The many lives of Nitrogen

from sky to earth and back again

(depending on your perspective)

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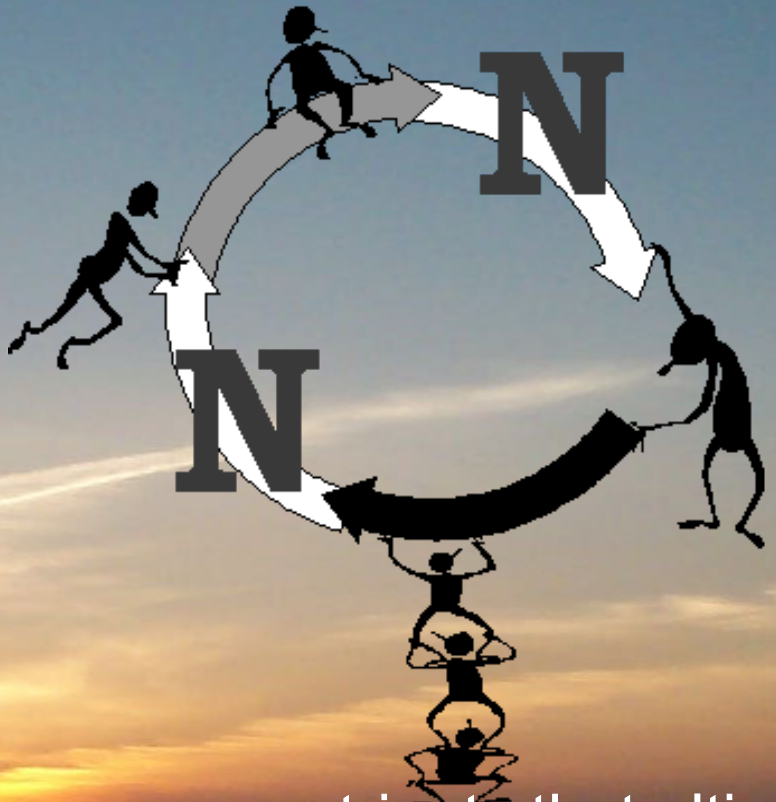
Nitrogen Cycle

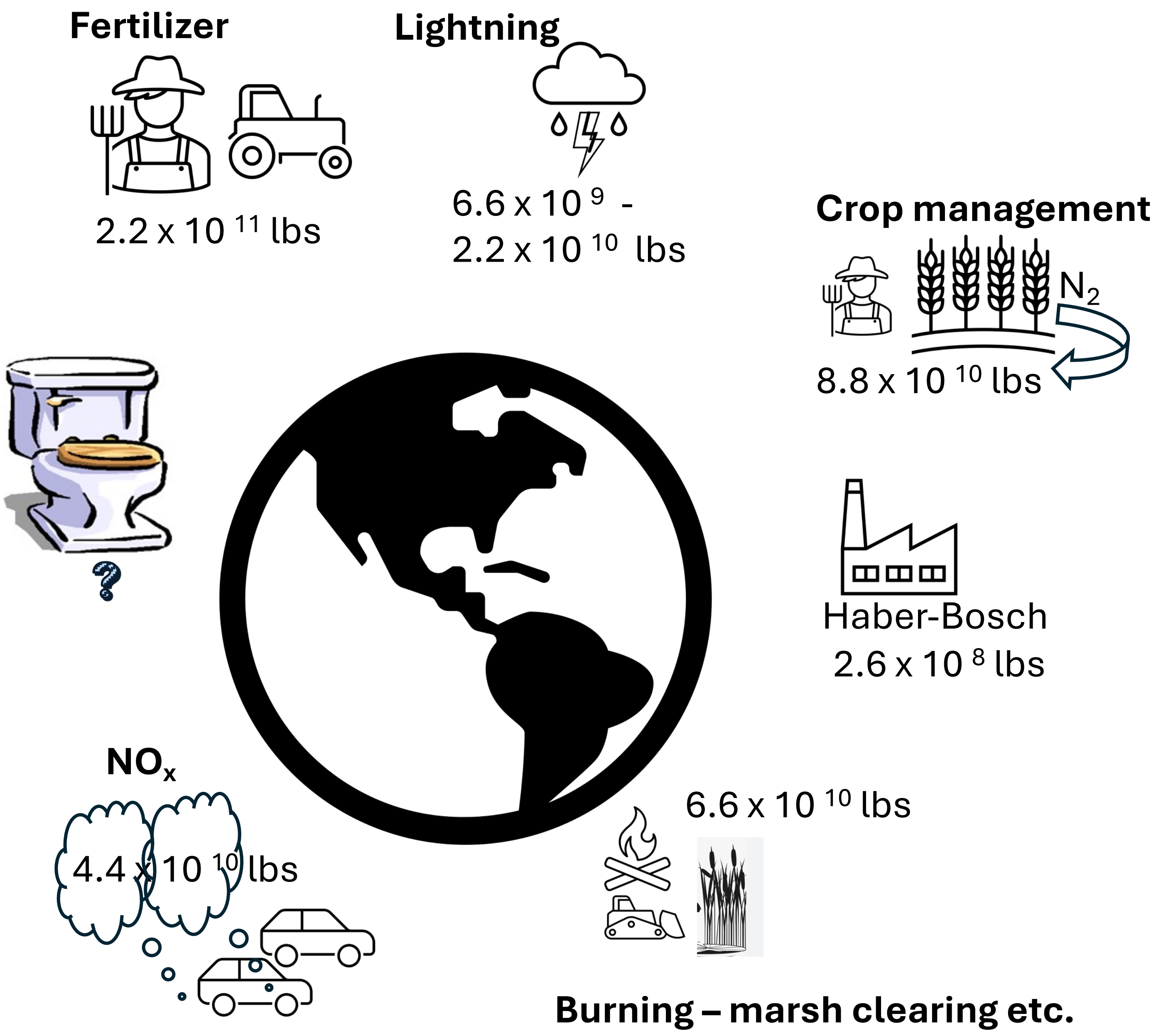
The Big Picture



The Zen of N

WE are part of the nitrogen cycle. We take in nitrogenous nutrients that ultimately came from organisms that fixed atmospheric nitrogen gas (or plants that got their nitrogen from commercial fertilizers). We excrete what nitrogen we don't need, primarily as urea, into our septic tanks. Bacteria in the septic tank anaerobically ammonify the nitrogen. Other bacteria aerobically nitrify the ammonia in the soil as wastes pass through the leachfield. If we introduce nitrified waste to the right anoxic setting, we can denitrify the wastewater or turn the nitrate into nitrogen gas. And the cycle continues…..

Thinking globally about reactive nitrogen



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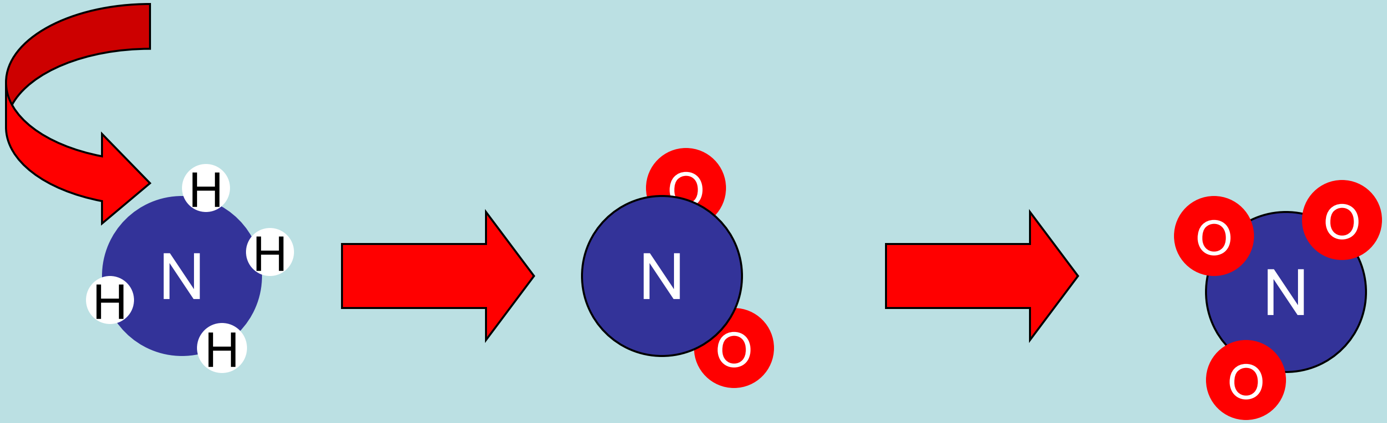
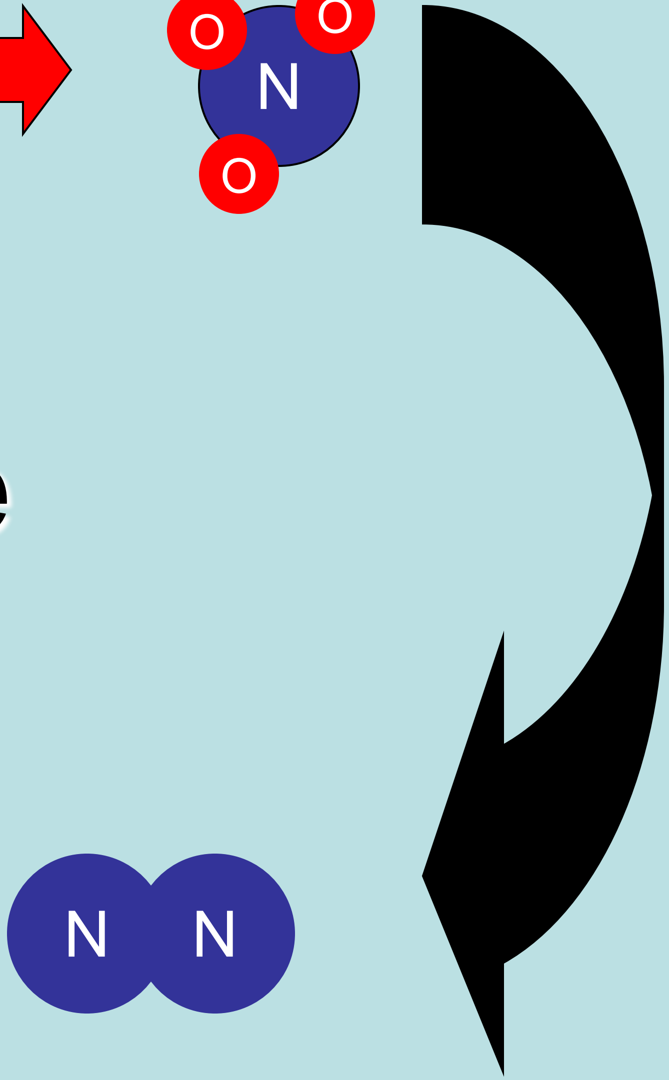
Bringing it down to earth
Nitrogen cycling in onsite
wastewater treatment
systems



