Online Capacity Building of SAARC Professionals on Commercial Scale Biogas Plants
August 23-27, 2021

Technologies for resource recovery from commercial-scale biogas plants

Aug. 27, 2021, 3:30 – 4:10 pm

Prof Sanjeev Kumar
HRED, IIT Roorkee, India
sanjukec@hre.iitr.ac.in

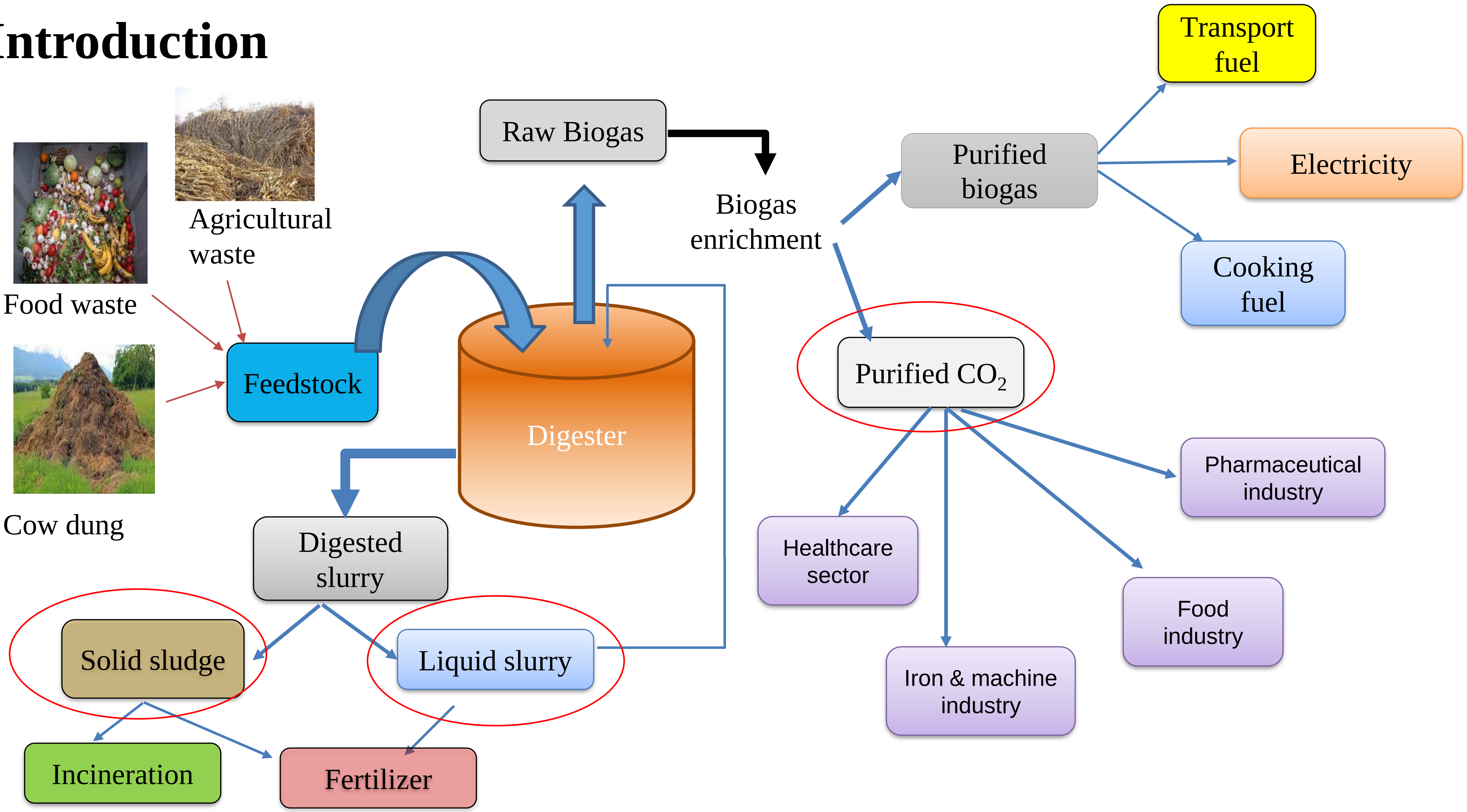
Contents

- Biogas plant – as biorefinery
- Resource recovery technologies – Gaseous streams
- Resource recovery technologies – liquid and solids
- Challenges and future outlook

Learning objective:

- to learn about possible methods of multiple resource recovery from commercial scale biogas plant

Introduction



Resource recovery technologies

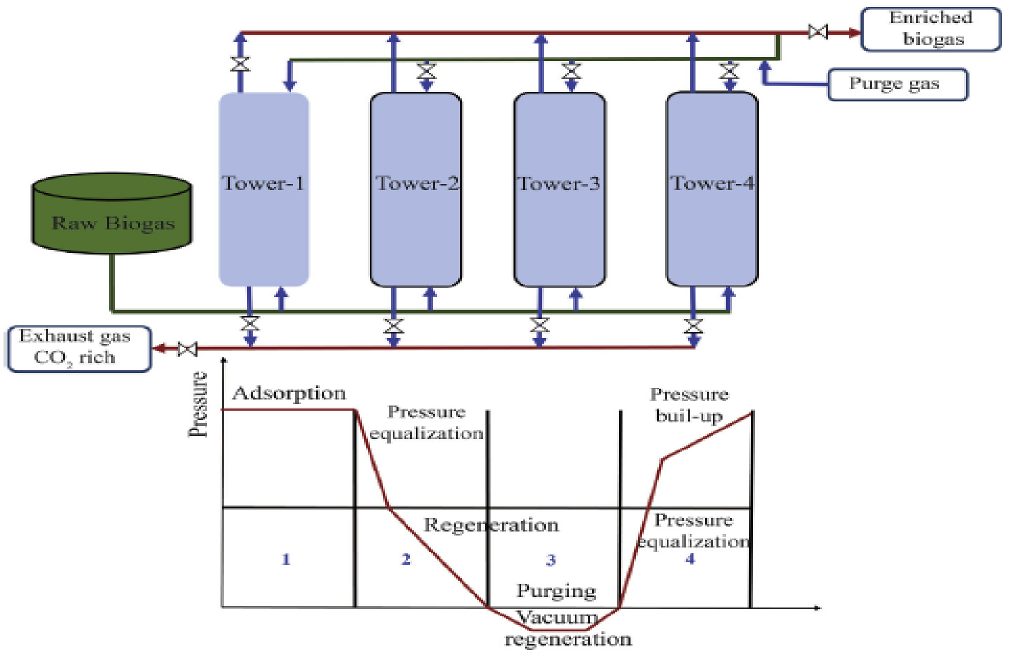
A. Waste CO_2 recovery technologies from biogas upgradation

- Absorption,
- Water scrubbing,
- Pressure swing adsorption,
- Cryogenic separation

Resource recovery cont….

