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An Integrated Pathogen Control, Ammonia and Phosphorus Recovery System for Manure and/or Organic Wastes

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CLIMATE FRIENDLY FARMING™

Center for Sustaining Agriculture & Natural Resources

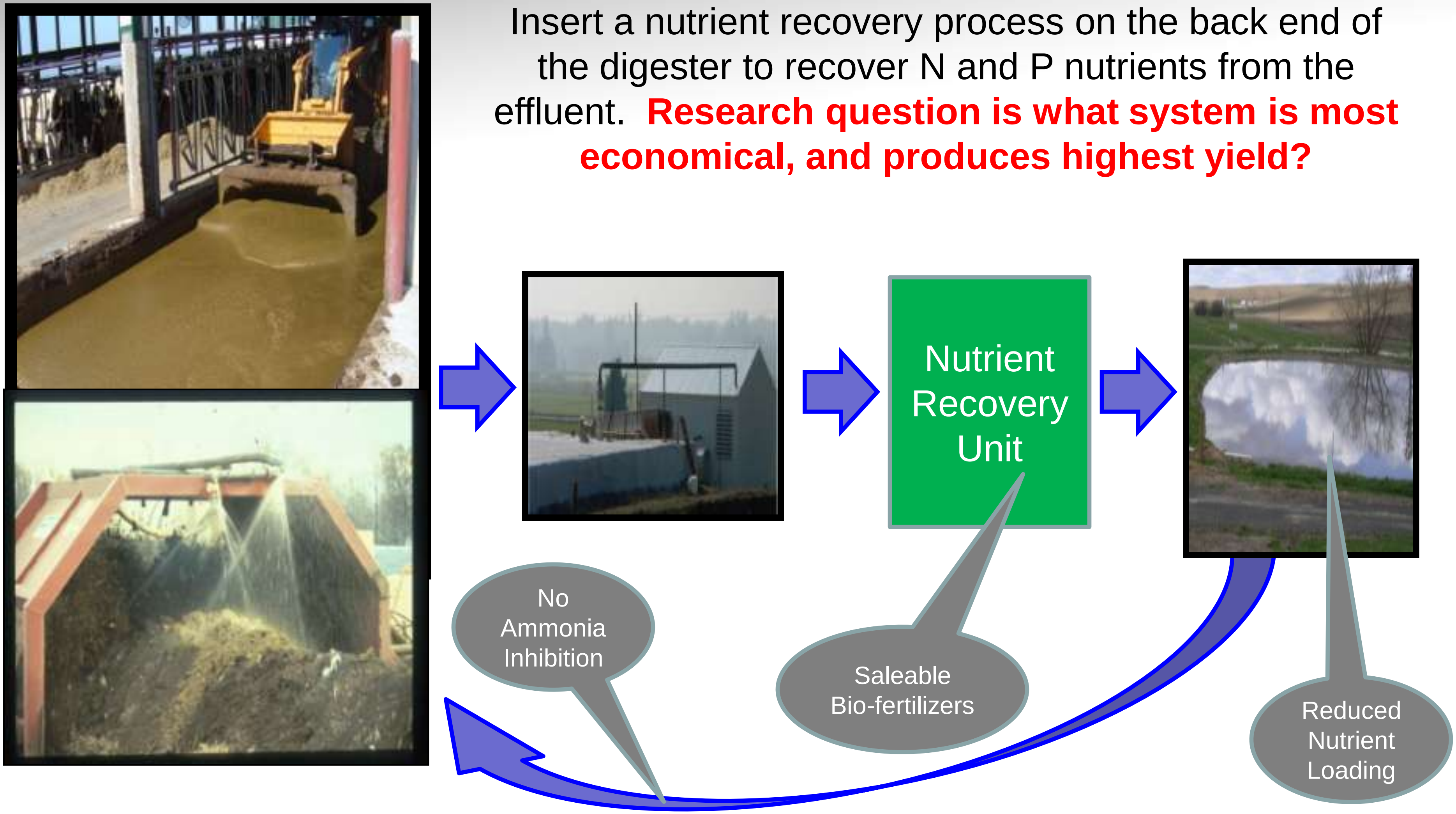
The Problem

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.

Total Ammonia: 2-7 g N/L
Total Phosphorus: 0.5-1.5 g P/L

The 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?**



Concepts Guiding Approach

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

- Ammonia is best recovered through **ammonia stripping**. However, stripping is strongly influenced by temperature, pH, **solids content**—hence solids must first be removed and temperature/pH elevated (Frear et al, 2010).

- 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). Thus need for removing solids also accomplishes recovery of P. **BUT how to best remove solids**?

- Temperature can come from waste engine heat **BUT how to raise pH**?

