July 10, 2019

# Installation and Evaluation of a Lagoon-Based Nitrification Denitrification for Treatment of Digested, Solid/Liquid Treated Dairy Manure

## Final report to the Washington state Conservation Commission—Distillation Grants Program

## A. The Technology

***Part of an Integrated Process***

The George DeRuyter and Son (GDR) and D&A dairies combine their manure streams for sequential treatment across multiple technologies designed to protect soil, water, air and climate impacts while also producing renewable fuel and valuable bedding and fertilizer co-products. The modified nitrification/denitrification (NDN) process to be demonstrated in this $250,000 Washington State Conservation Commission grant is installation and evaluation of the last step in this integrated sequence. In brief the sequence of treatment is (Figure 1):

- Treatment of manure flows in a mesophilic anaerobic digester to produce renewable natural gas (RNG) while also significantly reducing indicator pathogens and odor-causing volatile organics.
- Subsequent solids/liquid separation of digestate into a liquid effluent and a fibrous solids that is utilized as animal bedding for the dairies.
- Further treatment of the liquid effluent in a dissolved air flotation (DAF) system to remove suspended solids, for production of a low-solids liquid fertilizer suitable for delivery within central pivot cropping systems and a clay-like, nutrient-rich fine solids for densification of nitrogen and phosphorous nutrients into a solid fertilizer product for use either on farm fields or export.
- With installation of NDN, final treatment of the liquid effluent for partial conversion of reactive nitrogen to inert, non-reactive nitrogen gas, thereby reducing total nitrogen loading to the farm, and reducing environmental and economic costs associated with manure hauling necessary to meet nutrient management plans.

Importantly, all steps are iterative and connected, with each preceding step necessary to adequately treat through the ensuing step. Put another way, a breakdown in operations anywhere upstream of the processes, leads to cumulative reductions in ability to downstream process, and not achieving total system and farm goals. From a solids and nutrient perspective, process goals for the integrated system are to: (1) partition >90% of total phosphorous away from the liquid and into the solids, particularly the fine solids so that phosphorous to fields can be more efficiently managed; (2) greater than 95% reduction of total suspended solids (TSS) in the final liquid fertilizer for center pivot application to fields; and (3) high reduction of total nitrogen loading (via partitioning of solids and NDN) in the final liquid fertilizer to reduce hauling costs.

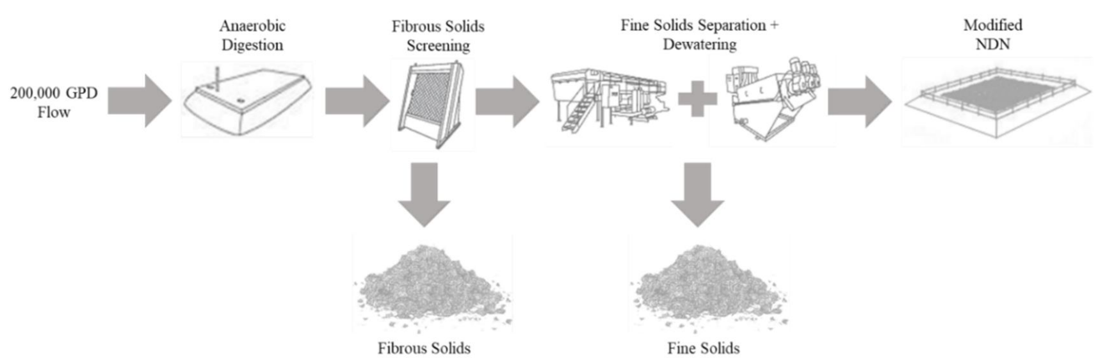


Figure 1. Dairy Integrated Manure Management with NDN Integration

***The modified NDN System***

Classic NDN works according the general principles laid out in Figure 2. In short, nitrogen-containing liquid is exposed to air so that aerobic microorganisms can convert the organic and ammonia-nitrogen into a different form, namely nitrite/nitrate. The aerated liquid enters a quiet zone so that microorganisms can be more readily settled for its subsequent recycling with nitrite/nitrate-rich liquid to the anoxic zone in the front-end of process. Once in the anoxic zone, a completely different consortia of anoxic bacteria convert the nitrite/nitrate to non-reactive nitrogen gas for its harmless release to the atmosphere. New liquid plus some unreacted nitrogen in the recycled liquid continue the process by again being aerated, but this time with recycled bacterial seed to aid the process. Input and recycled flows are balanced against a desired sizing and reaction time of the system, yielding a continuously produced final low-nitrogen liquid to a storage lagoon awaiting its final use as a crop fertilizer.

