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Elio Dinuccio - Part 2 - CCP and mitigation strategies

UP FARMING Torino, April 2023

Erasmus+

UP FARMING

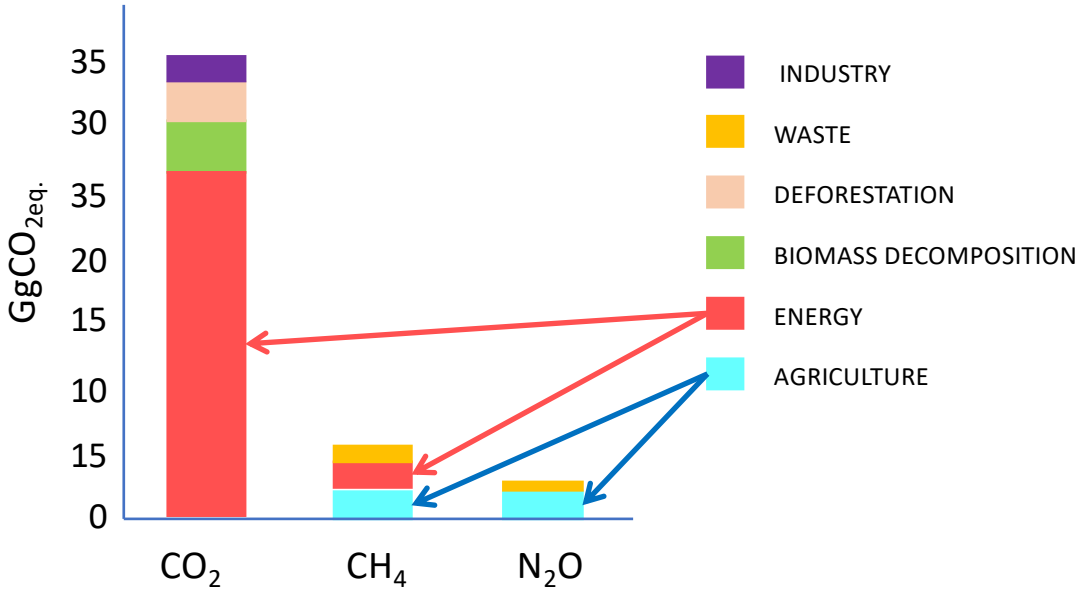
Elio Dinuccio

Mitigations measures

Gas	Method (examples)
CH_4	Anaerobic digestion (biogas)
	Cover on stored slurry
	Acidification
	Capturing and using biogas from stored slurry
N_2O	Anaerobic digestion (biogas)
	Nitrification inhibitors
	Timing of applications
NH_3	Cover on solid/liquid manure
	Acidification
	Application system
	Timing of applications

METHANE EMISSION – A PROBLEM BUT ALSO A RESOURCE

METHANE vs. OTHER GREENHOUSE GASES & SECTORS



Energy Sector Methane Recovery and Use _ The Importance of Policy – pag 9
© OECD/IEA, 2009 _ International Energy Agency (IEA)- (dati da fonte USEPA)

CO_2 EMISSIONS ARE PREDOMINANT

↓

NEVERTHELESS

↓

CH_4 ENERGETIC AND CLIMATIC CHARACTERISTICS

METHANE

Main component of natural gas

It is produced by natural degradation of organic matter (from livestock farms, agriculture activity, urban wastes..)

Can by produced by anaerobic digestion (BIOGAS)

METHANE

- <u>High calorific potential</u> (amount of heat produced during the complete combustion of a mass unit of fuel, or a volume unit in the case of a gas).
  - Methane → 8250kcal/m^3
  - Gasoline → 10200 kcal/kg
- High GWP (=28) compared to CO_2 (=1) → high benefit when used for energy production

Using CH_4 to produce energy: efficient reduction of GHG emission, recovery of high-value energy and possibility of local (in farm) utilization

How to produce CH_4 in agriculture?

Anaerobic digestion of animal manures and agriculture feedstocks (energy crops, ag-by products)

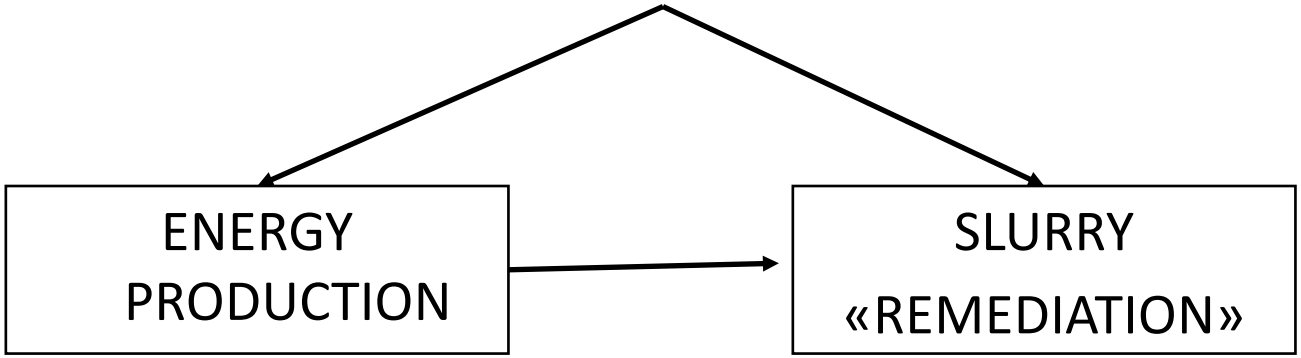
BIOLOGICAL CONVERSION OF BIOMASS: OVERVIEW AND DETAILS ON ANAEROBIC DIGESTION

ANAEROBIC DIGESTION OF BIOMASS

NATURAL PROCESS

FIRST OBSERVED AROUND 1300

MAIN ANAEROBIC DIGESTION (A.D.) OBJECTIVES



AN ADDITIONAL ADVANTAGE OF A.D. IS A MORE SUITABLE AGRONOMIC UTILISATION OF SLURRIES

ANAEROBIC DIGESTION: the concept

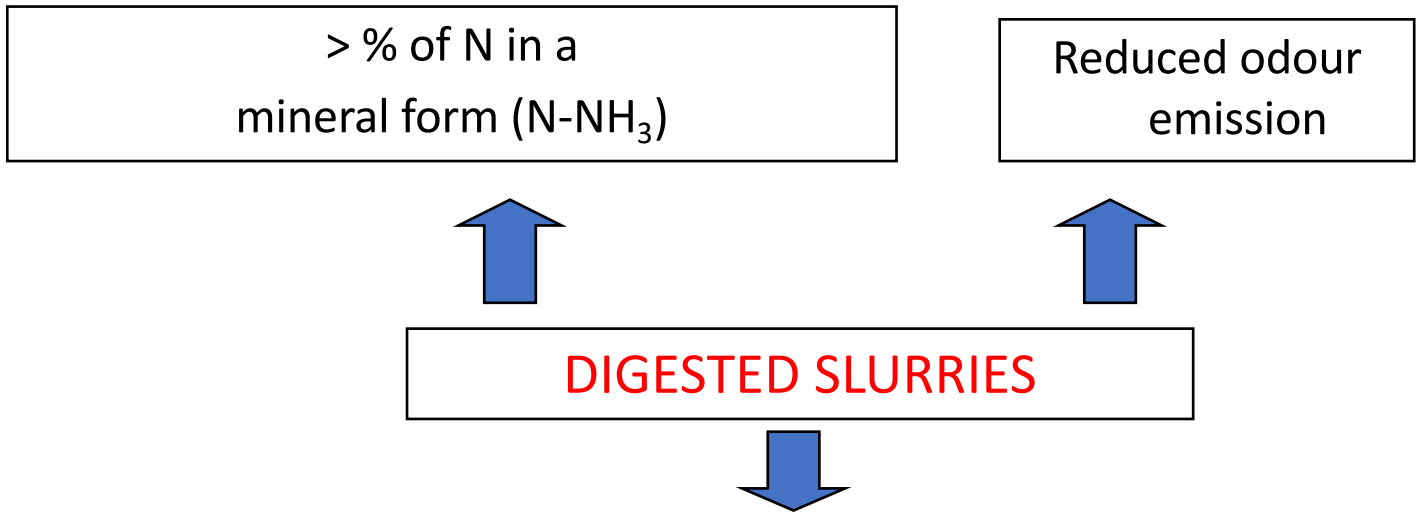
ORGANIC MATTER (Volatile Solids – VS)

ANAEROBIC DEGRADATION

BIOGAS (CH_4/CO_2 + trace gases)

DIGESTED SLURRY

CHARACHTERISTICS OF DIGESTATE (why slurry «remediation»?)



