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Linkages: Water and Renewable Energy

Recovering Ammonia for Hydrogen Biofuel Production during Anaerobic Digestion

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- Contributors
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  - Miss Liang Chen
- Collaborators
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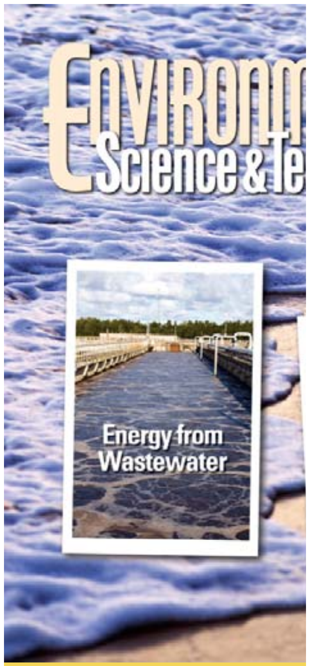
Dr. David Babson

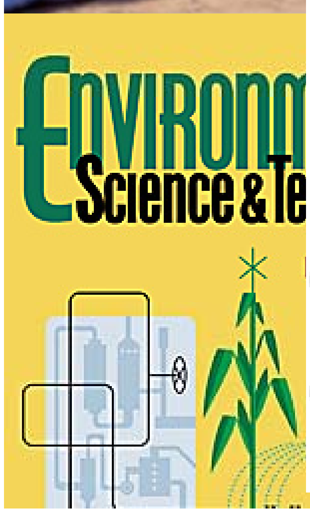
Prof. Shaurya Prakash
The Ohio State University

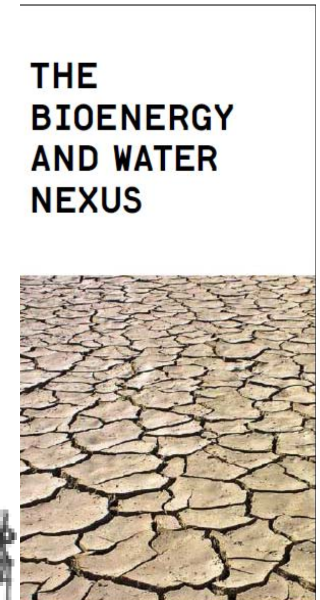
Background

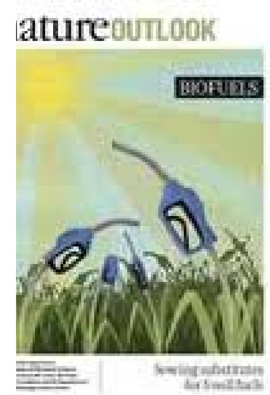
Water and Renewable Energy

Renewable energy efforts may have unforeseen environmental consequences for local water supplies and wastewater treatment systems.









We need to be (more) sustainable…

CSI: Environment

Anaerobic Digestion

Advantages

- Established technology for many wastes
  - sludges, solid waste, manures, food and crop wastes
- Scalable
- Methane has existing infrastructure/end uses

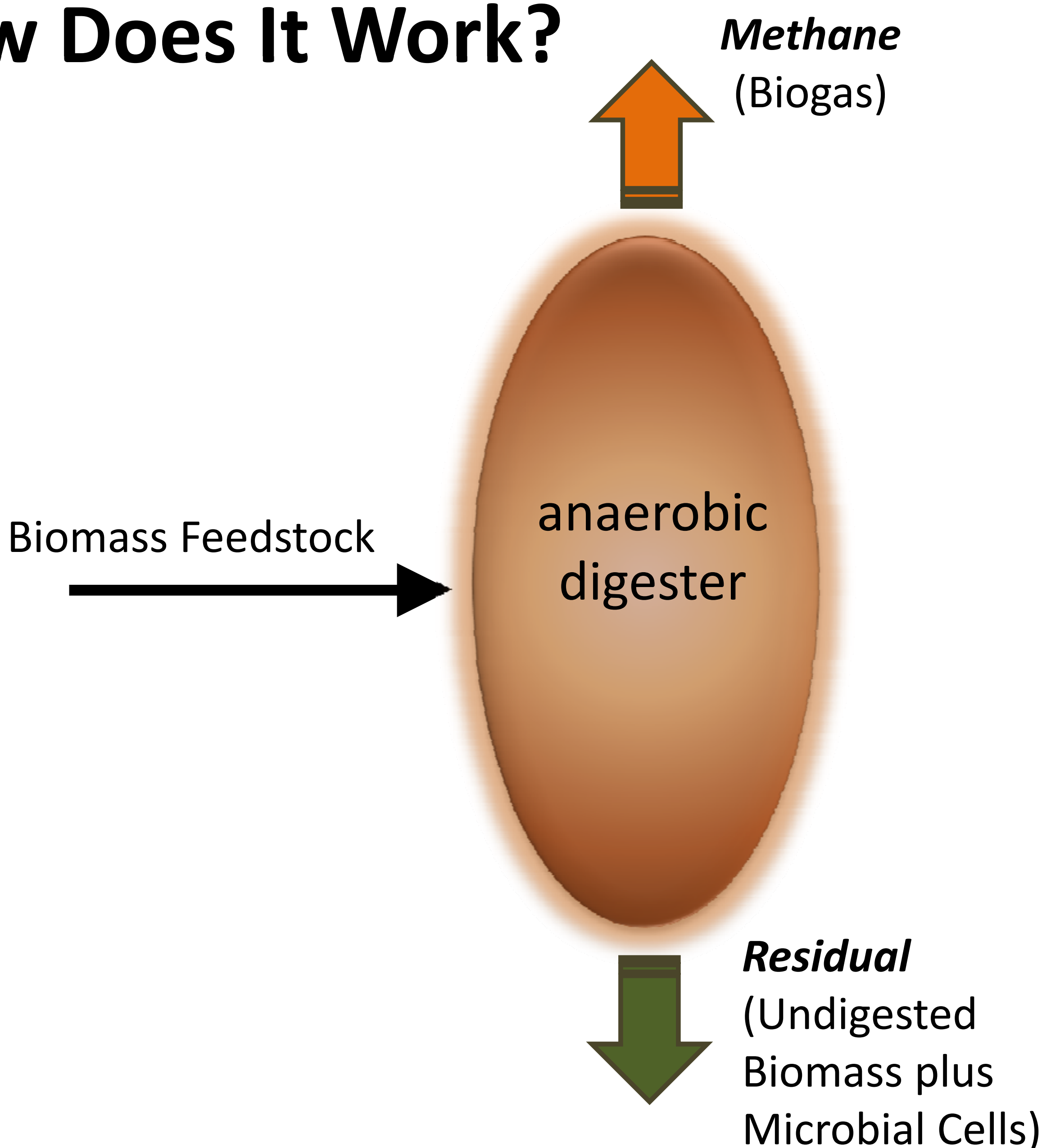
Disadvantages

- Conversion efficiency is low
- Process can be finicky
- N and P are liberated
- Residuals need further treatment and disposal

