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

Fundamentals on Biogas Production Process

Aug. 24, 2021, 2:30 – 3:25 pm

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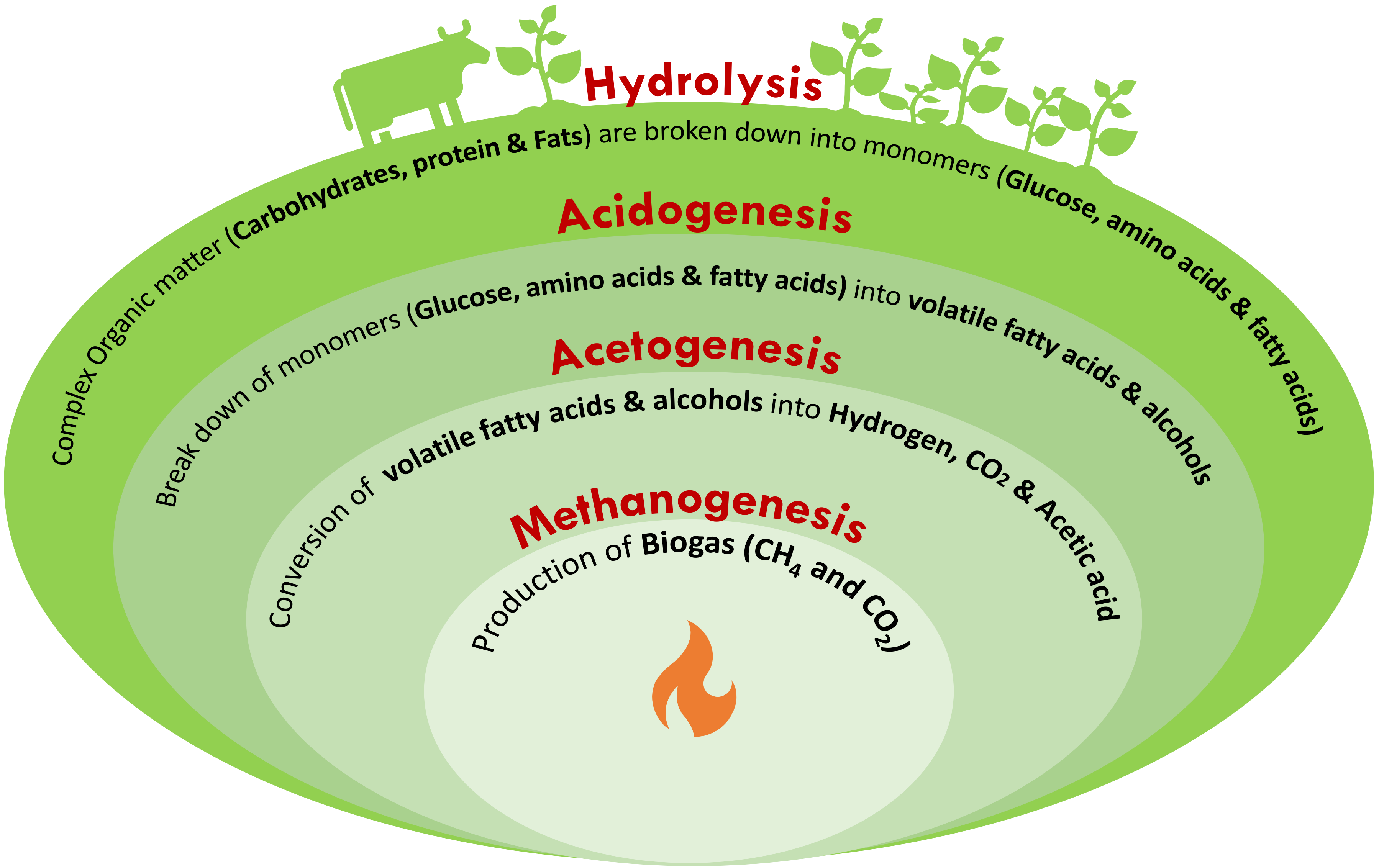
Contents

- ❑ Biogas production process: four steps involved
- ❑ General biochemical aspects of the biogas production process
- ❑ Process parameters for substantial biogas production
- ❑ Problems associated with biogas production and troubleshooting
- ❑ Recent advances in biogas production technology

Learning objective

- ➢ To learn the fundamentals on biogas production process, problems associated with the biogas process and possible remedial actions.

