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Comparative Emergy Evaluation of Nutrient Removal and Nutrient Recovery Technologies and the Implications to Nutrient Management

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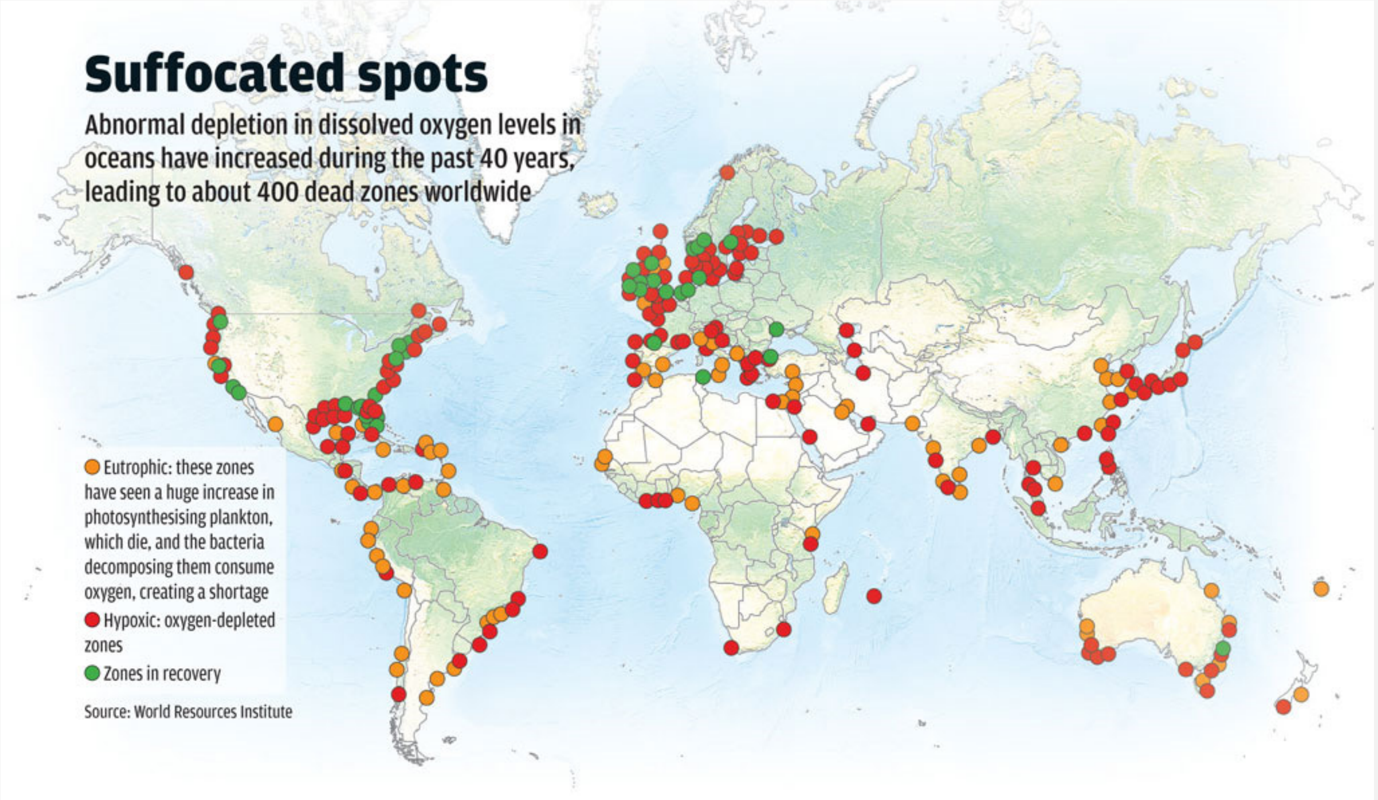
Importance of Nutrient Removal/Recovery



- Eutrophication is the enrichment of an ecosystem with chemical nutrients, typically compounds containing nitrogen, phosphorus, or both.

- Clean Water Act (CWA) requires wastewater treatment plants (WWTPs) to reduce nutrient discharge levels to prevent eutrophication

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Study Objectives and Approach

- Aims to address

  1) how the regulatory rules drive the system changes;

  2) how the conventional system can be transitioned to more cost effective more sustainable alternatives in nutrient management.

