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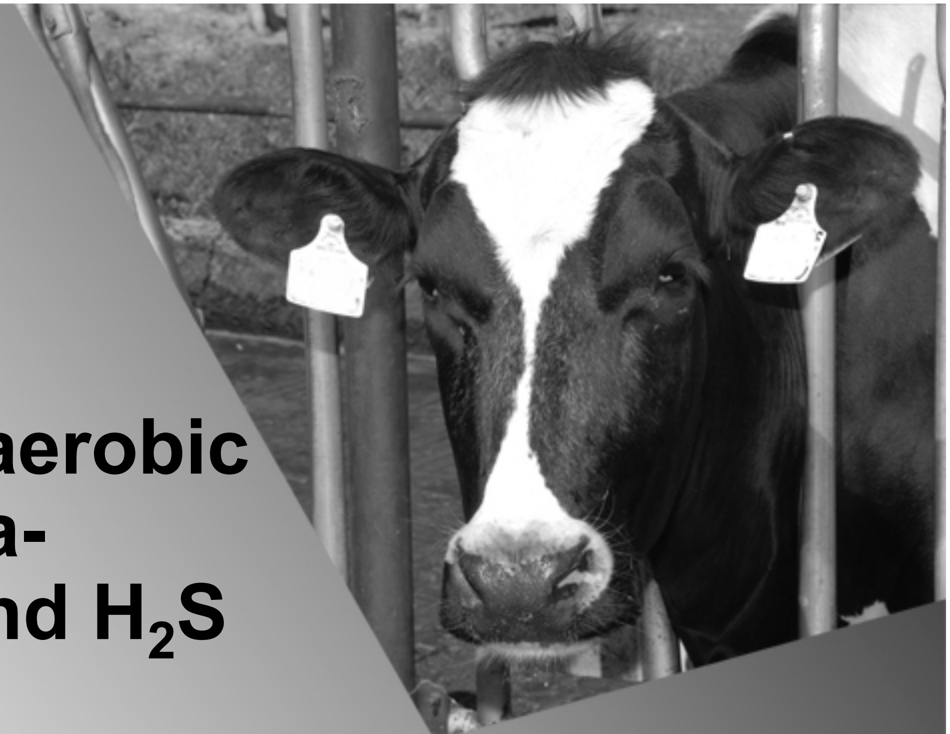

Commercialization of Anaerobic Digestion, Ammonia-Phosphorus Recovery and H_2S Scrubbing System

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WCTA Breakfast: A New Golden Age of Agriculture
Seattle WA

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CLIMATE FRIENDLY FARMING™

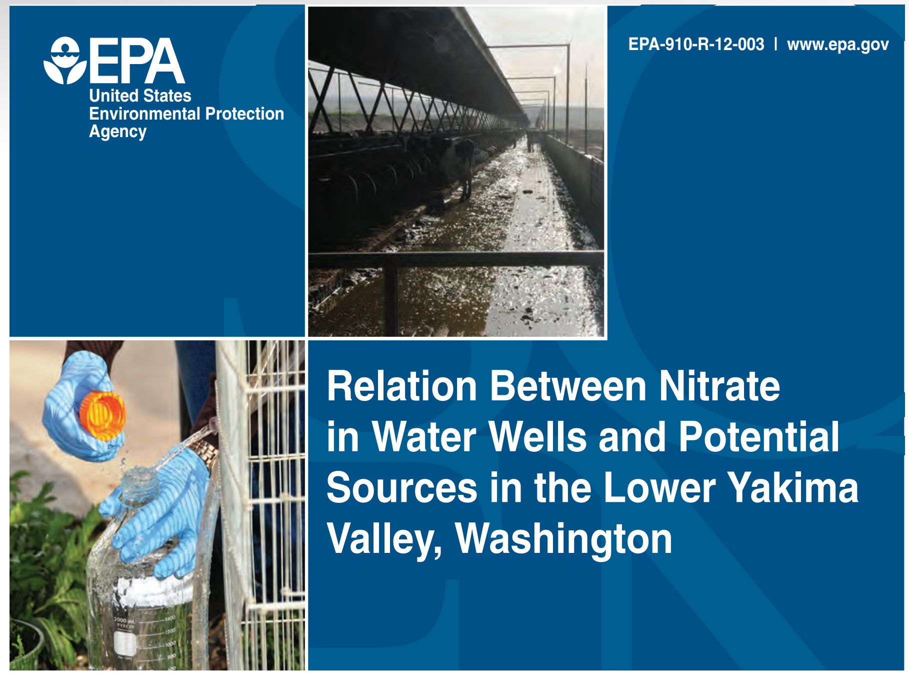
Center for Sustaining Agriculture & Natural Resources

