RESOURCE RECOVERY FROM FECAL SLUDGE
AN ELEMENTAL APPROACH

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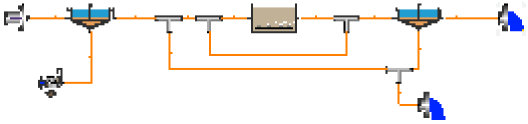
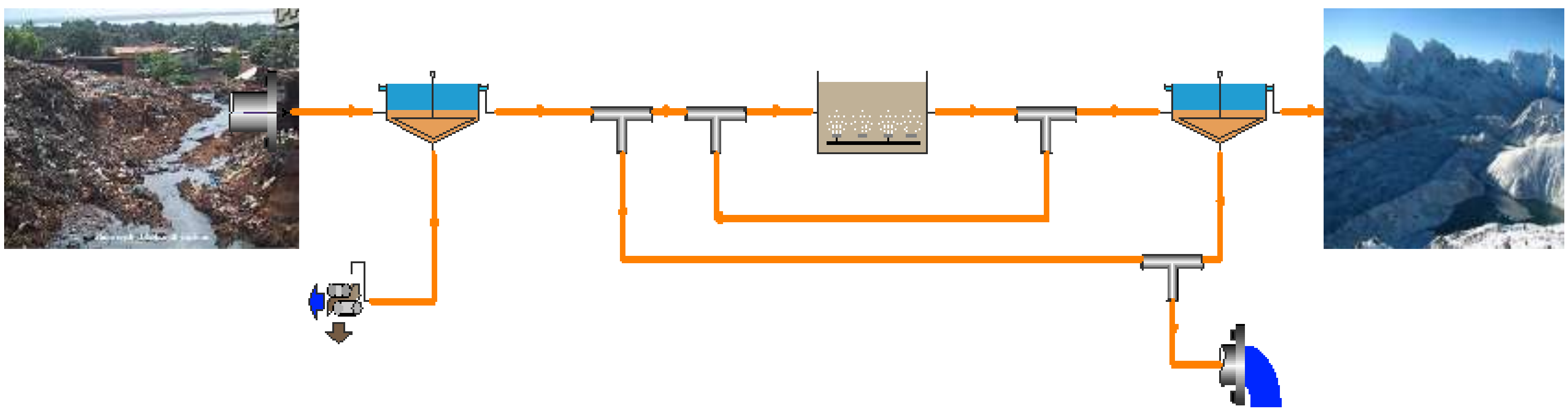
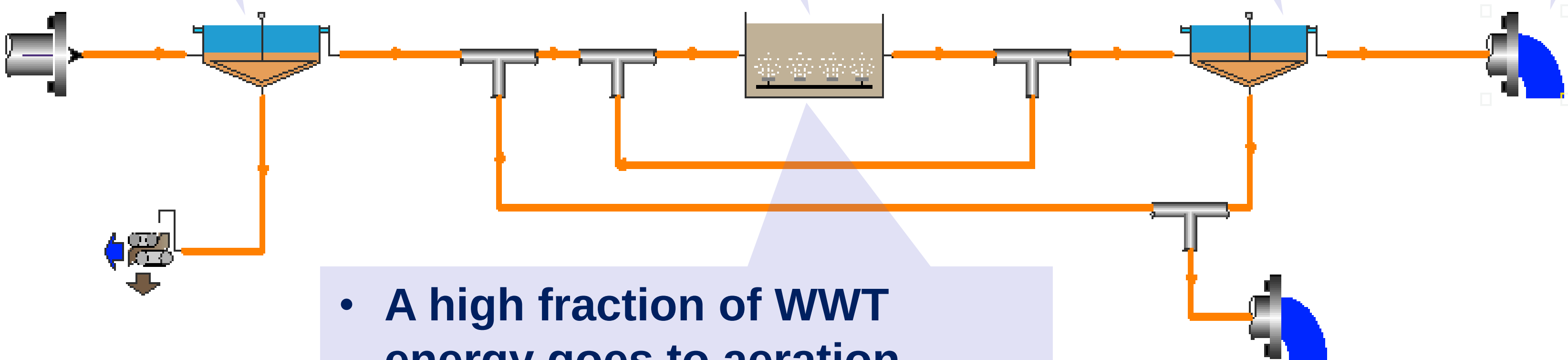
Columbia University



