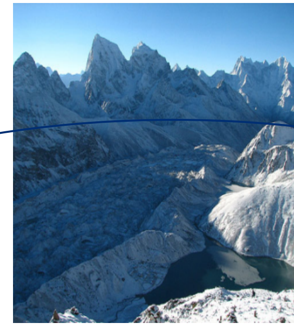


Biological conversion of solid and liquid streams

Kartik Chandran, Columbia University

WTERT 2014

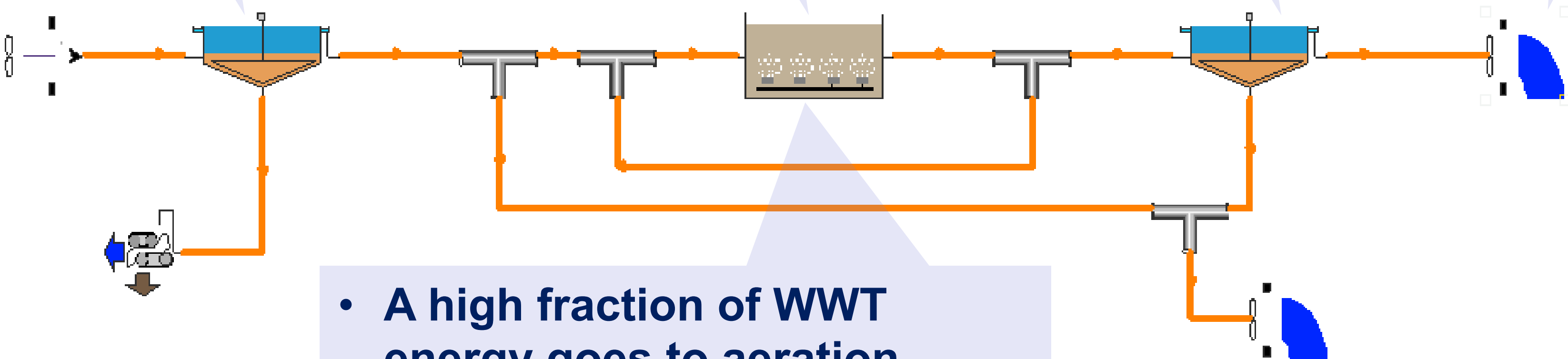
Brief overview of biological waste treatment

Solids, inerts separation

Aerobic C &N removal

Recycle of bacteria

Disinfection and discharge



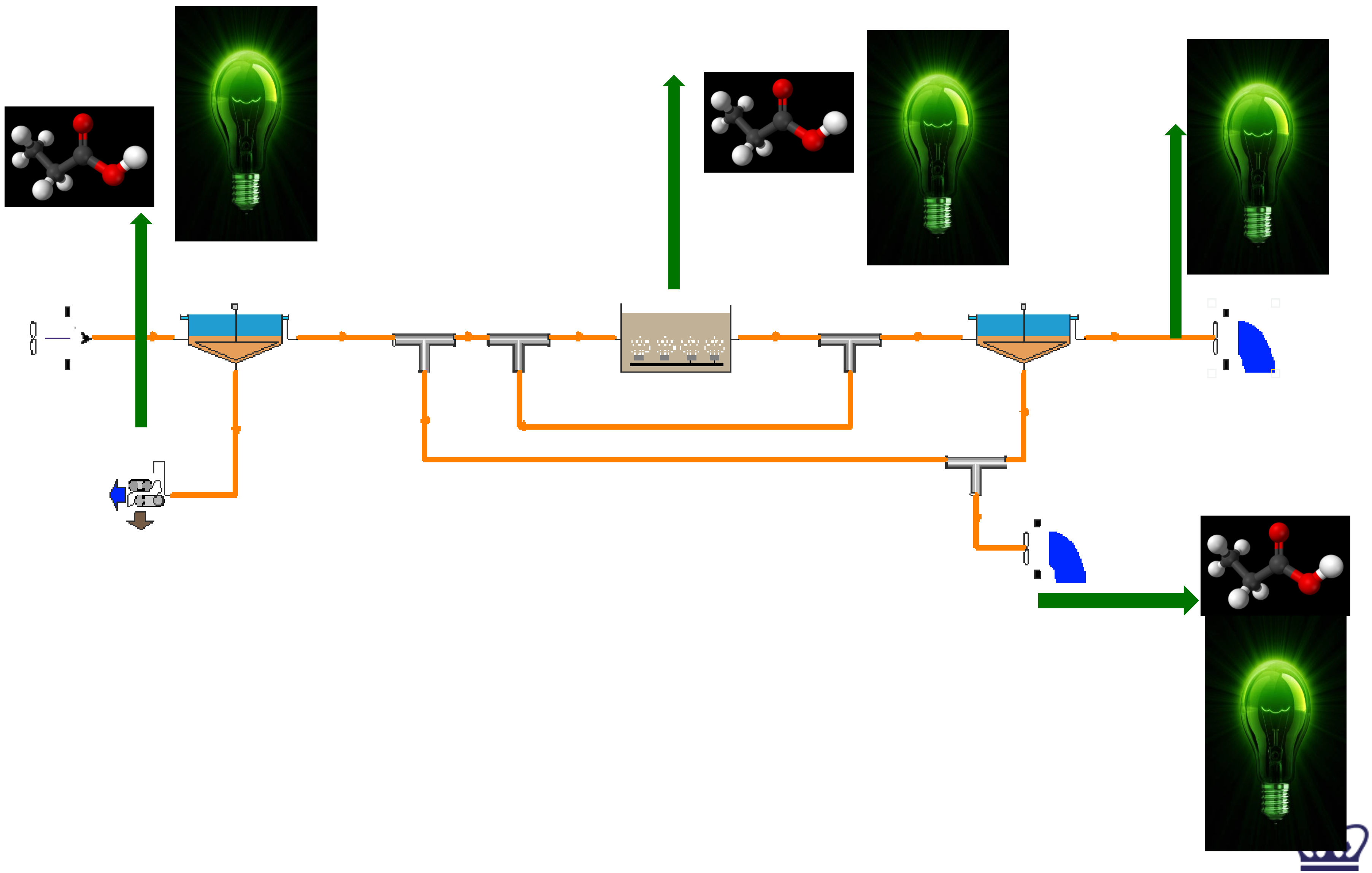
- A high fraction of WWT energy goes to aeration
- $MM in organic chemical purchase
- Bacteria could produce unwanted products (N_2O)