The Situation/Solution

Phosphorus/Nitrates/Ammonia

99% of large dairy CAFOs are in a state of phosphorus overload to their soils—primarily due to expense of transporting liquid manure to distant fields—concern of eutrophication;

Yakima Basin exceeds federal PM 2.5 standards which are in part due to ammonia concentrations that can worsen particle/smog production



Reports of excessive nitrate levels in well water in both dairy sectors in Washington State. Recently, unprecedented agreement between Washington dairy CAFOs and EPA on practices and technologies to be implemented for improved control of potential manure nutrient contaminants (US-EPA, 2013b).

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AD as a Partial Solution

AD mitigates numerous air, water and climate environmental concerns while producing renewable energy **however** little advantage is gained for CAFO or industry producers concerned with their overall nutrient loading to fields.

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Nutrient Solution

Insert a nutrient recovery process on the back end of the digester to recover N and P nutrients from the effluent. **Research question is what system is most economical, and produces highest yield?**

Nutrient Recovery Unit

No Ammonia Inhibition

Saleable Bio-fertilizers

Reduced Nutrient Loading

What Approach?

- AD process leads to 30-40% shifts from organic nitrogen to **ammonia** nitrogen leading to elevated effluent ammonia concentrations (EPA Agstar, 2005)—lending the recovery process to be **ammonia stripping**.

- Traditional **ammonia air-stripping and steam stripping,** require **costly alkali** inputs to elevate pH or **high thermal inputs**, respectively, as well as towers that are prone to **solids clogging**. Thus, can a system be developed removing these concerns?

Table 1. Properties of the anaerobically digested dairy manure

	TAN (mg/L)	DIC (mg/L)	Alkalinity (mg $CaCO_3$/L)	pH	Dissolved CO_2 (mL/L)*
AD Influent	1,760 ± 95	984 ± 27	8,960 ± 460	6.95 ± 0.14	527 ± 104
AD Effluent	2,550 ± 148	1,451 ± 31	14,230 ± 853	7.80 ± 0.19	846 ± 121

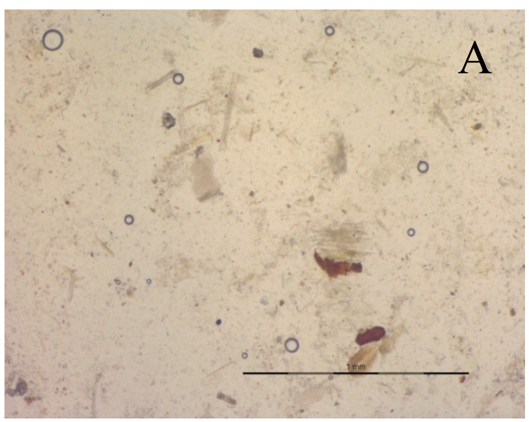
Values are mean of duplicate tests

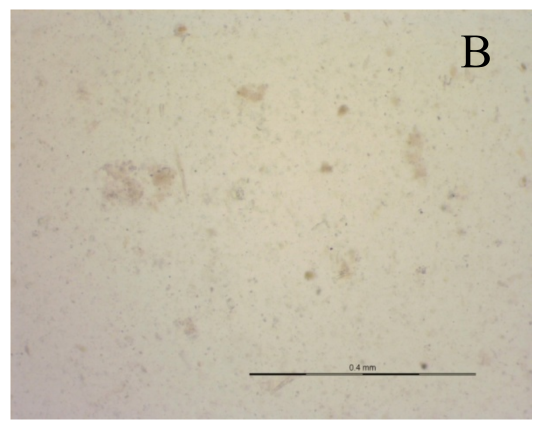
*Tested from the collected gas by applying vacuum of 27 in. Hg for 2 hours at 55°C

What Approach?

