Evaluation of Nutrient Recovery Technologies for Dairy Manure and Digestate

Growing Forward 2

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1. Executive Summary

Nutrient recovery is a process that enables the removal and concentration of nutrient by-products from agricultural manures or anaerobic digestate (the output from anaerobic digesters). Nutrient recovery technologies (NRTs) can facilitate improved nutrient management on agricultural operations with excess nutrients. NRTs produce a concentrated nutrient by-product that may more easily be transported off-farm and/or potentially transformed into a commercially saleable nutrient product.

At the time of writing this report, the suitability and economic feasibility of nutrient recovery technologies for B.C.'s agricultural sector were not well understood. The purpose of this report is therefore to evaluate these technologies for B.C.'s dairy farms, both with and without anaerobic digesters. Dairy manure is the focus of this report because there are a large number of dairy farms in B.C., and these farms produce a liquid by-product (manure or digestate) that is costly to transport.

The types of nutrient recovery technologies evaluated in this report are mechanical, biological and chemical. Of all the nutrient recovery technologies installed on dairy farms in Europe and North America, centrifuges, a mechanical separation technology that uses high rotational speeds to separate small suspended solids from liquids, are seen as the best fit for most B.C. dairy farms. For most on-farm anaerobic digesters in B.C., centrifuges are also seen as the best fit. However, if the co-digestion of off-farm feedstocks high in nitrogen and/or phosphorous increases the level of nutrient recovery required beyond that achievable with centrifuges, then membranes, flocculation, or other nutrient recovery technologies may be more appropriate.

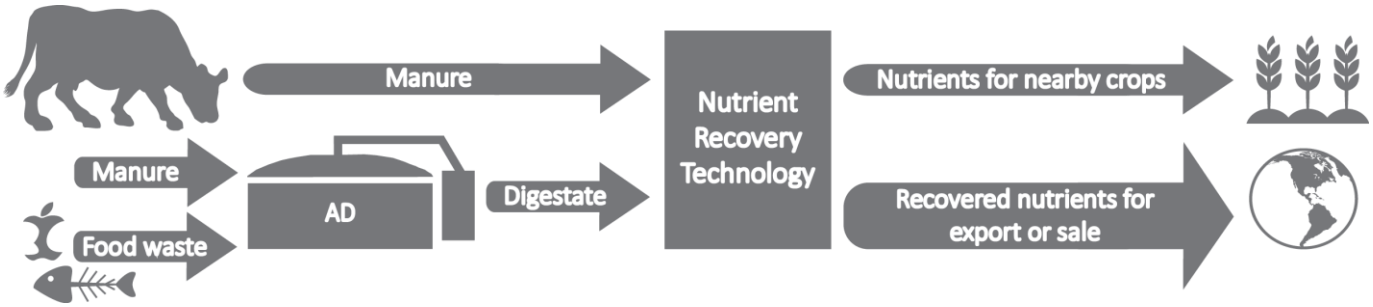
None of the nutrient recovery technologies evaluated in this report are economically feasible for B.C. dairy farms. However, if a nutrient recovery technology could be shared amongst several farms, such as a mobile system, costs would be significantly reduced. Furthermore, economic feasibility is based solely on estimated revenues generated from the sale of nutrient-rich products and bedding savings. If the environmental benefits of nutrient recovery technologies were to be monetized (e.g., when NRS enable large farms to increase animal numbers without acquiring more land).

2. Introduction

NRTs can be of particular interest to farms that have excess nutrients (e.g., when manure nutrients exceed crop requirement). Excess land application of nutrients can result in the movement of N and P from soil to water, or air can contribute to a number of environmental concerns, including pollution of waterbodies, habitat loss, and soil greenhouse gas emissions. NRTs can be an option for farms with nutrient excess to export nutrients and minimize environmental risks.

Nutrient Recover Technologies (NRTs) are able to recover a portion of the nutrients from manure or digestate, which allows for excess nutrients to be exported out of nutrient dense areas and enables their sale into local market not traditionally accessible to manure or digestate (Figure 1). However, at the time of writing this report, the suitability and economic feasibility of NRTs for B.C.'s agricultural sector were not well understood. The purpose of this report is therefore to identify and assess NRTs installed in North America and Europe that could be used by B.C. dairy farms.

Figure 1. Nutrient Recovery Process



3. Manure and Digestate

3.1 Dairy Manure

While dependent upon animal and manure management practices, the average milking cow produces roughly 45 tonnes/year (50 m^3/year) of 'by-product'; manure, waste feed, bedding, waste water, etc.[1] A 140 milking cow dairy, roughly the average sized B.C. dairy farm,[2] therefore produces an estimated 6,300 tonnes/year of by-product (herein referred to as 'manure' for simplicity). Depending upon management practice, manure can have a Dry Matter (DM) content of 1% – 8%[3]. While the nutrient ratio of dairy manure varies depending upon a variety of factors, including type and age of animal, diet, milk production, etc., it is generally accepted to be roughly five parts N to one part P (5:1).[4]
Of the N in dairy manure, about half is ammonia-nitrogen.[5] Because ammonia-nitrogen readily volatizes upon exposure to air, roughly half of this ammonia-nitrogen (roughly 25% of total N) can be

[1] Chastain J & Camberato J. (2004). Dairy manure production and nutrient content. Confined animal manure managers' certification program manual: Dairy version. Clemson University Extension.
[2] http://www2.gov.bc.ca/gov/content/industry/agriculture-seafood/animals-and-crops/animal-production/dairy.
[3] *Ibid.*
[4] Dairy manure nutrient content and forms. Manure Technical guide series; University of California cooperative extension.
[5] Frear, C., *et al.* (2011). Evaluation of co-digestion at a commercial dairy anaerobic digester. Clean Air, Soil and Water 39 (7), 697–704.

lost during manure handling, storage, and field application.[6] Due to these losses, it is generally accepted that when land applied, dairy manure has an N to P ratio ranging from 3:1 to 4:1.

Within B.C., most dairy farms grow silage corn and/or silage grass to feed their cows. While the nutrient requirements (kg/ha) of corn and grass vary, both crops require an N to P ratio of roughly 7:1. When land applied, dairy manure has an N to P ratio from 3:1 to 4:1 (i.e., there is too much P relative to N for corn and grass needs). Therefore, when dairy farms apply manure to meet the N needs of their crops, the amount of P applied exceeds crop requirements, resulting in the over-application of P. For dairy farms with insufficient land on which to spread their manure, a second issue is that the amount of N and P available might be too much for their crops, causing the over-application of both N and P in fields.

3.2 Digestate

Anaerobic Digestion (AD) is a process that converts manure and other organic by-products, such as food processing waste, into biogas. 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 DM content, buffering capacity, and bacteria present in dairy manure make it a great feedstock for the AD process.

Although AD changes the form of N and P in dairy manure[7], these nutrients are not reduced during the AD process, and are therefore found in the digester's effluent, known as 'digestate.' As with dairy manure, digestate has low DM content of 4% – 10% depending upon digester design and co-digested feedstocks. The N and P content in digestate varies depending on the type of co-digested feedstocks.

Similarly to manure, if dairy farms use digestate to meet the N needs of their crops, the amount of P in digestate usually exceeds crop requirements; resulting in the over-application of P. For dairy farms with insufficient land on which to spread their digestate, or for farms that co-digest large volumes of high protein feedstocks, such as animal and animal by-products, a second issue is that the amount of N and P available might be too much for their crops, causing the over-application of both N and P in fields.

4. Nutrient Recovery Technologies

NRTs are a potential solution to enable farms with nutrient excess to bring their cropping system into equilibrium by matching nutrient land application rates (from manure/digestate and chemical fertilizers) with crop nutrient requirements. Because the greatest need for most dairy farms is to reduce the amount of P applied from manure, these NRTs should recover little N and sufficient P to enable an N to P ratio of 7:1 (roughly the average N to P ratio required for silage corn and grass). For digestate, NRTs should recover sufficient N and P to ensure that remaining nutrients meet crop nutrient requirements in nearby fields.

[6] Meisinger, J., and Jokela, W. (2000). Ammonia volatilization from dairy and poultry manure. Managing Nutrients and Pathogens from Animal Agriculture. 28–30 March: p. 334–354.
[7] *Ibid*.

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. The greatest reason for this variability is because of the contrasting nutrient management needs in different areas of Europe and North America. 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.

