Potential for CCUS in Luxembourg

Case study: **CCUS and Circular Agriculture**

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The food production system

Linear food production system = 26% GHG_G

Non-food= 74% GHG_G

Emissions in Agriculture:

- Diffuse, variable, and difficult to measure with precision
- Interlinkages with other sectors (transport, energy, industry)
- CO_2, CH_4, N_2O, (NH_3)
- Prone to circularity !

CCUS : 8% GHG_G

LULUC = 6%
Crops = 5%,
Animals = 5%

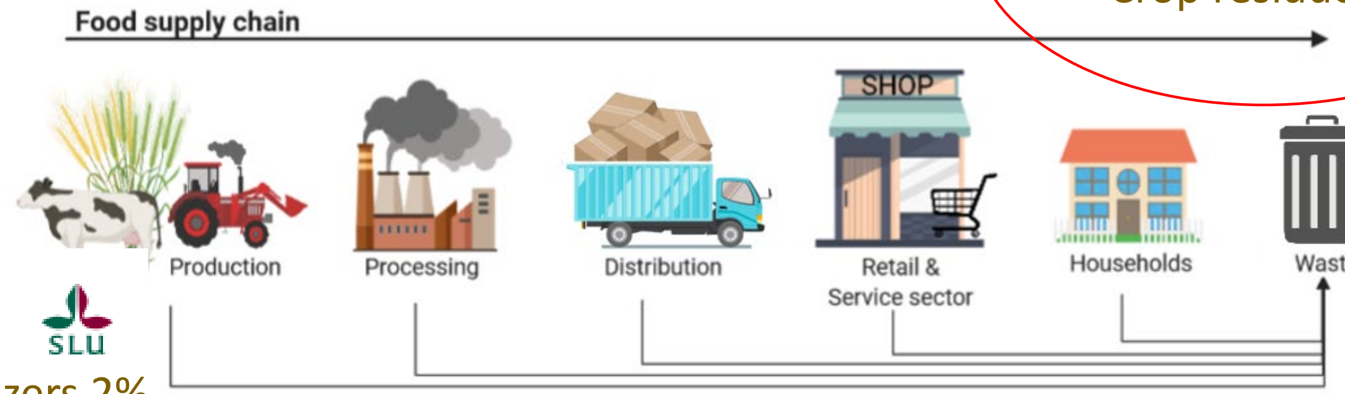
≈GHG_G (%)

Supply chain = 5%

Waste$_{org}$ = 3%
Manure = 3%
Crop residues = 2%

How to reduce emissions ?

- No-till, pastures, no-soja, agrofor.
- Change your diet (red meat & rice)
- Waste management



Fertilizers 2%

Nutrients

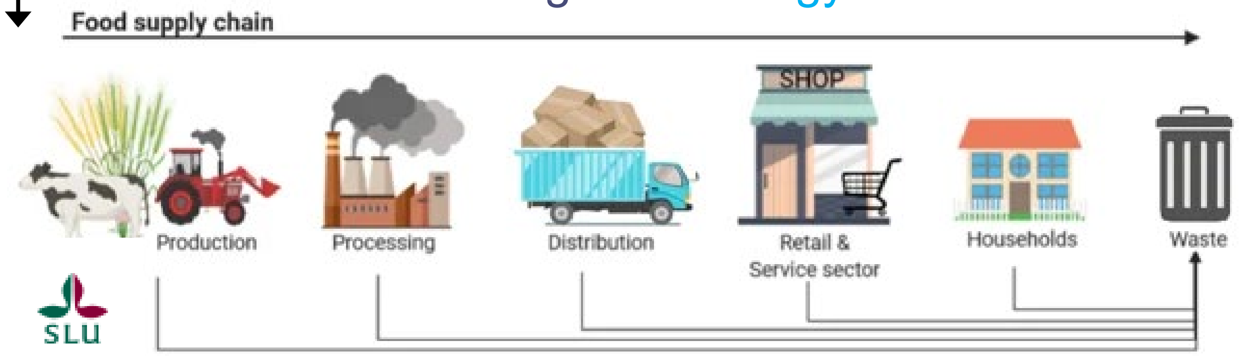
https://blogg.slu.se/food-system-group/

From linearity towards circularity

Biogas captures CO_2, CH_4, N_2O, H_2, NH_3

Biogas recycles C_{org}, fertilizers, and water

Biogas as energy source



https://blogg.slu.se/food-system-group/

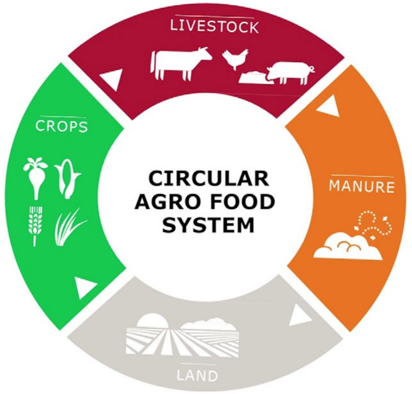
Emissions from waste management

WWTP (Water) → CO_2, CH_4, N_2O, N_2, *E*

Landfill → CO_2, CH_4, NH_3, H_2, H_2S *E*

Incineration → CO_2, SO_2, NOx, ***E*** ✓ Wood

Composting → CO_2, CH_4, N_2O, N_2, NH_3, *E*



Waste management through biogas

1. Captures emissions (8% GHG_G)
2. Uses = emissions-to-energy
3. CO_2 usages in agriculture
4. Returns C_{org} to soils
5. Contributes to "sequestrate" SOC

100-year global warming potential (GWP_{100})

CO_2 = 1 CH_4 ≈ 28

N_2O ≈ 298 H_2 ≈ 12

NH_3 = indirect GHG (fine particles)

Environ Sci Technol. 2023 Jan 31;57(6):2235–2247. doi: 10.1021/acs.est.2c05846
Sand, M., Skeie, R.B., Sandstad, M. et al. A multi-model assessment of the Global Warming Potential of hydrogen. Commun Earth Environ 4, 203 (2023). https://doi.org/10.1038/s43247-023-00857-8
Chen, SL., Chang, SW., Chen, YJ. *et al.* Possible warming effect of fine particulate matter in the atmosphere. *Commun Earth Environ* **2**, 208 (2021). https://doi.org/10.1038/s43247-021-00278-5