- Use emergy to provide system analysis, which quantifies direct and indirect contributions; from the elemental resource flow, to the entire treatment plant operational requirements.

- Influent wastewater flow and nutrient levels, capital, operational data were collected from previous nutrient removal studies and for nutrient recovery from Ostara Nutrient Recovery Technologies, Inc.

- All UEVs used and given hereafter (including those referenced in the text) were corrected to the **1.20 E25 sej/yr** global emergy baseline (Brown et al., 2016)

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Biological Nutrient Removal (BNR)

- Biological nutrient removal (BNR) treatments remove total nitrogen (TN) and total phosphorus (TP) from wastewater through the use of chemicals and microorganisms under different environmental conditions in the treatment process (Metcalf and Eddy, 2003)

- Common BNR system configurations included in the study:
  - Modified Ludzack-Ettinger (MLE) Process
  - Bardenpho Process (Four-Stage)
  - Modified Bardenpho Process (5-Stage with modifications)
  - Modified University of Cape Town (MUCT) Process

- Additional tertiary treatments to adhere to stringent discharge regulations:
  - Membrane Bioreactor
  - Membrane Filtration
  - Denitrification Filter
  - Reverse Osmosis

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Nutrient Recovery and Benefits

- Nutrient recovery is the practice of recovering nutrients (nitrogen and phosphorus) from wastewater and converting them into an environmental friendly fertilizer used for ecological and agricultural purposes

- Industrial phosphate fertilizers are manufactured using phosphate rock, which is a non-renewable resource

- Nutrient recovery provides a self-sustainable solution to WWTPs
  - revenue generation from fertilizers
  - reduces fouling of equipment with involuntary precipitation of struvite
  - helps meet the discharge limits

- Phosphate precipitation from wastewater is less energy intensive and economical (easily added to WWTP with a little infrastructure investment)

Urine as a Nutrient Source

- Source separate the flows to maximize recovery
- Struvite crystalization

$$Mg^{2+} + NH_4^{+} + PO_4^{3-} = MgNH_4PO_4 \cdot 6H_2O$$

Magnesium Ammonium Phosphate

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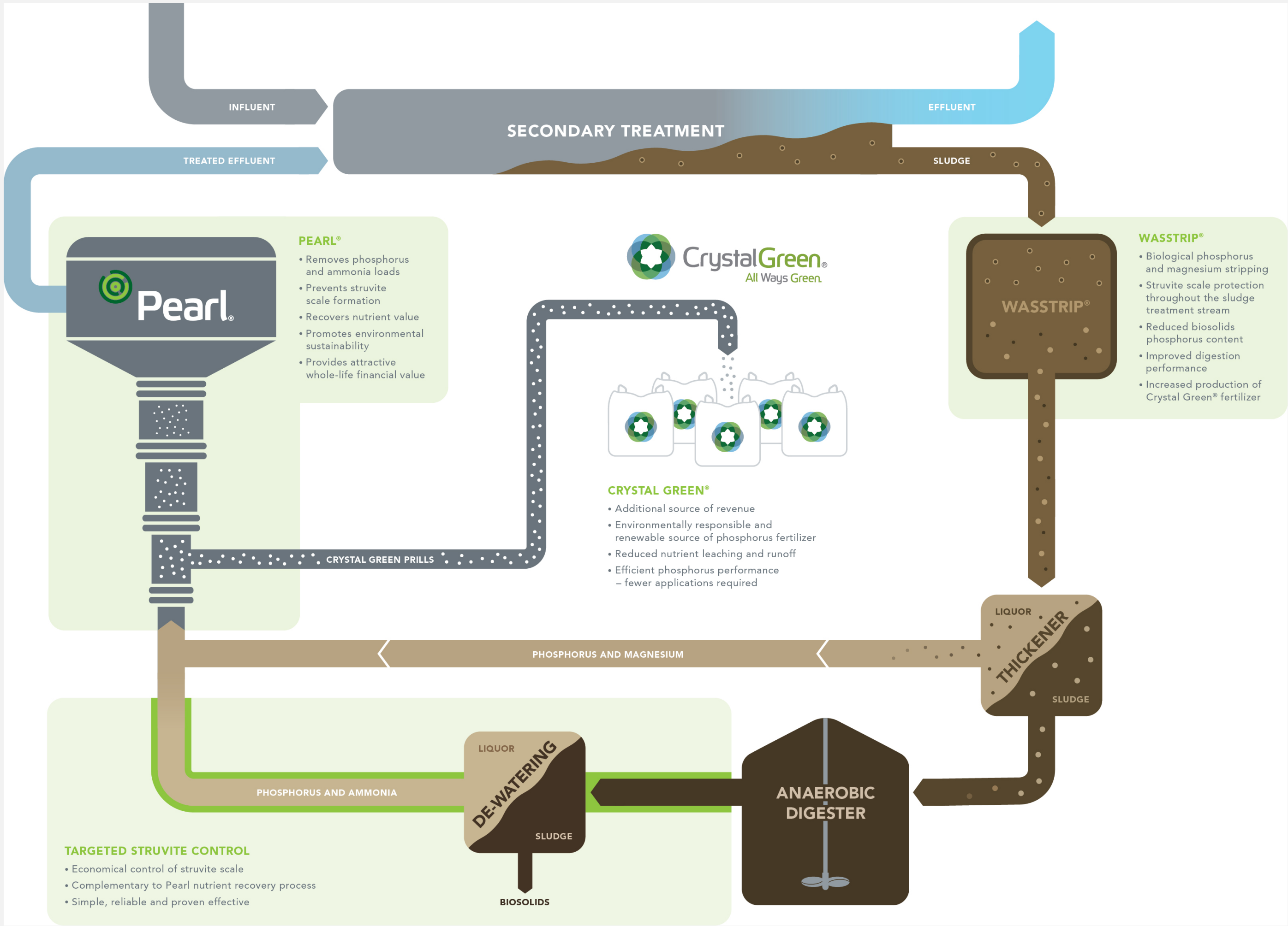
Nutrient Recovery Technology Considered for Comparison