Biogas production…

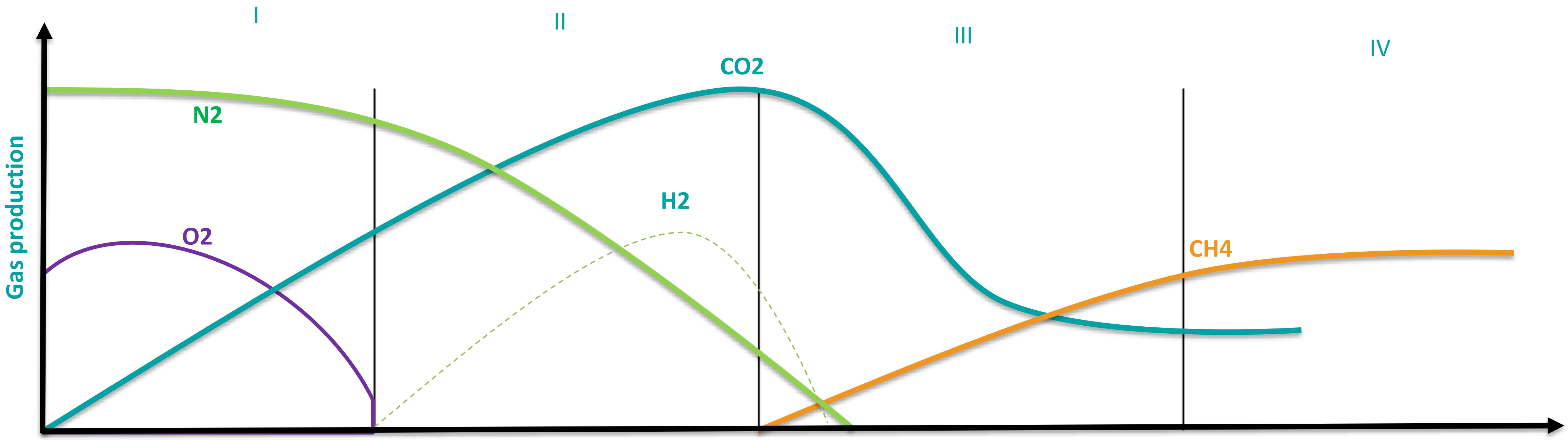


Biochemical aspect…

Hydrolysis	Acid formation	Methane formation

Protein carbohydrate fats —Oxidation→ *Fatty acids alcohols* —Acetogenesis→

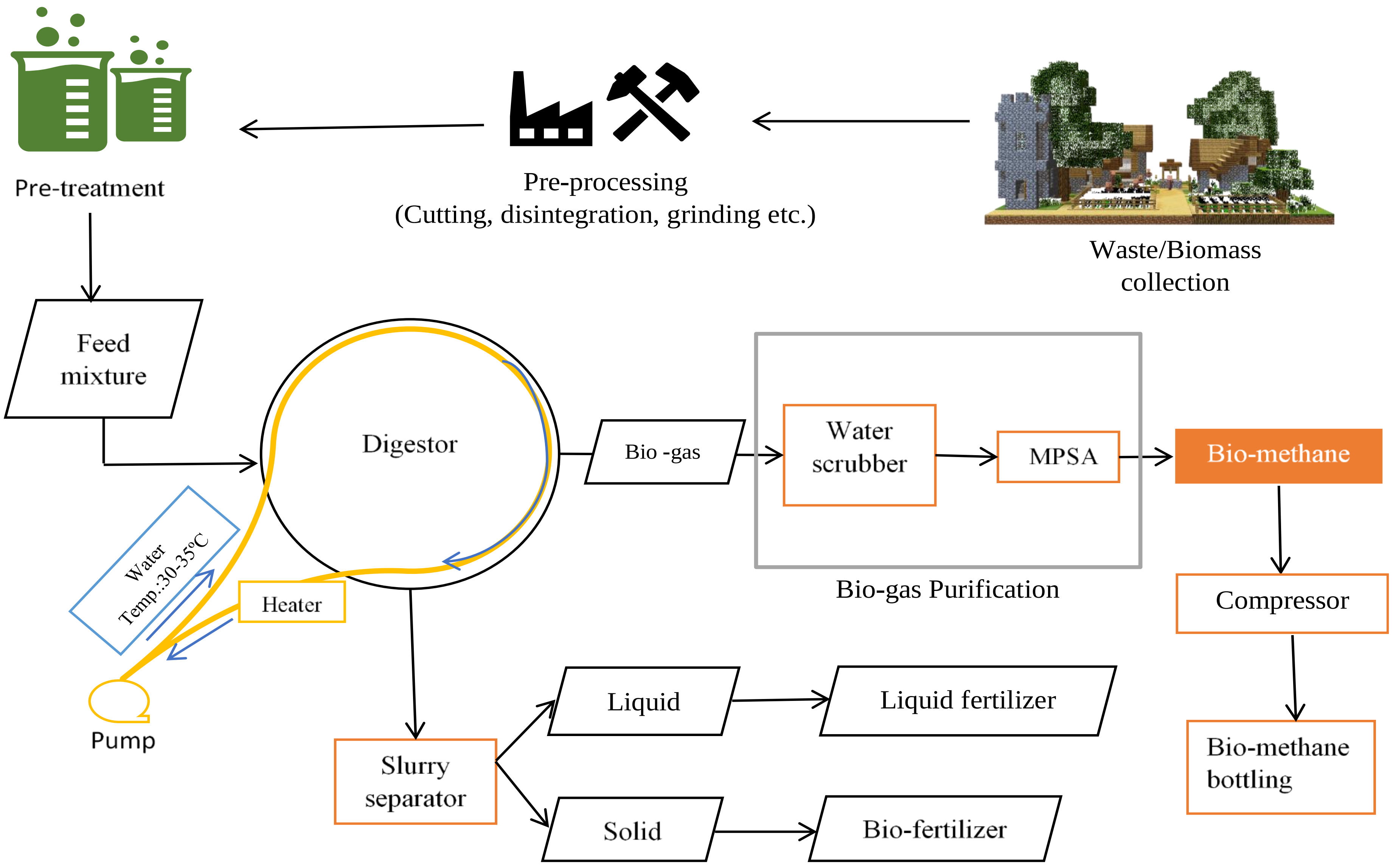
- CH_3COOH (*Acetic acid*) —Methanogenesis→ $CH_4 + CO_2$
- $2CH_3CH_2OH + CO_2$ (*Ethanol*) → $CH_4 + 2CH_3COOH$
- $CO_2 + 4H_2$ (*Carbon dioxide*) → $CH_4 + 2H_2O$



Composition of Biogas

Gas	Composition (%)
Methane (CH_4)	50-75
Carbon dioxide (CO_2)	25-50
Hydrogen (H_2)	0-1
Nitrogen (N_2)	0-10
Hydrogen sulphide (H_2S)	0-3

Biomethane Production Overview



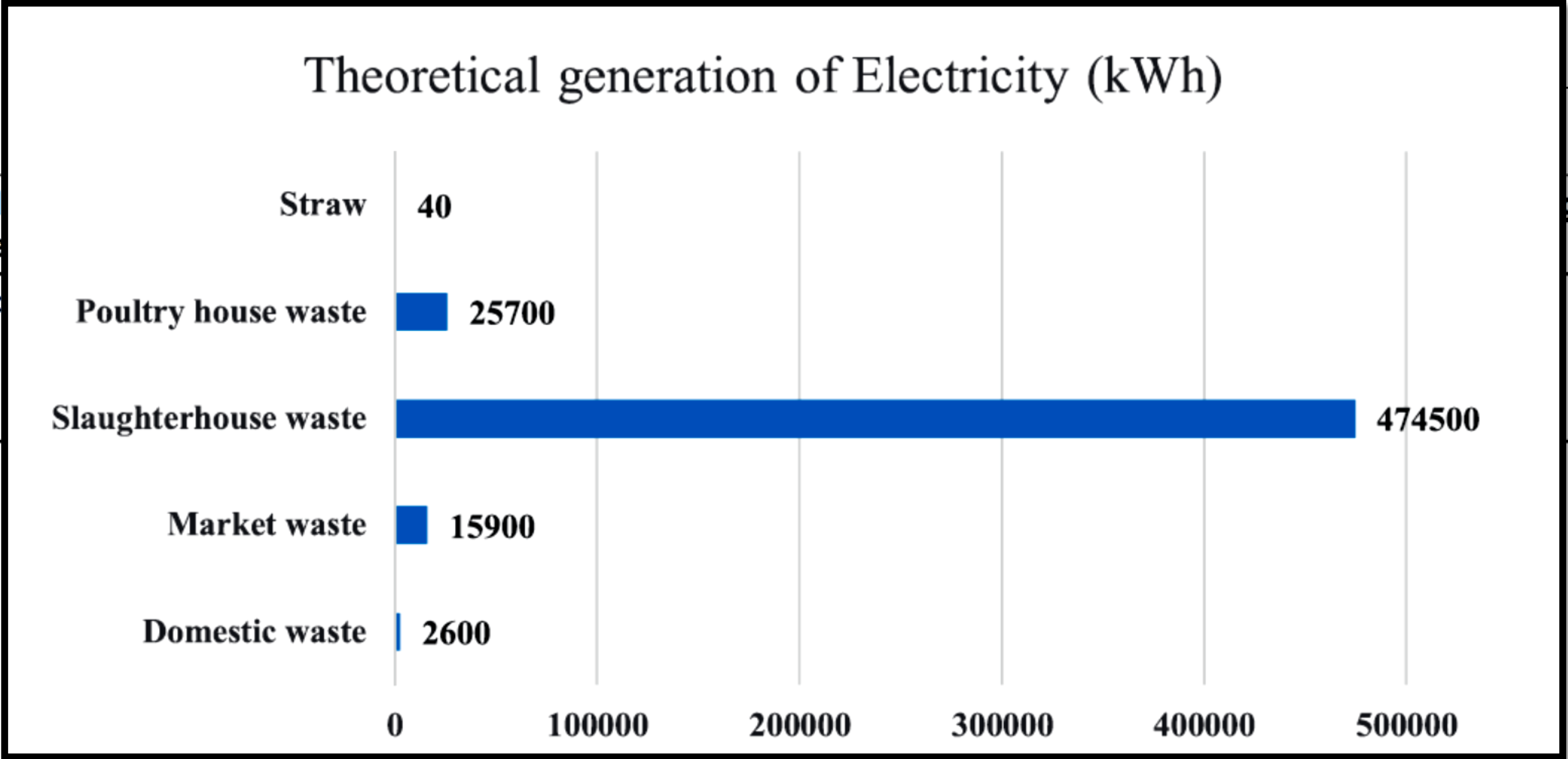
Waste to Biogas generation potential in Hazaribagh, Bangladesh: A case study