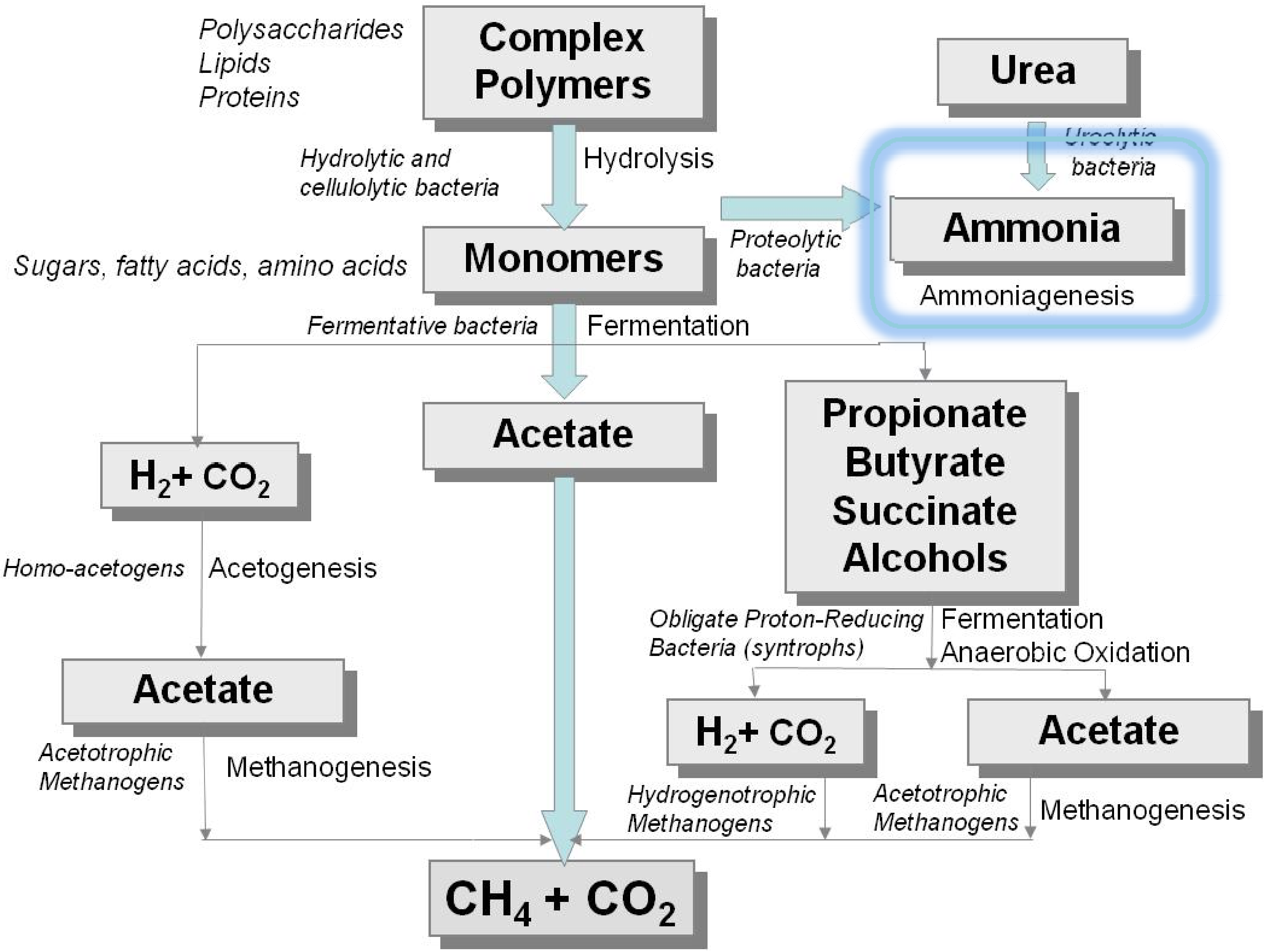
Low Tech

High Tech

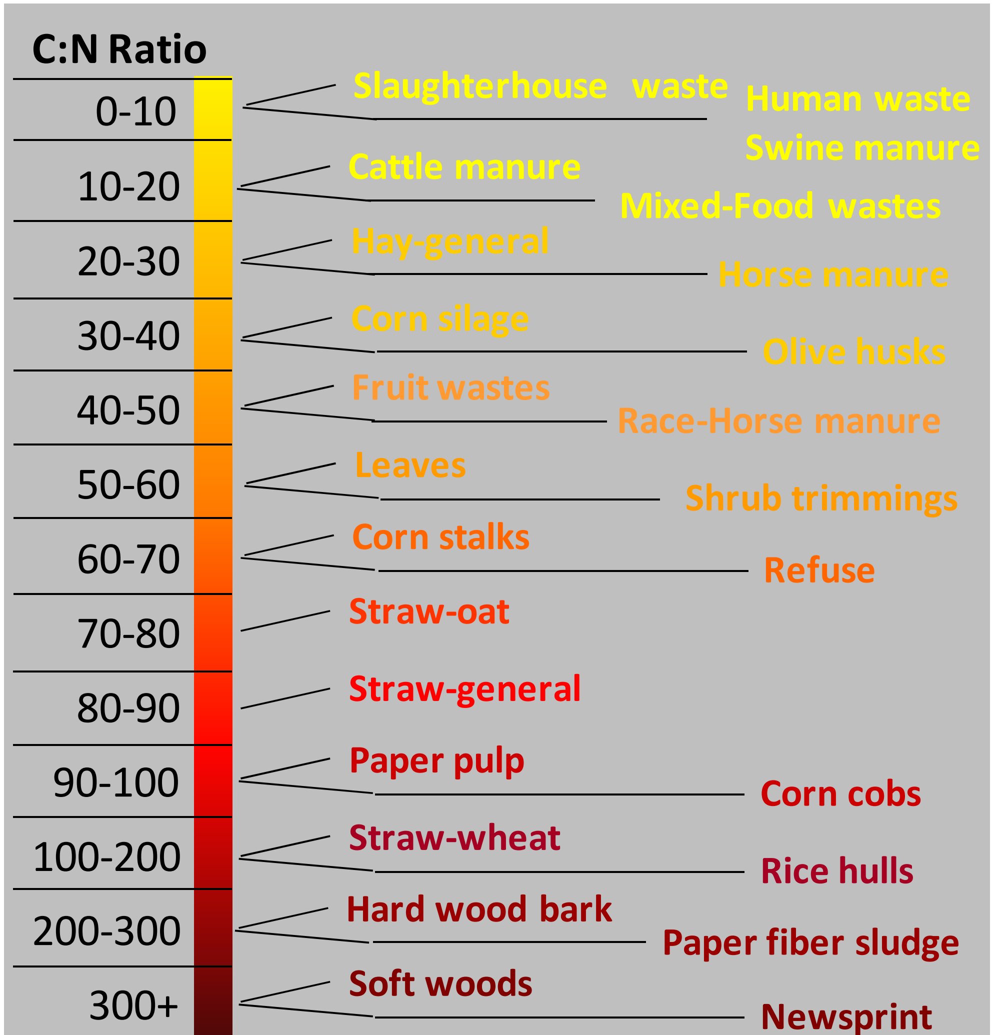
How Does It Work?



