Emerging Nutrient Recovery, Mitigation and Partitioning Technologies for Treatment of Dairy Manure

Innovation Center for U.S. Dairy Commissioned NR Report

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Google: “Emerging Nutrient Recovery Technology”
Outline

• Business Case Considerations for Nutrient Recovery
• Phosphorus Treatment Options
• Nitrogen Treatment Options
• Combined Treatment Options
• Product Commercialization
Dairy industry can generate value by repurposing food waste from landfills, converting into renewable energy, harvesting nutrients (N & P) and providing for ecosystem services - resulting in a business model that enables a 21st century food system and bioeconomy for agriculture.
Business Case for Nutrient Recovery

While co-digestion business model is well developed, albeit under electrical pricing pressure, new Nutrient Recovery unit installations can add ecosystem 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
Role of 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/hr.
- Stabilize volatiles, reduce solids, separate fiber, shift nutrients towards inorganic form\(^2\).

\(^1\) Wilkie 2000  \(^2\) Frear et al, 2011
Value of 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 volatile solids\(^2,3\).

- Waste organics increase energy generation potential 2 to 4x that of dairy manure.

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

- Estimated 100 years of supply.
- Remaining reserves of poor quality (costly to harvest, heavy metals).
- 90% and 50% of ingested P is excreted by human and animal.
- Agricultural/hydrologic systems serve as sink for P release.

Vaccari 2009; Cornell et al, 2009; Jonsson et al 2004; Smil 2000
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
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, $90-100/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.
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 USDA/EPA should be aware of capital and O/M costs to accomplish such recovery.

<table>
<thead>
<tr>
<th>Key Technology</th>
<th>Representative process</th>
<th>Performance</th>
<th>Operating Cost</th>
<th>Capital Cost</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modern P</td>
<td>Primarily P</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1' and 2' Mechanical Screens</td>
<td>US Farm Systems</td>
<td>TN 15-30%, TP 15-25%</td>
<td>$5-6</td>
<td>$32-36</td>
<td>Commercial</td>
</tr>
<tr>
<td>Centrifuge-No Polymer/Coagulant</td>
<td>Alfa Laval, Westfalia, Kyte, Sweco</td>
<td>TN 24-30%, TP 50-65%</td>
<td>$25-50</td>
<td>$57-136</td>
<td>Commercial</td>
</tr>
<tr>
<td>Lime Precipitation</td>
<td>Chemical Lime Company</td>
<td>TN 30-40%, TP 70-80%</td>
<td>$30-60</td>
<td>$60-80</td>
<td>Pilot</td>
</tr>
<tr>
<td>Mechanical + Polymer/DAF</td>
<td>DVO Phosphorus</td>
<td>TN 45-55%, TP 85-90%</td>
<td>$25-30</td>
<td>$90-100</td>
<td>Commercial</td>
</tr>
<tr>
<td>Mechanical + Polymer Belt Press</td>
<td>AWS, Env. Resolutions, Kemira</td>
<td>TN 35-45%, TP 75-85%</td>
<td>$50-75</td>
<td>$120-140</td>
<td>Commercial</td>
</tr>
<tr>
<td>Struvite Crystallization</td>
<td>Multiform Harvest, Ostara, Phosstrip</td>
<td>TN 30%, TP 75%</td>
<td>$90-110</td>
<td>$100-150</td>
<td>Commercial</td>
</tr>
<tr>
<td>Mechanical + Electrocoagulation</td>
<td>Utah State University</td>
<td>TN 30-50%, TP 80-90%</td>
<td>$140-160</td>
<td>$200-225</td>
<td>Pilot</td>
</tr>
<tr>
<td>Mechanical Screening + Membrane</td>
<td>Pro Dairy, LWR</td>
<td>TN 71-73%, TP 80-90%</td>
<td>$125-150</td>
<td>$275-330</td>
<td>Pilot</td>
</tr>
</tbody>
</table>
| Enhanced Biological Phosphorus     | Phosstrip, Phoredox, NC Systems                        | 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.
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

- **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 N₂

- **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 N₂
Nitrogen Treatment

Notable extra cost to reduce/recover N. Decision tied to complexity of producing, storing, blending, and marketing N-product.