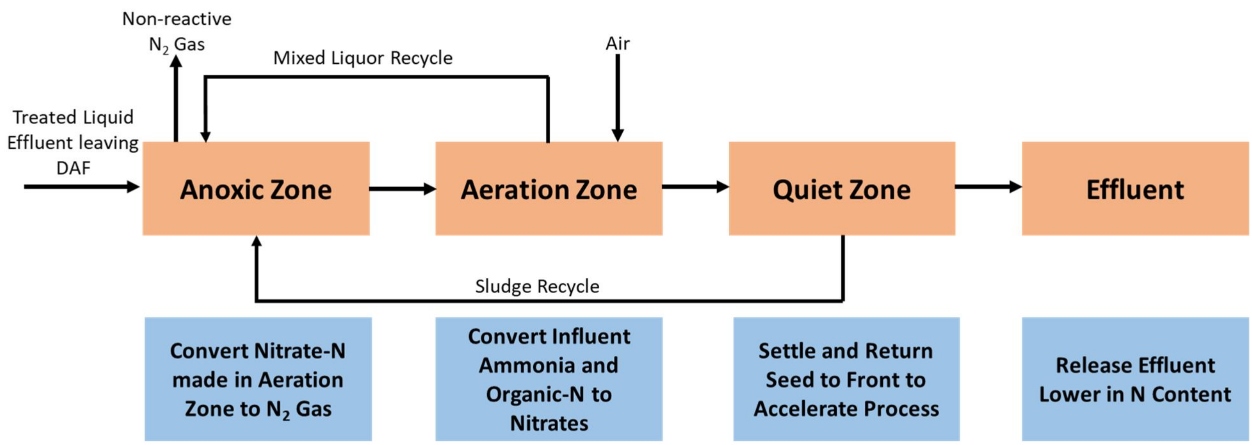


Figure 2. Basis process of NDN

While NDN is a well-vetted and commercialized technology within the wastewater industry, particularly at municipal wastewater treatment facilities (WWTF), application to digested dairy manure is not, requiring some modifications. The first, modification relates to cost. While designed for impressive performance, in the range of 95% nitrogen reduction, installations at WWTF are very costly from both a capital and operating structure, something simply not viable within a farm setting. To overcome this financial hurdle, the design must be to utilize existing infrastructure as much as possible for reduction of capital expenditures, and to accepting a loss in degree of performance to save on operating expenses. Additionally, WWTF designs are built around wastewater with relatively low solids and nitrogen content, with dairy manure, even after pretreatment, of a considerably higher concentration for both. To address this, modifications to design as well as operating parameters, and importantly reduction in performance, must be completed and accepted.

Figure 3 is a collage of photos and design schematic for the modified NDN for installation just south of the existing anaerobic digester, solid/liquid and DAF separation systems. Effluent leaving the DAF gravity feeds to a diversion box that will allow out-of-spec effluent during periods of maintenance to the preceding equipment to be sent away from the NDN lagoon and instead to the NDN overflow storage lagoon. During periods of diversion, this will protect the

NDN lagoon system from excessive mass loading and bacterial upsets. During periods of normal operation, full flow from the preceding systems enters the NDN lagoon in the upper left corner. The existing storage lagoon was emptied and cleaned of solids for preparation of equipment insertion, as described in the schematic with the respective anoxic, aeration, and quiet zones, outfitted with aerators, sensors, mixers, and pump—all controlled via a containerized control box. Floating baffle curtains tied with weights to bottom of lagoon are used to divide the lagoon into quadrants for operation of the respective zones. Arrays of aerators are also placed at the bottom of the aeration zones, tied to blowers for aeration of the system. Lastly, pumps and mixers are used to feed recycled sludge and liquid to the anoxic zone, while excess treated flow is pumped as effluent to the second storage lagoon.