Area of Hazaribagh = 5.65 km²

Population density = 32.856/km²

Biomass energy situation in Bangladesh [44].

Technology	Potential	Target capacity	Achievement
Domestic biogas system	8.8 million m^3	1,00,000 biogas plants	Ongoing project
Biomass gasification	300 MW	3 MW	≤1 MW
			1 MW



The estimated … generation from each substrate

Feedstock sourc…	Theoretical generation of Electricity (kWh)
Domestic waste	2600
Market waste	15,900
Slaughterhouse waste	474,500
Poultry house waste	25,700
Straw	40

have question marks about the data quality.

(Hasan and Ammenberg 2019)

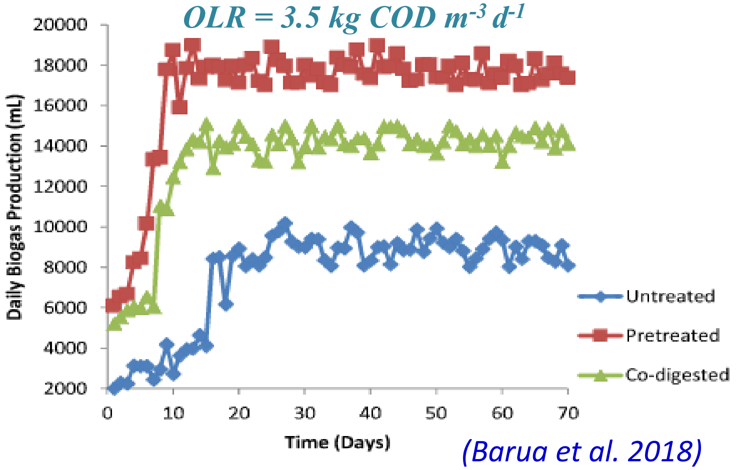
Centre for research on aquatic resources, Kerala, India

2 REGION

THE HINDU
TUESDAY, JULY 20, 2021

From menace to fuel, the turnaround story of water hyacinth

Social entrepreneurs and researchers explain the methods involved in the production of biogas from water hyacinth to Agriculture Minister P. Prasad during a demonstration recently.



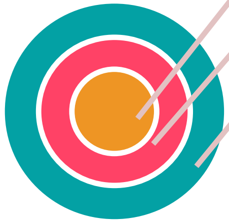
(Barua et al. 2018)

Water content (%)	90
Dry matter (%)	
Cellulose	24
Hemicellulose	30
Lignin	16
Ashes	20
Elemental composition (%)	
C	38.4
H	5.85
O	28.1
N	2.9
S	0.47
P	0.77
K	2.78
Ca	1.32
Na	1.44

(Rathod et al. 2018)