- Lower total solids (TS) content
- Higher fluidity
- Lower COD/BOD
- Lower power requirements for pumping
- Higher distribution uniformity when land applied
- Potential lower NH_3 and GHG emissions

ANAEROBIC DIGESTION PROCESS

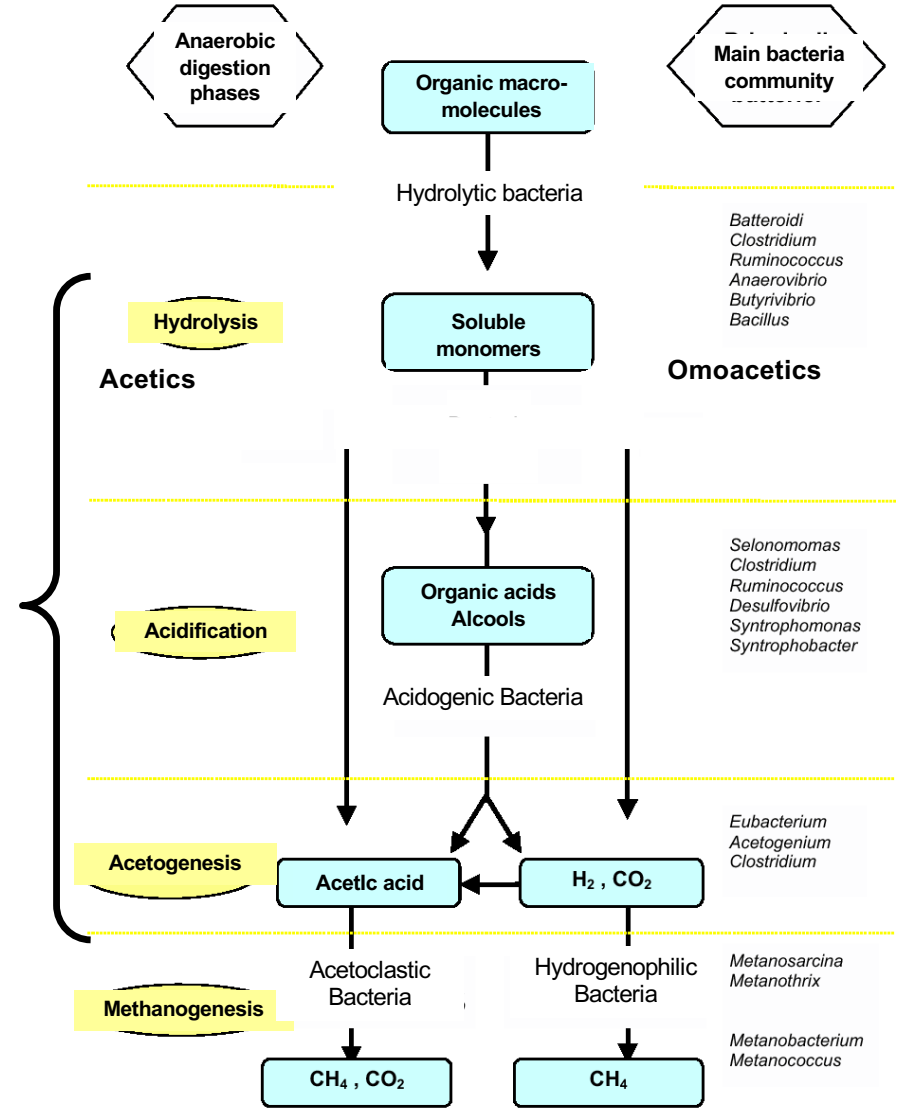
Anaerobic digestion process layout.

Carbohydrates,fats and proteins converted in monosaccharydes and fatty acids

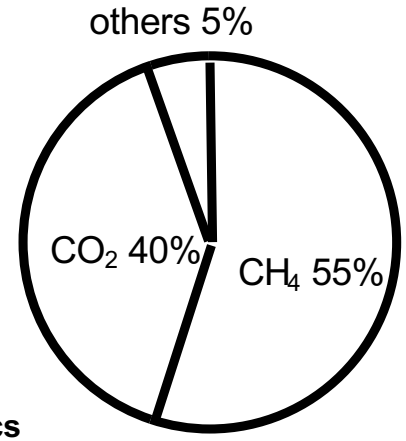
Monomers converted into H2, CO2 volatile fatty acids (1)

H2, CO2 volatile fatty acids are partially converted into acetic acid

H2, CO2, acetic acid converted into Methane (2)



BIOGAS COMPOSITION



characteristics	CH_4	CO_2	H_2S	H_2	Typical Biogas 60%CH_4 40% CO_2
volume (% of total)	50-75	20-45	0,1	0,0-10	100
Upper thermal power (kCal/Nm^3)	**8500**	**-**	**-**	**2600**	**6130**
limit of flammability in air (% of volume)	5-15	-	4-46	6-71	6-12
Volumic mass (kg/m^3)	0,72	1,98	1,54	0,99	1,22
Odour	none	none	Rotten egg	none	Rotten egg and ammonia

1 Nm^3 of BIOGAS = 0,6 litre of DIESEL

MAIN PARAMETERS WHICH INTERACT ON THE ANAEROBIC DIGESTION PROCESS

The higher part (80-90%) of the chemical energy contained in the available organic matter is transformed in methane – only a little fraction is necessary for the cellular growth

- **SUBSTRATE**
- **TEMPERATURE**
- **pH**
- **HYDRAULIC RETENTION TIME**
- **ORGANIC LOADING RATE**

MAIN PARAMETERS WHICH INTERACT ON THE ANAEROBIC DIGESTION PROCESS

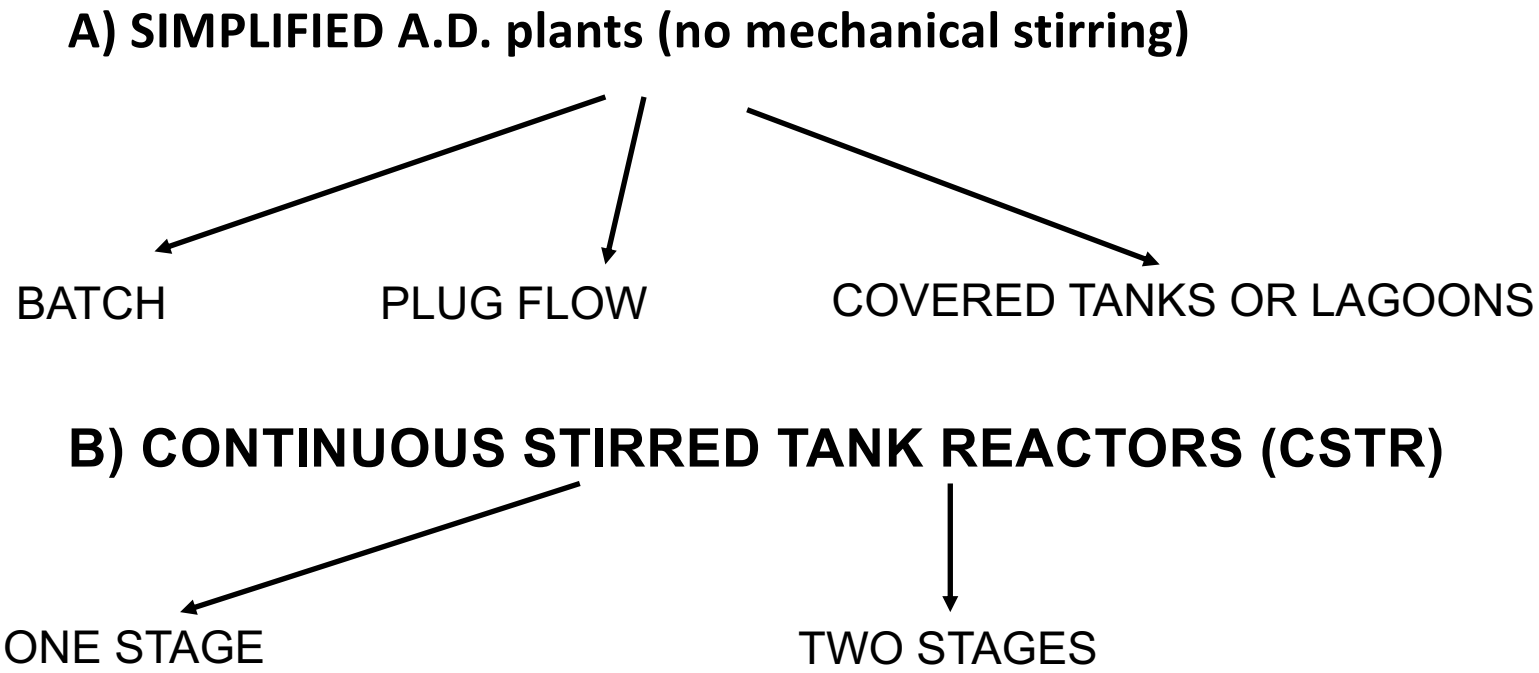
➢ Type and digestability of substrates

Average biogas yield of some common substrates

	Nm^3/t SV	Nm^3/t W.B.
Pig slurry	450	20
Cattle manure	240	43
Maize silage	730	230
Maize residues from drying	640	510
Tomatoes skins	420	135
Rice straw	415	340
whey	950	60