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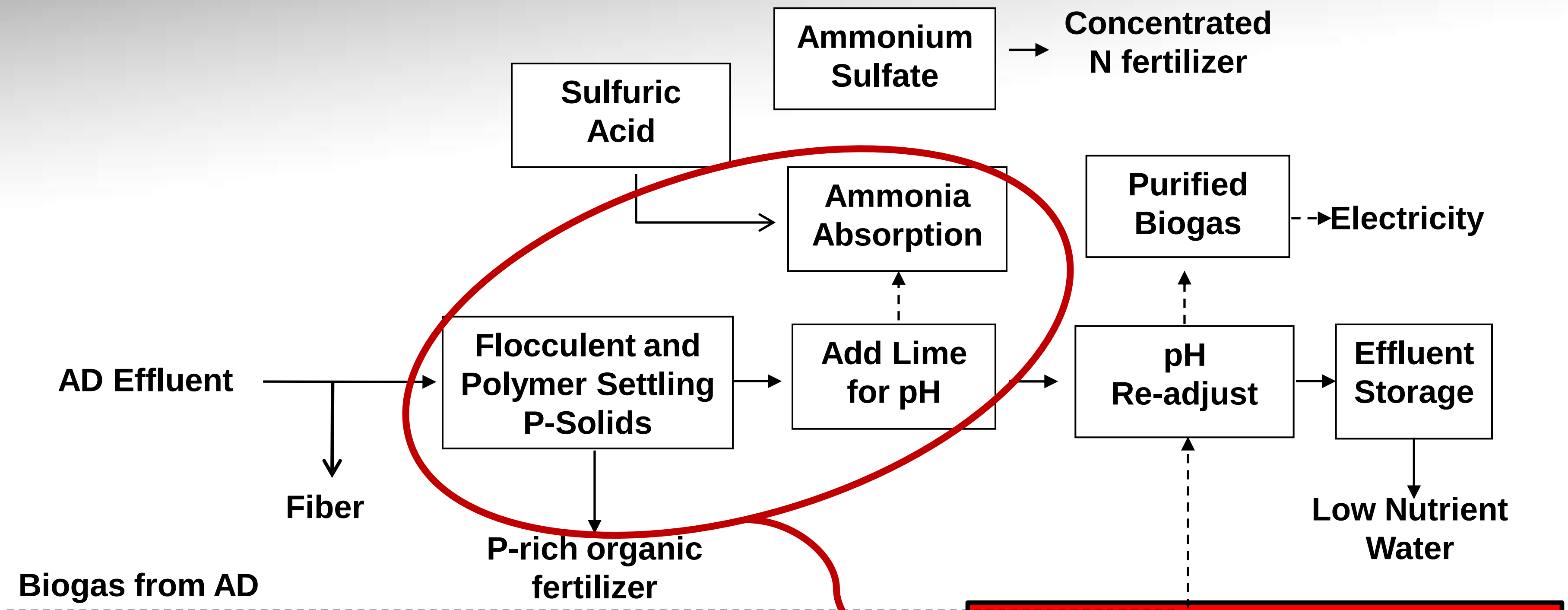
Integrated Concept



Impractical approach is to first separate solids with coagulant/polymers and then raise pH for stripping by adding lime or lye

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Non-Practical P-Solids Removal Approach

Polymer/Coagulant Approach

- Commercial-scale coagulant and polymer system on Big Sky Dairy in Jerome ID (AL-2 Teknik, Hovborg, Denmark).
  - Alum (195 mL/m^3 @ $1.72/L) with polymer (1,250 mL/m^3 @ $3.84/L)
  - Retention of coarse fibers in effluent required as bulking agent
  - Belt press dewatering followed by compost processing of collected solids

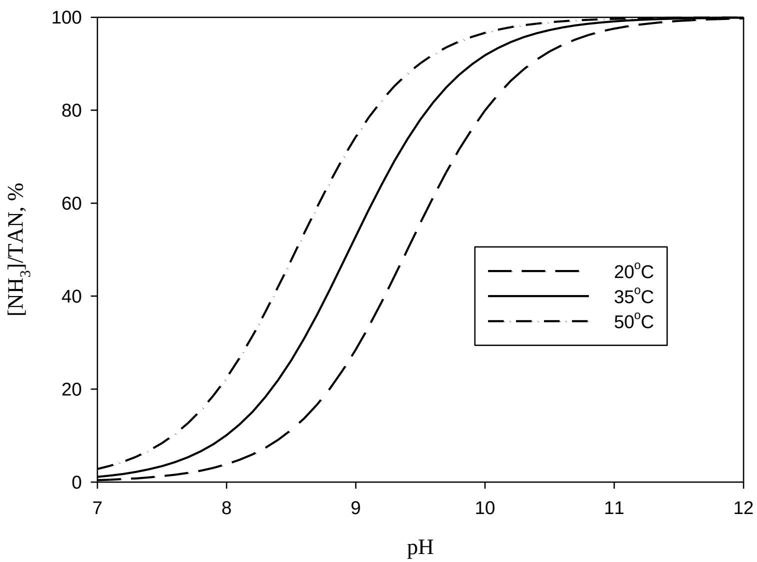
	TS Reduction (%)	*TP Reduction (%)*	*TN Reduction (%)*
Performance	72.3 ± 3.0	83.1 ± 3.7	38.2 ± 2.4

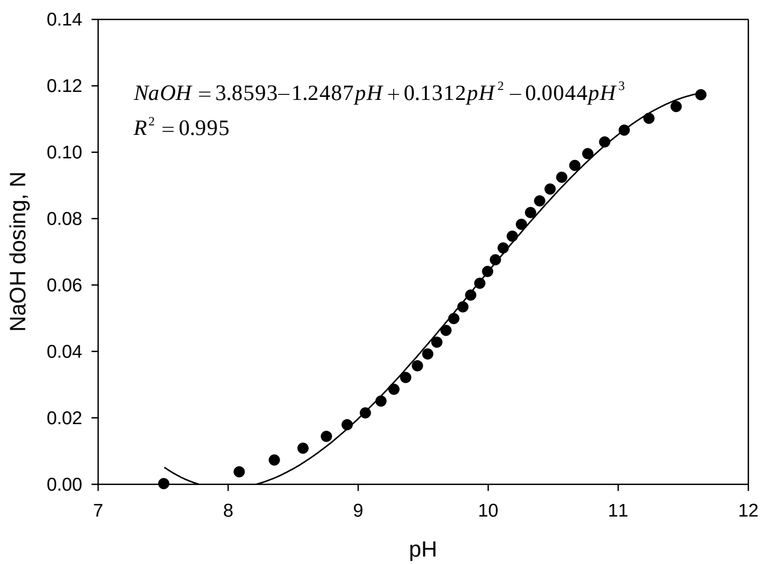
	Chemical Cost	*Electrical Cost*	*Capital Cost*
Cost Analysis	$2.90/m^3	$0.07/m^3	$80-100/cow

•Total cost is **$2.97/m^3** of effluent treated, or roughly 1¢/gallon treated unless loss of fibrous solids and composting are considered which then makes it **6.95/m^3** or $0.026/gallon.

