, and manure management systems must be capable of facilitating this feeding regime.

Dairy operations are particularly well-suited for AD systems. A solids content of 7% – 10% is common for operations with slatted floor, alley scraper or manual manure collection systems. Those with flush barns will likely have to low of a solids content, resulting in decreased biogas production per tonne of manure, and are not suitable for digesters unless water is removed.

Beef feedlot manure management practices make it not suitable for AD systems. Many beef cattle operations are primarily outdoor feedlot operations in which cattle manure is deposited into the feeding pens and will have a significantly higher solids content (above 25% is common). As well, manure collection and management is intermittent, whereas an AD requires continuous feed.

Poultry manure is a highly challenging feedstock for AD systems as a result of its high solids content (40% – 60%), and high N content. An excess of N in an AD system can result in biological inhibitions and system failure. While it may be possible to use in an AD system, poultry manure should only be included only as an additional feedstock.

End Use Markets

Digestate, material which has been through the AD process, has favourable qualities as compared to raw feedstocks, and is being used directly as a stable fertilizer and soil amendment. Further processing of digestate with solids separation technology makes it an excellent source for livestock bedding. The nutrient availability in digestate also makes it a good fit for further processing with nutrient recovery technologies (nutrient availability facilitates nutrient recovery). For example, some flocculation technologies that are considered in this report are only applicable to digestate and not to any other raw manure. Likewise, the ammonia-N stripping biological NRT is a natural fit with digestate than manure because AD increases the proportion of N in ammonia form, raises pH and produces free heat.

Economic Info:[5]

A British Columbia on-farm AD benchmark study was recently completed to provide a point of reference from which individuals and groups in the agricultural sector in B.C. can inform decisions relating to the development of on-farm AD systems. The study aimed to establish electricity and biomethane tariffs and funding benchmarks to make AD systems economically viable. Although an AD project is highly site specific, this gives us a point of reference for costs of small, medium and large facilities.

Capital costs associated with the installation of AD systems were estimated based on leading AD technologies from multiple jurisdictions. The total budget of an AD system would include the capital costs, of the AD unit and the co-generation unit or biogas upgrading system, project development, operating expenses and other costs. If a nutrient recovery system is required to ensure compliance with a NMP there would be significant additional capital cost. These systems are typically intensive and are considered independently further in this report.

[5] British Columbia On-Farm Anaerobic Digestion Benchmark Study – pg 25

The required energy tariffs and funding requirements change based on the farm size, and generally the AD system becomes more economically viable as the farm size (or manure input) goes up. Table (2) below shows the range of capital costs for the sites investigated in the benchmarking study. To be economically viable the AD systems require electricity or biomethane tariffs as shown or alternatively they require a level of funding for the capital costs.

Table (2): Anaerobic digester economic comparison based on size of farm

	Input of (__%) of Non-Agricultural Feedstock (%)	**Capital cost range (Millions)**	**Electricity tariffs needed**	**Biomethane tariffs needed**	**Funding needed at current SOP***	**Funding needed at current biomethane rate** ($15.28/GJ)**
small farms (i.e. < 100 lactating cows or 3,500m3/year agriculture feedstock)	**25%**	$1.5 - $2.5	$0.54 – $0.55/kWh	$94 - $97 /GJ	100%	100%
	49%	$2.3 - $3	$0.25 – $0.35/kWh	$30 – $45/GJ	90% - 95%	80% -85%
medium-sized farms (i.e. 100 – 250 lactating cows, or 3,500m3 – 9,000m3/year agricultural feedstock)	**25%**	$1.6 - $3	$0.36 – $0.43/kWh	$46 – $71/GJ	100%	90% – 100%
	49%	$2.5 – $3.7	$0.19 – $0.29/kWh	$21 – $34/GJ	60% – 85%	0% – 60%
large-scale farms (i.e. 251+ lactating cows or greater than 9,001m3/year agricultural feedstock)	**25%**	$2.5 – $7.5	$0.19 – $0.35/kWh	$18 – $41/GJ	60% – 100%	40% – 85% funding
	49%	$2.3 - $8.2	$0.16 – $0.20/kWh	$14 – $18/GJ	35% - 80%	0% – 35%

* B.C. Hydro currently has a Standing Offer Program (SOP) that pays $0.10/kWh for renewable electricity.
**in the benchmarking study, FortisB.C. allowed their biomethane tariff of $15.28/GJ. In the near future FortisB.C. may pay more per Gigajoule of Renewable Natural Gas because of recent changes made to the Clean Energy Act.

For small farms in B.C it is unlikely that AD systems will be economically viable because the required tariffs and funding amounts are much higher than currently available. For medium-sized farms it is unlikely that more than a small handful of AD systems will be economically viable because the required tariffs and funding amounts are also not currently available. But as the tariffs for renewable energy are increased, or the necessary funding is made available they may become more viable.

For large-scale farms, AD systems that digest 49% non-agricultural feedstocks and produce biomethane may be economically feasible using the biomethane tariffs that are currently available ($14 – $18/GJ) and may require no additional funding to achieve a positive return on investment. However to produce electricity, they would require either a higher electricity tariff ($0.16 – $0.20/kWh) or government funding (45% – 55%). Although an AD project is very highly site specific.

In terms of infrastructure, electricity production scales-down more than biomethane production allowing smaller scale AD units. But to be economically viable according to the benchmarking study, B.C. hydro needs an electricity tariff of $0.14/kWh – $0.20/kWh, or the provincial government will need to provide 40% – 50% funding per AD unit. Changes made to the Clean Energy Act in March 2017 enable utilities providers to pay more per Gigajoule of Renewable Natural Gas, up to $30/GJ (previously $12-13/GJ). In the near future, facilities producing biomethane for sale to FortisB.C. may be more financially favourable. However, on-farm AD systems must be in locations favourable to the FortisB.C. grid, which may limit the biogas option to a small percentage of farms.

Conclusions:

Anaerobic digestion is not a solution to nutrient management problems as it allows more nutrients to be brought onto a farm, but if a proper nutrient management plan is in place and the AD system is combined with export/upgrading of nutrients it may provide diversification of revenue for the farm and prevent nutrient overloading.

Only AD systems able to generate biogas from at least 200 lactating cows, with favourable manure collection methods, and in locations favourable to natural gas infrastructure, are likely to adopt AD.[6]

Gasification and Pyrolysis

Gasification and pyrolysis are thermal conversion technologies to turn wastes into gas or electricity generation. *Pyrolysis* is a thermochemical decomposition of waste at relatively high temperatures 800 – 1,400^{o}C in the absence of oxygen to make char, bio oil and syngas. Gasification is a similar process with the main product being a combustible gas called syngas and a by-product ash. Syngas can be utilised in a range of applications to produce renewable heat, or heat and electricity, but the quality and energy content of syngas greatly affected by type of technology and feedstock used.

There are over 150 gasification applications worldwide, but mostly used for specialized waste such as wood waste. Nexterra provides a proven commercially available technology of combined heat and power (CHP) bioenergy system from wood (bark/chips, sawdust). Gasification of agricultural residues, including poultry litter, manures, and animal carcasses, are under development and in the research

[6] British Columbia On-Farm Anaerobic Digestion Benchmark Study

phase. All commercially available technology is operated a large scale, considered industrial, and are not suitable for on-farm.

Recently, B.C. Agriculture, AGRI and ARDCorp have completed two feasibility studies on proposed gasification plants. Both feasibility studies were for large scale gasification plants located adjacent to another facility that could utilize the energy generated from the gasification plant. There are no known small scale systems used commercially in agriculture, although there may be small scale systems in the beginning research phase. Small systems have been successful for other materials such as wood chips, but manure is a very different feedstock.

One of the feasibility studies focused on a feedstock mix of poultry litter, and specified risk material (SRM), with fairly high moisture content. The other study was on a mix of Poultry litter and used horse bedding. The energy generation potential and costs of the plants is listed in table 3. It was found that a significant amount of energy would be needed to remove moisture from the feedstocks to allow gasification. This significantly increased the costs of operation and infrastructure required.

The success of a gasification plant is feedstock. Currently most gasification technologies require low moisture content feedstock. The two major findings from the feasibility studies were about the feedstock and the location. The feedstock had to be reduced to <12% moisture content for efficient gasification[7]. Poultry litter alone or in a mixture with woody bedding material is the ideal feedstock for gasification or pyrolysis. As well, the process produces significant heat; so not only does the facility need to be located in close proximity to the feedstocks, it will require a location with a sufficient on-site heat demand. Additionally, it will need to be able to connect to the B.C. Hydro grid with minimal difficulties.