Shifting from Resource Removal to **Resource Recovery**

Article by K. Chandran, Columbia Magazine, Fall 2012

K. Chandran, 2014, Elsevier

Engineered Resource Recovery from 'Waste' Streams

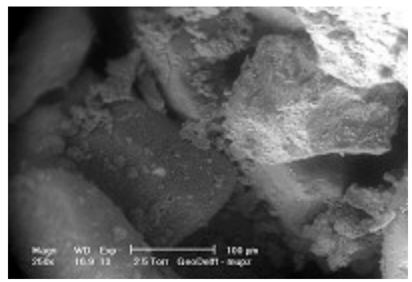


Recovery of C, N and P

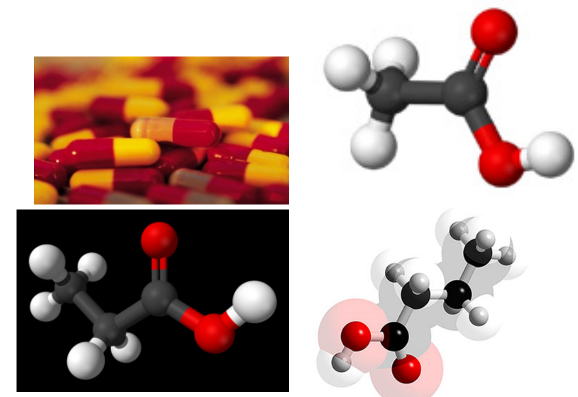
All based on anaerobic technologies

- **Engineering microbial processes for synthesizing commercial products**

Biofuels



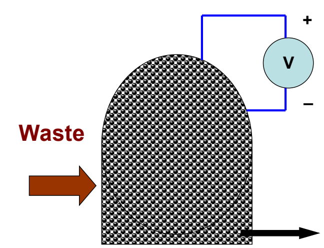
Biogrout, SmartSoils®



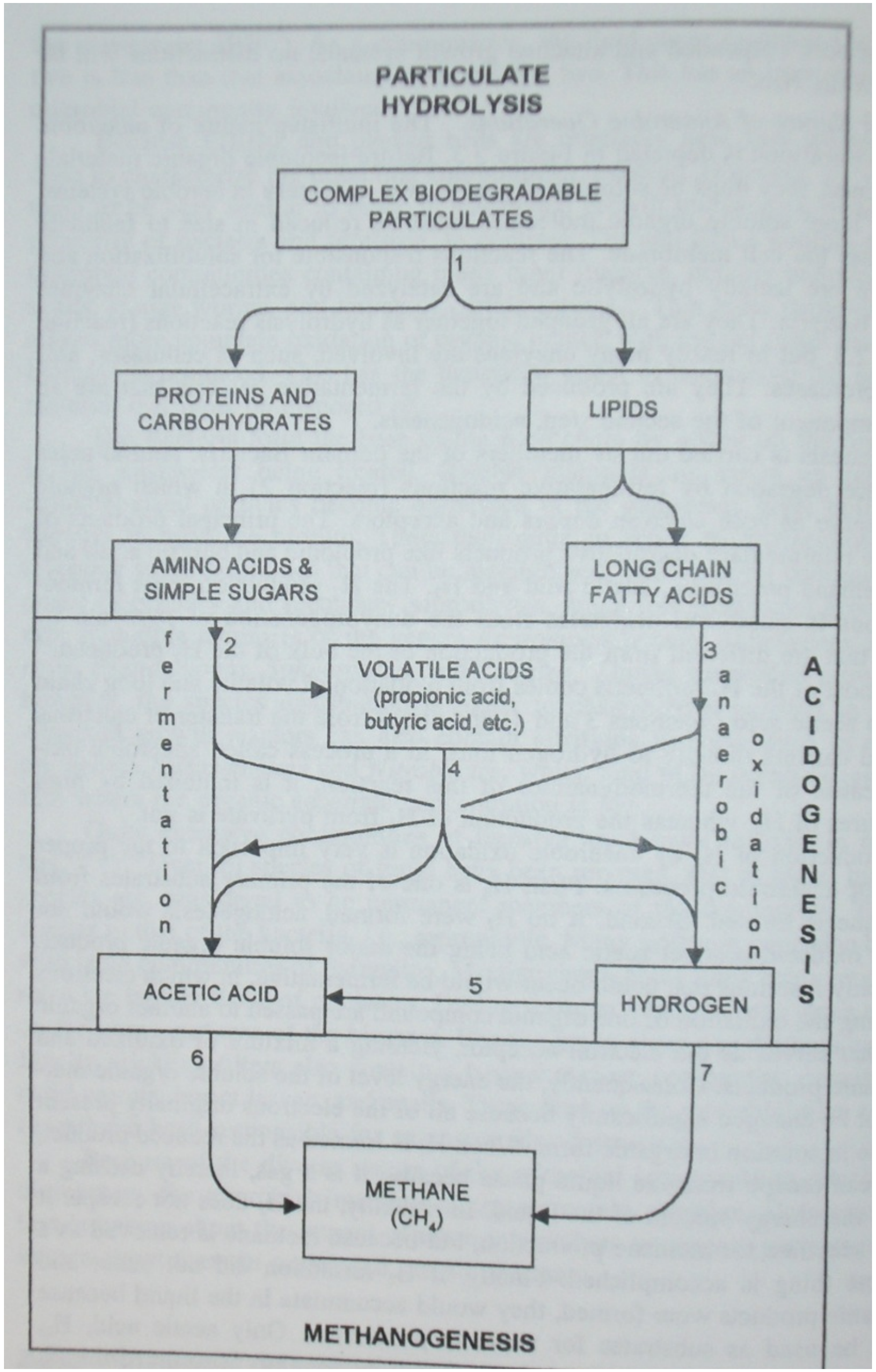
Commercial chemicals

Bioplastics

Biofertilizers

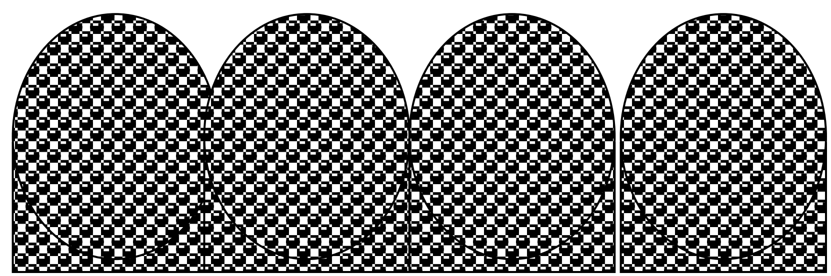


Electricity



Anaerobic digestion

- Three stages
  - – Hydrolysis
  - – Fermentation
  - – Methanogenesis
    - Slowest and most sensitive step