What is the Biogas process = Anaerobic Digestion by microbes

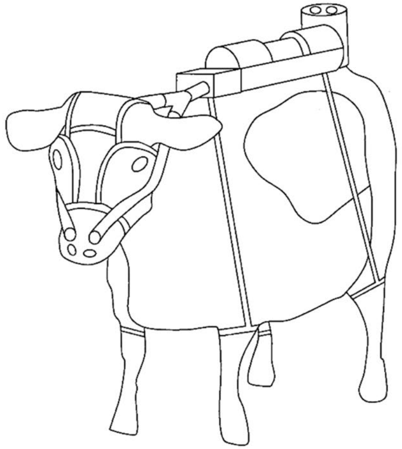
Water bodies
Freepik

Termites
Pixabay

Organic matter → CH_4+CO_2+trace gases

Digestive tract of animals

Rice paddy fields
(1.3% GHG_G)
Eduardo Prim



Palangi et al., 2022

250-500l/day

50% of us

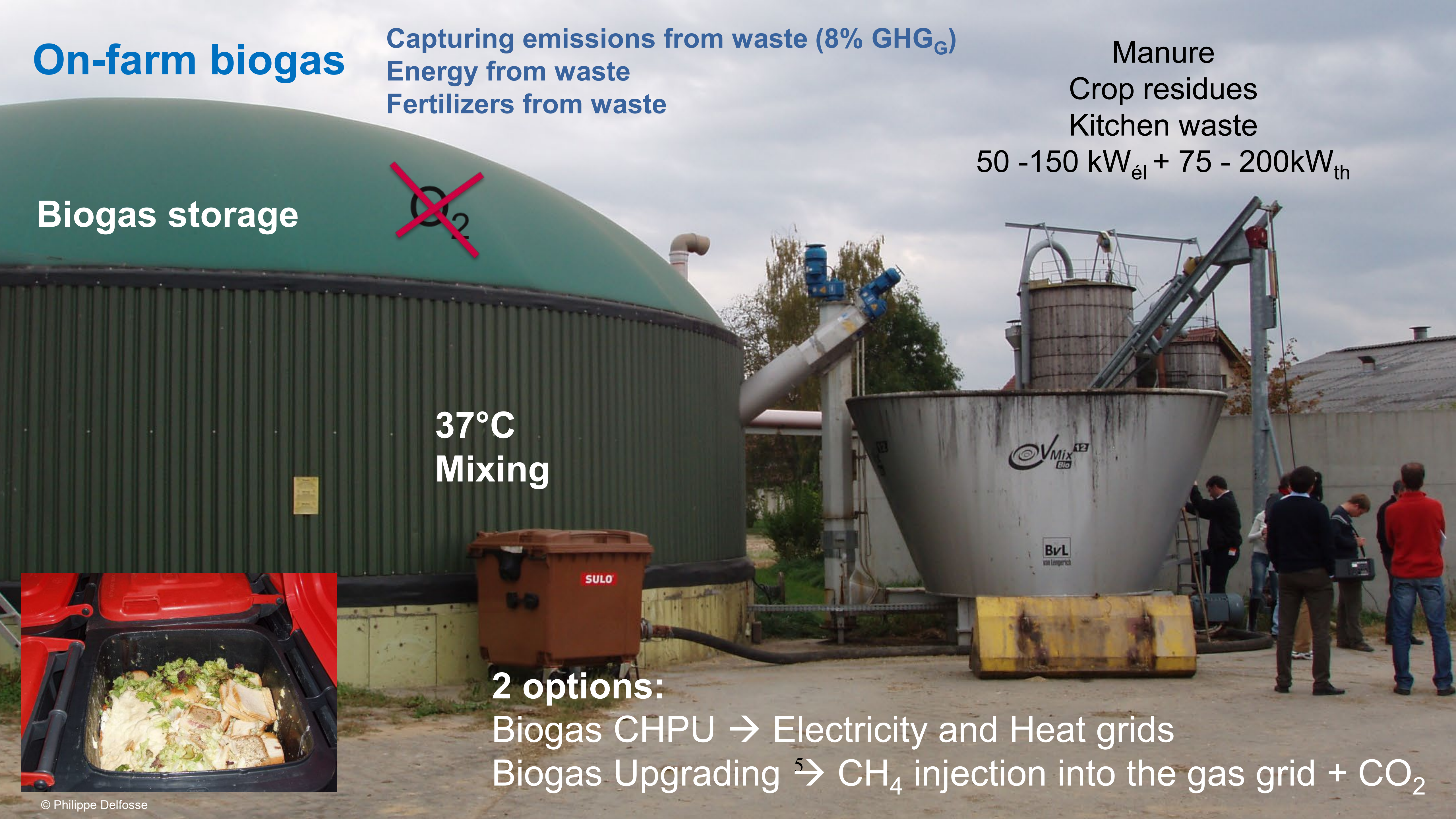
Adrie & Alfons Kennis, 2012

➡ Natural and ancient process

On-farm biogas

Capturing emissions from waste (8% GHG_G)
Energy from waste
Fertilizers from waste

Manure
Crop residues
Kitchen waste
50 -150 $kW_{él}$ + 75 - 200kW_{th}



Biogas storage

~~O_2~~

37°C
Mixing

2 options:

Biogas CHPU → Electricity and Heat grids
Biogas Upgrading → CH_4 injection into the gas grid + CO_2