Nitrogen
A Brief Primer for the Onsite Professional



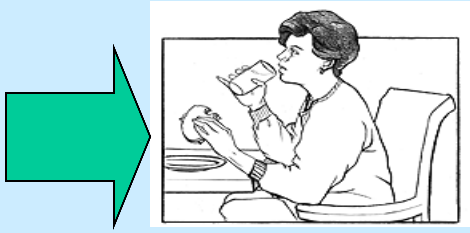
It's all about the biology

(sort of)

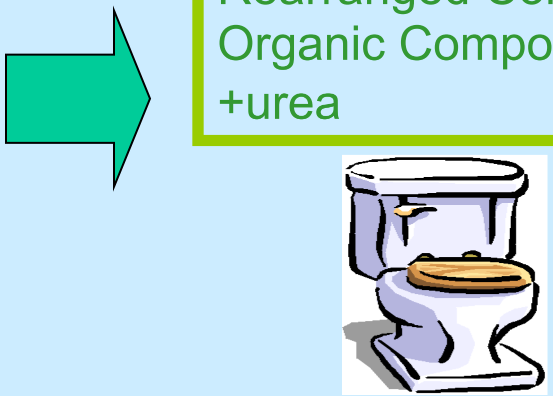
Before we begin

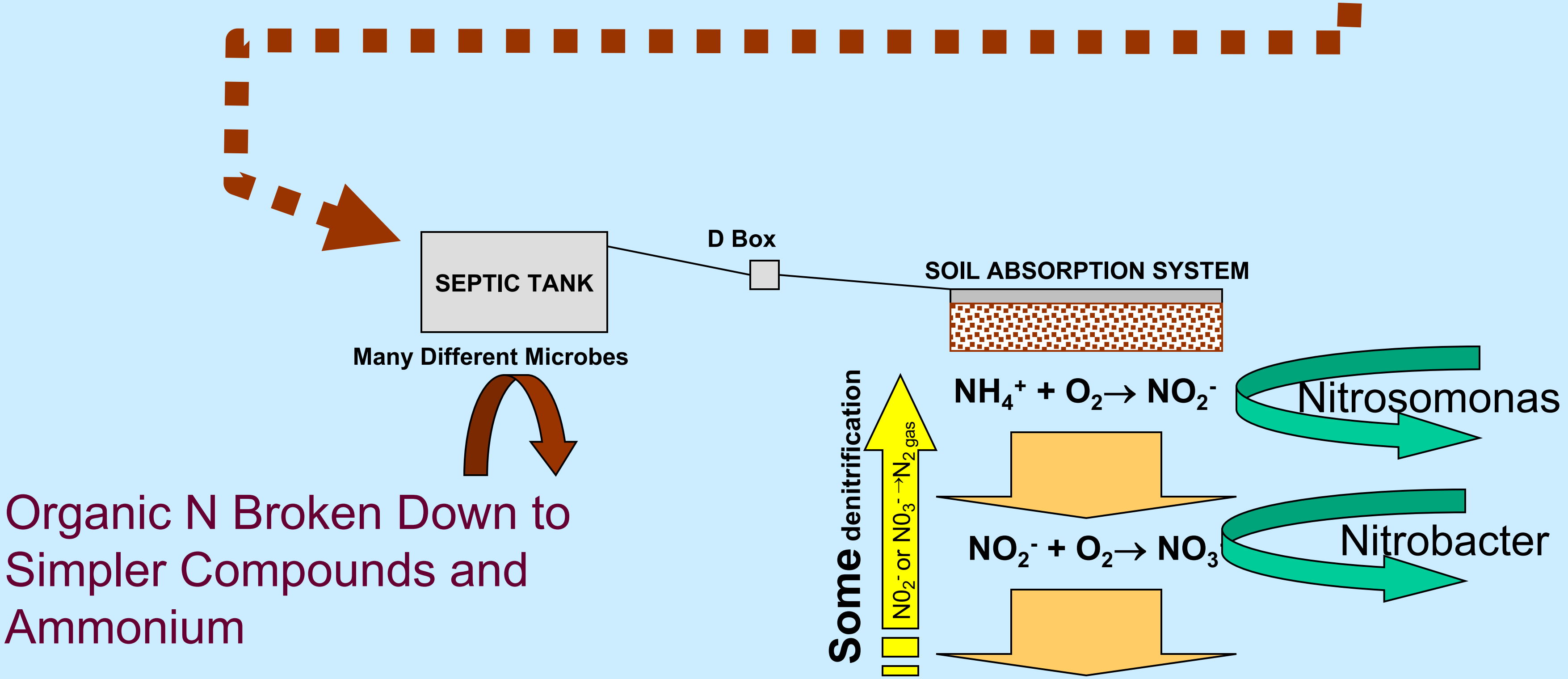
Nitrogen cycling takes many convoluted and interesting paths. This presentation only focuses on the ones relating to reactive nitrogen in onsite wastewater treatment and the impact of the remains on the environment from the human perspective. Nitrogen cycled long before we bipeds decided to use clean water to convey our wastes, and it will cycle long after we are gone in ways that we still don't fully understand.

Complex Organic Compounds



Rearranged Complex Organic Compounds +urea






KUBOTA
SVL
First stop – the septic tank
(after the toilet or graywater fixture)

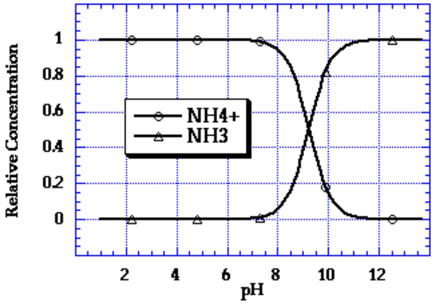
The septic tank is the first step in the processing of wastewater for the onsite septic system

Approximately 80-95% of all organically bound nitrogen exits the septic tank as ammonia(ium)

(dependent on residence time in the tank, temperature and other factors)

UREA IS THE MOST ABUNDANT NITROGEN-CONTAINING COMPOUND IN THE WASTE FROM OUR BODIES AND IS DERIVED FROM THE BREAKDOWN OF FOOD

Organic N (TKN) broken down to simpler compounds and ammonium



http://compost.css.cornell.edu/odors/ammonia.htm

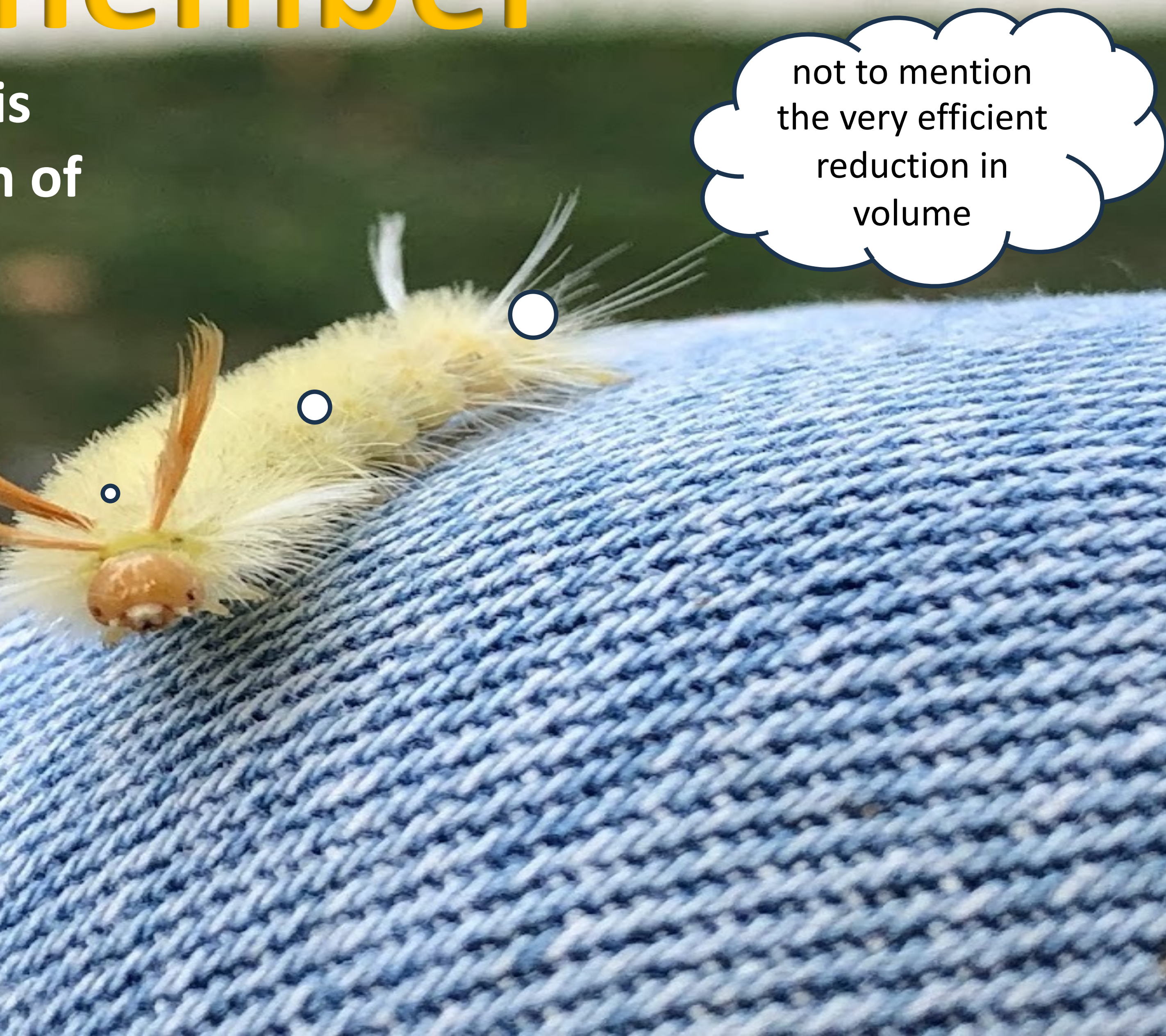
l

Ammonification

Points to remember

The septic tank is a bioreactor that is responsible for initial mineralization of wastewater components