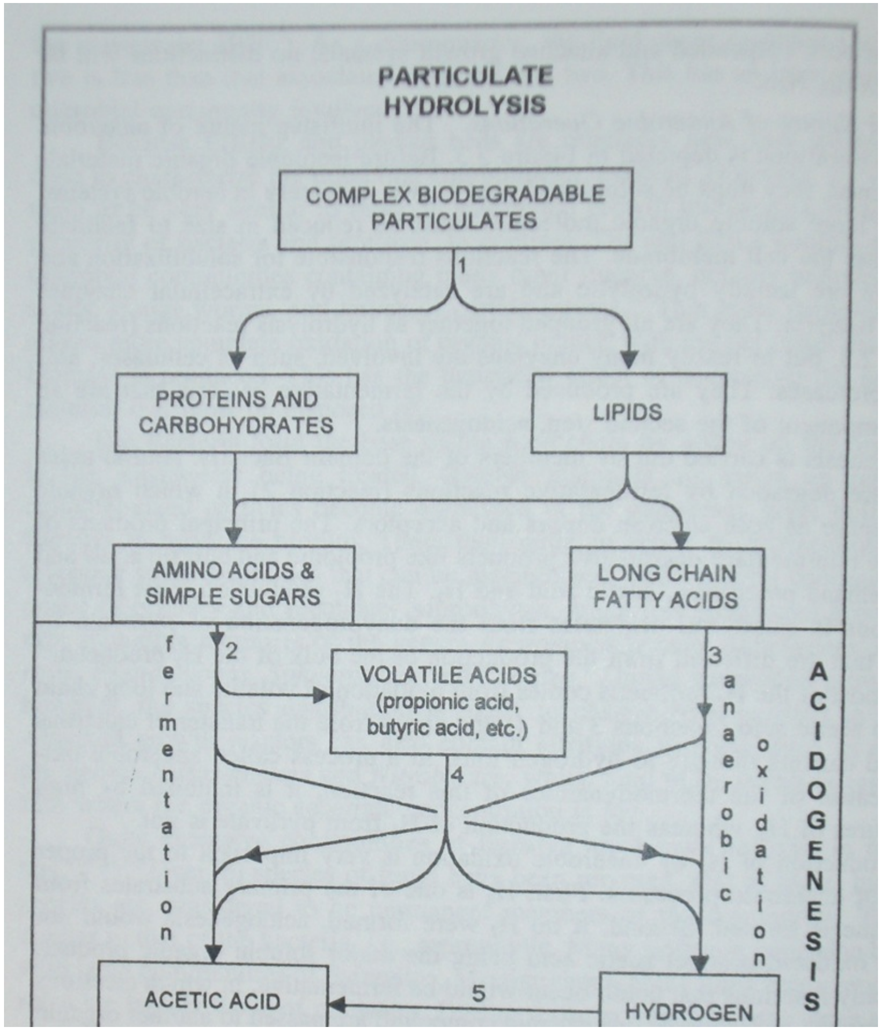


‘Direct’ energy is not the only endpoint

Dual-Phase Digestion and Fermentation of AS

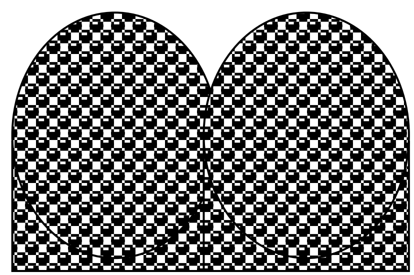
PDS fermentation and storage at 26th Ward WPCP in New York City, 2002

- 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



Anaerobic Fermentation

- Two stages
  - Hydrolysis
  - Fermentation

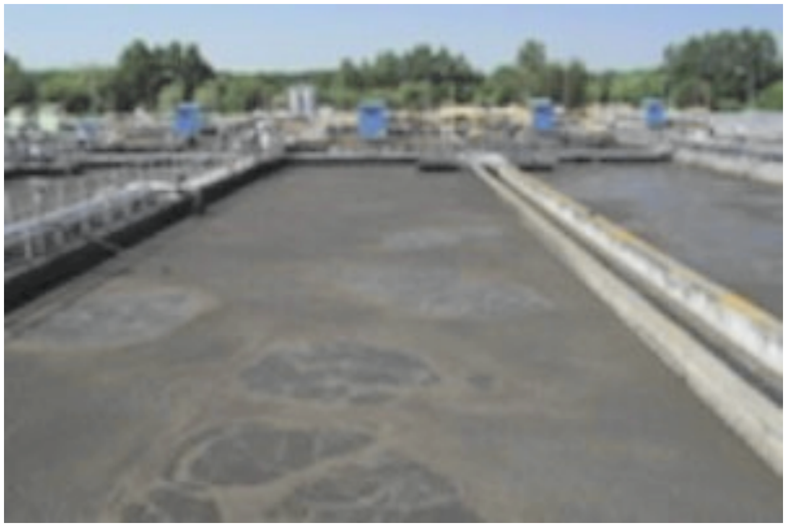


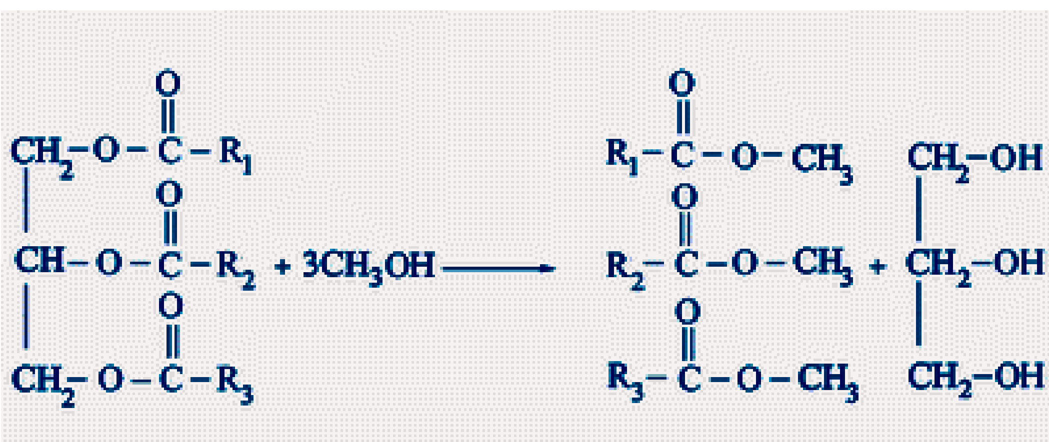
Fermentation as a platform

- VFA for N and P removal
  - Using different types of biomass
  - Including food waste
- Chemicals
  - solvents, pharmaceuticals
- Biofuels
- Methanogenesis still can be conducted downstream
  - And probably needs to be conducted