Process parameters…

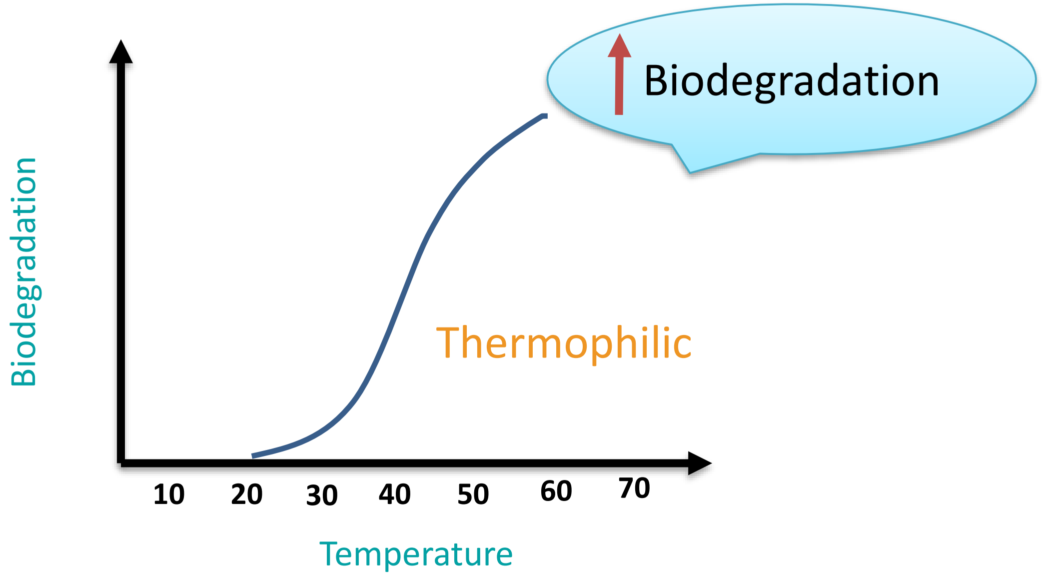
Temperature

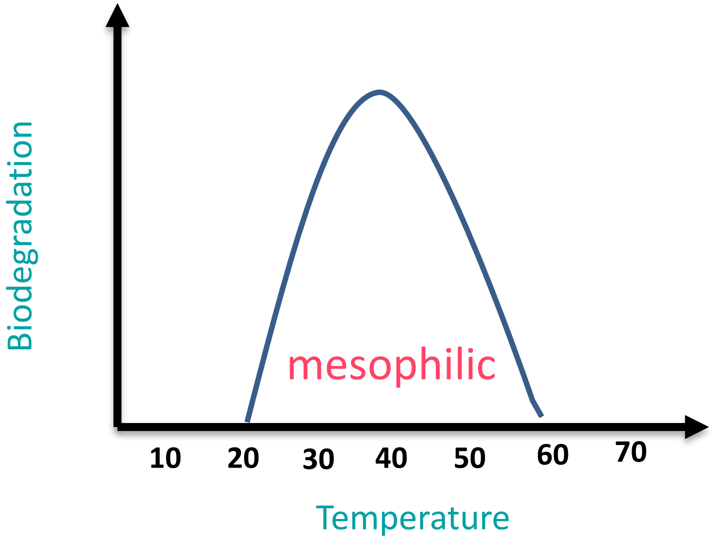


Thermophilic (45-60℃)

mesophilic (25-45℃)

Psychrophilic (<25℃)





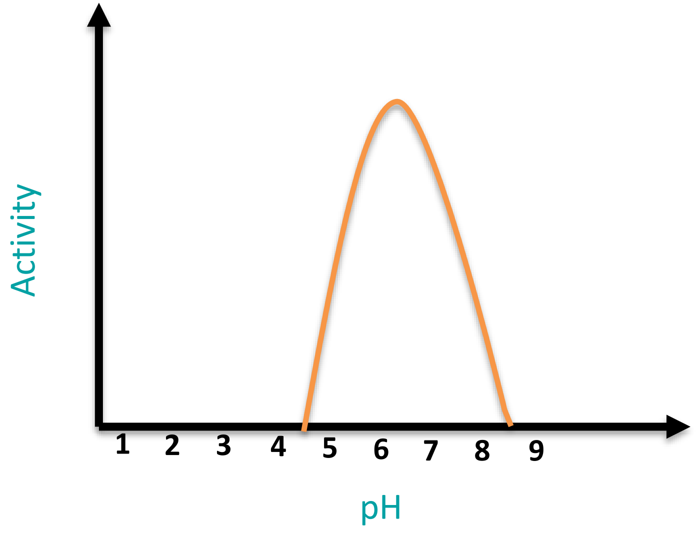
- Mesophilic range process - The optimum temperature is 35-37℃
- When the ambient temperature goes down to 10℃, gas production virtually stops.
- Proper insulation of digester helps to increase gas production in the cold season

Wu et. al. 2006

Cont'd…

pH

- At early stage of decomposition, organic acid are formed ------ pH drop at about 5.
- The optimum pH of hydrolyzing and acid-forming bacteria is in a range from pH 5.2 to 6.3
- Once microorganism breakdown the organic acids then the pH again rise
- The optimum biogas production is achieved when the pH value of input mixture in the digester is between 6 and 7.
- Methanogenic bacteria are very sensitive to pH and do not thrive below a value of 6.5.



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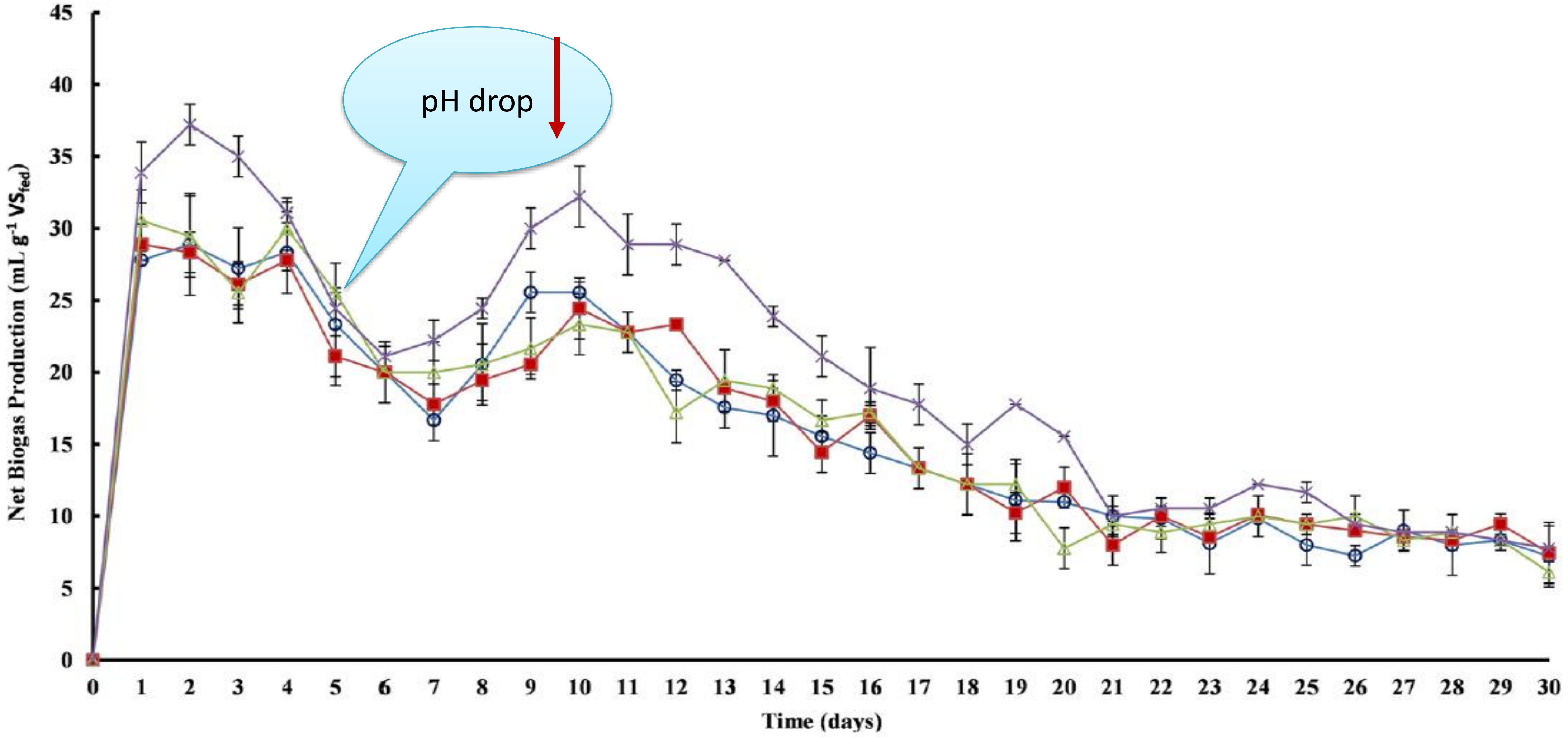