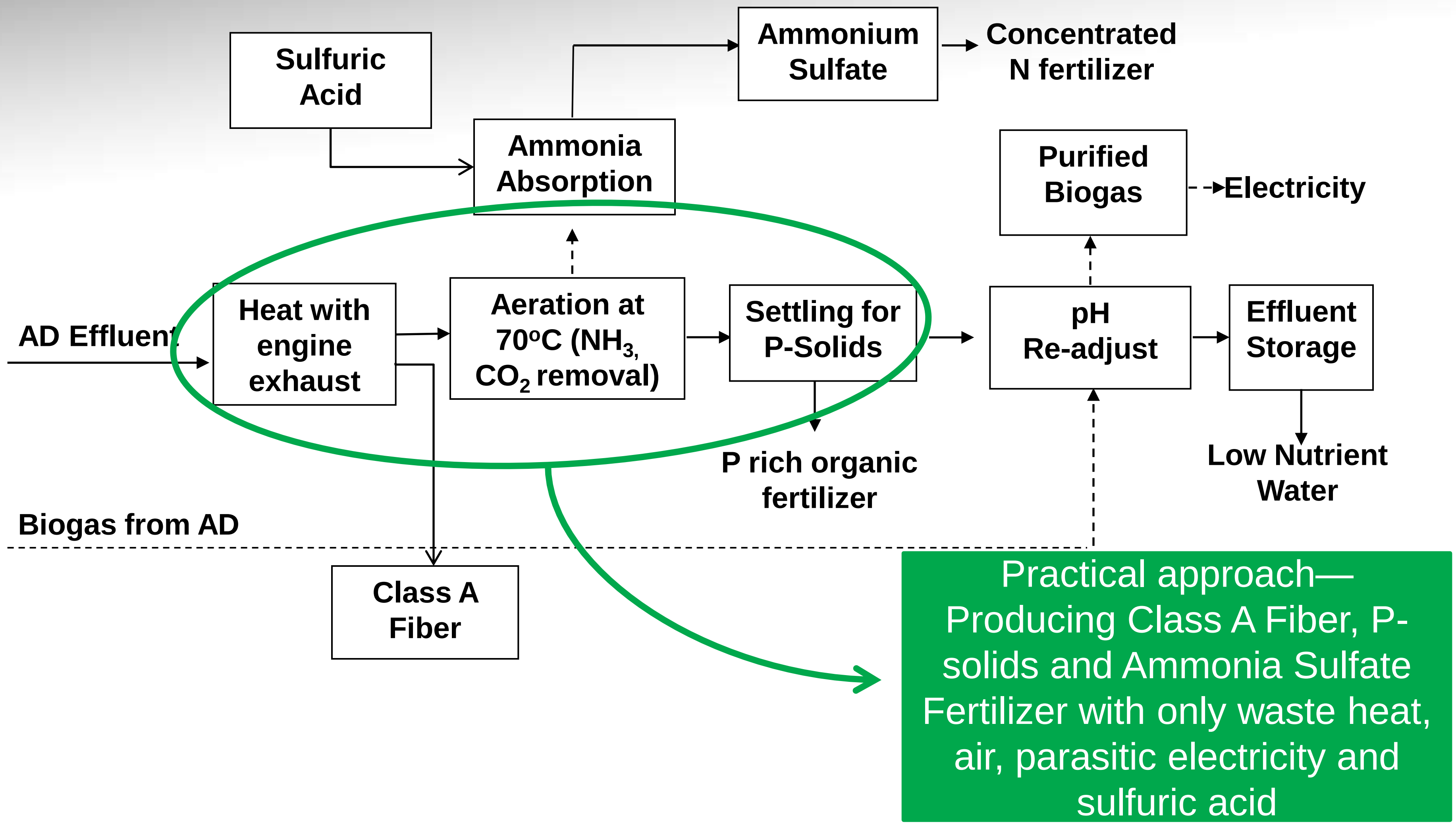
Non-Practical pH Elevation for Stripping

- Ammonia equilibrium strongly affected by pH and temperature with elevation of both parameters leading to significant increases in free ammonia necessary for ammonia stripping.
- pH dosing experiments determines chemical quantity and cost curves necessary for treatment of **highly buffered AD effluent**
- After solids removal, necessary lime addition to achieve pH range of 10-10.5 is between 10-11 kg lime/m^3 manure at a cost of **\$1/m^3**.



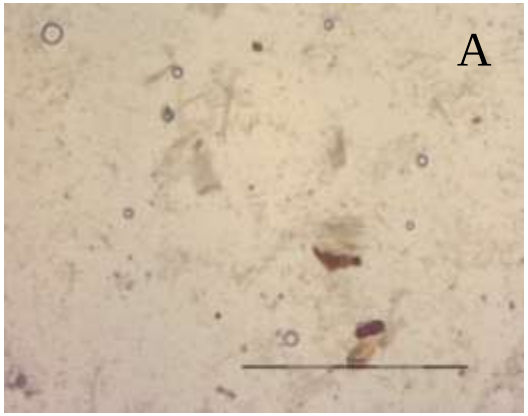


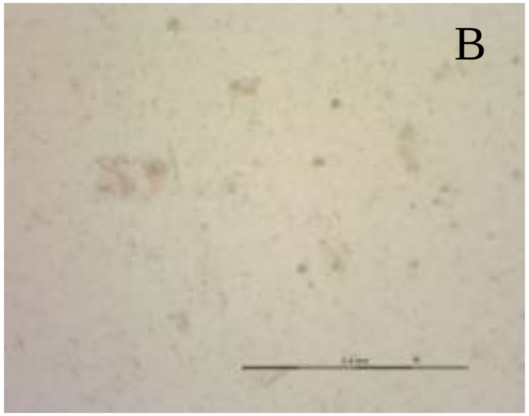
Patented Integrated Approach



P-Solids Removal and pH Rise *via* Aeration

- AD process elevates the effluent alkalinity through increased levels of carbonates, bicarbonates, and supersaturated carbon dioxide.
- Presence of supersaturated CO_2 in-part responsible for P micro-solids not settling under natural conditions—removal of gases results in significant P-solids settling while also elevating pH for subsequent ammonia stripping operation.