- The majority of **phosphorus** in AD effluent can be tied up as suspended, colloidal, **micro-solids** bound with calcium and magnesium ions. (Zhang and Chen, 2008; Güngör and Karthikeyan, 2008).

- The solids are of such small, colloidal nature that they often stay suspended, requiring costly chemical additions to flocculate and settle. **Could the aforementioned dissolved gases be causing interference?**



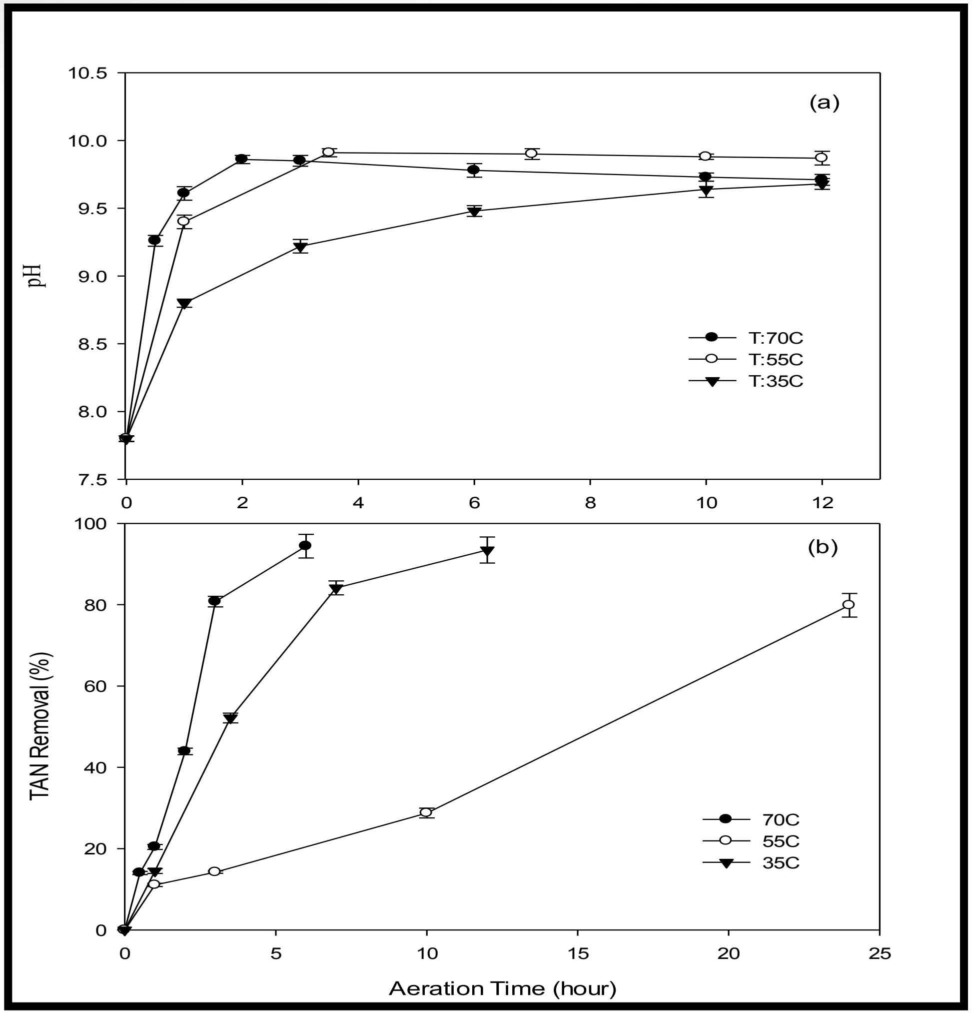


Microscope images of AD manure effluent with (a) micro-bubbles of gas present and evolving and (b) without gas present after aeration treatment

Laboratory Proof of Concept

CO_2 Stripping for pH Elevation and Ammonia Removal

Laboratory results confirm that simple aeration and subsequent CO_2 stripping leads to effective pH elevation (~10) and subsequent ammonia stripping (~80% removal) —especially at elevated temperature of around 55C which is feasible with waste engine heat.