Anaerobic Digestion of Biomass



Ammonia and C:N Ratio



After: On-farm Composting Handbook. Cornell. Characteristics of Raw Materials http://compost.css.cornell.edu/OnFarmHandbook/apa.taba1.html

- Ammonia released is a function of the organic nitrogen in the feedstock
- The C:N ratio is the ratio of carbon to nitrogen (g/g)

C:N Ratio and Ammonia Toxicity

- As C:N ratio↓ the total ammonia nitrogen (TAN) ↑
- TAN as low as 1.5 g/L may inhibit digester microbial communities
- To control ammonia toxicity
  - Increase feedstock C:N
  - Remove ammonia

Ammonia/Ammonium

$$NH_3 + H^+ \leftrightarrow NH_4^+$$

Total Ammonia-N (TAN)

$$NH_3 + NH_4^+$$

The Nitrogen Cycle

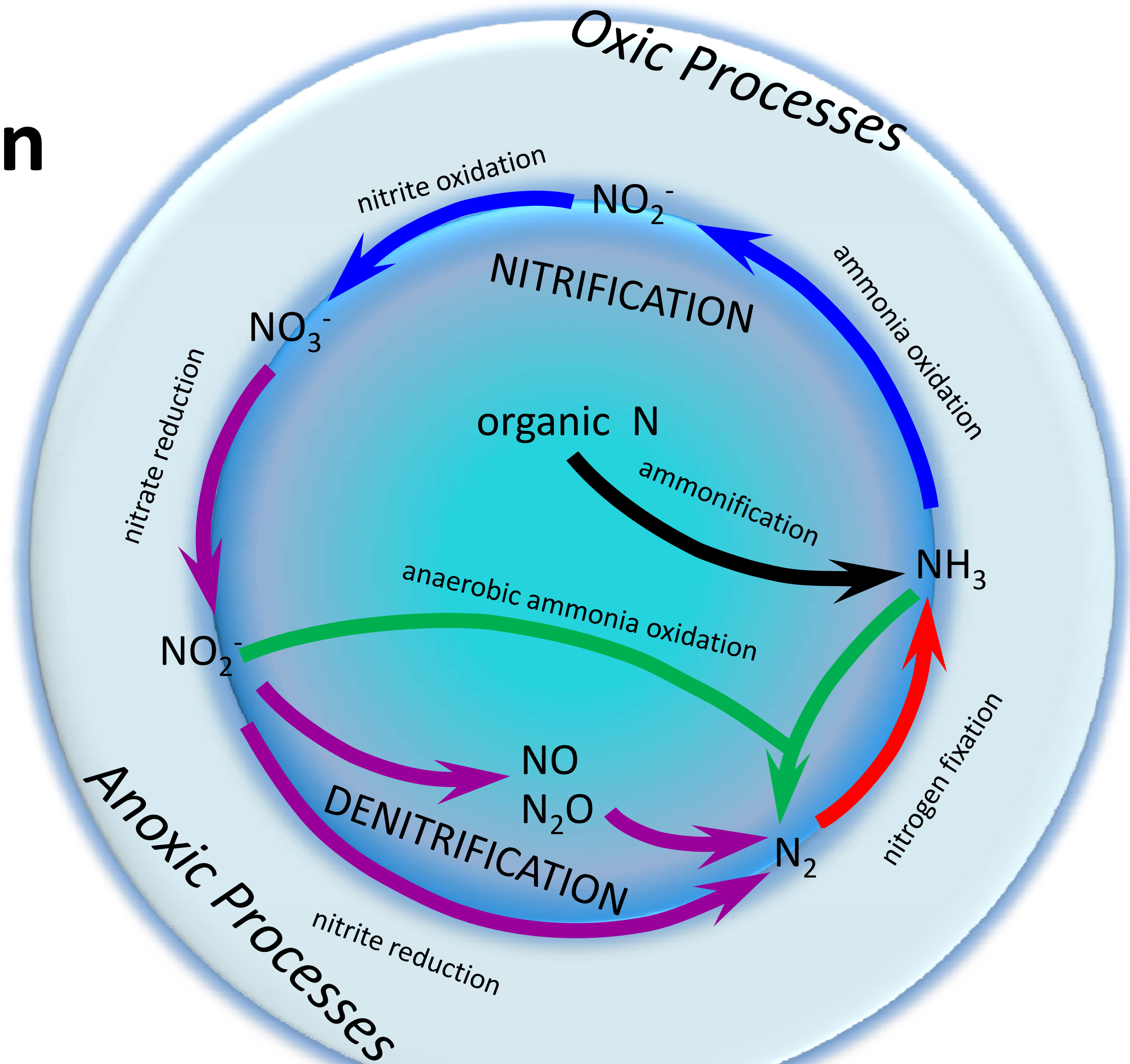
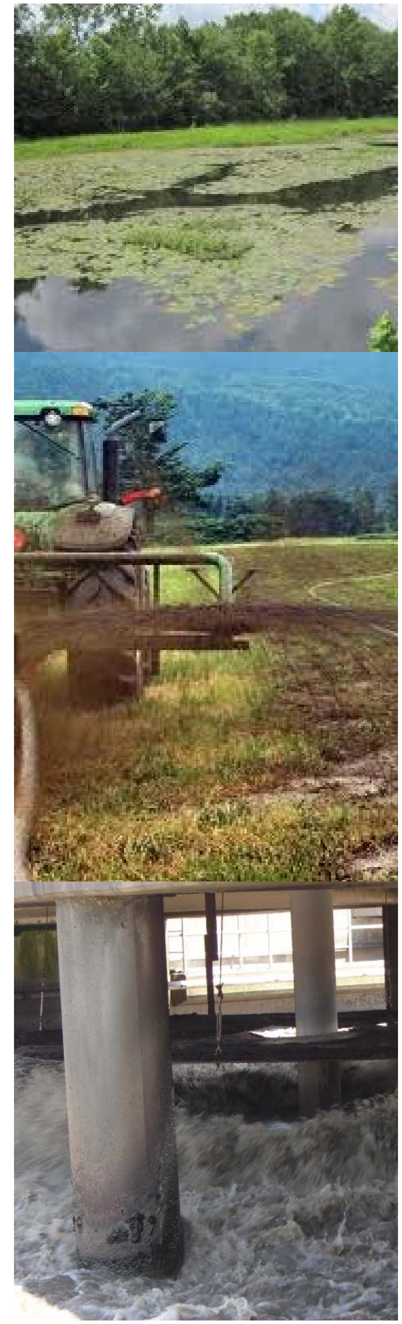