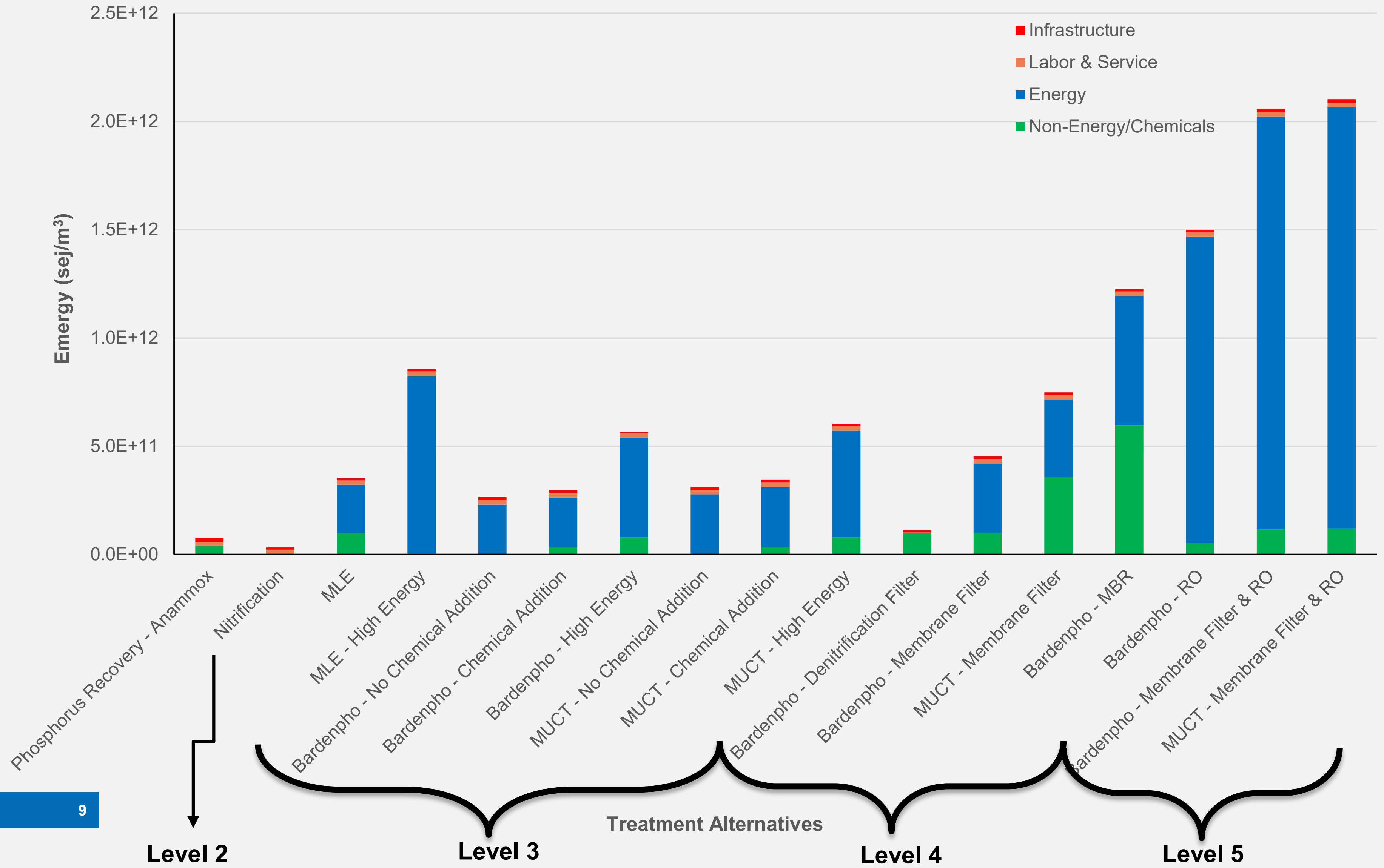
- In addition to Phosphorus precipitation, partial nitration anammox was considered for nitrogen reduction in the nutrient recovery alternative.