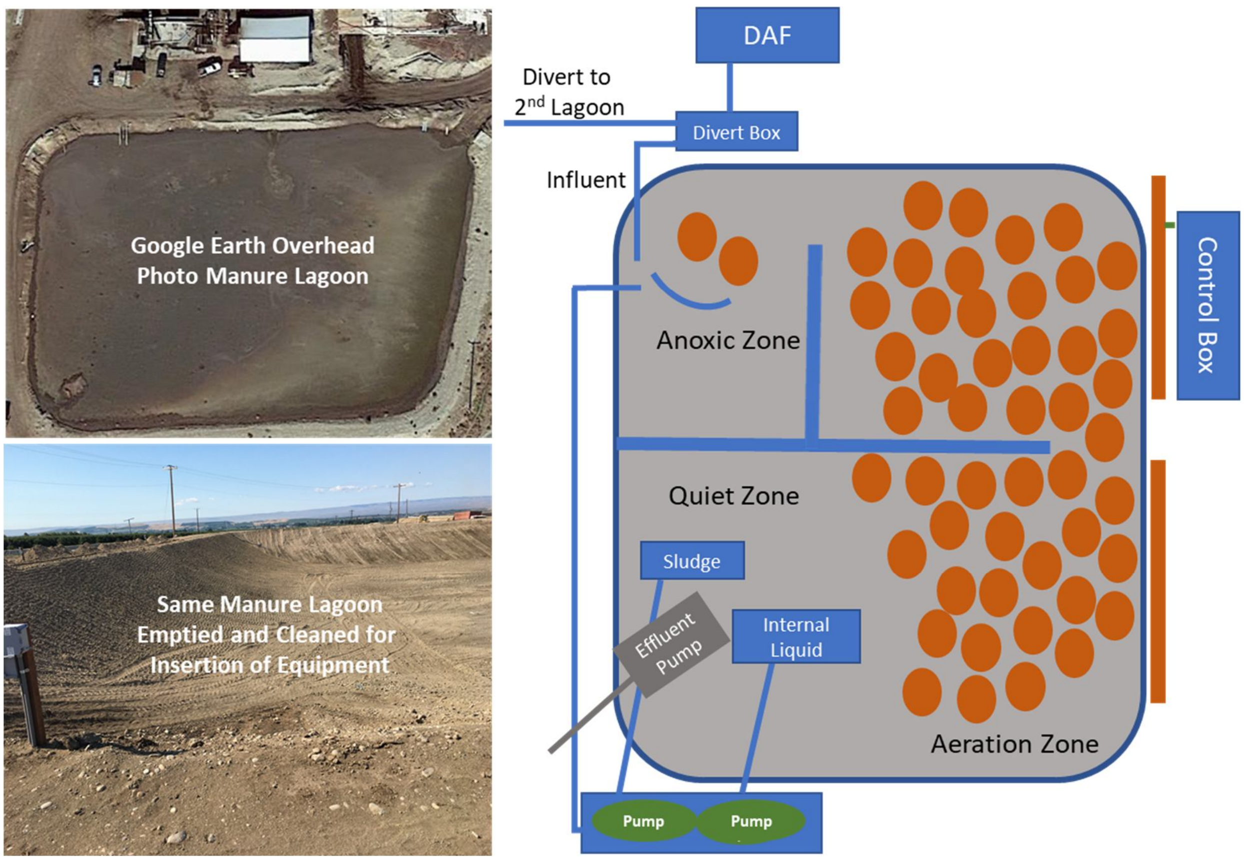


Figure 3. Photos and schematic of NDN lagoon and NDN system: (a) overhead image of existing storage lagoon to be converted to NDN system; (b) photo of that same lagoon after being emptied, cleaned and prepped for equipment insertion; (c) how the existing lagoon is divided into active NDN quadrants with appropriate NDN equipment (orange are submerged micro-aerators, thick blue lines are floating baffle curtains)

Table 1 is a summary of the design parameters for the modified NDN installation. From available data on expected influent flows, nitrogen, BOD, and alkalinity, as well as specifications for utilized micro-aerators and blowers, the required aeration rates, air flow, and blower requirements were calculated for effective nitrification/denitrification to occur.

Table 1. Design parameters

| Parameter | Unit | Value |
|---|---|---|
| Flow Rate | GPD | 135,000 |
| Influent Concentrations | mg/L | 850 TAN; 1,200 TKN; 500 BOD; 10,000 alkalinity |
| Lagoon Volume | gallons | 3,525,000 |
| Zone Volumes by % | % | 75% aeration; 15% quiet; 15% anoxic |
| Hydraulic Retention Time | days | 9.2 days in aeration zone |
| Actual $O_2$ Requirement | lbs. $O_2$/day | 4,996 |
| Standard $O_2$ Requirement | lbs. $O_2$/day | 16,117 |
| Air Flow Requirement | $ft^3$ air/min | 2,157 |
| Blower Requirement | HP | 86 |
| Recycle Rates | % | 200% mixed liquor; 15% sludge |