1. Pressure swing adsorption

- The adsorbates (gas molecules) trapped by molecular sieve
- Besides CO_2 , other molecules such as H_2S, NH_3 and H_2O can be co-adsorbed
  - Operation pressures : 1 to 10 bar
  - Operation temperature: 5 to 35˚C

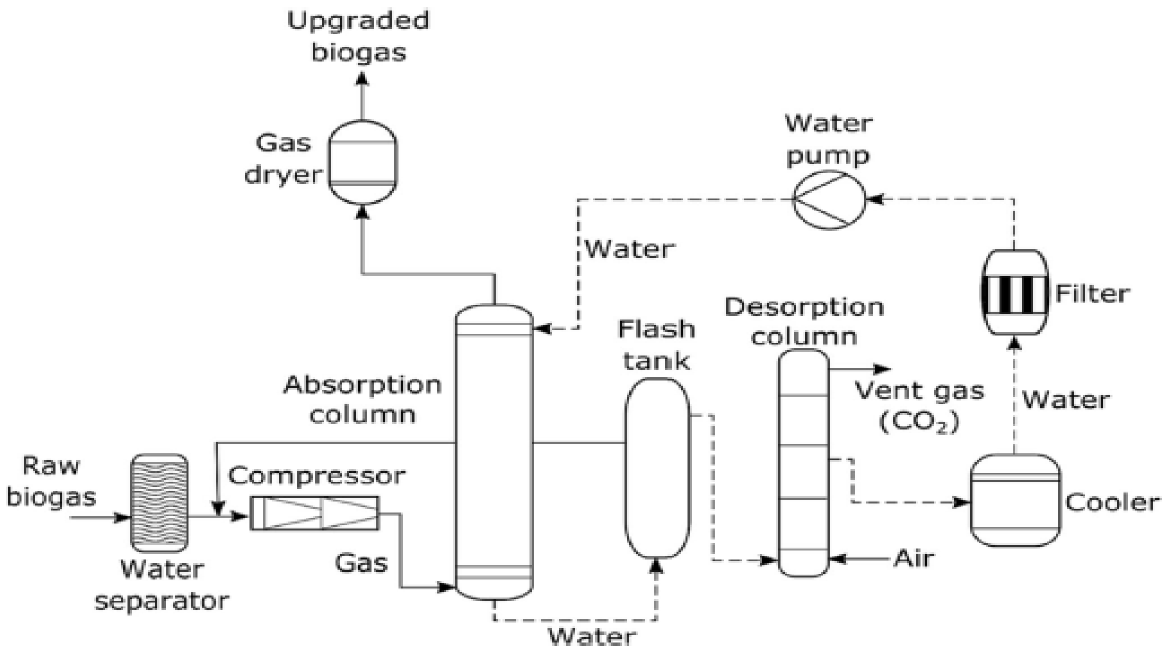


Pressure swing adsorption process (Shah et al., 2021)

2. Absorption techniques

a. Water scrubbing (physisorption)

- Implies the dissolution of gas or vapor in a liquid
- Low temperatures and high pressures
- CO2 and other acidic (e.g. H2S) and basic(e.g. NH3) gas components are absorbed in parallel



Water scrubber process (Struk et al., 2020)

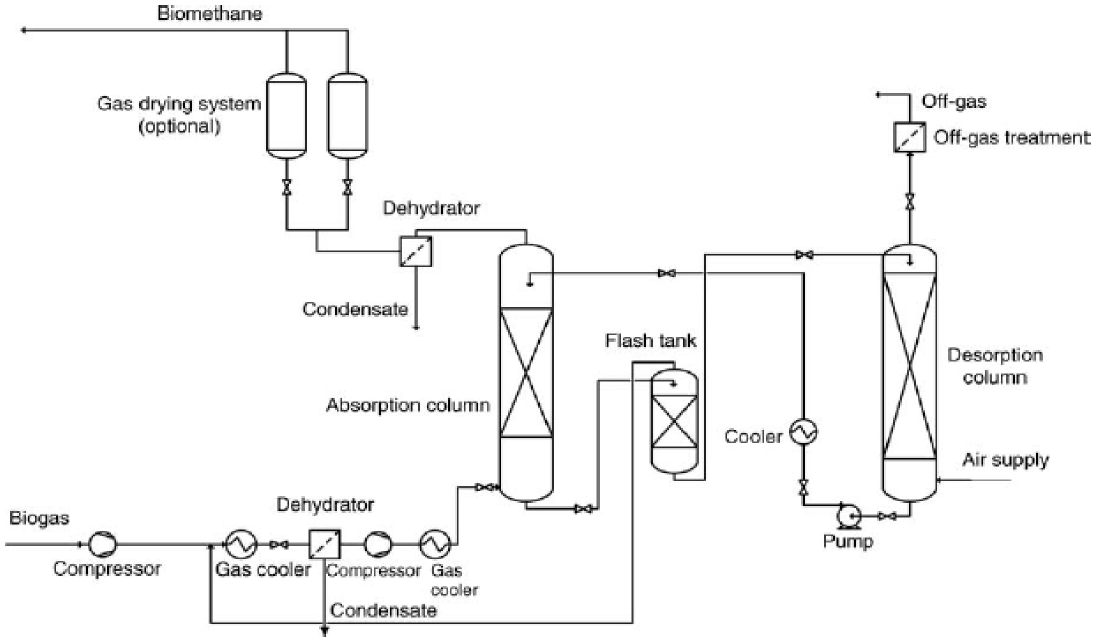
Resource recovery cont.….

b. Physical absorption by organic solvents

- Organic reagent (e.g. Polyglycol dimethyl ethers) serves as absorption agent
- Operation temperature in the absorption column is 10–20°C
- Absorbed of CO_2 can be purified

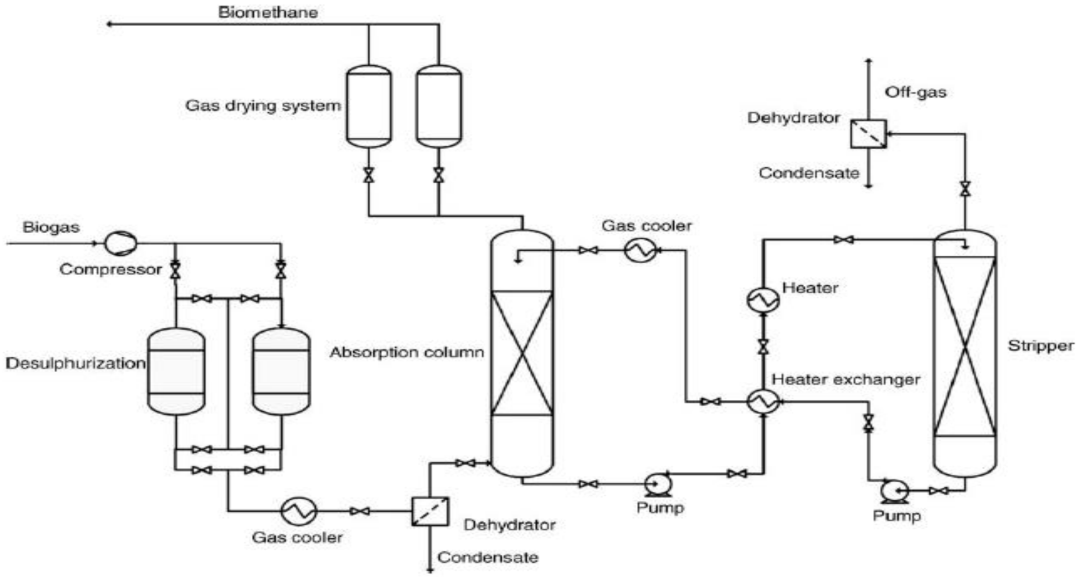
c. Chemical absorption by organic solvents (amine scrubbing)