Rana et al. 2020

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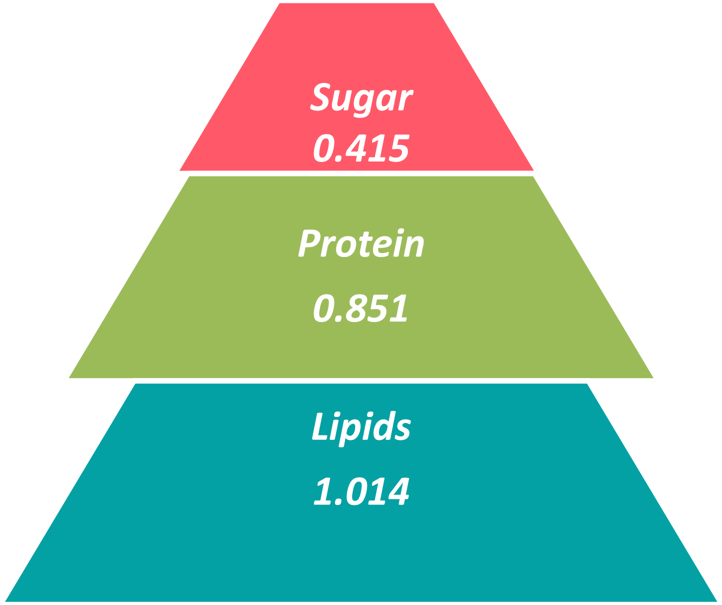
Feedstock & Nutrient level

- Carbon--- Energy
- Nitrogen --- Protein synthesis
- Phosphorus and potassium --- cell reproduction and metabolism
- Optimum **C/N ratio = 25:1 – 30:1**
- Macronutrients such as cobalt (Co), nickel (Ni), molybdenum (Mo) and selenium (Se), are vital for the survival of the microorganisms



Biogas potential (m^3/ kg VS) from various feedstock

Hydraulic Retention Time (HRT)

- HRT is a measure of the average length of time that a soluble compound remains in a constructed bioreactor

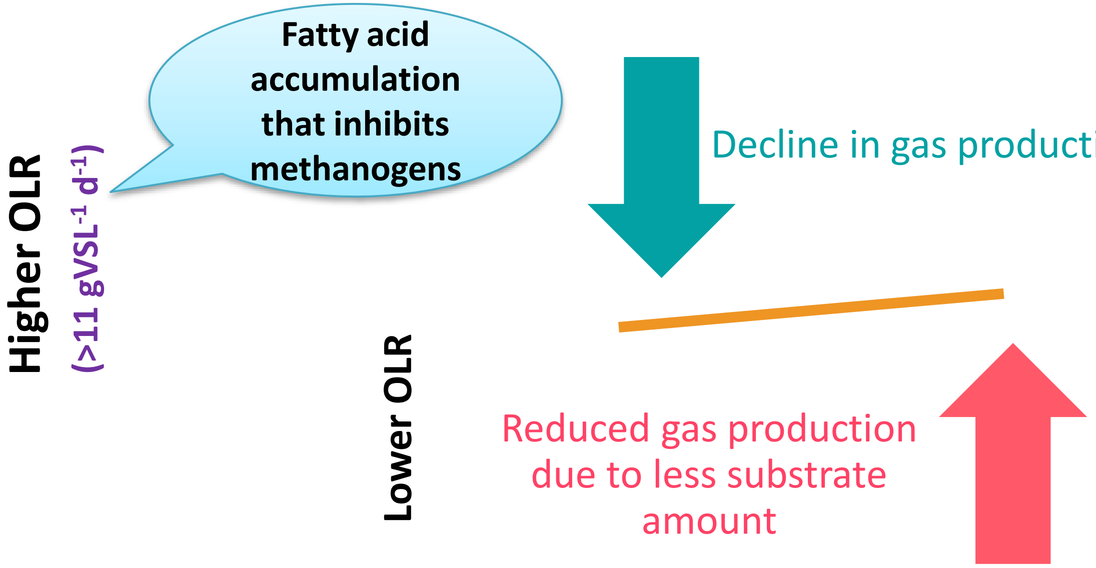
$$HRT(\Theta) = \frac{Volume\ of\ digester\ [m^3\ ]}{Substrate\ flow\ rate\ [m^3/d]} = \frac{V}{Q}$$

- A digester must have a volume of 50 to 60 times the slurry added daily.
- Higher the temperature, the lower the retention time.

Organic loading rate

- Organic loading rate (OLR) is the amount of raw materials fed per unit volume of digester capacity per day.

$$\text{OLR}=\frac{\textit{flowrate X Subtract concentration}}{\textit{Volume}}=\frac{Q\,S}{V}$$

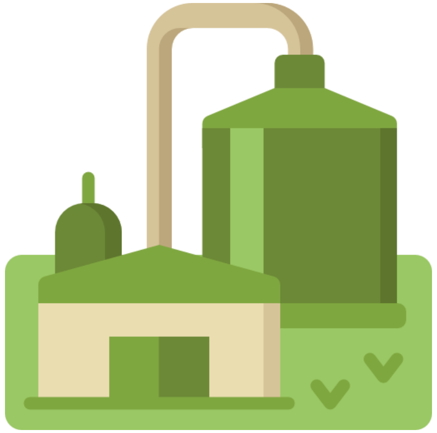


Inhibitors

Inhibitor	Inhibitory concentration	Comments
Oxygen	> 0.1 mgL^{-1}	Inhibition of obligate anaerobic methanogenic archaea
Hydrogen sulphide	> 50 mgL^{-1}	Inhibitory effect rises with falling pH value
Volatile fatty acids	>2,000 mgL^{-1} HAc (pH = 7.0)	Inhibitory effect rises with falling pH value. High adaptability of bacteria
Ammoniacal nitrogen	>2000 mgL^{-1} NH_4^+ (pH = 7.0)	Inhibitory effect rises with rising pH value and rising temperature. High adaptability of bacteria
Heavy metals	Cu > 50 mgL^{-1} Zn > 150 mgL^{-1} Cr > 100 mgL^{-1}	Only dissolved metals have an inhibitory effect. Detoxification by sulphide precipitation
Disinfectants, antibiotics	-	Product-specific inhibitory effect

