REVIEW OF EMERGING NUTRIENT RECOVERY TECHNOLOGIES AND DISCUSSION ON PERFORMANCE/COST STRUCTURES FOR WSU/DVO INTEGRATED APPROACH

Capturing Valuable Nutrients from Manure: Part 2

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Outline

- Role of Anaerobic Digestion, Organic Waste, Co-Digestion and Wastewater Application/Treatment
- Phosphorus Treatment Options
- Nitrogen Treatment Options
- Combined Treatment Options/Capabilities
- WSU DVO System
- Partitioning Example
- Considerations for Federal/State Government and Project Developers

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Anaerobic Digestion

- Remove 90% of odors[1].
- Destroy 99% or >2.0 log of indicator pathogens in manure[2].
- Reduce GHG emissions by 3-4 MT CO_{2eq}/cow year compared to baseline[2].
- Produce renewable energy at a rate of 0.25 KW/cow/yr or 167 DGE/cow/yr[2].
- Stabilize volatiles, reduce solids, separate fiber, shift nutrients towards inorganic form[2].

[1] Wilkie 2000 [2] Frear et al, 2011

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Organic Waste

- 26-40% of all US food wasted—2% of US energy consumption embedded in this loss[1].
- Diverted use (no landfilling) leads to doubling of economic benefit to state, 1/5 reduction in treatment costs, and significant reductions in odor, GHG, and VOC[2,3].
- Waste organics represent significant recovered energy potential—2 to 4x that of dairy manure.

[1] Kantor and Lipton (1997); [2] Goldman and Ogishi, 2001, Bloom 2010; [3] Mata-Alvarez et al, 2000, Bernstad et al, 2011

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Manure Wastewater

- Each cow annually excretes 60 and 7 kg of N and P, respectively[1]
- Trend towards larger CAFOs which apply at a rate 3x that of smaller farms. Only 23% and 1% of large CAFOs applying manure at agronomic rates for N, P respectively[2,3,4]
- Impacted soils lead to concerns in N/P eutrophication, nitrate-induced conditions, PM-2.5, ammonia health, GHG release, yield loss, etc.

[1] ASAE 2005; [2] USDA NASS, 2010; [3] Macdonald and McBride 2009;[4] Ribaudo et al. 2003

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Case Study and Expansion

While co-digestion business model is developed, albeit under electrical pricing pressure, new NR unit installations can add eco-system benefits while still supplying total system economic viability.

Revenue Items

- •CHP/CNG
- •Fiber/Peat
- •Carbon Offset
- •RIN/RECs
- •Tipping Fee
- **•Renewable Fertilizers**
- **•Farm Manure Mgmt. Savings**

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Phosphorus Treatment

Nearly 80% of digested dairy manure phosphorus is in the form of suspended fine solids[1]—lending at least some of P removal to a mechanical approach.

Industry Mainstay
Primary and Secondary Screening

- Various forms and sequence of screens allows for separation of desired fibrous solids (8-10 yards/cow/year) as well as secondary non-fibrous solids.
- **15-30%** recovery of phosphorus and nitrogen from liquid stream.
- **$5-6**/cow/year—O/M costs, **$32-36**/cow—Capital costs.
- Fiber product has 70% moisture—**$5-15/yard** revenue.

[1] Gungor and Karthikeyan, 2008; Pastor et al., 2010

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Phosphorus Treatment

Given the degree of P-impacted soils near/around dairy CAFOs, important to achieve at least 75-80% recovery of phosphorus.

Next Generation Available

Solids/Polymer Coagulation

- **80-90%** recovery of phosphorus and **35-55%** nitrogen from liquid.
- **$25-75/cow/year**—O/M costs, **$120-150/cow**—Capital costs.
- Cost affected by amount/type polymer/coagulant.
- Drying, organic cert. are concern.

Struvite Crystallization

- **75%** recovery of phosphorus and **30%** nitrogen from liquid.
- **$90-110/cow/year**—O/M costs, **$100-150/cow**—Capital costs.
- Nice crystal product.
- Effective NPK formulation.
- Limited drying and modifying.
- No organic cert.

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Phosphorus Treatment

While other approaches with intriguing possibilities and their own set of concerns do exist, analysis demonstrates that **polymer/coagulation** and **struvite crystallization** technologies (in conjunction with fibrous screening) appear to offer the most viable approaches to maximum, primary P removal.

Note that costs/concerns do still exist and markets need to be developed and Project Developers as well as agencies should be aware of capital and O/M costs to accomplish such recovery.