- Different alkanolamine solutions can be used for the separation of CO_2
  - Monoethanolamine (MEA), Diethanolamine (DEA) and Methyldiethanolamine (MDEA)
- Off-gas does not require further treatment
- 80%-90% removal of CO_2



Physical absorption using organic solvents

(Beil & Beyrich, 2013)



Chemical absorption using organic solvents

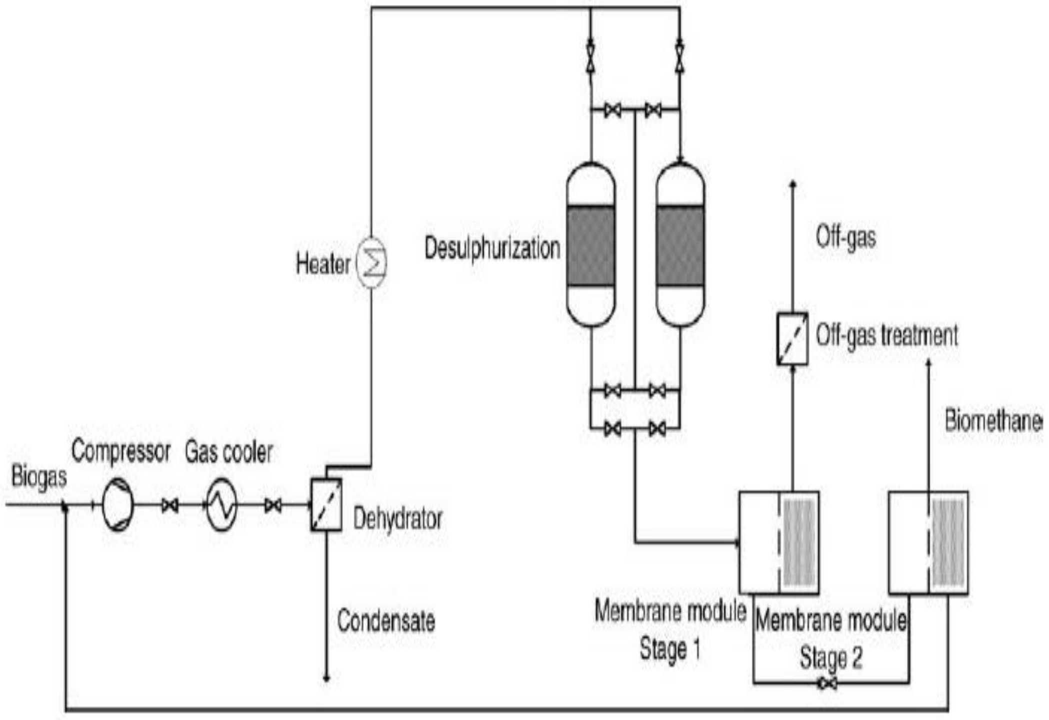
(Wellinger et al., 2013)

Resource recovery cont.....

3. Membrane separation/ gas permeation

- Three different flows

  -The feed (raw biogas), -The permeate (CO_2 rich gas), and -The retentate (CH_4 rich gas)
- Polymer membrane:Cellulose acetate and aromatic polyimides

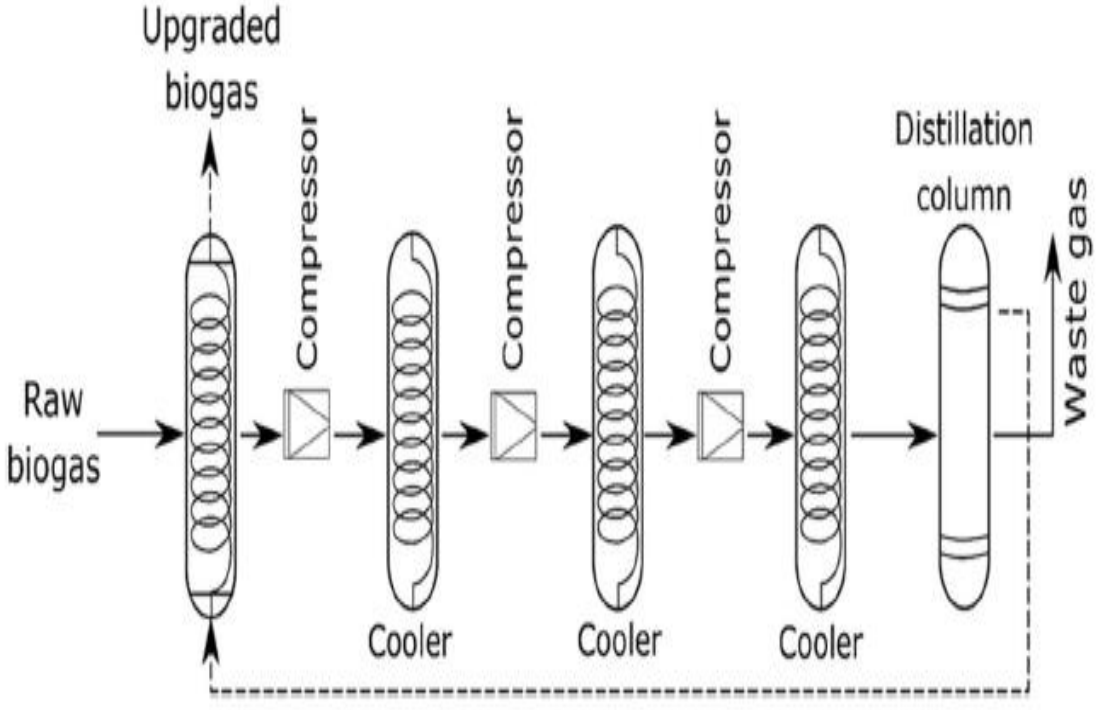


A two-stage membrane separation system

(Beil & Beyrich, 2013)

4. Cryogenic separation

- Uses the effect of different boiling points of methane (-161ºC) and sublimation points of carbon dioxide (-78.48ºC)