4.1 Mechanical Recovery Technologies

A widely used type of manure and digestate management technology in Europe and North America is mechanical recovery, in which screens, screw or belt presses are used. 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). Due to their low nutrient recovery potential, mechanical technologies such as screens, screw or belt presses, are not considered further in this study.

Importantly, over 85% of P in manure and digestate is bound to small suspended solids.[8] Therefore, to increase P recovery, advanced mechanical NRTs such as centrifuges, membranes and dryers have been developed. Centrifuges spin at high speeds to create a strong centripetal force that separates materials of different densities, such as suspended solids from liquids. Membranes act as a filter, letting liquids flow through while catching suspended solids and other substances. Dryers evaporate the water, leaving behind solids. These advanced mechanical NRTs have a much higher nutrient recovery potential than screens, screw or belt presses.

4.2 Chemical Recovery Technologies

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.

A second type of chemical NRT is struvite precipitation. The basic principle underlying struvite precipitation is that in high pH environments where magnesium, ammonia and phosphate 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.

[8] Gungor, K., and Karthikeyan, K. (2008). Phosphorus forms and extractability in dairy manure: a case study for Wisconsin on-farm anaerobic digesters. Bioresource Technology 99(2):425-36.

4.3 Biological Recovery Technologies

A biological NRT is ammonia-N stripping, where soluble ammonia becomes gaseous at certain temperatures and pH ranges. Achievement of the required temperature and pH, and subsequent stripping of ammonia gas, 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.[9]

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 (PAOs). By storing P in greater quantities than needed for their own cell components, these organisms concentrate P in their biomass, creating a sink for P which can be more easily collected. Once collected, P in the biomass still requires separation before it can be used.[10] As EBPR requires readily biodegradable carbon, which is destroyed during AD to make biogas, this approach is unsuitable for digestate.

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 R&D is still required to overcome some very high technical and economic barriers.

5. Technology Requirements

As part of evaluating NRTs from North America and Europe, it is necessary to determine which technology characteristics are most desirable for B.C. dairy farms. Once these characteristics are known NRTs can be compared.

- Nutrient recovery efficiency: Nutrient recovery efficiency should be no greater than that required by the dairy farm, as greater recovery will result in insufficient nutrients for nearby crops. As noted earlier, both corn and grass require an N to P ratio of roughly 7:1, when land applied, dairy manure has an N to P ratio from 3:1 to 4:1. Therefore, if dairy farms apply manure to meet the N needs of their crops, the amount of P applied is roughly twice crop requirements. As such, P recovery should be ~50%, while N recovery should be as minimal as possible because most if not all of the N in dairy manure is required for nearby crops. For digesters, N and P recovery efficiencies should be sufficient to meet crop nutrient requirements of nearby fields and will depend upon the type of feedstocks co-digested with manure.
- Cost: NRTs with the lowest capital and operating costs (energy, chemical inputs, planned maintenance, etc.) that are able to meet required nutrient recovery efficiencies from manure or digestate will be the most desirable for dairy farms.

[9] Most current projects process inputs with a higher ammonia-N concentration than dairy manure or digestate, such as poultry manure.
[10] Yanosek, K. (2002). Enhanced biological phosphorus removal from dairy manure to meet nitrogen: phosphorus crop nutrient requirements. Biological Systems Engineering, Virgnia Polytechnic Institute and State University. Blacksburg, VA.

- Nutrient quality: Recovered nutrients from manure and digestate should be as free from pathogens as possible, have known nutrient release rates, and have physical properties that make it easy to store, transport, and land apply with conventional technologies. The greater the nutrient quality, the easier it will be for dairy farms to sell.
- Commercialized: Commercialized NRTs are those that have gone through R&D, innovation and demonstration, and have been purchased by dairy farms. The benefit of commercialized NRTs that have been widely installed on dairy farms is that the technology has been proven under 'real world' conditions and thus installation and operation is less risky.
- Size and mobility: The average number of milking cows on a B.C. dairy farm is ~140. NRT should therefore be sized appropriately for dairy farms with 140 milking cows. Alternatively, the NRT should have a small enough footprint to be mobile. Mobility will enable several dairy farms to share a technology, greatly reducing individual farm cost.
- By-products: Some NRTs produce by-products, such as bedding material. As with recovered nutrients, the greater the quality and consistency of the by-products, the easier it will be for dairy farms to use or sell.
- Versatility: B.C. dairy farms generally bed cows on wood chips/sawdust. NRTs that don't need to separate the fibre from manure or digestate prior to nutrient recovery will require less ancillary technologies.

6. Technology Review

The following is a high-level review, in alphabetical order by technology type (mechanical, chemical and biological), of NRTs for dairy manure and/or digestate that have been installed and operated on dairy farms in Europe or North America. NRTs from other industries, such as wastewater treatment, which may potentially work with dairy manure or digestate have not been included in this review due to lack of real-world examples or experiences recovering nutrients from dairy manure or digestate.

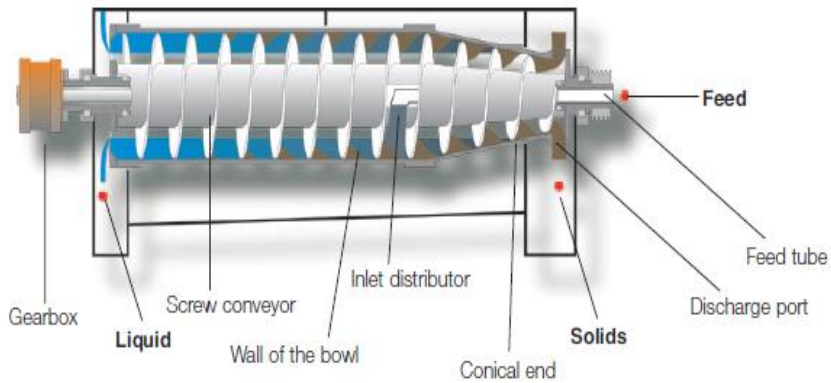
Information in this review has been collected from company literature, websites, reports, and interviews. Because NRT developments are evolving quickly, this document should be considered as a time-sensitive snapshot of a rapidly changing industry. Most NRTs in the European and North American marketplace are designed for larger (>400 milking cow). Furthermore, manure management practices, bedding materials, setup, process flow, etc. vary between dairy farms. As such, despite best efforts to collect accurate information, all costs and performances should be regarded as rough estimates only.

6.1 Mechanical Nutrient Recovery Technologies (Centrifuge)

Alfa Laval (B.C., Canada)

Alfa Laval supplies a centrifuge NRT. Solid-liquid separation takes place in a horizontal cylindrical bowl equipped with a screw conveyor. The centrifugal force created by the screw conveyor spinning at high speeds causes sedimentation of the solids on the bowl's wall. Solids leave the bowl through solids discharge openings as a ~25% DM, nutrient-rich cake containing roughly 20% of the N, 60% of the P and 50% of the K in the feedstock.

Suitable for manure or digestate, pre-removal of large fibre is recommended to increase technology life and performance. If sand is used for bedding this should be separated prior to the centrifuge, avoiding wear on the technology and preventing the sand from ending up in the cake.



Alfa Laval's horizontal cylindrical bowl decanting centrifuge.

There are five Alfa Laval systems on dairy farms globally.[11] Designed to be stationary but potentially mobile due to its small footprint, the smallest Alfa Laval unit produced (ALDEC10) is intended for farms with ~180 milking cows (flow rate of ~1 m^3/hour). If installed on a 140 milking cow dairy farm with 5% DM fibre bedding manure, the ALDEC 10 would cost an estimated $100,000 to purchase (CAPEX) and $21,000/year ($0.41/cow/day) to operate (OPEX). This system would produce an estimated 1,000 tonnes/year of 25% DM P-rich cake.

Note: While CAPEX for the ALDEC10 would be the same for farms with 1 – 180 milking cows, OPEX would be somewhat proportionality lower for smaller farms as the technology wouldn't be used as frequently. CAPEX for larger Alfa Laval systems, such as the ALDEC20 and ALDEC30 which are four and eight times larger than the ALDEC10, is only estimated to be 100% and 200% more, respectively.

