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Manure anaerobic digestion and fertilizer production - assessment of technology energy demand

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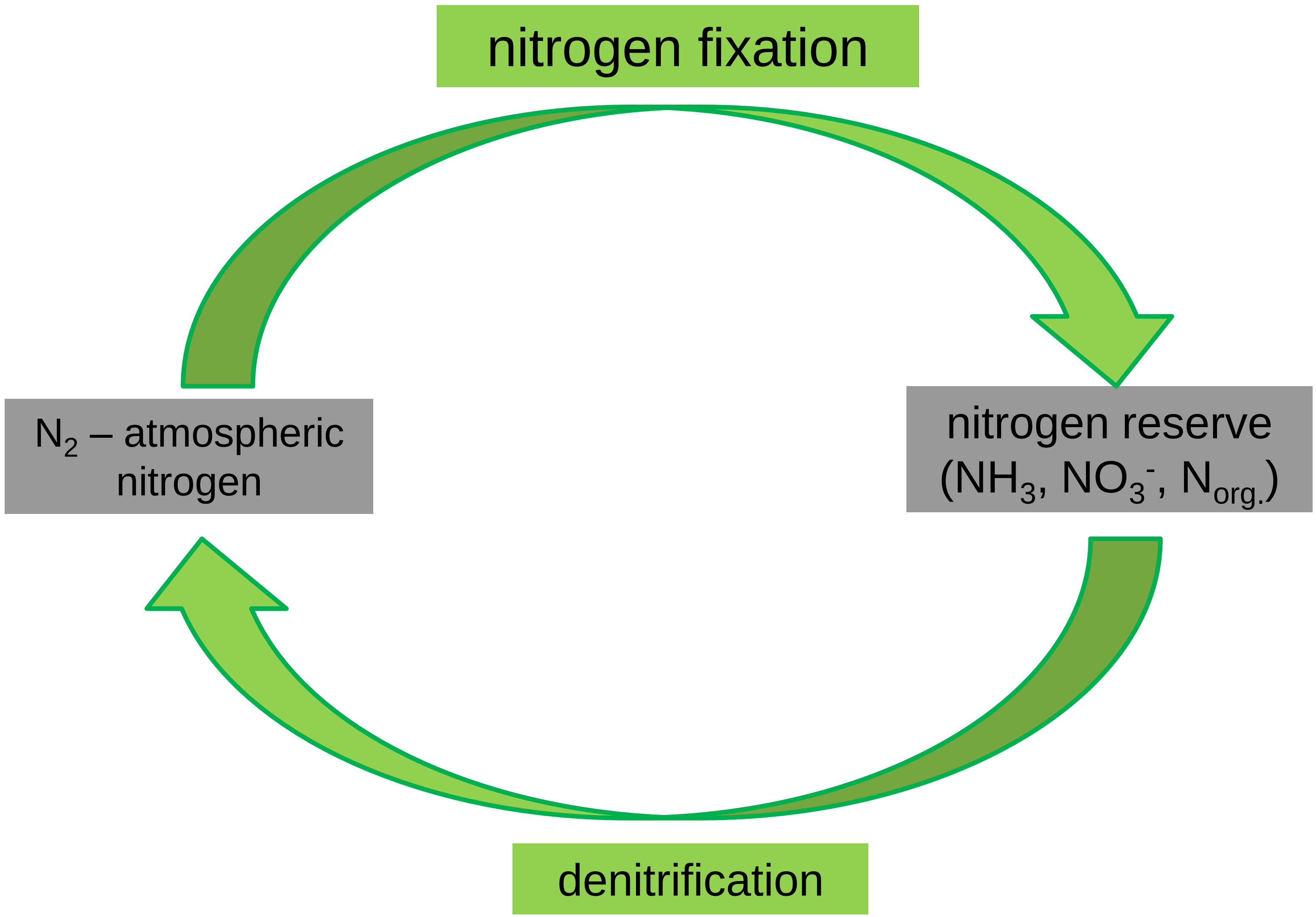