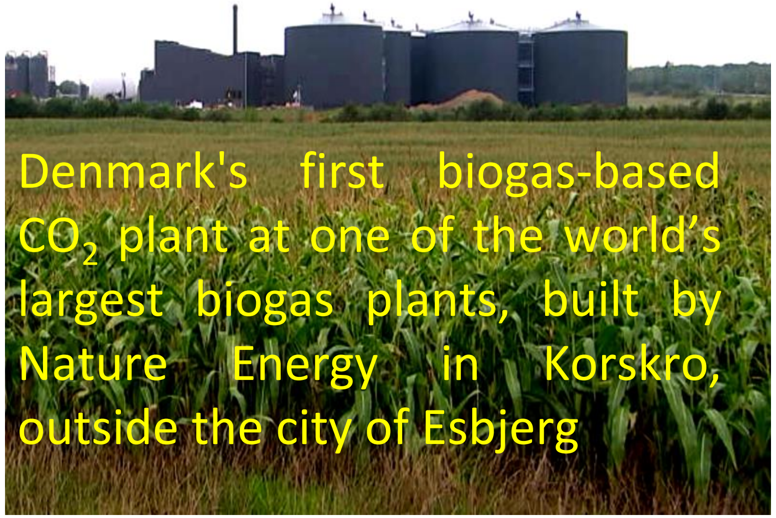


Cryogenic separation system

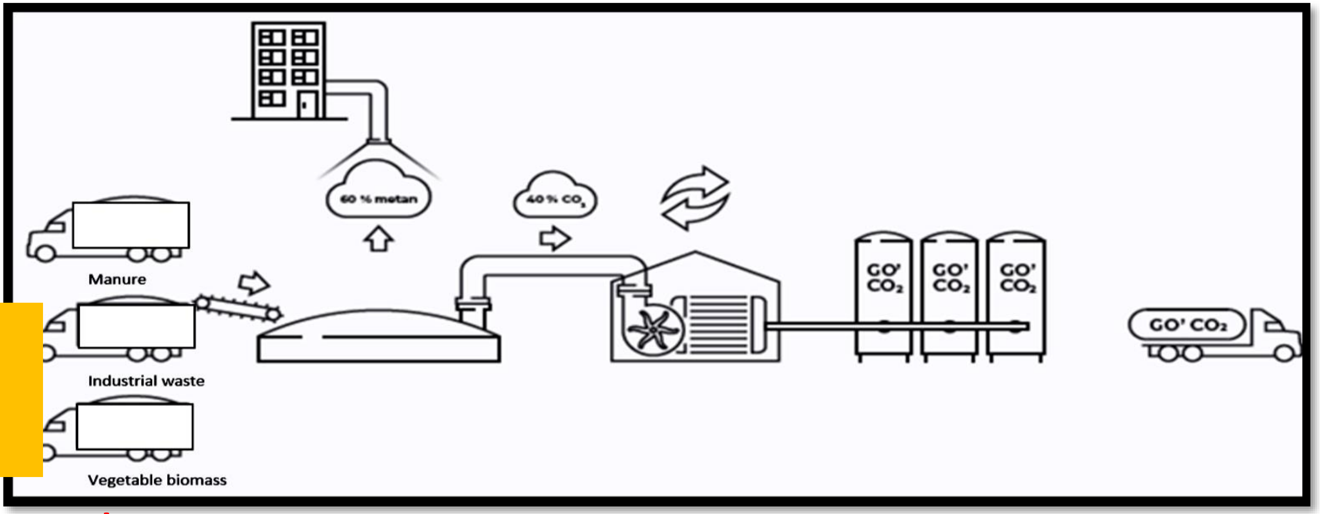
(Struk et al., 2020)

Food grade sustainable CO_2 from a large biogas facility:

Case study on ***The Korskro Biogas Plant, Denmark***



- Feedstock: 1 million tonnes biomass (80 % animal manure)
- Biogas - 49 million m^3 per year
- Upgraded to biomethane quality and injected in the gas grid
- CO_2 is captured and transferred to the CO_2 facility



Denmark CO_2 market is 65,000 tonnes/yr

Production of ≈ 16,250 tonnes of CO_2 for commercial use

The seven step purification process for food grade CO_2

Filtering → washing → distillation → compressing → condensation → drying → cooling

Source: IEA Bioenergy

Valorization of Digested slurry

- The digested can be used as it is produced or processed
- To reduce nutrient load of the remaining effluent,
- To produce marketable bio-fertilizer,
- To reduce the volume of effluent
- Thus to reduces transportation cost

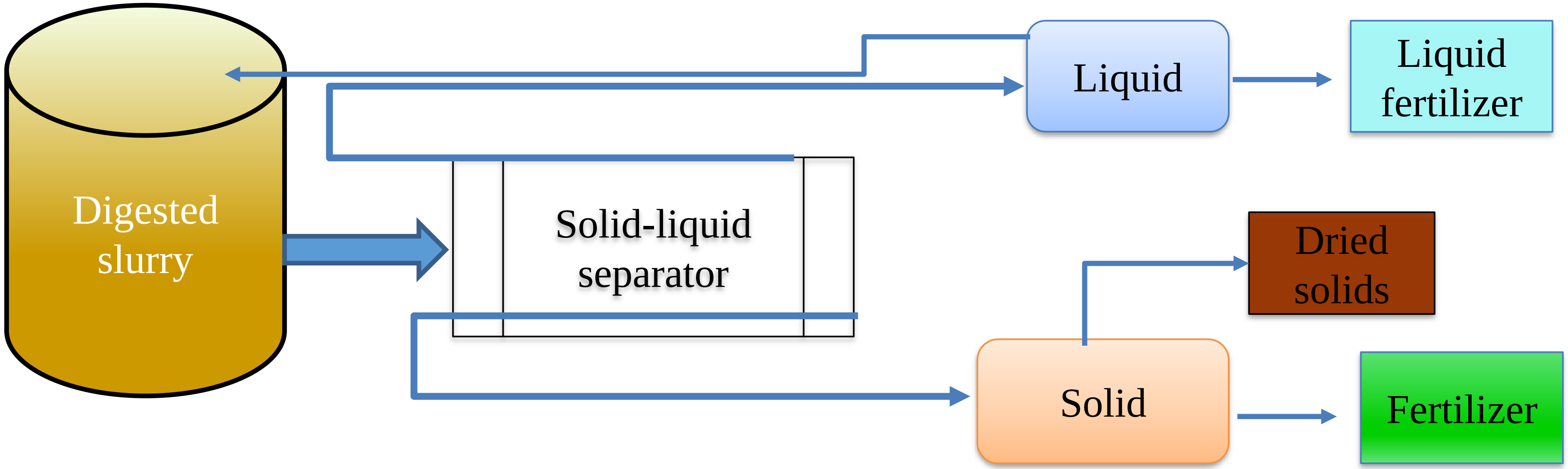
Digested processing cont…

➢ **Processing methods includes two steps**

a. Digestate conditioning:

- Quality and marketability of the digestate is improved to produce standardized bio-fertilizers (solid or liquid)