Nutrient Removal and Recovery Technology Considered in the Study

Treatment Level (Effluent Limits)	Nutrient Removal/Recovery Process	Energy (kWh/m³)	Influent Ammonia (mg/L as NH_3-N)	Influent P (mg/L as P)
Recovery	Phosphorus Recovery - Anammox	0.68*	799*	266.52*
Level 2 (TN – 8 mg/L, TP – 1 mg/L)	Nitrification	0.23	24	10
	MLE	0.28	23	8
	MLE - High Energy	0.59	32	8
	Bardenpho - No Chemical Addition	0.29	23	8
Level 3 (TN – 4-8 mg/L, TP – 0.1-0.3 mg/L)	Bardenpho - Chemical Addition	0.29	23	8
	Bardenpho - High Energy	0.58	22	5
	MUCT - No Chemical Addition	0.35	23	8
	MUCT - Chemical Addition	0.35	23	8
	MUCT - High Energy	0.561	22	5
	Bardenpho - Denitrification Filter	0.534	22	5
Level 4 (TN – 3 mg/L, TP – 0.1 mg/L)	Bardenpho - Membrane Filter	0.4	23	8
	MUCT - Membrane Filter	0.45	23	8
	Bardenpho - MBR	0.53	22	5
Level 5 (TN - <2 mg/L, TP <0.02 mg/L)	Bardenpho - RO	0.596	22	5
	Bardenpho - Membrane Filter & RO	2.4	23	8
	MUCT - Membrane Filter & RO	2.45	23	8

* Electricity and concentrated sludge nutrient concentration values are provided here, when diluted with wastewater volume, equivalent to influent levels shown for nutrient removal

Total Emergy Comparison between Different Nutrient Removal and Recovery Technology