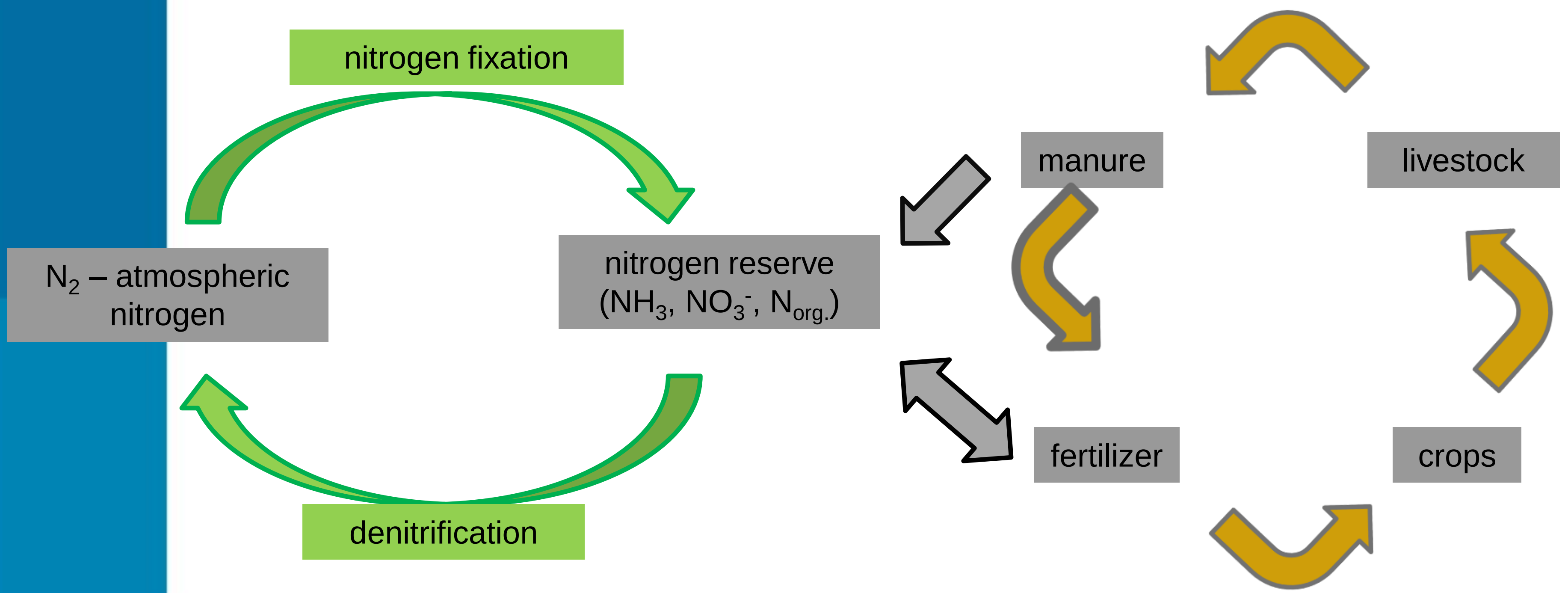
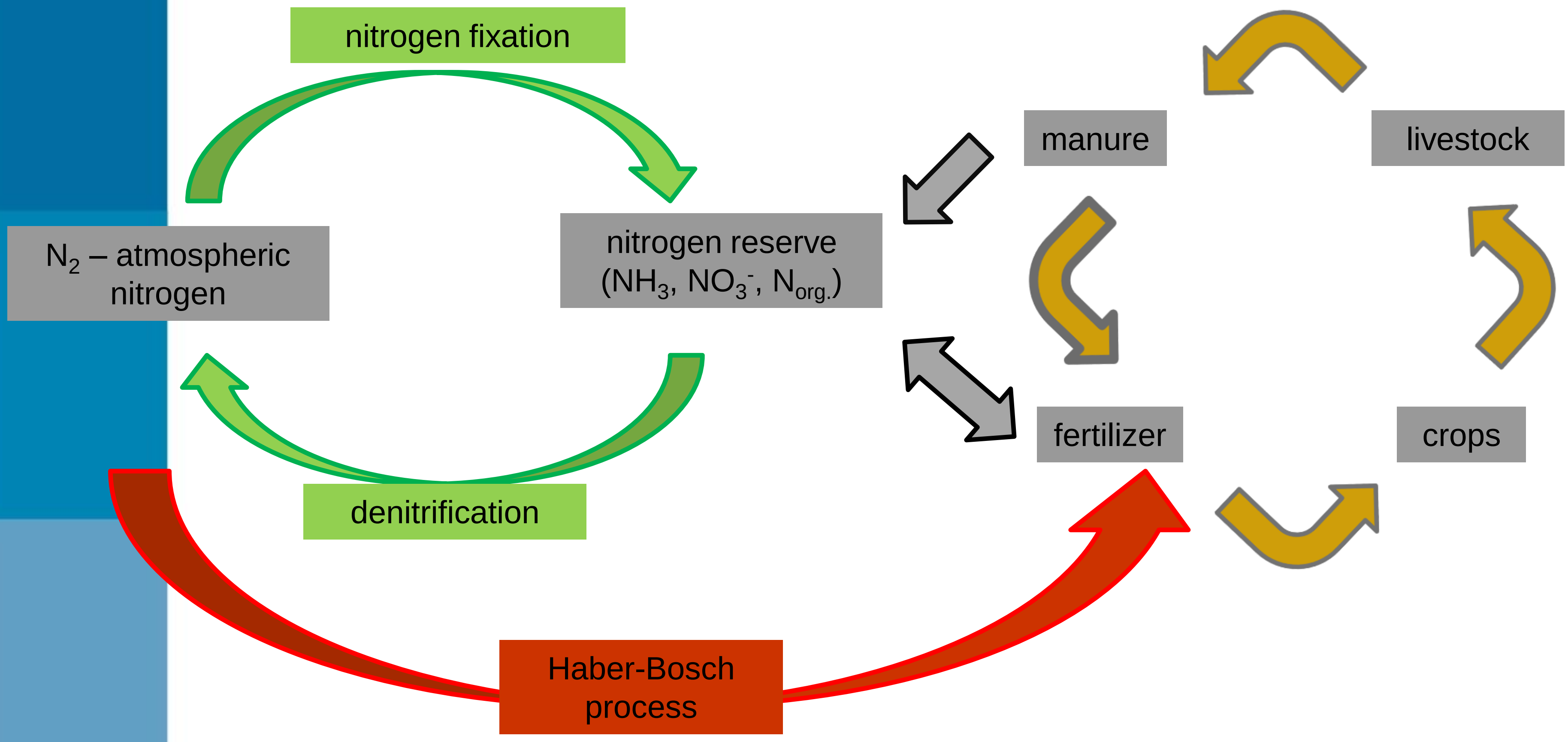
Nitrogen cycle in the nature