A growing sector in the EU – growth trend for biomethane

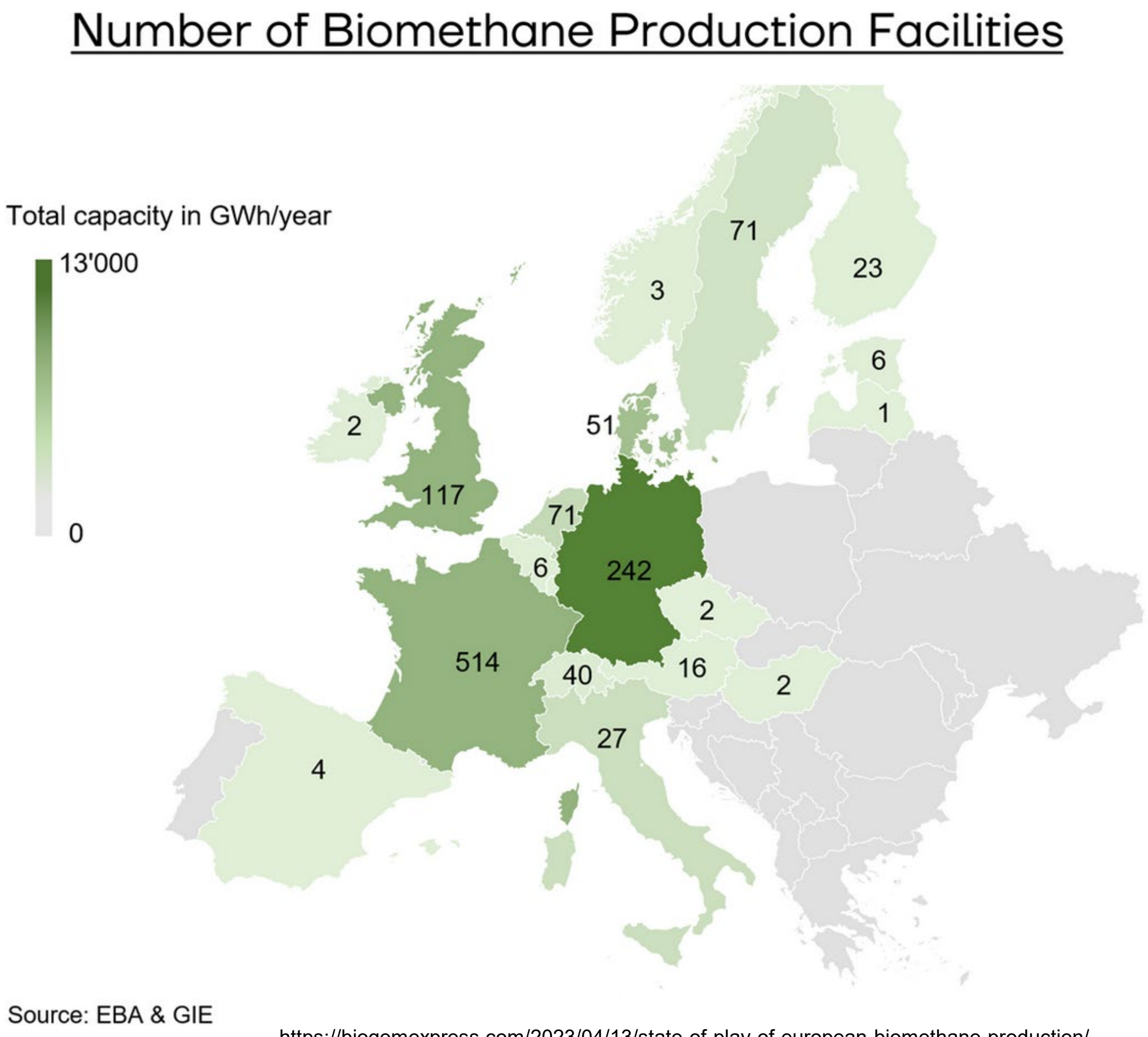
2023 → Biogas upgrading and injection

- **20 000** biogas plants (electricity + heat)
- **1 400** biomethane plants in Europe

2030 Mainly manure valorisation for energy

- The EU's **REPowerEU Plan** has a target to produce **35 billion m³** (bcm/a) of biomethane
- ≈ 350 TWh/a (terawatt-hours)
- ≈ 10 Cattenom (35 TWh/a)

© EDF – CNPE de Cattenom



https://biogemexpress.com/2023/04/13/state-of-play-of-european-biomethane-production/

Luxembourg biogas status quo – Significant drop
Urgent to put the PNEC measures and Stratégie Biogaz 2023 in force

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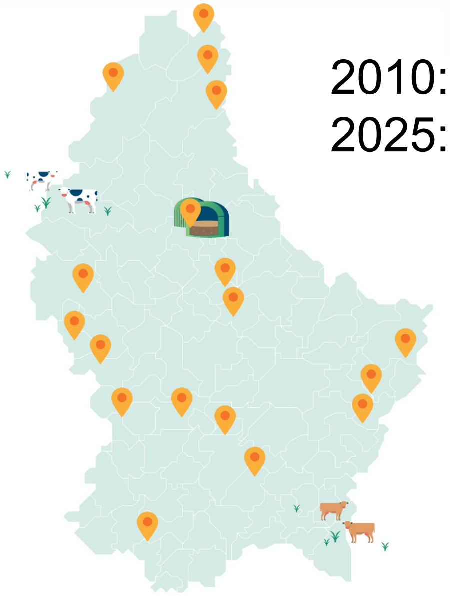
19 (23) biogas plants in activities, a large cooperative closing soon

- 300 000 t of manure are digested = 15% of 2 Mt produced
- 61 000 t of energy crops (800 ha) = 0.6% of the Utilized Agricultural Area (133kha)
- 64 000 t of national organic waste + 17 000 t imported
- 43 GWh_{el} + 67 GWh_{th} + 47 GWh_{gas} ≈ **157 GWh/a**
- **Past** 186 GWh; **LUXRES (2007) Potential 2020 = 331 GWh/a**



2010: 29 plants
2025: 19 plants

Potential for growth (PNEC/Strat. Biogaz)

- 1 Mt of manure (20-25 Nm^3/t)
- 75% of org. waste + green cuttings
- Max 1500 ha of Energy Crops
- 100 GWh_{el} + 170 GWh_{th} + 60 GWh_{gas} ≈ **330 GWh/a**

Potential (Biogas done right; Barn to Reactor)

- + 0.7 Mt of manure ≈ 280 GWh/a (CH_4: 40-55 Nm^3/t)
- + 32 000 t of waste currently composted ≈ 20 GWh/a (60 Nm^3/t)
- 280 GWh/a + 20 GWh/a + 157 GWh/a ≈ **457 GWh/a**
- CH_4 45 MNm^3 + CO_2 50 MNm^3 ≈ **100 - 200 kt biogenic CO_2**

https://data.public.lu/fr/datasets/waste-and-ressources-biowaste/

What emissions can be capture with biogas in Luxembourg?