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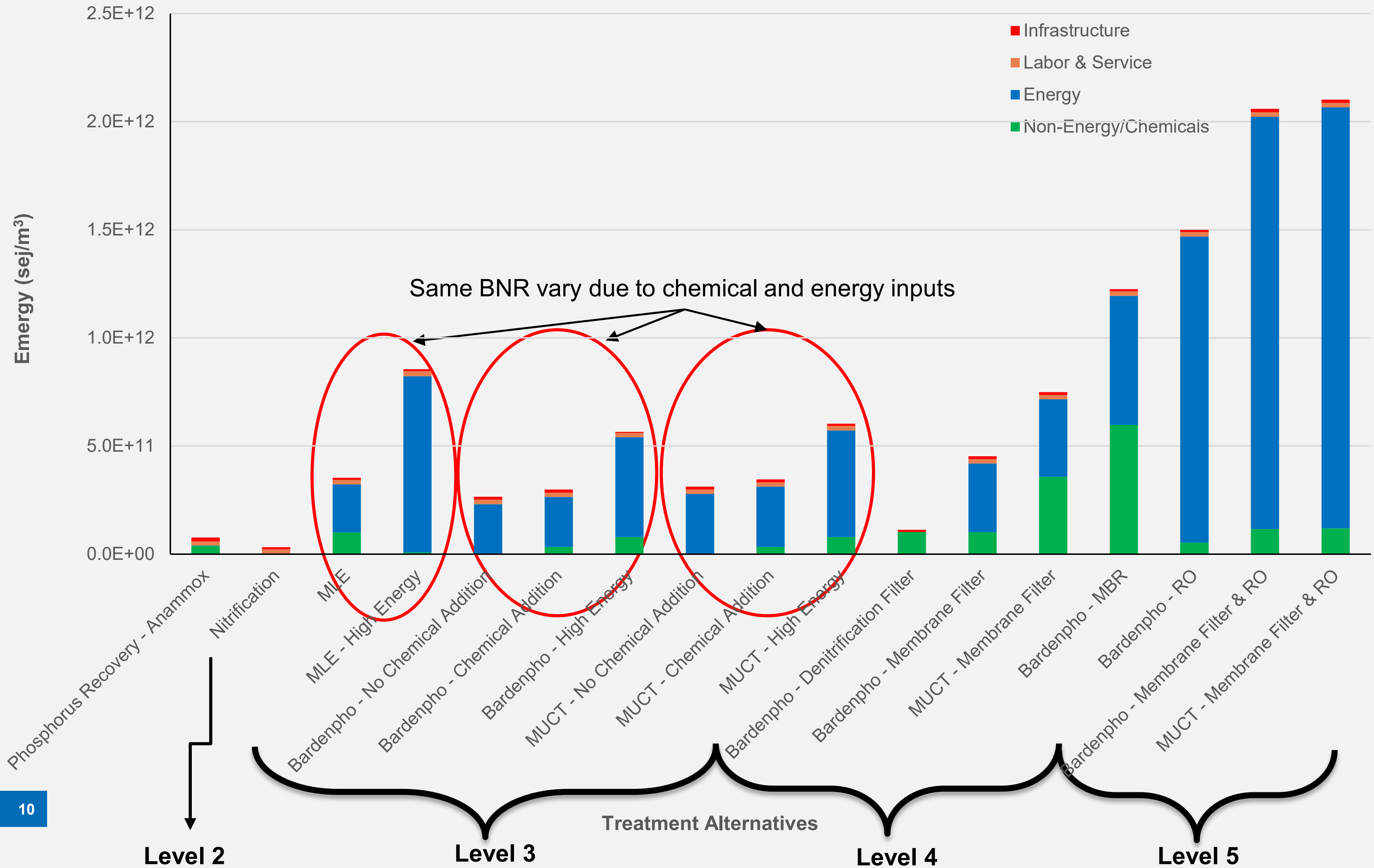