Chemical Equilibria Involved

$CO_2(aq) \longrightarrow CO_2(g)\uparrow$

$H_2CO_3 \longrightarrow H_2O + CO_2(aq)$

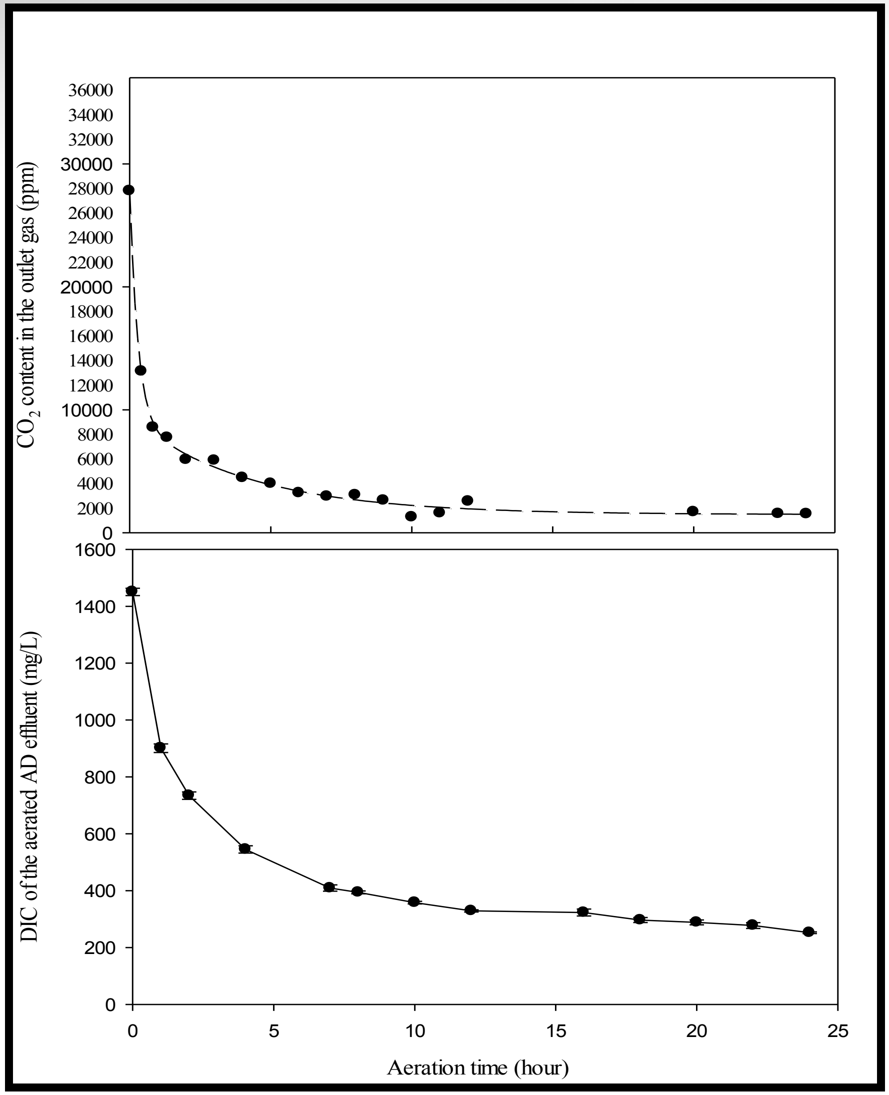
$HCO_3^- + H_2O \longrightarrow H_2CO_3 + \mathbf{OH^-}$