Fecal Sludge management Conference, Durban,
October 30th, 2012

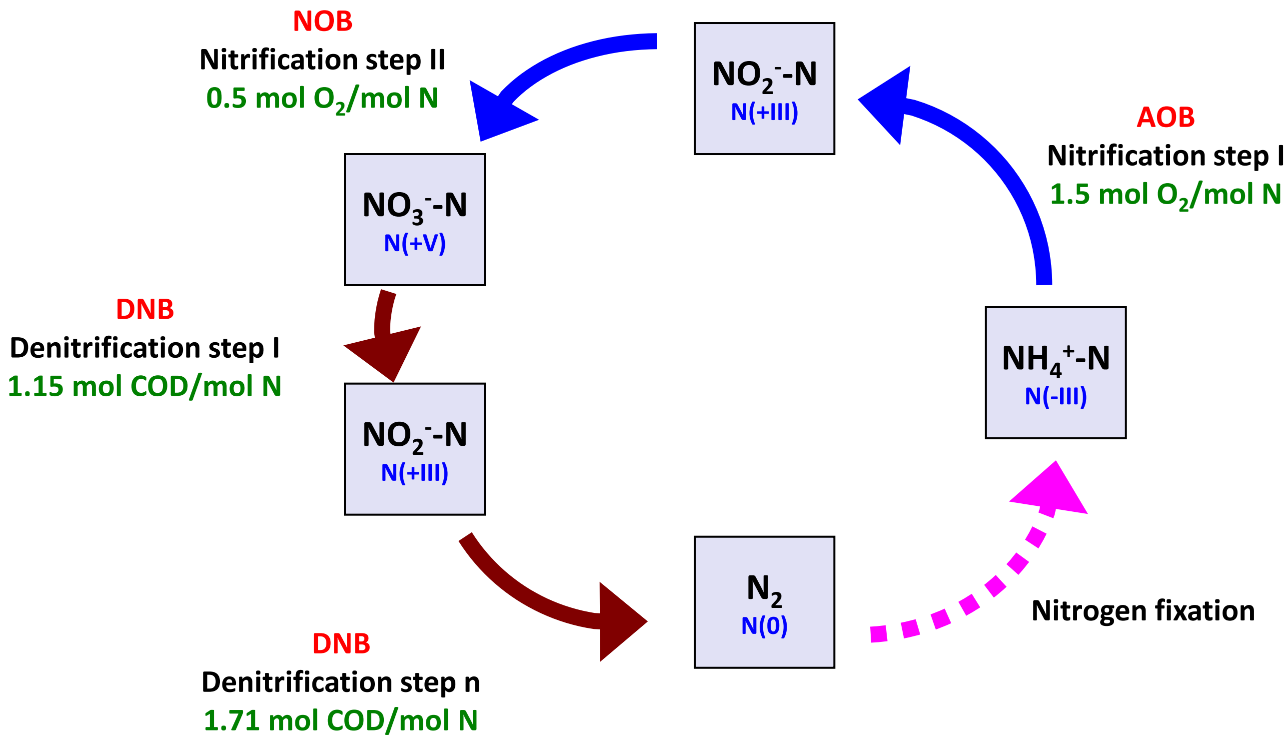


Brief overview of biological treatment

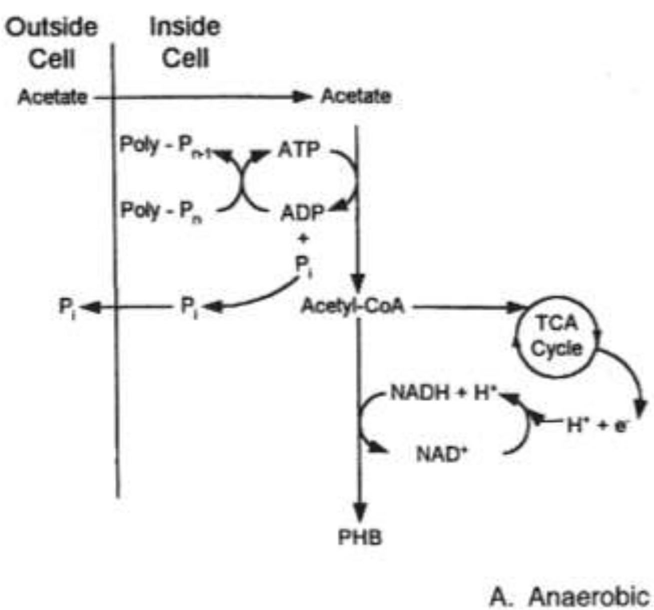


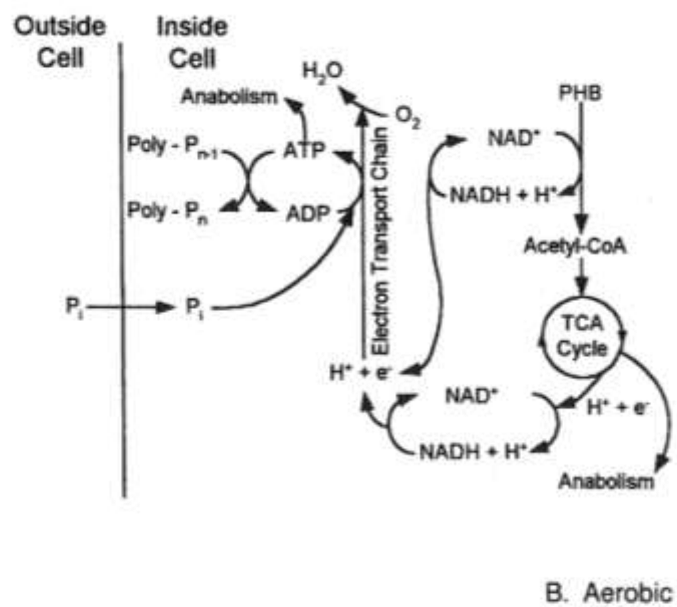
- A high fraction of WWT energy goes to aeration
- $MM in organic chemical purchase
- Bacteria could produce unwanted products (N_2O)