Key Technology Primarily P	Performance	Operating Cost /cow/year	Capital Cost /cow	Scale
1' and 2' Mechanical Screens	TN 15-30%, P 15-25%	$5-6	$32-36	Commercial
Centrifuge-No Polymer/Coagulant	TN 24-30%, TP 50-65%	$25-50	$57-136	Commercial
Lime Precipitation	TN 30-40%, TP 70-80%	$30-60	$60-80	Pilot
Mechanical + Polymer/DAF	TN 45-55%, TP 85-90%	$25-30	$130-150	Commercial
Mechanical + Polymer Belt Press	TN 35-45%, TP 75-85%	$50-75	$120-140	Commercial
Struvite Crystallization	TN 30%, TP 75%	$90-110	$100-150	Commercial
Mechanical + Electrocoagulation	TN 30-50%, TP 80-90%	$140-160	$200-225	Pilot
Mechanical Screening + Membrane	TN 71-73%, TP 80-90%	$125-150	$275-330	Pilot
Enhanced Biological Phosphorus	TP 42-91%	$150-170	$275-300	Pilot

Table not intended to be complete evaluation of all technologies or companies, nor are cost estimates final, and are only approximate

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Nitrogen Treatment

Ammonia/Organic N ratio is roughly 1:1 and 2:1 in non-digested and digested dairy manure, respectively. Being soluble, ammonia-N more difficult and costly to recover at large percentages.

- *Organic N Recovery via Screens/Polymer Coagulation*
  - **35-55% TN recovery** at $25-75 O/M and $120-150 Capital
  - Simultaneous recovery of P
- *Ammonia Recovery (Various Stripping or Membranes)*
  - **40-70% TN recovery** at $80-160 O/M and $375-550 Capital
  - Saleable ammonium salt product, solution or crystals
- *Partial Nitrification/De-nitrification*
  - **80-90% TN loss** at $60-80 O/M and $300-400 Capital
  - Long retention time, loss to N_2
- *Nitrification/De-nitrification*
  - **80-90% TN loss** at $80-100 O/M and $300-400 Capital
  - Scale and size issues, carbon input costs, loss to N_2

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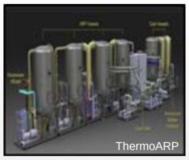
Nitrogen Treatment

Notable extra cost to reduce/recover N with considerations needed in regard to recovering N or blowing it off as N_2. Decision tied to complexity of producing, storing, blending, and marketing N-product.



Key Technology Primarily N	Performance	Operating Cost /cow/year	Capital Cost /cow	Scale
Flash Distillation of Ammonia	TN 60-70%	$80-120	$475-550	Pilot
Chemical Ammonia Stripping	TN 50-60%	$120-160	$375-425	Pilot
Non-Chemical Ammonia Stripping	TN 40-60%	$80-120	$375-425	Commercial
Nitrification/Denitrification	TN 80-90%	$80-100	$300-400	Pilot
Partial Nitrfication/Denitrification	TN 80-90%	$60-80	$300-400	Lab
Gas-Permeable Membranes	TN 60-70%	NA	NA	Lab

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Combined Treatments

- As many farms are under greater pressure for P management and the cost of N recovery is comparatively more costly, it makes sense to use P only recovery technologies for these P management situations.
- In regard to those under N management concerns, because of cost, it makes sense to utilize combined technologies that remove high percentages of both N and P.
- While the focus of this presentation is mostly AD followed by nutrient recovery technology, it is very important to note that alternative renewable energy systems such as combustion/pyrolysis/gasification can also recover nutrients, including potassium (K).
- Algae as a bio-treatment within an algal fuel bio-refinery is an active concept.

Algevolve, 2013

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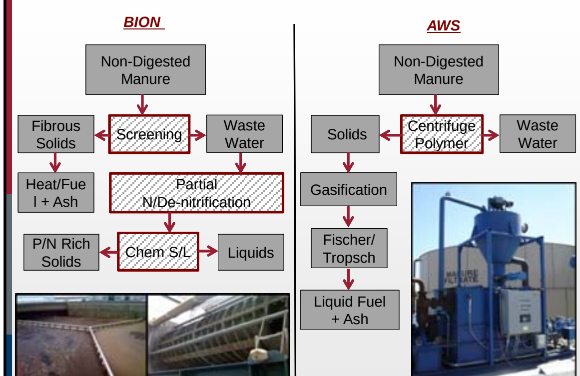
Non-AD Based Examples



BION System, 2011

Agricultural Waste Solutions (AWS), 2010

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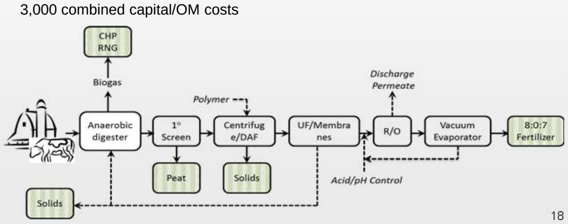
Salt Removal/Clean Water