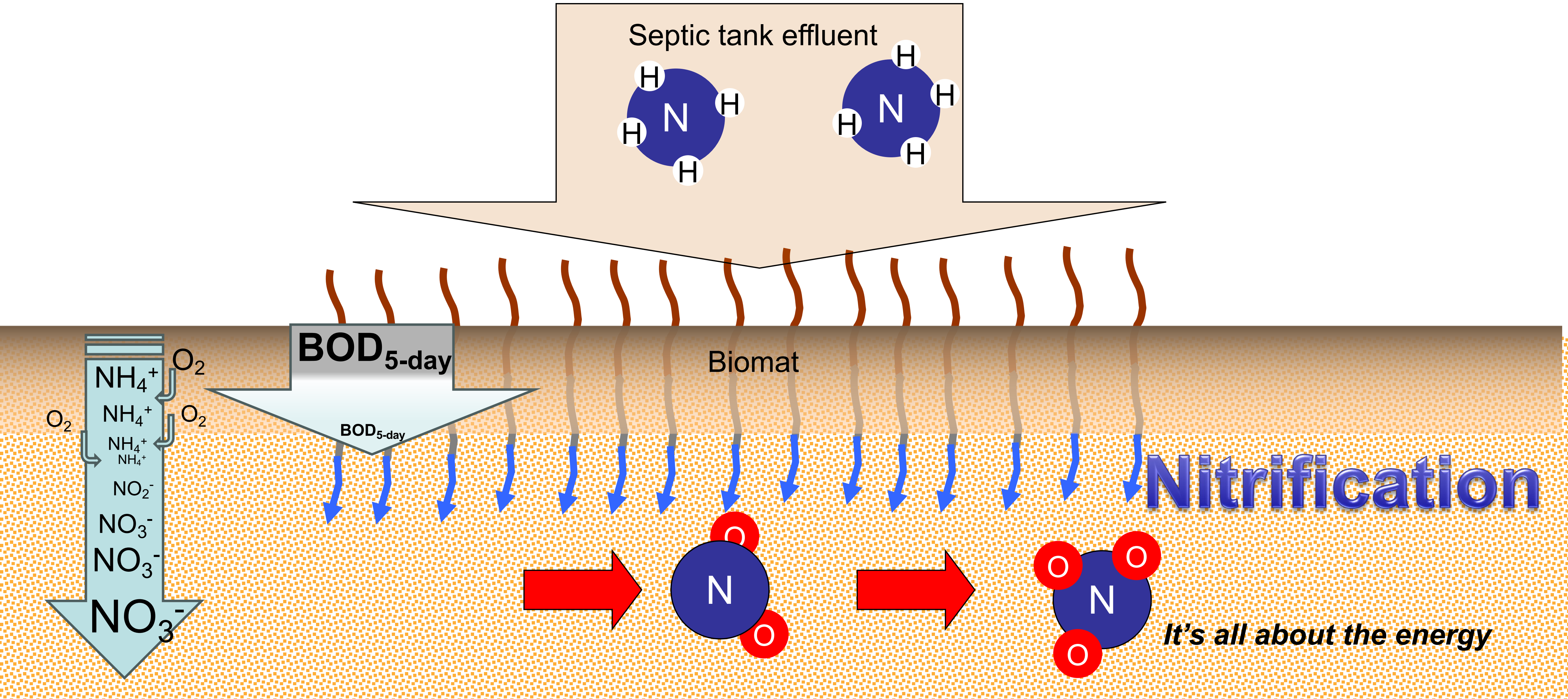
Regarding nitrogen, biological breakdown
of nitrogen-containing components
Results in ammonium (NH_4^+) – or at pH>8 ammonia (NH_3)

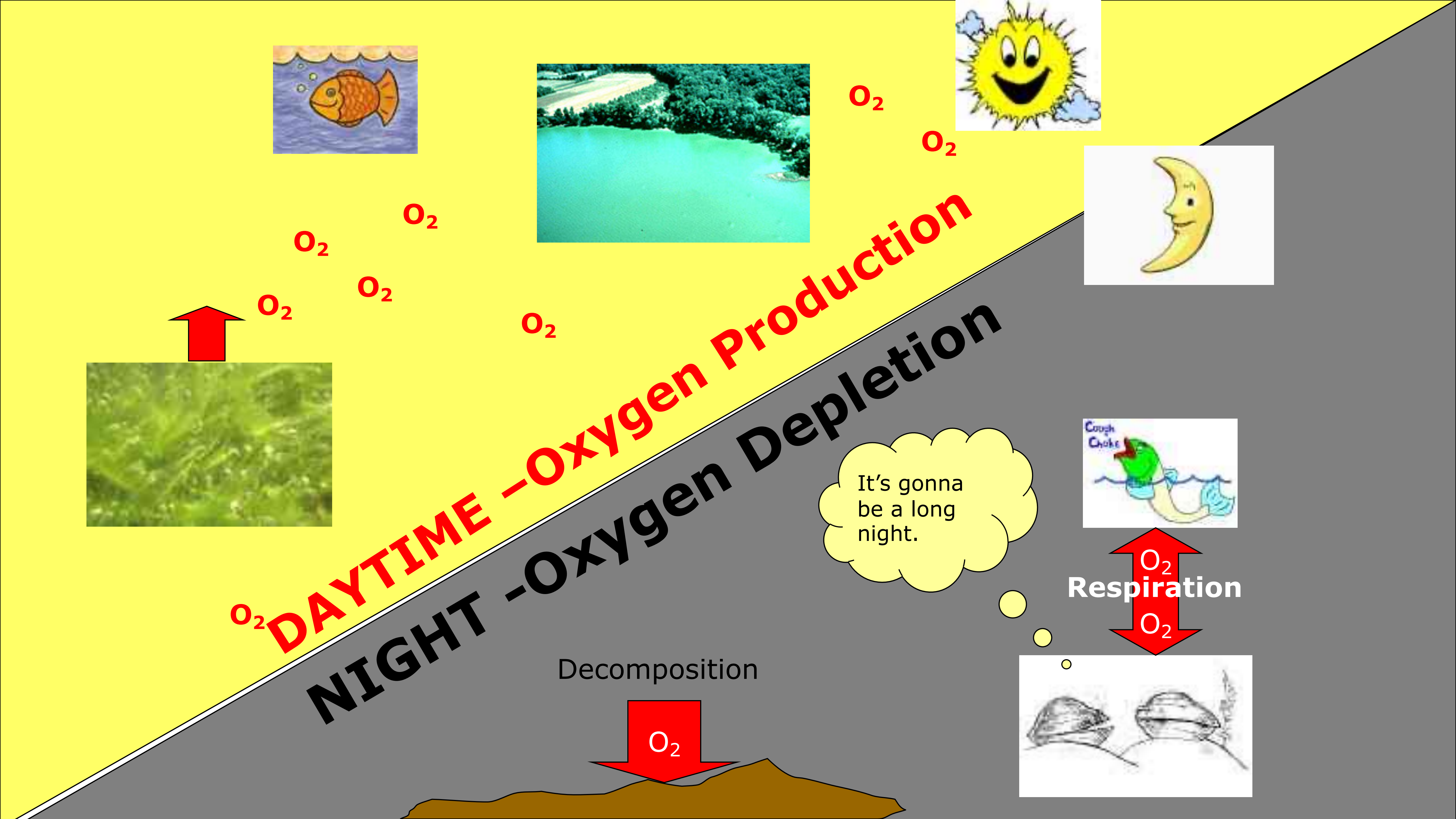



Life after the septic tank …
To the leachfield (a.k.a. soil absorption system, soil treatment area or that spot in the yard that is really green.
H-10

The major nitrogen transformation occurring directly beneath the soil treatment area is the oxidation of ammonium to nitrite and then to nitrate

- *it is biologically mediated*




DAYTIME –Oxygen Production
NIGHT -Oxygen Depletion
O2
O2
O2
O2
O2
O2
O2
O2
O2
It's gonna be a long night.
Cough Choke
O2
Respiration
O2
Decomposition
O2

A few things about Nitrification

(Conducted by aerobic autotrophic bacteria)

Nitrosomonas (and others) *Nitrobacter and others*

$NH_4^+ > NO_2^- +$ ENERGY $> NO_3^- +$ ENERGY

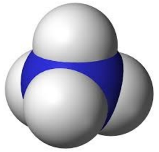
For EACH milligram of ammonium that is oxidized to nitrate:

- **3.96 mg of O_2 are utilized**
- **7.01 mg of alkalinity are removed**
- **0.16 mg of inorganic carbon are utilized**
- **0.31 mg of new cells are formed**

The soil absorption system must have an adequate supply of air if its operation is to be sustainable

Without adequate oxygen, nitrification will not take place, the bacterial community in a soil absorption system will become anaerobic and bacteria will produce exogenous polysaccharides that will clog soil interstices and impede wastewater treatment and movement.