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

Effect of Aeration on Chemical Equilibria

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

$H_2CO_3 \longrightarrow H_2O + CO_2\,(aq)$

$HCO_3^- + H_2O \longrightarrow H_2CO_3 + OH^-$

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

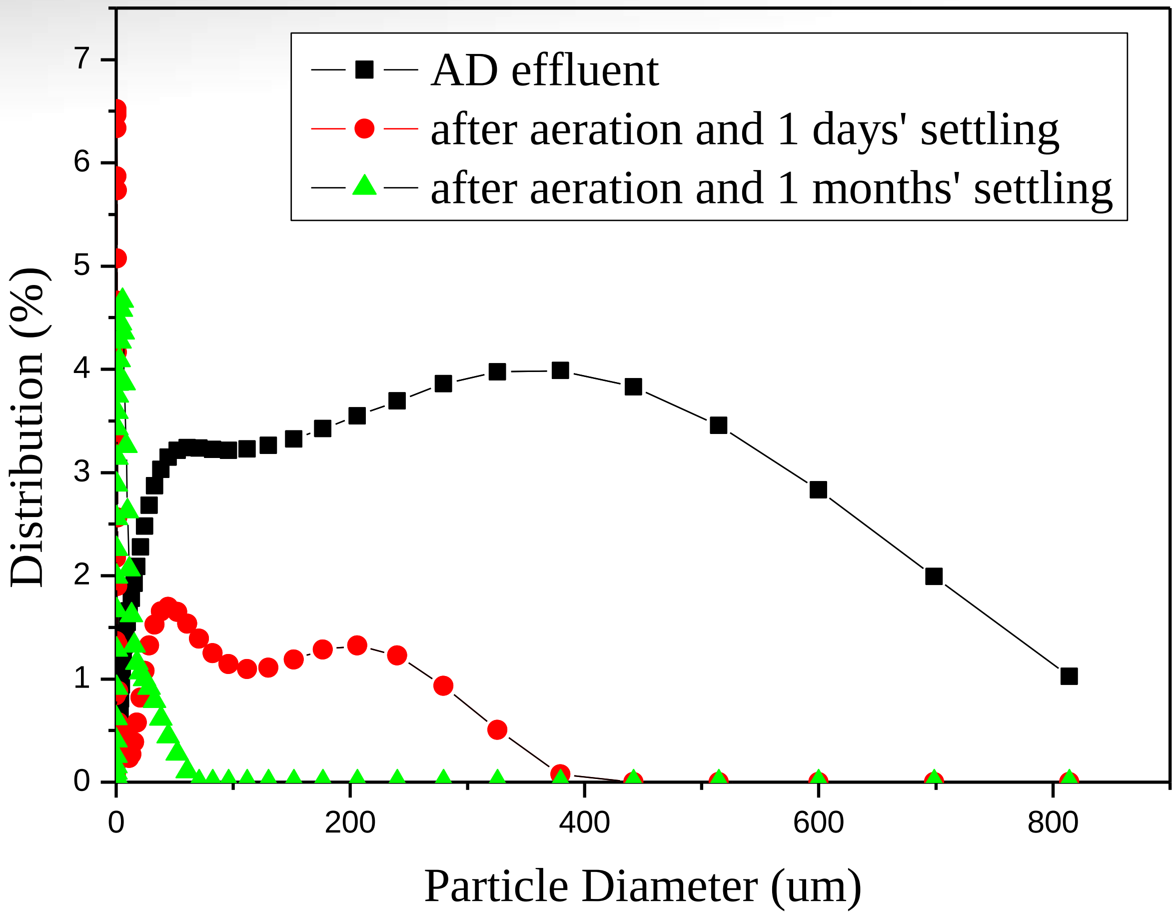
$[OH^-] \uparrow$ causes pH $\uparrow$

$[OH^-]$ reacts with NH_4^+

$NH_4^+ + OH^- \longrightarrow NH_3 \uparrow + H_2O$

$(NH_4)MgPO_4 \cdot 6H_2O\,(s) \longrightarrow NH_4^+ + Mg^{2+} + PO_4^{3-} + 6H_2O$

Effect on Solids Removal and Solids Distribution



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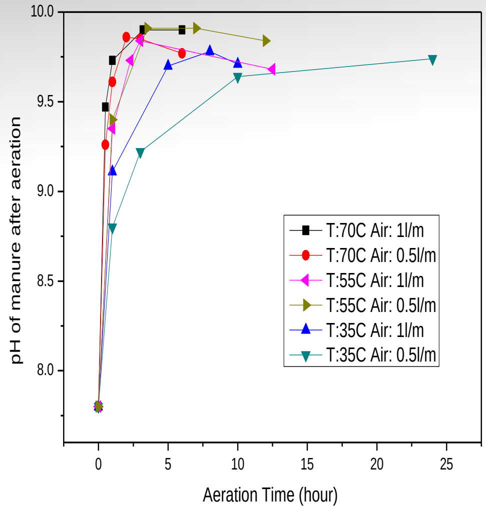
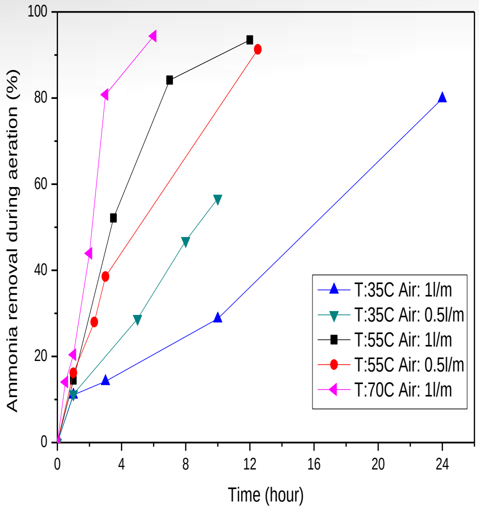
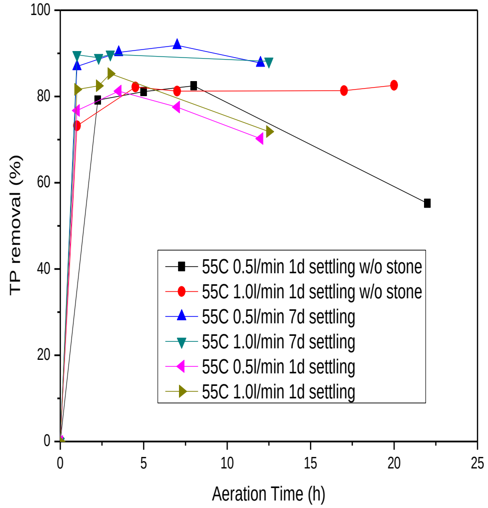
Performance of Aeration System