Proteins
Fats
Starch
Sugars
> Cellulose
Hemicellulose
> Lignin

Common types of A.D. plants



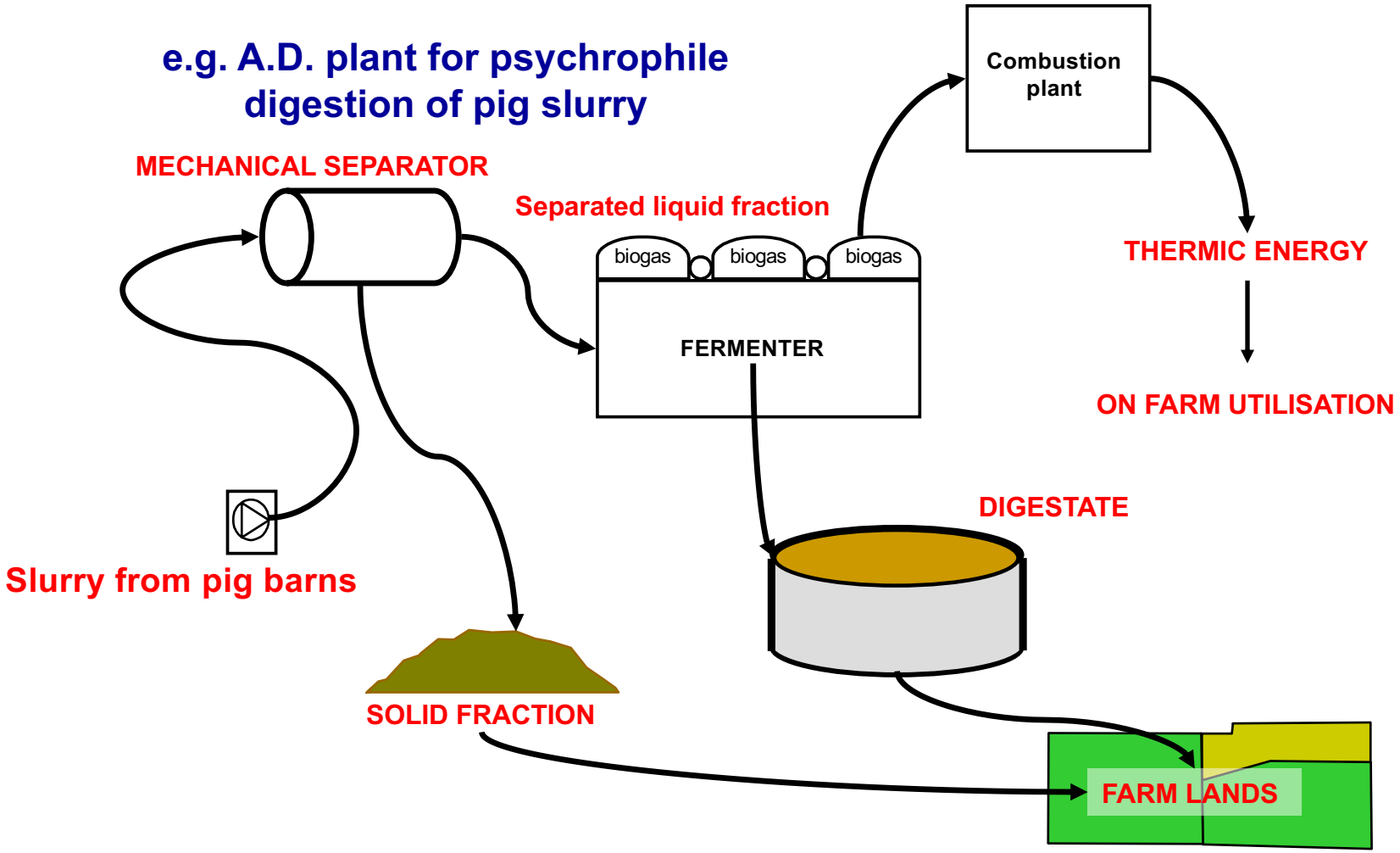
A.D. PLANTS TYPOLOGIES

SIMPLIFIED A.D. PLANTS

- Can be heated or not
- To reduce the investment costs pre-existing stuctures can be converted into a fermenter (e.g. slurry storage tanks)
- The existing manure management of the farm is not changed
- Low investment and management costs
- The simplified plants are farm-scale installations (the produced energy is not sold but used within the farm)
- No mixing systems → often mechanic separation and digestion of liquid fraction only