Capture | **Uses**

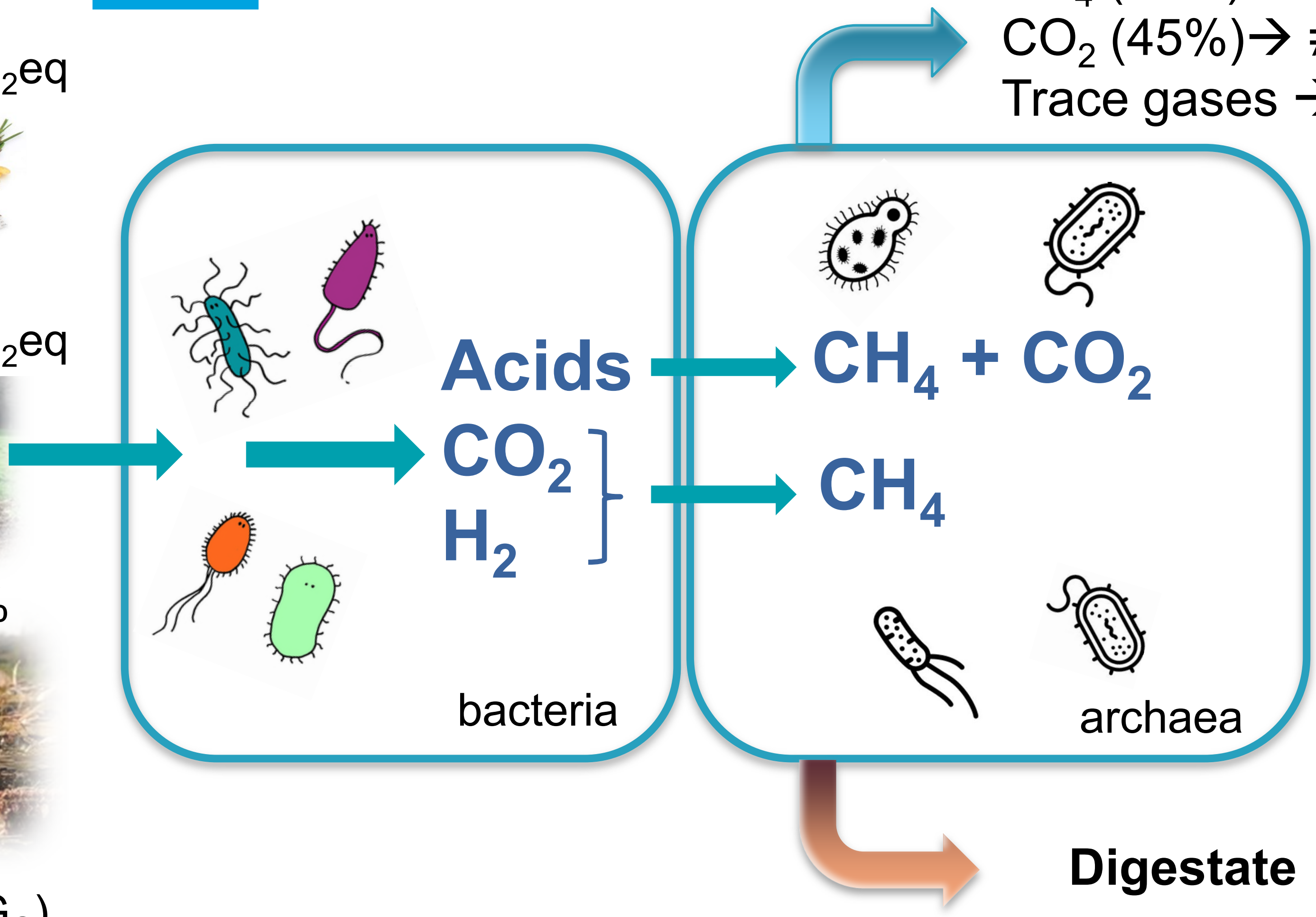
Waste organic matter

≈900 kt CO_2eq

≈150 kt CO_2eq

2%

(GHG_G)



Biogas

CH_4 (55%) → *E* & Processes (NH_3, 50% pop.)
CO_2 (45%)→ ≠ uses (**agric** & Ind.)
Trace gases → upgrading