Table (3): Gasification plant comparison

	Energy produced	**Feedstock volume**	**Capital costs And (operating costs)**	**Funding likely need for economic viability**
Nexterra facility on UB.C. campus	2 MW electricity and 3 MW of thermal energy	N/A	N/A	N/A
Poultry litter and animal carcass gasification plant[8]	20.8MW Heat*	52,500 tonnes/year	$49,950,000 ($850,000/yr)	$24 Million**
Poultry liter and horse bedding gasification plant[9]	3.95MW of renewable electricity and heat and 1.85MW of heat	50,000 tonnes/year	$29,315,000 ($1,733,000/yr)	$11.7 million***

* Located on a cement plant site, the gasification plant will supply about 75 GJ/h of energy to the cement kiln
**Based on a net present value of 0% and real ROE of 3.5%

[7] Used Horse Bedding & Broiler Litter Gasification Feasibility 2015
[8] Project Definition and Feasibility Study for Poultry Litter and Animal Carcass Gasification Plant 2010
[9] Used Horse Bedding & Broiler Litter Gasification Feasibility 2015

***Based on an internal ROR of 16.1%

Environmental:

From a nutrient removal perspective, gasification and pyrolysis would be considered to be 100% removal of the nutrients from the manures that are inputted into the system, since the products are fully utilized or disposed of off-site. Although N would be released in the air emissions associated with electricity generation or the burning of the Syngas. There are very little nutrients in the bio oil or the ash product produced.

Economic:

All economic info that has been derived is for large scale gasification plants. There are no known small scale systems that are currently available for agriculture. A gasification plant in B.C. would be a centralized facility that would collect wastes from several farms (10+, depending on size). It would not likely be placed on a farm as they are industrial facilities. The costs from two reports suggest a range from $29 Million - $49 Million in capital costs plus operating costs.

Conclusions:

The feedstock for gasification or pyrolysis is the key driver for feasibility. Moisture content and contaminants affect the infrastructure needs and therefore the overall feasibility. Diary manure is not a feasible feedstock for this technology, but poultry litter and beef feedlot manures could be considered after analysis of the feedstocks. Siting of the facility is also a key driver, as the costs are reduced if the facility links with another facility that could utilize the energy generated.

3. COMPOSTING

Composting is the managed aerobic decomposition of manure or other organic materials to a condition sufficiently stable for beneficial storage and use. Compost, the resulting product, is an odorless, low-moisture-content, fine textured material that can be used as a fertilizer or bagged and sold for use in nurseries and gardens. Composting is a tool for the management of agricultural wastes, and can be used to produce soil amendments for field application.[10]

Solid manures such as poultry manures, manure from beef operations, and solids separated from dairy manure or dairy bedding are suitable feedstocks for composting. The optimal moisture content of feedstock is 45- 60% moisture[11]. If the moisture content is greater than 60%, water will force air out of pile pore spaces, resulting in anaerobic conditions. Liquid dairy manure is typically greater than 80% moisture, beef cattle manure is on average 60% moisture and poultry litter is on average 40% moisture.[12]

[10] Compost Farm Practice Factsheet
[11] Compost Facility Operator Manual
[12] Compost Facility Operator Manual

Raw liquid dairy manure is not suitable for composting due to its high liquid content unless a dry material such as bulking agent is added. Alternately, dairy manure can undergo a solids separation technology and only the solids are composted.

Environmental:

One of the many benefits to composting is that when compost is used as a soil amendment it enables the soils to retain and utilize the nutrients longer, which can lead to improved matching of the crops needs. If compost is land applied properly based on timing and rates, it can lead to reduced nutrient leaching; even so, composting it is not considered a nutrient reduction technology.

During composting, the organic N in mature becomes more stabilized and is not as readily available for mineralization as that found in raw organic materials[13]. There is little information available on the effect of land applying compost on nitrate leaching; however it is expected that the mineralization rate can be reduced from 35 %/66%[14] (cow and poultry manures respectively) to 8-12%[15] for finished compost. The reduced mineralization rate helps to match the crops needs more closely and can potentially reduce nitrate leaching. [16] Some nitrate losses into the groundwater can be expected, but it can be assumed that losses are usually less than if the same amount of N was applied in forms of mineral fertilizer or direct manure application. [4]

Another thing to note is the volume reductions. During the composting process, the total volume of the composted material decreases and may shrink between 40 ‐ 60% by volume[17], which can make handling and transportation of compost easier than its raw manure counterparts.

Economic:

Composting methods vary in their degree of management and infrastructure requirements. Facilities are used to store and manage both raw materials and finished compost. The infrastructure needs may include impervious pads or buildings, equipment for ventilation and mobile equipment.[18] Composting system complexity can vary from simple open piles, open bunkers, covered piles, to heavily managed systems like in-vessel/container systems.[19] The costs associated with composting vary greatly based on the complexity and the size of the farm or if manures are composted at a centralized facility. Table (4) shows the capital cost ranges shown per tonne of manure throughput assuming a minimum of 50,000 throughput tonnes per year. This is a very large scale facility and could be scaled down for on-farm composting. An average feedlot produces 11,000 tonnes per year and an average poultry farm produces 213 tonnes per year (calculation in appendix).

[13] Compost Maturity and Nitrogen Release Characteristics in Central Coast Vegetable Production, 2002
[14] Nitrogen and Carbon Mineralization Dynamics of Manures and Composts
[15] Compost Facility Operator Manual
[16] Compost Maturity and Nitrogen Release Characteristics in Central Coast Vegetable Production, 2002
[17] Compost Facility Operator Manual
[18] Compost Farm Practice Factsheet
[19] http://www.compost.org/pdf/compost_proc_tech_eng.pdf

The total cost of a composting facility is hugely variable and on-farm composting could range from $8.5K – $5.5 Million, depending on the type, amount and handling techniques of manures and the complexity of the compost system.

Table (4): Potential Capital Costs of Composting[20, 21]

System	Cost to produce compost $/tonne of throughput	Capital costs
Open Pile	Static : $15- $40 Including turning aeration : $40-$60	
Open Windrow	Static : $15- $40 Including turning aeration : $40-$70	
Open Bunkers	$15- $40	
Covered Pile	$100- $150	
Vertical silo System	$300- $500	
Container system	$300- $500	
Tunnel System	$300- $500	
Transportation cost*	$16/tonne compost or $8.8 /tonne manure**	
Average of Compost systems	$40-$500/tonne manure capital costs	$8.5K – $106K for poultry operations $1.4K - $5.5M for beef feedlot operations

*based on Poultry litter transportation, assuming a 2 hr travel time for 25 tonnes in a truck. Calculation in appendix.
**Assuming a 45% mass reduction

Compost is a relatively stable product that can be used on farm or transported off-farm. Because of its moisture content it is much easier to transport then raw liquid dairy manure. Compost is similar in consistency to raw poultry manures, so it would likely have similar transportation costs.

An off-farm end market for compost is not identified; however in the current waste management climate the local governments are now composting much of their organic wastes due to waste diversion strategies making it a competitive market for selling compost22. Therefore, the generation of compost currently is much more than the market demand and an end market will not be identified.

Conclusions:

Composting is a relatively well known technology for agricultural operations. But composting is not a N removal technology and its ability to prevent leaching is unknown. Because of its moisture content, compost is much easier to transport than raw liquid dairy manure. Compost does produce a stable

[20] What is the highest and best use of Organic Solid Waste: Production of Compost or Production of Energy? 2012
[21] http://www.compost.org/pdf/compost_proc_tech_eng.pdf
[22] City of Vancouver solid waste division report 2011

product that can be used on farm or transported off-farm. For poultry and beef manures, the benefit of composting comes from the volume reductions. The reduced weight and stability of compost means that the compost can be stored and transported more easily to value-added markets.

However, the costs and availability of markets associated with composting may offset these benefits.

Raw dairy manure, without separating solids, is not suitable for composting due to its high liquid content. For dairy manures to be directly composted, large amounts of bulking material must be brought on farm and this is not typically done. Consequently, for dairy manures composting is typically done after using a solids separation technology to significantly reduce the liquid content, creating a solids fraction and a high N liquids fraction (see the section on solids separation for more details). Alternatively, dairy manure that has been digested in an anaerobic digester can be composted.

Overall, composting is not a solution on its own to reduce N excess on farms. The feedstock source, moisture content and final products must be taken into account when deciding on composting.

4. MANURE INJECTION TECHNOLOGY

The conventional means of applying manure in B.C. is to broadcast apply it onto the surface of tillage or grassland using a splashplate. The method of manure application can significantly impact the nutrient losses in the soil.

Efficient liquid manure application systems (commonly called 'manure injection') offer a number of advantages over broadcasting:

- reduces odours and ammonia emissions
- ability to place nutrients directly into the seedbed
- reduces loss of nutrients to the environment
- increases ability to offset fertilizer costs

The main reason farmers use a manure injection as an application method is because it may improve the amount of nutrients available to the plant and therefore may improve yield. Manure injection technologies reduce the loss of N to surface runoff and as ammonia emissions to the atmosphere. The ammonia emissions reductions that can be achieved have been well documented. However, because there is less N lost as ammonia and more N is conserved for plant growth, there is no net reduction of N being applied. Therefore, this is not considered an option for reducing N leaching. In reality, on some soils there is a risk that nutrients from injected manure will move directly into tile drains and surface waters.

5. NUTRIENT RECOVERY TECHNOLOGIES

Nutrient recovery technologies (NRTs) are a potential solution to enable farms with nutrient excess to bring their cropping system into equilibrium. NRTs can concentrate nutrients into a soil amendment product, and can also make transport more economically viable. There are many manure and digestate NRTs currently available or under development in Europe and North America. These technologies vary considerably in their process, cost, application and nutrient recovery capabilities. Despite this variability, in general mechanical, chemical and biological NRTs can be used as standalone technologies, or in combination with other technologies, to recover nutrients from dairy manure and digestate.