Alfa Laval's NRT at a Glance

Recovery efficiency	Cost*	Mobile	Cake quality	Development	By-product	Smallest size**	Versatility
20% N 60% P 50% K	CAPEX = $100,000 OPEX = $21,000/year	Potentially	25% DM	Five farms worldwide	None	180 milking cows	Large fibre pre-removal needed

** Doesn't include the cost of pre-removing large fibre or technology maintenance costs.*
*** Technology can be used on smaller farms if operated at a reduced capacity.*

DariTech (Washington, USA)

DariTech's supplies a centrifuge NRT. Solid-liquid separation takes place in a horizontal cylindrical bowl equipped with a screw conveyor. The centrifugal force created by the screw conveyor spinning at high speeds causes sedimentation of the solids on the wall of the bowl. Solids leave the centrifuge as a ~22% DM, nutrient-rich cake containing roughly 20% of the N, 50% of the P and 25% of the K in the feedstock.

[11] Such as the Vander Made Farm in Ohio, where manure from 1,600 cows is treated to produce a P-rich cake.

Suitable for manure or digestate, pre-removal of large fibre is recommended to increase technology life and performance. If sand is used for bedding this should be separated prior to the centrifuge, avoiding wear on the technology and preventing the sand from ending up in the cake.

At the time of writing this report, there are half a dozen DariTech systems on dairy farms in Washington State.[12] Designed to be stationary but potentially mobile due its small footprint, the smallest DariTech unit produced (DT1035) is intended for farms with ~480 milking cows (flow rate of ~2.7 m^3/hour). If installed on a 140 milking cow dairy farm with 5% DM fibre bedding manure, the DT1035 would cost an estimated $290,000 to purchase (CAPEX) and $21,000/year ($0.41/cow/day) to operate (OPEX). This system would produce an estimated 1,200 tonnes/year of 22% DM P-rich cake.

Note: While CAPEX for the DT1035 would be the same for farms with 1 – 480 milking cows, OPEX would be somewhat proportionality lower for smaller farms as the technology wouldn't be used as frequently. CAPEX for a larger DariTech system, such as the DT1430 which is twice the size of the DT1035, is only estimated to be 25% more.

DariTech's NRT at a Glance

Recovery efficiency*	Cost**	Mobile	Cake quality	Development	By-product	Smallest size***	Versatility
20% N 50% P 25% K	CAPEX = $290,000 OPEX = $21,000/year	Potentially	22% DM	Half dozen farms in the USA	None	480 milking cows	Large fibre pre-removal needed

** N and K recovery efficiencies and OPEX are estimates from a previous study and were not provided by DariTech.*
*** Doesn't include the cost of pre-removing large fibre or technology maintenance costs.*
**** Technology can be used on smaller farms if operated at a reduced capacity.*

GEA (Illinois, USA)

GEA supplies a centrifuge NRT. Solid-liquid separation takes place in a horizontal cylindrical bowl equipped with a screw conveyor. The centrifugal force created by the screw conveyor spinning at high speeds causes sedimentation of the solids on the wall of the bowl. Solids leave the bowl as a ~25% DM, nutrient-rich cake containing roughly 20% of the N, 50% of the P and 25% of the K in the feedstock.

Suitable for manure or digestate, pre-removal of large fibre is recommended to increase technology life and performance. If sand is used for bedding this should be separated prior to the centrifuge, avoiding wear on the technology and preventing the sand from ending up in the cake.

There are dozens of GEA systems on dairy farms globally. Designed to be stationary but potentially mobile due to its small footprint, the smallest GEA unit produced (AGM25) is intended for farms with ~400 milking cows (flow rate of ~2.3 m^3/hour). If installed on a 140 milking cow dairy farm with 5% DM fibre bedding manure, the AGM25 would cost an estimated $300,000 to purchase (CAPEX) and $19,000/year ($0.37/cow/day) to operate (OPEX). This system would produce an estimated 1,000 tonnes/year of 25% DM P-rich cake.

[12] Example includes the Mensonides Dairy in Mabton, Washington, where manure from 5,000 cows is treated to produce P-rich cake.

Note: While CAPEX for the AGM25 would be the same for farms with 1 – 400 milking cows, OPEX would be somewhat proportionality lower for smaller farms as the technology wouldn't be used as frequently. CAPEX for a larger GEA system, such as the AGM100 which is four times larger than the AGM25, is only estimated to be 100% more.

GEA's NRT at a Glance

Recovery efficiency*	Cost**	Mobile	Cake quality	Development	By-product	Smallest size***	Versatility
20% N 50% P 25% K	CAPEX = $300,000 OPEX = $19,000/year	Potentially	25% DM	Many farms worldwide	None	400 milking cows	Large fibre pre-removal needed

** With flocculants, N and P recovery efficiency can be as high as 50% and 90%, respectively.*
*** Doesn't include the cost of pre-removing large fibre or technology maintenance costs.*
**** Technology can be used on smaller farms if operated at a reduced capacity.*

6.2 Mechanical Nutrient Recovery Technologies (Membrane)

Livestock Water Recycling (Alberta, Canada)

Livestock Water Recycling (LWR) supplies a membrane NRT. Feedstock is fed to a primary solid-liquid separator to extract all fibre. The fibre-free feedstock is then mixed with polymer and sent to a back-washable media filter where finer solids are removed inside a specially designed tank system. The finer solids are put through a screw press to produce a ~25% DM, nutrient-rich cake containing roughly 75% of the N, 90% of the P and 40% of the K in the feedstock. Clarified liquid then enters a membrane system. 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.

Suitable for manure or digestate[13] (if sand is used for bedding this must be separated prior to the membrane technology), there are thirteen LWR systems on dairy farms in the US. Designed to be stationary and predominantly for farms with >1,100 milking cows (flow rate of >6.3m^3/hour), if designed for a 140 milking cow dairy farm with 5% DM fibre bedding manure, LWR's system would cost an estimated $500,000 to purchase (CAPEX) and $18,000/year (~$0.35/cow/day) to operate (OPEX). This system would produce an estimated 1,100 tonnes/year of 25% DM P-rich cake and concentrated liquid fertilizer.

Note: While above CAPEX for the LWR system would be the same for farms with 1 – 140 milking cows, OPEX would be somewhat proportionality lower for smaller farms as the technology wouldn't be used as frequently. CAPEX for a LWR system eight times larger (for 1,100 milking cows instead of 140) is only estimated to be 100% more.

[13] If certain additives, such as ferric chloride, are added to the digester the polymer may not work effectively.

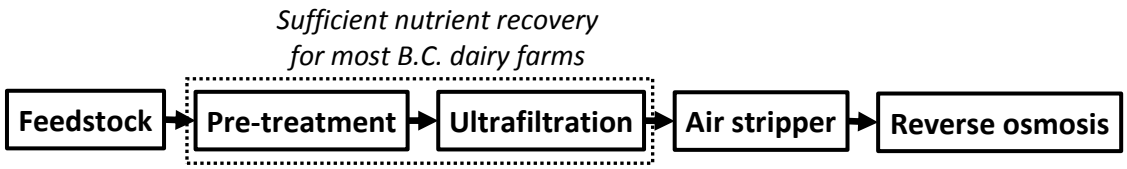
LWR's NRT at a Glance

Recovery efficiency	Cost*	Mobile	Cake quality	Development	By-product	Smallest size**	Versatility
>95% N >95% P >95% K	CAPEX = $500,000 OPEX = $18,000/year	Not possible	25% DM	Thirteen farms in the US	Ammonia fertilizer	Intended for >1,100 milking cows	No fibre pre-removal needed

** Doesn't include technology maintenance costs.*
*** Technology can be designed for smaller farms.*

McLanahan (Pennsylvania, USA)

McLanahan supplies an ultrafiltration and air stripping NRT. Feedstock is fed to a 0.03 µm ultrafiltration membrane where all suspended solids are captured to produce a ~7% DM nutrient-rich cake containing 50% of the N, 95% of the P and 30% of the K in the feedstock. Once all suspended solids are captured, air stripping and absorption is used to volatilize ammonia before it is absorbed with a solution of sulfuric acid to create ammonium sulfate solution. Ammonia recovery rates can vary from 40 – 80% depending upon conditions, while average ammonium sulfate concentration is 35%. The ammonium sulfate 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[14], pre-removal of large fibre and sand is required for technology performance.



McLanahan has only installed one NRT demonstration project to treat 10% of the manure from Car-Min-Vu Farms' 850 milking cows in Webberville, Michigan. It is anticipated that a full-scale system will be installed on a US dairy farm in 2016. Designed to be stationary and predominantly for farms with >1,000 milking cows (flow rate of >6 m^3/hour), if designed for a 140 milking cow dairy farm with 5% DM fibre bedding manure, just the ultrafiltration membrane would cost an estimated $200,000[15] to purchase (CAPEX) and $22,000/year (~$0.43/cow/day) to operate (OPEX). This system would produce an estimated 3,800 tonnes/year of ~7% DM P and N-rich cake (~1,100 tonnes if dried to 25%DM).