$2HCO_3^- \longrightarrow H_2CO_3 + CO_3^{2-}$

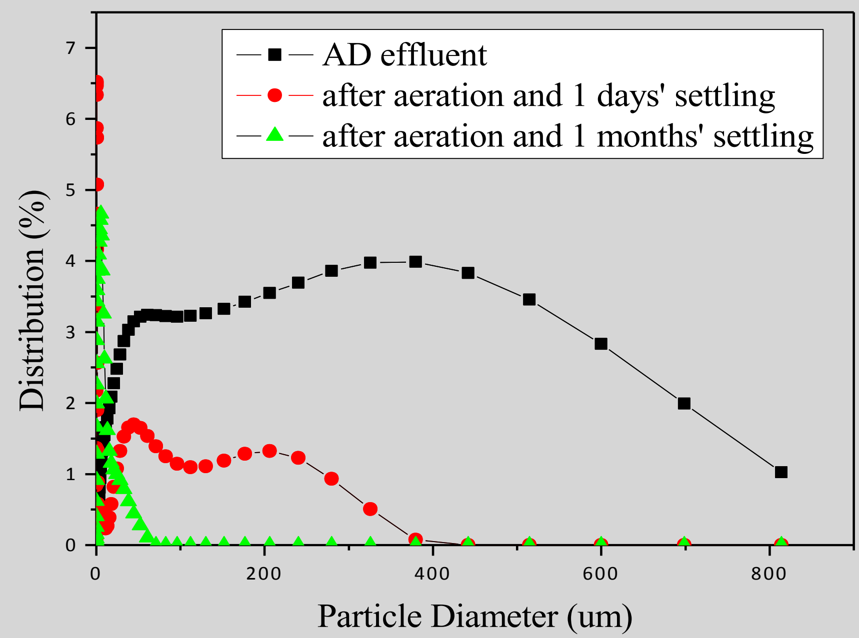
$CO_3^{2-} + H_2O \longrightarrow HCO_3^- + \mathbf{OH^-}$

$NH_3(aq) \longrightarrow NH_3(g)\uparrow$

$NH_4^+ + OH^- \longrightarrow NH_3(aq) + H_2O$



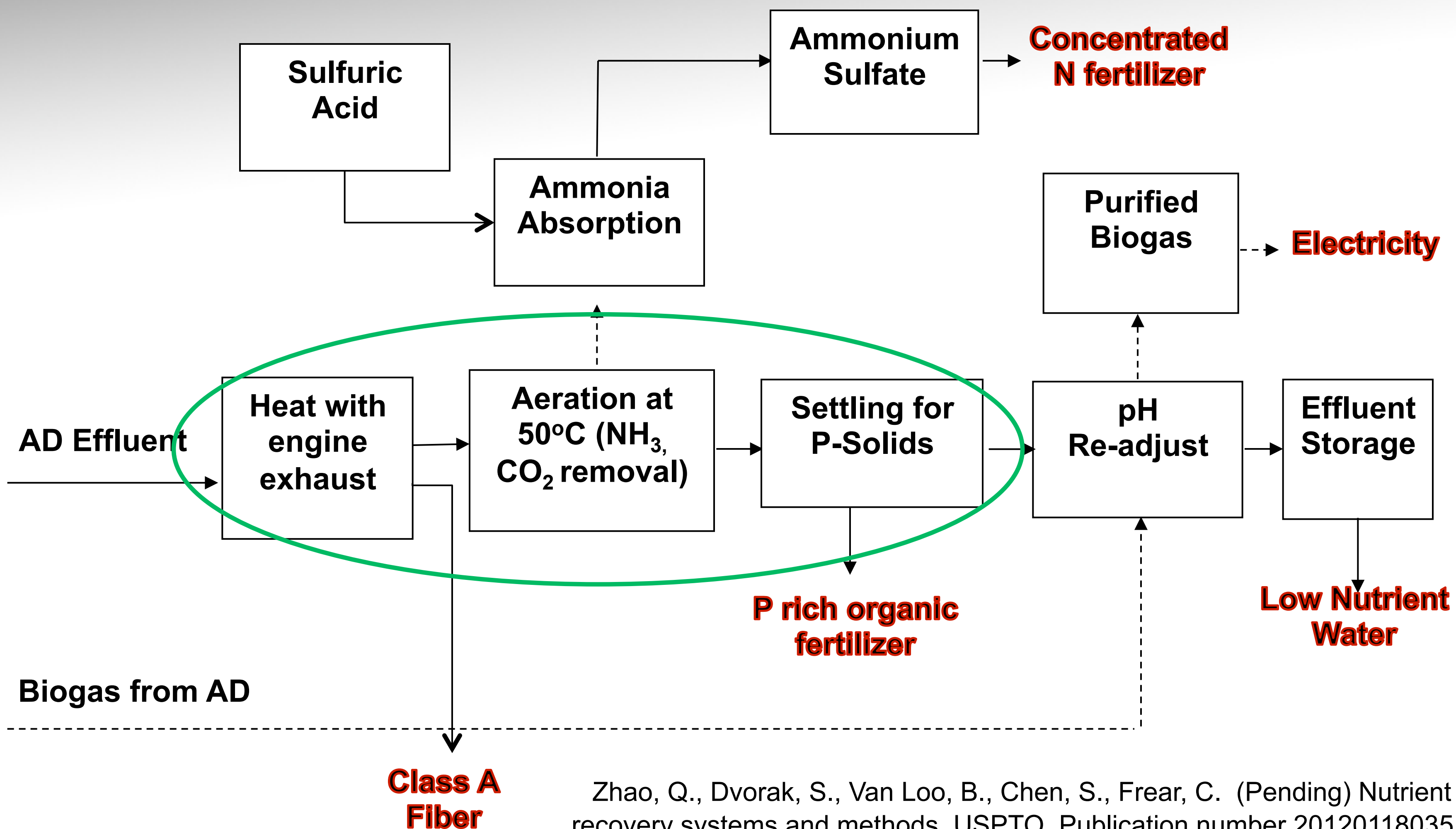
Effect on Solids Removal and Solids Distribution