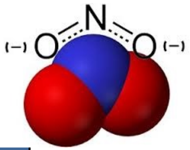
Summary



ammonium
(from septic tank)

Is a cation (positively charged ion) that can get adsorbed to certain soils and organic matter

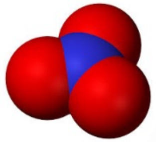
Needs O_2, alkalinity, >10°C – uses inorganic C for growth



nitrite

Is formed from ammonium by a specialized bacterium (like Nitrosomonas) and this is a very transient form of nitrogen.

Needs O_2, alkalinity, >10°C – uses inorganic C for growth

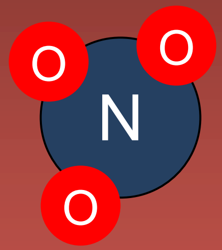


nitrate

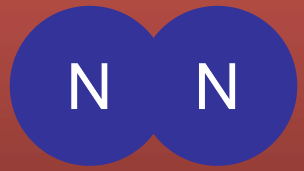
The most oxidized form of nitrogen formed by a specialized type of bacteria (like Nitrobacter and others)

Nitrate is very mobile in soil
- Does not adsorb
- Does not react to form immobile species

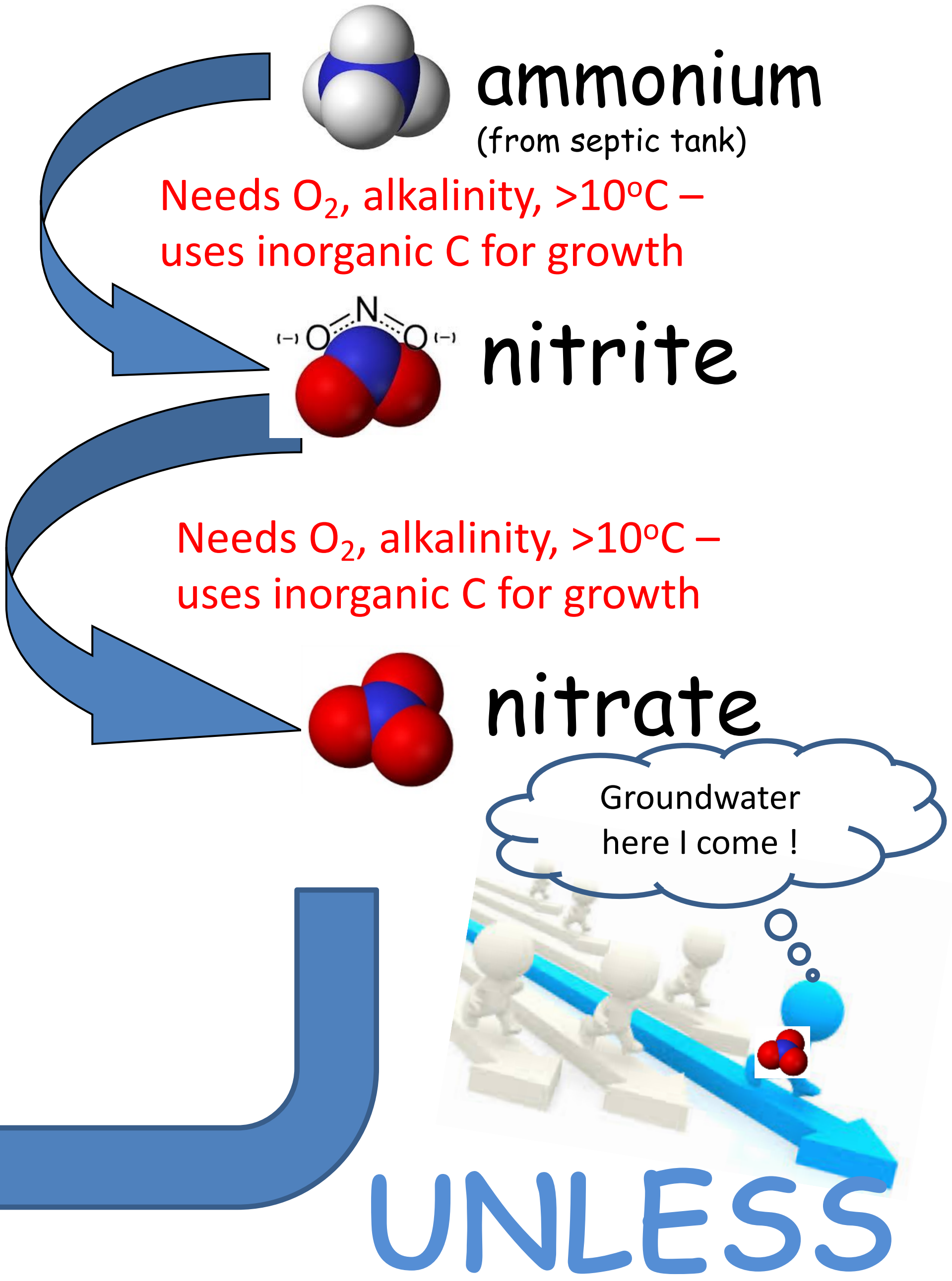
De - nitrification

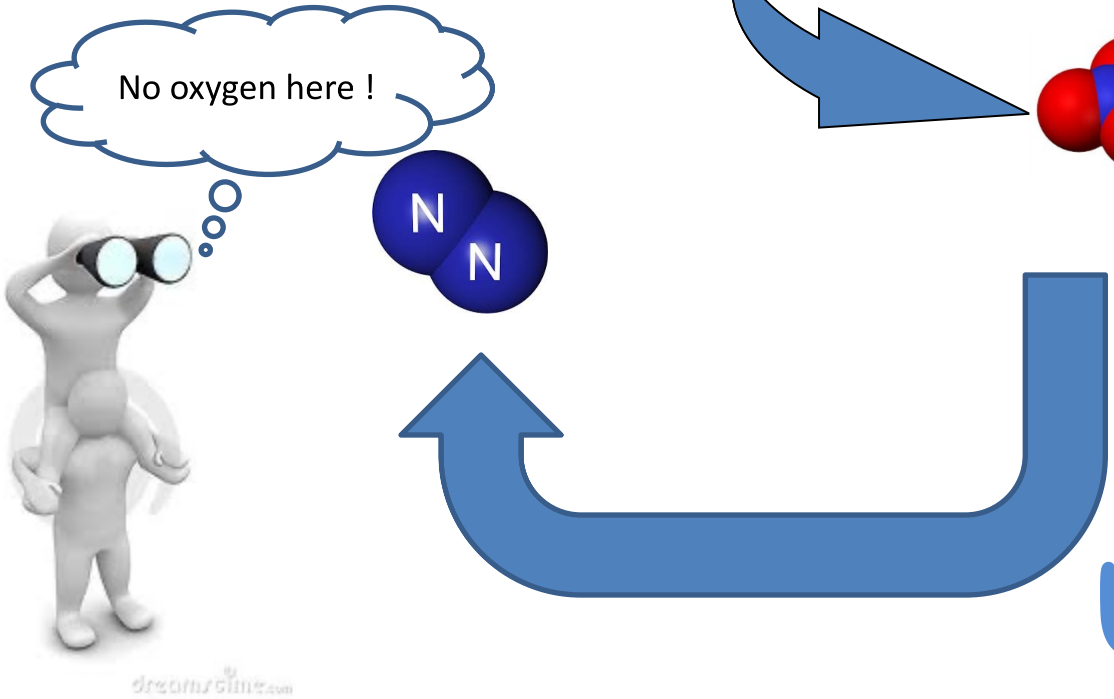


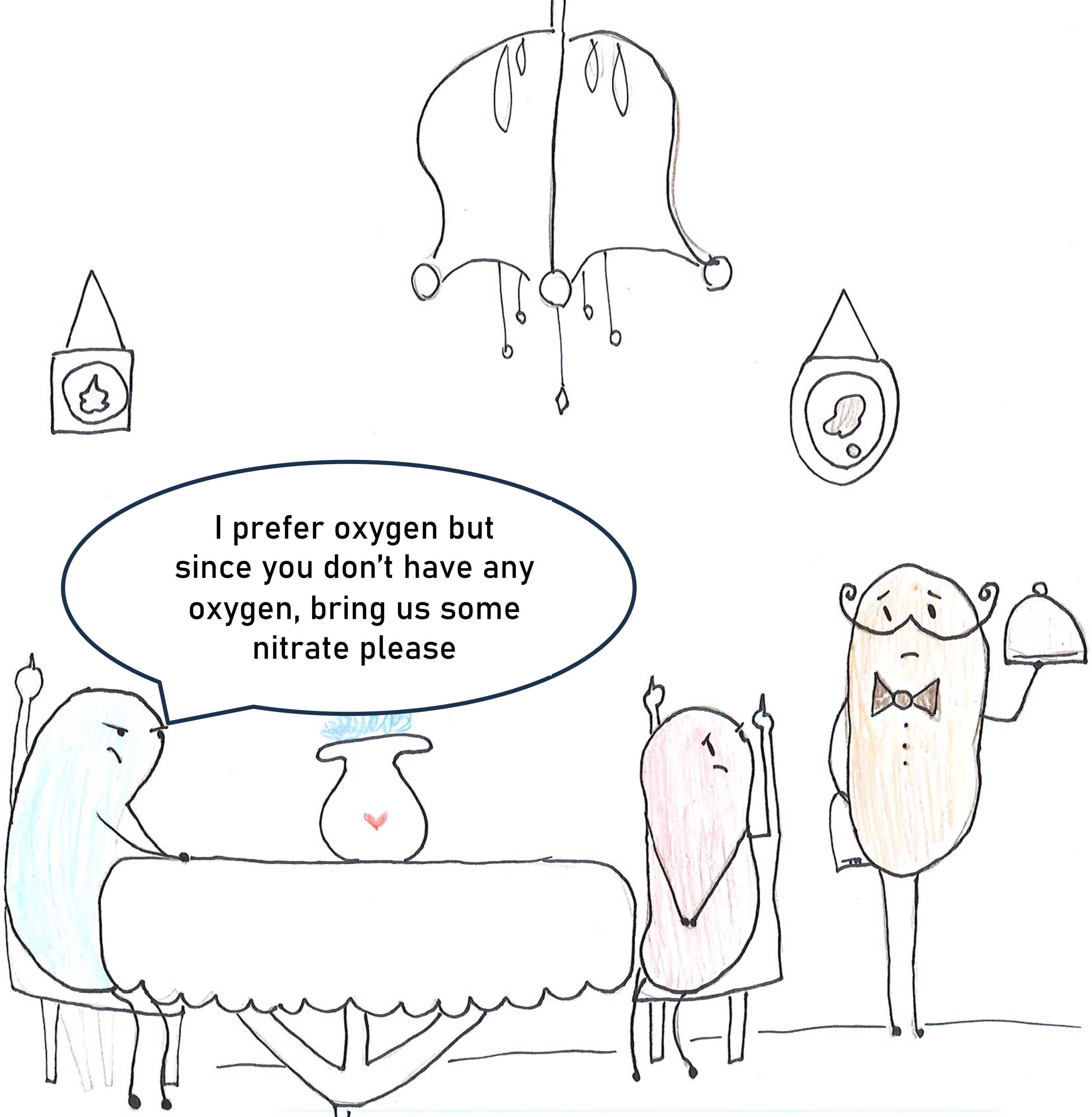
The reduction of nitrate (NO_3^-) in the absence of oxygen to nitrogen gas