Digestate

NPK, C_{org}, H_2O

Return of C_{org} to soils
Helps maintaining SOC

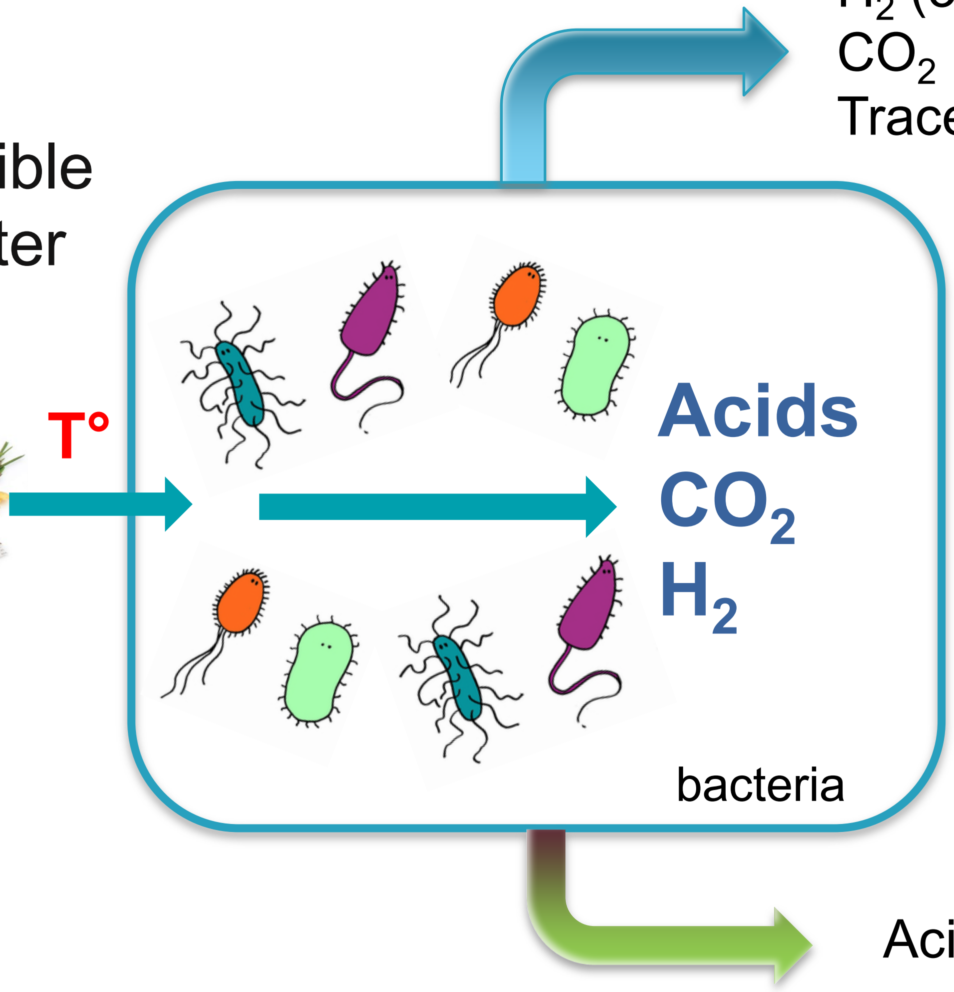
B. Tsachidou et al., 2021 (JEMA)

Tweaking the biogas process → BIO-H_2 & Green Chemistry

Biogas

H_2 (30%) → *E* & Processes (NH_3)
CO_2 (70%)→ ≠ uses
Trace gases

Highly digestible organic matter

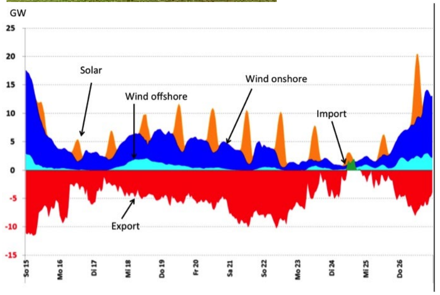


Kitchen waste
Sugars
Glycerin

Acids → Green Chemistry (polymers)

Tweaking the biogas process – Storage of Renewable Energy

Intermittent RE



CO_2 use

Electrolyzer

H_2O → CO_2, H_2

60% eff

O_2 Hospital, Ind.

Biological methanation

CH_4 (**90%**) → ***E*** & Processes

CO_2 (10%)→ ≠ uses

Trace gases

$$4\,H_2 + CO_2 = CH_4$$

Heat + 2 H_2O

archaea

Digestate = NPK, C_{org}, H_2O

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LIST

BRs

Methane and CO_2 upgrading technologies in force in Luxembourg

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Ahmad Naquash et al., 2022
https://doi.org/10.1016/j.rser.2021.111826

Biogas → CH_4
Biogas → CO_2

Amine adsorption
1 biogas plant
[CO_2] + air

Cryogenic Distillation
9 WWTP [liquid CO_2]

0.45€/kg

SIVEC

BIOGAS VEREENEGUNG

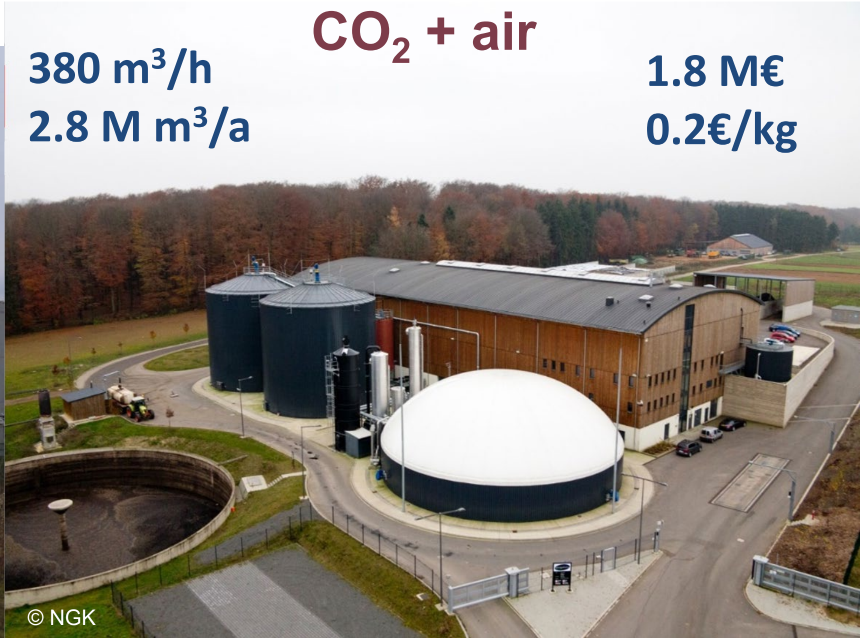
Membranes
[CO_2]

Water Scrubbing
2 biogas plants
CO_2 + air

170 m^3/h
1.250 M m^3/a

1.5 M €
0.3€/kg

© François Delion



380 m^3/h
2.8 M m^3/a

1.8 M€
0.2€/kg

© NGK

The future of biogas in Luxembourg ?
Optimized biogenic CO_2 recovery

Biogas grid ?
CO2 grid ?