Biological N-removal



Biological phosphorous removal

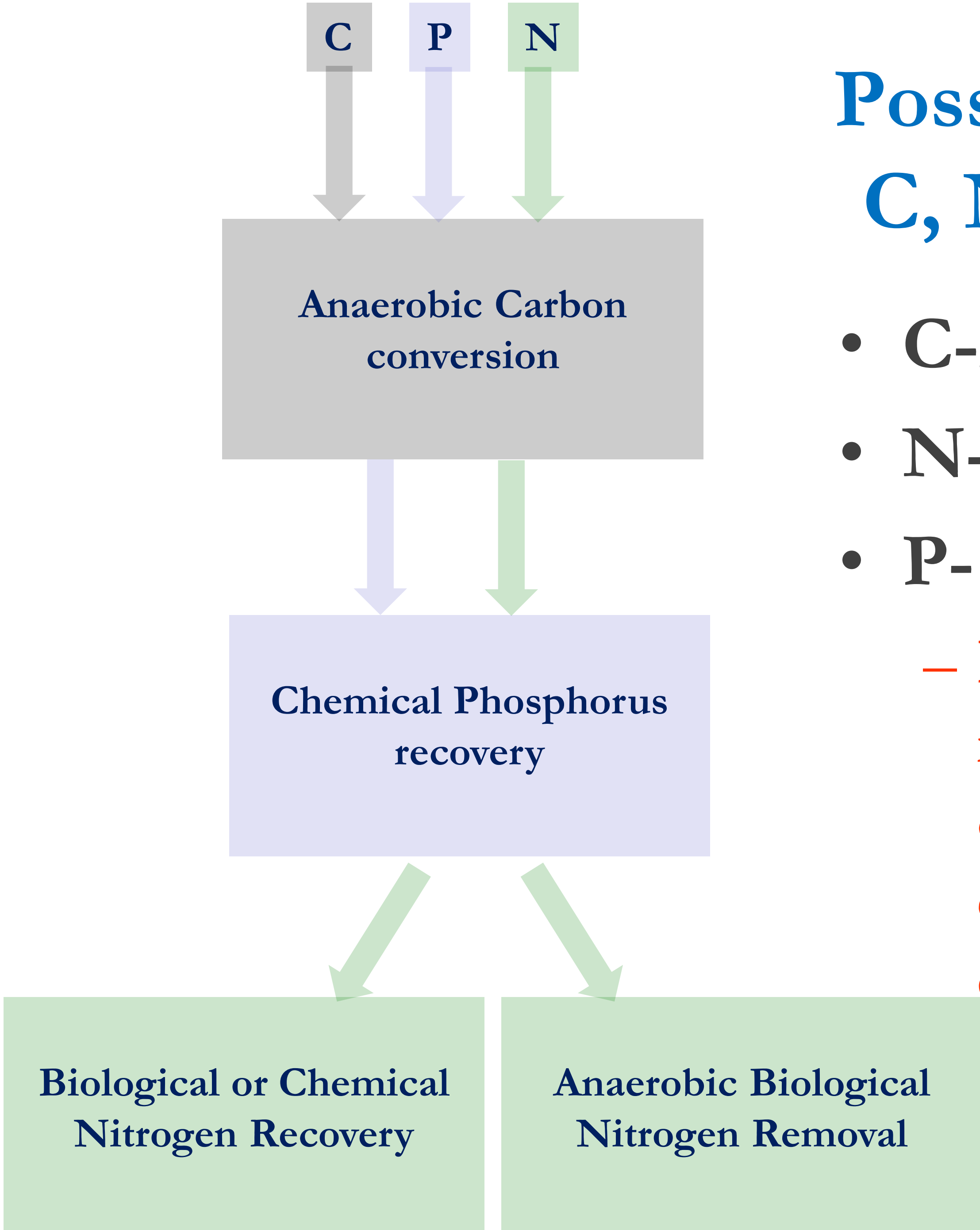




Grady et al., 1999

Mass loading of organics and nutrients entering 14 NYC WWTPs

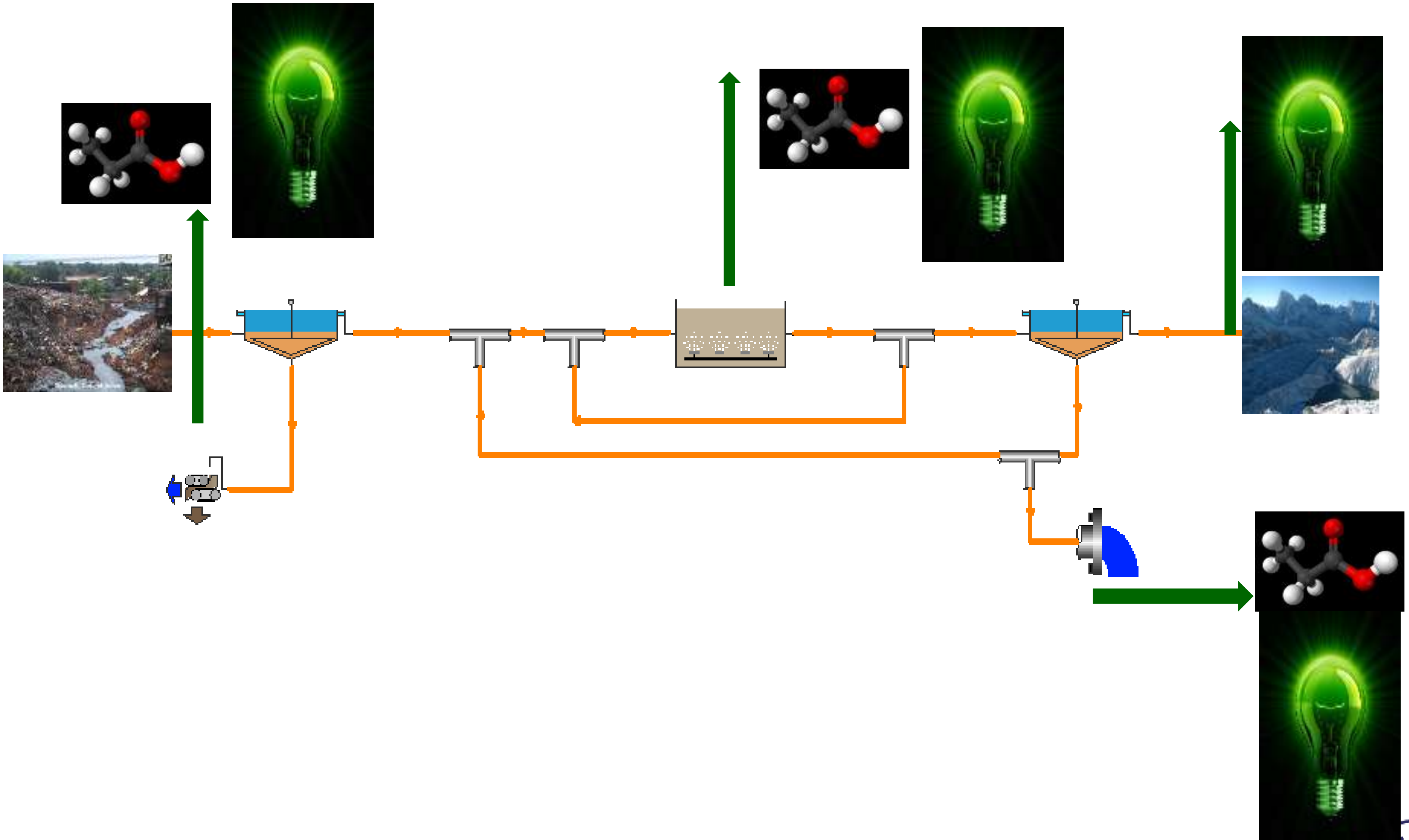
- Flow: 1.2 billion gallons per day
  - 1860 tons of organic carbon per day
  - 280 tons of N(-III) per day
  - 60 tons of P(+V) per day

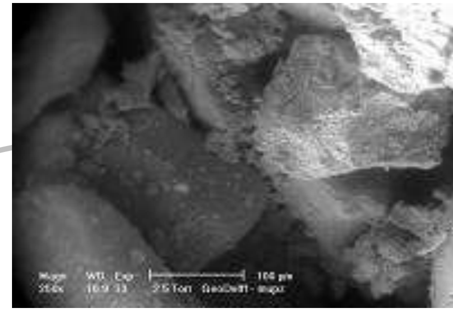


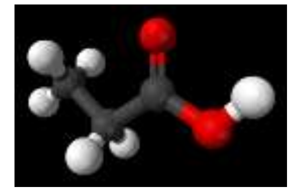
Possible flowsheet for C, N and P recovery

- C-reduction
- N-no redox cycling
- P- no redox cycling
  - How to monetize recovery of energy or chemical resources with environmental process objectives