Two reports have been completed recently in response to information needed on nutrient recovery technologies: Evaluation of Nutrient Recovery Technologies for Dairy Manure and Digestate (referred to throughout document as NRT report) and Regional Nutrient Management Planning Pilot Project Feasibility Study for Mobile Centrifuge Unit and Group Manure Injector (March 2015). Information in this section is summarized from these two reports.

Mechanical Recovery Technologies

These technologies remove the larger fibers in manure and digestate, which if sufficiently cleaned, can be re-used for bedding. Used on dairy farms in both Europe and North America since the 1970s to reduce bedding costs, maximize liquid storage, and make manure storage, handling and transportation easier, the N and P recovery abilities of these technologies are low (~10 – 20% total N and P). Advanced mechanical NRTs such as centrifuges, membranes and dryers have been developed to increase P recovery; these advanced mechanical NRTs have a much higher nutrient recovery potential than screens, screw or belt presses.

Solid Liquid manure separation and bedding recovery technology

Solid liquid manure separation technologies, involves the partial removal of solids from liquid manure (slurry). The process converts the initial slurry manure product into two streams: solids and liquids.[23]

Solid/liquid manure separation is generally conducted using a gravity system or mechanical separation system. The gravity separation system involves the use of settling basins where solids settle to the bottom and the liquid portion remains at the top and is pumped out to a separate tank for storage or application. The mechanical separation system uses some form of mechanical process to separate liquids from solids. A variety of systems are available on the market such as vibrating screens, roller systems, rotary centrifuges, and screw presses. The appropriate type of mechanical separation system will depend on the specifics of the manure and farm in question. With all types of mechanical separation systems, the solid component is separated from the liquid component and the streams are stored separately.

Bedding Recovery Systems take the manure from a dairy operation and convert a portion of it into bedding material for cows through a composting process. A bedding recovery system is a two-step process:

Step 1. Liquid/slurry manure is separated into solid and liquid streams using a solid/liquid manure separator, such as a screw press. The purpose is to reduce the separated solid component to

[23] Report: Beneficial Management Practices, Series 3: Treatment Systems for Solid or Liquid Manure (0201) http://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/agricultural-land-and-environment/waste-management/manure-management/382000-1_socioeconomic__environmental_review_of_bmps_2014.pdf)

approximately 65% to 68% moisture content. Solids can be separated from manure as well as anaerobic digestate.

Step 2. The separated solids are then fed into a drum that rotates and draws in fresh air to feed the aerobic bacteria creating ideal conditions for composting. When the composting process is complete, the solids are ready to be used as livestock bedding.

The solid component produced from either of these can have a variety of uses such as land application, green bedding, soil amendments or solids can be composted for use or sale.

Typical uses for the liquid component are use in in-barn flushing systems; or as a source of irrigation water.

Environmental:

The main process of solid liquid separation produces solid and liquid components with different N:P ratios. The N is concentrated into liquid fraction of the output and the P is split between the liquid (~80%) and solid (~20%) fractions. The solid liquid separation technology can lead to a decrease in the volume of manure being applied and a change in the nutrient content of the manure if only the liquid fraction of manure is applied on-farm, and the solid portion is used elsewhere.

Economic:

The BMP Program has cost-shared the implementation of solid-liquid separation equipment, bedding recovery units and nutrient recovery technology since the 2009/10. For example in 2013/2014 the cost share was 30% up to $50,000. A Beneficial Management Practices (BMP) review was completed on this technology that included the feasibility and average costs of implementing the systems on dairy farms in B.C..

The economic information on this technology was derived from the BMP review. Solid component of solid/liquid manure separation is more cost effective to transport due to its lower moisture content and the liquid component is easier to apply/irrigate due to reduced viscosity. Therefore the solid component can be easily transported for use on site, removal off site or further treated to make bedding. However, taking the additional step to bedding creates a higher initial investment cost and ongoing operating costs.

The average implementation cost of a solid liquid separation technology BMP project was $175,000.[10] Each farm that implemented a solid/liquid separation or a bedding recovery system experienced annual increase in repair and maintenance costs, and operational costs as shown in Table 5.

These costs are generally attributed to the additional power (mostly hydro-electricity) needed to operate the systems.

Co-Benefits:

Solid liquid separation technology can be used as bedding recovery units to generate bedding on site and replace the costs of bringing in bedding to farms. On dairy farms in B.C. it is estimated that a bedding recovery unit could save on average a $21,800 - $33,400 per year in bedding costs and additional revenue from fertilizer savings, manure application costs, bedding sales, crop yield changes, and animal health costs.

Table (5): Average costs of solid liquid separation technology and bedding recovery units for B.C. farms[24]

	Capital Costs	Operational costs	Co-Benefits Savings*
Solid/Liquid Separation	$155K	$26K /yr	$36K per year
Bedding Recovery Systems	$238K	$11K /yr	$40K

Conclusions:

Solid liquid separation mainly applies to dairy manure. It concentrates the N in the manure into a liquid that is typically applied on site as irrigation, fertilizer or used as wash water. It does not reduce the overall N content from manures. It is typically used to separate the solid fraction that can be used as a fertilizer, compost or as bedding material. It has been considered as a P recovery option and not as an N recovery technology (although minimal <20% P reductions, 0% N removed from farm). Solid liquid separators such as screw presses have been used as a first step for other nutrient recovery options.

Centrifuge

Centrifuges spin at high speeds to create a strong centripetal force that separates materials of different densities, such as suspended solids from liquids. If sand is used for bedding this should be separated prior to the centrifuge, avoiding wear on the technology. The manure separation process for most systems includes a de-waterer and roller press to remove the fibrous solids and a centrifuge to separate the fine solids and liquids. Some units also contain a pre-treatment tank for optional use of chemicals to increase separation efficiency. The volume of each fraction and its nutrient concentration varies by the animal type, manure management practice, type of feed and bedding, and the specific separation technology.

Centrifuges are the most widely used NRT in US and Europe and are typically used to dewater slurries or flush swine barns in the USA.[25] A centrifuge removes typically 70-85% of suspended solids in fresh flushed dairy or swine manure waste.[26] This allows for more accurate application of the solids to land (or for export). The remaining effluent (liquids fraction) still contains nutrients but at a lower level.

[24] Beneficial Management Practices, Series 3: Treatment Systems for Solid or Liquid Manure (0201) http://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/agricultural-land-and-environment/waste-management/manure-management/382000-1_socioeconomic__environmental_review_of_bmps_2014.pdf
[25] Environmental Technology Verification Report 2003 (triton report)
[26] Environmental Technology Verification Report 2003 (triton report)

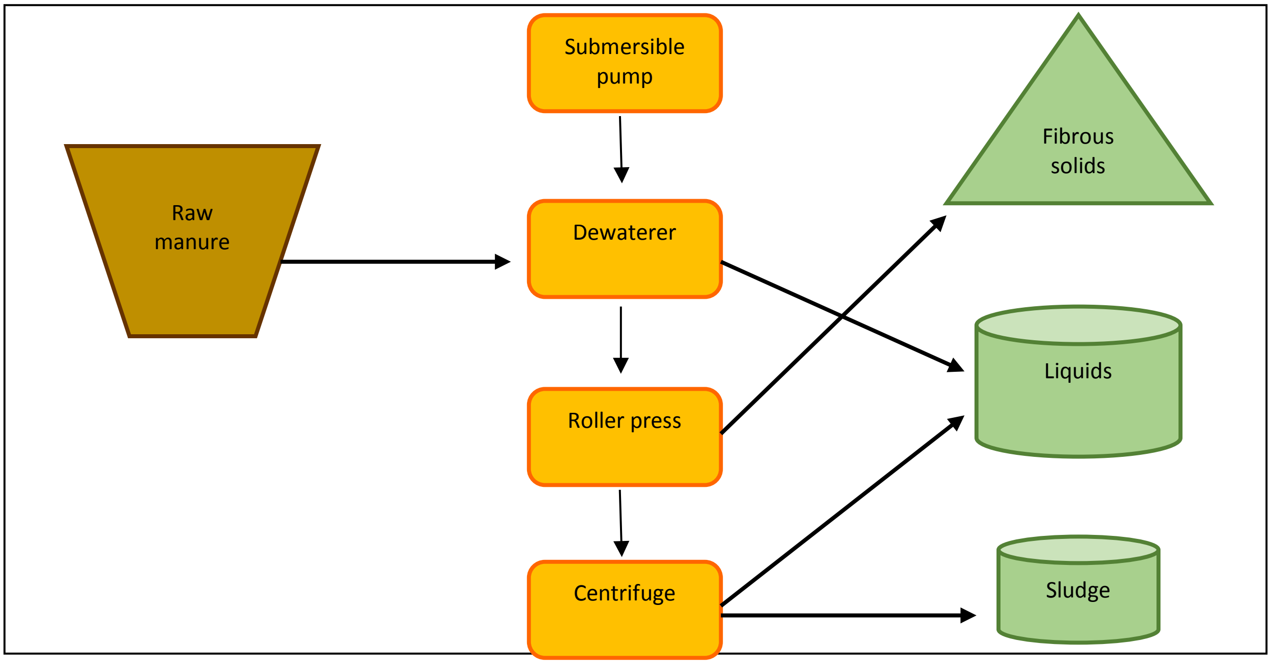


Figure (1): Flow diagram showing separation process from raw manure to end-products.