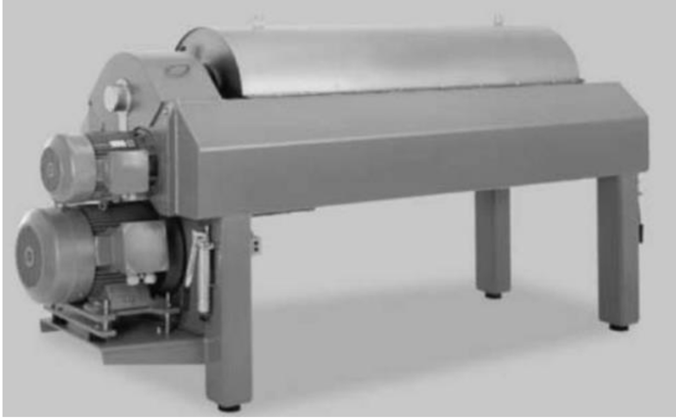
b. Digestate treatment:



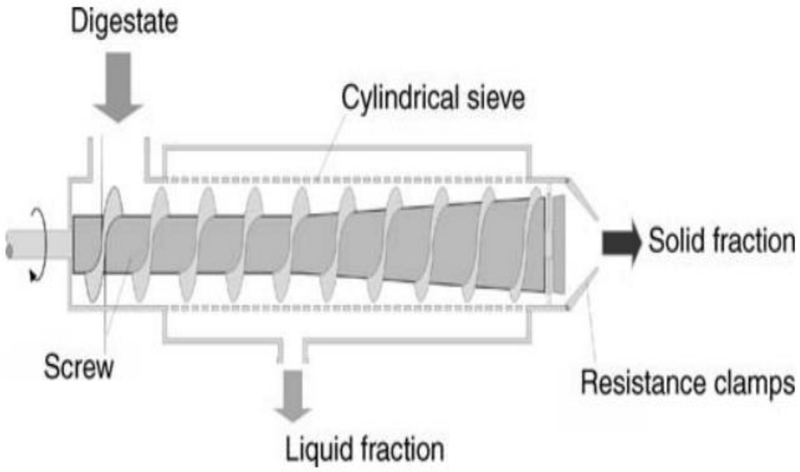
Digested processing cont…

1. Solid–liquid separation technologies

a. Decanter centrifuges,
b. Screw press separators,
c. Bow sieves,
d. Double circle bow sieves,
e. Sieve belt presses, and
f. Sieve drum presses.



Decanter centrifuge



Screw press separators

- Decanter centrifuges, and Screw press separators are two most popular methods
    - Simple, efficient and low cost systems
- Screw press separators mainly used in energy crop digestion
    - Fiber rich digestate
    - Decanter centrifuges are used in manure co-digestion

Digested processing cont.…

➢ **Solid and liquid fraction processing**

1. Processing of the solid fraction

a. Direct application as a soil improver

b. Composting

- To improve nutrient concentration
- Require organic fibrous material such as woodchips for composting
- Application in vermiculture using earthworm.

http://www.bspnepal.org.np/

Digested processing cont.…

c. Drying

i. Solar radiation
ii. Excess heat from CHP plant

- Dry solid application in horticulture and gardening sectors
  - For e.g.: Mushroom cultivation

2. Processing of the liquid fraction

a. Direct uses as nitrogen-rich liquid fertilizer

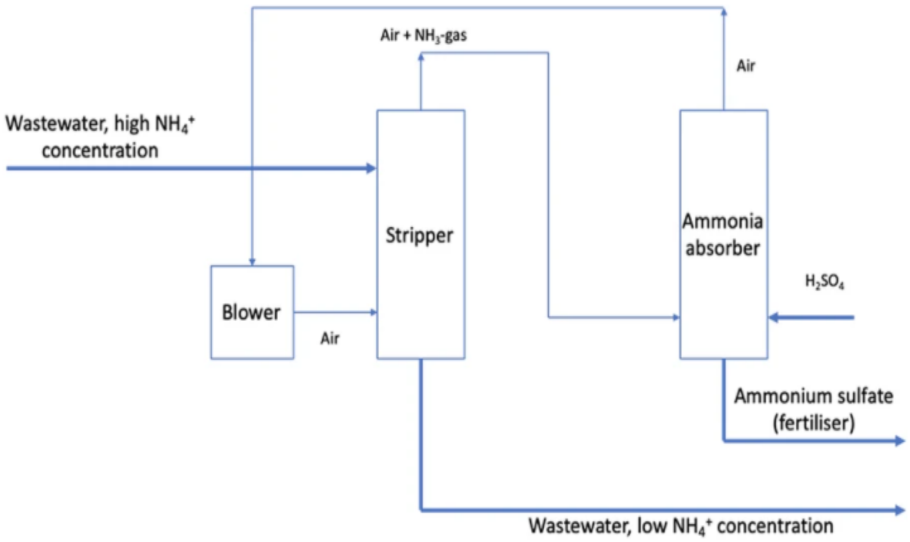
Sun drying of biogas slurry

(Yadav et al., 2013)

Digested processing cont. . . .

b. Ammonia stripping

- Applied to digested slurry containing high concentrations of ammonia
- High temperature and pH increase the process efficiency
- Stripped ammonia gas is recovered by absorption to an acid, commonly sulphuric acid
- Produces a low pH ammonium sulphate
  - fertilizer for use on soils with alkaline or neutral reaction

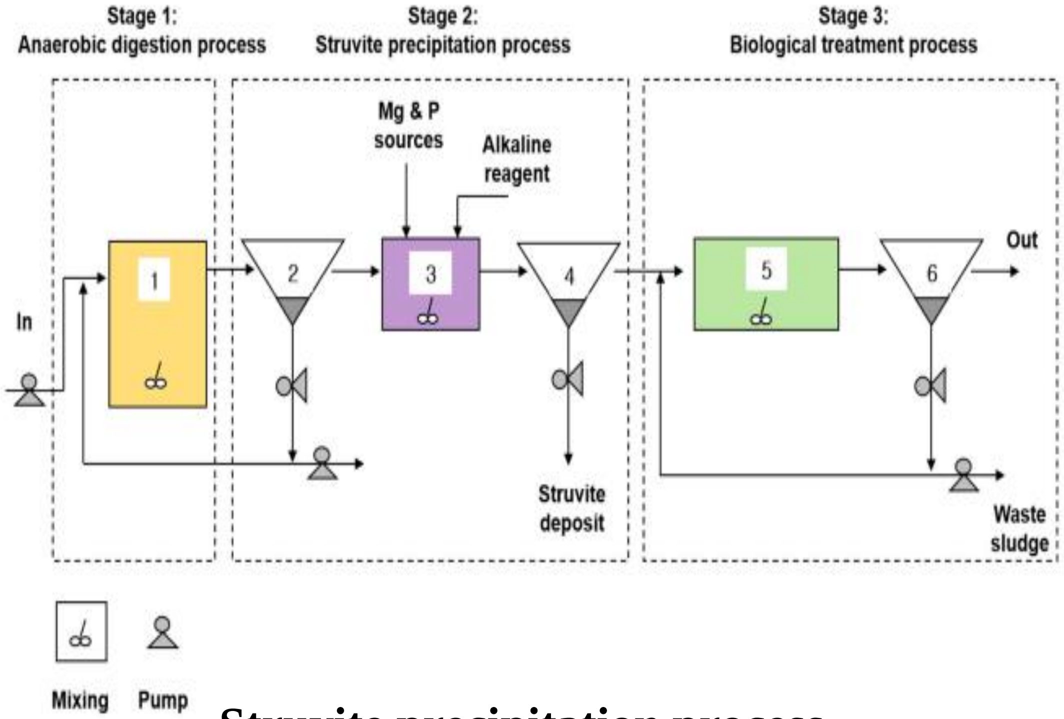


Ammonia stripping process

(Lorick et al., 2020)