A.D. PLANTS TYPOLOGIES

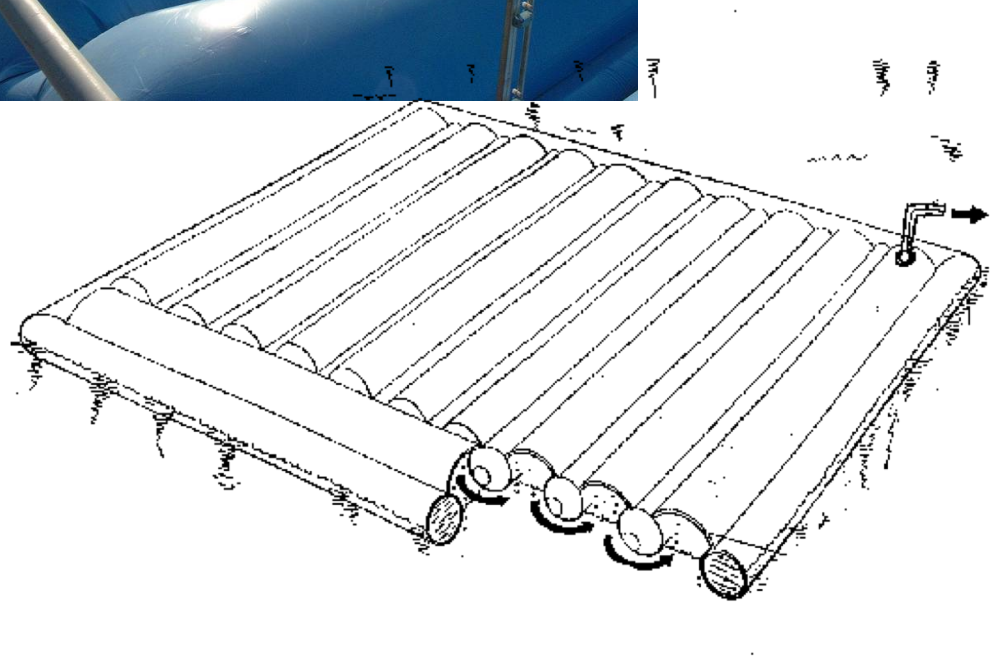
Not heated SIMPLIFIED A.D. PLANTS



A.D. PLANTS TYPOLOGIES

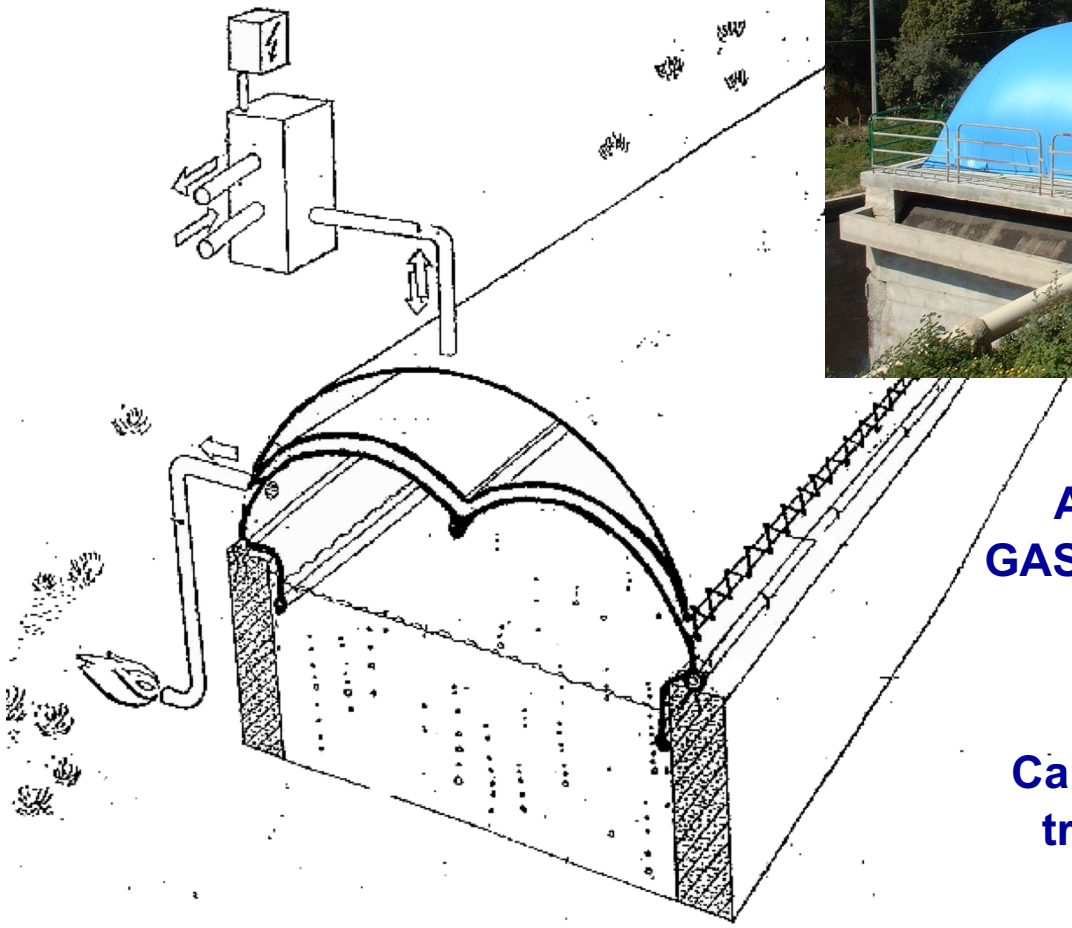
Not heated SIMPLIFIED A.D. PLANTS

Floating system for biogas recovery



A.D. PLANTS TYPOLOGIES

Not heated SIMPLIFIED A.D. PLANTS



AIR - PRESSURIZED GASOMETRIC COVERAGE

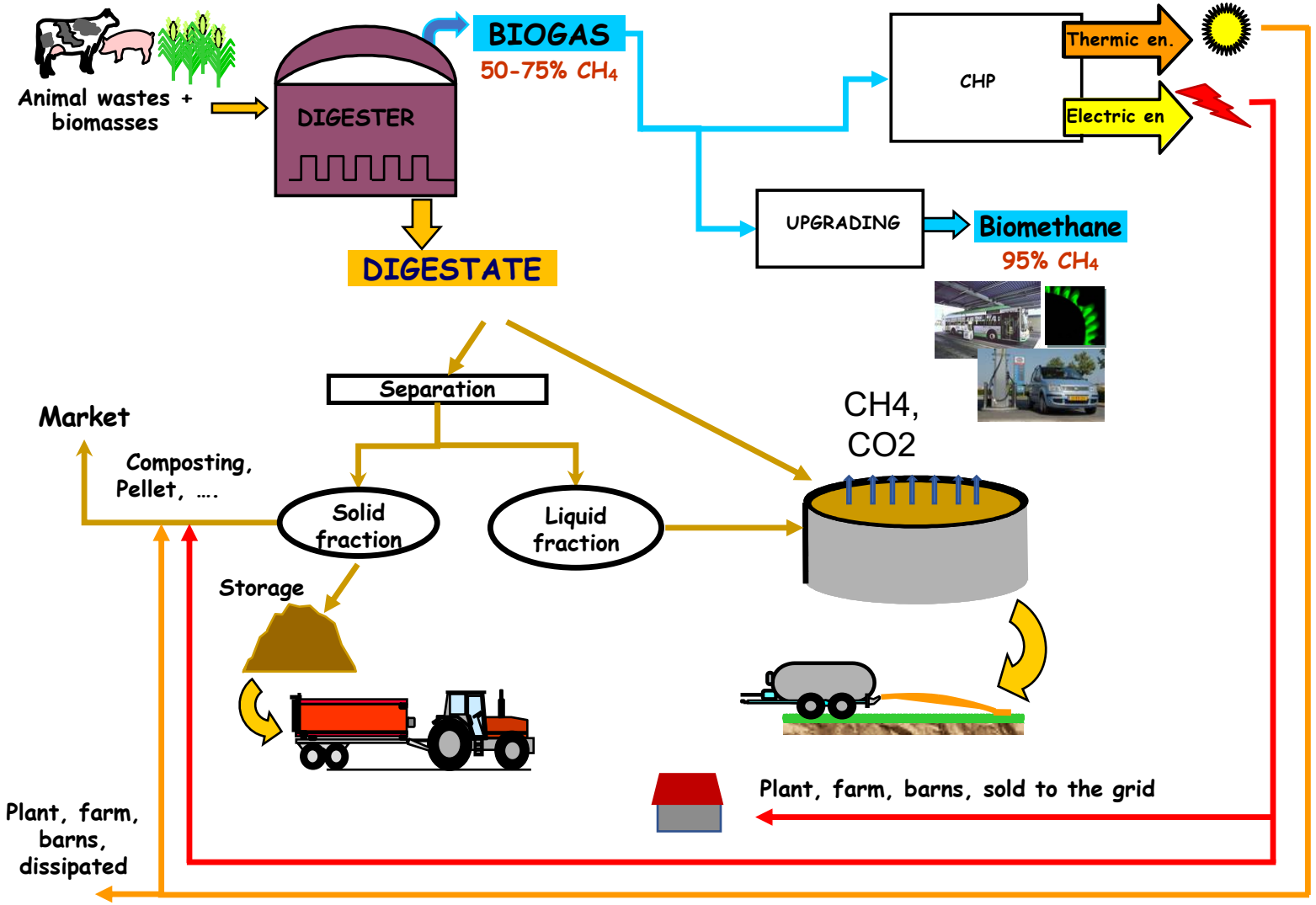
Can be mounted also on traditional fermenters

A.D. PLANTS TYPOLOGIES

TRADITIONAL A.D. PLANTS
(CSRT: Completely Stirred Reactor Tanks)

- Heated - mesophilic
- presence of mixing systems
- more «complex» structures compared to simplified digesters
- higher investment and management costs (mixing, feeding, heating…)

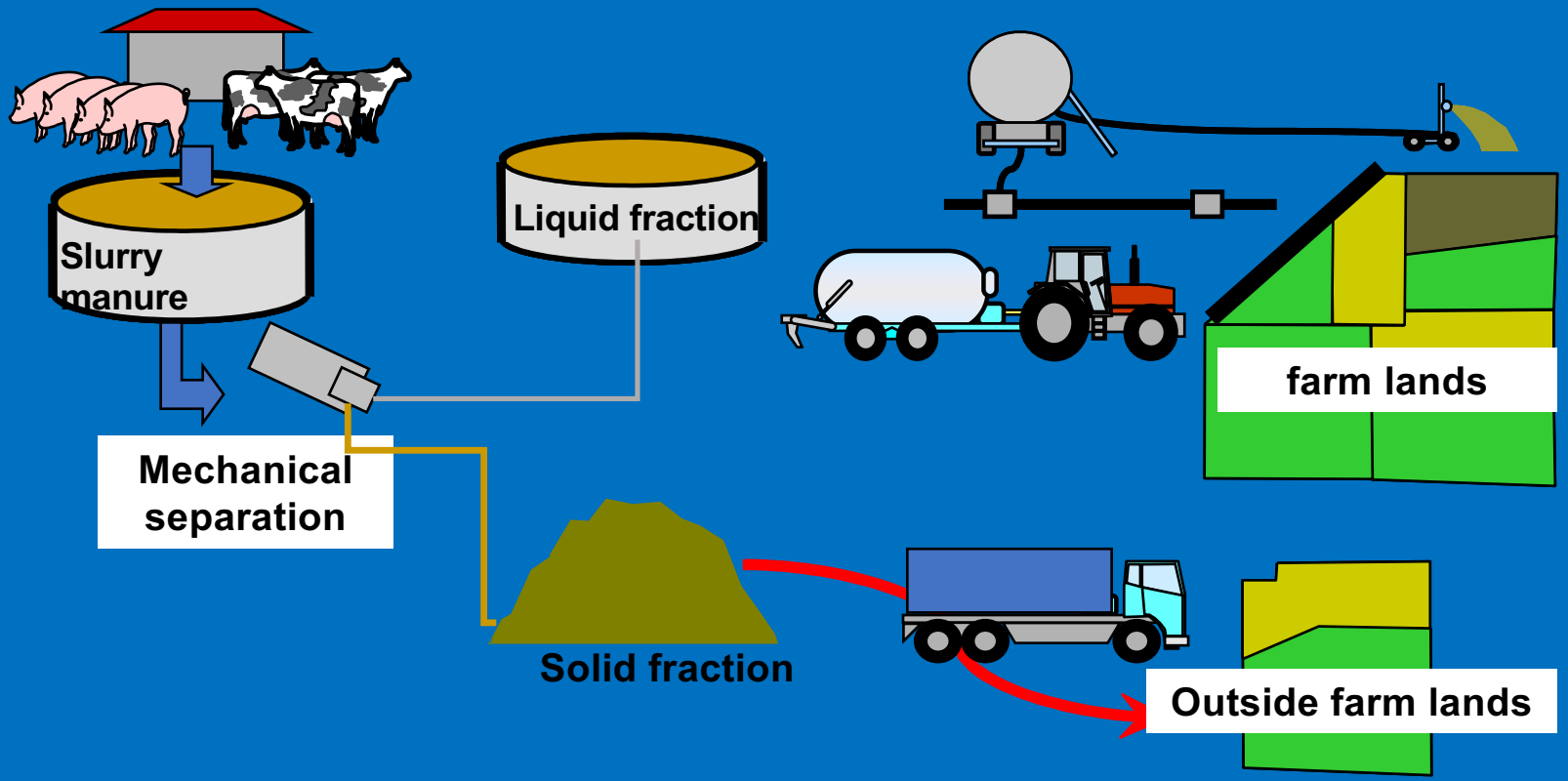
Layout of A.D. inputs and outputs



How to reduce manure volume

SOLID-LIQUID SEPARATION OF ANIMAL SLURRY

partial removal of suspended particles from the liquid manure



Main Characteristics of Liquid fraction

- **Reduced amount of total solids**
  - *Improved slurry handling properties*
  - *land application in crops post emergence is possible*
- **Lower P and N content**
  - *higher volume application rates are possible*
- **N mostly in mineral form**
  - *immediately available for the crops*

POSSIBLE UTILIZATIONS OF SLURRY LIQUID FRACTION

☞ **applied with irrigation water**
(FERTIGATION)

☞ **further refined:**

- membrane filtration
- evaporation
- struvite crystallization
- NH_3 stripping
- ...

Main Characteristics of solid fraction

Higher concentrations of total solids, N, P, and trace elements than raw slurry

- *higher value of the product*
- *possible alternative use (compost, feedstock for biogas plants..)*
- *can be more conveniently transported to outside farm areas*

N in organic form

- *good for soil amendment*

POSSIBLE USES OF SLURRY SOLID FRACTION

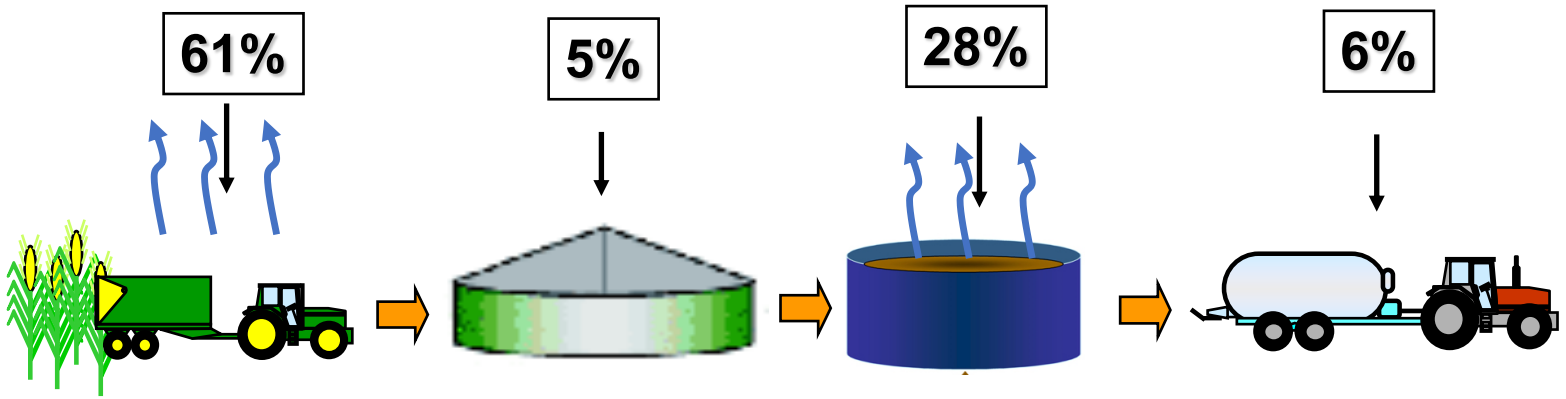
- **Export to outside farm areas**

- **Composting**
- **Organic-mineral fertilizers production**
- **Bedding material**
- **Energy production:**
  - feedstock for A.D. plants
  - pelletizing → combustion