Using just aeration followed by 1-3 days of gravity settling in weir basins, a significant improvement in both solids and phosphorus removal can be accomplished (~60% TSS and 80% TP removal). The result is an organic solid with fertilizer dry weight values of ~2:4:1 NPK, although the product after weir recovery and non-active dewatering is roughly 50% moisture.

Patent/Licensing

Patented Integrated Approach



Zhao, Q., Dvorak, S., Van Loo, B., Chen, S., Frear, C. (Pending) Nutrient recovery systems and methods, USPTO, Publication number 20120118035, priority date 06/10/11.

Commercial Demonstration

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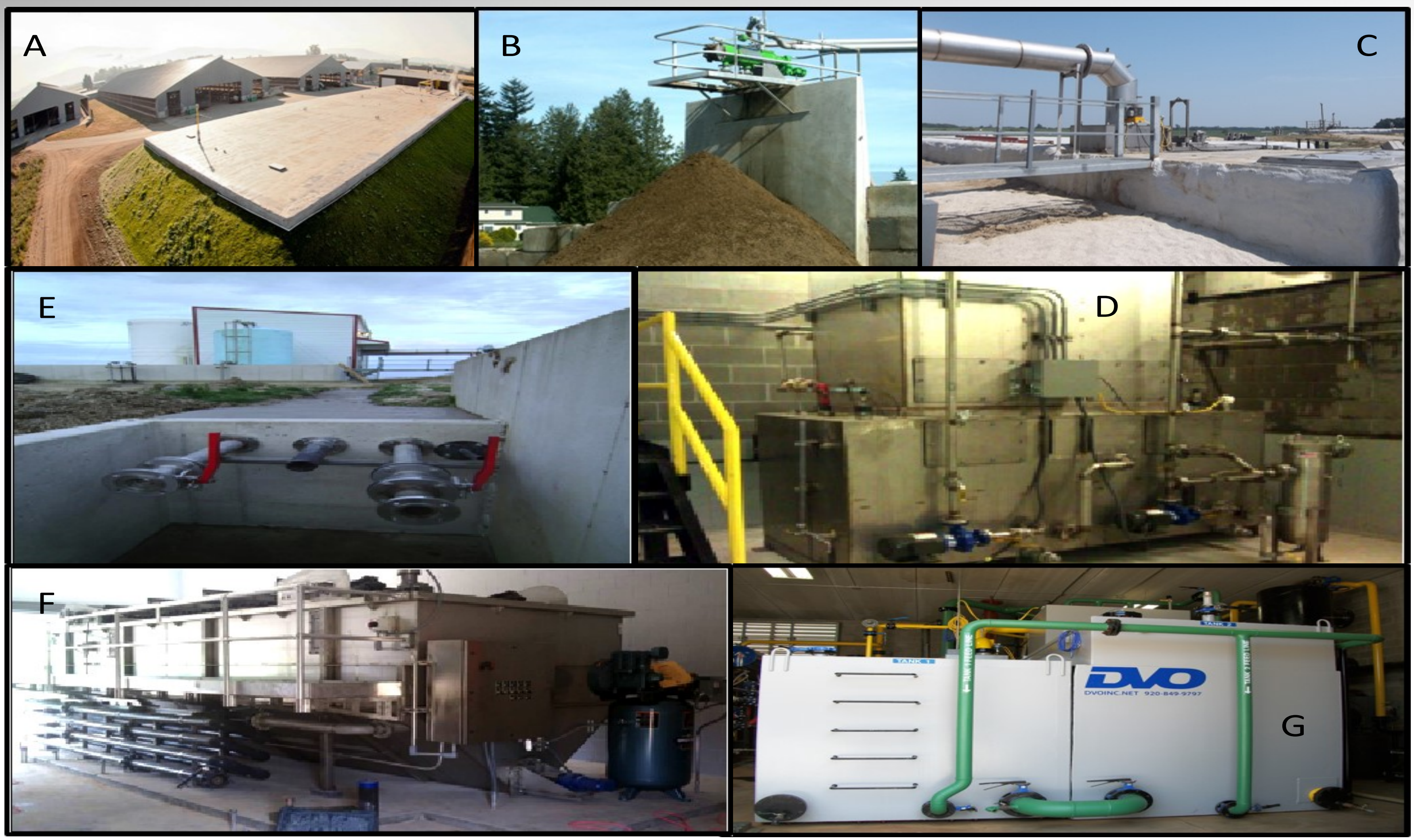
Commercial Demonstration