Engineered Resource Recovery from 'Waste' Streams

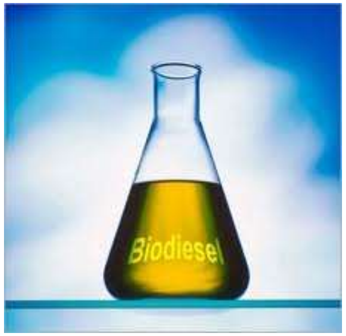


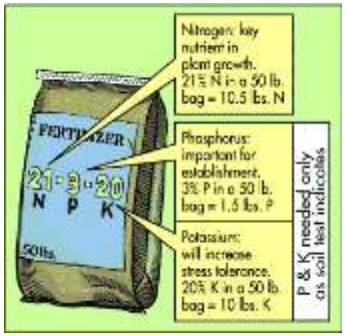





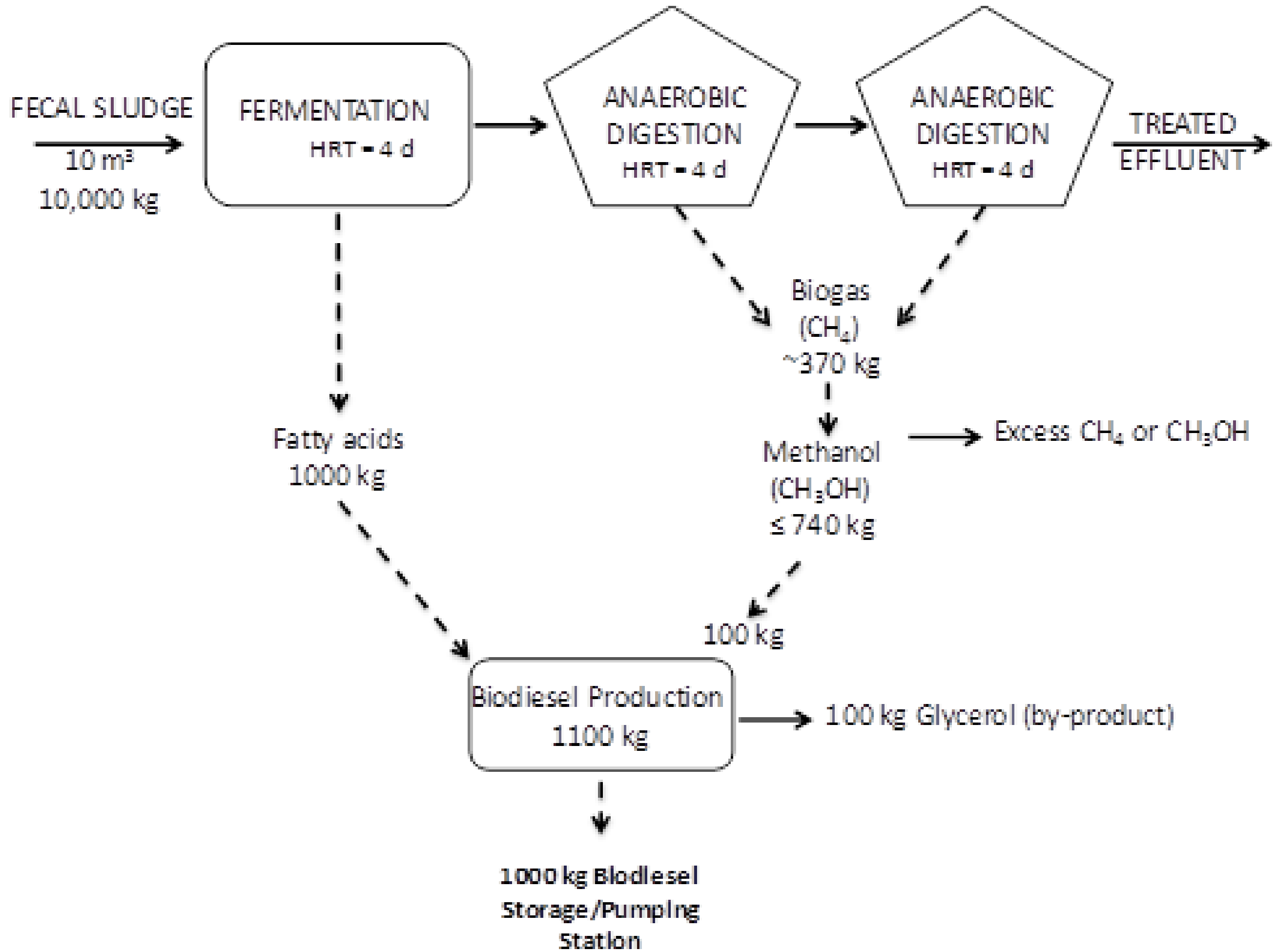

Conversion of fecal sludge into biodiesel





Faecal Sludge to Biodiesel

Process Schematic



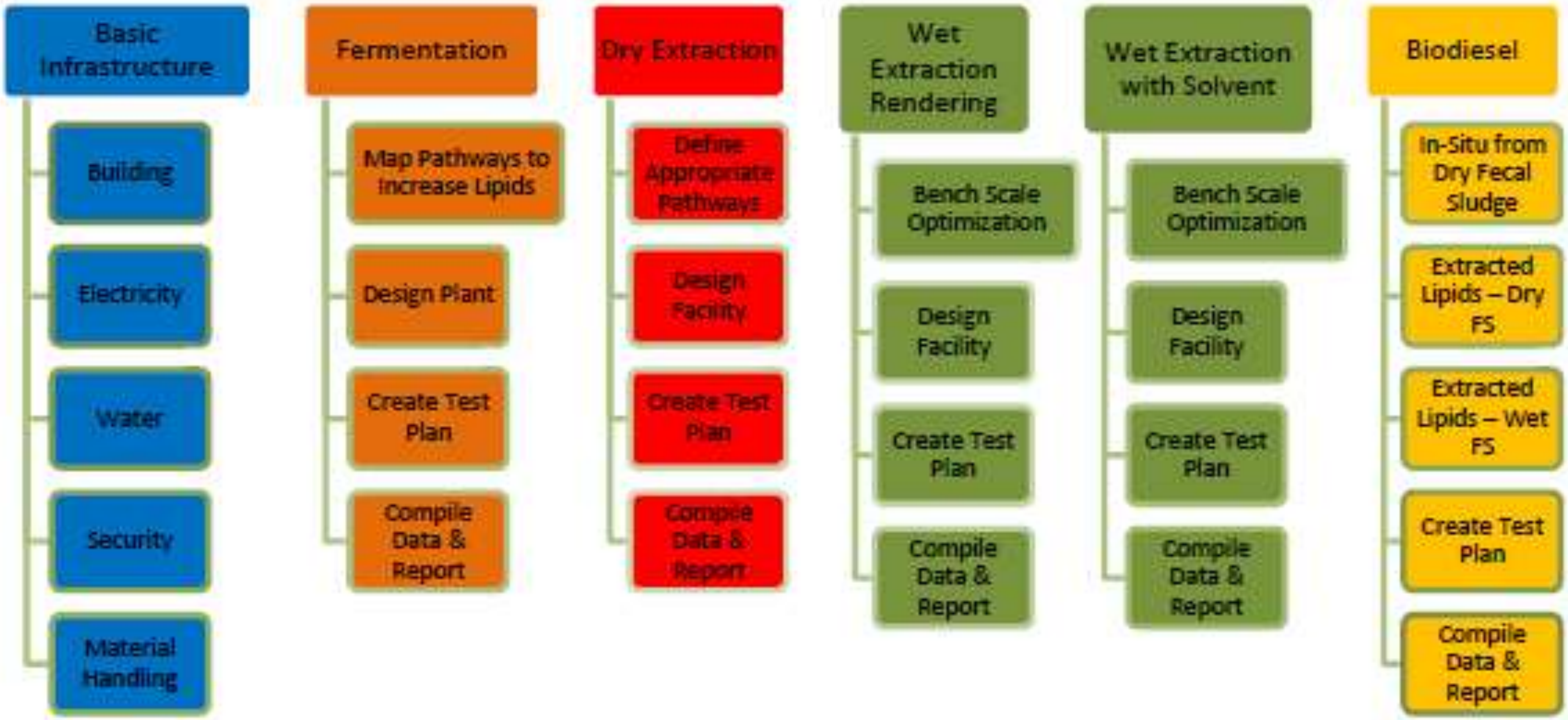
Piloting in Kumasi, Ghana

- Entirely surrounded by FS lagoons and landfill
- Facility completely off-grid
  - No municipal water, or power available on site

Piloting in Kumasi, Ghana

- Q=10,000L/d
- HRT = 12d
- Feedstock – fecal sludge
- End products – methane, chemicals, biodiesel

