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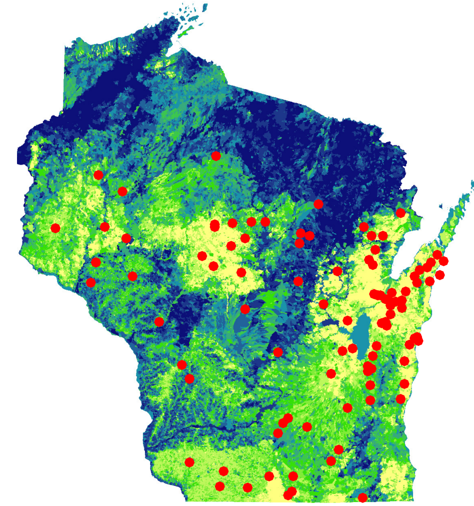

Manure Management:
Systems Analysis and Decision-Making

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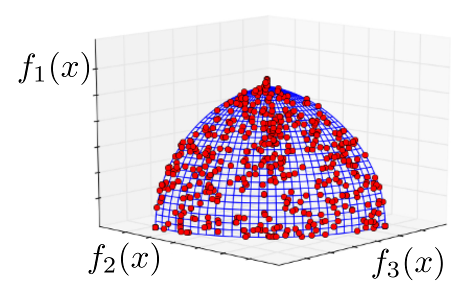
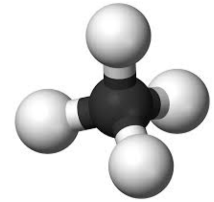
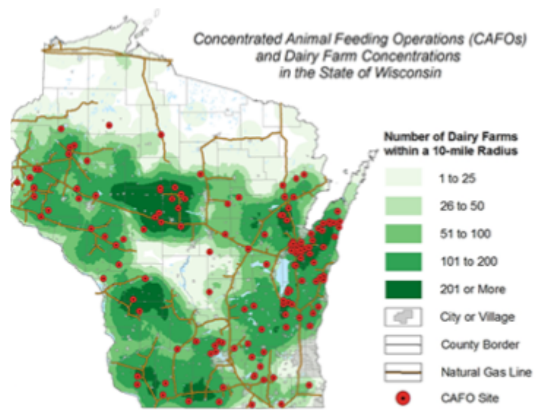
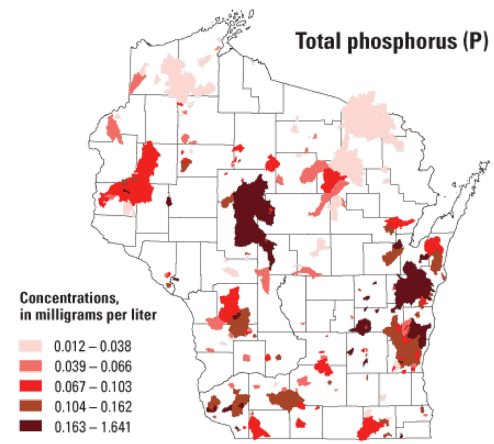


Manure Management



Source	Methane Potential (tonnes/yr)
Wastewater	2,339,339
Landfills*	2,454,974
Animal manure	1,905,253
IIC organic waste	1,157,883
Total	**7,857,449**