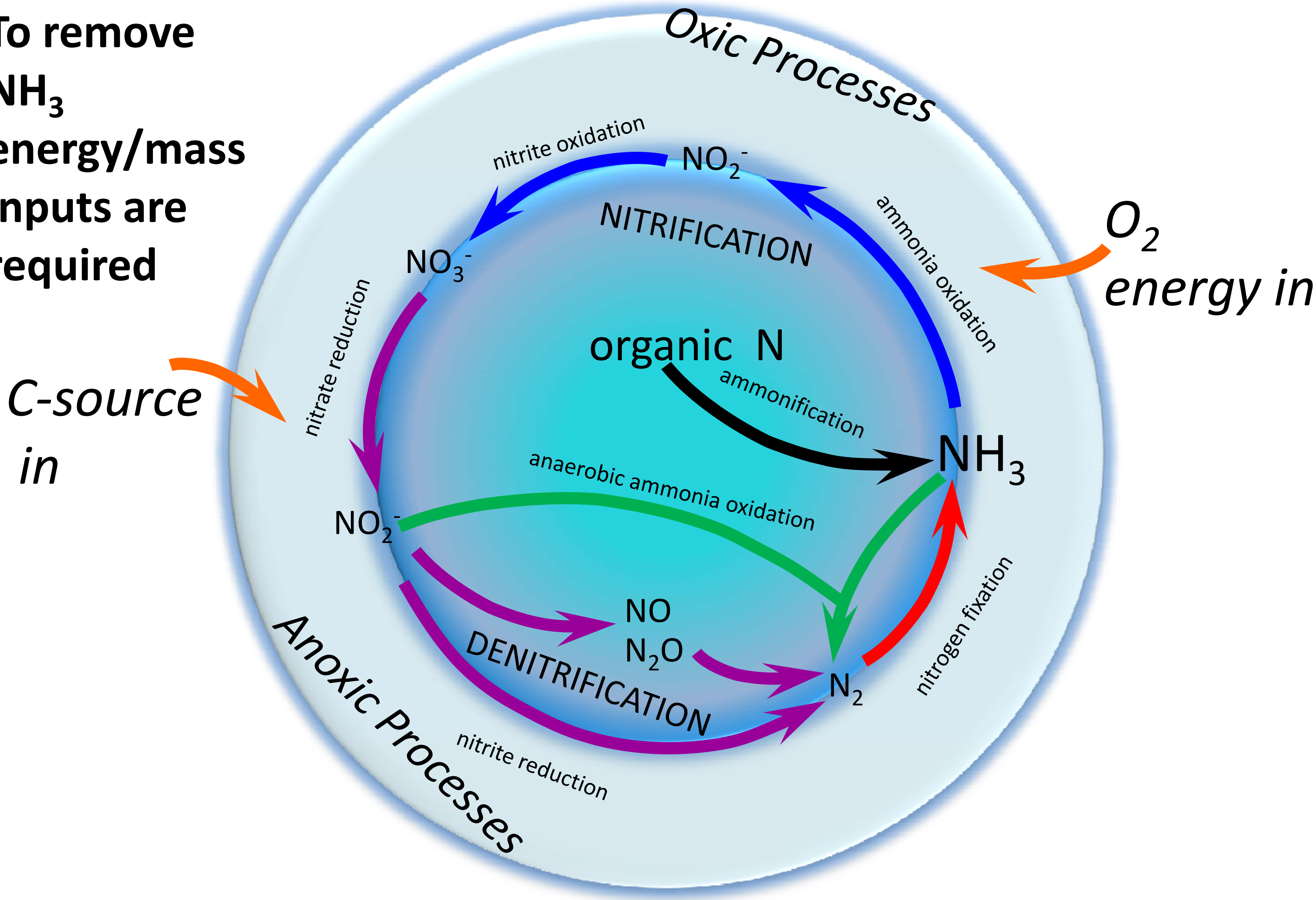
Image modified from

Ammonia

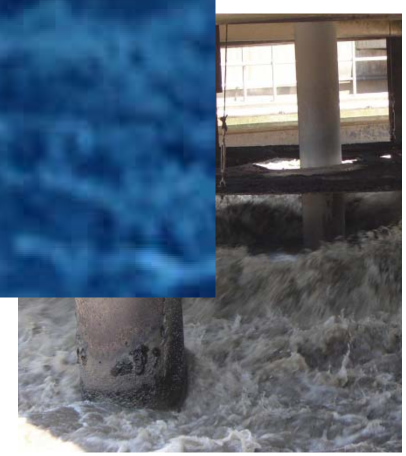
- Ammonia causes eutrophication and is toxic to aquatic life, so it must be carefully managed
  - Used as a fertilizer
  - Treated/removed
- In population centers far from agricultural systems, use as fertilizer may not be economical or energy efficient
  - Net food importers
  - Net nutrient importers
- Traditional treatments are aerobic, energy intensive processes



To remove NH_3 energy/mass inputs are required

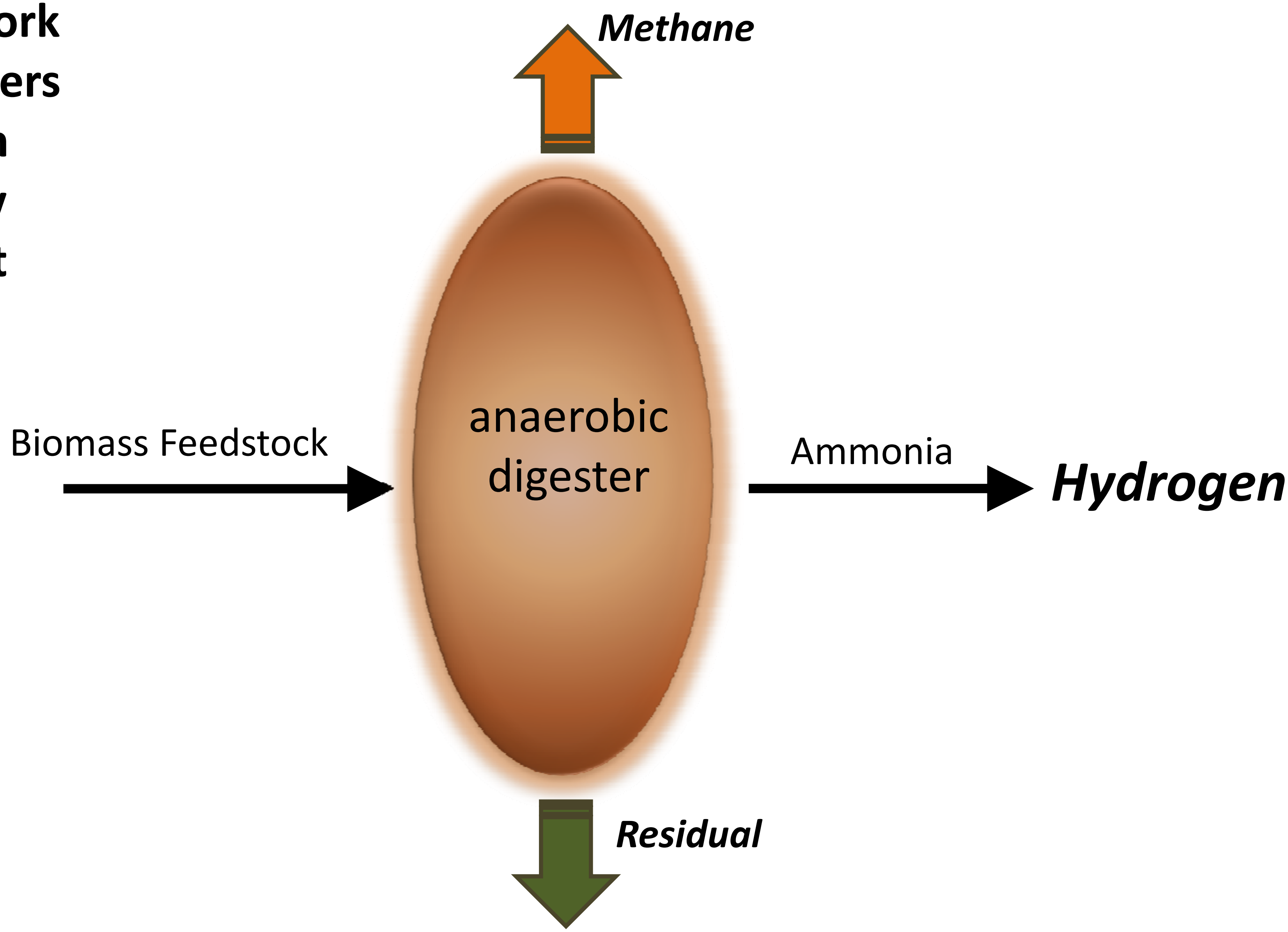


Aerobic Treatment to Remove Ammonia



Is There Another Way?