Organic sludge to biodiesel

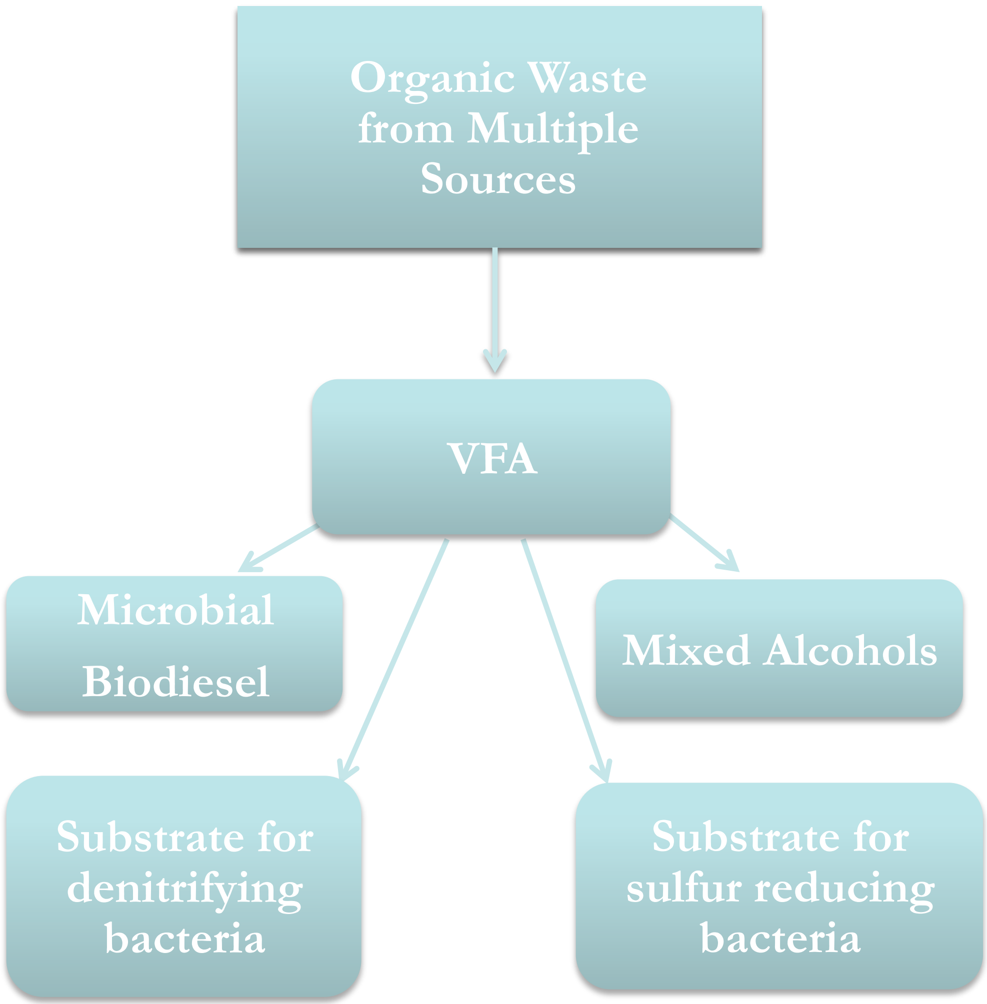
VFA as a central intermediate





- Using the lipid content of sludge
- Using MeOH for fuel production

R-X TO BIODIESEL PLATFORM



- A novel and extremely flexible platform technology which can be used to convert different organic feed stocks including food waste, sewage sludge, or industrial high-strength organic waste into biodiesel.

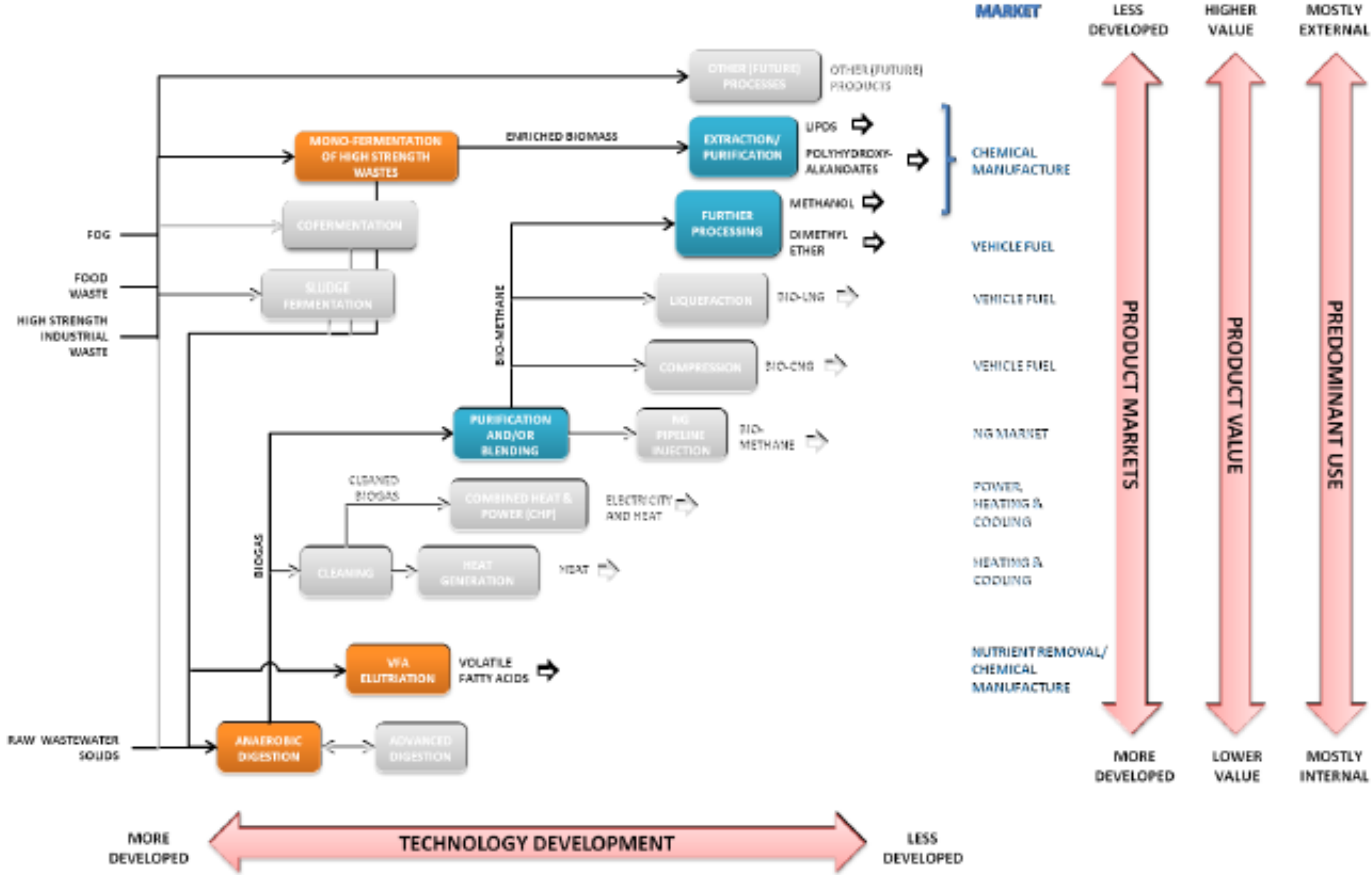
- Based on our results, and combined with *in-situ* extraction of lipids from the waste, up to 40% increase in the final yield of biodiesel can be achieved. Further increase is possible through improvements in the VFA yield from the fermenter.