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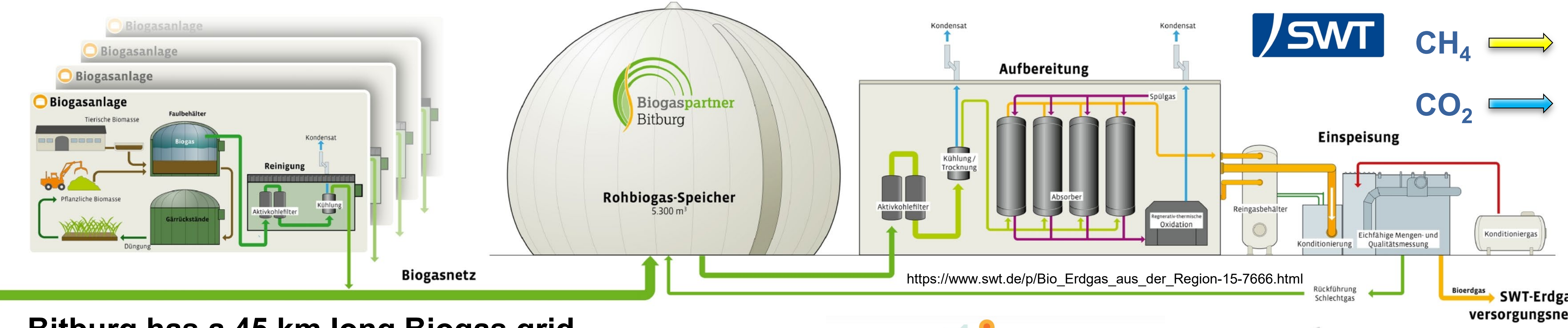
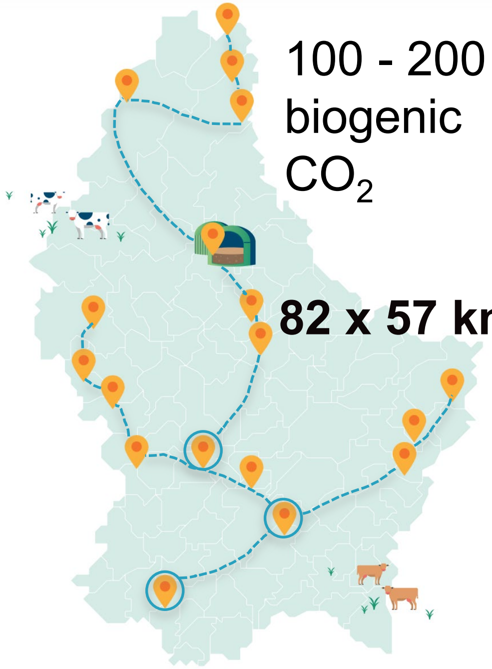


https://www.swt.de/p/Bio_Erdgas_aus_der_Region-15-7666.html

CH_4 → ✓

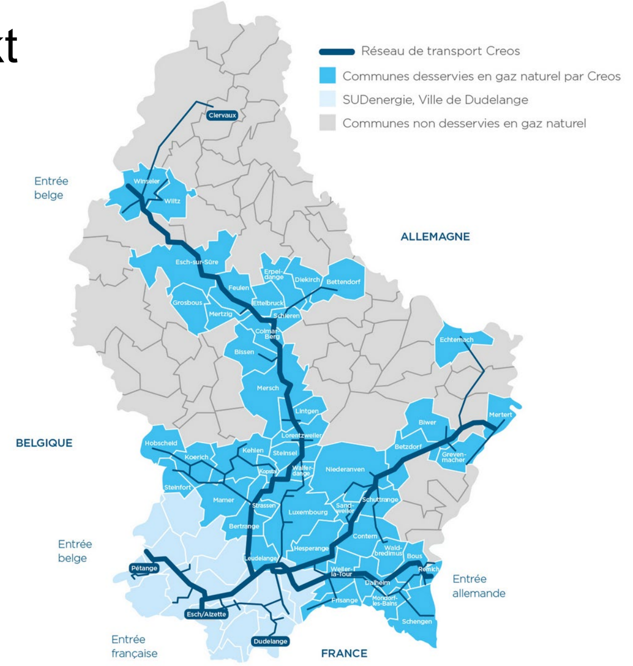
CO_2 → ?

Bitburg has a 45 km long Biogas grid



100 - 200 kt biogenic CO_2

82 x 57 km



CO_2 use in Agriculture – Greenhouse production 0.6ha

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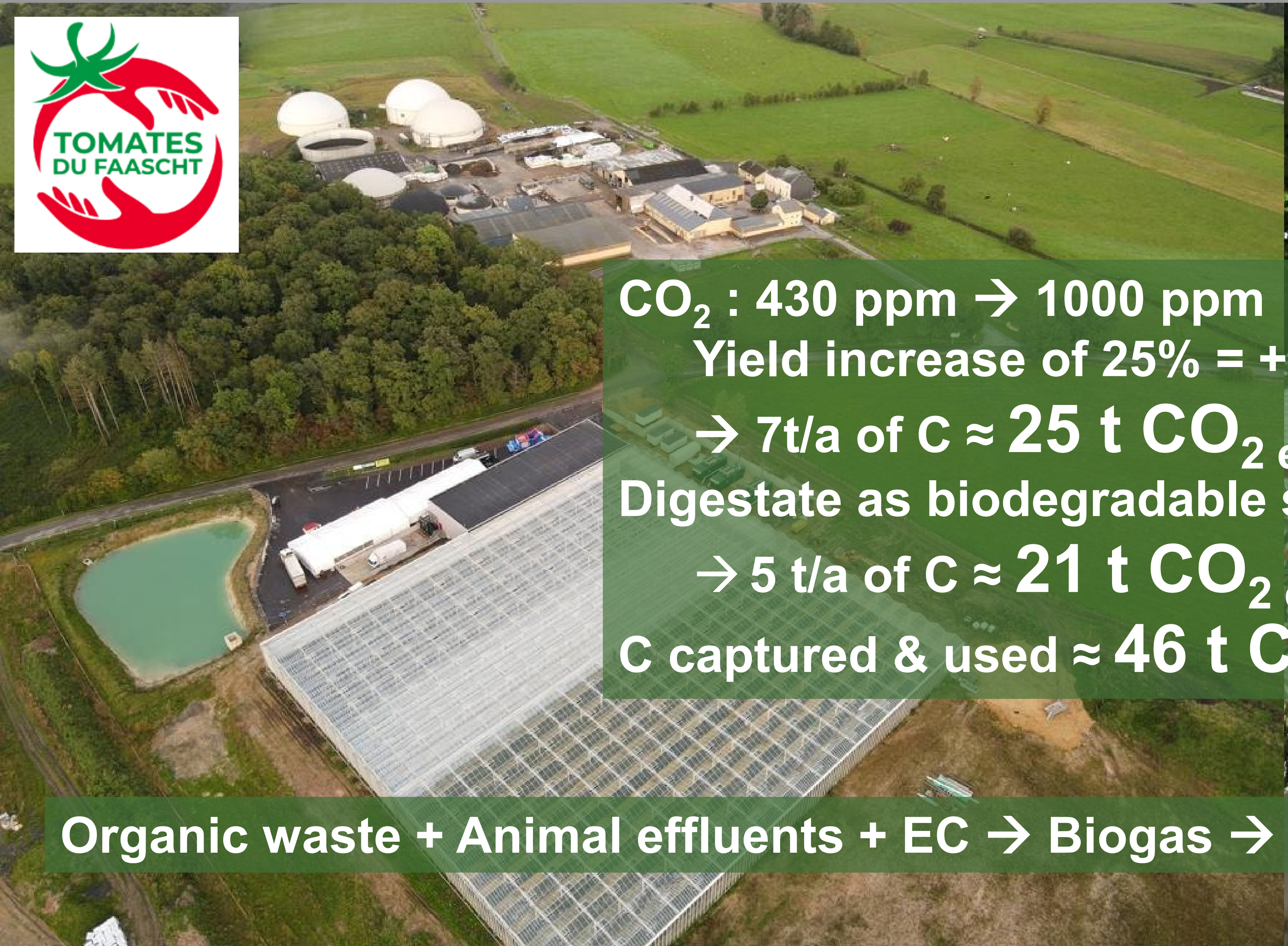