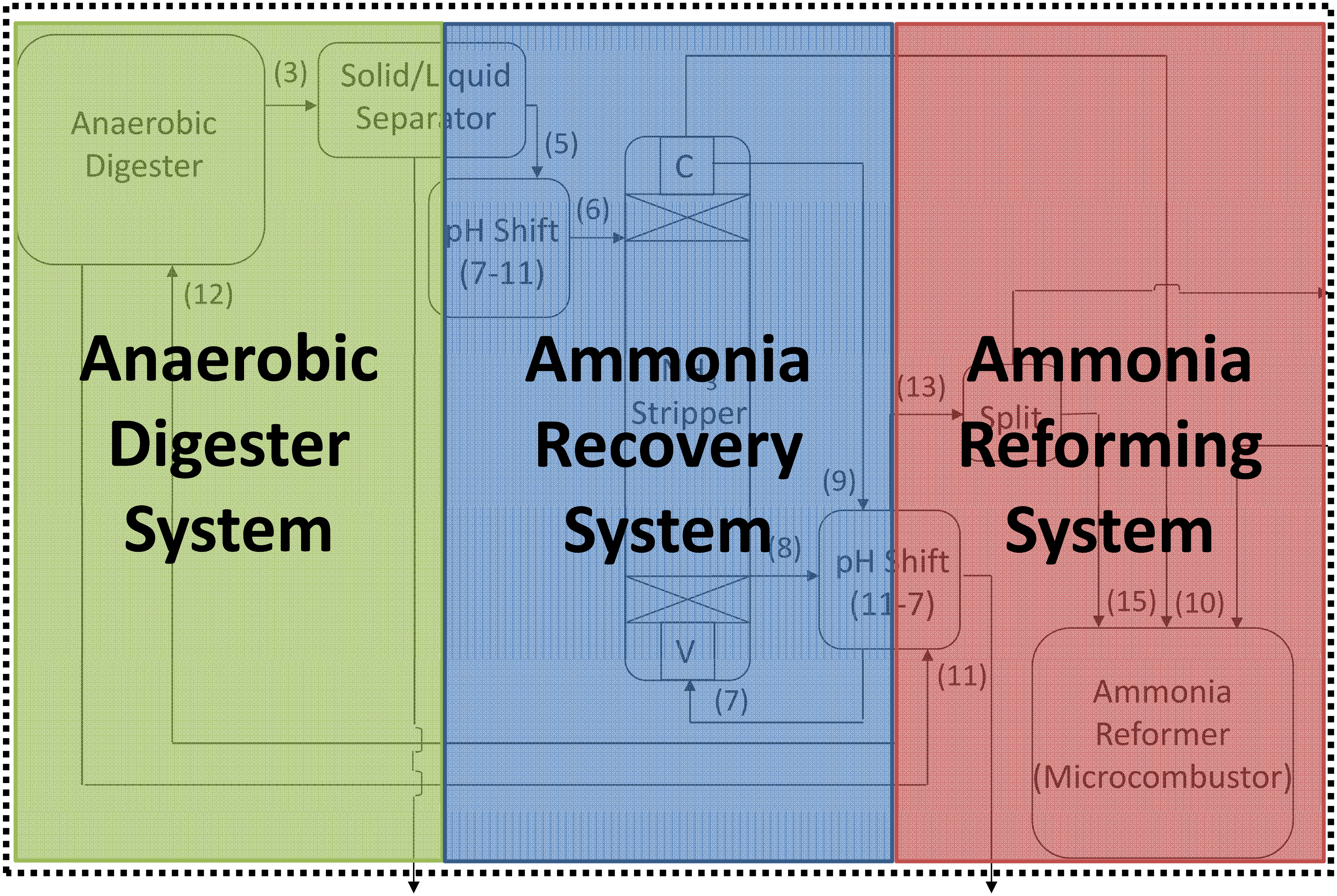
Our work considers NH_3 an energy output



Anaerobic Digestion Bioammonia to Hydrogen (ADBH) System

- Could bioammonia liberated during anaerobic degradation of biomass be converted to hydrogen, as part of an integrated anaerobic digestion system?
- Is the energy balance favorable for this process?
- Establish theoretical design and conduct energy balance

ADBH System: Three Integrated Systems

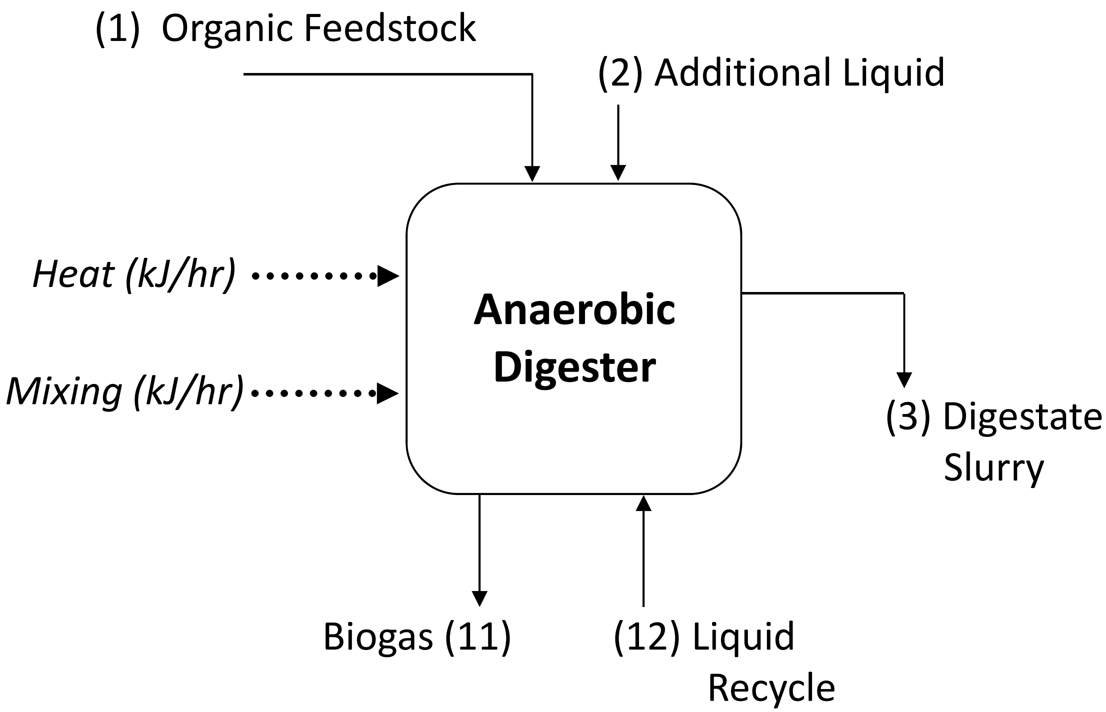


Trial Variable Inputs

Parameter Description	Input Value
Dry-Solids Flow	1,000 kg/hr
Degradable Organic Fraction (DOF)	0.80
Moisture Content (wt.% water)	90.0%
Aqueous Ammonium Loading	100 mg NH_4^+-N/L
Percent Recycle	65.0%
Ambient-Digester Temperature Difference	40.0 K
Internal Heat and Power Efficiency	0.35
C:N Ratio	**Variable (3.0 to 136)**