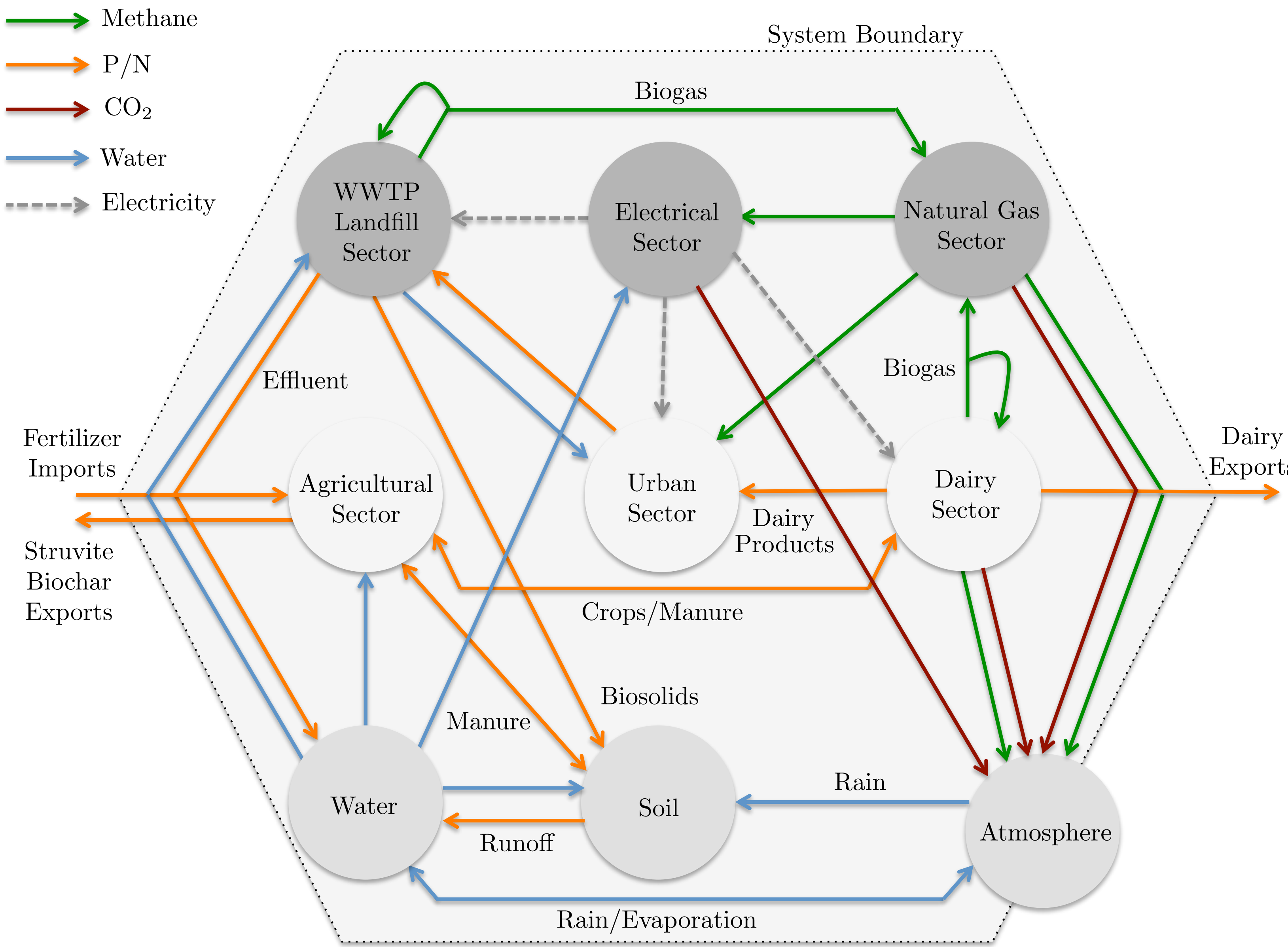
Some Info:

U.S. Farm Animals Produce <u>2 Times</u> 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)