- Removal of salts and movement towards production/utilization of clean water is at another level of complexity and cost.
- Using many of the already described, sequential steps, it is then possible to use additional operations involving membranes and reverse osmosis to produce both a near complete clean water AND concentrated nutrient/salt rich fertilizers.
- While potentially organically certifiable fertilizers as well as response to salt concerns can be realized, energy/input costs are high and on the order of $2,000-3,000 combined capital/OM costs



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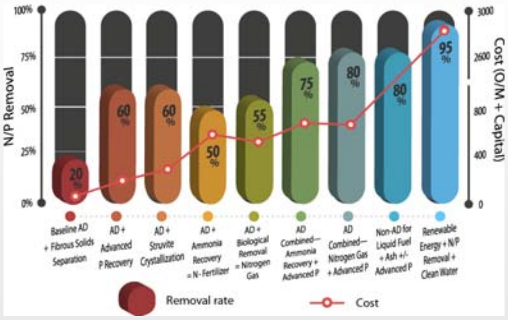
Summary of Systems

Below is a visual summary of the class of options potentially available for combined renewable energy/fuel production and nutrient control for mitigation of multiple environmental threats.



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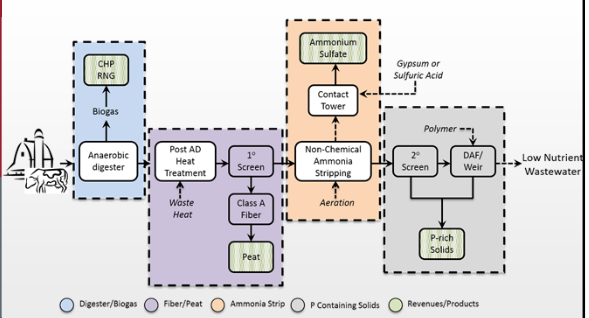
WSU DVO System



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WSU DVO System

Figure: Demonstration Sites

A—800-cow dairy, Lynden WA

B—1,500-cow dairy, Enumclaw WA

C—1,500-cow dairy, Chilton WA

D—1.5 M layer, Fort Recovery OH

	Unit Operations				Total System [c]
	AD	Fiber/Peat	Ammonia [a]	2º Solids/P [b]	
Production	110 ft^3 of biogas cow^{-1} day^{-1}	9-10 yards fiber cow^{-1} y^{-1}	1/4 dry ton AS cow^{-1} y^{-1}	1/2 dry tons solid cow^{-1} y^{-1}	---
N Removal (%)	---	15-20	40-50	10-15	65-85
P Removal (%)	---	12-18	---	60-70	72-88

Figure: NR products (a) fiber/peat; (b) ammonium sulfate solution; (c) fine solids rich in P

WSU DVO System

Capital (167,000 gpd: 3,150 WCE plus 30% v/v substrates ~ 5,200 WCE)		$2.75 Million Capital Cost	
Expenses	($/day)	Revenue	($/day)
Electricity (195 Kwh/h @ $0.06/Kwh)	281	Ammonium Sulfate (3.1 tons @ $250/ton)	775
Sulfuric Acid ($200/ton)	420	P-Solids (6.5 tons @ $80/dry ton)	520
DAF Dewatering ($0.001/gallon treated)	167	Based on potential wholesale value of $250/ton AS fine solids (Spring 2013) and $80/ton for the P-rich solids with an assumed value of high nutrient compost (Spring 2013)	
O&M (labor, contingency parts)	343		
Heat (assume thermal available CHP)	---		
Storage (assume on-site storage)	---		
Transportation (assume near sales)	---		
Total	1,211	Total	1,295

System in need of further demonstration of process improvements

•Small bubble aeration—enhanced performance, effect on cost

•Gypsum acid replacement—cost reductions, organic certification

•Crystallization—Enhanced sales/markets via sale of solid product

•Fertilizer markets, eco-system credits, nutrient trading, etc.

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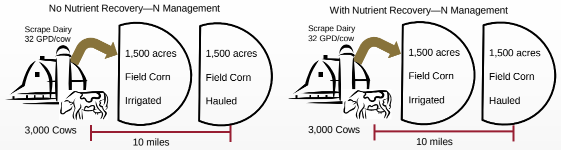
Partitioning Example



While only a rough example, partitioning of nutrients into separate concentrated forms can lead to significant farm savings based on hauling costs, targeted fertilizer usage, requirement of less land, and potential excess nutrient sales.