- Multiple endpoints can be achieved in conjunction using VFAs produced from anaerobic digestion of waste streams.

Alternate chemicals from sewage sludge or wastewater

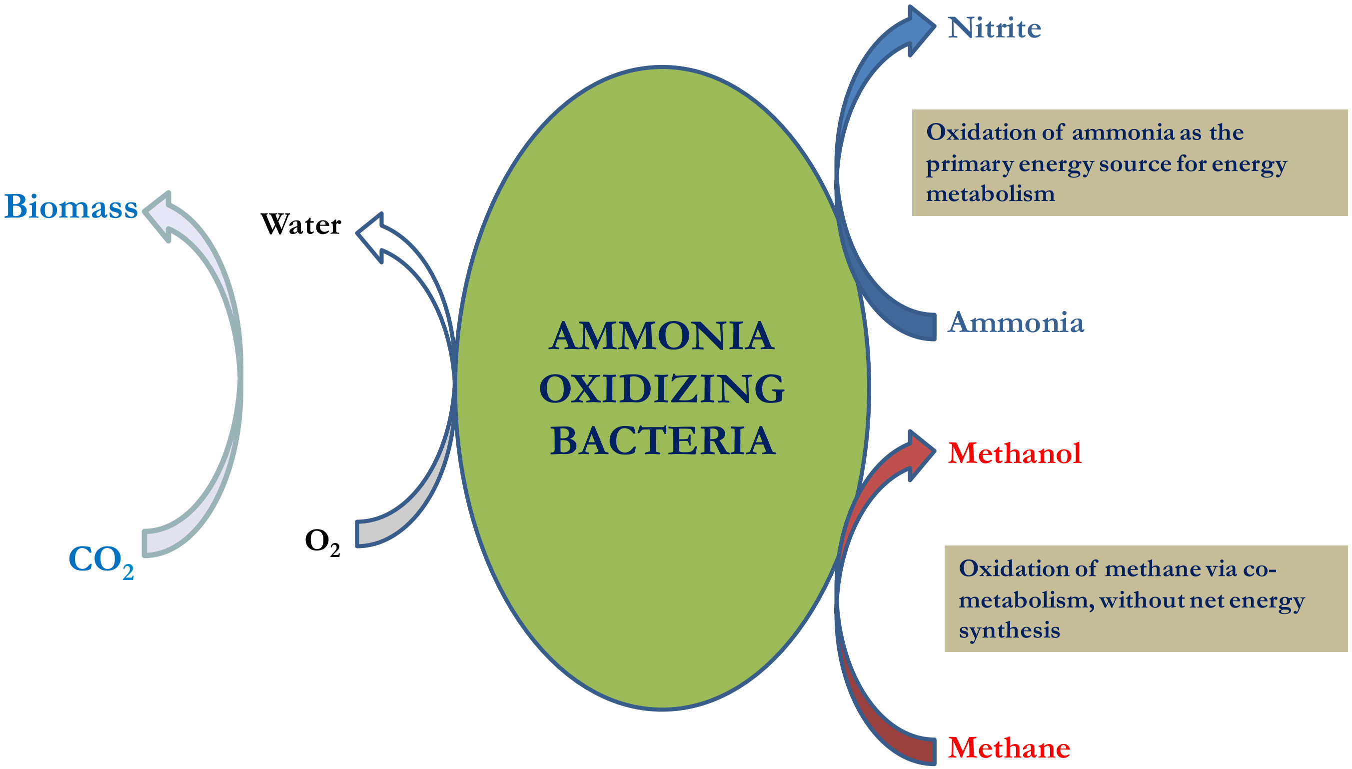
Chemical	Price	Platform technology	Application
Succinic acid	$9.9	Fermentation	Nutraceutical
Ethyl acetate	$5.64	Fermentation	Solvent
Methyl acetate	$5.39	Fermentation	Solvent
1,3 propanediol	$8.83	Fermentation	Industrial monomer
Butyric acid and butanol	$3.00 - $6.80	Fermentation	Biofuel

The connection to food



MARKET
LESS DEVELOPED
HIGHER VALUE
MOSTLY EXTERNAL
OTHER (FUTURE) PROCESSES
OTHER (FUTURE) PRODUCTS
MONO-FERMENTATION OF HIGH STRENGTH WASTES
ENRICHED BIOMASS
EXTRACTION/ PURIFICATION
LIPIDS
POLYHYDROXY-ALKANOATES
CHEMICAL MANUFACTURE
COFERMENTATION
FURTHER PROCESSING
METHANOL
DIMETHYL ETHER
VEHICLE FUEL
FOG
FOOD WASTE
HIGH STRENGTH INDUSTRIAL WASTE
SLUDGE FERMENTATION
BIO-METHANE
LIQUEFACTION
BIO-LNG
VEHICLE FUEL
COMPRESSION
BIO-CNG
VEHICLE FUEL
PURIFICATION AND/OR BLENDING
NG PIPELINE INJECTION
BIO-METHANE
NG MARKET
CLEANED BIOGAS
COMBINED HEAT & POWER (CHP)
ELECTRICITY AND HEAT
POWER, HEATING & COOLING
BIOGAS
CLEANING
HEAT GENERATION
HEAT
HEATING & COOLING
VFA ELUTRIATION
VOLATILE FATTY ACIDS
NUTRIENT REMOVAL/ CHEMICAL MANUFACTURE
RAW WASTEWATER SOLIDS
ANAEROBIC DIGESTION
ADVANCED DIGESTION
PRODUCT MARKETS
PRODUCT VALUE
PREDOMINANT USE
MORE DEVELOPED
LOWER VALUE
MOSTLY INTERNAL
MORE DEVELOPED
TECHNOLOGY DEVELOPMENT
LESS DEVELOPED