c. Struvite precipitation

- Requires the addition of magnesium and phosphate to facilitate ammonia removal
- Standardized nitrogen fertilizer product recovery
- High market value fertilizer



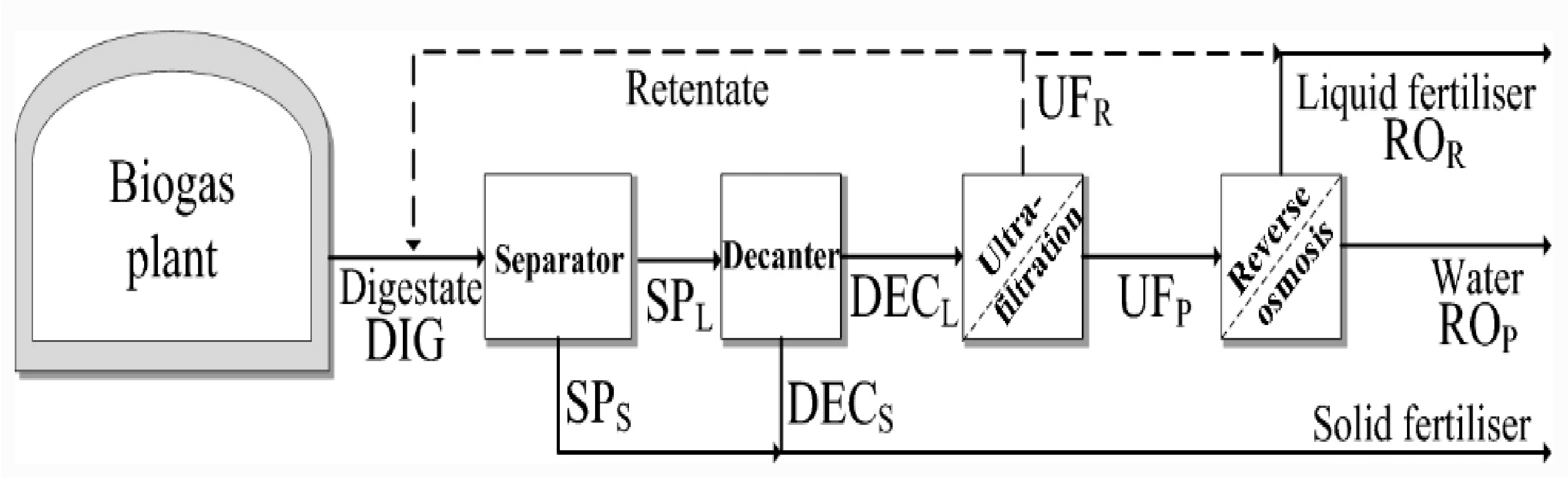
Struvite precipitation process

(Ryu et al., 2020)

Digested processing cont.…

d. Membrane filtration

- Can performed after solid removal
- Can purify only a limited amount of the digestate
- Ultrafiltration followed by reverse osmosis used to remove ammonia and chemical oxygen demand (COD)
-



(Gienau et al., 2018)

Case study: Nutrient recovery from digestate

SwissFarmerPower Biogas plant, Switzerland

digesters and storage-tanks

FACTS

–Manure, biowaste and industrial biogenic waste

– Total biogas production = 3.4 Million m3/year

– Biomethane into the gas grid ≈ 19 GWh natural gas annually

Table 1: SFPI biogas plant – inputs and outputs

Input	Tonnes/year
Pig manure	30,000
Industrial waste	15,000
Biowaste	16,000
Total	61,000
Output	
Solid digester output	13,000
Liquid fertilizer	10,000
Permeate	> 30,000
Total	53,000

Solids- post-composting process to achieve a high quality product

liquid digestate - treated in a series : centrifuge to ultrafiltration and finally reverse osmosis

Over 30,000 tons of permeate are recovered from the reverse osmosis – used for cleaning purposes in plant

Biogas cleaning (PSA)