FNR 2012

Problem associated with biogas production and troubleshooting

	Causes	*Troubleshoot*
 Gas yield dropped	•Drop in quality of substrates	✓ Assure substrates mixing and quality
	•Drop in temperature	✓ Check the heating system
	•Inhibitory compounds	✓ Check the level of potential inhibitory compounds
	•Non-homogenous substrates	
	•Reducing of methanogenic bacteria	✓ Add digestate from another digester (if the methanogenic bacteria as drop)

https://www.biogasworld.com/biogas-plant-troubleshooting/

Cont'd…

Regular measurements of free volatile organic acids (FOS) and total inorganic carbonate (TAC) is the best practice to monitor the stability of the digester

Protocol: https://mantech-inc.com/blog/automated-fos-tac-ratio-cod-biogas-applications/

- A FOS/TAC value of 0.3-0.4 is considered optimal.
- Above this range, there is excessive biomass input
- Below this range, there is too little biomass input

FOS/TAC ratio increased

Causes

- **VFA rate is too high**
- **Change in feedstock**
- **Lack of buffer**
- **Inhibitory compounds**

Troubleshoot

✓ **Reduce organic loading rate(OLR)**

✓ **Use more manure in the mixture**

https://www.biogasworld.com/biogas-plant-troubleshooting/

Cont'd…

pH dropped

Causes

- If Feeding rate is too high or variable
- When Operating temperature have changed
- When the agitation is not working

Troubleshoot

- ✓ Reduce the feed substrates until system returns to normal
- ✓ Use only manure until system returns to normal

https://www.biogasworld.com/biogas-plant-troubleshooting/

Cont'd…

Foaming

Causes

- Due to high protein content
- Air is introduced in the digestion
- Variable Temperature

Troubleshoot

- ✓ Reduce or stop feeding
- ✓ Analyze substrates
- ✓ Reduce air introduction

https://www.biogasworld.com/biogas-plant-troubleshooting/

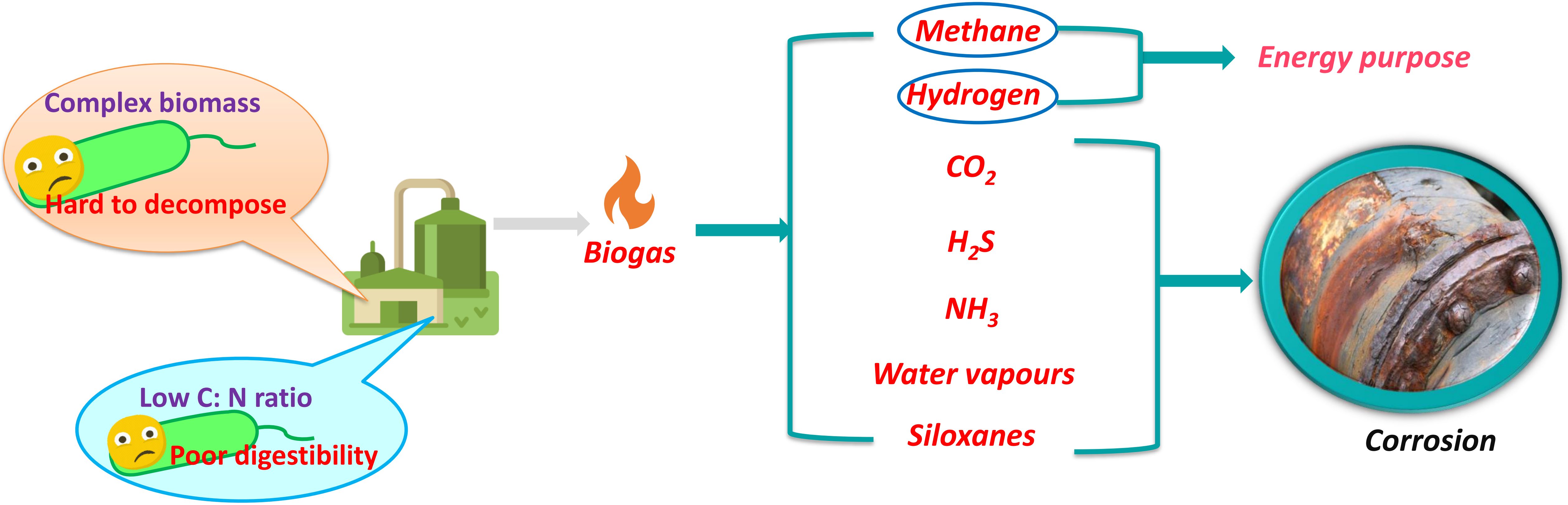
Cont'd…

Methane concentration dropped

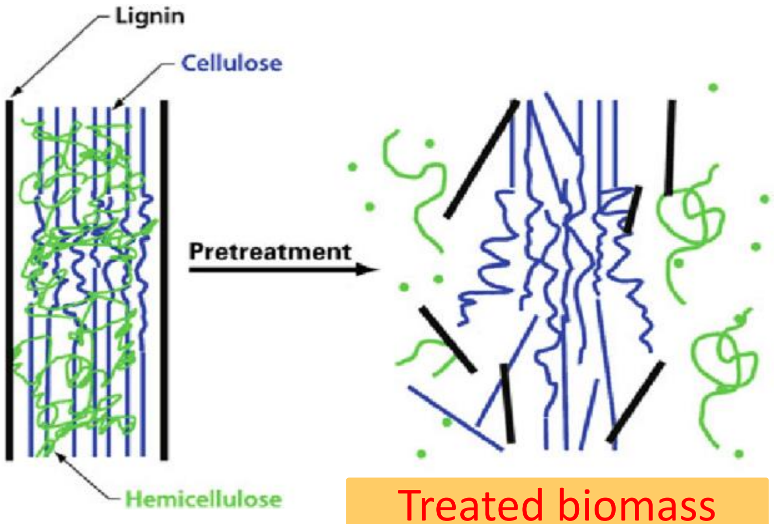
Causes	*Troubleshoot*
•Drop in the quality of substrates	✓ Assure substrates mixing and quality
•Drop of temperature	✓ Check heating system
•Compounds inhibition	✓ Check level of potential inhibitor compounds

https://www.biogasworld.com/biogas-plant-troubleshooting/

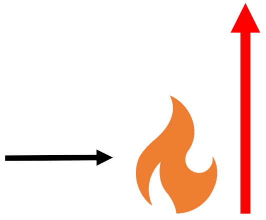
Recent advances in biogas production



Biomass pretreatment



Treated biomass



Biogas

Lignocellulosic Biomass = Cellulose (30-65%) + Hemicellulose (10-35%) + Lignin (1-30%)