Note: While above CAPEX for the McLanahan system would be the same for farms with 1 – 140 milking cows, OPEX would be somewhat proportionality lower for smaller farms as the technology wouldn't be used as frequently. CAPEX for a McLanahan system seven times larger (for 1,000 milking cows instead of 140) is only estimated to be 100% more.

[14] Digestate has better results than manure because its warmth (35°C) and homogeneity improves the efficiency of ultrafiltration.
[15] CAPEX 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. This is highly optimistic compared with similar technologies. As such, a more realistic cost estimate has been used.

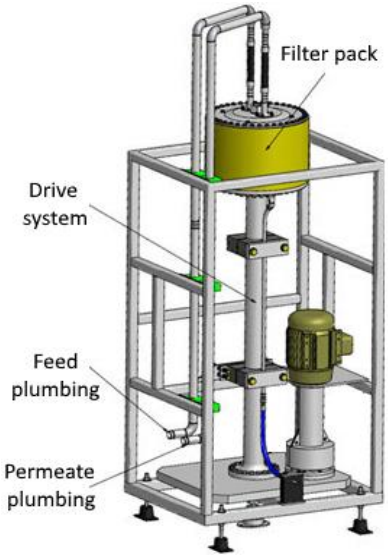
McLanahan's NRT at a Glance

Recovery efficiency*	Cost**	Mobile	Cake quality	Development	By-product	Smallest size***	Versatility
50% N >95% P 30% K	CAPEX = $200,000 OPEX = $22,000/year	Not possible	7% DM	Demo farm project only	None	Intended for >1,000 milking cows	Large fibre pre-removal needed

** If air stripping and absorption is used, capture efficiency for N and P is >90%.*
*** Costs only include pre-treatment and ultrafiltration, and doesn't include the cost of pre-removing large fibre, cake dewatering, or technology maintenance costs.*
**** Technology can be designed for smaller farms.*

New Logic Research (California, USA)

New Logic Research (NLR) supplies a membrane NRT. Using membranes of various porosities from microfiltration to reverse osmosis, a resonant frequency is used to vibrate the membrane surface 50 times per second. The shear waves created from this vibration prevents a laminar boundary layer from forming, thereby preventing fouling of the membrane surface and avoiding the need for cleaning. For increased nutrient recovery performance, Vibratory Shear Enhanced Processing (VSEP) filter packs can be fitted with reverse osmosis membranes.



New Logic Research's VSEP technology.

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. Suitable for manure or digestate, pre-removal of large fibre and sand is required to prevent damage to the pumps and membranes.

The VSEP technology has been installed on a few farms in Europe. Designed to be stationary but potentially mobile due to the technology's small footprint and skid-mounting[16], the smallest VSEP unit produced (i18) is intended for farms with ~180 milking cows (flow rate of ~1 m^3/hour). If installed on a 140 milking cow dairy farm with 5% DM fibre bedding manure, the i18 would cost an estimated $320,000 to purchase (CAPEX) and $14,000/year ($0.27/cow/day) to operate (OPEX). This system would produce an estimated 2,200 tonnes/year of 10% DM P and N-rich cake (~1,100 tonnes if dried to 25%DM).

Note: While CAPEX for the i18 would be the same for farms with 1 - 180 milking cows, OPEX would be somewhat proportionality lower for smaller farms as the technology wouldn't be used as frequently. CAPEX for a larger VSEP system, such as the i84 which is four and a half times larger than the i18, is only estimated to be 50% more.

[16] The VSEP i18 (9ft tall) and i36 (11ft tall) could be mobile, while the i84 (17ft tall) is likely too tall.

New Logic Research's NRT at a Glance

Recovery efficiency*	Cost**	Mobile	Cake quality	Development	By-product	Smallest size***	Versatility
50% N >90% P 30% K	CAPEX = $320,000 OPEX = $14,000/year	Potentially (for smaller systems)	10% DM	Few farms in Europe	None	180 milking cows	Large fibre pre-removal needed

** If fitted with reverse osmosis membranes, capture efficiency for N, P and K is >95%.*
*** Doesn't include the cost of pre-removing large fibre, cake dewatering, or technology maintenance costs.*
**** Technology can be used on smaller farms if operated at a reduced capacity.*

6.3 Mechanical Nutrient Recovery Technologies (Dryer)

Dorset Green Machines (Aalten, Netherlands)

Dorset Green Machines (DGM) supplies NRT consisting of a number of separate technologies. These technologies, which can be combined to meet specific needs, include a pre-treatment thickener, conveyor belt dryer, and water wash.

DGM's pre-treatment thickener has rotating plates that are repeatedly submersed into a tank containing manure or digestate. As the plates lift out of the tank, warm air is used to dry any attached feedstock to 12% DM. Once at 12% DM the feedstock is transported to a conveyor belt dryer consisting of perforated steel plates pulled by a roller chain. Inside the belt dryer feedstock is dried to 85% DM by warm air. Alternatively, if manure or digestate is already at >7% DM, feedstock can be dried using the belt dryer without the pre-treatment thickener.[17] Once dry, feedstock is transported to a final storage location where it can be pressed into pellets.

Photo of the DGM conveyor belt dryer and water wash drying digestate in Germany.

If necessary a wash system can be installed to clean reject air from the dryer by bringing it into contact with sulphuric acid, thereby 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.

Suitable for manure or digestate (if sand is used for bedding this must be separated prior to the drying technology), there are hundreds of DGM systems drying digestate and poultry manure on farms in Europe. Designed to be stationary, and ideally situated near a free heat source for the drying process,

[17] This is achieved by mixing some of the dried feedstock with incoming feedstock to increase the incoming feedstock's DM to 12%.

the smallest DGM dryer produced is intended for farms with ~130 milking cows (flow rate of ~0.8 m^3/hour). If designed for a 140 milking cow dairy farm with 5% DM fibre bedding manure, DGM's pre-treatment thickener and dryer would cost an estimated $300,000 to purchase (CAPEX) and $10,000/year ($0.20/cow/day) to operate (OPEX) if free heat is available. This system would produce an estimated 300 tonnes/year of 85% DM P-rich cake.

Note: While above CAPEX for the DGM thickener and dryer would be the same for farms with 1 – 130 milking cows, OPEX would be somewhat proportionality lower for smaller farms as the technology wouldn't be used as frequently. CAPEX for a DGM thickener and dryer system six times larger (for 800 milking cows instead of 130) is only estimated to be 300% more.

DGM's NRT at a Glance

Recovery efficiency*	Cost**	Mobile	Cake quality	Development	By-product	Smallest size***	Versatility
20% N 50% P 25% K	CAPEX = $300,000 OPEX = $10,000/year	Not possible	85% DM	Hundreds of farms in Europe	None	130 milking cows	No fibre pre-removal needed

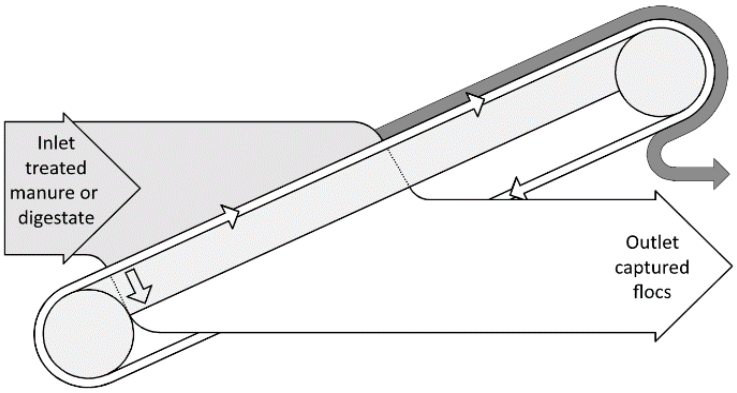
** If water wash technology is used, recovery efficiency for N, P and K = >90%.*
*** OPEX assumes locally available free heat source (>40°C) and doesn't include technology maintenance costs.*
**** Technology can be used on smaller farms if operated at a reduced capacity.*

6.4 Chemical Nutrient Recovery Technologies (Flocculation)

AL-2 (Hovborg, Denmark)

AL-2 supplies a flocculation NRT. Feedstock is first mechanically chopped before a coagulant (alum) and polymer are added. The flocs of suspended solids are then removed using a mechanical band filter. The band filter is similar to an angled conveyor belt, but with a fibre cloth with pore diameters from 40µm to5mm . As the flocs are placed on the cloth, liquid passes though while the particles remain. A scraper or brush unit removes the flocs at the top of the belt, before the back of the filter cloth is cleaned with water. The ~12% DM flocs containing 20% of the N, 90% of the P and 15% of the K in the feedstock, are sent to a screw press to increase DM to 25%.