Ultrafiltration unit

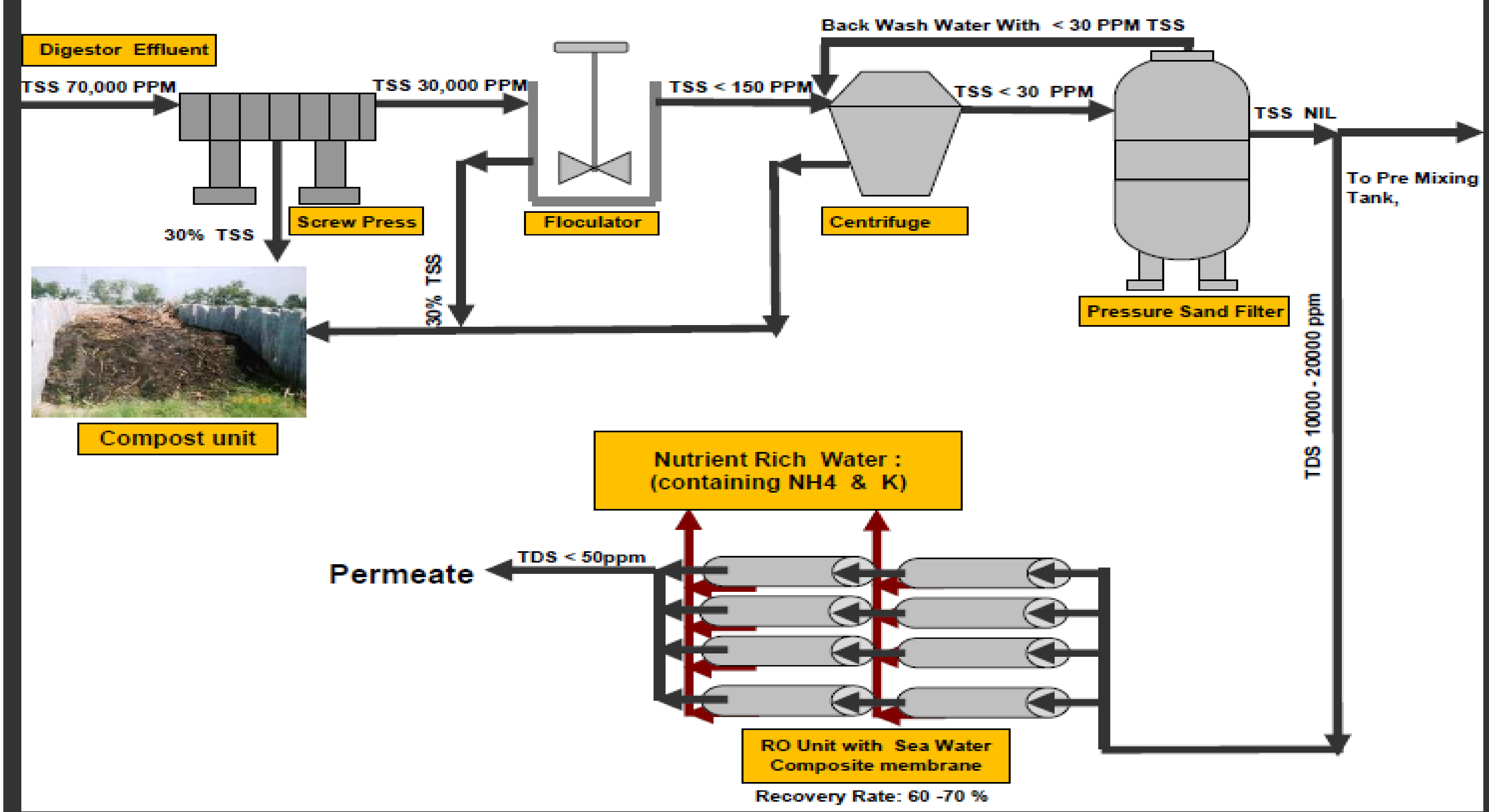
Digestate transporter

Case study: Waste-to-Energy Plant, Namakkal District, Tamil Nadu

- 120,000 tons/ year of chicken litter and other organic residues from starch and sugar industries
- 6 units of 1 MW Biogas Power Plants
- ***Annual power generation of 20,000 MWh - being fed into the southern electricity grid***
- 36,000 tons/year of Solid Organic Fertilizer
- 72,000 KL/year of Liquid Fertilizer
- Organic fertilizer unit comprises solid separation and liquid treatment units:
  - Screw press (or fabric filter)
  - Flocculation system
  - Centrifuge + Press sand filter (or pressure sand filter + micro filter)
  - UF + RO Unit

https://www.devalt.org

Schematic of Organic Fertilizer Unit



More than 10 years production of fossil free automotive fuel and certified digestate from food waste: Case study on NSR biogas plant, Sweden

Facts & Figures

Organic waste capacity	160 000 tons/year
Methane in raw gas	65–72%
Biogas production	80 GWh
Digestate production	145 000 tons
Digester tanks	2 x 3000, 1 x 6000 m^3
Post-digestion tanks	2 x 1000 m^3
Digester temperature	37 °C
Digestate pipeline	10 km

Three upgrading units:

PSA	350 Nm^3/h
Water scrubbers	650, 1400 Nm^3/h

Operational start-up	1996

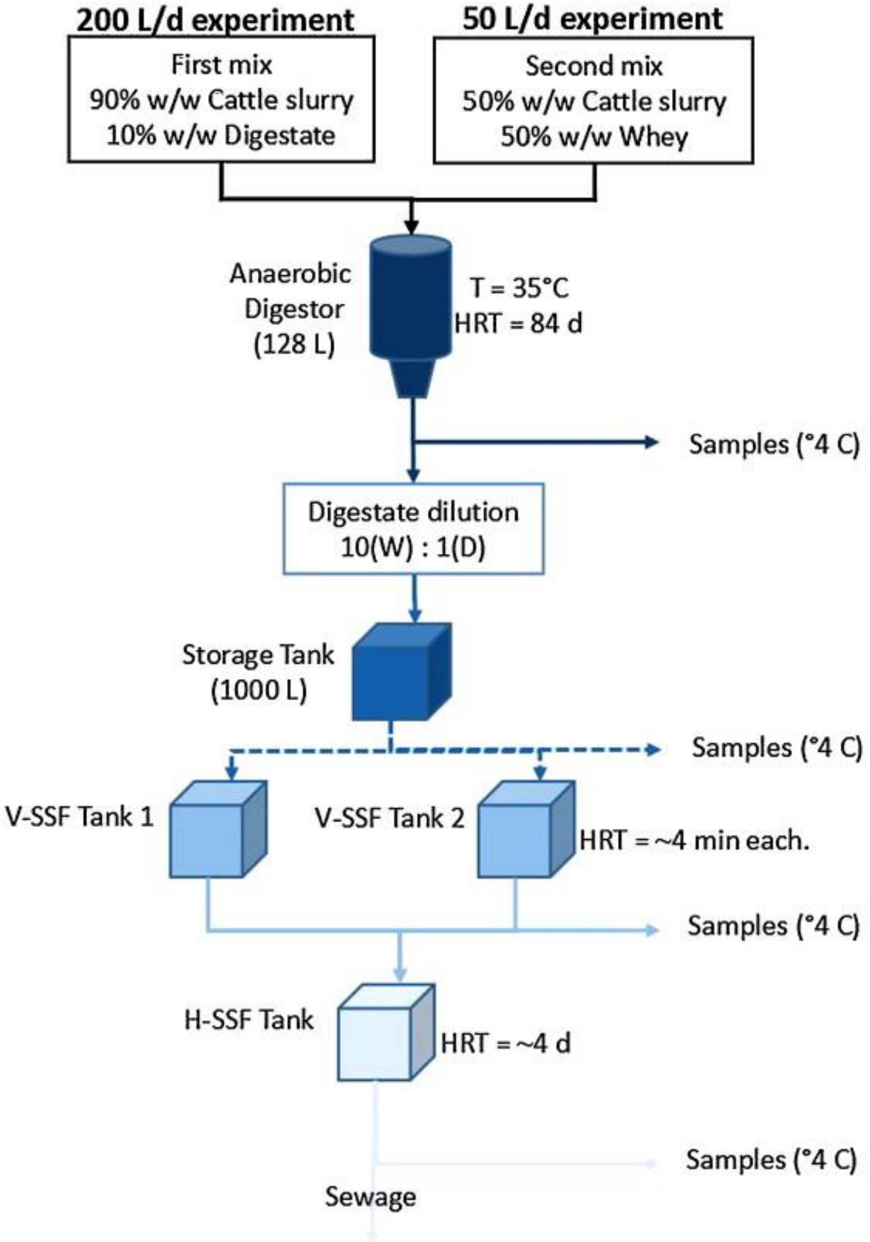
biogas upgrading -water scrubbing (1400 m3 raw biogas/h) .