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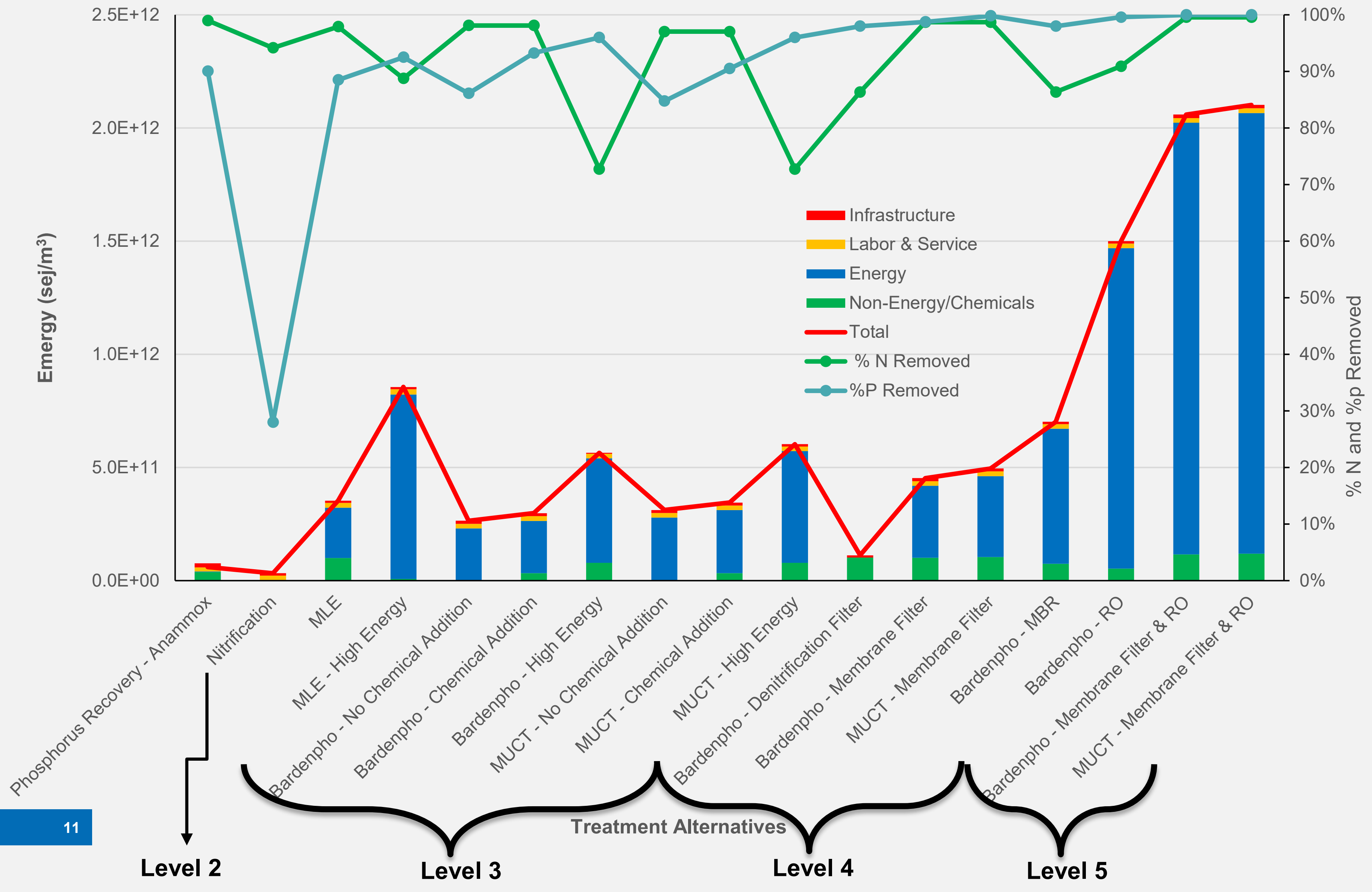

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Results and Discussions

- Stringent nutrient reduction regulations lead to trade-offs that need to be further evaluated to choose the most sustainable treatment alternative

- This study shows that avoiding additional nutrient removal treatment processes would be significant in summarizing the benefits of nutrient recovery process

- Emergy analysis justifies the nutrient recovery from wastewater sludge and provides a sound economic and ecological comparison of removal and recovery treatment alternative independent of the perceived monetary value

- Among the nutrient removal treatment alternatives, the study results show that the energy and non-energy (chemicals) inputs can lead to significant variation in emergy of the process

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Selected References

- Eastern Research Group, Inc. (2018). *Life Cycle and Cost Assessments of Nutrient Removal Technologies in Wastewater Treatment Plants*, Report Prepared for U.S.EPA (draft).

- Arden, S., Ma, X. and Brown, M. (2018) *Holistic Analysis of Urban Water Systems in the Greater Cincinnati Region: (2) Resource Use Profiles by Emergy Accounting Approach*. Submitted to Environmental Science and Technology (ES&T).

- Rahman, M.S., Eckelman, J.M., Onnis-Hayden, A. and Gu, A.Z.(2016) *Life-Cycle Assessment of Advanced Nutrient Removal Technologies for Wastewater Treatment*. Environmental Science and Technology, 50, pp 3020 - 3030

- Foley, J., de Haas, D., Hartley, K. and Lant, P. (2010) *Comprehensive life cycle inventories of alternative wastewater treatment systems.* Water Research, 44, pp 1654 – 1666.