TOMATES DU FAASCHT

CO_2 : 430 ppm → 1000 ppm

Yield increase of 25% = +DM 14 t/a

→ 7t/a of C ≈ **25 t $CO_{2\ eq}$**

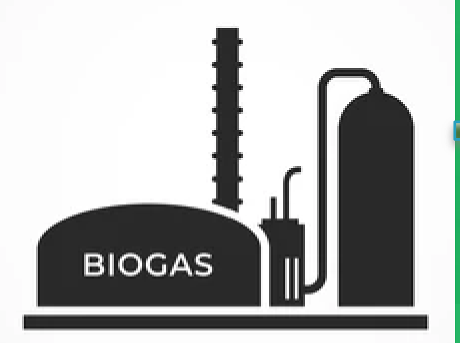
Digestate as biodegradable substrate

→ 5 t/a of C ≈ **21 t $CO_{2\ eq}$**

C captured & used ≈ **46 t $CO_{2\ eq}$**

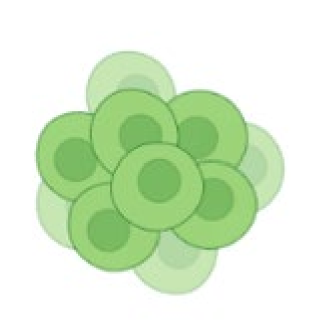
Organic waste + Animal effluents + EC → Biogas → Energy + Fertilizers + CO_2

CO_2 use in Agriculture – Greenhouse production 0.6ha



NPK
CO_2

Microalgae



© Philippe Delfosse

50-100 t CO_2/ha/a

Organic waste + Animal effluents + EC → Biogas → Energy + Fertilizers + CO_2

Increasing Soil Organic C (SOC) in agricultural soil is not easy !

- Soil is the largest continental C reservoir (2000 Gt)
- Soil loses 2.5 Gt of C per year (erosion, deforestation, drought)
- 1t food produced → 4 t of soil washed to the ocean
- SOC in Forest (80t/ha), Pasture (80t/ha), Cropland (50t/ha)
- Average SOC = 0.5% – 2.5% → **Maintain it !**

SOC requires adequate farming practices !

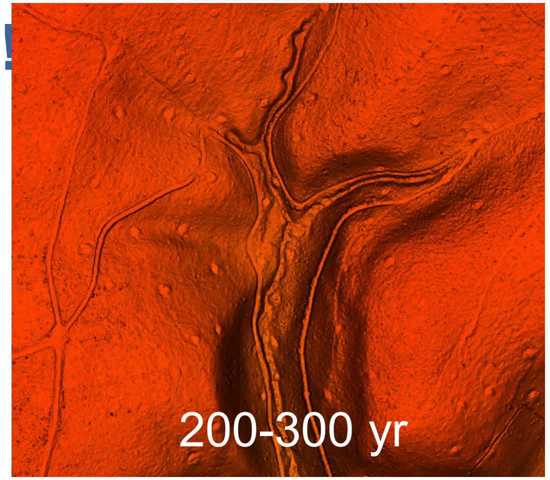
- ✓ No-till (no disturbance of the ecosystem)
- ✓ Permanent crops and Pastures (*idem*)
- ✓ Organic agriculture (10-40% increase in SOC)
- ✓ Biogas Digestates cycle C back and preserves SOC
- ✓ Chemical fertilizers reduces SOC
- ✓ Agroforestry, Cover crops (erosion)
- ✓ Biochar (long term sequestration, effects ?)