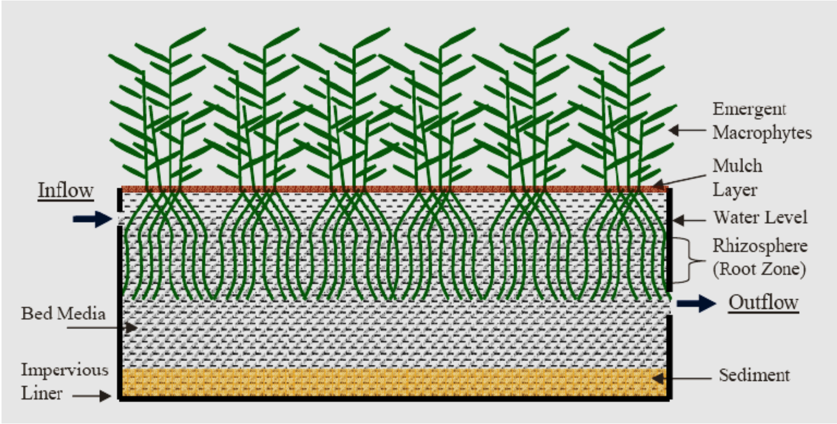
- From 160,000 tons of digested food waste in the biogas plant ≈ 490 tons of N, 90 tons of P, and 170 tons of K are available for recirculation as fertilizer each year.
- The digestate is certified according to the Swedish certification system SPCR 120 - approved for fertilizing cultivated crops aimed for the food industry.

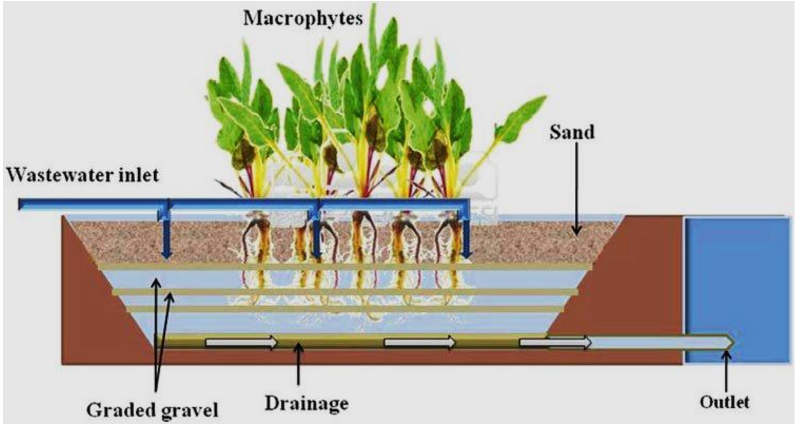
Source: IEA Bioenergy Task 37, members of Sweden

Constructed wetland treatment of agricultural effluent from an anaerobic digester:

Research paper by ***Comino et. al., 2013*** https://doi.org/10.1016/j.ecoleng.2013.01.027







Treatment potential

	Slurry digestate			
	Inlet	VSS-F A	V-SSF B	Outlet
pH	8.2	7.8	7.8	7.8
Chemical oxygen demand (mg/L)	1192	1030	524.6	279.8
Chlorides (mg/L)	203.5	184	165	67.5
N-NH4 (mg/L)	120	48	43.2	15.4
N-NO3 (mg/L)	47.6	22.7	18.5	6.2
P-PO4 (mg/L)	44	38.8	11.7	5.56
EC (µs/cm)	2130	1300		886
Total dissolved solids (ppm)	1065	650		443
Salinity (PSU)	1	0.6		0.4

Challenges and future outlook

- Reduction in energy consumption
- Handling both H_2S and CO_2 in a single unit
- Minimizing cost per unit of enriched biogas
- Attempts are needed to treat and recycle the liquid from the digestate – as dilution water
- Designing of large throughput and reliable system that can sustain rapid cycling towards circular economy
- Replication of resource recovery role models in SAARC member states

References

1. Beil, M., & Beyrich, W. (2013). Biogas upgrading to biomethane. The Biogas Handbook: Science, Production and Applications, 342–377. https://doi.org/10.1533/9780857097415.3.342
2. Struk, M., Kushkevych, I., & Vítězová, M. (2020). Biogas upgrading methods: recent advancements and emerging technologies. Reviews in Environmental Science and Biotechnology, 19(3), 651–671. https://doi.org/10.1007/s11157-020-09539-9
3. Wellinger, A., Murphy, J., & Baxter, D. (2013). The biogas handbook. In The biogas handbook. https://doi.org/10.1533/9780857097415
4. Allegue, L.; Hinge, J.; Institute, K. A.-D. T.; 2012, undefined. Biogas and Bio-Syngas Upgrading. *teknologisk.dk* **2012**.
5. Shah, G.; Ahmad, E.; Pant, K. K.; Vijay, V. K. Comprehending the Contemporary State of Art in Biogas Enrichment and CO2 Capture Technologies via Swing Adsorption. Int. J. Hydrogen Energy 2021, 46 (9), 6588–6612. https://doi.org/10.1016/j.ijhydene.2020.11.116.
6. Bio-CNG Plant Spectrum Renewable Energy Limited, Kodoli, Kolhapur
7. https://www.mahaurja.com/meda/data/off_grid_bio_energy/Success%20Story%20on%20%20Bio%20CNG.pdf
8. Gienau, T.; Brüß, · U; Kraume, · M; Rosenberger, · S. Nutrient Recovery from Anaerobic Sludge by Membrane Filtration: Pilot Tests at a 2.5 MWe Biogas Plant. 2018, 7, 325–334. https://doi.org/10.1007/s40093-018-0218-6.
9. Lorick, D.; Macura, B.; Ahlström, M.; Grimvall, A.; Harder, R. Effectiveness of Struvite Precipitation and Ammonia Stripping for Recovery of Phosphorus and Nitrogen from Anaerobic Digestate: A Systematic Review. Environ. Evid. 2020 91 2020, 9 (1), 1–20. https://doi.org/10.1186/S13750-020-00211-X.
10. Ryu, H. D.; Lim, D. Y.; Kim, S. J.; Baek, U. Il; Chung, E. G.; Kim, K.; Lee, J. K. Struvite Precipitation for Sustainable Recovery of Nitrogen and Phosphorus from Anaerobic Digestion Effluents of Swine Manure. *Sustain.* **2020**, *12* (20), 1–15. https://doi.org/10.3390/su12208574.
11. Yadav, A.; Gupta, R.; Garg, V. K. Organic Manure Production from Cow Dung and Biogas Plant Slurry by Vermicomposting under Field Conditions. Int. J. Recycl. Org. Waste Agric. 2013 21 2013, 2 (1), 1–7. https://doi.org/10.1186/2251-7715-2-21.

SAARC ENERGY CENTRE

Energy for Peace & Prosperity

Online Capacity Building of SAARC Professionals on Commercial Scale Biogas Plants

August 23-27, 2021

Thank you