Crystalline

Complex cross-linkage

Recalcitrant

Hard to decompose during anaerobic digestion

Pretreatment methods

Physical: Bead milling, High-pressure homogenization — Energy Intensive

Thermo-chemical: Acids, base | Oxidizing agents, solvents — Hazardous, high cost

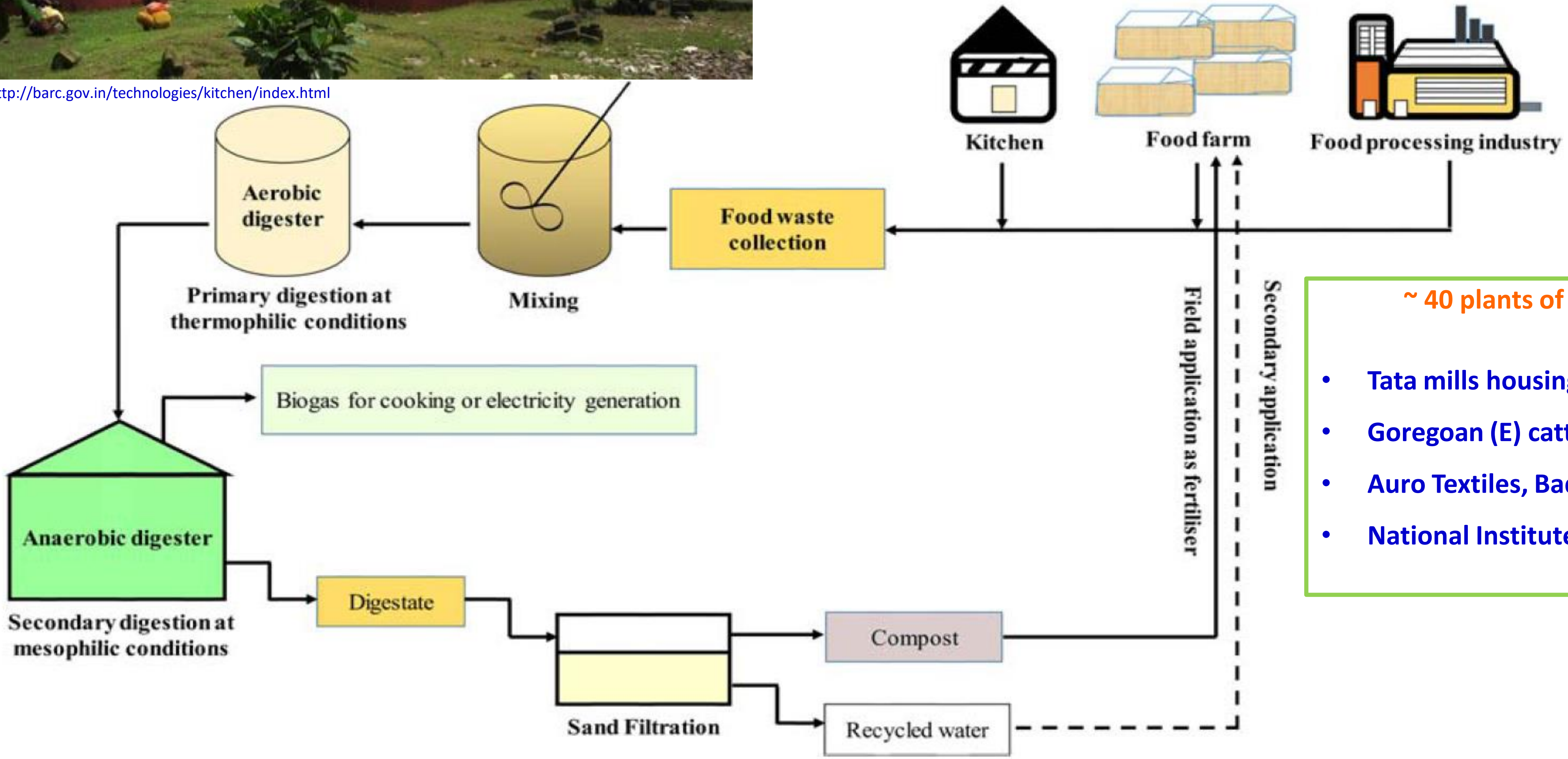
Physio-chemical: Microwave, ultrasound, electric pulse, steam explosion — Green technology

Biological: Biological: Enzyme & microorganisms — Green technology, Mild reaction conditions,

At R&D Stages

http://barc.gov.in/technologies/kitchen/index.html

Biological pretreatment

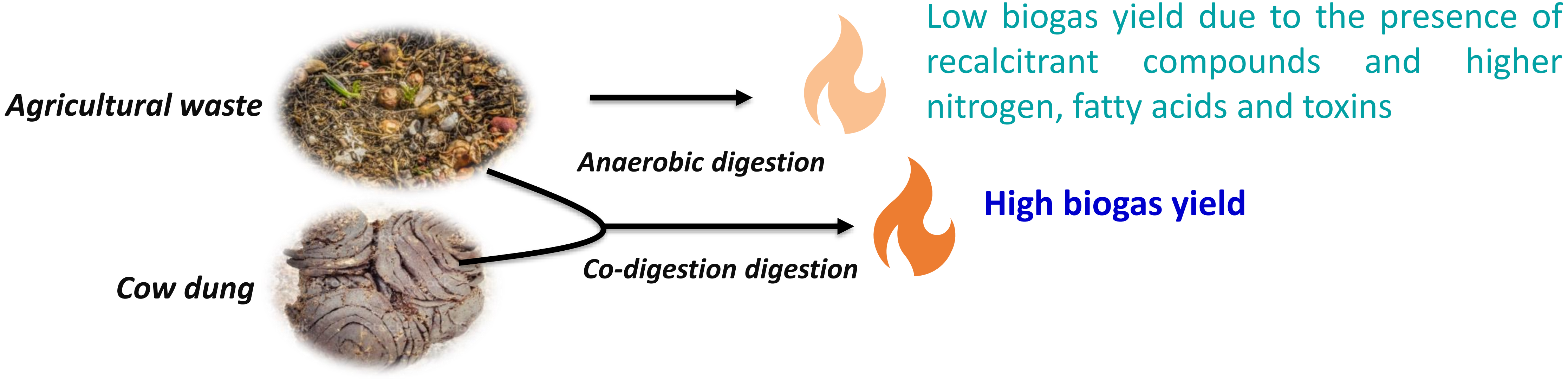


~ 40 plants of 1-5 TPD commissioned

- Tata mills housing society, Mumbai, INDIA
- Goregoan (E) cattle farm, Mumbai, INDIA
- Auro Textiles, Baddi, INDIA
- National Institute of Technology, Trichy, INDIA