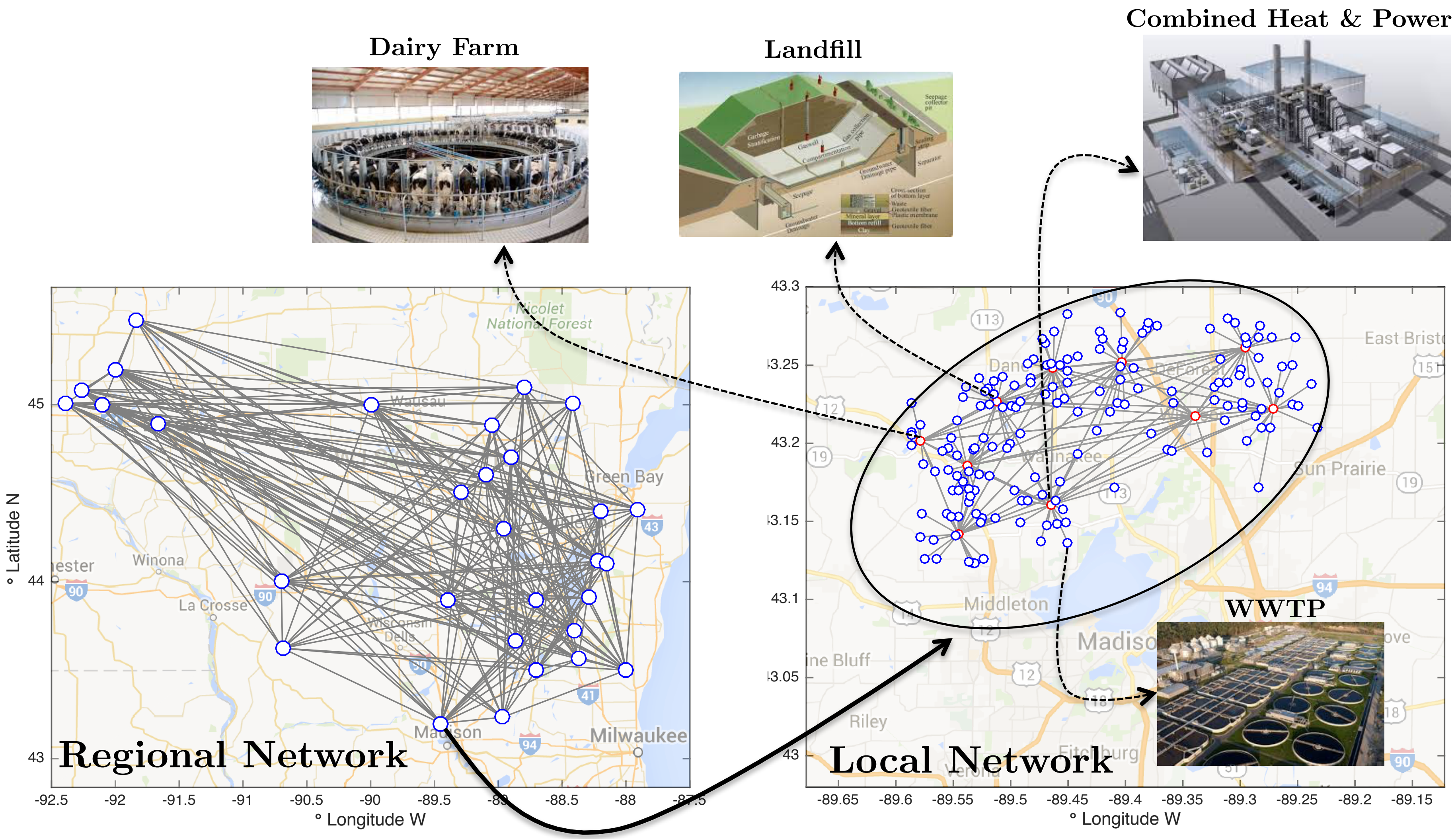
Questions:

- **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?**

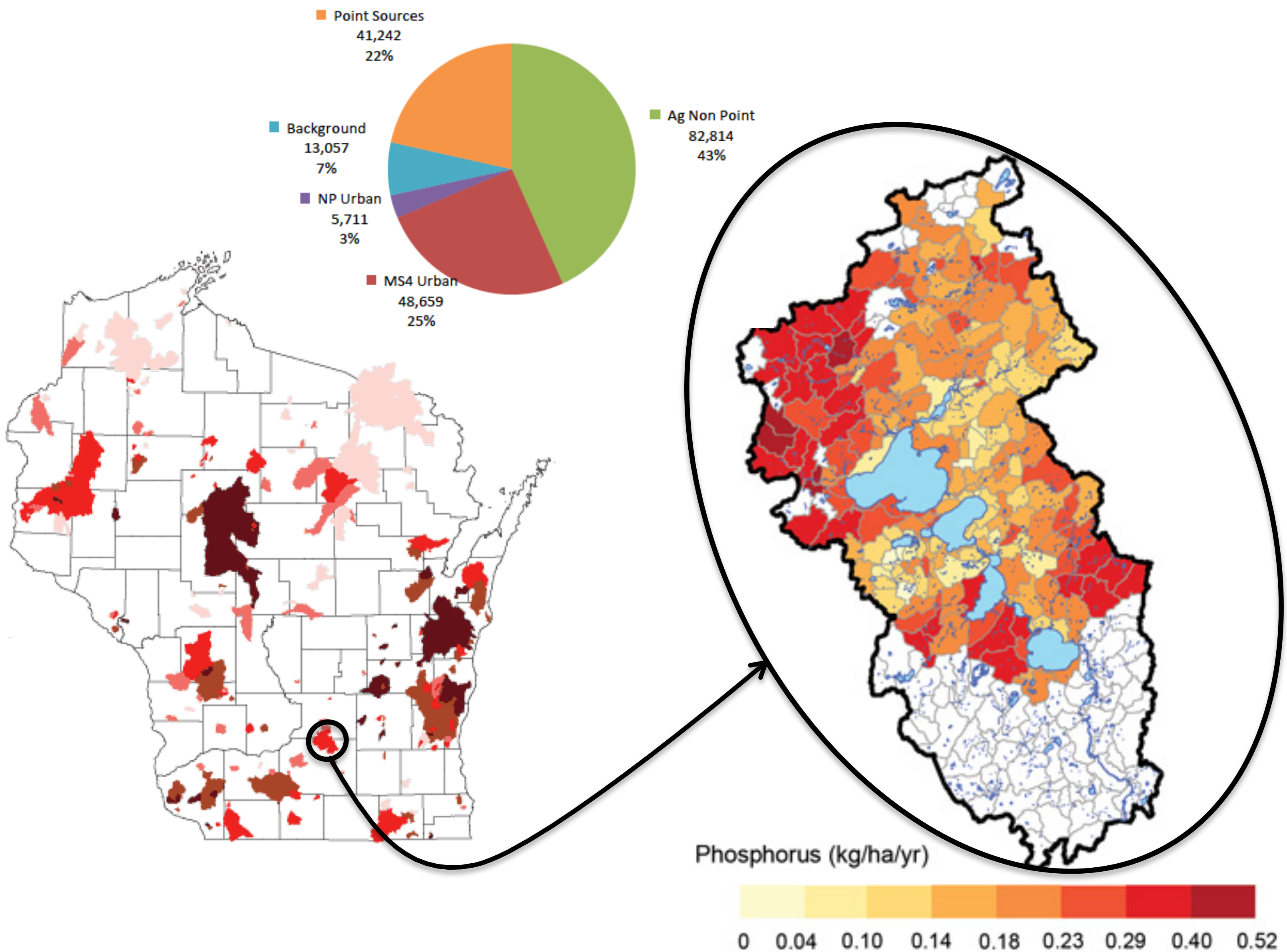
Food-Water-Energy Nexus



Navigating Complexity



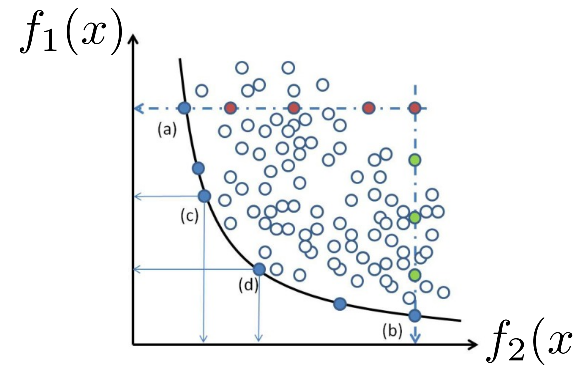
Navigating Complexity



Resolving Conflicts Among Stakeholders

Multi-Objective Optimization

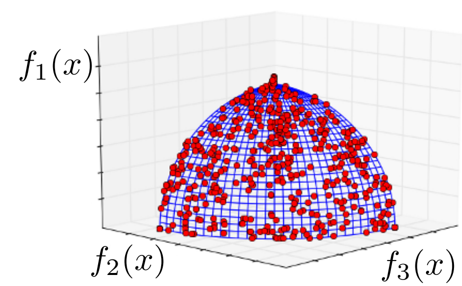
$$\min_{x} \{f_1(x), f_2(x), ..., f_N(x)\}$$
$$\text{s.t.} \quad g(x) \leq 0$$



Weighted Form

$$\min_{x} w_1 f_1(x) + w_2 f_2(x) + \ldots + w_N f_N(x)$$
$$\text{s.t.} \quad g(x) \leq 0$$

$$\min_{x} \mathbf{w}^T \mathbf{f}(x)$$
$$\text{s.t.} \; g(x) \leq 0$$



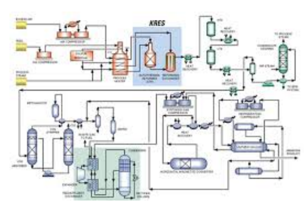
Goals:

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

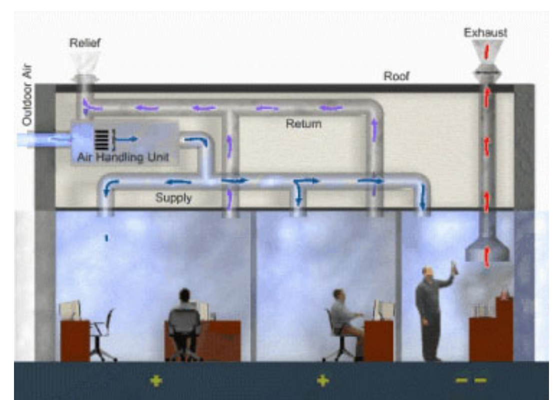
High Cost
Low Environmental Impact

Low Cost
High Environmental Impact

Stakeholders

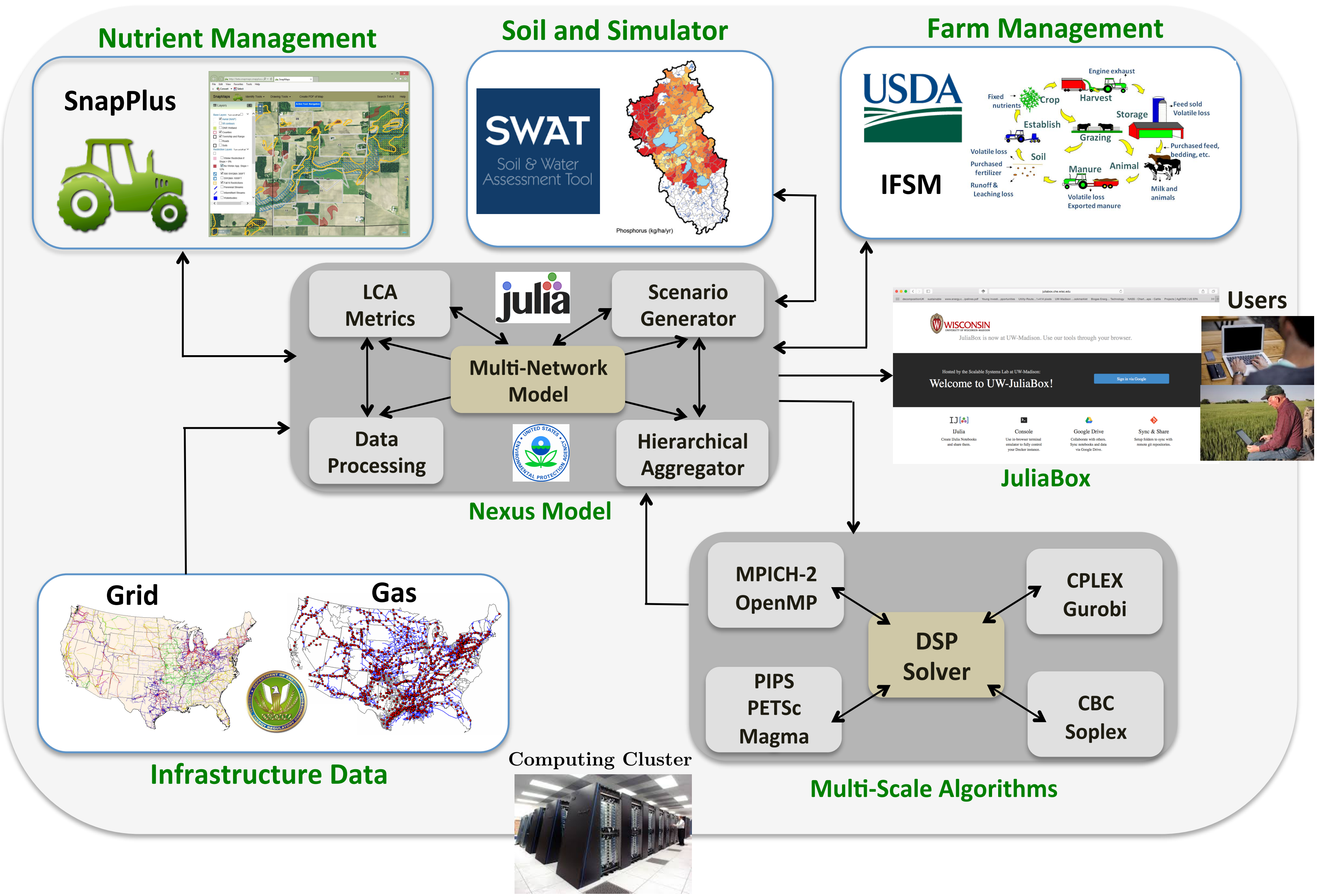


Stakeholders

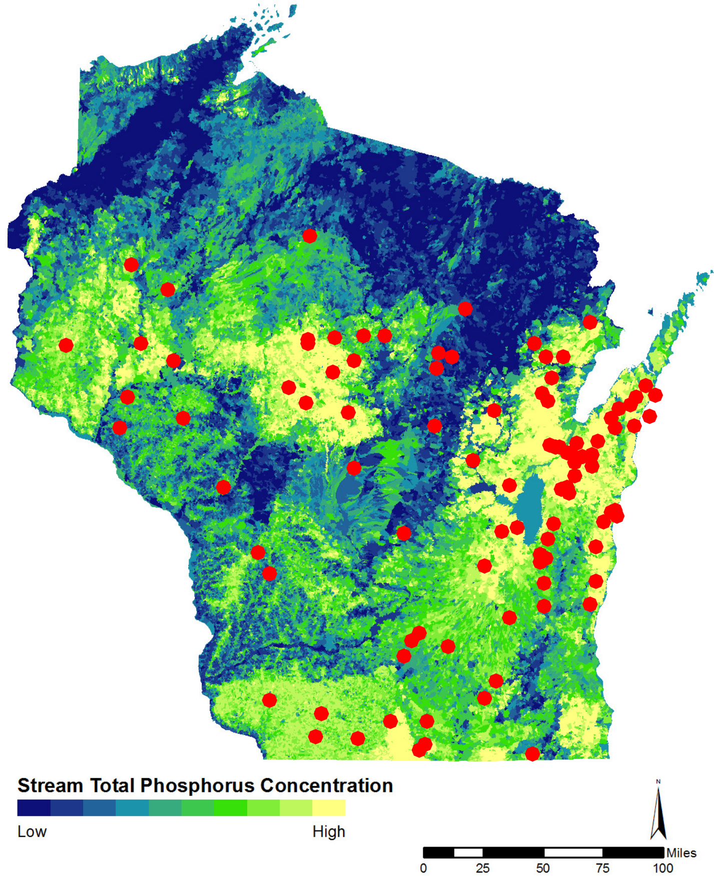