FS2BD Project Map



Brief process calculations

Parameter	Value
Process design flow	10,000 L/d
Inherent lipid content	50 kg/d
Biodiesel potential	57 L/d biodiesel

Parameter	Value
Methane produced	45 m^3/d, assuming 0.3 m^3/ kg COD removed and 50% COD removed
N-recovered	20 kg/d, assuming 2000 mg NH_3/L in FS
P-recovered	2.75 kg/d, assuming 275 mg P/L in FS

Fecal sludge to biodiesel

- Construction complete
- Processing of FS and conversion experiments ongoing
- Developing lab and testing facilities onsite

Opportunities for increasing process efficiency

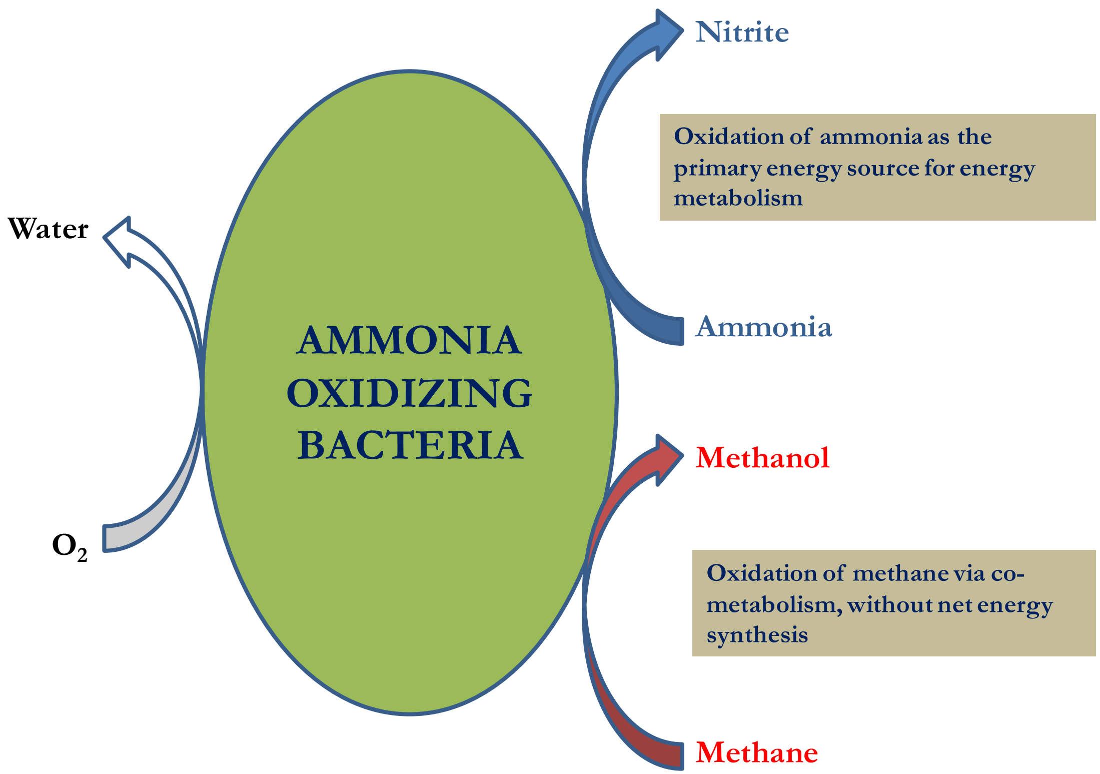
Internally producing lipids

Parameter	Value
Process design flow	10,000 L/d
Inherent lipid content	50 kg/d
SC-VFA yield expected	60 kg COD/d Assuming: 20 g COD/L in the influent FS Assuming: 30% VFA COD/FS COD by fermentation
Lipids produced	1067 – 6933 g lipids/d
Total lipids	51067 -56933 g/d
Biodiesel potential	58 – 65 L/d biodiesel

- **Also vastly opens up the choice of substrate feedstocks**

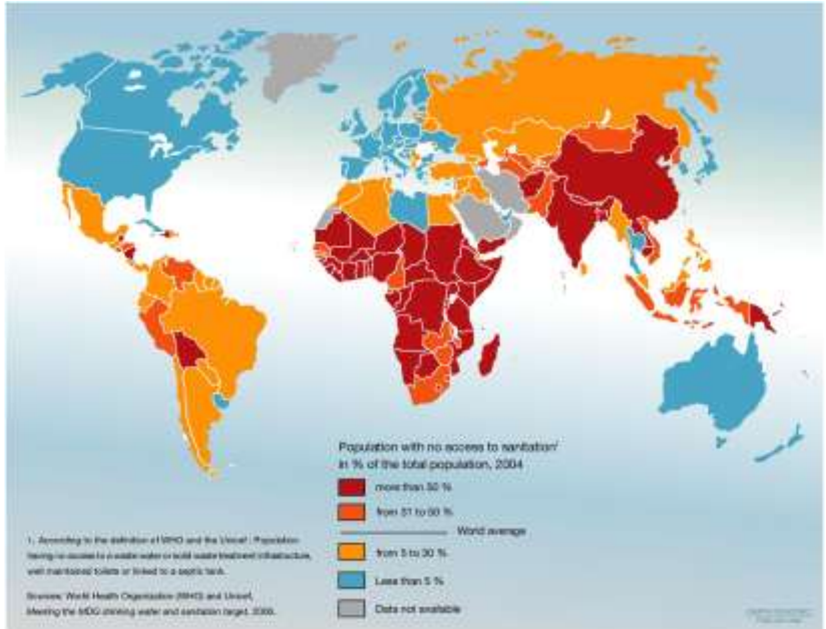
Chemical Recovery

Methane to bio-methanol



- Concomitant oxidation of CH_4 and CO_2 fixation
- Prospect of combining C &N cycles

Resource recovery is not the panacea



Food security	Food security	Food security
Technology and engineering	Technology and engineering	Technology and engineering
Recover C-energy	Recover C-energy	Recover C-energy
Recover P	Recover P	Recover P
Recover N	Recover N	Recover N

Contact information

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Acknowledgements

The Bill & Melinda Gates foundation

Fecal Sludge to Biodiesel project team

Alternate feedstocks and endpoints

- Waste cooking oil
  - Evaluate biodiesel yield and quality after multiple use
  - Follows direct biodiesel pathway
- Any organic stream, literally
  - Follows fermentation pathway
- Bio-butanol possible with high carbohydrate wastes

Are there other benefits?

Environ. Sci. Technol. 2010, 44, 4505–4511

N_2O Emissions from Activated Sludge Processes, 2008–2009: Results of a National Monitoring Survey in the United States

JOON HO AHN,[†] SUNGPYO KIM,[†,‡] HONGKEUN PARK,[†] BRIAN RAHM,[†] KRISHNA PAGILLA,[‡] AND KARTIK CHANDRAN*,[†]

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...neered BNR facilities, while effective to varying degrees in reducing aqueous nitrogen pollution could emit up to 7% of the influent nitrogen load as gaseous nitrous oxide (N_2O) and nitric oxide (NO), as described for the nitrifying B-stage of the Dokhaven-Sluisjesdijk WWTP in The Netherlands (1). Such emissions are deleterious to the environment. The greenhouse equivalence of N_2O is about three hundred times that of carbon dioxide and both N_2O and NO contribute to depletion of the ozone layer (2).