Suitable for manure or digestate (if sand is used for bedding this must be separated prior to the flocculation technology), there are a half dozen AL-2 systems on dairy farms in the USA and more globally. Intended to be stationary but potentially mobile, and predominantly for farms with >1,200 milking cows (flow rate of >6.8 m^3/hour), if designed for a 140 milking cow dairy farm with 5% DM fibre bedding manure, AL-2's system would cost an estimated $280,000 to purchase (CAPEX) and $17,000/year ($0.33/cow/day) to operate (OPEX). This system would produce an estimated 1,200 tonnes/year of 25% DM P-rich cake.



AL-2's band filter.

Note: While above CAPEX for the AL-2 system would be the same for farms with 1 – 140 milking cows, OPEX would be somewhat proportionality lower for smaller farms as the technology wouldn't be used as frequently. CAPEX for an AL-2 system eight times larger (for 1,200 milking cows instead of 140) is only estimated to be 250% more.

AL-2's NRT at a Glance

Recovery efficiency	Cost*	Mobile	Cake quality	Development	By-product	Smallest size**	Versatility
20% N 90% P 15% K	CAPEX = $280,000 OPEX = $17,000/year	Potentially	25% DM	Many farms worldwide	None	Intended for >1,200 milking cows	No fibre pre-removal needed

** Doesn't include technology maintenance costs.*
*** Technology can be designed for smaller farms.*

DVO (Wisconsin, USA)

DVO supplies a flocculation NRT. Feedstock is fed to a primary mechanical screen to extract coarse fiber, before a secondary mechanical screen is used to extract smaller fibre. This fibre, which has 25 – 35% DM, can be used as bedding. Once fiber is removed, clarified liquid is sent to a Dissolved Air Flotation (DAF) unit where polymer is used to flocculate and raise any remaining solids to the surface. The flocs of suspended solids are skimmed and partially dewatered with an auger screw press 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.

Suitable only for digestate[18] (if sand is used for bedding this must be separated prior to the flocculation technology), there are two DVO systems on dairy farms in North America.[19] Designed to be stationary and intended for farms with >880 milking cows (flow rate of >5 m^3/hour), if designed for a 140 milking cow dairy farm with 5% DM fibre bedding manure, DVO's system would cost an estimated $210,000 to purchase (CAPEX) and $16,000/year (~$0.31/cow/day) to operate (OPEX). This system would produce an estimated 200 tonnes/year of bedding and 900 tonnes/year of 25% DM P and N-rich cake.

Note: While above CAPEX for the DVO system would be the same for farms with 1 – 140 milking cows, OPEX would be somewhat proportionality lower for smaller farms as the technology wouldn't be used as frequently. CAPEX for a DVO systems six times larger (for 880 milking cows instead of 140) is only estimated to be 100% more.

[18] If certain additives, such as ferric chloride, are added to the digester the flocculation process may not work effectively.
[19] These are George DeRuyter Dairy in Outlook Washington, and Herrema Dairy in Indiana (each with thousands of milking cows).

DVO's NRT at a Glance

Recovery efficiency*	Cost**	Mobile	Cake quality	Development	By-product	Smallest size***	Versatility
50% N 90% P 20% K	CAPEX = $210,000 OPEX = $16,000/year	Not possible	25% DM	Two farms in USA	Bedding	Intended for >880 milking cows	Only works with digestate

** Includes nutrients captured in course fiber (bedding material).*
*** Doesn't include technology maintenance costs.*
**** Technology can be designed for smaller farms.*

Trident Processes (B.C., Canada)

Trident supplies a flocculation NRT. Feedstock is fed into a mechanical rotary screen to extract 17% of coarse fiber, which is sent to a screw press with tapered screw and conical screen to be squeezed and washed, producing 35% DM bedding material. The clarified liquid from the rotary screen and screw press is sent to a hydration unit where polyacrylamide polymer is added before entering the DAF unit.

The DAF unit removes suspended organic material by injecting pressurized air to create micro bubbles that float suspended particles to the surface. The suspended particles are removed and gravity-fed to a multi-disc press where a screw press and dewatering cylinder increases 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. Suitable for manure or digestate[20] (if sand is used for bedding this must be separated prior to the flocculation technology), there are three Trident systems on dairy farms in North America.[21] Designed to be stationary, the smallest Trident unit is intended for farms with >260 milking cows (flow rate of >1.5 m^3/hour). If designed for a 140 milking cow dairy farm with 5% DM fibre bedding manure, Trident's system would cost an estimated $450,000 to purchase (CAPEX) and $34,000/year (~$0.67/cow/day) to operate (OPEX). This system would produce an estimated 200 tonnes/year of bedding and 900 tonnes/year of 25% DM P and N-rich cake.

Note: While above CAPEX for the Trident system would be the same for farms with 1 – 140 milking cows, OPEX would be somewhat proportionality lower for smaller farms as the technology wouldn't be used as frequently. CAPEX for a Trident system seven times larger (1,000 milking cows instead of 140) is only estimated to be 50% more.

Photo of the Trident NCT at Seabreeze Farm in Delta, B.C.

[20] If certain additives, such as ferric chloride, are added to the digester the flocculation process may not work effectively.
[21] These systems are at Seabreeze Farm in B.C., Canada, and Fair Oaks Farms, IN, U.S.

Trident's NRT at a Glance

Recovery efficiency*	Cost**	Mobile	Cake quality	Development	By-product	Smallest size***	Versatility
50% N 90% P 20% K	CAPEX = $450,000 OPEX = $34,000/year	Not possible	25% DM	Three farms in North America	Bedding	Intended for >260 milking cows	No fibre pre-removal needed

** Includes nutrients captured in course fiber (bedding material).*
*** Doesn't include technology maintenance costs.*
**** Technology can be designed for smaller farms.*

6.5 Chemical Nutrient Recovery Technologies (Struvite)

Multiform Harvest (Seattle, USA)[22]

Multiform Harvest supplies a struvite crystallization NRT. Feedstock is pumped through a cone-shaped up-flow fluidized bed reactor where conditions are created for the dissolved P and ammonia to combine with magnesium chloride to crystallize into struvite (magnesium ammonium phosphate). This struvite contains roughly 20% of the N and 80% of the P in the feedstock. Suitable for manure or digestate, pre-removal of bedding fibre and sand is required for technology performance.

There is one Multiform Harvest system on the 1,200 milking cow Jones Dairy in Maryland. This system cost $420,000 to install and has operating costs of ~$20,000/year. Designed to be stationary and intended for farms with >540 milking cows (flow rate of >3.1 m^3/hour), if designed for a 140 milking cow dairy farm with 5% DM fibre bedding manure, Multiform Harvest's system would cost an estimated ~$175,000 to purchase (CAPEX) and $15,000/year (~$0.29/cow/day) to operate (OPEX). This system would produce an estimated 10 tonnes/year of P-rich struvite.[23]

Note: While above CAPEX for the Multiform Harvest system would be the same for farms with 1 – 140 milking cows, OPEX would be somewhat proportionality lower for smaller farms as the technology wouldn't be used as frequently. CAPEX for a Multiform Harvest system eight times larger (for 1,200 milking cows instead of 140) is only estimated to be 150% more.

Multiform Harvest's NRT at a Glance

Recovery efficiency	Cost*	Mobile	Cake quality	Development	By-product	Smallest size**	Versatility
20% N 80% P N/A K	CAPEX = $175,000 OPEX = $15,000/year	Not possible	Struvite	One farm in the US	None	Intended for >540 milking cows	All fibre pre-removal needed

** Doesn't include the cost of pre-removing fibre or technology maintenance costs.*
*** Technology can be designed for smaller farms.*

[22] Because it was not possible to speak to anyone from Multiform Harvest, information was taken from documents found on the internet and has not been confirmed by anyone at the company.
[23] Estimate based on the production of 20 tonnes/year at the flush barn Jones Dairy in Maryland.