Laboratory results have confirmed the hypothesis in regard to aeration and subsequent CO_2 stripping leading to enhanced P-solids settling, pH elevation and ammonia stripping—especially at elevated temperature







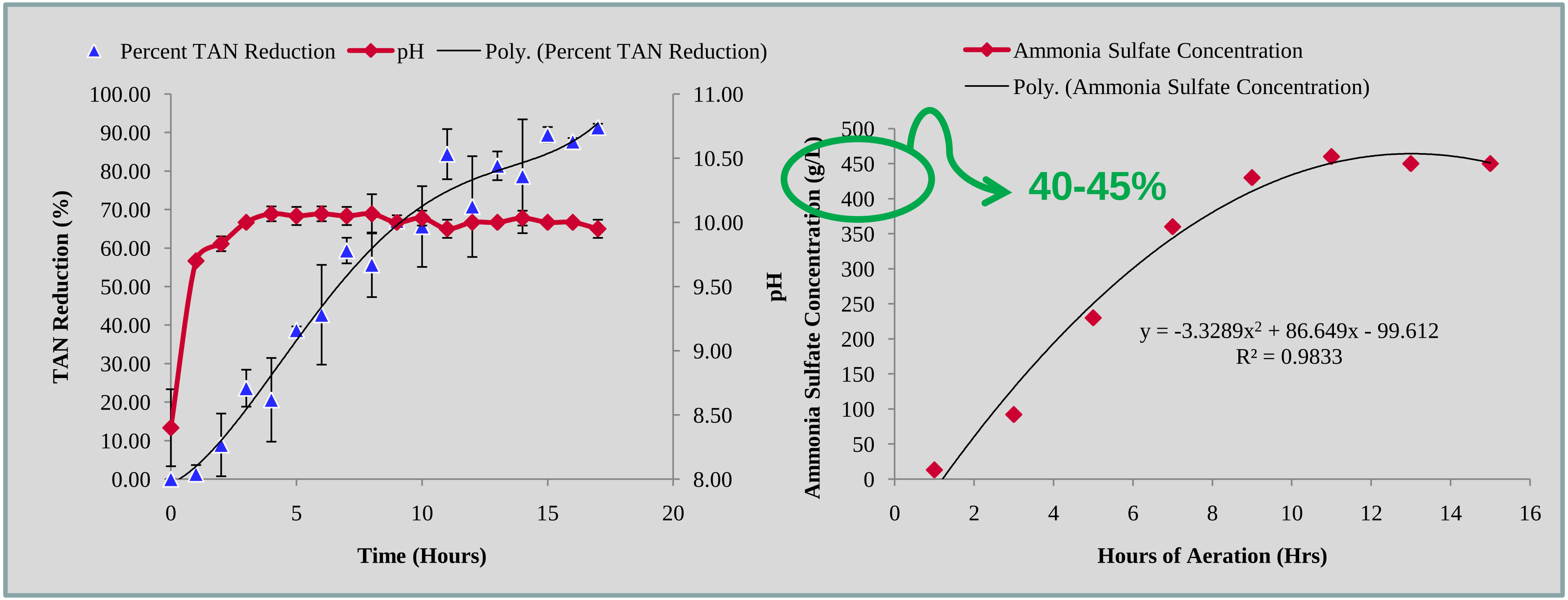
Pilot Testing of Aeration System

Laboratory success has led to pilot testing at three different locations and scales.

- Continuous P-treatment (Big Sky Dairy, Jerome ID)
- 2,000 gallon batch (Boss Dairy, Chilton WI)
- 5,000 gallon batch (Fair Oaks Dairy)

Pilot Performance (N Recovery)

- Pilot runs consistently show an ability to raise pH to 10.0 and remove 80% TAN with 15 hours of aeration at 55C and with aeration rate of 40 gallons/cfm using micro-diffusers



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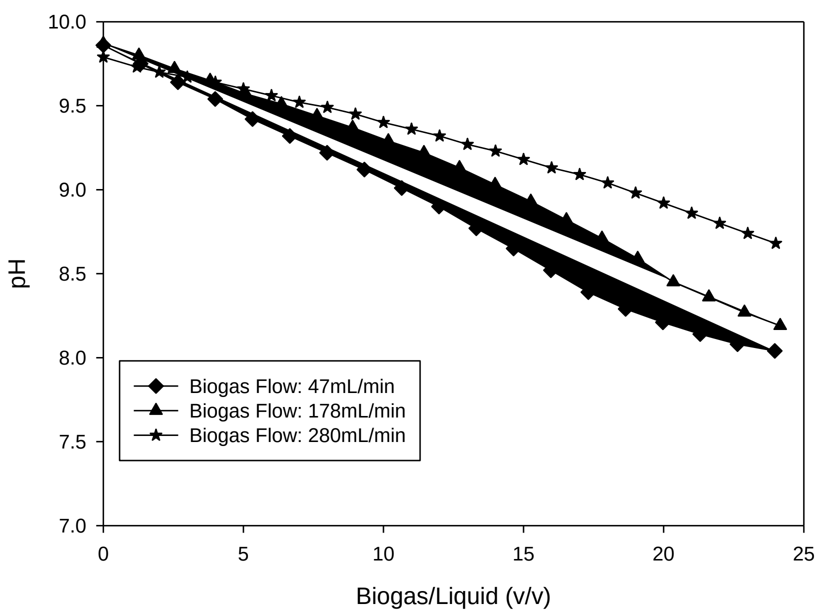
Pilot Performance (P recovery only)