Conditions are present that allow for the reduction of nitrate to nitrogen gas. This is done by bacteria (Pseudomonas dentrificans for instance) but they must have enough carbon and anoxic conditions.



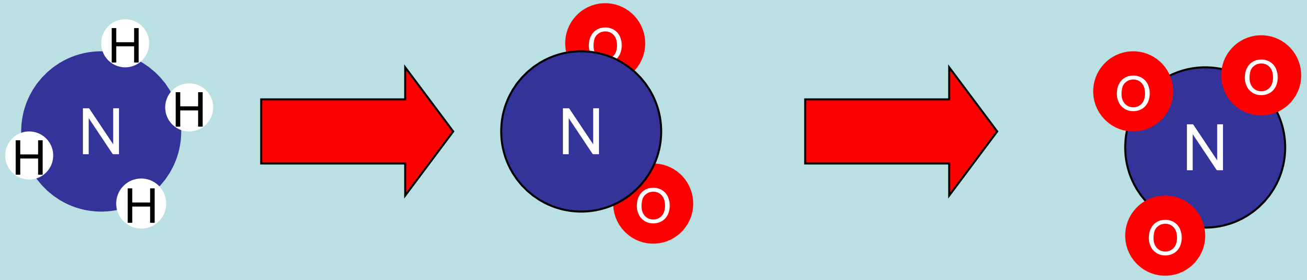




The microbes responsible for denitrification are facultative anaerobes which means that they can derive their required energy in the presence of oxygen or in the absence of it.

They much prefer oxygen

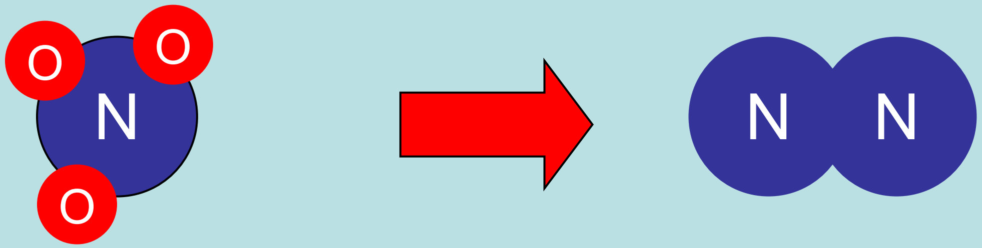
Denitrification (nitrogen removal) is a sequential process..



No oxygen no nitrate

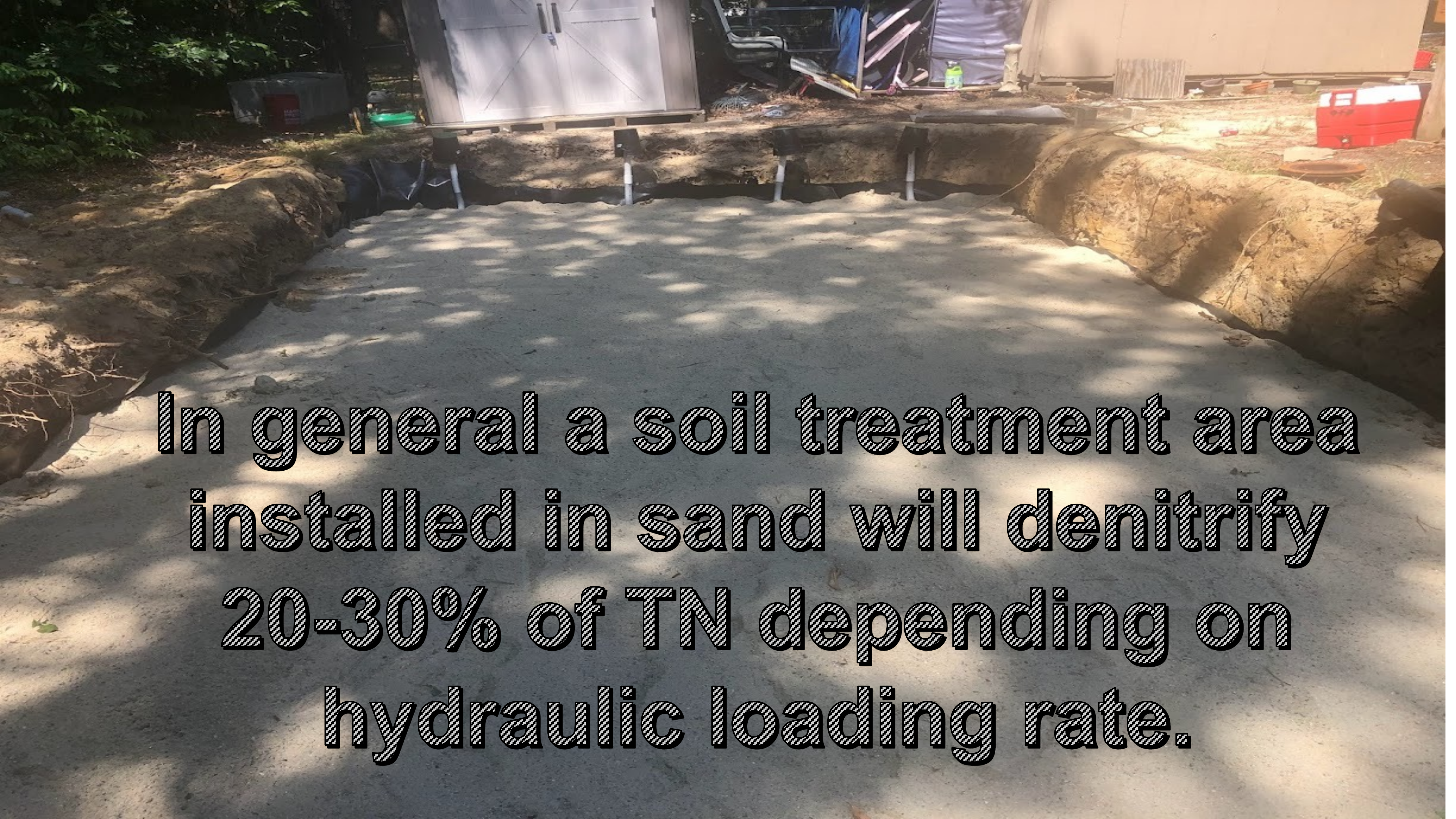
Ammonium (from septic tank) is converted to nitrate by specialized bacteria in an aerobic environment of the soil treatment area.

Then..

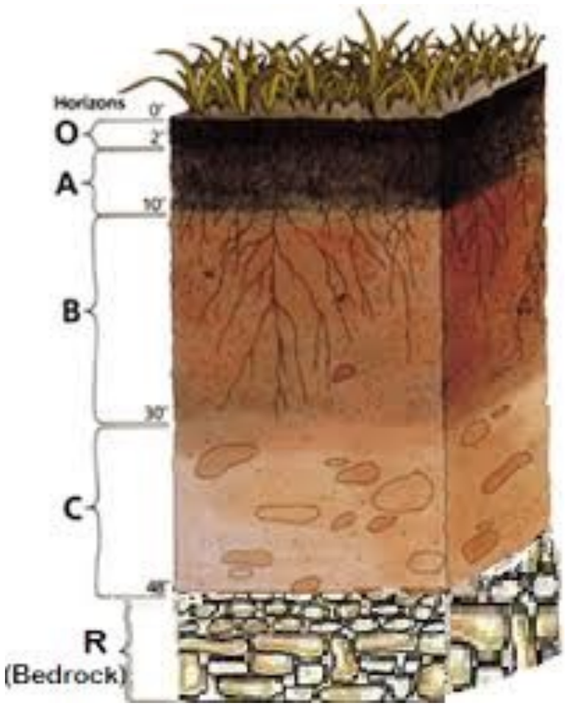


Too much oxygen
no nitrogen gas

Nitrate is reduced to nitrogen gas by a range of bacteria in an anoxic environment.


In general a soil treatment area installed in sand will denitrify 20-30% of TN depending on hydraulic loading rate.

The ideal situation for denitrification



Soil is porous enough to drain (but not so porous that they drain too quickly)

Warm enough to support nitrification and denitrification

Moisture enough to impede airflow for denitrification (but not so much to impede nitrification)

There is enough remaining carbon at the spots where the nitrate is present, there is limited air exchange and that denitrification can take place……………

Get the picture?

Table 2-9. Comparison of STUMOD Estimated Nitrogen Removal to Reported Measured Data.