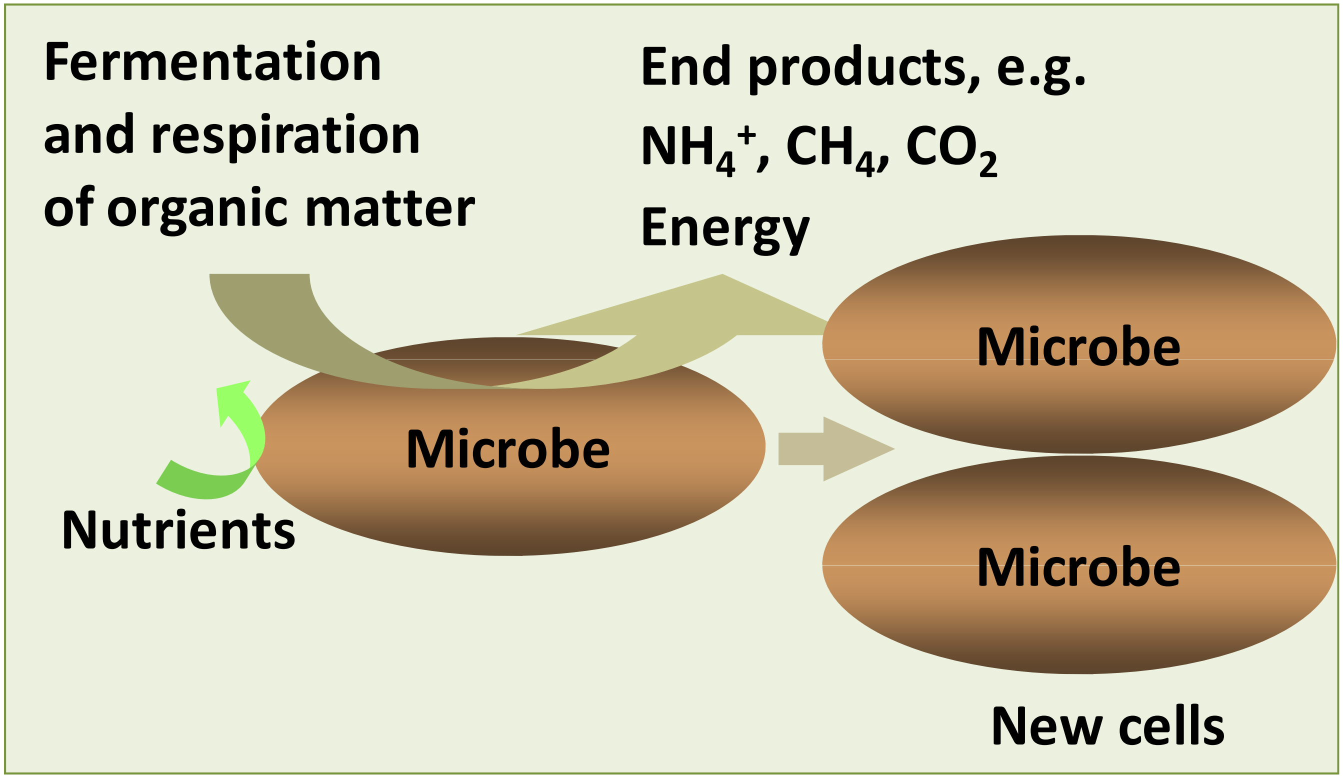
ADBH System: Anaerobic Digester

Inputs and Outputs



- Energy
  - Heat
    - Influent heating
    - Heat loss across the digester boundary
  - Mixing