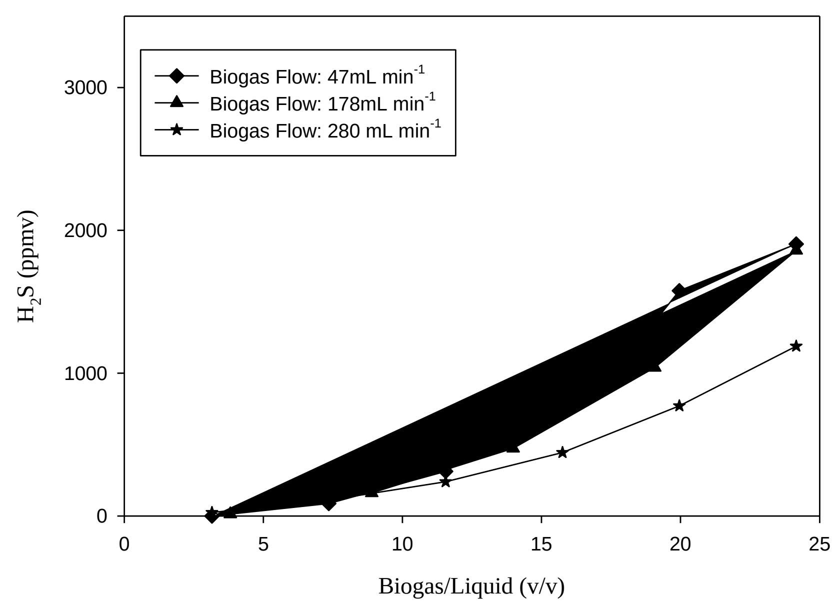
- System can be operated so that only phosphorous solids reduction is achieved
- With only limited aeration (6 hours at 40 gallons/cfm and 35^{o}C) followed by subsequent fiber removal and settling in existing settling weirs, the system was able to achieve 80% P removal.
- Equivalent performance to AL-2 but only input is electricity for aeration blowers—existing capital equipment already available.

6 hours of aeration in effluent pit of 35^{o}C using 40 gallons/cfm, followed by fiber separation; then an additional 18 hours of aeration at 25^{o}C and 1-3 days settling	TS %	VS %	TKN g/L	TAN g/L	TP mg/L
AD Effluent	5.15	3.28	4.03	2.61	564.53
6 Hrs Air @ 35C, 40 gal/cfm	5.37	3.41	4.09	2.65	587.38
Fiber Separation (18 mesh)	4.47	2.49	3.87	2.64	600.43
18 Hrs Air @ 25C, 40 gal/cfm	4.37	2.48	3.71	2.48	580.85
1 Day Settling	2.27	1.21	3.01	2.23	133.79
2 Days Settling	2.24	1.17	2.94	2.23	124.00
3 Days Settling	2.19	1.14	2.92	2.22	114.21
Total Reduction (%)	**59.22**	**66.57**	**28.61**	**16.23**	**80.56**

Biogas Scrubbing and pH Control

- High pH effluent needs pH control while biogas needs removal of acidic impurities—biogas scrubbing/pH return stripping tower.
- Synthetic biogas mimics a typical gas composition for dairy AD biogas, namely 62.1% CH_4, 37.7% CO_2, and 2,000 ppm H_2S.
- Various biogas flow rates (low, medium, high) and gas/liquid ratios (5-25) tested were tested.





Pilot Performance (Full System)

- Performance data at full system pilot operation are still coming in as of this presentation—results are showing the following:
  - Class A fiber
  - 80% TP removal with a corresponding final effluent solids concentration of 2%
  - 80% TAN removal which is subsequently converted to ammonia sulfate
  - Production of 40% by weight AS slurry at pH = 7 using two tower approach

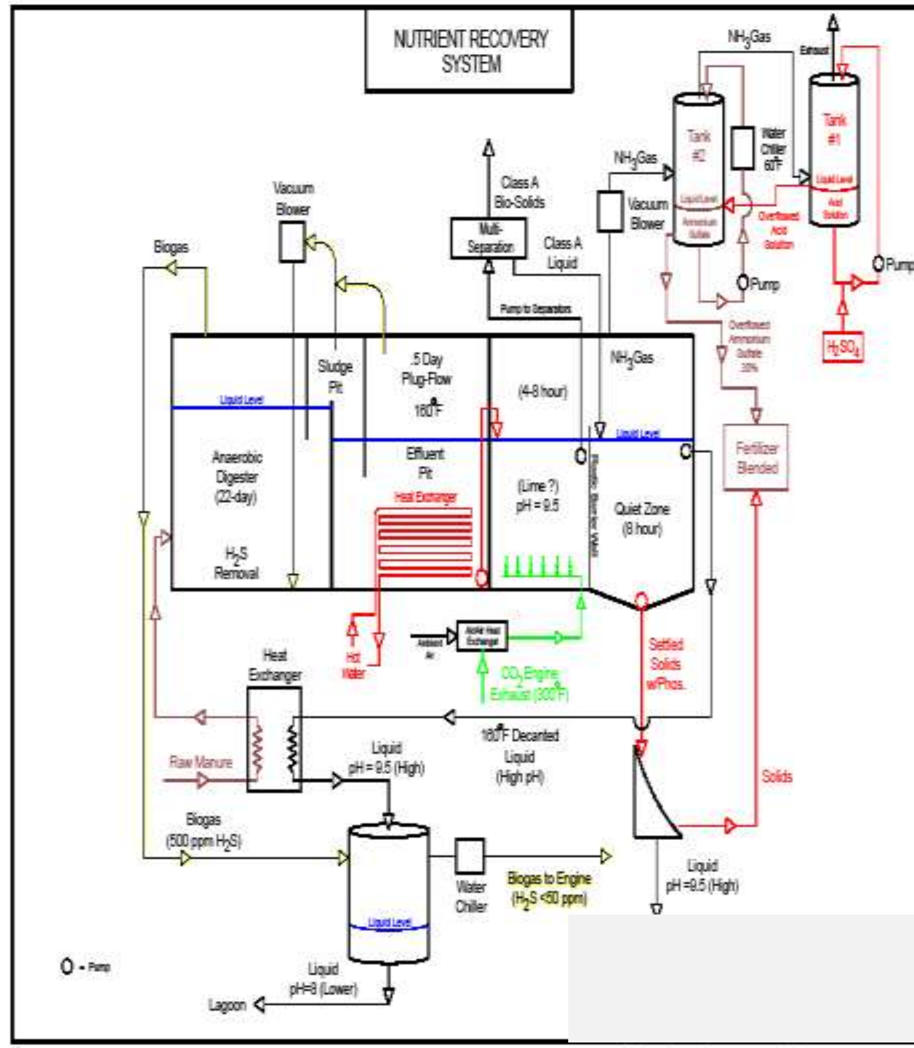
- Approximate operating conditions are:
  - 1/2 hour 70°C plug-flow heat of effluent using waste engine heat
  - Class A fiber removal using mechanical separators
  - 15 hours of covered aeration (micro-aerators, 40 gallons/cfm, 55°C)
  - Ammonia sulfate production with two tower acid dosing system