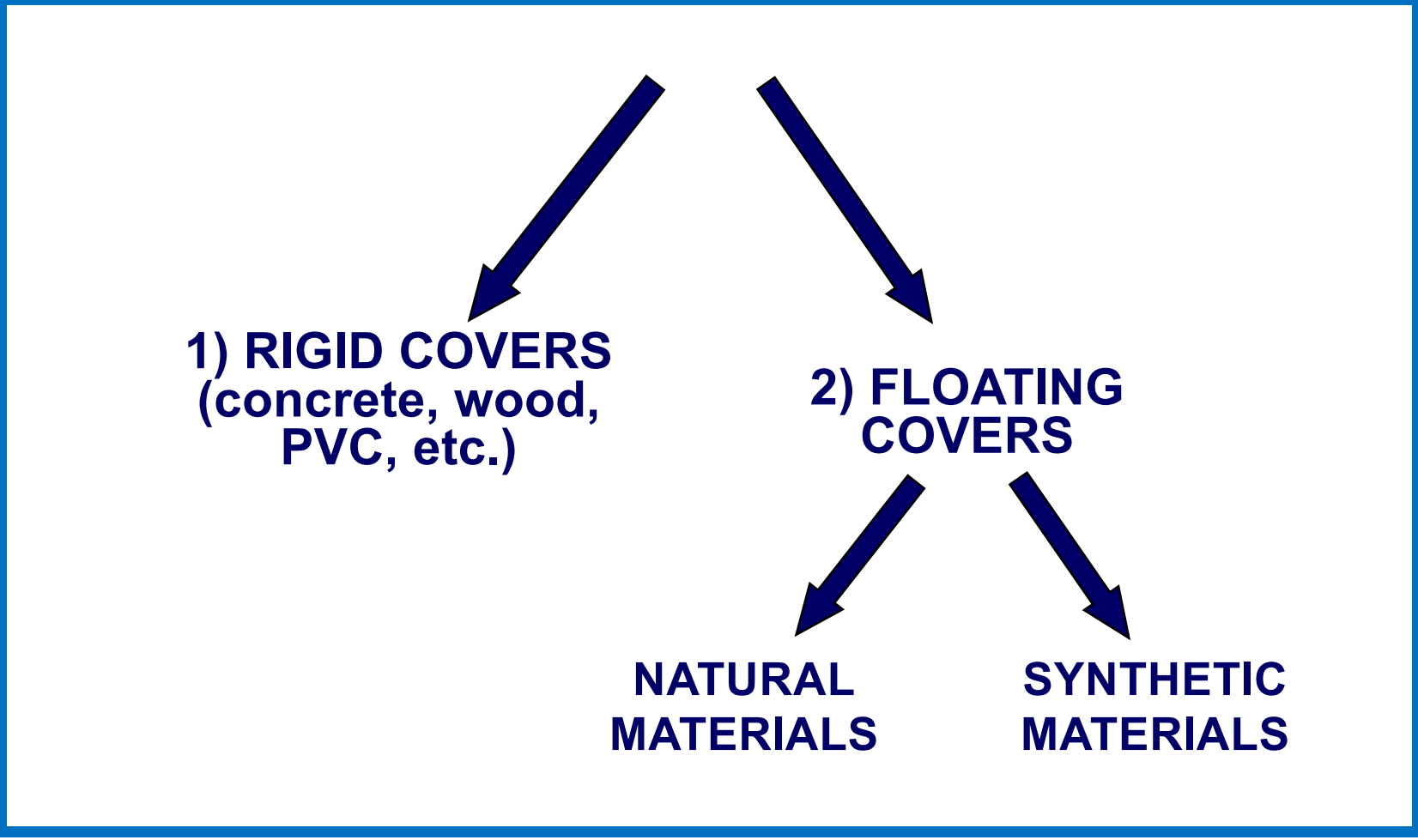
POSSIBLE USES OF SLURRY SOLID FRACTION

- **Drying and pelletizing**

The CO_2eq. emissions produced during anaerobic digestion process



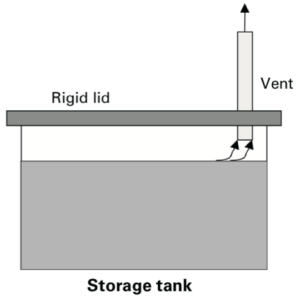
Mitigations measures: covers for storage tanks

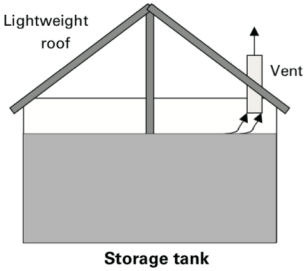


Mitigations measures: covers for storage tanks

1) RIGID COVERS

- **Expensive**
  - **May not be suitable for biogas collection**
    - **Difficult to install on existing stores**





Mitigations measures: covers for storage tanks

➢ **2) FLOATING COVERS (NATURAL MATERIALS)**

Natural crust

Straw

Maize stalk

Wood shavings

Vegetable oils

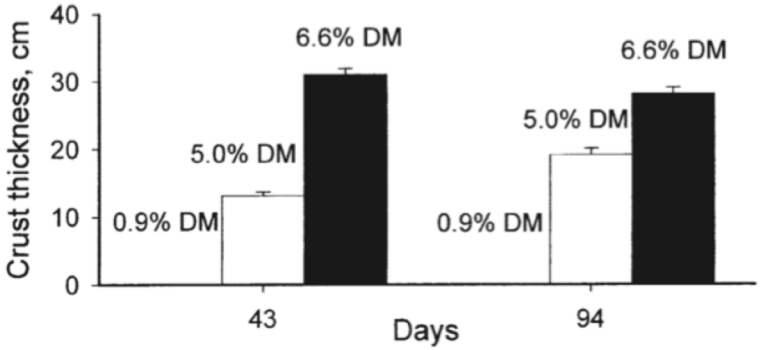
Leca® balls

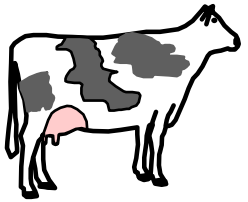
Perlite

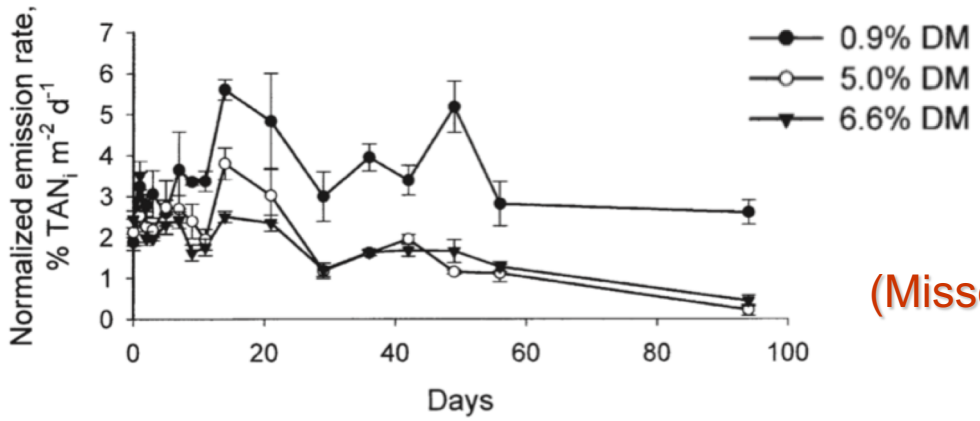
Mitigations measures: covers for storage tanks

Effect of slurry total solids on crust formation over the slurry surface and on emissions of NH_3

(Cattle slurry)







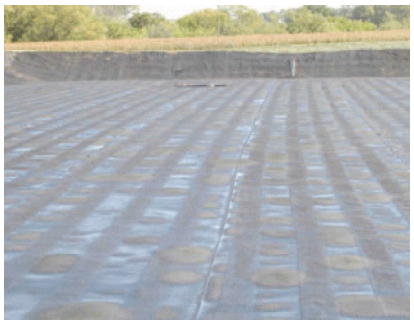
(Misselbrook et al., 2005)

Mitigations measures: covers for storage tanks

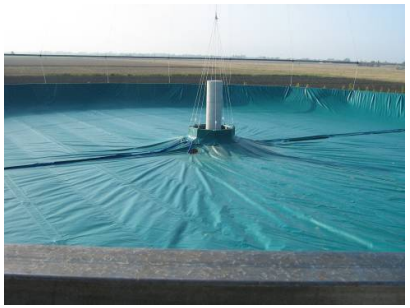
➢ **2) FLOATING COVERS (SYNTHETIC MATERIALS)**

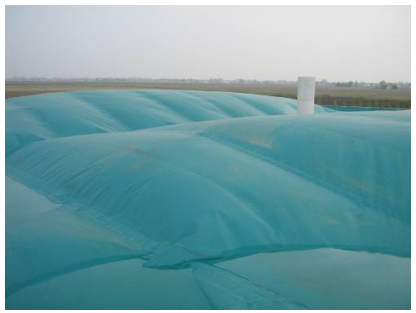
plastic sheets

Exa covers



Geotextile





Covering system able to recover biogas emissions

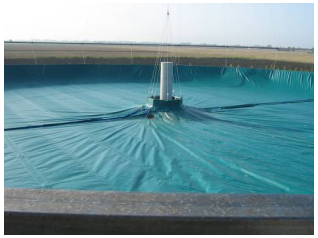
SIREMA PROJECT:
testing cover systems for slurry tanks

- **Light expanded clay aggregate (Leca® balls)**

- **Floating closed-cell polyethylene membrane (Ecomembrane®)**

- **Floating closed-cell polypropylene hexagonal plates (Hexa Cover® tile)**

- **Floating covering system (Ecomembrane®) able to recover biogas emissions from slurry tanks**