Stoichiometry of Biomass Conversion



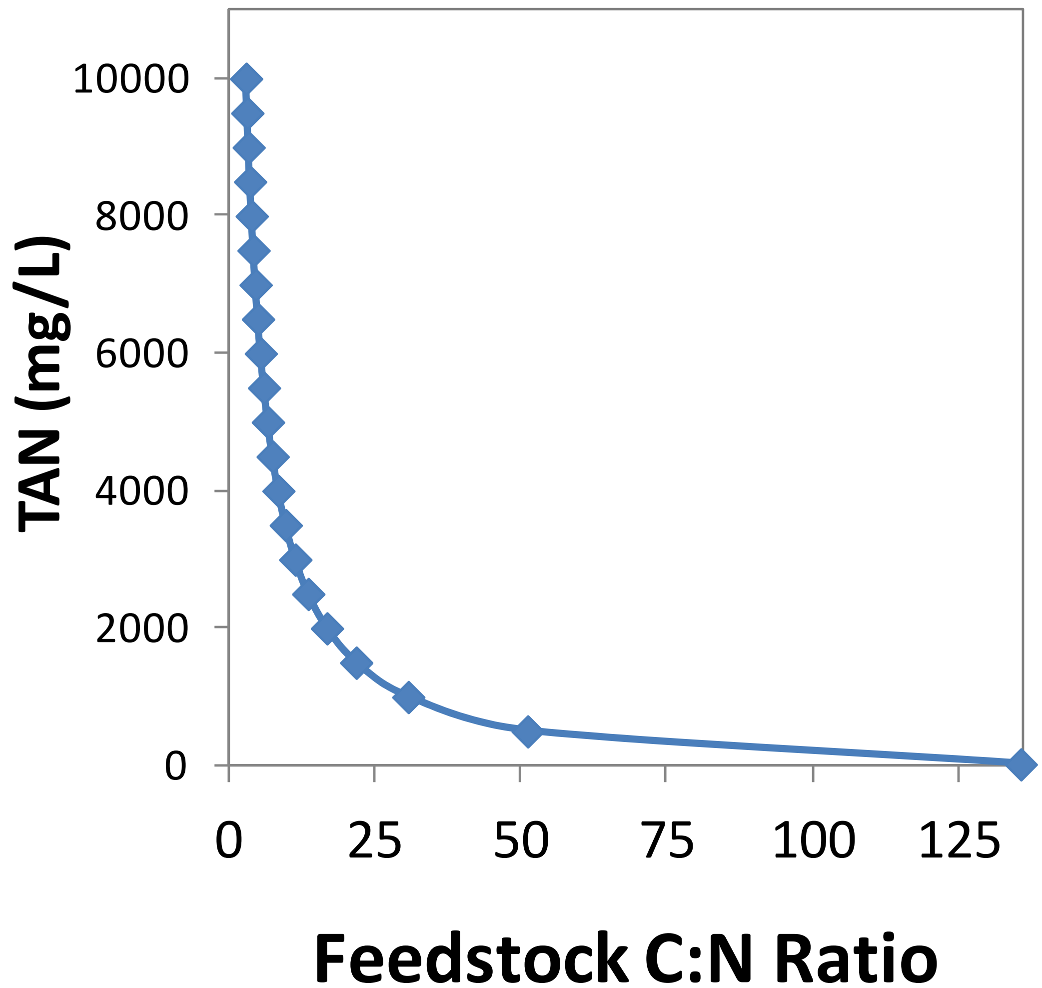
Overall Stoichiometry

$C_aH_bO_cN_d$ + (2a + d – c – 0.45·e·f_s – 0.25·e·f_e) H_2O $\rightarrow$

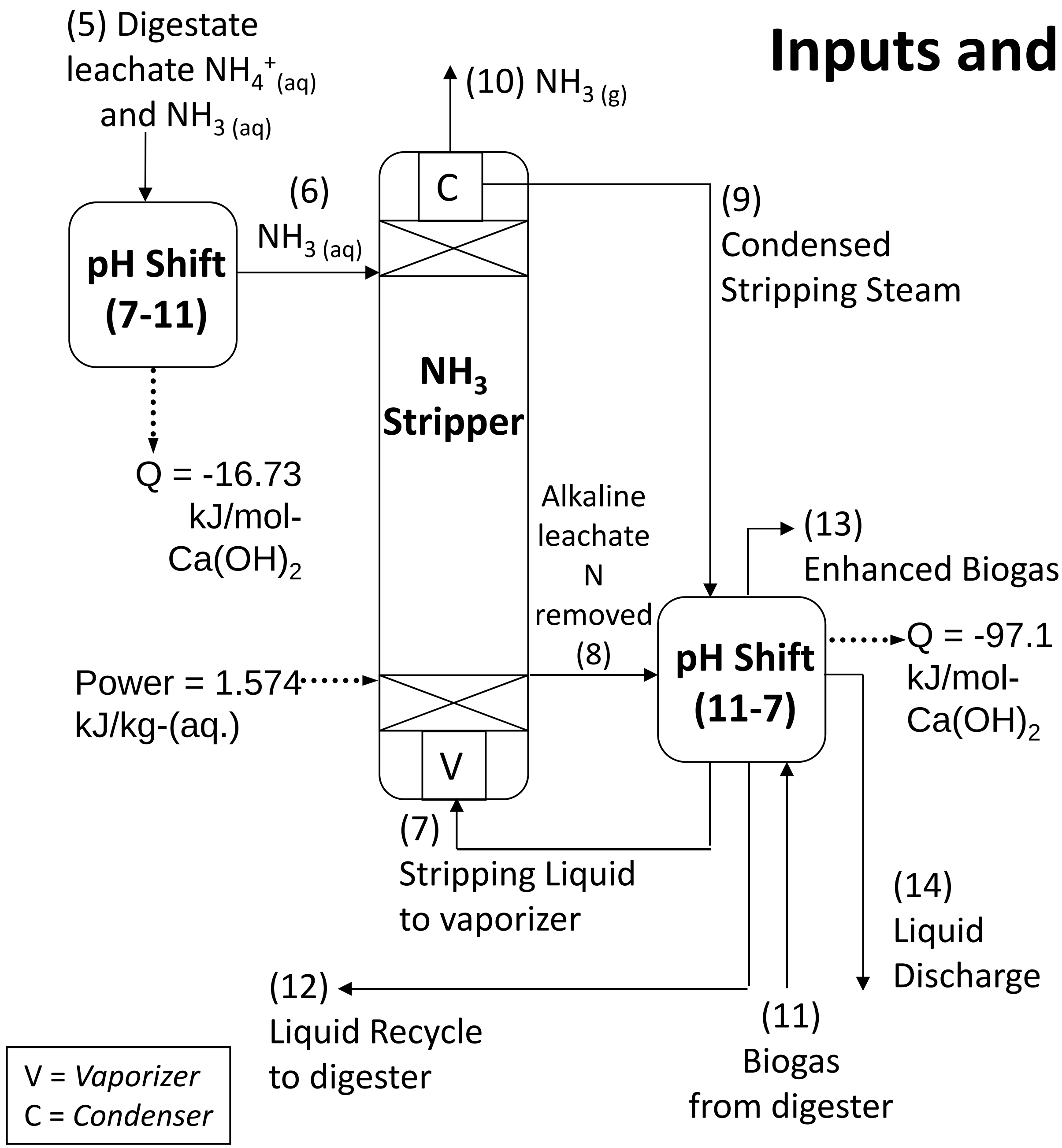
(0.125·e·f_e) CH_4 + (a – c – 0.2·e·f_s – 0.125·e·f_e) CO_2 + (0.05·e·f_s) $C_5H_7O_2N$

+ (d – 0.05·e·f_s) NH_4^+ + (d – 0.05·e·f_s) HCO_3^-

C:N Ratio and TAN



ADBH: Ammonia Recovery System



Inputs and Outputs

- Energy
  - Stripping power
  - Mixing enthalpy in pH-shift reactors
  - Velocity gradient mixing in pH-shift reactors

ADBH: Ammonia Reforming System

- Chemistry
  - Combustion to heat catalyst $CH_4 + 2\ O_2\ (Air) \rightarrow CO_2 + 2\ H_2O$
  - Reforming $2\ NH_{3\ (g)} \rightarrow N_{2\ (g)} + 3\ H_{2\ (g)}$