Agriculture and natural nitrogen cycle.



Modern intensive agriculture interupts natural nitrogen circulation.



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Haber-Bosch process (HB)

$$N_2 + 3\ H_2 \rightarrow 2\ NH_3$$

- Due to high activation energy requires high temperature and pressure (20-40 MPa, 400-650 °C).

- Hydrogen is obtained from methane (natural gas) in steam reforming.

- Fixation of 1 t of nitrogen consumes 13 700 kWh (49 GJ) of raw energy.

- **HB relies on fossil fuels!**

Nitrogen cycle alteration causes environmental problems.

- Eutrophication of water due to excess nutrition availability – 85% of ammonia produced is consumed as fertilizer.
- Greenhouse effect and climate change due to CO_2 emission – nitrogen fertilizer production consumes around 8.5% of total world natural gas production.

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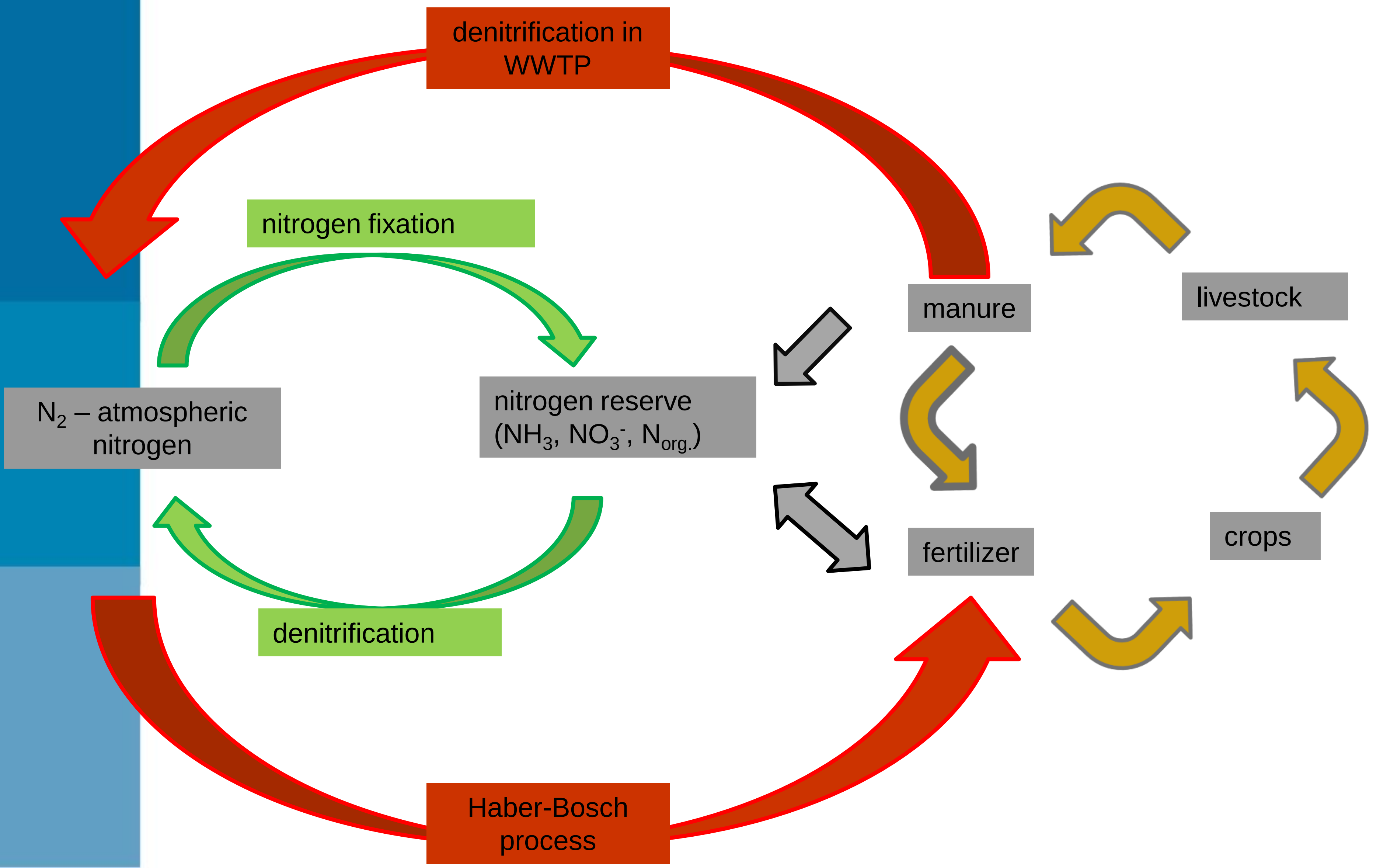

How much nitrogen can we recover form manure?

World nitrogen in animal manure.

Animal	Population [millions] (year 2017)	Average manure production [t/day]	Nitrogen concentration	Available nitrogen [M t]
Cattle	995	0.04-0.06	0.1%-0.5%	14.2-106.4
Swine	769	0.027-0.038	0.3%-0.7%	18.5-72.8
Poultry	22 705	0.00001-0.000019	0.9%-1.5%	0.7-2.3
Total				**33.4 - 181.5**

World agriculture nitrogen demand estimated for 2018 – **120 milion t**.