UBC (Vancouver, Canada)

Dr. Victor Lo at UBC has developed a microwave enhanced oxidation (MW/H_2O_2-AOP) NRT. This process combines microwave irradiation with hydrogen peroxide to generate hydroxyl radicals that react with organic compounds. Desired amount of hydrogen peroxide is introduced into the microwave chamber simultaneously with the pre-treated liquid manure or digestate at the beginning of the treatment. The clear solution after the MW/H_2O_2-AOP treatment process is ideal for struvite (magnesium ammonium phosphate) crystallization to recover 15% of the N, 90% of the P and 80% of the K from the feedstock.

Suitable for manure or digestate once pre-treated with solid-liquid separation technology, such as a screw or roller press, there are two MW/H_2O_2-AOP systems in B.C. The first is a 5kW 915 MHz continuous flow system at UBC in Vancouver, the second is a 6kW 2450 MHz continuous flow system at the UBC Dairy Centre in Agassiz, B.C. Designed to be stationary but potentially mobile due to its small footprint, the smallest MW/H_2O_2-AOP unit is intended for farms with ~70 milking cows (flow rate of ~0.4 m^3/hour). If designed for a 140 milking cow dairy farm with 5% DM fibre bedding manure, the MW/H_2O_2-AOP system would cost an estimated $300,000 to purchase (CAPEX) and $35,000/year (~$0.68/cow/day) to operate (OPEX). This system would produce sufficient magnesium ammonium phosphate solution for an estimated 10 tonnes/year of P-rich struvite.

Note: While above CAPEX for the UBC system would be the same for farms with 1 – 70 milking cows, OPEX would be somewhat proportionality lower for smaller farms as the technology wouldn't be used as frequently. CAPEX for a UBC system five times larger (for 350 milking cows instead of 70) is lower per cow. How much is unknown.

UBC's NRT at a Glance

Recovery efficiency	Cost*	Mobile	Cake quality	Development	By-product	Smallest size**	Versatility
15% N 90% P 80% K	CAPEX = $300,000 OPEX = $35,000/year	Potentially	Magnesium ammonium phosphate solution	Two demo systems at UBC	None	Intended for >70 milking cows	All fibre pre-removal needed

** Doesn't include the cost of solid-liquid separation, drying of ammonium sulfate solution, or technology maintenance costs.*
*** Technology can be designed for smaller farms.*

6.6 Biological Nutrient Recovery Technologies

Regenis/DVO/WSU (Washington, USA)

Regenis has partnered with DVO and Washington State University (WSU) to develop a CO_2 ammonia stripping NRT. Taking advantage of the fact that ammonia becomes gaseous at certain temperature and pH ranges, Regenis' system doesn't require alkali chemicals or stripping towers to volatilize the ammonia before creating ammonium sulfate. 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.

A more natural fit with digestate than manure, because AD increases the proportion of N in ammonia form, raises pH and produce free heat, pre-removal of large fibre and sand is required for technology performance. Regenis' system is currently being demonstrated on the 3,000 milking cow Big Sky Dairy in Jerome, Idaho, to recover nutrients from digestate. Designed to be stationary and predominantly for farms with >530 milking cows (flow rate of >3 m^3/hour), if designed for a 140 milking cow dairy farm with 5% with fibre bedding manure, the system would cost an estimated $100,000 to purchase (CAPEX) and $23,000/year ($0.45/cow/day) to operate (OPEX). This system would produce an estimated 25 tonnes/year of ammonium sulfate solution.

Note: While above CAPEX for the Regenis system would be the same for farms with 1 – 140 milking cows, OPEX would be somewhat proportionality lower for smaller farms as the technology wouldn't be used as frequently. CAPEX for a Regenis system four times larger (for 530 milking cows instead of 140) is only estimated to be 100% more.

Regenis' NRT at a Glance

Recovery efficiency	Cost*	Mobile	Cake quality	Development	By-product	Size**	Versatility
50% N 0% P 0% K	CAPEX = $100,000 OPEX = $23,000/year	Not possible	ammonium sulfate solution	Demo farm project only	None	Intended for >530 milking cows	Large fibre pre-removal needed

** Doesn't include the cost of pre-removing large fibre, drying of ammonium sulfate solution, or technology maintenance costs.*
*** Technology can be designed for smaller farms.*

6.7 Summary

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 (Figure 2 and 3). Although cost recovery per unit of P can be higher than other NRTs (Figure 4), 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).

Membrane NRTs recover ~50% of the N and almost all of the P in manure or digestate to produce a <10% DM nutrient-rich cake. Depending upon nutrient recovery efficiency, this NRT can be cost competitive with most other NRTs (Figure 2 and 3), while cost recovery per unit of P is also comparable (Figure 4). This NRT has only been adopted by a small handful of dairy farms in Europe and North America.

Dryer NRTs recover <25% of the N and ~50% of the P in manure or digestate to produce a ~85% DM P-rich product. Cost competitive with other NRTs if free heat is available (Figure 2 and 3), this NRT has a somewhat higher cost recovery per unit of P (Figure 4), and has been widely adopted by dairy farms in Europe. If sufficient free heat is not available, operating costs can increase tenfold.[24]

[24] A rough estimation is that 2GJ of heat is required to dry dairy manure from 140 milking cows to 85% DM. If using natural gas, this would cost ~$100,000/year.

Flocculation NRTs, when combined with simple dewatering technologies, recover ~50% of the N and almost all of the P in manure or digestate to produce a ~25% DM nutrient-rich cake. More commonly associated with digestate, this NRT is cost competitive with other NRTs (Figure 2 and 3), has comparable P recovery costs (Figure 4), and has been adopted by several dairy farms in Europe and North America.

Struvite NRTs recover almost all of the P and none of the N to produce P-rich crystals or liquid. While cost competitive with other NRTs (Figure 2 and 3) and with comparable cost recovery per unit of P (Figure 4), this NRT is still under development and has only been adopted by one or two dairy farms in North America as a demonstration project.

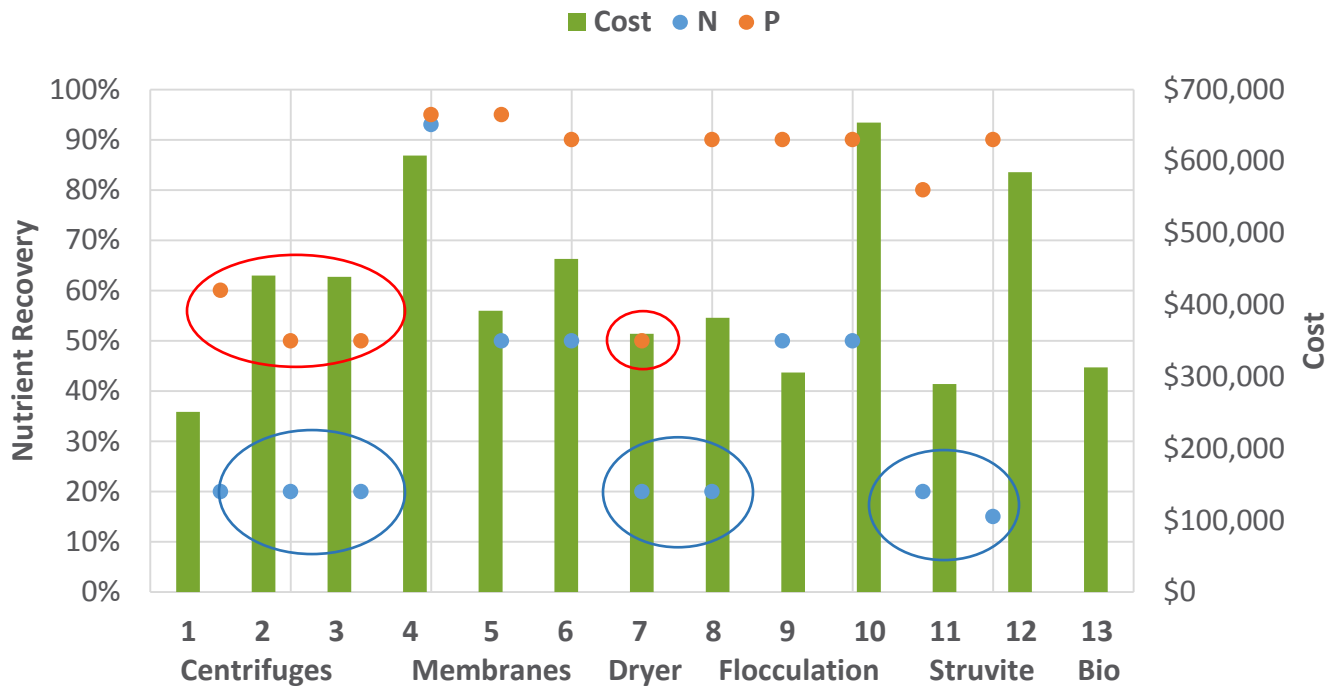
Ammonia-N stripping NRTs, more effective with digestate than manure, recover ~50% of the N and none of the P in manure or digestate to produce an N-rich solution. While this NRT can be cost competitive with other NRTs (Figure 2 and 3), it is still under development and is much more suited to higher ammonia-N feedstocks, such as poultry manure.