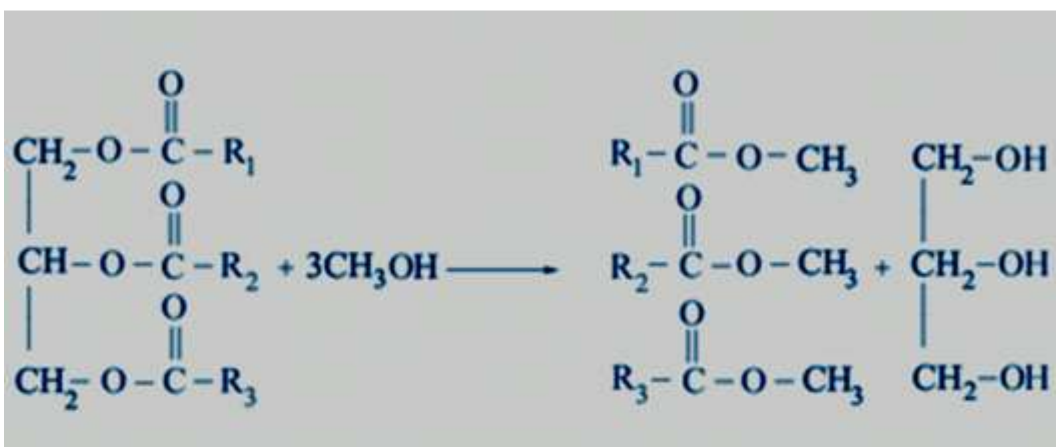
Although, from a fundamental perspective, N_2O and NO are known intermediates in denitrification (3, 4) and nitrification (5–9), the net-contribution of BNR processes to N_2O emissions from wastewater treatment has only recently been acknowledged (10). Based on the latest U.S. Environmental Protection Agency (USEPA) report on sources and sinks of N_2O from wastewater treatment operations, denitrification in anoxic zones is implicated as the dominant source of N_2O ...

- N_2O is produced during both nitrification and denitrification
  - Redox cycling of N
- Poorly designed and operated ww treatment plants produce and emit higher N_2O

Ahn et al., 2010a,b, Yu et al., 2010, Yu & Chandran, 2010, Lu & Chandran, 2010, Chandran et al., 2011


Resource recovery - Sometimes low tech is enough

Sewage sludge to biodiesel



- Using the fat content of biosolids
- Using MeOH for fuel production instead of N-removal

Laws and Regulations

Summary of the Clean Water Act

33 U.S.C. §1251 et seq. (1972)

The Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. The basis of the CWA was enacted in 1948 and was called the Federal Water Pollution Control Act, but the Act was significantly reorganized and expanded in 1972. "Clean Water Act" became the Act's common name with amendments in 1972.

Under the CWA, EPA has implemented pollution control programs such as setting wastewater standards for industry. We have also set water quality standards for all contaminants in surface waters.

The CWA made it unlawful to discharge any pollutant from a point source into navigable waters, unless a permit was obtained. EPA's National Pollutant Discharge Elimination System (NPDES) permit program controls discharges. Point sources are discrete conveyances such as pipes or man-made ditches. Individual homes that are connected to a municipal system, use a septic system, or do not have a surface discharge do not need an NPDES permit; however, industrial, municipal, and other facilities must obtain permits if their discharges go directly to surface waters.

Compliance and Enforcement

- Clean Water Act Compliance Assistance
- Clean Water Act Compliance Monitoring: investigations and inspections
- Water Enforcement

History of this Act

Quick Links

- PDF of CWA, from U.S. Senate (234 pp, 571K, About PDF)
- The official text of the CWA is available in the *United States Code* on FDSys, from the US Government Printing Office

How do I...?

Find regulatory info:

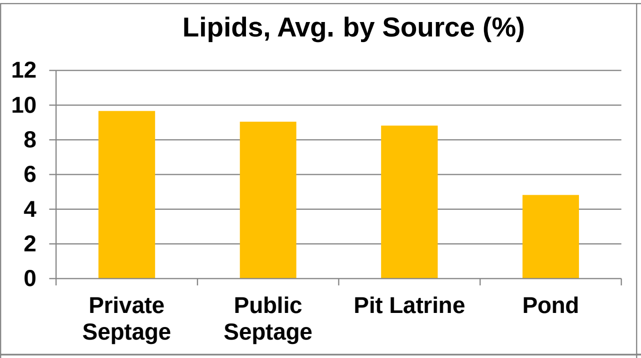
- By topic
- By sector

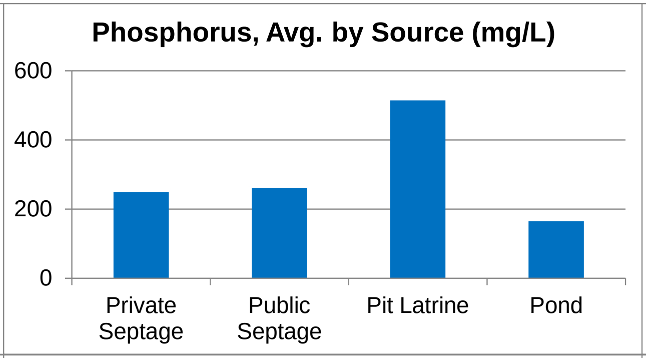
Get involved with EPA regulations

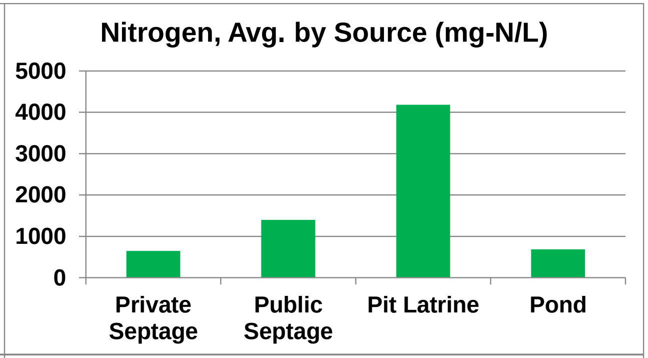
Learn about:

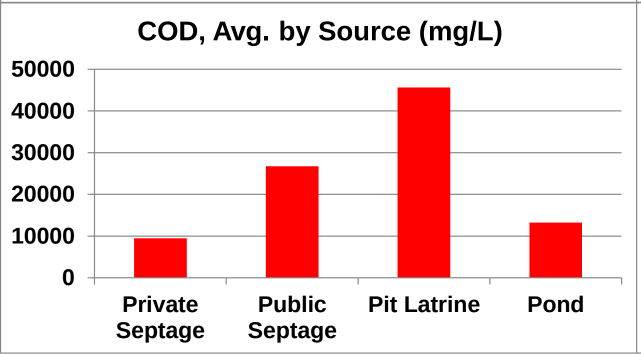
- The Basics of the Regulatory Process
- Compliance
- Enforcement