Manure fertilization problems

- Only limited amount of manure may be applied.
- Fertilization with manure cause emission of malodors.
- The concentration of nitrogen in manure is relatively low – expensive transport.
- The concentration of primary nutrients (NPK) is to low to be classified as fertilizer according to EU regulations.
- Manure application is allowed seasonally – storage requirements.

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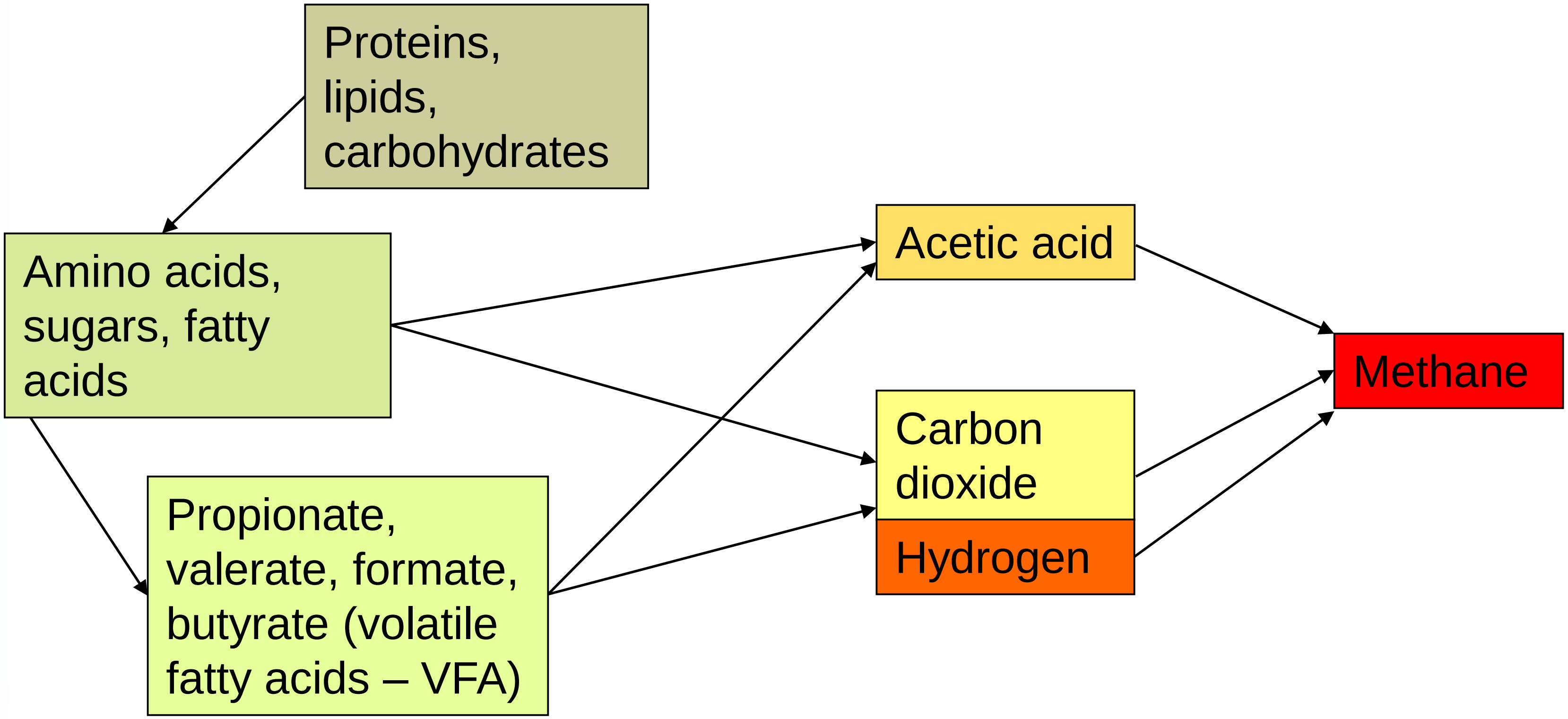
How to recover and process nitrogen and other nutrient from manure to obtain mineral fertilizer?