There are multiple stationary centrifuge units available for manure separation, mostly from Europe and the United States (US). The units listed in Table 6 represent makes used in literature and/or available through local dealers[27]. A small centrifuge with a small footprint can potentially be made mobile with the addition of own power source, and a trailer for mobility. Most centrifuges available that are considered small units by industry standards but are too large for use as a stationary unit by a single B.C. dairy. There are other technology suppliers out there, but no easy to access information on usage in dairy manure was available. More information is needed.

Centrifuge NRTs recover <25% of the N and ~50% of the P from manure or digestate to produce a ~25% DM P-rich cake, and are cost competitive with other NRTs.[28] Although it has been found that in the fibrous separated solids up to 50% of the organic N can be removed.[29] Local data is necessary to obtain more accurate nutrient removal efficiencies as current data is from Europe and the US or simply not available.

This NRT has been widely adopted by dairy farms in Europe and North America, and has the potential to be mobile (moving from farm to farm).

[27] Evaluation of Nutrient Recovery Technologies for Dairy Manure and Digestate
http://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/agricultural-land-and-environment/waste-management/manure-management/evaluation_of_nrt_dairy_manure_digestate.pdf
And
RNMP Feasibility Study for Mobile Centrifuge Unit and Group Manure Injector 2015
[28] Evaluation of Nutrient Recovery Technologies for Dairy Manure and Digestate
http://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/agricultural-land-and-environment/waste-management/manure-management/evaluation_of_nrt_dairy_manure_digestate.pdf
[29] Ma, Jingwel, Nick Kennedy, Georgine Yorgey and Craig Frear. 2013. *Review of emerging nutrient recovery technologies for farm-based anaerobic digesters and other renewable energy systems*

Table (6): Commercially available centrifuge suppliers

	Recovery efficiency	Mobile?	Smallest size	Capital Cost (operating costs)	Availability/usage
Alfa Laval*	20% N 60% P 50% K	potentially	180 milking cows	$100,000 ($21,000)	five Alfa Laval systems on dairy farms globally
Daritech / DT1035 Vision DT1448	20% N 50% P 25% K	Y	480 milking cows	$290,000 - $567,700 ($256,423)	half a dozen DariTech systems on dairy farms in Washington State.
GEA AGM25 **UCD 205 Skid**	20% N ** 50% P 25% K	Y	~400 milking cows	$300,000 - $717,700 ($244,687	dozens of GEA systems on dairy farms globally
Triton TS-5000	25% N 50% P	N/A	N/A	http://www.kcentrifuge.com/centrifuge-inventory/centrifuge-details.asp?product=93	Research phase for dairy manure

* Doesn't include the cost of other need components, such as pre-removing large fibre, trailer for mobility, generator, pumps, etc.
** With flocculants, N and P recovery efficiency can be as high as 50% and 90%, respectively.

Environmental:

Case studies:[30]

- A recently initiated study for the Chesapeake Bay area includes construction and field testing a full-scale mobile treatment system to include an auger press and centrifuge combined with chemical treatment and filtration that would remove up to 99% P. No further information is available as this work is in the initial stages.

- A trial-based mobile centrifuge unit developed in Chico, California was tested using dairy and hog manure. Although most manures were from a flush system with less than 2.7% total solids, the unit was able to successfully separate manures with up to 6% solids. With the use of a flocculent, 90% of the total P was removed from raw manure.

End use markets:

Potential markets and end uses are only discussed for the fibrous and sludge fractions. The transportation costs of the liquid fraction would be too expensive and would not likely be recovered.

[30] RNMP Feasibility Study for Mobile Centrifuge Unit and Group Manure Injector 2015

Potential markets and End uses of the fibrous solid fraction and sludge:

- Fertilizer and soil amendment for on-farm use in place of current poultry manure. The problem with adding poultry manure is the high concentration of P. This would be alleviated by incorporating separated fibrous dairy manure solids
- Bedding material for the cows
- Export to other farms or local gardens as manure
- The N in the fibrous solids can be used as a replacement for urea fertilizer
- The P-laden sludge fraction would be most useful as a fertilizer.
- The sludge could be exported in bulk to areas with low P soil contents but these markets are not likely in Canada or even in the US[31]

It is difficult to put an exact value on the marketability of ether of the solid components since costs depend on the fertilizer form required by a potential market.

Economic:

For a mobile unit it is estimated that one centrifuge unit would have the ability to service sixteen farms on a monthly basis (estimated monthly volume of 685,000 litres/farm). Based on a 10 year lifespan, the total estimated costs of the DariTech and GEA mobile centrifuge units are $2,564,230 and $2,446,870 respectively. Considering the costs and technological requirements of the unit, it is unlikely that an individual dairy farmer would finance or operate such a unit. Mobile centrifuge units are viable options for manure separation, and are commercially available. Therefore it is likely that a third-party, likely a custom manure applicator would manage the process as a value-added service.

Conclusions:

A centrifuge removes typically 70-85% of suspended solids, and 20%-50% of the N. The remaining effluent (liquids fraction) still contains nutrients but at a lower level.

Potential markets for the fibrous and sludge fractions would need to be investigated for B.C.. Liquid transportation costs are too expensive.

Considering the costs and technological requirements of the unit, it is unlikely that an individual dairy farmer would finance or operate such a unit. Therefore it is likely that a third-party, likely a custom manure applicator would manage the process as a value-added service. Mobile centrifuge units are viable options for manure separation, and are commercially available. Site specific information is required to calculate the costs, and local data is necessary to obtain more accurate nutrient removal efficiencies.

[31] RNMP Feasibility Study for Mobile Centrifuge Unit and Group Manure Injector 2015

Membrane/ Ultrafiltration NRTs

Membranes act as a filter, letting liquids flow through while catching suspended solids and other substances. Two membrane technologies were looked at in the NRT report.[32] Both membrane systems are suitable for manure or digestate but if sand is used for bedding this must be separated prior to the membrane technology.

Environmental:

Livestock Water Recycling (LWR) supplies a membrane NRT combined with a primary solid-liquid separator and a screw press. It produces a ~25% DM, nutrient-rich cake containing roughly 75% of the N, 90% of the P and 40% of the K in the feedstock. The liquid then enters a membrane system for further N recovery. The membrane system removes all salts and larger particle sized microbes to produce clean water for re-use in barns or irrigation. Ammonia removed by the membrane system is then concentrated into liquid fertilizer. The total nutrient recovery is >95% N, >95% P and >95% K. New Logic Research (NLR) supplies a membrane NRT combined with reverse osmosis. New Logic's VSEP technology can produce a ~10% DM nutrient-rich cake containing 50% of the N, >90% of the P and 30% of the K in the feedstock.

Ultrafiltration is a variety of membrane filtration in which uses pressure or concentration gradients to a separation through a semipermeable membrane. *McLanahan combines ultrafiltration with air* stripping and absorption to volatilize ammonia and absorb into a solution. Ammonia recovery rates can vary from 40 – 90%. The solution can be further dehydrated to create a dry product. If cleaner water is required, reverse osmosis can be used to remove potassium, remaining P, most metals, and all pathogens. Suitable for manure or digestate, pre-removal of large fibre and sand is required for technology performance. This system would produce a ~7% DM P and N-rich.

Table (7): Membrane/ Ultrafiltration technology comparison

	Recovery efficiency	*Mobile?*	*Smallest size*	*Capital Cost (operating costs)*	*Availability/usage*
Livestock Water Recycling - Membrane (Alberta, Canada)	>95% N >95% P >95% K	Not possible	Intended for >1,100 milking cows **	$500,000 ($18,000/year)	Thirteen farms in the US
McLanahan - Ultrafiltration and air stripping (Pennsylvania,	50% N* >95% P 30% K	Not possible	Intended for >1,000 milking cows **	$200,000*** ($22,000/year)	Demo farm project only

[32] Evaluation of Nutrient Recovery Technologies for Dairy Manure and Digestate http://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/agricultural-land-and-environment/waste-management/manure-management/evaluation_of_nrt_dairy_manure_digestate.pdf

USA)					
New Logic Research - Membrane (California, USA)	50% N**** >90% P 30% K	Potentially (for smaller systems)	180 milking cows	$320,000 ($14,000/year)	Few farms in Europe

* If air stripping and absorption is used, capture efficiency for N and P is >90%.
** Technology can be designed for smaller farms.
*** Estimate provided by McLanahan for >1,000 milking cow farms was US$350/cow, resulting in CAPEX of $60,000 for a 125 milking cow farm , a more realistic cost estimate is used as scale down to this level generally results in higher $/Cow.
**** If fitted with reverse osmosis membranes, capture efficiency for N, P and K is >95%.