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Commercial Demonstration

Anaerobic Digestion—20+ day digestion for reduction of GHG, pathogens and production of biogas. **110 cubic feet per cow per day plus more if co-digest.**

Fiber Production/Separation—The material leaving the digester is sent through a dewatering screen to separate out large fibrous solids. These fibrous solids are used either as animal bedding or sold as soil amendment and/or peat replacement. **10 yards per cow per year at $5-10 per yard.**

Aerated Ammonia Stripping—Remove 60% of ammonia from the manure effluent while also removing gases to settle out phosphorus in a later step.

Production of Ammonium Sulfate—Capture ammonia as a salt by adding acid. **0.5 tons ammonium sulfate solution per cow per year at 8% nitrogen and 10% sulfur. $100-140/ton.**

Commercial Demonstration

Recovery of Phosphorus Solids— A continuous flow process using dissolved air flotation (DAF) has been developed to lift the separated solids and skim them off for collection—using far less polymer/coagulant than typical processes**. 80% removal of phosphorus from the manure stream. 3 tons of wet phosphorus solids per cow per year with a 3% phosphorus content by dry weight. $30/wet ton.**

Biogas Cleaning/pH Return—A final process strategically bubbles raw biogas through the remaining liquid. During the process corrosive hydrogen sulfide gas is scrubbed from the biogas and enters the liquid while also returning the liquid pH near to neutral. This liquid is then stored and applied to fields. The biogas is cleaner for enhanced use. **100% removal while returning pH of waste stream to near neutral. Roughly $100,000 annual operational cost savings as compared to other removal systems.**

Techno-Economics

Recent nutrient recovery cash flow statement for 13,574 wet cow equivalent system involving three linked dairies in Washington State, USA

Expenses	($/day)	Revenue	($/day)
Electricity (550 kWh/h @ $0.06/kWh	800	Ammonium Sulfate (24 tons/day @ $120/ton)	2,880
Sulfuric Acid (6.25 tons/day @ $200/ton)	1,250	Organic Solids (50 dry tons/day @20/ton)	1,000
Dewatering Solids Cost (DAF operation)	550		
O&M (3% capital)	500		
Labor (8 hours per day @ $20/h)	160		
Total	**3,260**	**Total**	**3,880**

The annual cash flow not considering taxes and debt service is roughly ¼ million dollars, which is not a lot on a project this size, but note that the dairies presently spend millions of dollars a year to manage nutrients and still are in threat of being shut down due to environmental concerns related to nutrient overloads on soils. The cost savings to the dairy enterprise is therefore significantly more than this $250,000 annual revenue.

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Concerns

- Products need to be transformed into more desirous forms/qualities such as solid ammonium sulfate and pelletized solids—allows for greater market and price penetration
- Heat balance is difficult to manage with RNG and all of the demands for available waste heat
- Continued refinement of system so that recoveries and efficiencies as well as capital costs are improved
- Continued sales/installation to solidify construction/operation history and improve financing options
- Policy, regulatory drivers to add incentive and potential revenues—particularly in the US, presently more interest and potential sales internationally.

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