Nitrogen recovery in three steps

- Concentration of diluted nutrient.
- Stabilization and release of the nutrient.
- Nutrient recovery.

Stabilization - Anaerobic digestion



- energy recovery
- nutrient release
- reduction of malodors (short organic acids)

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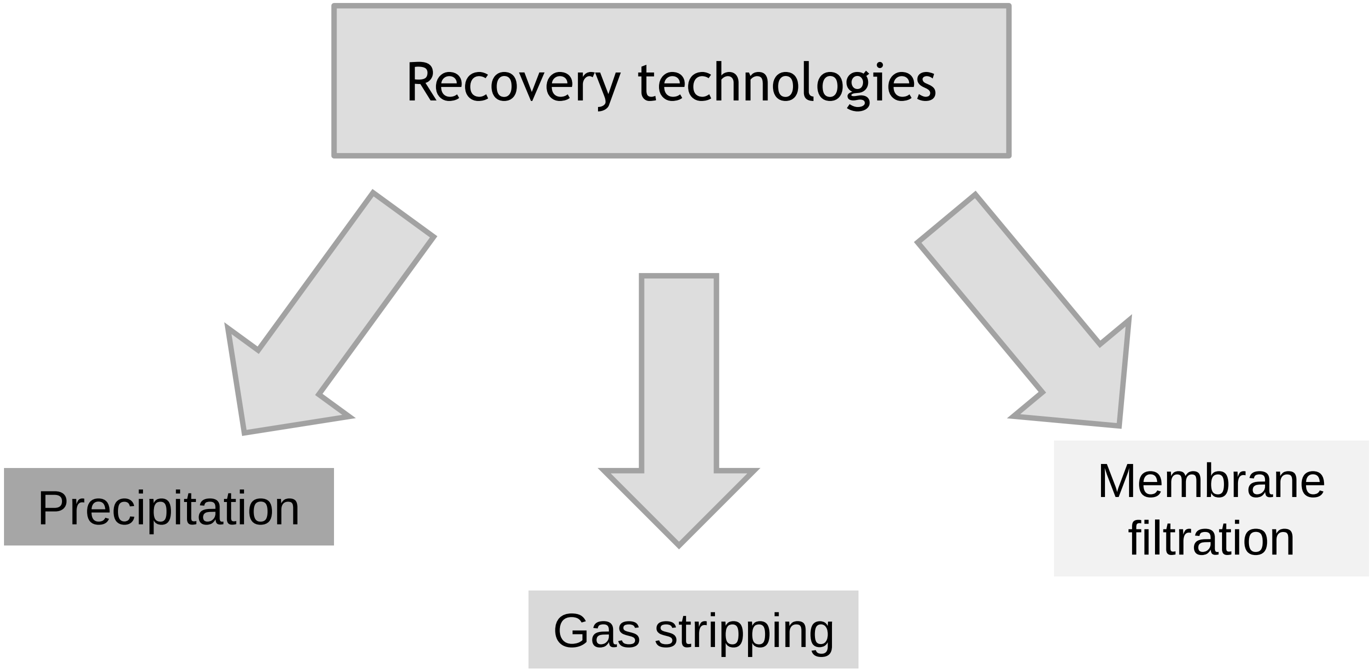
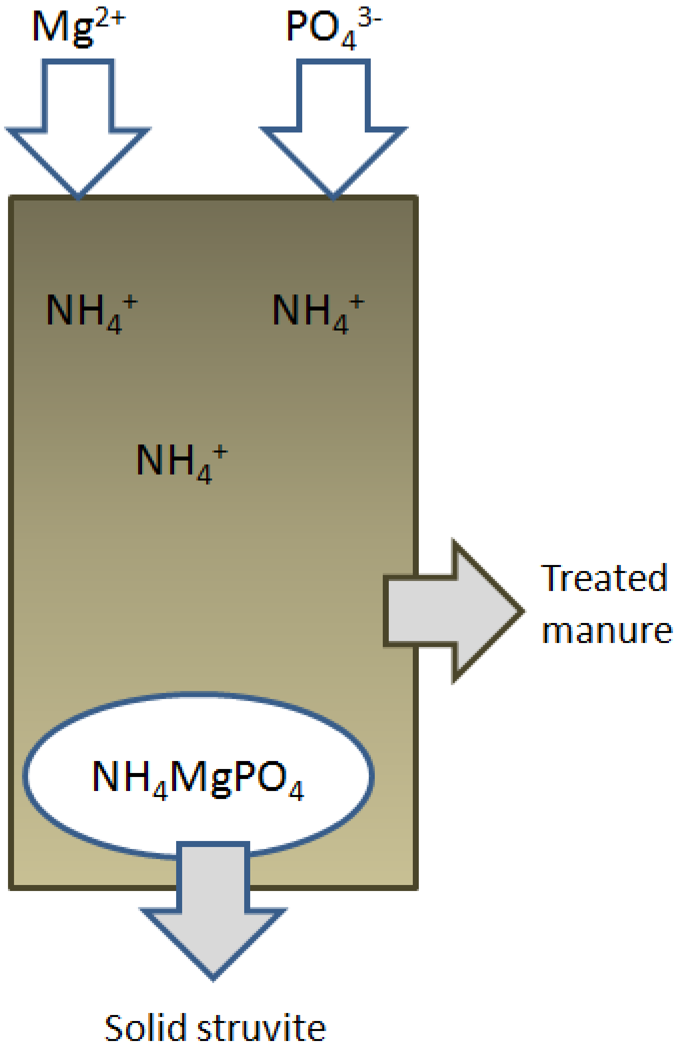
Difficulties in manure anaerobic digestion