Figure 2: Nutrient Recovery Performance and Cost*

Technology Type	Company Name	N % Recovery	P % Recovery	Cost ('000)
Centrifuges	1. Alfa Laval	20	60	$250
	2. DariTech	20	50	$440
	3. GEA	20	50	$440
Membrane	4. LWR	95	95	$610
	5. McLanahan	50	95	$390
	6. NLR	50	90	$460
Dryer	7. DGM	20	50	$360
Flocculation	8. AL-2	20	90	$380
	9. DVO	50	90	$310
	10. Trident	50	90	$650
Struvite	11. Multiform H	20	80	$290
	12. UBC	15	90	$590
Biological (BIO)	13. Regenis	50	0	$310

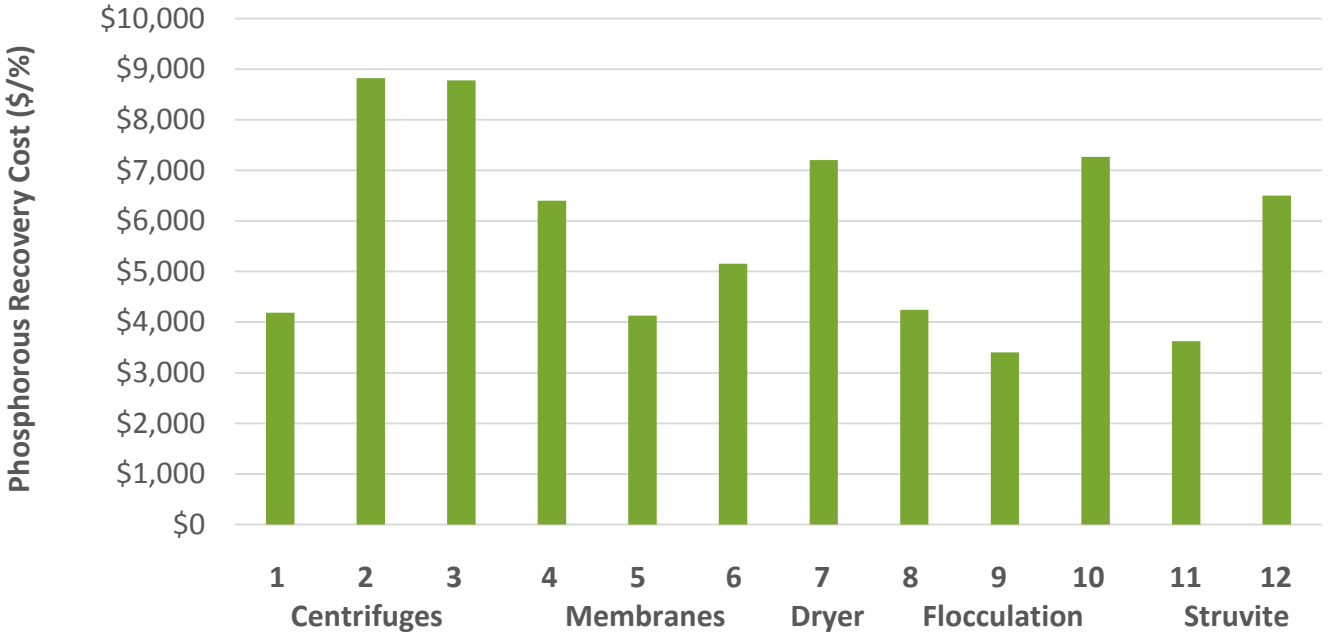
** Cost estimated as capital cost and six years of operating costs (excluding technology maintenance costs).*

Figure 3: Nutrient Recovery Performance and Cost*



** Cost estimated as capital cost and six years of operating costs (excluding technology maintenance costs).*

Figure 4: Phosphorous Recovery Cost



Note: Regenis' NRT isn't included in the above graph as it doesn't recover any P.

7. Economic Feasibility

NRTs are not economically feasible for the average sized 140 milking cow B.C. dairy farm. For example, assuming optimistic revenues of $10/tonne for nutrient-rich cake, $30/tonne for bedding, $400/tonne for ammonium sulfate, and $1,000/tonne for struvite[25], only one of the reviewed NRTs (DGM's belt dryer) generates sufficient revenues to cover operating costs, and only then if sufficient free heat is available. If free heat is not available, revenues are not sufficient to cover operating costs.

The scale up factor for NRTs isn't linear (i.e., a system twice the size is much less than twice the price). As such, NRTs are more economically feasible for larger dairy farms. However, even though larger NRTs have lower capital cost per unit of manure or digestate processed, only two of the reviewed NRTs (DGM's dryer and DVO's flocculation system) generate sufficient revenues on a 500 milking cow dairy farm to cover operating costs. Again, this assumes sufficient free heat is available for DMG's dryer.

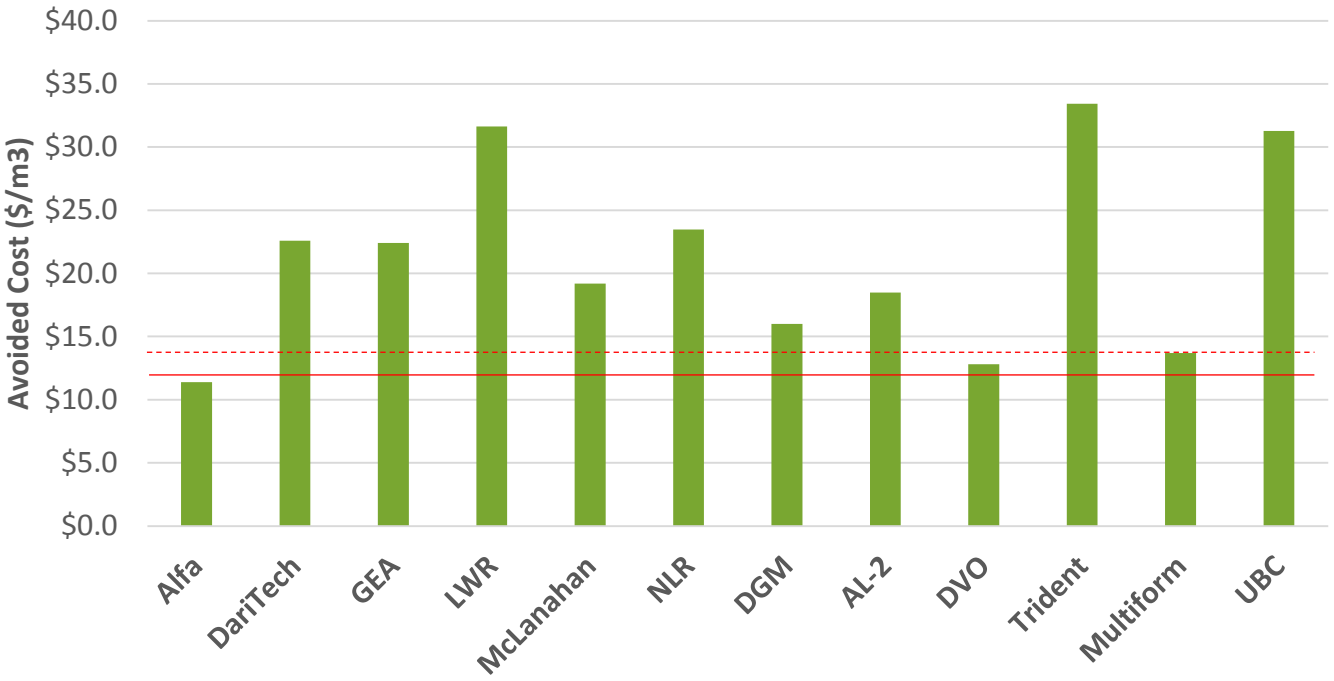
One way to reduce the cost and thereby improve economic feasibility would be for several farms to share a NRT. For example, a centrifuge that processes 25,000 m^3/year of manure is less than twice the cost of a centrifuge for 7,000m^3/year. Centrifuges, unlike most other NRTs and due to their small footprint, 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 increase DM content.