Conclusions:

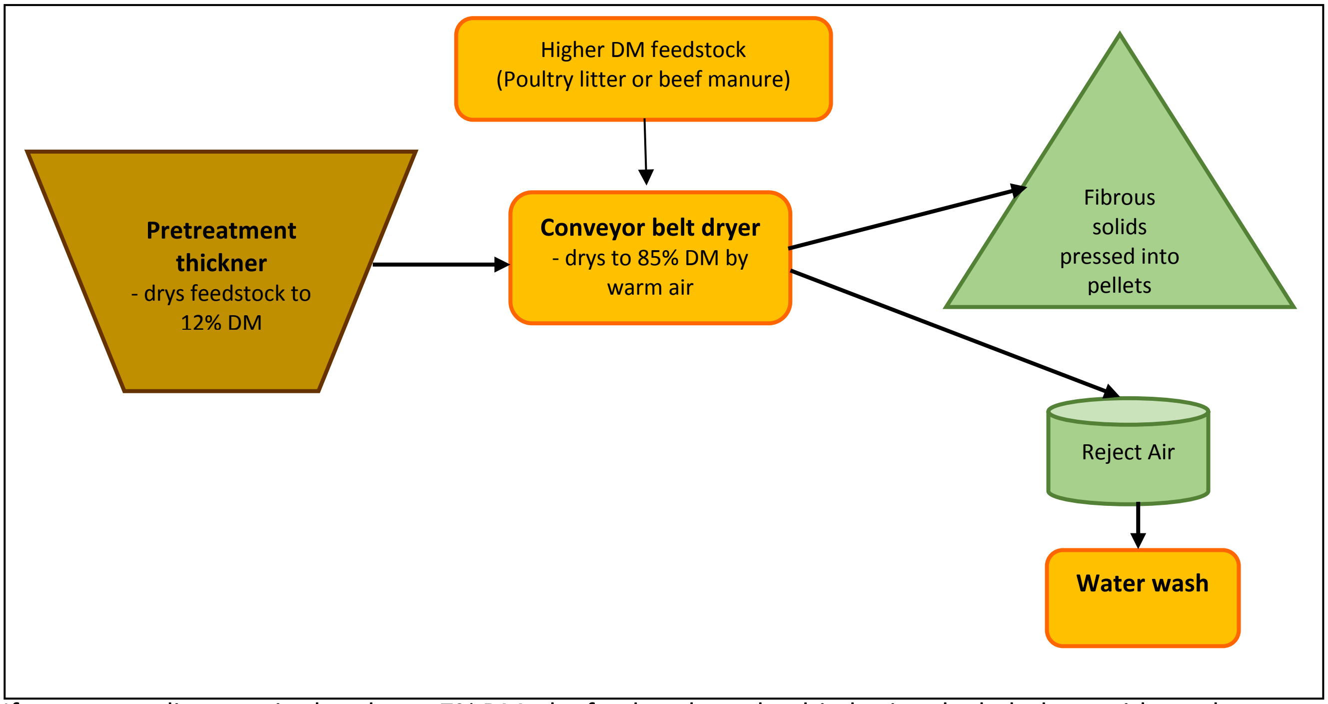
Membrane or ultrafiltration is currently being used on liquid dairy manures, but may be able to be applied to beef feedlot manure but it is not suitable for solid poultry manure. The resulting products are a cake that is easily transported off farm and clean wash water or for irrigation. The technology is currently in the commercial or research phase and is primarily designed for larger scale farms. Smaller scale units could be investigated with the suppliers. Another option is to reduce components to reduce the overall capital costs, although this would reduce the nutrient recovery capability. For instance the final membrane in the Livestock Water Recycling system may be able to be removed and there would still be roughly 75% of the N and 90% of the P overall nutrient recovery, although the waste water would still have nutrients and not be 'clean water'.[33]

The end use markets of the nutrient rich cake that is produced would need to be investigated on a site by site basis.

[33] This is the writers opinion and would need to be verified with the technology suppliers.

Drying and Pelletizing

Dryers evaporate the water, leaving behind solids. One technology, Dorset Green Machines (DGM), was investigated through the NRT report. The technology consists of a number of separate technologies. These technologies, which can be combined to meet specific needs:



If manure or digestate is already at >7% DM, the feedstock can be dried using the belt dryer without the pre-treatment thickener which is useful for beef feedlot manures or for poultry litter.

A sulphuric acid wash system can be installed to clean reject air from the dryer, converting ammonia into ammonium sulphate. A water curtain is also used to capture any dust. Nutrient recovery for the thickener, belt dryer and wash system is roughly >90% of the N, P and K in the feedstock, while for the thickener and belt dryer it is roughly 20% of the N, 50% of the P and 25% of the K.

There are hundreds of DGM systems drying digestate and poultry manure on farms in Europe. The system is designed to be stationary, and ideally situated near a free heat source for the drying process, the smallest DGM dryer produced is intended for farms with ~130 milking cows. This system would produce an estimate 85% DM P-rich cake and ammonium sulfate.

Table (8): Dryer technology comparison

	*Recovery efficiency**	*Mobile?*	*Smallest size*	*Capital Cost (operating costs)*	*Availability/usage*
Dorset Green Machines (Aalten, Netherlands)	20% N 50% P 25% K	Not possible	130 milking cows	$300,000** ($10,000/year***)	Hundreds of farms in Europe

* If water wash technology is used, recovery efficiency for N, P and K = >90%
**For DGM's pre-treatment thickener and dryer only
***if free heat is available

Conclusions:

A dryer can currently be used on liquid dairy manures, but may be able to be applied to beef feedlot manure and solid poultry manure to create a cake that is easily transported off farm. The end use markets for the cake and the ammonium sulphate would need to be investigated in B.C. and could be site specific based on the cake that is produced. The nutrient recovery potential is 20% but can go as high as 90% if water wash technology is used along with the unit.

The technology is currently in the commercially available phase and is designed for larger or small scale farms. The availability of waste heat is very important for the dryer. The costs above assume the system has free access to waste heat, so the technology may not be feasible for sites without access to waste heat.

Flocculation NRTs

A widely adopted chemical NRT is flocculation, whereby flocculants (also known as coagulants), or polymers are used to bind together the small suspended solids in manure and digestate, making them easier to collect and separate. Once separated, the suspended solids can be dewatered using mechanical technologies such as screw or belt presses to increase DM content.

Three flocculation NRT systems were looked at in the NRT report. Two of the units are suitable for manure or digestate (if sand is used for bedding this must be separated prior to the flocculation technology) and one is suitable only for digestate. These processes have only been used on liquid dairy manure (and digestate from AD units) and are not suitable for beef feedlot manures or poultry manures.

DVO supplies a flocculation NRT Feedstock is fed to mechanical screens to extract coarse and small fiber which has 25 – 35% DM, and can be used as bedding. The clarified liquid is sent to the Dissolved Air Flotation (DAF) , i.e. the flocculation unit and the flocs are skimmed and de-watered using a screw press removal unit to increase DM from <4% to 25%, creating a nutrient-rich cake containing 50% of the N, 90% of the P and 20% of the K in the feedstock. This system is suitable only for digestate.

Table (9): Flocculation technology comparison

	Recovery efficiency	*Mobile?*	*Smallest size*	*Capital Cost (operating costs)*	*Availability/usage*
AL-2 (Hovborg, Denmark)	20% N 90% P 15% K	Potentially	Intended for >1,200 milking cows	$280,000 OPEX = $17,000/year	Many farms worldwide
DVO (Wisconsin, USA)	50% N 90% P 20% K	Not possible	Intended for >880 milking cows	$210,000 OPEX = $16,000/year	Two farms in USA
Trident Processes (B.C., Canada)	50% N 90% P 20% K	Not possible	Intended for >260 milking cows	$450,000 OPEX = $34,000/year	Three farms in North America

Trident mechanical rotary screen and screw press to remove coarse fiber producing 35% DM bedding material. The liquid is sent to the hydration unit and then the DAF unit, i.e. the flocculation unit, and the process finishes by removing the particles with a screw press and de-watering unit . This increases the DM from <4% to ~25%, creating a nutrient-rich cake containing 50% of the N, 80% of the P and 20% of the K in the feedstock. This system is suitable for manure or digestate.

Conclusions:

Flocculation units are currently being used on liquid dairy manures and AD digestate, but are not applicable to beef feedlot manure and solid poultry manure. The products from flocculation are a nutrient rich dry matter cake, which is easily transported off farm, and wash water. Two of the systems also create bedding. The end use markets for the cake and the bedding would need to be investigated in B.C. and could be site specific based on the cake that is produced.

The technology is currently in the commercially available phase but the extent to the installations is limited and still developing. Only one system is designed to be scaled down to allow implementation at B.C. scale farms.

All three technologies produce a nutrient rich cake which is great for transportation, but the technology is mainly used for P recovery and is not intended for N recovery (N recovery is 20-50%). A large amount of the N would remain in the wash water and because more water is added in the process, it would result in large volumes of dilute wash water (or irrigation water).

Struvite NRT

The basic principle underlying struvite precipitation is that in high pH environments where magnesium, ammonia and dissolved P are present, crystal struvite (magnesium ammonium phosphate precipitate) forms. Historically, and due to the presence of calcium-P precipitate in dairy manure, poor struvite crystallization performance has been observed. However, recent technology modifications have resulted in much improved performance with both dairy manure and digestate and two systems were found to exist but both in the trial and research phase[34].