- Odum, H.T. Environmental accounting. John Wiley & Sons: New York, 1996.

- Brown, M. T., Campbell, D. E., De Vilbiss, C., Ulgiati, S. (2016) *The Geobiosphere Emergy Baseline: A Synthesis.* Ecological Modelling.

- Fux, C. and Siegrist, H. (2004). *Nitrogen removal from sludge digester liquids by nitrification/denitrification or partial nitritation/anamox: environmental and economical considerations.* Water Science and Technology. 10, pp. 19-26

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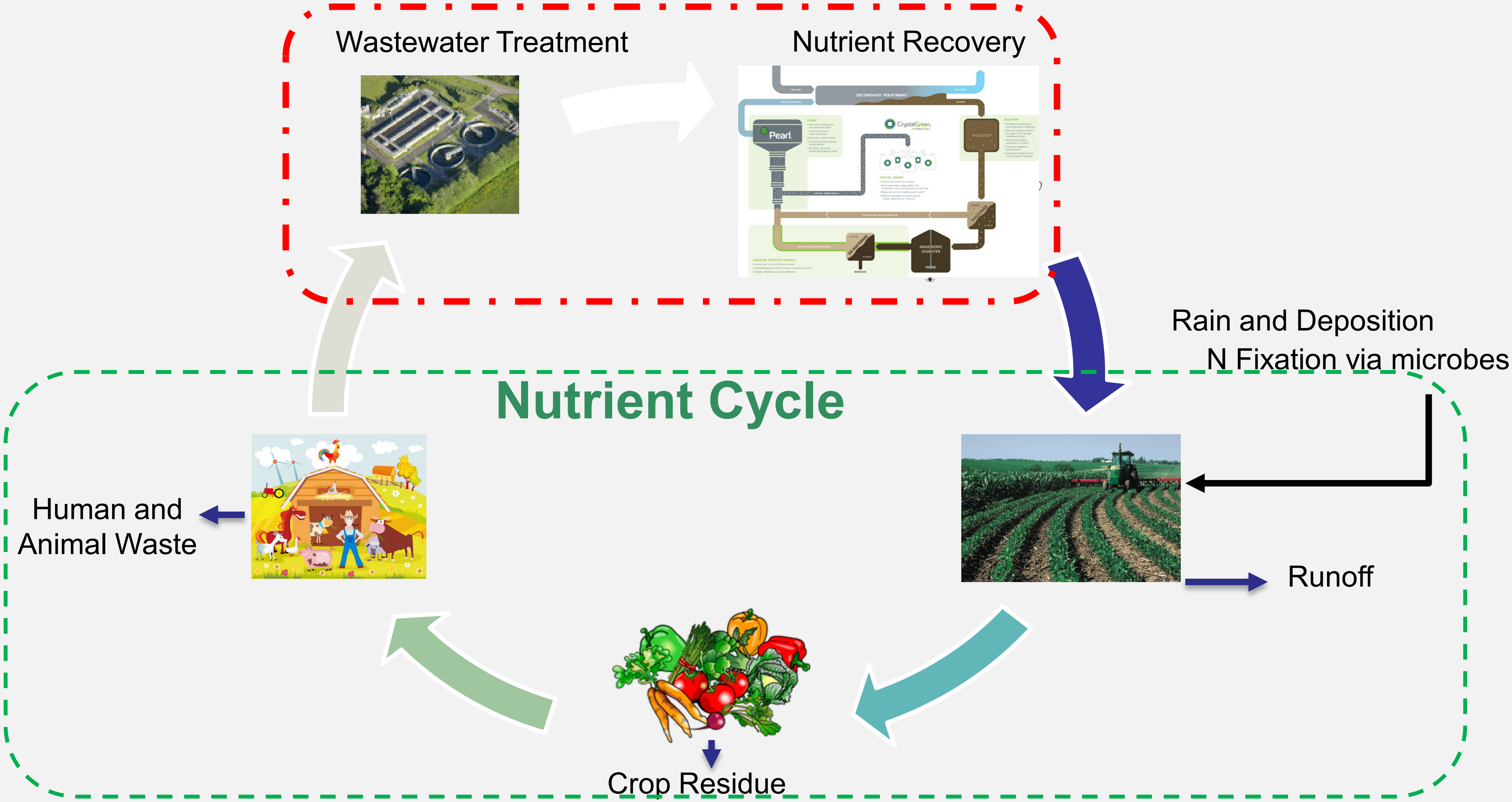
Future or Continued Work



Account for the benefits of nutrient recovery via efficient use of the struvite fertilizer and the flow of N and P nutrients in the food system, the economic, environmental and societal benefits of struvite recovery would be more perceptible.