Stakeholders

Computational Tools



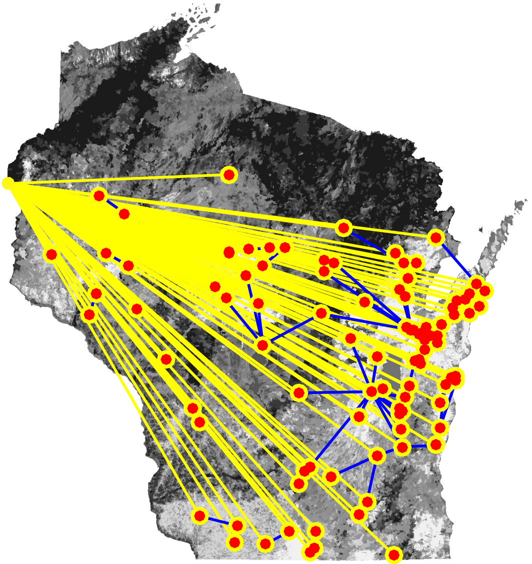
Case Studies on Struvite and Biogas Recovery

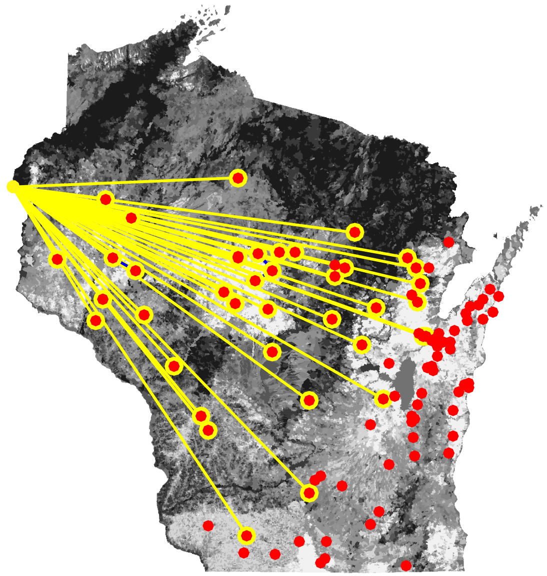


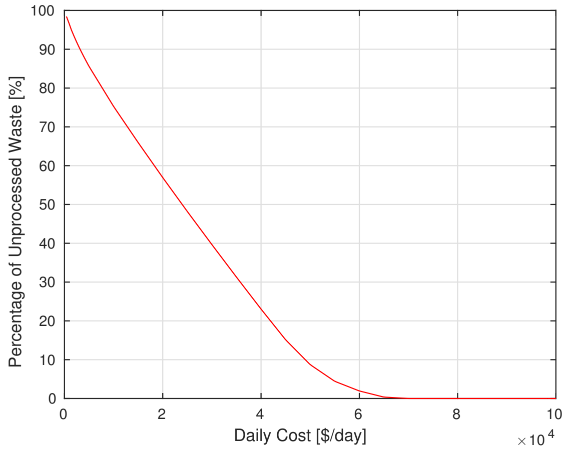
Goals:

- 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)