**B. Construction and Project Status**

The original project timeline, which was described as ambitious in the original proposal, was to have construction of the NDN occurring in the fall of 2018 when lagoons were emptied prior to required winter storage. This was to be followed by testing/evaluation later that next spring, upon return of appropriate weather for effective biological activity. Unfortunately, considerable hurdles were experienced that delayed this timeline. As noted, the NDN fits within a larger system, with required retrofits to the digester and separator systems (slope screens and DAF) also in need of design, construction and re-operation to steady-state. With a focus on maintaining dairy operations through a very difficult winter, as well as completing the delayed retrofits to the companion systems, construction of the NDN was not possible during the fall. As the lagoon to be used for the NDN was needed for winter storage and would not become available for emptying, dredging, and leveling until late spring/early summer, all aspects of NDN construction could not even begin to occur until June—leaving only enough time to begin construction and no time for start-up, testing, and evaluation. Below is a bulleted summary of the actual timeline of events completed and to be completed after required adjustments:

- Start of anaerobic digester and separator system retrofits in late summer 2018
- Completion of retrofits and production of biogas in January/February 2019
- Troubleshooting and modifications to digester/screens for achievement of pre-NDN steady-state—ongoing from March-July 2019
- Recovery of equipment, movement of equipment from pilot lagoon to new lagoon, as well as ordering of equipment/supplies October-June 2018-2019
- Emptying, dredging, and leveling of lagoon June 2019
- Estimated installation of micro-aerators and associated equipment within lagoon in July-August 2019
- Filling and seeding of NDN lagoon in August-September 2019
- Troubleshooting, testing, and steady-state of NDN September-November 2019

Figure 4 is a collage of photos showing status of construction as of early July, with all lagoon preparations, trenching, diversion boxes, electrical work, and placement of container/large equipment and aerators completed. Remaining construction/installation items include completion of all inter-ties and filling/seeding of lagoon for initial operations.

Figure 4. Construction

## C. Capital and Operating Costs by Scale

Table 2 is a summary of the projected capital costs for NDN installations on dairy lagoons, with projected costs for other scales based on costs for this demonstration. The NDN technology has been identified as a potential nutrient solution for large dairy flows, either from large dairy installations or installations utilizing high-flow flush systems (Frear et al., 2018). As a result, scaling is set for large systems, not small dairy systems. Frear et al., (2018) in their analysis of various NDN systems applied to animal manures identified a general capital cost range of $200-500/HWCE using similar HWCE and flow rate assumptions as here. As can be interpreted from the table, the capital costs for this NDN system are on the lower end, at roughly $150/HWCE, thanks in-part to the use of existing lagoon infrastructure and its simplified baffle curtains for zone partitioning, as opposed to use of dedicated concrete structures. The scaling factor is approximately linear (increased pumps, blowers, aerators, piping by flow rate increase) but difficult to assess, as the key is having a suitably sized, existing lagoon available for NDN use, that fits the hydraulic retention time and placement needs for the given flow rate and scale.

Table 2. Capital costs for systems at scales

| | **4,500 HWCE [a] 130,000 GPD** | **7,000 HWCE [a] 200,000 GPD** | **10,000 HWCE [a] 280,000 GPD** |
|---|---|---|---|
| NDN [b] | $650,000 | $1,000,000 | $1,400,000 |

[a] HWCE refers to Holstein wet cow equivalent, with an assumed approximate 35 gallons/HWCE/day manure production rate, although it could represent fewer HWCE and larger flush flows, based on known manure management flow ratios. GPD is discounted 20% as it is assumed that the flow is digested and screened through primary and DAF treatment to achieve an approximate >90% TSS removal.

[b] Assumes no cost for lagoon, its dredging and preparation.

Table 3 is a summary of the operating costs as determined by estimated electrical draw of equipment and required daily walk-through operations. Maintenance costs are estimated at 3% of capital, based on experience of equipment utilized. Frear et al., (2018) estimated average O&M expenses for the various NDN approaches for manure treatment at $15-50/HWCE, with O&M costs for this NDN at these scales at roughly $20/HWCE.