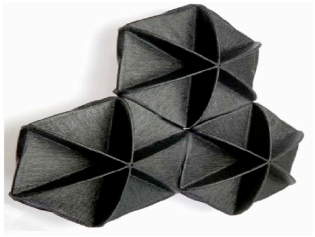
Main characteristics of the tested covering systems

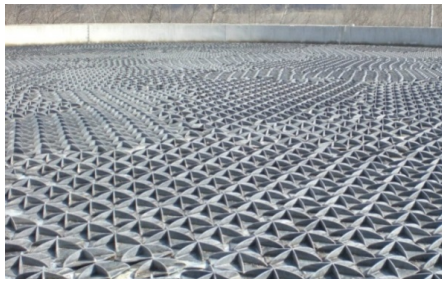
LIGHT EXPANDED CLAY AGGREGATE (Leca® balls)

- Clay based airfilled pebbles
- Light and floating material
- Porous
- Ø 8-20 mm
- Density: 330 kg/m^3
- Capital cost: 9.5 €/m^2
- Estimated life: 10 years (approx. 10% of the cover needs to be replaced annually)

Main characteristics of the tested covering systems

HEXA-COVERS® TILE

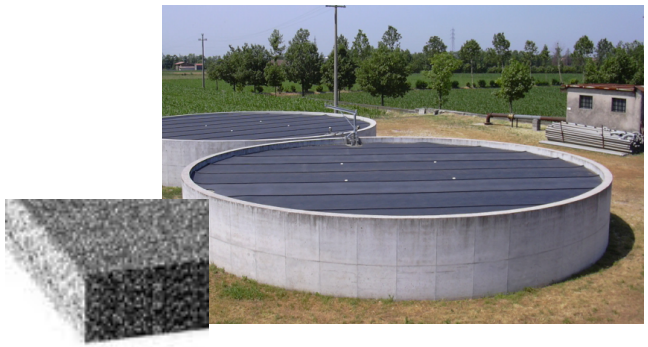




- Free floating plastic plates, hexagonal in shape
- Expanded closed cell polypropylene
- Resistant to chemical and weathering agents
- Ø 220 mm, 70 mm high
- Density: 500 kg/m^3
- Capital cost: 37.5 €/m^2
- Estimated life: 25 years

Main characteristics of the tested covering systems

Floating Joint Elements (Ecomembrane®)

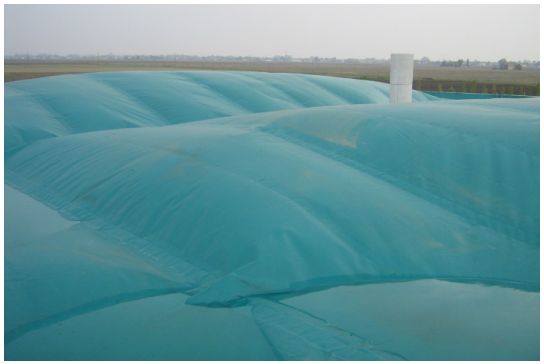


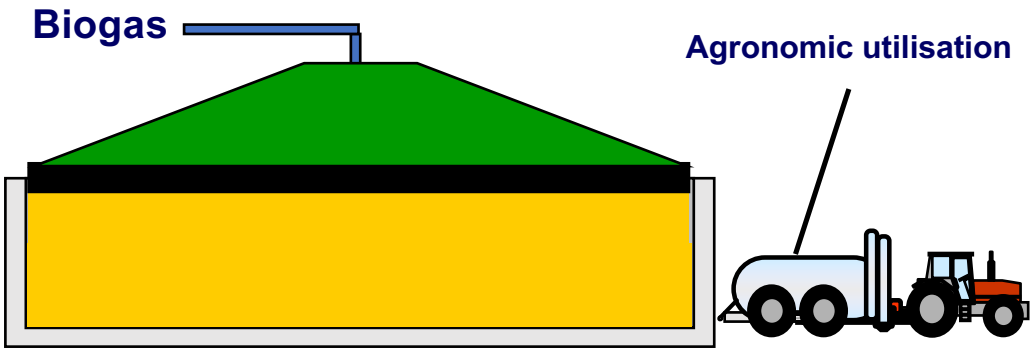
- Flexible floating sheets of closed cell polyethylene foam
- Resistant to chemical and weathering agents
- Thickness: ~ 15 mm
- Density of 60 ÷ 90 kg/m^3
- Capital cost: 32.0 €/m^2
- Estimated life: 10 years

Main characteristics of the tested covering systems

Membrane for biogas recovery (Ecomembrane®)

- Peripheric floating frame
- PVC based covering sheet
- Constantly floating over the slurry surface regardless of the filling level of the storage tank
- Capital cost: 60 €/m²
- Estimated life: 10 years