- Biogas yield is limited due to low digestibility of biomass in manure.
- Process may collapse due to toxic concentration of ammonia.
- High initial investment cost.

Nitrogen recovery possibilities



Precipitation



- Process requires addition of phosphate and magnesium.
- Equipment is relatively cheap.
- Direct energy input is low (stirring, pumping).

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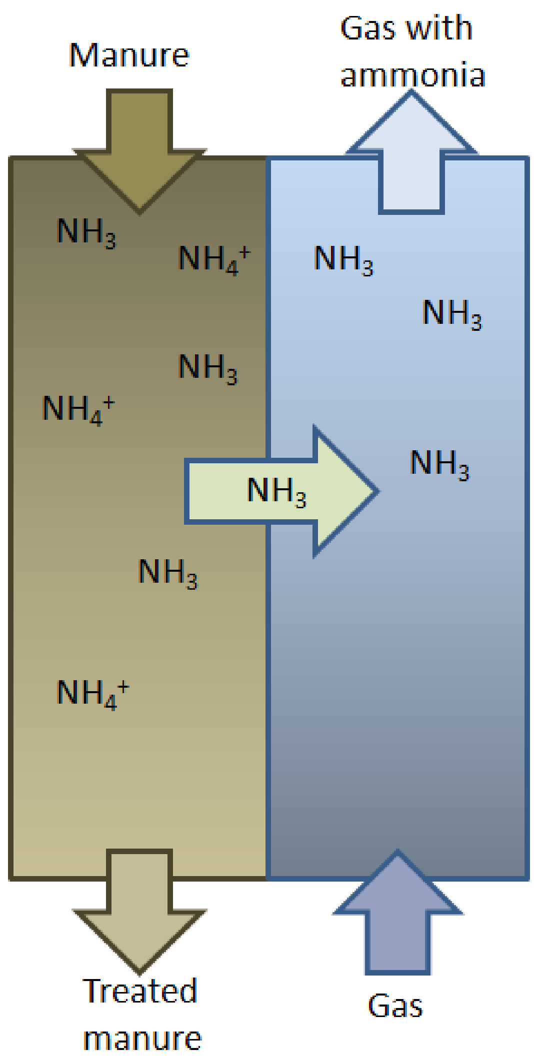
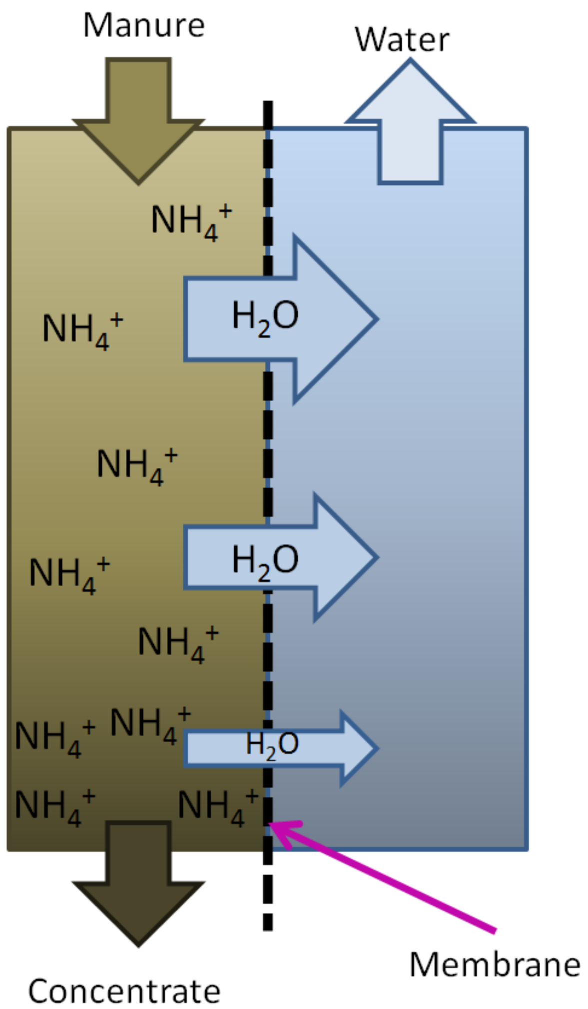
Gas stripping



- Process requires temperature and alkalinity regulation.
- Equipment is sophisticated.
- Direct energy input is around 2230 kWh/t_N

Membrane filtration



- Process may require alkalinity control and cooling.
- Equipment is expensive.
- Direct energy input is around 450 kWh/t_N

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Recovery products

Fertilizer	Processing method	N content [%]	Transport energy demand [kWh/t_N/km]	Nitrogen form
Ammonium sulfate	Gas stripping	0.212	0.56	NH_4^+
Concentrated ammonia solution	Reversed osmosis	0.020	5.95	NH_4^+
Struvite	Precipitation	0.070	1.71	NH_4^+

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Production and transportation energy costs

Fertilizer form	Production energy cost [kWh/t]	Nitrogen transportation cost [kWh/t N/km]
Urea - HB based fertilizer	13700	0.26
Raw manure/digestate	0	23.79
Ammonium sulfate	2230	0.56
Concentrate after reversed osmosis	450	5.95
Struvite after precipitation	40	1.71

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Production and transportation energy costs

Total energy cost [kWh/tN]				
Fertilizer form	**50 km**	**100 km**	**200 km**	**500 km**
Urea - HB based fertilizer	13712.8	13725.5	13751.1	13827.6
Raw manure/digestate	1189.7	2379.3	4758.7	11896.7
Ammonium sulfate	2258.1	2286.1	2342.2	2510.6
Concentrate after reversed osmosis	747.4	1044.8	1639.7	3424.2
Struvite after precipitation	125.6	211.2	382.4	895.9

Final conclusions

- Nitrogen derived from manure may cover significant part of agricultural nitrogen demand.
- Energy required for manure nitrogen recovery is far less than energy consumed in HB process.
- Manure processing may resolve part of problems with intensive animal breading.
- Fertilizers obtained from manure contain inappropriate ratio of nutrients.

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Challenges and perspectives

- Implementation of manure processing requires infrastructure investments.
- Conversion of manure derived nitrogen to nitrate would be desirable.

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