For the majority of dairy farms in Europe and North America, the key drivers for NRT adoption are to meet local nutrient management regulations, or expand herd size without having to acquire more land.[26] Because many dairy farms in the Lower Mainland and elsewhere in B.C. have twice as much P than needed for their crop needs, balancing the field application of dairy manure and digestate nutrients with local crop requirements would likely require many dairy farms to transport roughly half of their manure or digestate to areas with nutrient imbalances.

Under a scenario where dairy farms must transport half of their manure or digestate, NRTs for 140 milking cow farms become more feasible (Figure 5). For example, at an avoided cost of $12/tonne of trucked manure or digestate, and assuming the above mentioned revenues for nutrient-rich cake, bedding, ammonium sulfate and struvite, Alfa Laval NRT has simple paybacks of <6 years. At $14/tonne, DVO and Multiform Harvest's NRTs also have simple paybacks of <6 years.[27]

[25] Local markets for nutrient-rich cake, ammonium sulfate and struvite from dairy manure currently do not exist. Therefore the suggested prices are based on different revenue estimates from elsewhere coupled with assumptions about potential local markets.
[26] Very few dairy farms adopted NRTs to take advantage of a new business opportunities to sell their excess nutrients.
[27] This doesn't factor in the cost of acquiring additional N to offset that lost in the manure or digestate trucked away.

Figure 5: Avoided Trucking Costs Required for Six Year Payback for 140 Milking Cow Farm ($/tonne)



Note: Regenis' NRT isn't included in the above graph as it doesn't recover any P (i.e., will not reduce trucking costs).

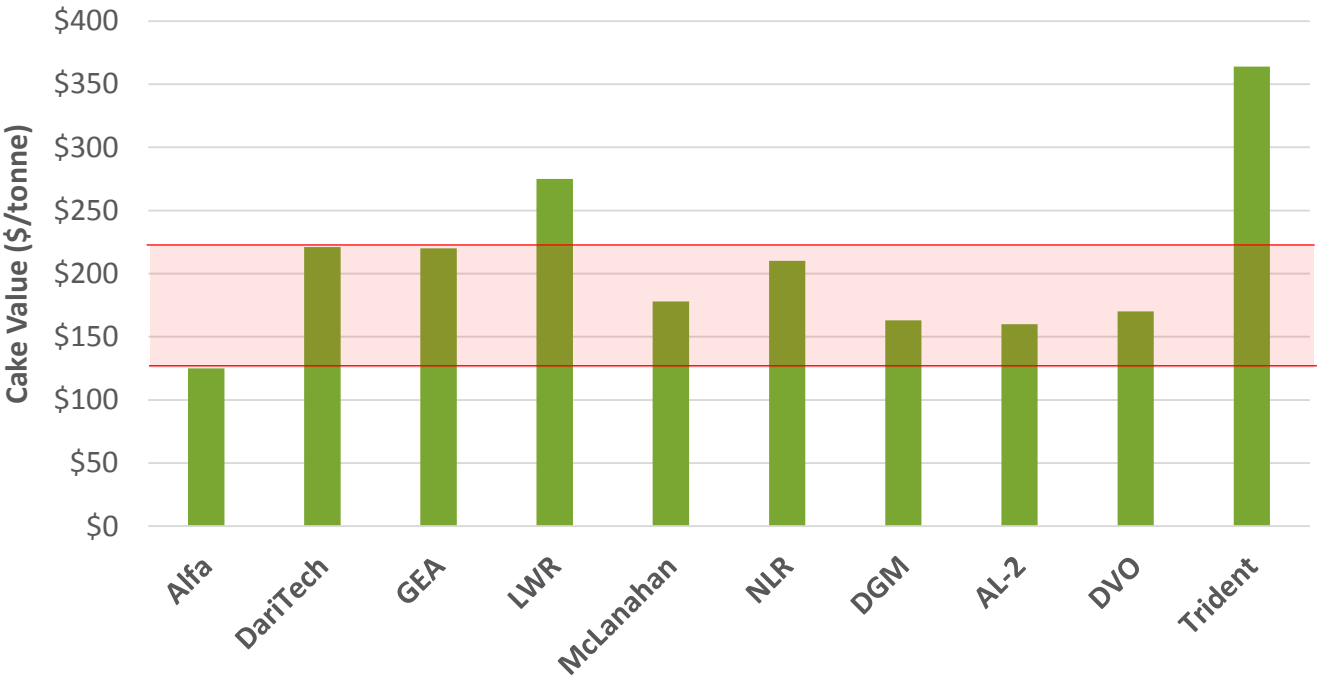
As with being more economically feasible for larger dairy farms, avoided cost per tonne of trucked manure or digestate is also lower for NRTs on 500 milking cow farms to have a simple payback of <6 years. For example, at an avoided cost of $6/tonne trucked manure or digestate, and assuming the above mentioned revenues for nutrient-rich cake, bedding, ammonium sulfate and struvite, Alfa Laval, AL-2, DVO, and DGM's (assuming free heat) NRTs have simple paybacks of <6 years. At $10/tonne, almost all reviewed NRTs have simple paybacks of <6 years.[28]

Most NRTs produce a low value, low DM (<25%) nutrient-rich cake. To date, and due to the lack of a mature market, experiences in B.C. and elsewhere have shown difficulty in selling this cake without further processing. As such the cake is often given away. To increase the desirability of this cake, some dairy farms are trying to produce a more marketable, higher-value product via downstream processing, such as drying. For 140 milking cow dairy farms, this downstream processing would need to increase the value of the nutrient-rich cake to $125 – $225/tonne for most NRTs to have a simple payback of <6 years (Figure 6).[29] For Multiform Harvest, Regenis and UBC's NRTs that produce struvite, ammonium sulfate, and magnesium ammonium phosphate solution, respectively, the cost of these products would need to increase roughly fifteen fold to achieve simple paybacks of <6 years.

[28] *Ibid.*
[29] Does not including necessary additional capital and operating costs to process the cake.

For dairy farms with 500 milking cows, downstream processing of the nutrient-rich cake would need to increase the value to $80 – $115/tonne for most NRTs to have a simple payback of ~6 years. For Multiform Harvest, Regenis and UBC's NRTs, the value of struvite, ammonium sulfate, and magnesium ammonium phosphate solution would need to increase roughly tenfold to achieve simple paybacks of ~6 years.

Figure 6: Value of Product to Enable Simple Payback of Six Years for 140 Milking Cow Farm ($/tonne)



8. Conclusion

Of all the NRTs installed on dairy farms in Europe and North America, centrifuges are seen as the best fit for most B.C. dairy farms. This mechanical separation technology, which has been widely adopted in Europe and North America, is able to recover around 50% of the P and less than 25% of the N from manure and digestate. Furthermore, centrifuges can achieve this nutrient recovery at costs that are comparable, if not lower, than other mechanical, chemical and biological NRTs. Mechanical dryers, if sufficient free heat is available, are also appropriate and can be cost effective for nutrient recovery from dairy manure and digestate. However, available free heat will prove to be a challenge for many dairy farms as its absence can increase operational costs tenfold.

For most on-farm anaerobic digesters in B.C., centrifuges are also seen as the best fit. However, if large volumes of high protein feedstocks, such as animal and animal by-products, are co-digested with manure then membranes, flocculation, or other NRTs that achieve greater nutrient recovery may be more suitable.

Currently, none of the NRTs evaluated in this report are economically feasible for B.C. dairy farms. However, this assessment is based solely on estimated revenues generated from the sale of nutrient-rich products and bedding savings. If the environmental benefits of NRTs were to be monetized, such as reduced nutrient leaching into waterbodies and reduced greenhouse gas emissions, if more stringent nutrient management regulations were introduced, or if dairy farms want to expand their herd size without having to acquire additional land, NRTs would become more economically feasible.

One way to reduce the cost and thereby improve the economic feasibility of NRTs would be for several dairy farms to share a single technology. Centrifuges, unlike most other NRTs and due to their small footprint, have the potential to be mobile units that move from farm to farm. However, designing a co-operative agreement for sharing a mobile centrifuge would need to be well designed and tested before dairy farms would consider this approach. Furthermore, there may be significant reticence to this approach, as technology sharing isn't currently widely practiced by B.C. dairy farms.