- Estimated operating costs (chemicals, electricity) at **$1.50/m^3** with potential revenue at **$3.50/m^3**

Full System Design

- The WSU Research Foundation has engaged in licensing and patent arrangements for the technology with GHD Inc. (Chilton WI), Andgar Corp. (Ferndale, WA), and BEST, LLC (Pullman, WA).

- Full scale demonstration Spring 2011 on two Washington State dairies (DeRuyter and Sons Dairy, Outlook WA and Vander Haak Dairy, Lynden WA) using USDA NRCS funding.

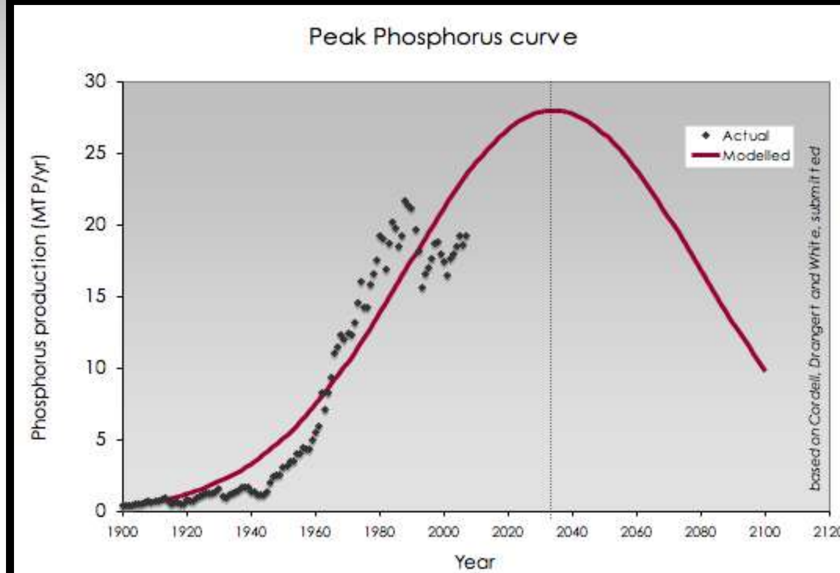


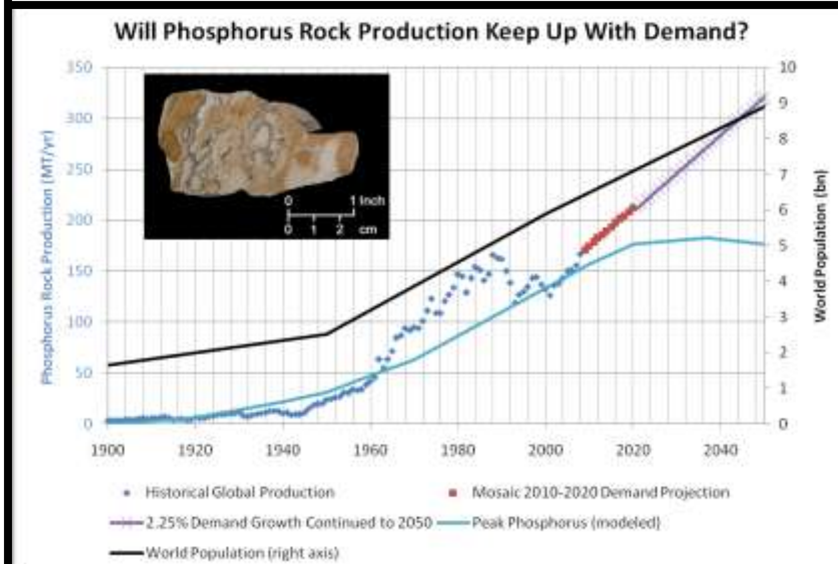
Implications

- The Pacific Northwest (PNW) is home to 400,000 dairy cattle, all living in relative proximity to the 5 million acres of important wheat/barley production in the region.