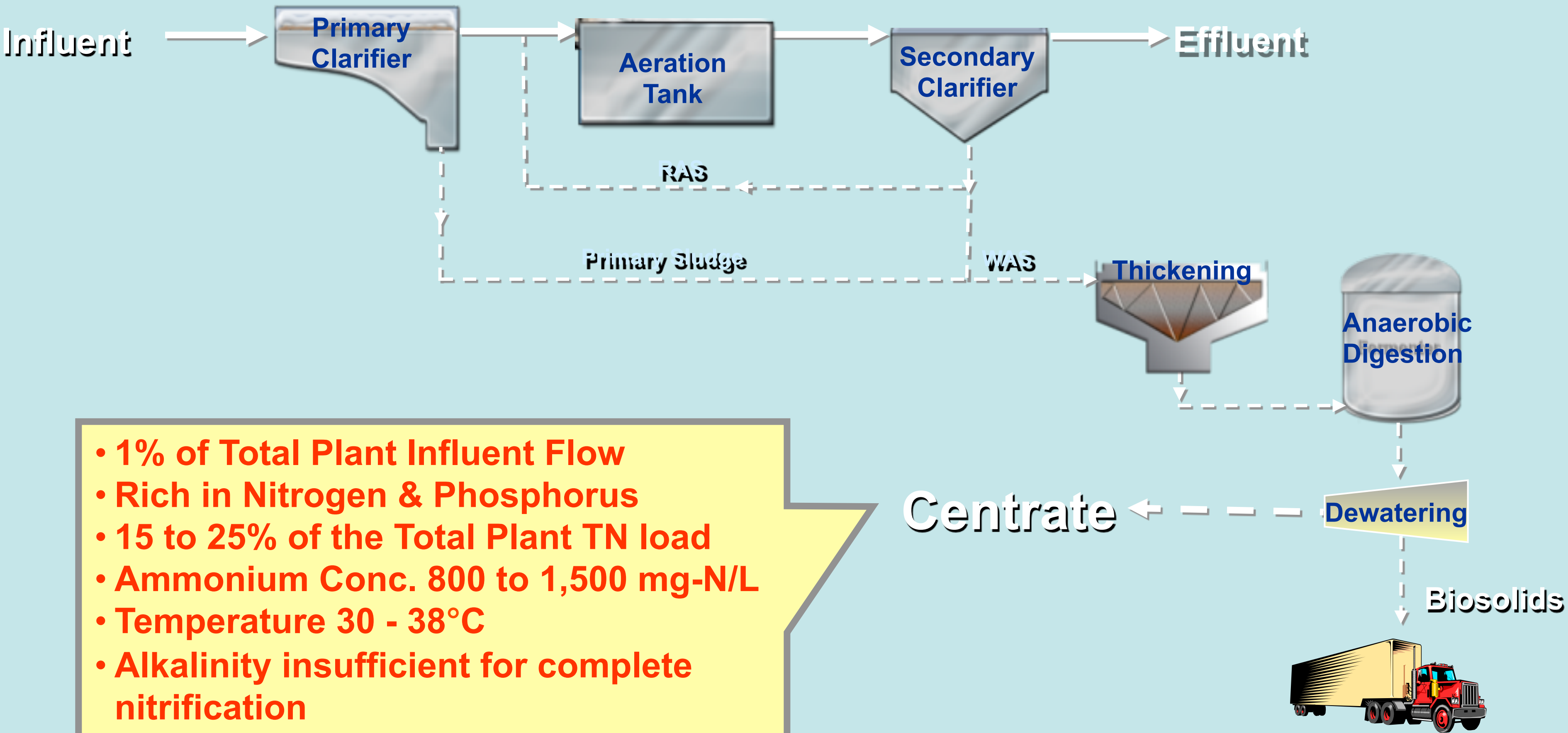
From Greenhouse Gas to Green Fuel



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

WERF Paul Busch Award, 2010
Taher and Chandran, 2013

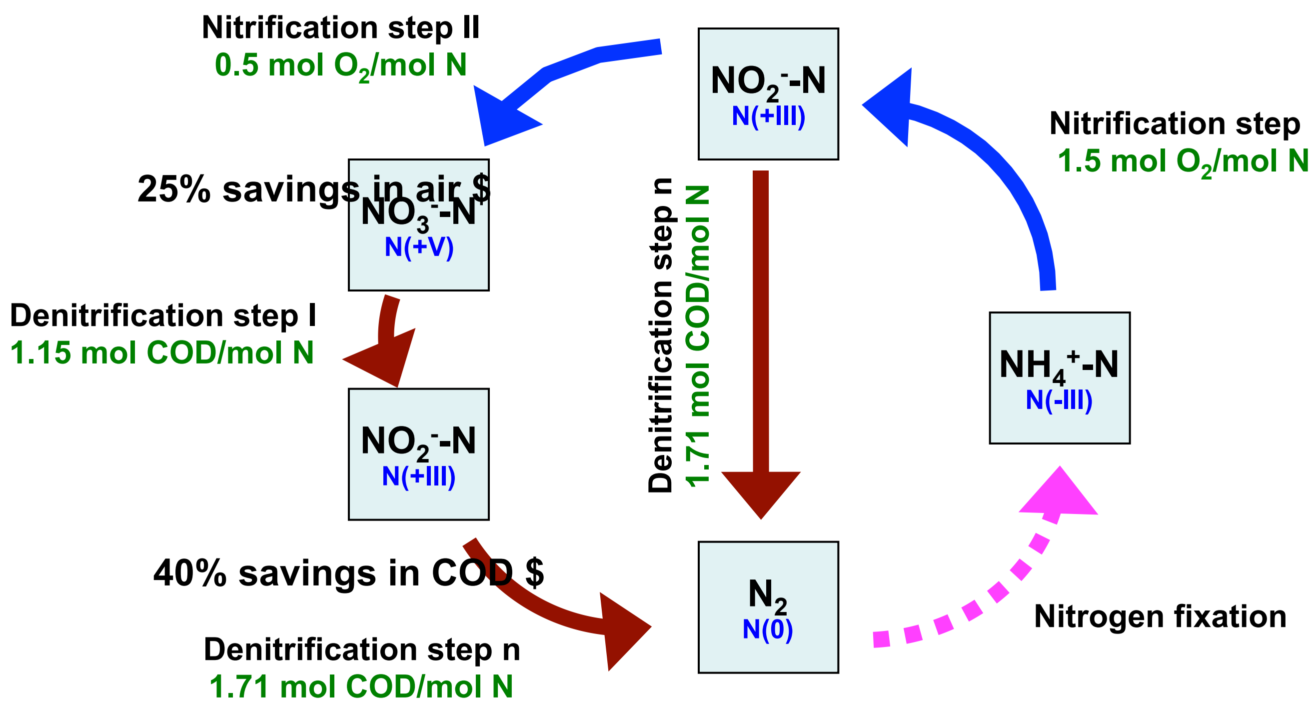
Recycle Streams with High Ammonia - Sidestream