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<tr>
<td>Primarily N</td>
<td></td>
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</tr>
<tr>
<td>Flash Distillation of Ammonia</td>
<td>AgroARP, ThermoARP</td>
<td>TN 60-70%</td>
<td>$80-120</td>
<td>$475-550</td>
<td>Pilot</td>
</tr>
<tr>
<td>Chemical Ammonia Stripping</td>
<td>Eawag, Chemical Lime Company</td>
<td>TN 50-60%</td>
<td>$120-160</td>
<td>$375-425</td>
<td>Pilot</td>
</tr>
<tr>
<td>Non-Chemical Ammonia Stripping</td>
<td>DVO Ammonia, ANAstrip, AMFER</td>
<td>TN 40-60%</td>
<td>$80-120</td>
<td>$375-425</td>
<td>Commercial</td>
</tr>
<tr>
<td>Nitrification/Denitrification</td>
<td>BioFas, Trevi, Agrimond, ReCip®</td>
<td>TN 80-90%</td>
<td>$80-100</td>
<td>$300-400</td>
<td>Pilot</td>
</tr>
<tr>
<td>Partial Nitrification/Denitrification</td>
<td>Anammox, Sharon, Canon, DEMON</td>
<td>TN 80-90%</td>
<td>$60-80</td>
<td>$300-400</td>
<td>Lab</td>
</tr>
<tr>
<td>Gas-Permeable Membranes</td>
<td>USDA-ARS</td>
<td>TN 60-70%</td>
<td>NA</td>
<td>NA</td>
<td>Lab</td>
</tr>
</tbody>
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Combined Treatments

• 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.

• Algae as a bio-treatment within an algal fuel bio-refinery is an active concept.

Algevolve, 2013
Non-AD Based Examples

**BION**

1. Non-Digested Manure
2. Screening
3. Partial N/De-nitrification
4. Chem S/L
5. ‘P/N Rich Solids

**AWS**

1. Non-Digested Manure
2. Gasification
3. Fischer/Tropsch
4. Liquid Fuel + Ash
5. Centrifuge Polymer
Combined Treatments

• Combined AD plus nutrient recovery systems are capable of removing 60% + nitrogen and 80%+ phosphorus, however costs are approximately $100+/cow/year for O/M and $425+/cow capital.

• Assuming digesters costs of $12-24/cow/year for O/M and $1,500-2,000/cow for capital, inclusion of nutrient recovery systems into a total project lead to 500% and 25% increases in costs, respectively.

• To offset these costs, project developers will have to develop Pro Forma that include higher or more revenue such as fertilizer products, soft-cost offsets to manure management, and credits.

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<tr>
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<th>Performance</th>
<th>Operating Cost /cow/year</th>
<th>Capital Cost /cow</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>N &amp; P Combined</td>
<td></td>
<td></td>
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<tr>
<td>Ammonia Strip + Polymer/DAF</td>
<td>DVO Integrated</td>
<td>TN 60-70%, TP 85-90%</td>
<td>$100-140</td>
<td>$425-475</td>
<td>Commercial</td>
</tr>
<tr>
<td>N/Denit. + Biological P</td>
<td>BioFas, Ekokan, Agrimond, ReCip®</td>
<td>TN 80-90%, TP 60-70%</td>
<td>$175-200</td>
<td>$500-550</td>
<td>Pilot</td>
</tr>
<tr>
<td>Partial N/Denit.+Chemical P</td>
<td>BION</td>
<td>TN 80-90%, TP 80-90%</td>
<td>NA</td>
<td>NA</td>
<td>Pilot</td>
</tr>
<tr>
<td>Combustion = CHP</td>
<td>Elimanure®, Fibrowatt</td>
<td>TN 40-50%, TP 100%</td>
<td>NA</td>
<td>NA</td>
<td>Pilot</td>
</tr>
<tr>
<td>Centrifuge + Gasification = Diesel</td>
<td>AWS</td>
<td>TN 50-60%, TP 80-90%</td>
<td>NA</td>
<td>NA</td>
<td>Pilot</td>
</tr>
<tr>
<td>Algae growth</td>
<td>ABNR™</td>
<td>TN 70-80%, TP 80-90%</td>
<td>NA</td>
<td>NA</td>
<td>Pilot</td>
</tr>
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AD Product Commercialization