Multiform Harvest processes the manure feedstock in a reactor that allows the dissolved P and ammonia to combine with magnesium chloride to for crystallized struvite. This struvite contains roughly 20% of the N and 80% of the P in the feedstock.

A University of British Columbia (UBC; Vancouver, Canada) research group uses a microwave enhanced oxidation process combining hydrogen peroxide, microwave irradiation, and sulphuric acid to solubilise nutrients and metals in manure into Struvite crystallization. The nutrient recovery is 15% of the N, 90% of the P and 80% of the K from the feedstock.

These systems are both suitable for manure or digestate, but pre-removal of bedding fibre and sand is required for technology performance. The UB.C. system also requires manure or digestate to be pre-treated with solid-liquid separation technology, such as a screw or roller press. Both systems would produce a P-rich struvite that is considered a commercially viable fertilizer form.

Table (10): Struvite technology comparison

	Recovery efficiency	*Mobile?*	*Smallest size*	*Capital Cost (operating costs)*	*Availability/usage*
Multiform Harvest (Seattle, USA)	20% N 80% P N/A K	Not possible	Intended for >540 milking cows	$175,000 OPEX = $15,000/year	One farm in the US
UB.C. (Vancouver, Canada)	15% - 25% N 90% P 80% K	Potentially	Intended for >70 milking cows	$300,000 OPEX = $35,000/year	Two demo systems at UB.C.

Conclusions:

Both technologies produce a P rich struvite which is great for transportation, but the technology is mainly used for P recovery and is not intended for N recovery (N recovery can be quite low, but has been seen as high as 25%). The end use markets for the struvite have yet to be investigated, but it looks promising as a commercially viable form of fertilizer that could be exported off farm and potentially to other areas of the world where there are P deficits.

[34] Evaluation of Nutrient Recovery Technologies for Dairy Manure and Digestate http://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/agricultural-land-and-environment/waste-management/manure-management/evaluation_of_nrt_dairy_manure_digestate.pdf

The technology is currently in the research phase and there are no know commercially available units. This technology could be scaled to larger or small farms.

Biological NRTs

A biological NRT is ammonia-N stripping, where soluble ammonia becomes gaseous at certain temperatures and pH ranges which can be accomplished through a variety of techniques. Once the soluble ammonia is in a gaseous form, it can be recovered/re-adsorbed in a solution or crystalline form. Suspended solids and P can then be removed from the effluent. This technology is a better fit with digestate than manure, as AD increases both pH and the proportion of N in ammonia form, and often provides excess heat which can be used in the stripping process. [35, 36]

A second type of biological NRT widely used in municipal wastewater processing is Enhanced Biological P Removal (EBPR) through consumption of P (and other nutrients, e.g. Mg) by P-accumulating organisms. Once collected, P in the biomass still requires separation before it can be used. As EBPR requires readily biodegradable carbon, which is destroyed during AD to make biogas, this approach is unsuitable for digestate, but is suitable for dairy manure.

A third, unproven biological NRT, is the use of microalgae to consume nutrients for growth. Once grown, the microalgae are harvested to produce a feed product or are used for bioenergy production (such as biodiesel). While this approach has received some attention over the past few years, considerable research and development (R&D) is still required to overcome some very high technical and economic barriers.

One biological NRT was presented in the NRT report as a possible suitable fit for the dairy industry. Another project, Wenning Poultry (USA), was found on a mix of poultry litter and AD digestate.

Table (11): Ammonia Stripping technology comparison

	Recovery efficiency	*Mobile?*	*Smallest size*	*Capital Cost* (operating costs)*	*Availability/usage*
Regenis/DVO/WSU (Washington, USA)	50% N 0% P 0% K	Not possible	140 milking cows	$100,000** ($23,000/year)	Demo farm project only

[35] Evaluation of Nutrient Recovery Technologies for Dairy Manure and Digestate http://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/agricultural-land-and-environment/waste-management/manure-management/evaluation_of_nrt_dairy_manure_digestate.pdf

[36] Most current projects process inputs with a higher ammonia-N concentration than dairy manure or digestate, such as poultry manure.

Wenning Poultry	55-65% N 80-90% P	No	1.5Million birds	n/a	Demo farm project only

* Doesn't include the cost of pre-removing large fibre, drying of ammonium sulfate solution, or technology maintenance costs.
** the capital costs for a Regenis system four times larger (for 530 milking cows instead of 140) is only estimated to be 100% more.

Regenis uses CO_2 ammonia stripping doesn't require alkali chemicals or stripping towers to volatilize the ammonia before creating ammonium sulfate. Pre-removal of large fibre and sand is required for technology performance. Regenis' ammonia stripping system can achieve 40 – 50% N recovery rates to produce a 35% ammonium sulfate solution. The ammonium sulfate solution can be further dehydrated to create a dry product.

At Wenning Poultry, dry poultry manure from a 1.5 M layer poultry operation is mixed with digested, treated effluent and then anaerobically digested. After AD, the effluent is treated by air stripping with a non-chemical methodology. Gaseous ammonia is then contacted with sulfuric acid to make ammonium sulfate solution. The resulting effluent is sent through a solids separation process to remove solids and P and produce mixing water for the front end of the process. The approximate operating costs were $100-160 /cow/ year, and capital costs were $400-500/cow.

The ammonia-N stripping biological NRT might be a more natural fit with digestate than manure, because AD increases the proportion of N in ammonia form, raises pH and produces free heat. Although it can be used on liquid dairy manures, it may be possible to use on solid poultry manures or beef feedlot manures; however that has not been investigated.

These systems are designed to be stationary and are only shown to be effective on farms with >530 milking cows. Although there is opportunity to investigate if the technology could scale down somewhat proportionality lower for smaller farms.

This system produces an ammonium sulfate solution which can be transported off farm in the form of a liquid or can be further processed to create a dry product that is cheap and effective for transportation. A site specific cost benefit would need to be completed. There are no identified end use markets for this system.

Conclusions:

While this NRT can be cost competitive with other NRTs, and is able to recover >50% of the N, it is still under development and is much more suited to higher ammonia-N feedstocks, such as poultry manure or to AD digestate because of the pH and free heat. The technology is currently commercially available although there is only one identified supplier at this time, Regenis, for a dairy farm application. With more investigation, there could be more commercially available and applicable systems. This technology could be scaled to larger or small farms.

6. AEROBIC TREATMENT FOR NITROGEN

Aerobic treatment of N is used in the wastewater treatment sector. It can be a cost and energy efficient process for removal of BOD (Biological Oxygen Demand) and the oxidation of nutrients for the wastewater sector. Aerobic treatment is a biological process, in the presence of oxygen microorganisms (aerobes) feed on complex materials present in wastewater and convert them into simpler substances.

Wastewater also contains high levels of nutrients such as N and P. N is typically removed through biological oxidation whereas P would be removed in a separate process and relies on chemical removal.

Numerous different suppliers have commercially available technology for the wastewater industry, these can include:

- Membrane Bioreactors
- Conventional Activated Sludge Systems
- Diffused aeration
- Ion-exchange nitrate removal
- Trickling Filters

Aeration can also be achieved naturally or through mechanical means. The N is converted into ammonia (NH_3) gas and aerated out of the system. Natural aeration basically relies on oxygen from the atmosphere that enters the lagoon liquid by diffusion (surface area and wind), but this has a very low efficiency of trapping oxygen and results in very low efficiency of N removal. In mechanically aerated lagoons, oxygen is introduced by some mechanism that beats air into the liquid or exposes more liquid surface area to the air with a portion of the oxygen dissolving during the process. This can achieve higher efficiency of NH_3 removal.

Aeration naturally or through mechanical means results in large amounts of NH_3 into the atmosphere and is not recommended for local air quality and odour concerns.

All of the wastewater treatment technologies would trap the N and remove it with various technologies it so that it would not be in the wastewater or as ammonia emissions. The systems are highly technical and require expert operation. The resulting costs of implementing and operating one of these systems would be high on any farms in B.C.

Manure total solids content has a significant impact on the aeration efficiency of aerators. If the manure total solids content increases from 0.5 to 4.0%, it can lead to an efficiency loss of 25% for the aerator.[37] It has been found that an increase in solids will linearly cause a reduction in aeration efficiency.

[37] https://www.extension.umn.edu/agriculture/manure-management-and-air-quality/manure-treatment/docs/aerobic-treatment.pdf

Therefore, it would be likely that a solid//liquid separation technology would need to be used on manures from B.C. farms to achieve the extremely low solids necessary for the units to be successful.

7. PRECISION APPLICATION EQUIPMENT FOR FERTILIZERS

Precision Agriculture is a farming management concept based on the observation and response to intra-field variations. The work scheme of Precision Agriculture can be summarized in three stages or phases: 1) geo-referenced information locally using certain sensors, 2) analysis of data obtained through an appropriate system of information processing, and 3) adjustment of the amount applied (fertilizers, pesticides, etc) depending on the needs of each location.

For fertilizers, precision application takes into account the expected plant nutrient demands and creates a variable dosage needed to complete the growth cycle.

Precision equipment can include anything from Controlled Release Fertilizer, variable rate release [38]fertilizers, chlorophyll sensors, and Precise Placement technologies.