Biogas Digestate

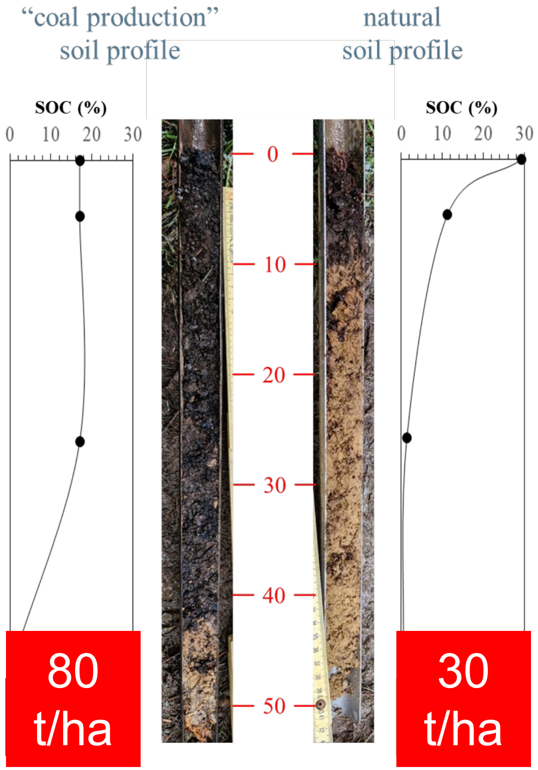
C_{stable} 45 kt/a

© Philippe Delfosse

Charcoal mounds Luxembourg Forest

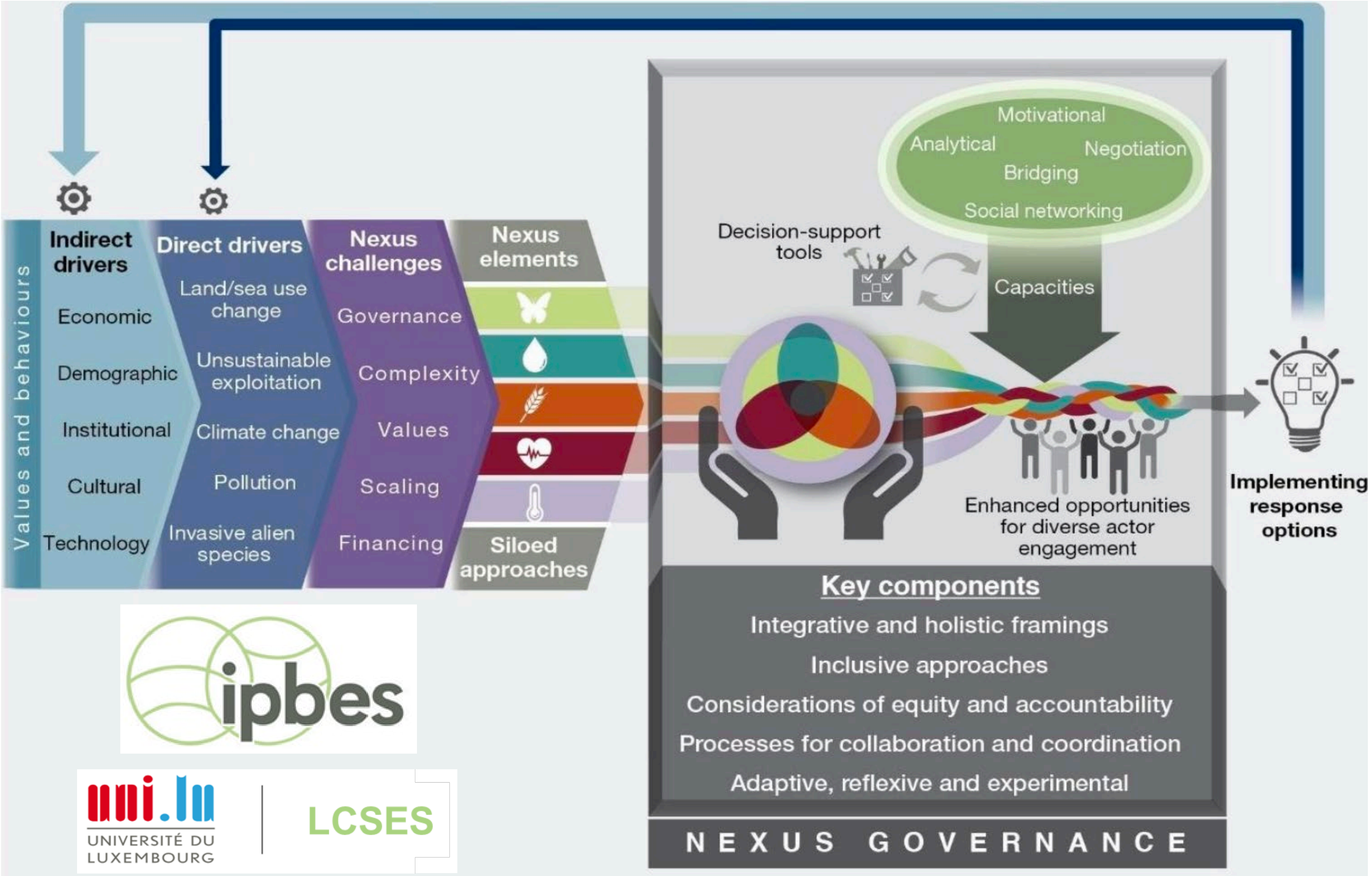


http://g-o.lu/3/Yrai



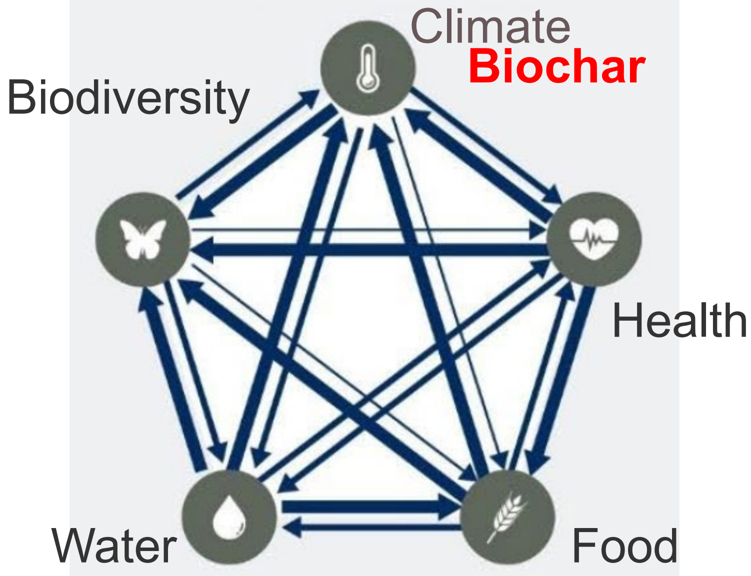
Christophe Hissler 2024, pers. com.
Bella Tsachidou et al. 2021

Luxembourg Centre for Socio-Environmental Systems (LCSES)



Ralf SEPPELT

Nexus approach



Thank you for your attention!