Consume some methane from biogas…

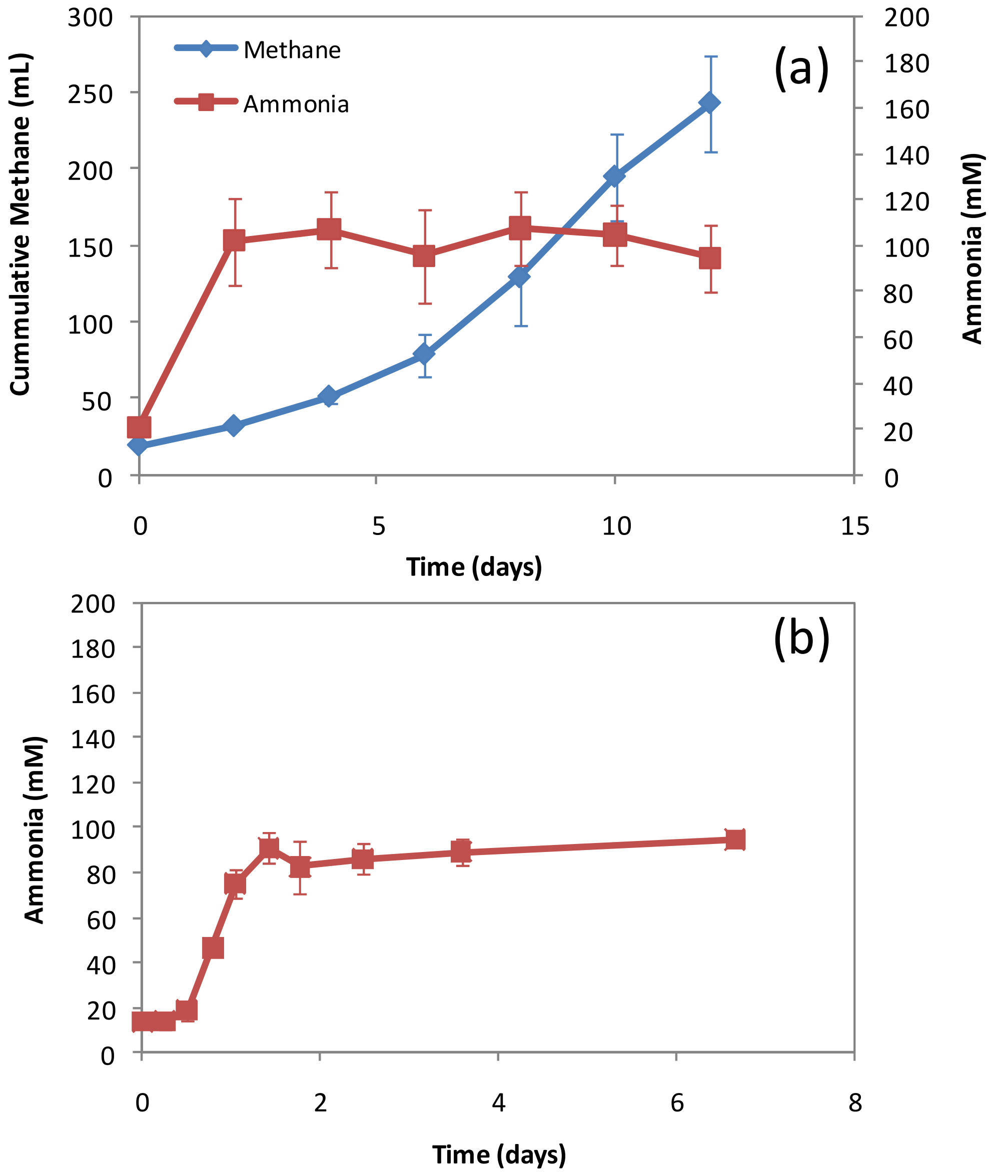
…to remove ammonia and

… produce hydrogen biofuel

Conclusion

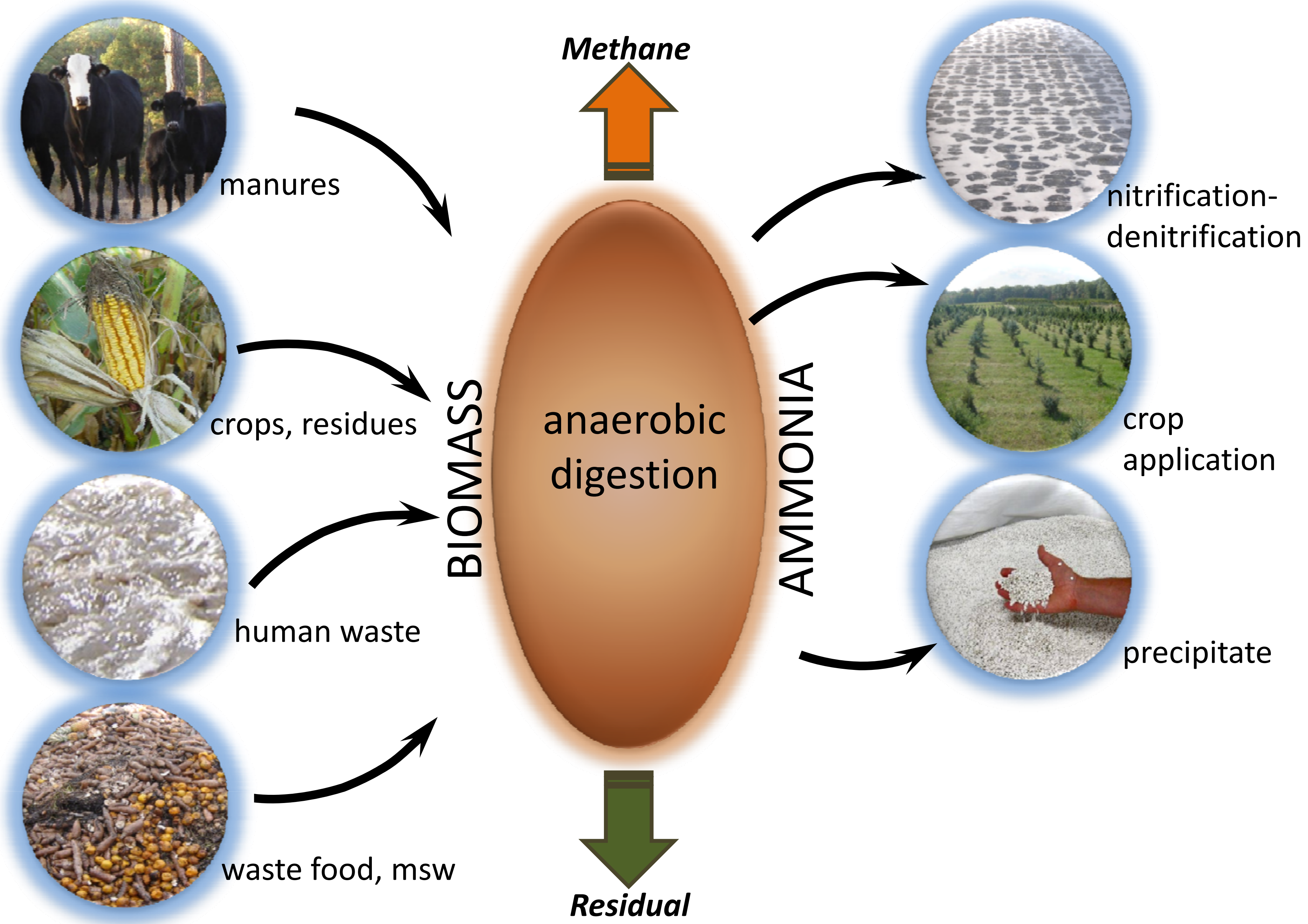
- The bioammonia to hydrogen process could increase the total energy recovery compared to the methane potential alone for digesters operated with feedstocks with C:N ratios less than ~17

Ammonia Release During Digestion



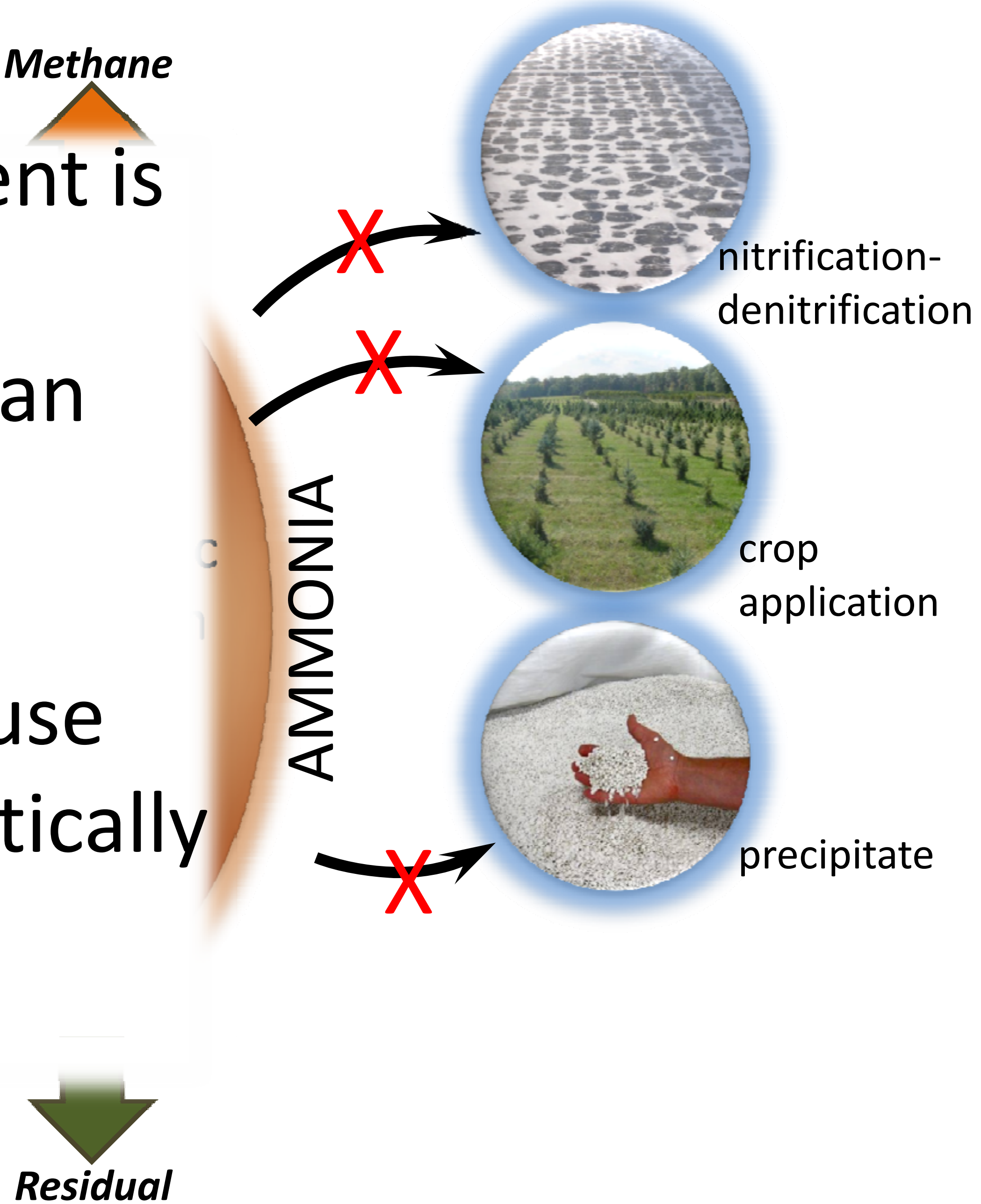
Ammonia is released rapidly from proteins and urea

Implications



Implications

- Traditional treatment is expensive
- For urban / suburban centers far from land/crop nutrient demand, fertilizer use may not be energetically or economically favorable



Implications

- A new paradigm considers waste ammonia as an energy source