To date, the first stage of precision agriculture has relied on data obtained through optical sensor technology. Precision variable rate application equipment has so far been restricted to commercial fertilizer. A viable method for directly assessing soil nutrient status at the precision scale has not been identified. Rather, precision fertilizer rates are predominantly determined via in season crop conditions, yield maps, and in for large areas soil mapping data.

In 2017/2018 the BMP Program added specialized modifications to equipment for improved fertilizer application to land under the Nitrous Oxide Emission Reduction BMP. Although GPS guided variable rate manure application technology has not been feasible, the BMP Program has historically included precision farming applications that reduce input application and overlap as well as specialized modifications to equipment for improved manure application to land. This technology improves application efficiency and the producer’s ability to uniformly apply at the planned rate.

8. NITRATE GROUNDWATER REMEDIATION

The below section includes the summarized findings of a literature scan that reviewied the technologies and processes available for nitrate groundwater remediation. Current systems being utilized or investigated for groundwater remediation can be classified or grouped into two separate categories; ‘above ground – water treatment’ and ‘In-Situ Denitrification’.

ABOVE GROUND WATER TREATMENT OPTIONS FOR NITRATES

There are many common and novel practices for nitrate treatment of water after it is removed from the aquifer. Most nitrate treatment systems are geared toward treating groundwater in above-ground water treatment systems.

A brief list of references for above ground water treatment options for Nitrates:

[38] http://www.agr.gc.ca/eng/science-and-innovation/agricultural-practices/soil-and-land/soil-nutrients/variable-rate-nutrient-application-should-i-consider-it-for-my-farm/?id=1368026127650

Nitrate Treatment Alternatives for Small Water Systems, June 2005, Washington State http://cals.uidaho.edu/edcomm/pdf/CIS/CIS0872.pdf
Treatment Technologies for Today and Tomorrow, Arizona State University http://www.swhydro.arizona.edu/archive/V8_N4/feature6.pdf
Summary from University of California, Davis, center for Watershed Sciences produced two reports, one on above ground nitrate treatment that is an excellent source for options for water treatment: 1) Drinking Water Treatment for Nitrate http://groundwaternitrate.ucdavis.edu/files/139107.pdf This report summarizes the options to treat drinking water and includes specific systems that treat nitrate in water treatment facilities. For each of the major treatment technologies, the report investigates design considerations, cost considerations, and advantages and disadvantages of each treatment type. The treatments included: • weak base anion (WBA) exchange and improvements in strong base anion (SBA) exchange such as low brine residual technologies; • biological treatment using fluidized bed, fixed bed, and membrane biofilm (MBfR) reactors; • and chemical reduction using media such as zero valent iron (ZVI) and sulfur modified iron (SMI).

IN-SITU DENITRIFICATION OPTIONS

As an alternative to groundwater extraction and treatment, under appropriate conditions, nitrate impacted groundwater can be addressed in situ (below ground). In situ methods can be less costly than above ground water treatment options and have the ability to directly target the groundwater contaminant plume while taking advantage of naturally occurring processes of denitrification. Two major categories of in-situ denitrification are generally considered: In-Situ Bioremediation (ISB), and Permeable Reactive Barriers (PRBs).

In situ bioremediation (ISB) is accomplished by injecting an electron donor into the groundwater plume such that bacteria can utilize the electron donor in the denitrification process, reducing nitrate to N gas. Nitrates can be reduced through biological denitrification or chemical denitrification.

Biological denitrification uses denitrifying bacteria to reduce nitrate to innocuous N gas in the absence of oxygen. The bacteria require an electron donor (substrate) such as sulfur or hydrogen and a carbon source for cell growth such as carbon dioxide, methanol, ethanol or acetate[39]. Chemical denitrification can be accomplished with reduction of nitrate by metals. Various metals have been investigated for use in nitrate reduction including aluminum and iron (both Fe_0 and Fe_{2+}), while copper, palladium, and rhodium can be used as catalysts in nitrate reduction[40].

According to the In Situ Bioremediation (ISB) Team of the Interstate Technology and Regulatory Council (ITRC)[41], the advantages of ISB include low-cost, rapid remediation, and the potential for "complete plume remediation," while the disadvantages of this remediation option include "impact

[39] http://groundwaternitrate.ucdavis.edu/files/139112.pdf
[40] http://groundwaternitrate.ucdavis.edu/files/139107.pdf
[41] http://groundwaternitrate.ucdavis.edu/files/139112.pdf

to geochemistry, biomass buildup, and unconverted nitrogen species". This can lead to the accumulation of other undesirable N species, such as nitrite or ammonium, in the groundwater or clogging of the aquifer due to biofilm build-up in the subsurface.

When applying this technology it is important to consider the mobility and mixing capability of water and the contaminants in the subsurface. According to the UC Davis research group they found for large unconfined plumes "subsurface heterogeneity of material properties, such as permeability, render any such injection procedure very inefficient because most of the injectate flows preferentially in relatively localized volumes of the subsurface, thereby bypassing most of the contaminant volume." [42]

PRBs can be used to remove nitrate from groundwater in situ through biological denitrification or chemical denitrification. Barriers containing reactive media can be installed in the path of groundwater flow supplying the necessary components for denitrification. PRB remediation systems can require significantly less maintenance than alternative remediation, however for PBRs to be effective the pollution should be no deeper than 50 feet. Trenching is a significant portion of the costs associated with the implementation of PRBs and the deeper the required barrier, the more costly the project. For depths greater than 30 feet, specialized equipment may be necessary.[43]

The application of all of the in-situ technologies is in the trial and case study phase. Several case studies out of the US have implemented both the ISB and PRB systems. The one case study discussed below conducted by Dr. Rudolf, in Ontario, Canada is the best example of ISB being applied in an unconsolidated aquifer in Canada.

Case Study: In-Situ Groundwater Remediation - Ontario

The technology "in situ groundwater remediation" may prove effective as an interim solution before the full influence of the BMPs arrive at the wells (Rudolph et al 2015[44]). The preliminary findings from a series of field investigations conducted between 2004 and 2011 at a site in southern Ontario indicates that this may be capable of attenuating nitrate to desirable levels. In the Ontario case it may avoid the need to construct permanent above-ground water treatment facilities that could eventually become redundant.

The pilot experiment was conducted to investigate this technology as an interim nitrate reduction solution until the sustainable influence of the BMPs is sufficient enough to reduce nitrate concentrations in the public supply wells to an acceptable level.

[42] http://groundwaternitrate.ucdavis.edu/files/139112.pdf
[43] http://groundwaternitrate.ucdavis.edu/files/139112.pdf
[44] Challenges and a Strategy for Agricultural BMP Monitoring and Remediation of Nitrate Contamination in Unconsolidated Aquifers
and
http://www.cwn-rce.ca/assets/End-User-Reports/Agri-Food/Rudolph/CWN-EN-Rudolph-2015-5Pager-Web.pdf, and https://www.groundwatercanada.com/contamination/agriculture-and-nitrates-2358

During the course of the long-term monitoring program, a pilot-scale groundwater remediation experiment was conducted close to the public supply wells where the nitrate mass flux in the aquifer converged towards the wells. In order to shorten the time until the full influence of the regional nutrient management BMPs is realized, a strategy was proposed with specific application to unconsolidated granular aquifers. A temporary remediation method based on in situ denitrification was implemented for reducing nitrate levels in public supply wells that involved the injection of a soluble carbon amendment into the aquifer at a location where the nitrate mass flux is high, with the intent of supporting the microbial degradation of dissolved nitrate. The total nitrate mass was reduced by approximately 50% within the treatment zone over a two month period. This study illustrated that the on-site denitrification scheme is a viable option to reduce nitrate concentrations in the aquifer in the short term, prior to reductions achieved by the BMPs.

A brief list of references for in-situ ground water treatment options for Nitrates:

<table>
<tr><td>Summary from University of California, Davis, center for Watershed Sciences produced two reports, the first report above was on water treatment above ground, and the second includes a summary of below ground (in-situ) nitrate removal in comparison with pump and treat options:

2) Groundwater Remediation and Management for Nitrate, Addressing Nitrate in California's Drinking Water http://groundwaternitrate.ucdavis.edu/files/139112.pdf, July 2012
This report explores methods and costs of remediation of groundwater nitrate contamination in the Tulare Lake Basin and Salinas Valley. It explores several options:
• Pump and treat
• Phytoremediation of nitrate in groundwater
• In situ Denitrification
• Pump and fertilize
This analysis shows that direct remediation to remove nitrate from large groundwater basins is extremely costly and not technically feasible. In situ remediation, though technologically infeasible as a regional remedy, is appropriate in certain areas of shallow groundwater with high contaminant levels. Traditional pump and treat (ex situ) methods are too slow to produce results on the regional scale in an acceptable time frame, prohibitively expensive, and impractical to implement.</td></tr>
<tr><td>Bank filtration refers to the withdrawal of surface water through an embankment.
http://ese.dgtlpub.com/2013/2013-06-30/pdf/In_situ_treatment_of_a_high_nitrate_loaded_groundwater_plume.pdf</td></tr>
<tr><td>A novel in situ membrane technology was developed to remove nitrate (NO3-) from groundwater. Membrane-fed hydrogen gas (H2) was used as an electron donor to stimulate denitrification. 2004
http://www.fwr.org/wrcsa/1325104.htm</td></tr>
<tr><td>Examining In Situ Bioremediation of Nitrate and Perchlorate, 2006
http://www.waterworld.com/articles/iww/print/volume-13/issue-1/feature-editorial/examining-in-situ-bioremediation-of-nitrate-and-perchlorate.html</td></tr>
<tr><td>Stimulating In Situ Hydrogenotrophic Denitrification with Membrane-Delivered Hydrogen under Passive and Pumped Groundwater Conditions, 2009</td></tr>
<tr><td>Spatial Variation in Denitrification and N_2O Emission in Relation to Nitrate Removal Efficiency in a N-Stressed Riparian Buffer Zone, 2006</td></tr>
<tr><td>Reduction of Nitrate in Groundwater by Fe(0)/Magnetite Nanoparticles Entrapped in Ca-Alginate</td></tr>
</table>