Soil Texture	HLR (cm d^{-1})	Effluent Conc. (mg-N L^{-1})	Depth (cm)	Measured (% removal)	STUMOD (% removal)	Experimental Setting	Reference
Sand	4.0	48.0	38	0.8	2.6	Laboratory	Potts et al., 2004
Sand	7.0	60.0	60	10.0	6.5	Laboratory	Beach, 2001
Sand	8.4	57	90	5.0	5.0	Laboratory	Van Cuyk et al., 2001
Sand	8.4	57	60	6.0	4.0	Laboratory	Van Cuyk et al., 2001
Sand	5.0	57	90	11.0	7.0	Laboratory	Van Cuyk et al., 2001
Sand	5.0	57	60	3.0	5.0	Laboratory	Van Cuyk et al., 2001
Sandy loam	2.16	61.3	61	36.0	21.0	Field	Andreoli et al., 1979
Sandy loam	2.16	61.3	122	38.0	62.0	Field	Andreoli et al., 1979
Sandy loam	4.0	82.3	60	43.3	37.7b, 43.7c	Field	Tackett, 2004
Sandy loam	2.0	14[a]	60	87.74	86.8	Field	Conn et al., 2009
Sandy loam	2.0	14 [a]	120	99.37	100.0	Field	Conn et al., 2009
Sandy loam	2.0	14 [a]	240	90.57	99.8	Field	Conn et al., 2009
Sandy loam	8.0	14 [a]	60	69.5	68.7	Field	Conn et al., 2009
Loamy sand	1.2	44.25	170	97.0	98.0	Field	Cogger and Carlile, 1984
Sandy clay loam	2.9	47.5	170	98.0	100.0	Field	Cogger and Carlile, 1984
Sandy clay loam	4.1	43.5	170	93.0	98.0	Field	Cogger and Carlile, 1984
Clay	0.4	44.25	170	97.0	100.0	Field	Cogger and Carlile, 1984
Clay	0.4	44.25	170	98.0	100.0	Field	Cogger and Carlile, 1984
Clay	1.0	44.25	170	98.0	99.0	Field	Cogger and Carlile, 1984
Clay	3.7	31.1	60	99.3	99.8	Field	Radcliffe unpublished[d]
Clay	3.7	31.1	90	99.9	99.9	Field	Radcliffe unpublished[d]

[a] Nitrified effluent as nitrate = 14 mg-NO_3 L^{-1}.

[b] Denitrification rate = 2.58 mg L^{-1} d^{-1}; default value provided in STUMOD.

[c] Denitrification rate = 3 mg L^{-1} d^{-1}; input parameter adjusted from default value.

[d] Data from field testing, see User's Guide, Appendix C.

Both the measured data and STUMOD output show a relatively higher removal in clayey

by:
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University of Georgia

2010

WERF

WERF
Water Environment Research Foundation
Collaboration. Innovation. Results.

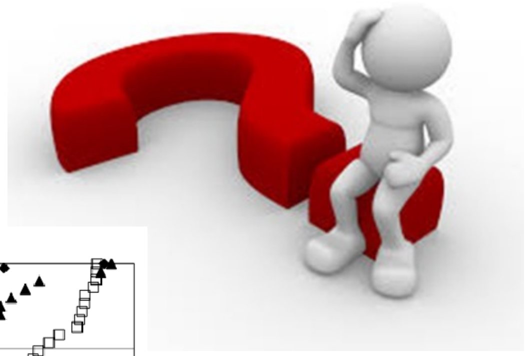
Quantitative Tools to Determine the Expected Performance of Wastewater Soil Treatment Units

GUIDANCE MANUAL

Co-published by
IWA Publishing

So, how can we make sense of it all?

Computer models or spreadsheets that incorporate literature values and help approximate nitrogen reductions in any given setting.



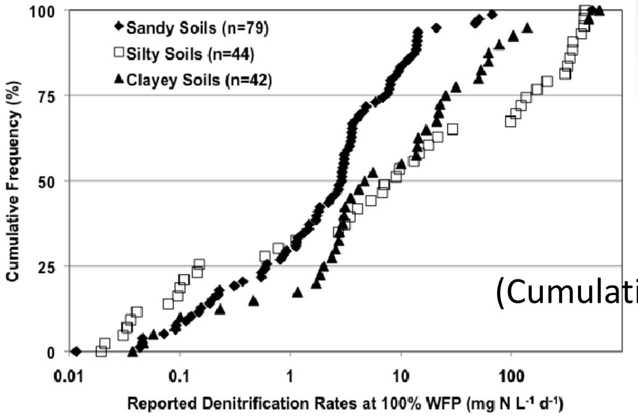


Figure 2-10. Maximum Denitrification Rates by Soil Group.
(165 data points assimilated from the literature, adapted from Tucholke, 2007)

CFDs
(Cumulative Frequency Distributions)

STUMOD
(Soil Treatment Unit Model)

N-CALC

HYDRUS

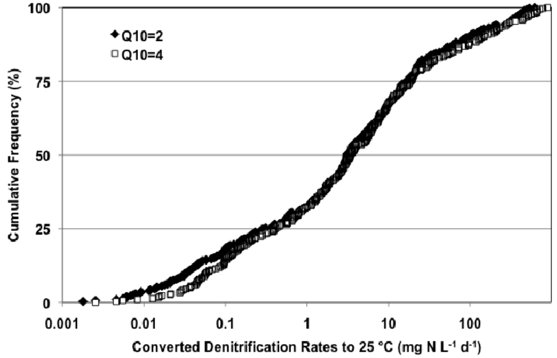


Figure 2-9. Comparison of Denitrification Rates as Function of Soil Temperature.
(306 data points assimilated from the literature adapted from Tucholke, 2007).

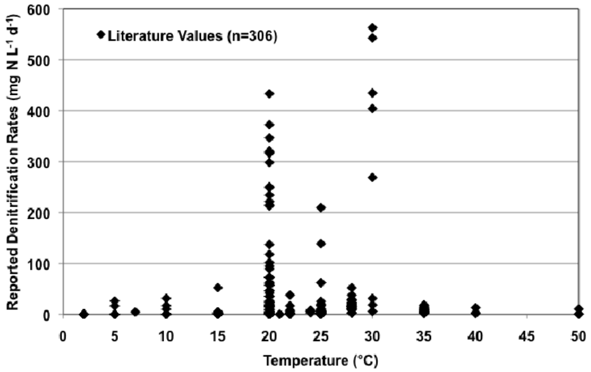


Figure 2-8. Denitrification Rates as Function of Soil Temperature.
Plot contains 306 data points assimilated from the literature (data from Tucholke, 2007).

Determining nitrogen-removing potential in your situation

Increasing complexity and cost

Best Guess

CFDs

Spreadsheet “model”

N-CALC

Computer model

STUMOD

HYDRUS

Develop site specific data

Tibetan approach

Where does denitrification take place?

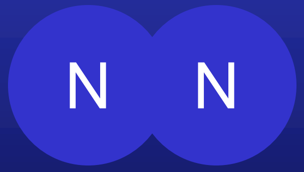
Wherever the conditions necessary occur

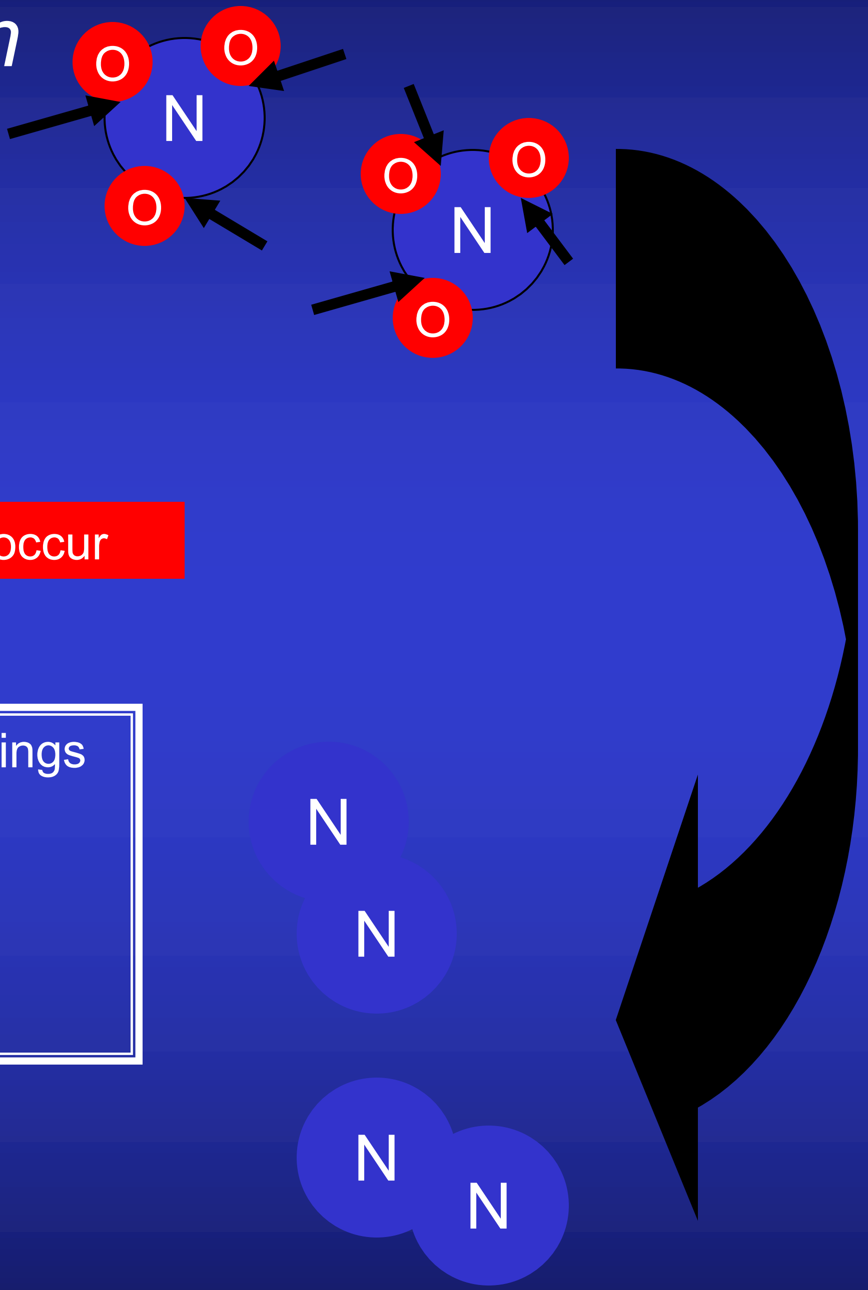
In Manipulated Onsite Wastewater Settings