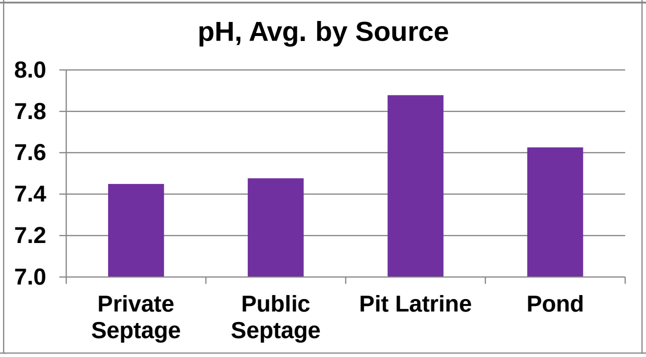
Characteristics of fecal sludge

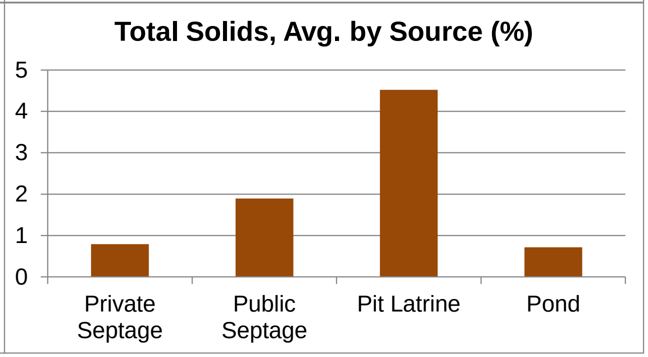








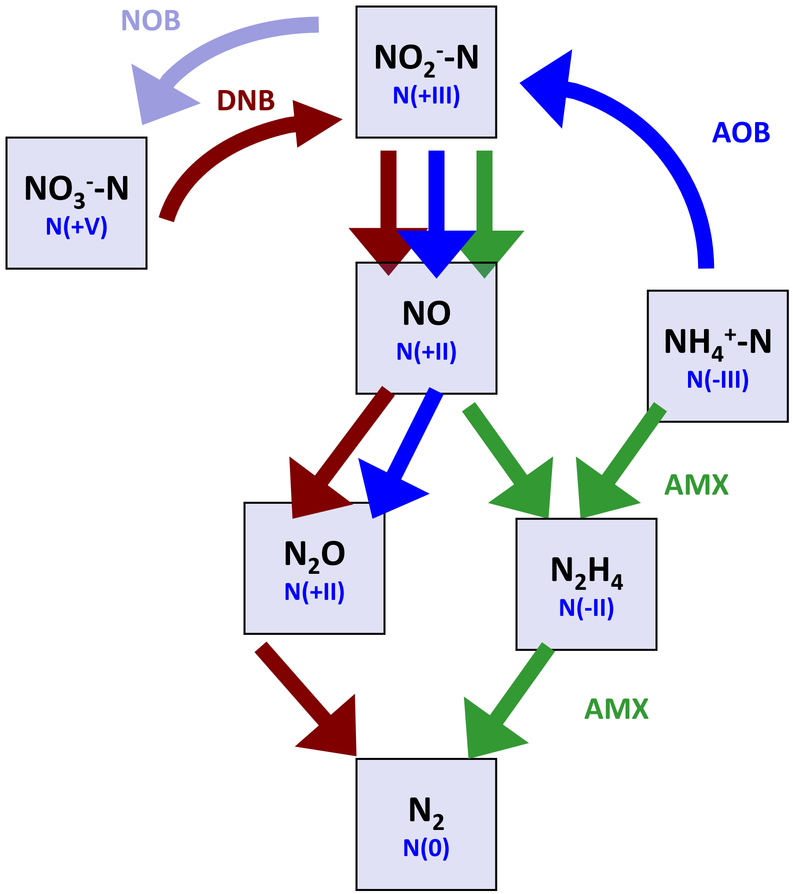




Wicked Problem, about 70% of the world’s population will live in cities by 2050





- Several intermediates reactive
  - NO_2^--N, NO, NH_2OH
  - Control expression of pathways
- How to resolve activities?
- How to resolve contribution to mass balances?

Ahn et al., 2008, Baytshtok et al., 2008, 2009, Park et al., 2010a,b, Lu et al., 2011a,b, Lu et al, 2012

Engineered BNR systems are typified by multiple activities in concert or competition

Fecal Sludge to Biodiesel

Project objectives

1) Develop a robust and efficient fermentation-based technology for producing biodiesel from FS.
2) Understand costs and potential revenue streams of fecal sludge-fed biodiesel production.
3) Identify and prepare for structures and procedures needed to successfully implement and operate a full-scale FS-fed biodiesel plant as a social enterprise in Ghana.

Fermentation-based technology for producing biodiesel from fecal sludge:

1. Fermentation of fecal sludge organics testing different biocatalysts.

2. *In-situ* acid catalyzed (trans)esterification of fatty acids for production of fatty acid methyl-esters.

3. Anaerobic digestion of residual streams.

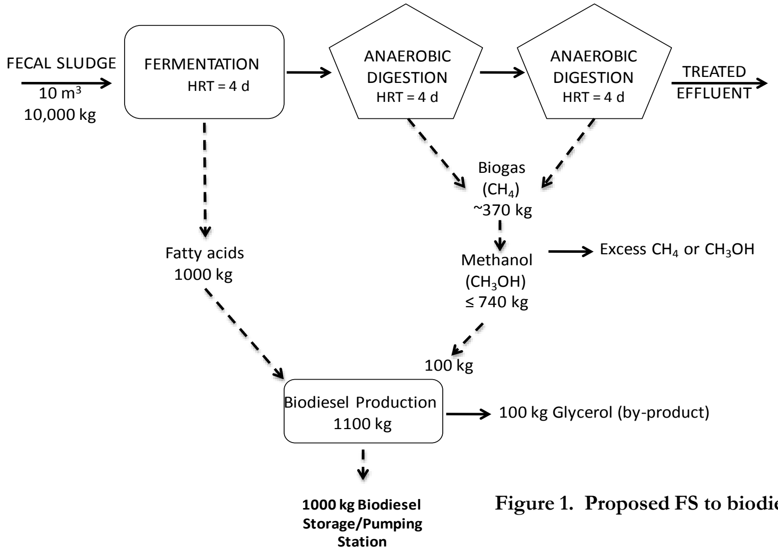


Figure 1. Proposed FS to biodiesel process

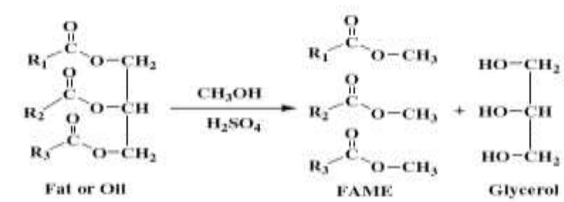


Figure 2. Acid-catalyzed transesterification of lipids to FAME and glycerol (Reproduced from Mondala et al. 2009).