Beads, 2015
In Situ Batch Denitrification of Nitrate-Rich Groundwater Using Sawdust as a Carbon Source, 2009
Degradation of nitrates with the participation of Fe(II) and Fe(0) in groundwater: A review, 2015

9. OVERALL CONCLUSIONS

- Anaerobic digestion (AD), composting and manure injection technologies are not considered nutrient recovery technologies (NRTs). They do assist in manure upgrading and improved nutrient management if implemented with a proper Nutrient Management Plan (NMP).
- AD or composting can produce a feedstock which is better suited for nutrient recovery by an NRT
- On its own, AD does not change the nitrogen mass of the material on farm, as AD operations in B.C. import additional N sources for optimal operation.
- Additionally, the AD process converts the N to a form that more readily converts to nitrate in soil.
- Most NRTs are focused on phosphorus (P) recovery and are not specifically designed to remove N.
- Biological NRTs, centrifuges, flocculation and ultrafiltration technologies could be examined further in consultation with agencies and industry as they appear to be the most cost-effective, feasible, and a good match for B.C. farm practices.
- Biological NRTs provide the most direct option for N removal.
- Advanced mechanical NRTs such as centrifuges, membranes and dryers have been developed to increase P recovery; these advanced mechanical NRTs have a much higher nutrient recovery potential than screens, screw or belt presses.
- NRTs can concentrate nutrients into a soil amendment product or fertilizer, and can also make transport more economically viable compared to the untreated manures, particularly if the untreated manure is a liquid.
- The majority of NRTs are designed for liquid manure (dairy manure) or AD digestate and not solid manure (beef manure and poultry litter).
- These technologies vary considerably in their process, cost, application and nutrient recovery capabilities.
- A site-specific analysis would need to be done to determine the viability of NRTs; however, it is likely that many technologies are not financially viable based on current B.C. market and regulatory conditions. Markets for end-products are emerging and value is unknown; ultimately, the nutrient rich end-product would need to be exported to a destination that requires the nutrient to have a positive impact.
- One way to reduce the cost and thereby improve economic feasibility for any of the technologies considered is to use economies of scale and for several farms to take part. Although, only some of the technologies that were investigated are suitable as mobile units.
- There are many common and novel practices for nitrate treatment of groundwater after it is removed from the aquifer. Most nitrate treatment systems are geared toward treating groundwater in above-ground water treatment systems.

10. TECHNOLOGY CONCLUSIONS:

Energy Recovery Options

Anaerobic digestion:

- Anaerobic digestion (AD) can produce biogas from manure however it does not reduce the quantity of manure or nutrients as it allows more nutrients to be brought onto a farm. But if it is combined with recovery of nutrients or export of digestate it may have potential.
- Additionally, the AD process converts the N to a form that more readily converts to nitrate in soil, so if digestate is land applied it has more N availability then its raw manure form.
- An AD facility could be located outside of the Hullcar region, but manure would need to be exported which is not financially feasible for liquid dairy manure (95% water).
- Only AD systems able to generate biogas from at least 200 lactating cows, with favourable manure collection methods, that digest non-agricultural feedstocks and are in locations favourable to natural gas infrastructure, may be economically feasible.

Gasification and pyrolysis:

- Thermal energy recovery technologies such as gasification, pyrolysis or incineration are generally not economically feasible ($25-$50 Million in capital costs) and are an industrial application and not suitable for farms.

Other Technologies

Composting

- Overall, composting is not a solution on its own to reduce N excess on farms and its ability to prevent leaching is unknown.
- Raw dairy manure, without separating solids, is not suitable for composting due to its high liquid content.
- Compost does produce a stable product that can be used on farm or transported off-farm. The reduced weight and stability of compost means that the compost can be stored and transported more easily to value-added markets.

Manure Injection

- Manure injection technologies reduce N losses from application, and more N is conserved for plant growth, there is no net reduction of N being applied. Therefore, this is not considered an option for reducing N leaching.

Nutrient Recovery Technologies Options

Solid Liquid manure separation and bedding recovery technology

- Solid liquid manure separation concentrates the N in the manure into the liquid which is used on farm.
- It does not reduce the overall N content from manures. It has been considered as a P recovery option (although minimal <20% P reductions).
- Solid liquid separators such as screw presses have been used as a first step for other nutrient recovery options.

Centrifuge

- Centrifuges which can remove water from manure mechanically and is a proven technology and most widely used NRT in US and Europe.
- Considering the costs and technological requirements of the unit, it is unlikely that an individual dairy farmer would finance or operate such a unit.
- Mobile centrifuge units are viable options, and are commercially available. Site specific information is required to calculate the costs, and local data is necessary.

Membrane/ Ultrafiltration NRTs

- Membrane or ultrafiltration is a high nutrient recovery option that is currently being used on liquid dairy manures, but may be able to be applied to beef feedlot manure but it is not suitable for solid poultry manure.
- The technology is currently in the commercial or research phase and is primarily designed for larger scale farms.

Drying and Pelletizing

- Commercially available dryers are currently being used on liquid dairy manures on larger or small scale farms, but may be able to be applied to beef feedlot manure and solid poultry manure.
- Drying and pelletizing may not be feasible for sites without access to waste heat to reduce the costs.

Flocculation NRTs

- Commercially available flocculation units are currently being used on liquid dairy manures and AD digestate and are not applicable to beef feedlot manure and solid poultry manure. Although small enough scale for B.C. farms may be challenging.
- The technology is mainly used for P recovery and is not intended for N recovery. It would result in more volume and dilute wash water (or irrigation water) with high N content.

Struvite NRT

- The technology is mainly used for P recovery and is not intended for N recovery.
- The technology is currently in the research phase and there are no know commercially available units.

Biological NRTs

- While this NRT can be cost competitive with other NRTs, and is able to recover >50% of the N, it is still under development and is not currently commercially available for manures.
- It is much more suited to higher ammonia-N feedstocks, such as poultry manure or to AD digestate.

Are there opportunities for economies of scale?

The average number of milking cows on a B.C. dairy farm is ~140. An NRT should be sized appropriately for dairy farms with 140 milking cows. But many systems are not feasible, logistical or economically viable at this size. Alternatively, the technology could have a small enough footprint to be mobile. Mobility will enable several dairy farms to share a technology, greatly reducing individual farm cost. The other option is to have a centralized facility for multiple farms.

One way to reduce the cost and thereby improve economic feasibility would be for several farms to share an NRT. For example, a centrifuge that processes 25,000 m_3/year of manure is less than twice the cost of a centrifuge for 7,000m_3/year. Centrifuges, unlike most other NRTs and due to their small footprint, have the potential to be mobile and move from farm to farm. Mobility of a NRT is important because transportation of manure or digestate to a large, centralized NRT is too expensive without pre-treatment to reduce the moisture content.

Appendix A:

Cost calculations:

Transportation costs of poultry litter are used to estimate the cost of transporting compost as the material is similar in moisture content.

Assumptions:

- Trucking companies charge $125/hr trucking rate and a $150 loading rate (it takes about 30 minutes to load the used litter into each truck). For all used litter that trucking companies deliver, the farmer accepting the used litter pays the trucking and loading charge, while broiler farmers pay nothing.
- A generally rule of thumb is that a 20,000 broiler barn will produce roughly 1 load of litter (1 load is 28 tonnes)
- For a 2 hr trip there, that would mean (4 hrs/load * $ 125 /hr/load +150$/load) /25 tonnes load = 26$/ tonne[45]

Calculation of manure amounts:

Beef cattle feedlots have on average:

- Moisture content is 60%

[45] Expert opinion AGRI waste Management Engineer, Jake Turek; From previous interviews with manure haulers.

- Bulk Density is 710 kg/m3[46]
- Volume produced is 34 L/day for 365 days per year.

Total per cow is 8.81 tonners per year

Total for feedlot based on an average feedlot of 1250 animals per year = 11,013 tonnes per yr

Poultry:

- Moisture content is 25%
- Bulk Density is 330 kg/m
- Volume produced is 0.096 L/day for 365 days per year.

Total per bird is 0.0116 tonners per year

Total for poultry operation based on an average size of 20,000 birds = 231 tonnes per yr.

[46] http://www1.agric.gov.ab.ca/%24department/deptdocs.nsf/all/agdex8875