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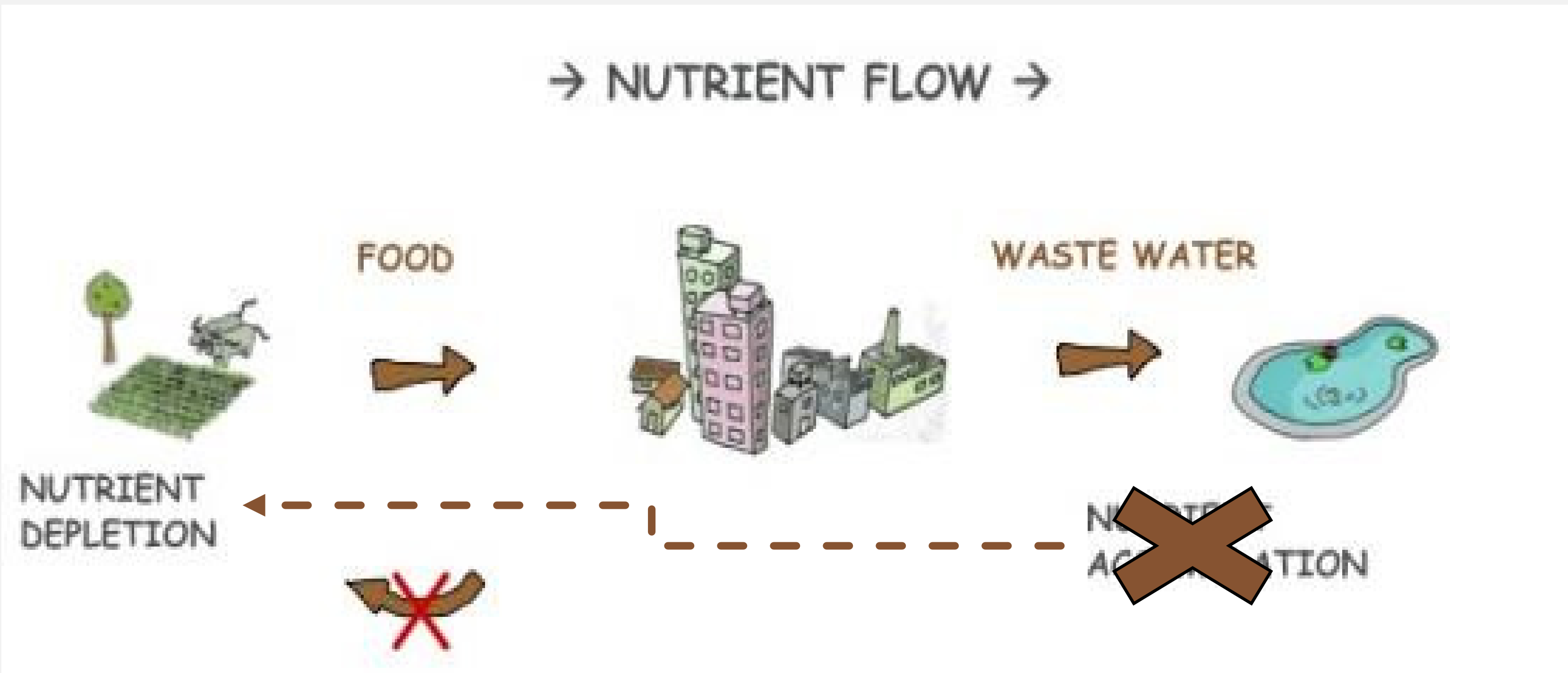
Thank you! Questions?



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Background Slides

Modified Ludzack Ettinger Process