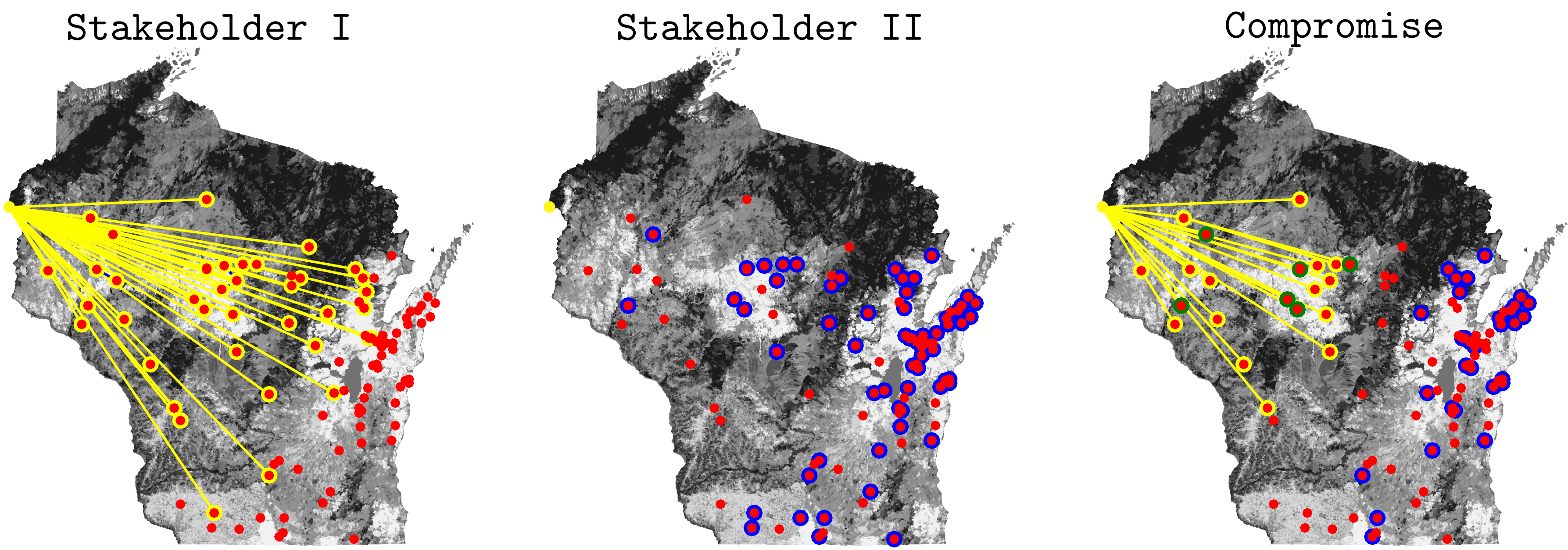






Budget (USD/day)	φ_I (USD)	φ_f (USD/day)	$\sum_{n,t} y_{n,t}$	$\varphi_{\mathtt{str}}$ (kg/day)	ϕ_u (%)	$h_{\mathtt{Waste}}$ (km/day)	$h_{\mathtt{str}}$ (km/day)	$\varphi_{f,waste}$ (USD/day)	$\varphi_{f,str}$ (USD/day)
500,000	102.95×10^6	485,898	101	6.59×10^5	0.00	34.97	170.02	448,014	37,281
70,000	102.61×10^6	55,944	100	6.59×10^5	0.00	47.86	144.69	18,557	37,387
55,000	102.27×10^6	40,991	100	6.30×10^5	4.43	22.81	346.16	5,342	35,649
45,000	93.60×10^6	32,179	96	5.59×10^5	15.13	7.21	341.99	818	31,361
35,000	75.10×10^6	24,713	77	4.53×10^5	31.27	6.81	328.29	532	24,181
25,000	57.30×10^6	17,151	59	3.41×10^5	48.18	6.72	300.44	405	16,746
15,000	38.38×10^6	9,742	41	2.24×10^5	65.94	5.47	257.38	213	9,530
10,000	28.78×10^6	6,058	32	1.63×10^5	75.25	4.97	216.14	177	5,881
5,000	16.70×10^6	2,713	18	0.95×10^5	85.57	0.95	164.58	25	2,688
3,000	11.01×10^6	1,492	12	0.63×10^5	90.45	0.43	132.30	10	1,481

Case Studies (Struvite + Biogas Recovery)