	Scenario 1--No Nutrient Recovery		Scenario 2--Nutrient Recovery	
	Field 1-Irrigated	FIeld 2-Hauled	Field 1-Irrigated	FIeld 2-Hauled
Acres Corn (#)	1,500	1,500	1,500	1,500
Yield (Bushels/acre)	200	200	200	200
Fertilizer Applied (tons NPK/year)	187.5/90/210	187.5/90/210	187.5/90/210	187.5/90/210
Lagoon Water Applied (%)	37.22	62.78	80	20
Fertilizer Cost ($)	130,507	67,953	5,812	192,647
Hauling Cost ($)		105,583		29,602
Excess Haul Cost ($)	42,975			
Sales Excess Bio-Fertilizer ($)			84,942	
Total Cost	$347,018		$143,120	

Fertilizer Yield/Nutrient Requirements: 1.25 lbs N/bushel; 0.6 lbs P/bushel; 1.4 lbs K/bushel at 200 bushels per acre yield
Fertilizer Prices: $1,100/ton N; $603/ton P; $797/ton K at retail and wholesale sales bio-fertilizer at 0.6 (Silva, 2011)
Nutrient recovery Assumptions: 60% recovery of N; 80% recovery of P and 30% recovery of K—80% of N as N product; rest as other mixed
Fuel Assumptions: 20 mile round trip; 5,000 gallon tankers, 5 MPG, $6/gallon fuel/insurance/labor costs—Bio-fertilizer haul at 0.1 cost ratio
Manure Assumptions: No loss of nutrients—assume as produced manure levels (Mukhtar, 2007)

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Tech Choice—Considerations

- *Manure is very different than municipal wastewater.* Technologies tested/developed for WWTF will not necessarily work under altered conditions including higher concentrations of solids and nutrients.
- *Not all manures are alike*. Within dairy are flush, scrape and dry lot manure handling procedures. Each produces a *very different* wastewater leading to technologies that may or may not work under the different processes.
- *Each project/area has varying contaminant concerns*. Areas might be under N, P or even salt management, leading to developers being more interested in particular technological approaches.
- *Removal vs. Recovery*. Some approaches convert reactive nitrogen into non-reactive nitrogen gas, thus not utilizing a potential nutrient in a positive manner—degree of focus on sustainability versus bottom line might be at issue here.

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Tech Choice—Considerations

- *Concept/Pilot vs. Commercially Available.* No substitutes for practical and scaled experience. Numerous lessons, strongly affecting cost, performance and viability are learned during scale up.
- *Sequential vs. Direct Treatment*. Heterogeneous waste with high solids and nutrient content often requires sequential treatment, lending an ear towards sequential removal of contaminants as opposed to more direct means.
- *Operating vs. Capital.* If appropriate and viable technologies are chosen, then capital is a one-time cost, which of course is preferably made low, but operating is an annual cost that can continually bring a project in the red. Caution for high electrical and chemical costs.
- *Product Sales.* Renewable fertilizer/amendment markets either don't exist or are immature. Caution in regard to price points and volume as well as hidden costs in storage, transportation, blending, quality of product, etc.

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Regulator—Considerations

- Requirement of BACT nutrient technologies do have costs associated with them and as a result any policy decisions must take into consideration *how and to whom these costs will be accommodated.*
- *A systems viewpoint is preferred*, *renewable energy production can be the economic and conversion facilitator* for nutrient recovery, but only if the economic margin gained by the energy production can incur the costs. Thus renewable energy policy decisions are key:
  - *CNG*—RIN value and category confidence, LCF standards, carbon markets, CNG engine certification, pipeline access/tariff standardization, infrastructure incentives, etc.
  - *CHP*—Elevated Renewable Energy Portfolios, carbon markets, alleviation of natural-gas linked deferred cost tables, etc.
- *White Elephants:* Beware nutrient markets producing 'white elephant' projects with high cost—best to have projects held to what market can demand with 'some' well conceived policy assistance.

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Regulator—Considerations

- *Nutrient Markets*—Generating new markets and competing against fossil fertilizer is complex, time-consuming and fraught with uncertainty. Policy could potentially leverage or spur the market to assist in its development.
- *Financing*—While renewable energy projects might receive external financing, non-proven nutrient recovery components perhaps required as a 'cost of doing business' are at best difficult to finance. Federal programs aimed at 'extra-value' funding would be useful.
- *Federal Center of Excellence*—Numerous additional technical needs are required for demonstration and further optimization of processes. Little access to federal dollars is available in this nutrient area (USDA NRCS, SBIR, etc.)
- *Big Picture*—Ammonia (PM 2.5, health) and nitrates are linked. Mitigating nitrate losses by blowing off ammonia in lagoons/guns makes little sense in larger picture. Similar to tight control of NOx so as to not allow GHG mitigation projects.

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