Rana et al. 2020

Co-digestion of substrates



- Co-digestion of the biomass with a high carbonic substrate (high C:N ratio)
- Co-digestion with substrates -------facilitate hydrolysis as well as balance the C/N ratio, inhibitors, pH, and total solid (TS) content.
- Co-digestion aids in reducing ammonia inhibition, along with enhancing biogas production from the feedstock by increasing its digestibility

➢ Biogas production through co-digestion in Fazilka, Punjab, India

1500 tons rice straw per year

Self consumption 3 MWh per day

18 MWh per day

http://www.knowledgebank.irri.org/step-by-step-production/postharvest/rice-by-products/rice-straw/off-field-rice-straw-management

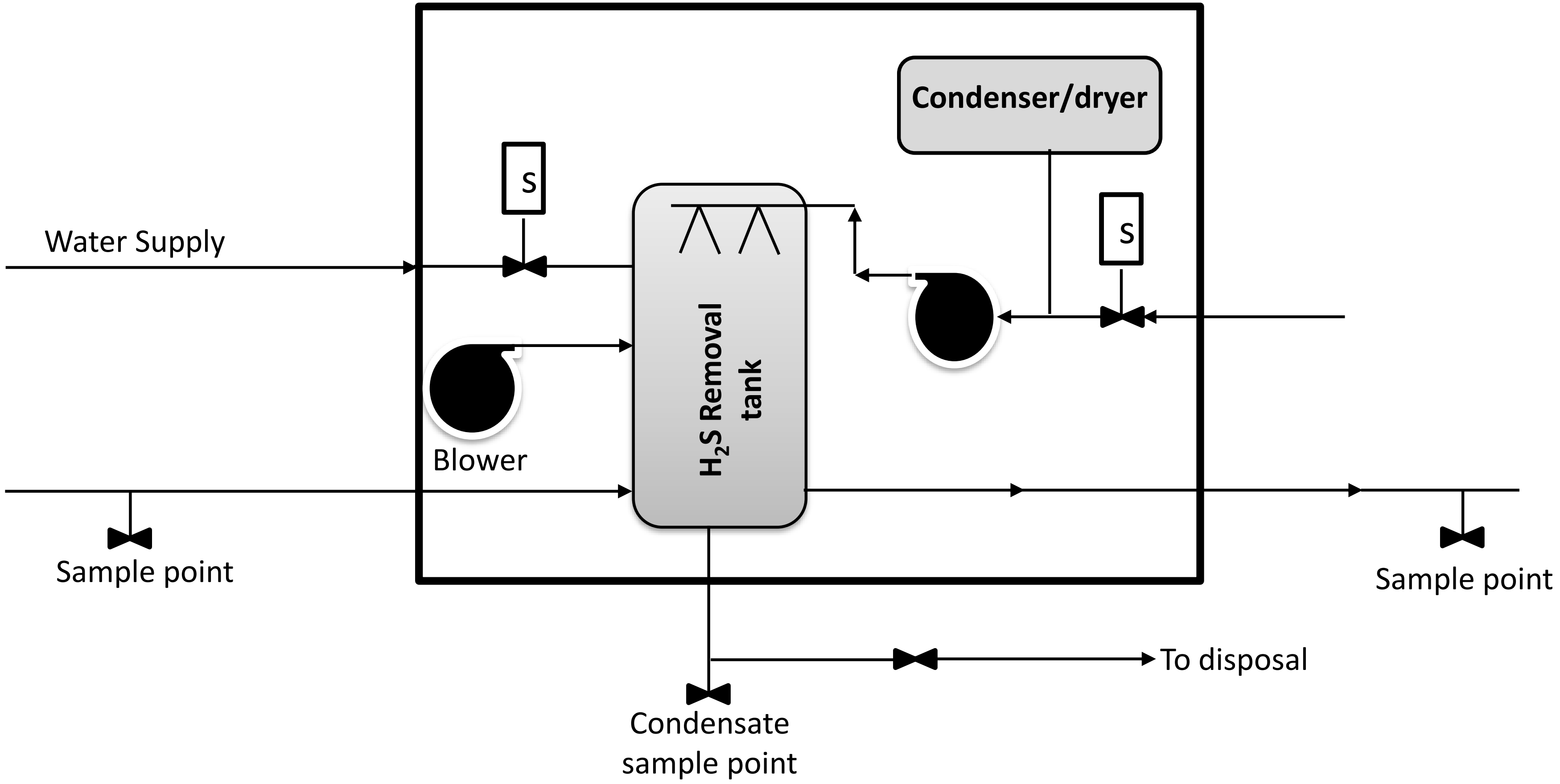
Biogas purification

Methods

1. Water scrubbing
2. Organic scrubbing
3. Chemical scrubbing
4. Pressure swing adsorption (mostly used at industrial level)
5. Membrane separation
6. Cryogenic separation
7. Biological Technology

H_2S Removal

https://www.slb.com/



granular iron oxide–based H_2S adsorbent

mixed metal oxide–based H2S adsorbents

Shah et al. 2013

Biological methods for H_2S removal

i. Chemotrophic and

ii. Photosynthetic

- End products are non-hazardous : Sulphur or sulphate
- The Sulphur can be utilized as a raw material to produce
  - Sulphuric acid,
  - Sulphur fertilizers and fungicides used in industry and agriculture

i. Chemotrophic method

- Microbial biodegradation of H_2S
  - Chemotrophic Sulphur oxidizing bacteria
    - E.g.-*Thiobacillus,Acidithiobacillus, Sulfolobus, Thiovulum, Thiothrix and Thiospira*
    - Utilized Sulphur compounds (e.g. sulphide, polysulphide, elemental sulphur, thiosulphate, sulphite) as chemical energy source , and
    - CO_2 as Carbon source

ii. Photosynthetic separation

- Purple sulphur bacteria, cyanobacteria, phototrophic members of phylum chloroflexi and heliobacteria and anoxygenic phototrophic sulphur bacteria
  - Utilized light as an energy source
  - Purple and green sulphur bacteria use reduced sulphur compounds as electron donors for photosynthetic CO_2 reduction

Conclusion and Process Outlook

- Biomass pretreatment is crucial to improve the biogas productivity.

- Co-digestion with suitable biomass may facilitate enhanced biogas productivity by reducing ammonia inhibition.

- Maintaining temperature in winters should be looked carefully.

- Rational selection of biogas upgrading technology is indispensable in accordance to capital cost, available land and water resources and biogas application.

- Effective management of digestate slurry may improve the overall process economics.

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Thank you