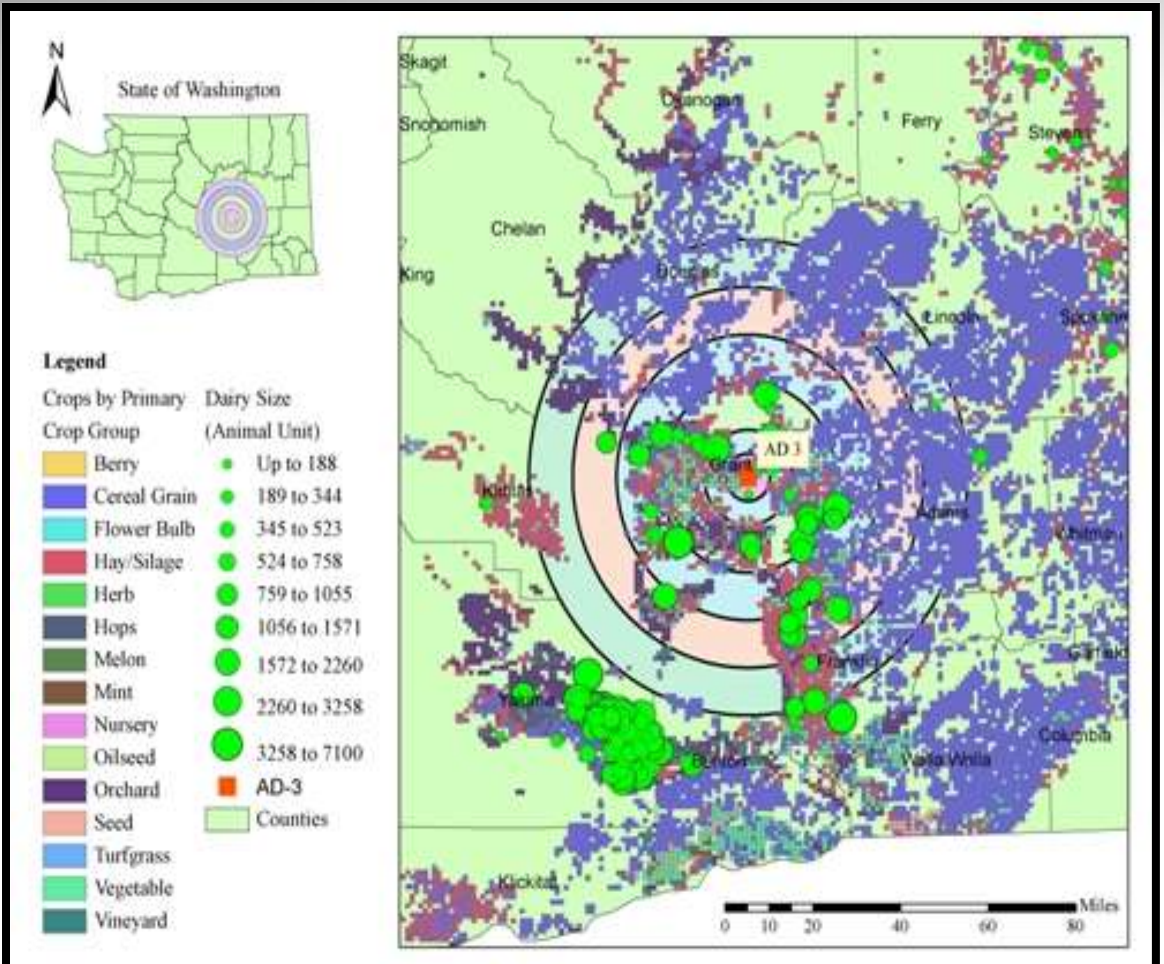
- Nutrient recovery from AD/NR operations on these dairies could supply and displace approximately 15% and over 100%, respectively, of the fossil fuel-based N and non-sustainable rock P fertilizer presently applied to these acres (USDA ERS, 2007, NASS 2009).

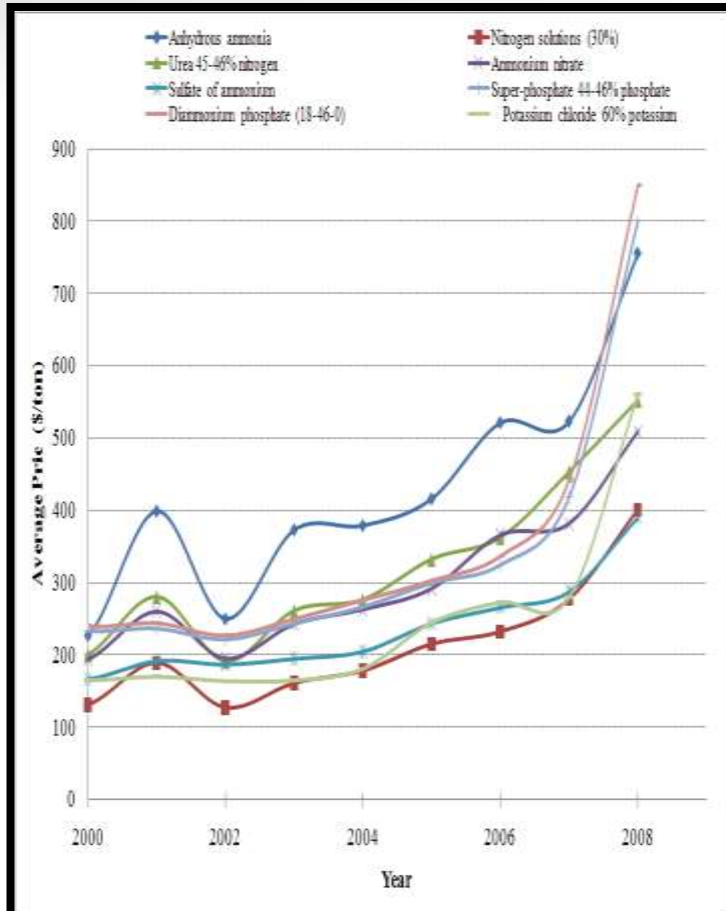
- Recovery and distribution assists in sustaining a viable dairy industry that presently experiences 36% and 55% of their farms with N and P overload concerns (USDA-APHIS, 2004).





Implications Continued





Recovery: 0.40 pounds N/cow/day and 0.12 pounds P/cow/day

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