- septic tanks
- “anoxic chambers”
- recycle chambers
- microzones

In Natural Settings

- sediments
- wet soils
- farmland





Denitrification

(at least 17 genera of bacteria are capable of denitrification)

$$NO_3^- + \text{ Carbon} > N_2$$

For EACH milligram of nitrate-nitrogen that is converted to nitrogen gas:

- **2.7 mg of methanol (if used as carbon source) are utilized**
- **3.57 mg of alkalinity are formed**
- **0.74 mg of new cells are formed**

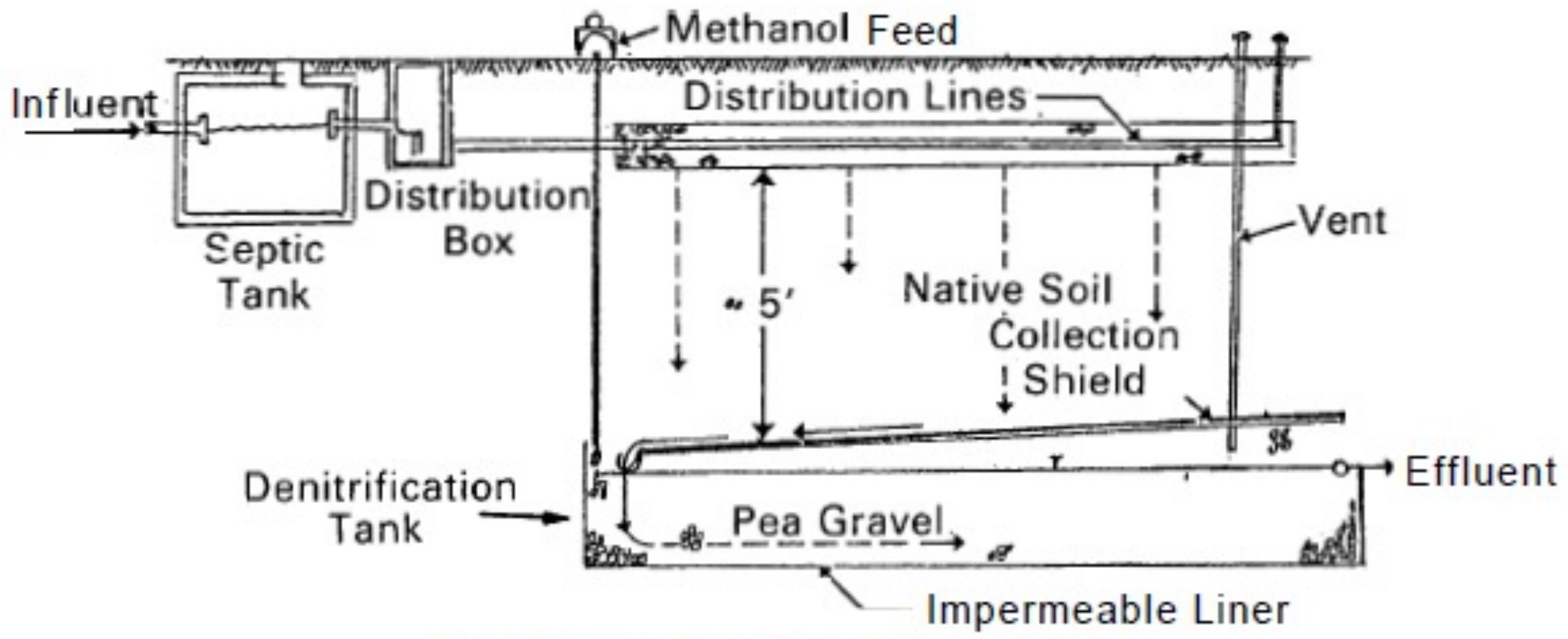
A Blast from the Past

1980

EPA features a profile system that interrupts nitrified percolate and supplies carbon for denitrification

Source:

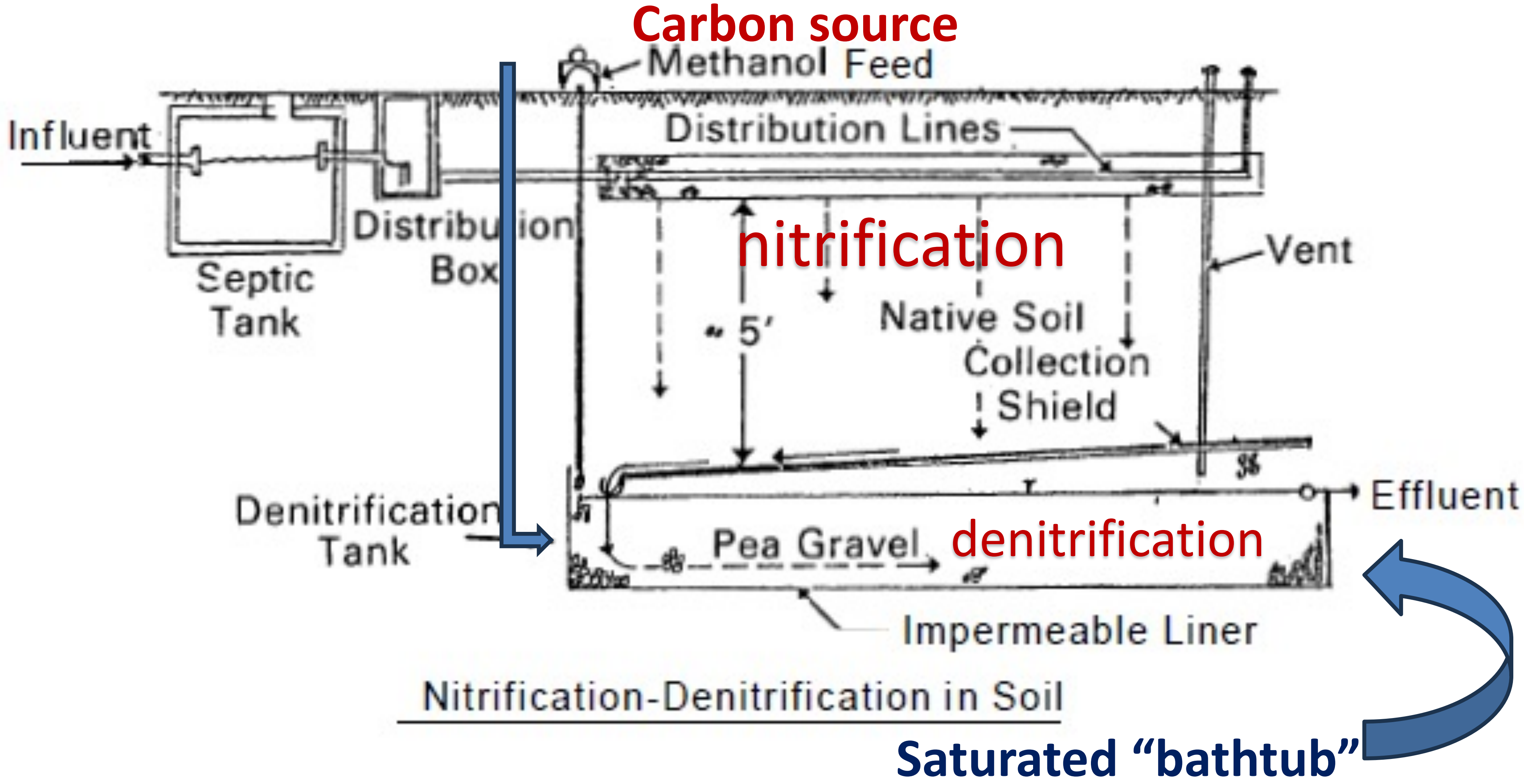
EPA 1980 ONSITE WASTEWATER TREATMENT AND DISPOSAL DESIGN MANUAL



Nitrification-Denitrification in Soil

Source:

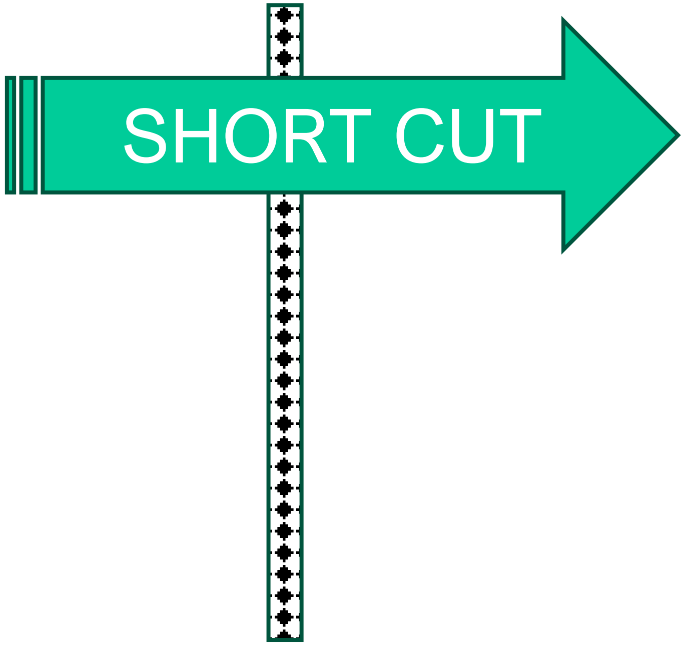
EPA 1980 ONSITE WASTEWATER TREATMENT AND DISPOSAL DESIGN MANUAL



Nitrification-Denitrification in Soil

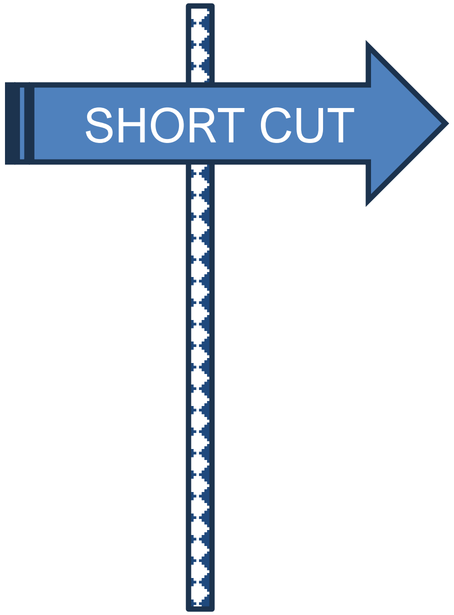
Before we leave the topic

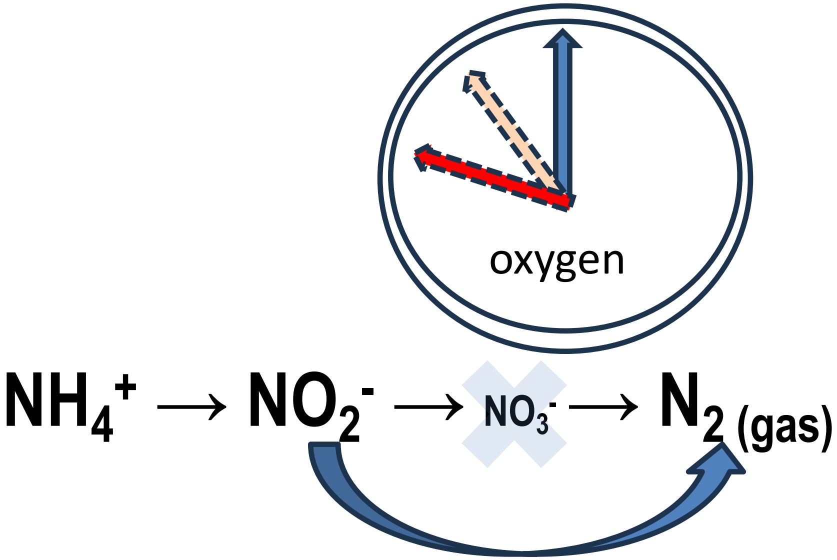
Short cutting the nitrogen cycle in onsite wastewater treatment



No matter how deep the soil treatment area, some nutrients are cycled though vegetation uptake

Restricting dissolved oxygen (DO) can decrease the growth rate of nitrite oxidizing bacteria (NOB) to achieve the enhancement of ammonia oxidizing bacteria (AOB)





Requires ~ 40% less carbon and 25% less oxygen

Nitritation- denitrification

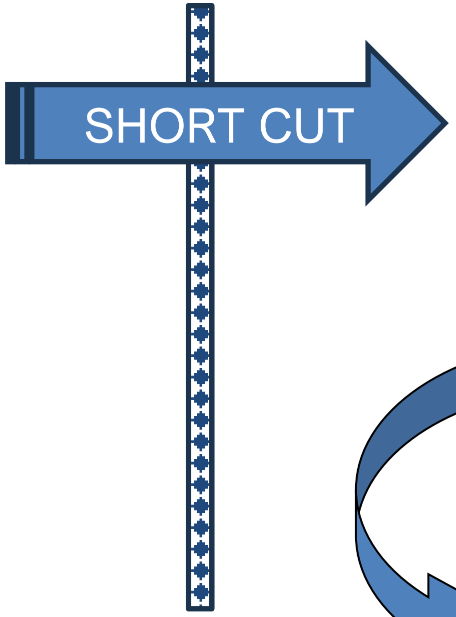
$$NH_4^+ \rightarrow NO_2^- \rightarrow N_{2\,(gas)}$$

Anammox (anaerobic ammonium oxidation)

Some denitrification worth a mention

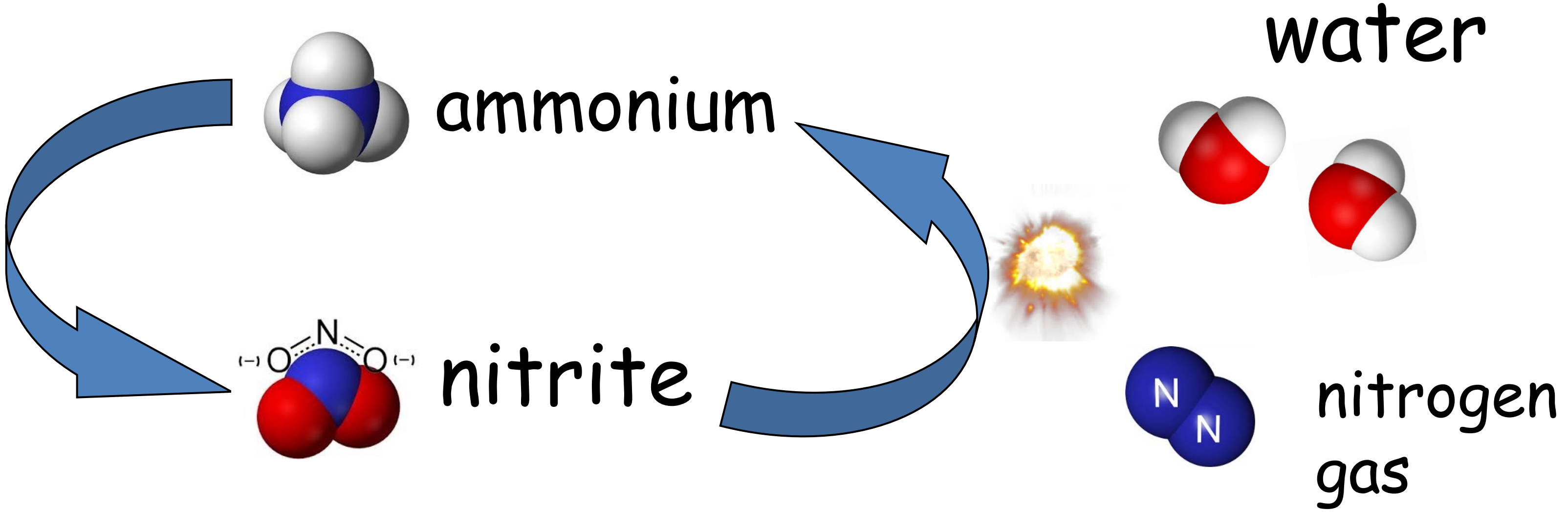
$NH_4^+ \rightarrow NO_2^- \rightarrow$ ~~NO_3^-~~ $\rightarrow N_{2\,(gas)}$

Requires ~ 40% less carbon and 25% less oxygen



Nitritation- denitrification

$NH_4^+ \rightarrow NO_2^- \rightarrow N_{2\,(gas)}$



Aerobic Denitrification

“There are more abilities of bacteria, fungi and archaea than dreamt of in all your biological meditations”

Sue D. Monas at the *Third Conference on Beneficial Microbes*, Madison Wisconsin 2018

Nitrogen

SUMMARY

Alternate less understood and difficult to manage denitrification pathways

Nitrification » plant biomass » decomposition » denitrification

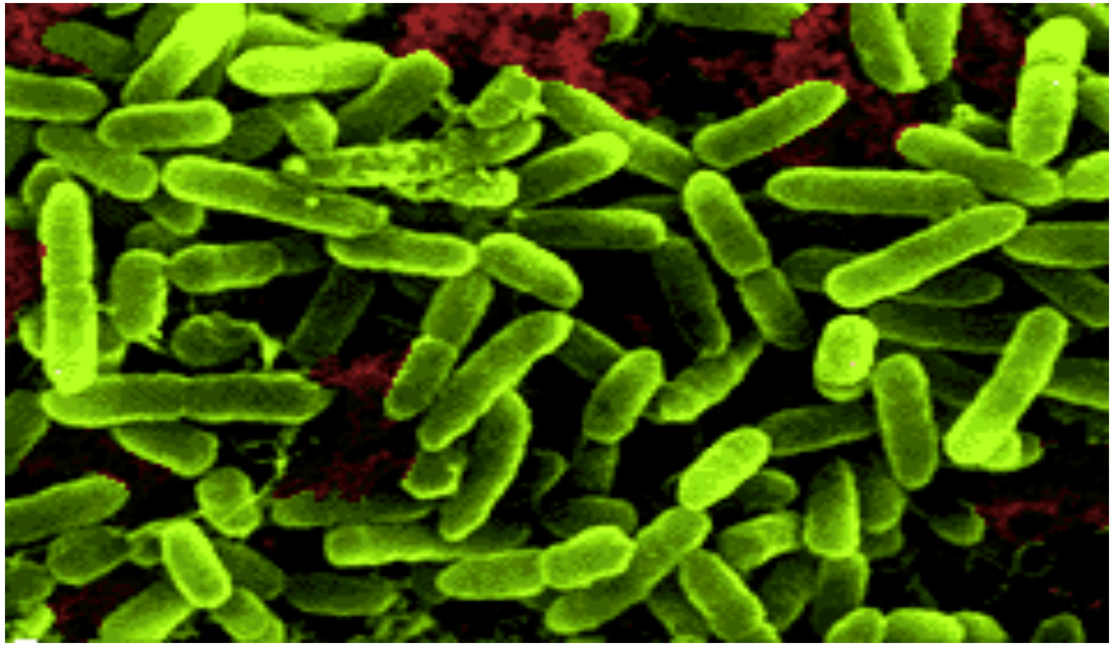
Nitrification - denitrification pathways

$NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^- \rightarrow N_{2\,(gas)}$

Important to Remember!

Important to Remember!

NITROGEN TRANSFORMATIONS IN WASTEWATER ARE MEDIATED PRIMARILY BY BACTERIA



It's all done by biology and it's all about ENERGY!

Questions ?