- 1% of Total Plant Influent Flow
- Rich in Nitrogen & Phosphorus
- 15 to 25% of the Total Plant TN load
- Ammonium Conc. 800 to 1,500 mg-N/L
- Temperature 30 - 38°C
- Alkalinity insufficient for complete nitrification
- Insufficient carbon for denitrification

- For a Bio-P plant with no iron addition:
    - Centrate TP = 200-800 mg/L

Engineered N-removal

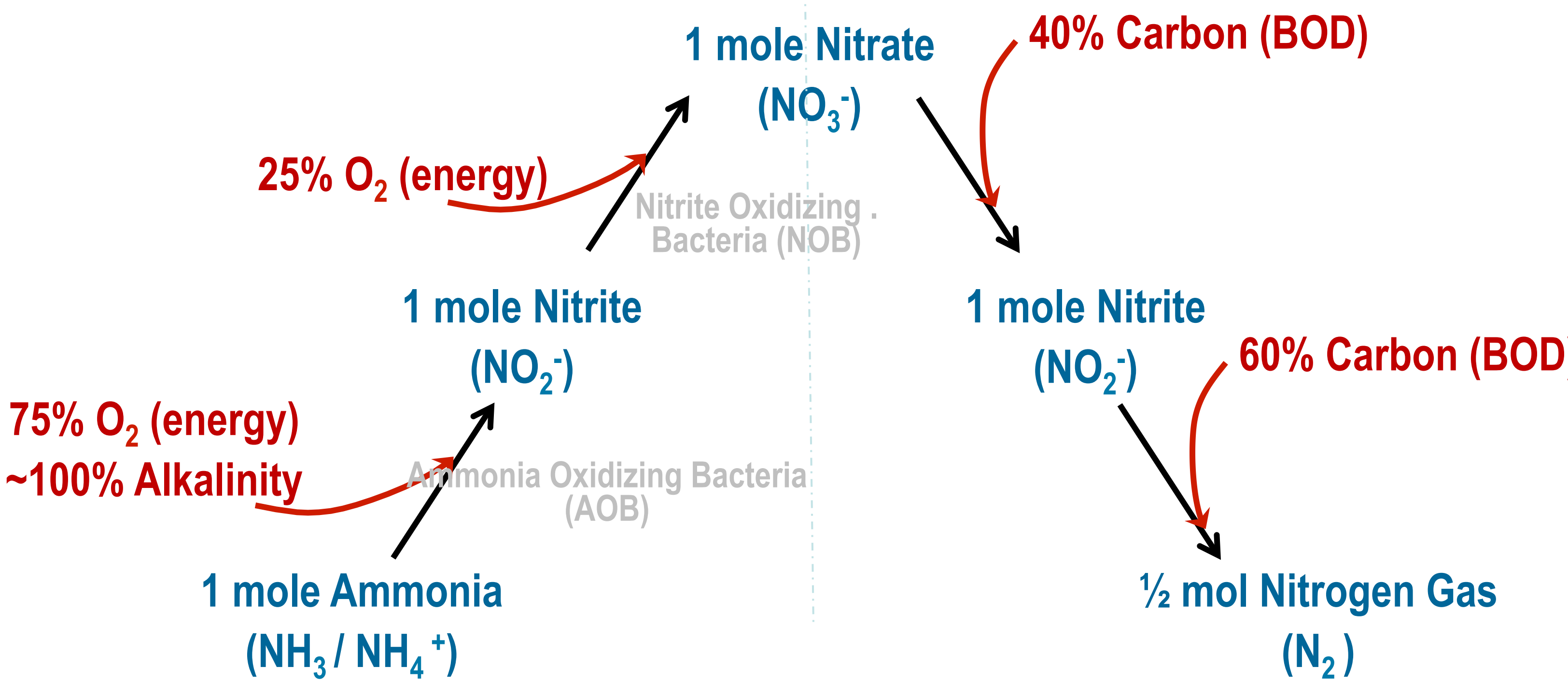


- N-removal results in doubling of aeration energy

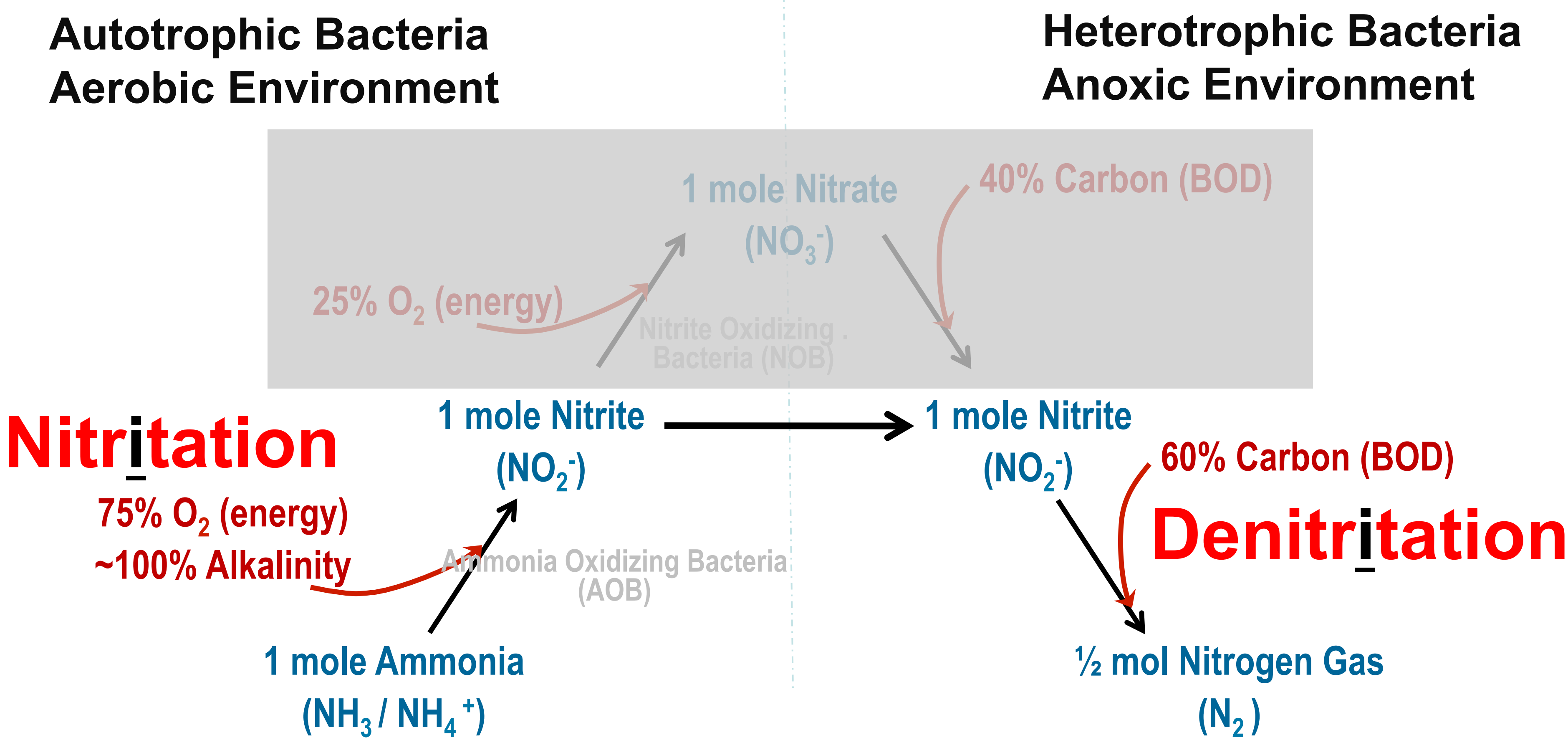
Conventional Nitrification-Denitrification