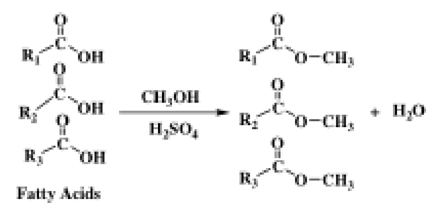
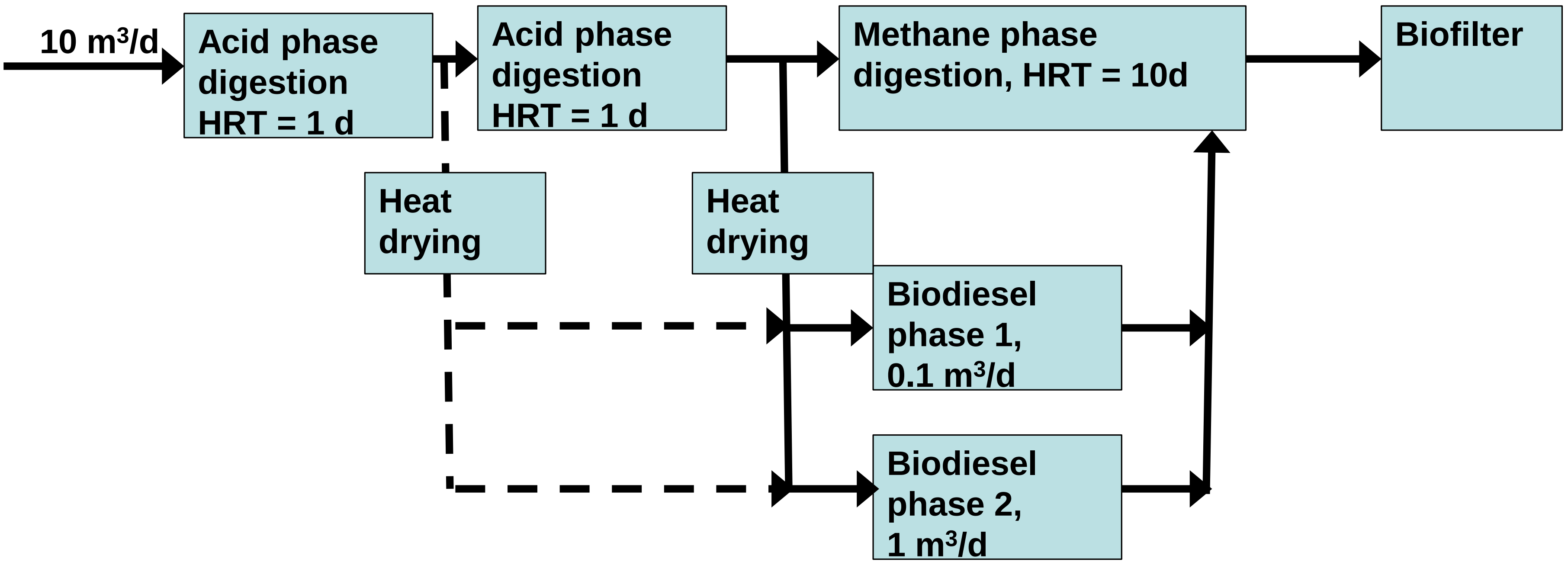


Figure 3. Acid-catalyzed esterification of fatty acids to FAME and water (Reproduced from Mondala et al. 2009).

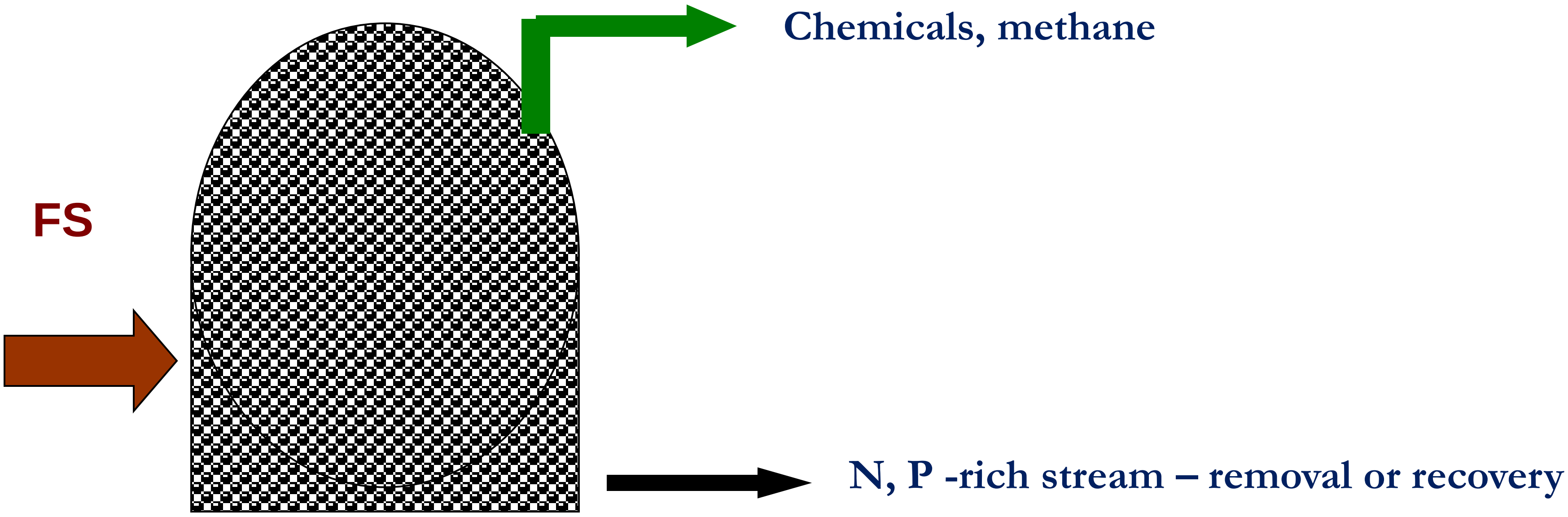
Adapted from CU Proposal Narrative and Appendix II: Sludge-fed Biodiesel Technology Landscape, 2011

Process schematic



Recovery of Carbon from FS

What our industry already knows and does



Still some limitations to widespread use of digester gas for energy

Dual-Phase Digestion and Fermentation of SS

PDS fermentation and storage at 26th Ward WPCP in New York City, 2002

- Fermentation of PDS to produce VFA
  - Used mainly for denitrification
  - Kinetics higher than MeOH
- Acid-digestion of surface froth and scum
  - Reduced foaming
  - VFA recovery