Ideal Stakeholder Solutions

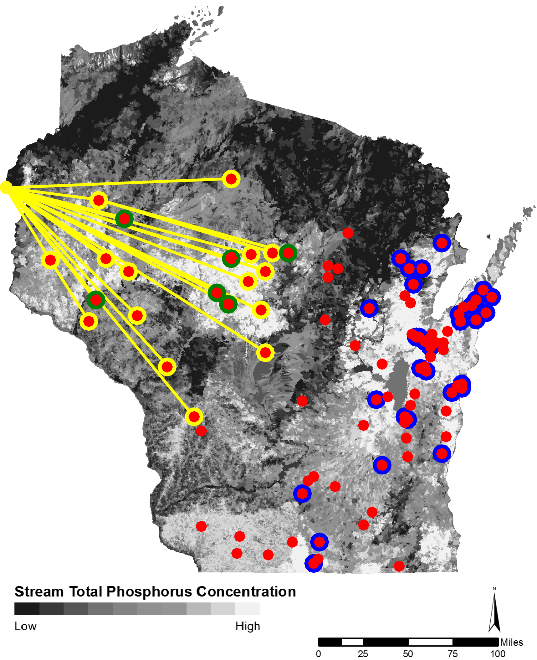
Stakeholder	w_{str} (%)	w_{bio} (%)	φ_{str} (kg/day)	φ_{bio} (m^3/day)	φ_I (USD)	φ_f (USD/day)	$\varphi_{f,waste}$ (USD/day)	$\varphi_{f,str}$ (USD/day)
I	100	0	2.24×10^5	0.00	38.07×10^6	9,786	278	9,508
II	0	100	0.00	2.33×10^5	105.48×10^6	550	550	0
III	50	50	1.08×10^5	1.45×10^5	85.12×10^6	3,340	109	3,231
IV	33	67	3.38×10^3	2.30×10^5	104.82×10^6	641	600	41
V	67	33	2.24×10^5	0.00	38.41×10^6	9,739	369	9,370

Compromise Solutions

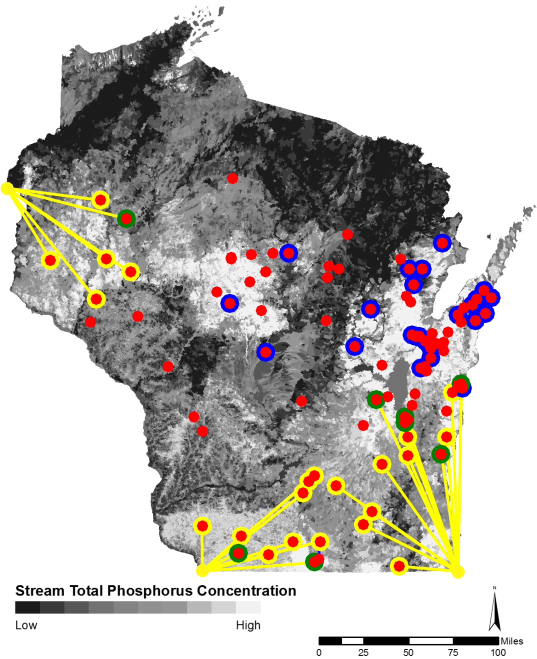
β	φ_{str} (kg/day)	φ_{bio} (m^3/day)	φ_I (USD)	φ_f (USD/day)	$\varphi_{f,waste}$ (USD/day)	$\varphi_{f,str}$ (USD/day)	d_I (%)	d_{II} (%)	d_{III} (%)	d_{IV} (%)	d_V (%)
0	1.24×10^5	1.29×10^5	79.47×10^6	4,114	225	3,889	45	45	0	12	12
0.5	1.25×10^5	1.29×10^5	79.23×10^6	4,147	130	4017	46	43	0	11	12
0.7	1.22×10^5	1.32×10^5	80.54×10^6	3,967	109	3,858	47	42	0	11	13
1	1.07×10^5	1.45×10^5	84.41×10^6	3,436	205	3,231	54	35	0	8	15

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

- **A Multi-Scale Platform for Technology Evaluation and Decision-Making in the Dairy-Water-Energy Nexus**, U.S. Department of Agriculture, 2016-2018.

- **Multi-Stakeholder Decision-Making for the Development of Livestock Waste-to-Biogas Systems**, National Science Foundation-CBET, 2016-2018.

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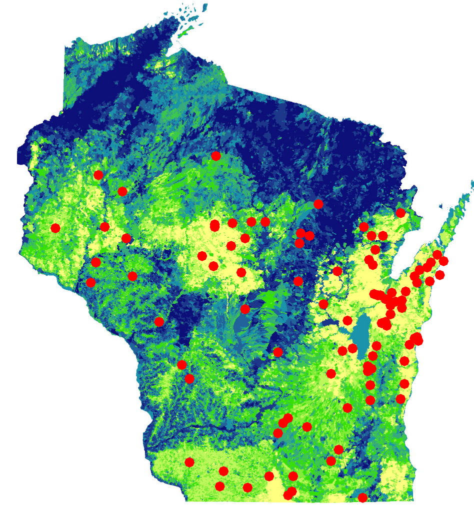

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