Table 3. Operating costs at various scales

| | **4,500 HWCE [a]<br>130,000 GPD** | **7,000 HWCE [a]<br>200,000 GPD** | **10,000 HWCE [a]<br>280,000 GPD** |
|---|---|---|---|
| Electrical [b] | $61,320 | $94,339 | $132,074 |
| Labor [c] | $25,550 | $25,550 | $25,550 |
| Maintenance [d] | $19,500 | $30,000 | $42,000 |
| Total | $106,370 | $149,889 | $199,624 |

[a] HWCE refers to Holstein wet cow equivalent, with an assumed approximate 35 gallons/HWCE/day manure production rate, although it could represent fewer HWCE and larger flush flows, based on known manure management flow ratios. GPD is discounted 20% as it is assumed that the flow is digested and screened through primary and DAF treatment to achieve an approximate >90% TSS removal.

[b] Assumes $0.07/kWh electrical pricing

[c] Assumes 2 hours/day labor at salary rate of $35/hour, no scale-up required for labor hours

[d] Assumes 3% of capital

### D. Assessment of Available Tax Credits and Cost Shares

The primary method for potential assistance with capital costs is NRCS EQIP funds, as the technology has potential for improving upon air quality, fuel savings, and climate emissions associated with long-term storage and hauling of ammonia-concentrated liquid manure. Unfortunately, for technologies such as this to qualify, they need to be an approved approach within existing standards, a process that will require time and effort from all. Hopefully, data from this demonstration can assist NRCS officials in supplying the required information and data to incorporate the technology into the standard(s).

EQIP is only a partial answer to capital costs, with operating costs also being an issue. Two of the most discussed pathways to offset some of the operating expenses are (1) nutrient trading and (2) biofertilizer incentive programs. As NDN is unique among other manure/nutrient control technologies in that it does not produce a fertilizer product, instead altering it to an innocuous loss of reactive nitrogen in the form of nitrogen gas, there is no hope of offset of operating costs via these two methods. Grants involving improvements in local air quality (Yakima region, for example, is a region marked by EPA for much-need air quality improvement) and vehicle fuel efficiencies/emissions could be alternative mechanisms for cost relief. Fortunately, in comparison to some of the other technology approaches, operating costs for the NDN technology are relatively low.

### E. Impacts to Soil, Water, Air and Climate

While the entire sequence of treatment steps leading up to and involving the NDN has numerous potential positive impacts to soil, water, air and climate, the focus in this demonstration is the NDN and its specific role. The primary goal of the NDN is to reduce the concentration of reactive nitrogen, primarily in the form of ammonia, within the liquid effluent—and to do so in an innocuous manner, via release of non-reactive nitrogen gas to the atmosphere.

From a global sustainability perspective, loss of reactive N is not ideal, given the high energy and greenhouse gas costs associated with the Haber-Bosch process for conversion of atmospheric N back into reactive N fertilizer. Another perspective, though, involves the unique localized situation some large dairies are in, requiring considerable acreage and potentially long and expensive hauls of manure to apply to those fields, for appropriate nitrogen management. Thus, to overcome this localized event of potential over supply of reactive nitrogen, one can simply alter its form, removing it from the equation. In the case of the dairies, capital and operating costs associated with NDN, are potentially paid for by offsets in trucking/hauling. Importantly, from an environmental perspective, the limited NDN emission costs (electrical operation of blowers, pumps, etc.) are potentially offset by reduction in baseline emissions. These baseline emissions include:

- Truck fuel usage, air emissions associated with those fuel emissions, greenhouse gas implications from those fuel emissions, and road traffic on county roads associated with extensive manure hauling
- Ammonia and associated PM 2.5 releases during long-term storage, potentially negatively impacting local air quality as well as down-wind soil deposition

Detailed emission accounting from both baseline and NDN operations would be required to completely understand this environmental balance and potential offset, but strong potential does exist for dairies under burdens of high N-loading requiring long and high-volume hauls of positively improving upon both their economic and environmental situations.

## F. Future Steps

With the delays encountered, an adjusted timeline has been required, with start-up and testing to be completed after the final report submission date. Specific steps required include finalization of the NDN system during the upcoming summer months, followed by operation throughout the fall to achieve steady-state and some performance data. Goals remain to show a >40% reduction in total nitrogen during the NDN processing step, as measured by influent/effluent total N, TKN, and ammonia tests as well as an accounting of potential economic and environmental gains associated with reduced hauling resulting from that nitrogen reduction.

## G. References

Frear, C., Ma, J., Yorgey, G., (2018). Approaches to nutrient recovery from digested dairy manure. Washington State University Extension, Pullman WA. EM112E.