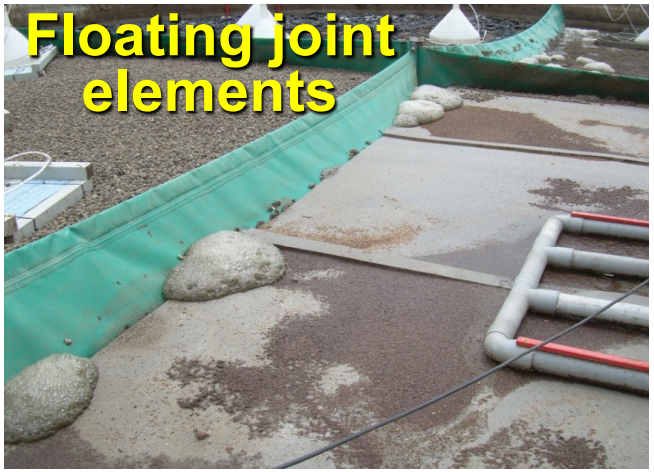




Crust formation over the slurry surface

SIREMA PROJECT: MAIN RESULTS

Biogas bubbles formation over the slurry surface



SIREMA PROJECT: MAIN RESULTS

Slurry surface covered by Hexa Cover®

with crust and biogas bubbles formation

without crust over the slurry surface

SIREMA PROJECT: MAIN RESULTS

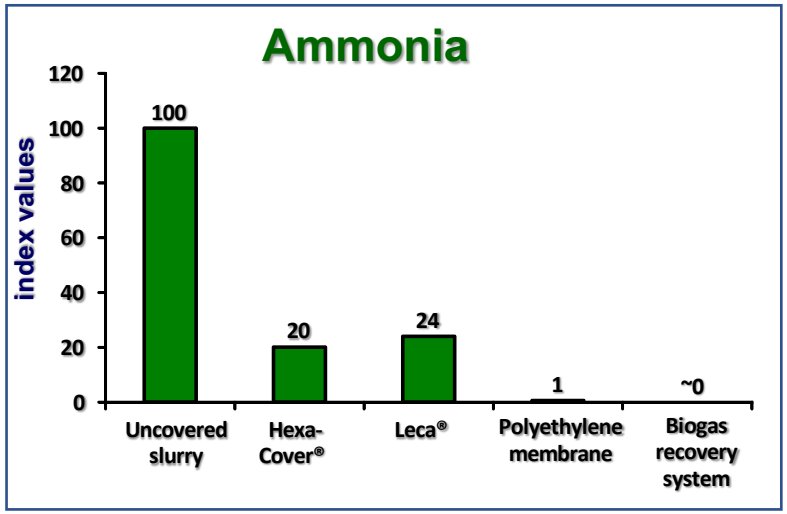
Slurry surface covered by Leca®

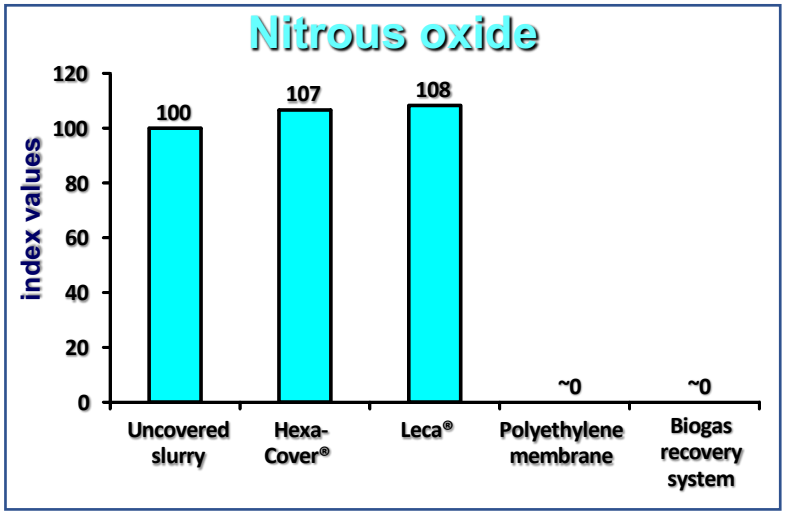
At the beginning of the trial

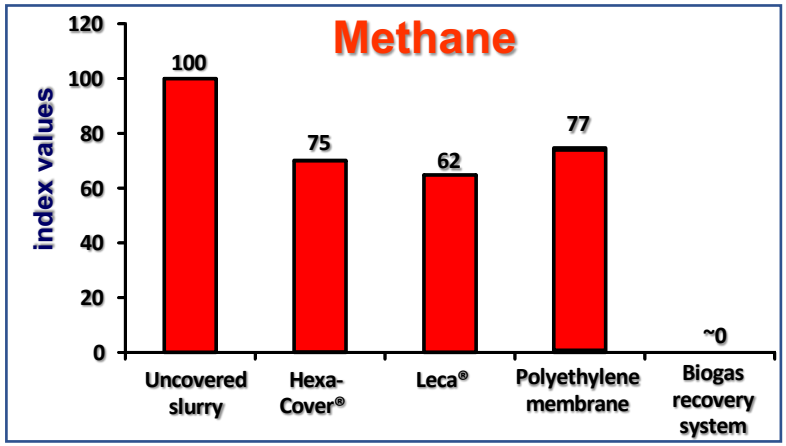
At the end of the trial

SIREMA PROJECT: MAIN RESULTS

Comparison of total emissions expressed as index values*



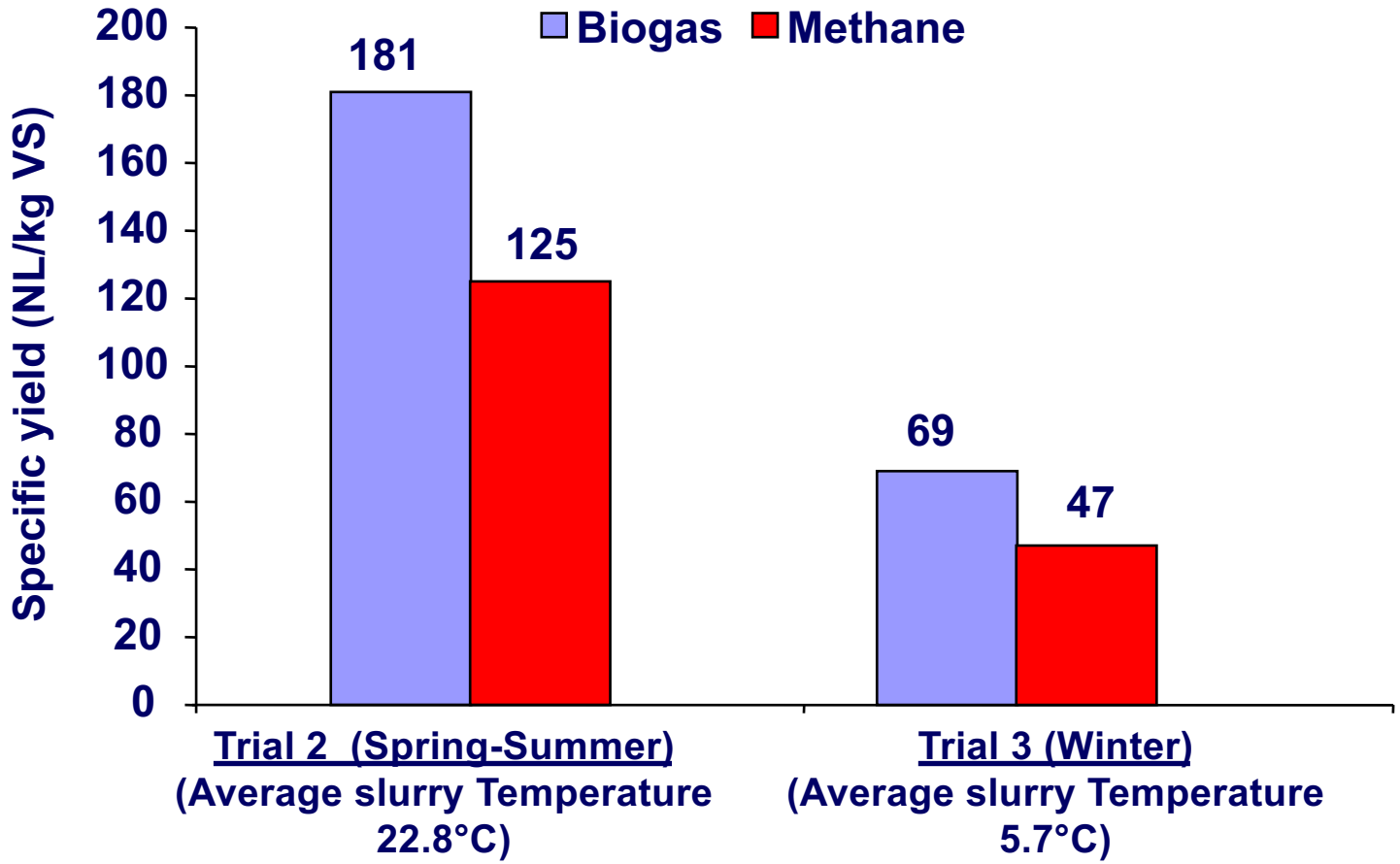




*emissions recorded from uncovered slurry = 100

SIREMA PROJECT: MAIN RESULTS

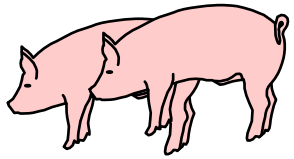
Biogas and methane yields measured during the trials from the slurry surface covered by the Membrane for biogas recovery



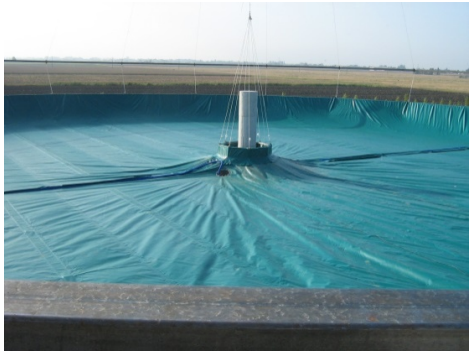
The potential of the Membrane for biogas recovery

By covering the slurry storage tanks of a medium-sized finishing pig farm (2000 heads) with the Membrane for biogas recovery it has been estimated to be possible:

a) to avoid the emission in atmosphere of:

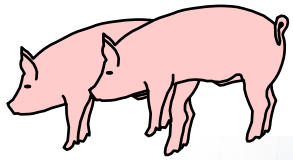


- **~1.87t NH_3-N per year (approx. 1350€ per year considering a current price of urea-based fertilizers of 0.72€/kg)**



- **~300t CO_2eq. per year**

The potential of the Membrane for biogas recovery



b) to collect, on average:

~2.5 Nm^3 methane per m^3 of stored slurry

↳ **~ 17,000 Nm^3 methane per year**

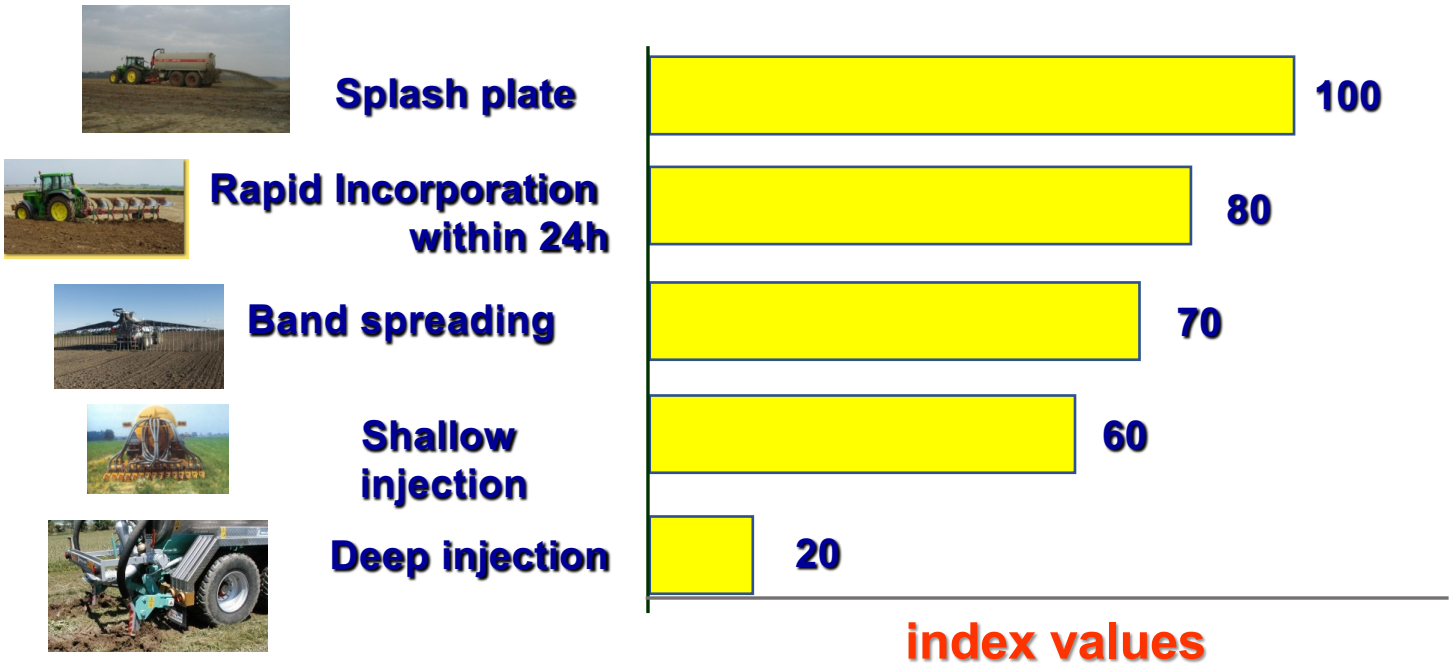
↳ **~ ~ 595 000 MJ per year**

↳ **= ~ 11800€ (at the Italian current price of natural gas – 0.70€/m^3)**

→ **Payback time of the floating cover < 4 year**

Mitigations measures: reduced NH_3 emission application techniques

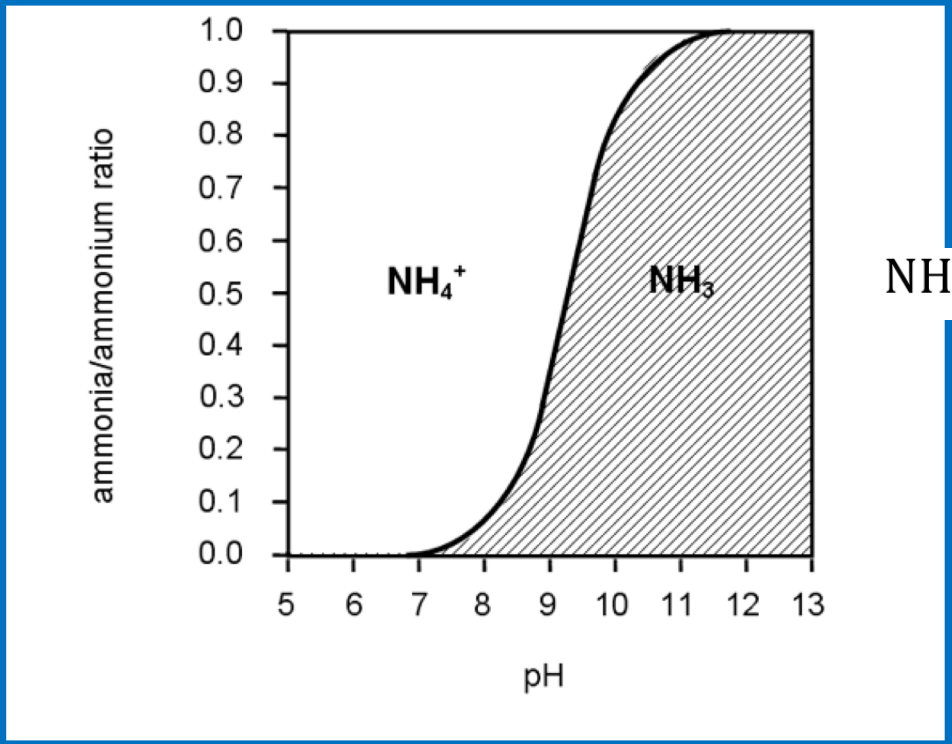
Comparison of total NH_3 emissions expressed as index values



Mitigations measures: acidification

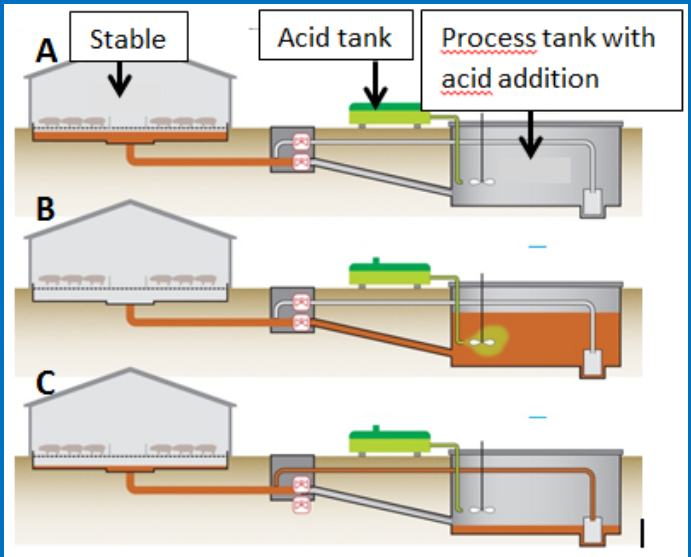
How acidification works:

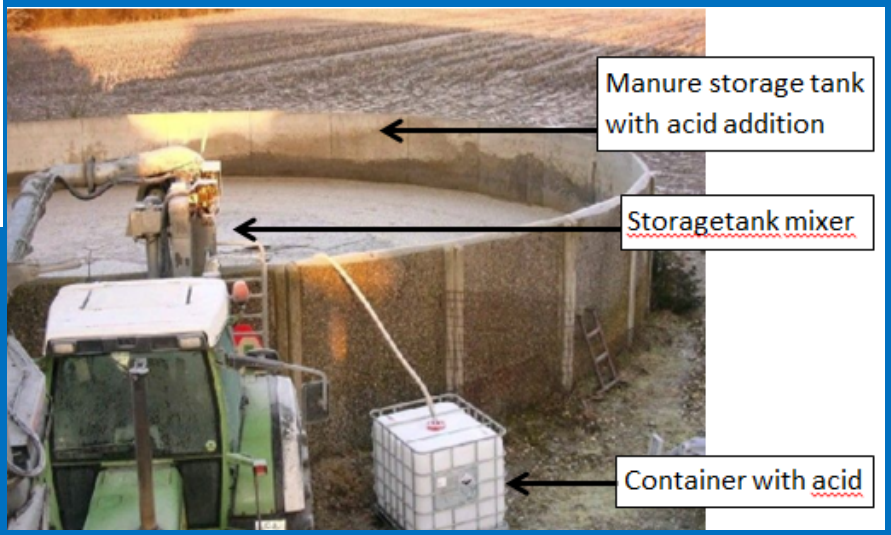
It creates conditions minimizing the concentration of NH_3 relative to NH_4^+



$$NH_3\,(g) + H^+\,(aq) \leftrightarrow NH_4^+\,(aq)$$

Mitigations measures: acidification





Problems:

- Foam formation
- Buffer capacity of the system (pH raises after fresh slurry addition)

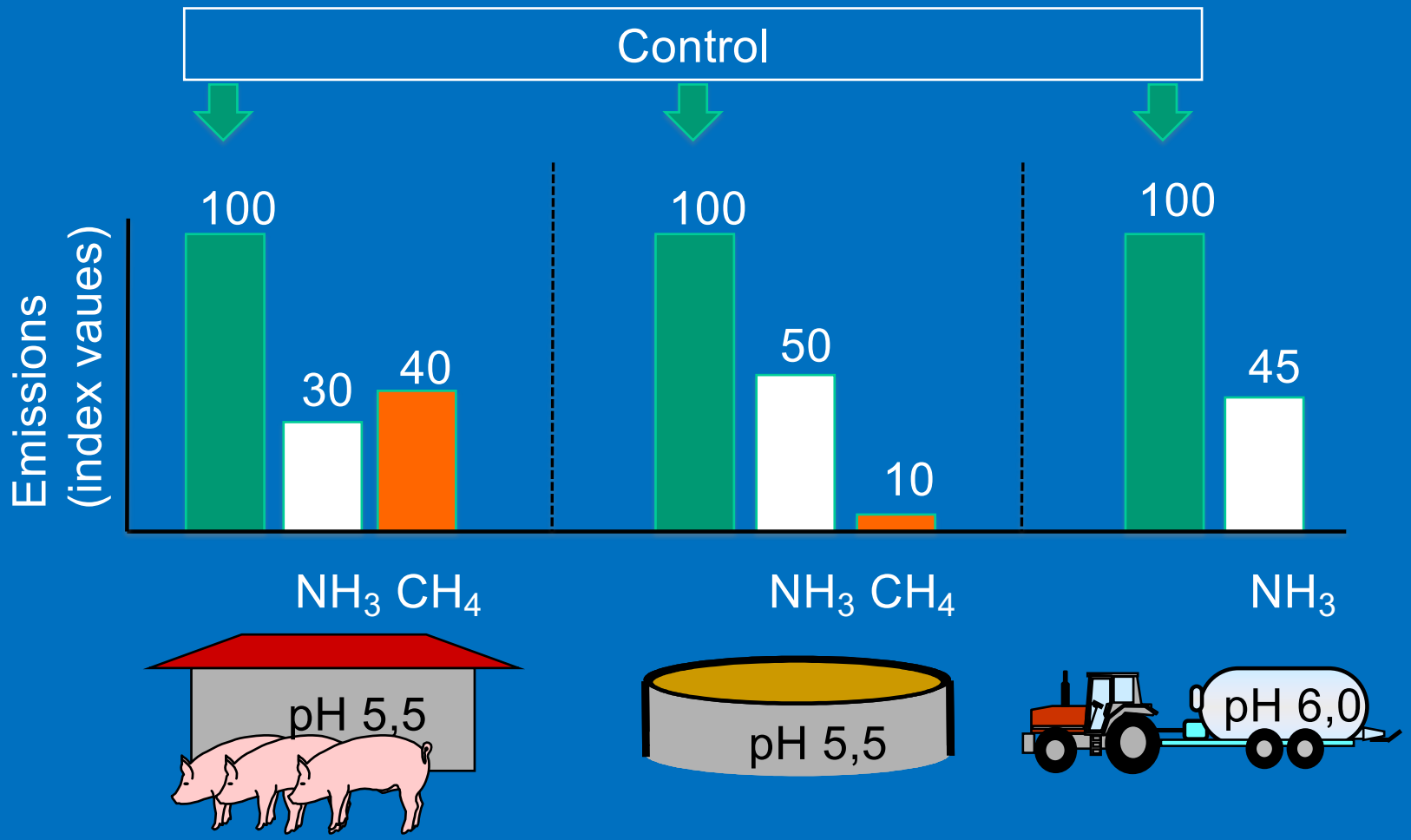
Acidification at land application

Concentrated sulfuric acid

pH probe

Control unit

Effect of acidification by H_2SO_4 on gaseous losses



Further advantages of acidification

- More available ammonia nitrogen (NH_4^+)
- Reduction of GHG emission
- Enhanced N e P absorption by the crops
- Higher crops yield (still under study)

Mitigations measures: acidification

Problems connected to acidification:

Use of concentrated sulfuric acid

- Hazard to human health at handling, transport and storage → normative limits

- Foam formation upon acidification

- Solid manures acidification (e.g. FYM and separated solid fraction) currently not possible with sulfuric acid

- Costs (according to acid type and target pH → sulfuric acid is the cheapest additive)

Mitigations measures: acidification

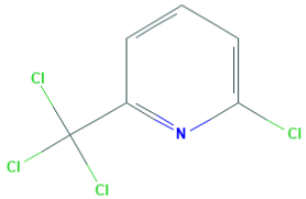
A possible alternative to sulfuric acid:

Powdery sulfur

Chemical reaction occurring in the manure after sulfur addition:

$$S^0 + 1/2\ O_2 + CO_2 + 2H_2O \leftrightarrow CH_2O + SO_4^{2-} + 2H^+$$

Nitrification hinibitors



Refluo/ fertilizzante di sintesi azotato