Manure Management:  
Systems Analysis and Decision-Making

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Manure Management

Some Info:
U.S. Farm Animals Produce **2 Times** the Amount of Waste of Entire Human Population
Single Dairy Cow Generates 20 Tons of Waste/year
There are 9 Million Cows in the U.S. (1.2 Million in Wisconsin)

Questions:
- What are Key Technologies and Locations Given Constrained Budgets?
- What are Optimal Investment, Financing, and Transportation Strategies?
- How to Reconcile Priorities (Geographical/Phosphorus/Methane/Health/Not-in-my-Backyard)?
- How to Deal with Complexity?
Food-Water-Energy Nexus

- Methane
- P/N
- CO₂
- Water
- Electricity

System Boundary

- WWTP Landfill Sector
- Electrical Sector
- Natural Gas Sector

Agricultural Sector
- Fertilizer Imports
- Struvite Biochar Exports

Urban Sector
- Dairy Products
- Crops/Manure
- Biosolids

Water
- Runoff
- Rain/Evaporation

Soil
- Manure

Dairy Sector
- Dairy Exports

Atmosphere

Biogas

Rain

P/N and Biogas are exchanged among the sectors.
Navigating Complexity

[Diagram showing different networks and facilities like Dairy Farm, Landfill, Combined Heat & Power, Regional Network, Local Network, and WWTP, with geographical coordinates and markers for each location.]
Navigating Complexity

Map of Wisconsin with a pie chart indicating the distribution of phosphorus sources:
- Point Sources: 41,242 (22%)
- Background: 13,057 (7%)
- NP Urban: 5,711 (3%)
- MS4 Urban: 48,659 (25%)
- Ag Non Point: 82,814 (43%)

Legend:
- Phosphorus (kg/ha/yr)
- Scale:
  - 0
  - 0.04
  - 0.10
  - 0.14
  - 0.18
  - 0.23
  - 0.29
  - 0.40
  - 0.52

Color gradient from light yellow to dark red represents the concentration of phosphorus.
Resolving Conflicts Among Stakeholders

**Multi-Objective Optimization**

\[
\min_x \{ f_1(x), f_2(x), \ldots, f_N(x) \}
\]
\[
\text{s.t. } g(x) \leq 0
\]

**Weighted Form**

\[
\min_x w_1 f_1(x) + w_2 f_2(x) + \ldots + w_N f_N(x)
\]
\[
\text{s.t. } g(x) \leq 0
\]

**Goals:**
- Multiple Decision-Makers and **Priorities** → Ambiguity, Disagreement
- Identify Alternatives that **Maximize Collective Satisfaction**
- Identify **Impact of Opinions** on Final Decision

High Cost  
Low Environmental Impact

Low Cost  
High Environmental Impact

Power Plant I  
Power Plant II

Stakeholders

Stakeholders

Stakeholders
Computational Tools

Nutrient Management
- SnapPlus

Soil and Simulator
- SWAT
- Multi-Network Model
- Data Processing
- Hierarchical Aggregator
- Nexus Model

Farm Management
- USDA
- IFSM
- Users
- JuliaBox

Infrastructure Data
- Grid
- Gas

Computing Cluster
- Computing Cluster

Multi-Scale Algorithms
- MPICH-2
- OpenMP
- CPLEX
- Gurobi
- PIPS
- PETSc
- Magma
- CBC
- Soplex

Hierarchy Aggregator

Scenario Generator

LCA Metrics
Case Studies on Struvite and Biogas Recovery

Goals:

- Consider manure of **100 largest CAFOs** in the State of Wisconsin
- Identify optimal **sizing and location** for struvite and biogas recovery
- Consider a spectrum of **available budgets**
- Reconcile **priorities** from different types of **stakeholders**
- Analyze impact of **final destinations** of recovered products on system layout
Case Studies (Struvite Recovery)

Unconstrained Budget

Constrained Budget

<table>
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<tr>
<th>Budget (USD/day)</th>
<th>$\varphi_f$ (USD)</th>
<th>$\varphi_f$ (USD/day)</th>
<th>$\sum_{n,t} y_{n,t}$</th>
<th>$\varphi_{str}$ (kg/day)</th>
<th>$\phi_u$ (%)</th>
<th>$h_{\text{Waste}}$ (km/day)</th>
<th>$h_{\text{str}}$ (km/day)</th>
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Case Studies (Struvite + Biogas Recovery)

Ideal Stakeholder Solutions

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<tr>
<th>Stakeholder</th>
<th>(w_{\text{str}}) (%)</th>
<th>(w_{\text{bio}}) (%)</th>
<th>(\varphi_{\text{str}}) (kg/day)</th>
<th>(\varphi_{\text{bio}}) (m³/day)</th>
<th>(\varphi_I) (USD)</th>
<th>(\varphi_f) (USD/day)</th>
<th>(\varphi_{f,\text{waste}}) (USD/day)</th>
<th>(\varphi_{f,\text{str}}) (USD/day)</th>
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<td>600</td>
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<td>V</td>
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Compromise Solutions

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<th>(\beta)</th>
<th>(\varphi_{\text{str}}) (kg/day)</th>
<th>(\varphi_{\text{bio}}) (m³/day)</th>
<th>(\varphi_I) (USD)</th>
<th>(\varphi_f) (USD/day)</th>
<th>(\varphi_{f,\text{waste}}) (USD/day)</th>
<th>(\varphi_{f,\text{str}}) (USD/day)</th>
<th>(d_{I}) (%)</th>
<th>(d_{II}) (%)</th>
<th>(d_{III}) (%)</th>
<th>(d_{IV}) (%)</th>
<th>(d_{V}) (%)</th>
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Case Studies (Struvite + Biogas Recovery)

**Compromise Solution**
(Single Collection Point)

**Compromise Solution**
(Multiple Collection Points)

**Key:** Final use of recovered products influences technology placement.
Acknowledgements


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