Autotrophic Bacteria
Aerobic Environment

Heterotrophic Bacteria
Anoxic Environment



Nitritation-Denitritation = "Nitrite Shunt" (2.0)



Advantages:

- 25% reduction in oxygen demand (energy)
- 40% reduction in carbon (e^- donor) demand
- 40% reduction in biomass production

Partial Nitritation-Anammox = "Deammonification" (3.0)

ANAMMOX
"Anaerobic" Ammonia Oxidation - (New Planctomycete - Strous et al, 1999)

$$NH_4^+ + 1.32\ NO_2^- + 0.066\ HCO_3^- + 0.13\ H^+ \rightarrow$$
$$0.26\ NO_3^- + 1.02 N_2 + 0.066\ CH_2O_{0.5}N_{0.15} + 2.03\ H_2O$$

Autotrophic Bacteria
Aerobic Environment

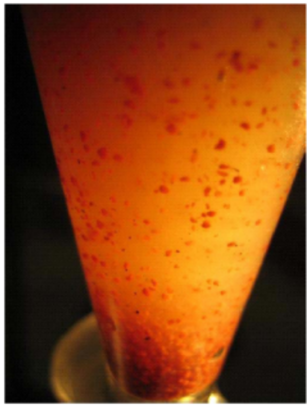
0.5 mole Nitrite
(NO_2^-)

37% O_2 (energy)
~50% Alkalinity

Ammonia Oxidizing Bacteria
(AOB)

1 mole Ammonia
(NH_3 / NH_4^+)

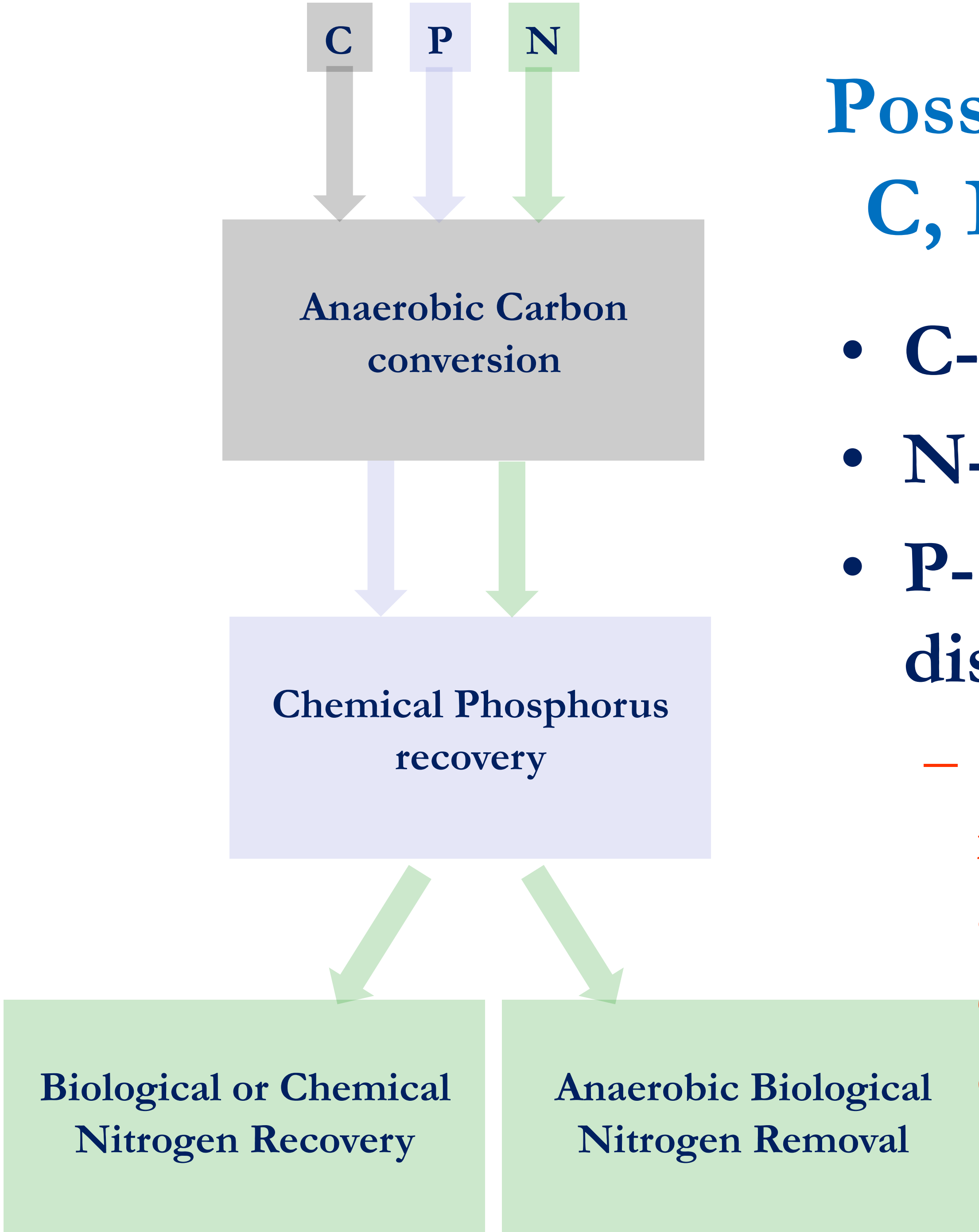
Autotrophic Anoxic Environment



½ mol Nitrogen Gas (N_2) +
a little bit of nitrate (NO_3^-)

Advantages:
- 63% reduction in oxygen demand (energy)
- Nearly 100% reduction in carbon demand
- 80% reduction in biomass production
- No additional alkalinity required

- **Sewage treatment in NYC**
- **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-recovery
- N-removal or recovery
- P- recovery (not discussed)
  - How to monetize recovery of energy or chemical resources with environmental process objectives

Contact information

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