Safety Hazard Assessment of Biogas Cleaning and Upgrading Process: A Case Study

AICHE Seminar 2021

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Study collaboration

Special Recognition - Diego Di Domenico Pinto

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Introduction

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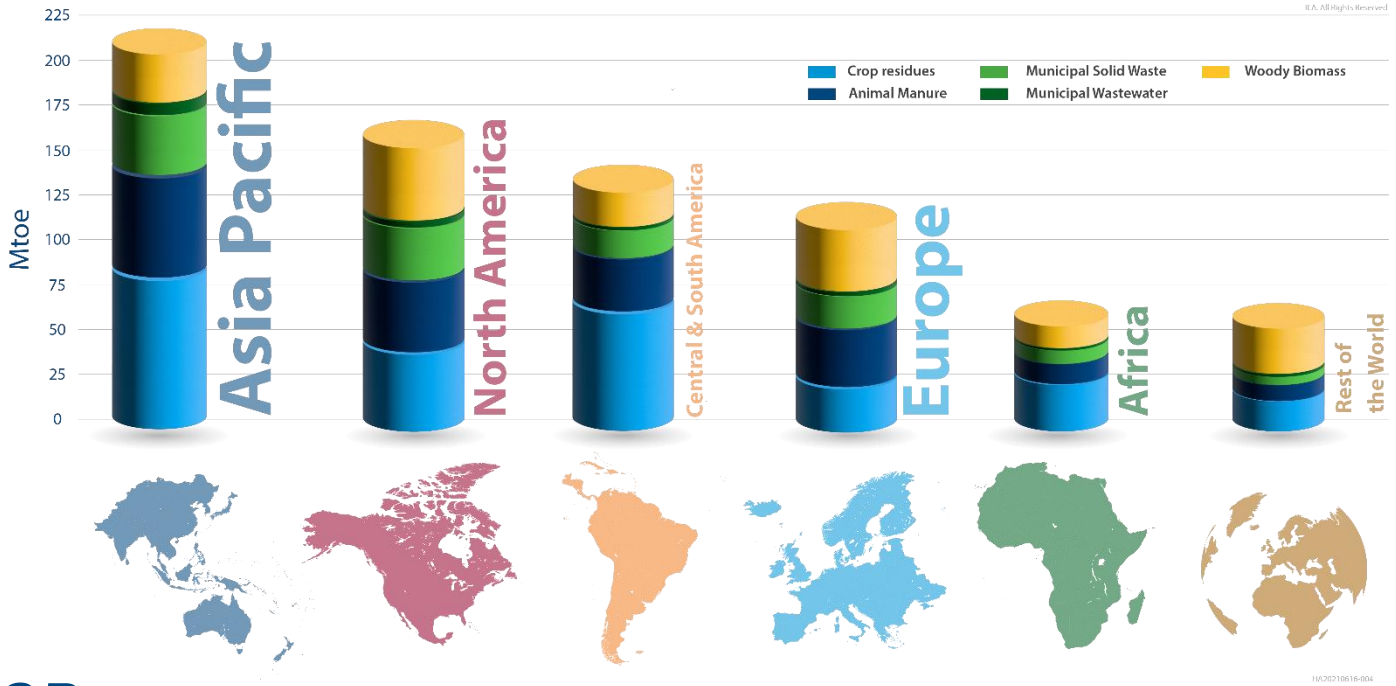
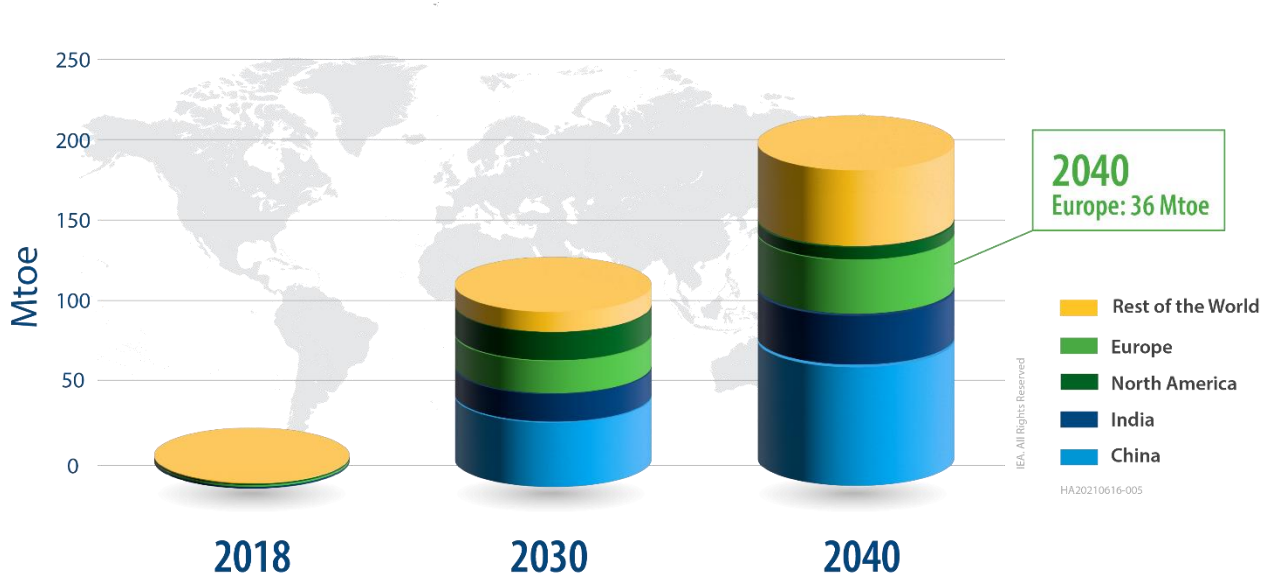
Introduction

- Production potential for biogas or biomethane by feedstock source, 2018



Introduction

- Outlook for global biomethane consumption by region in the Sustainable Development Scenario, 2018-2040



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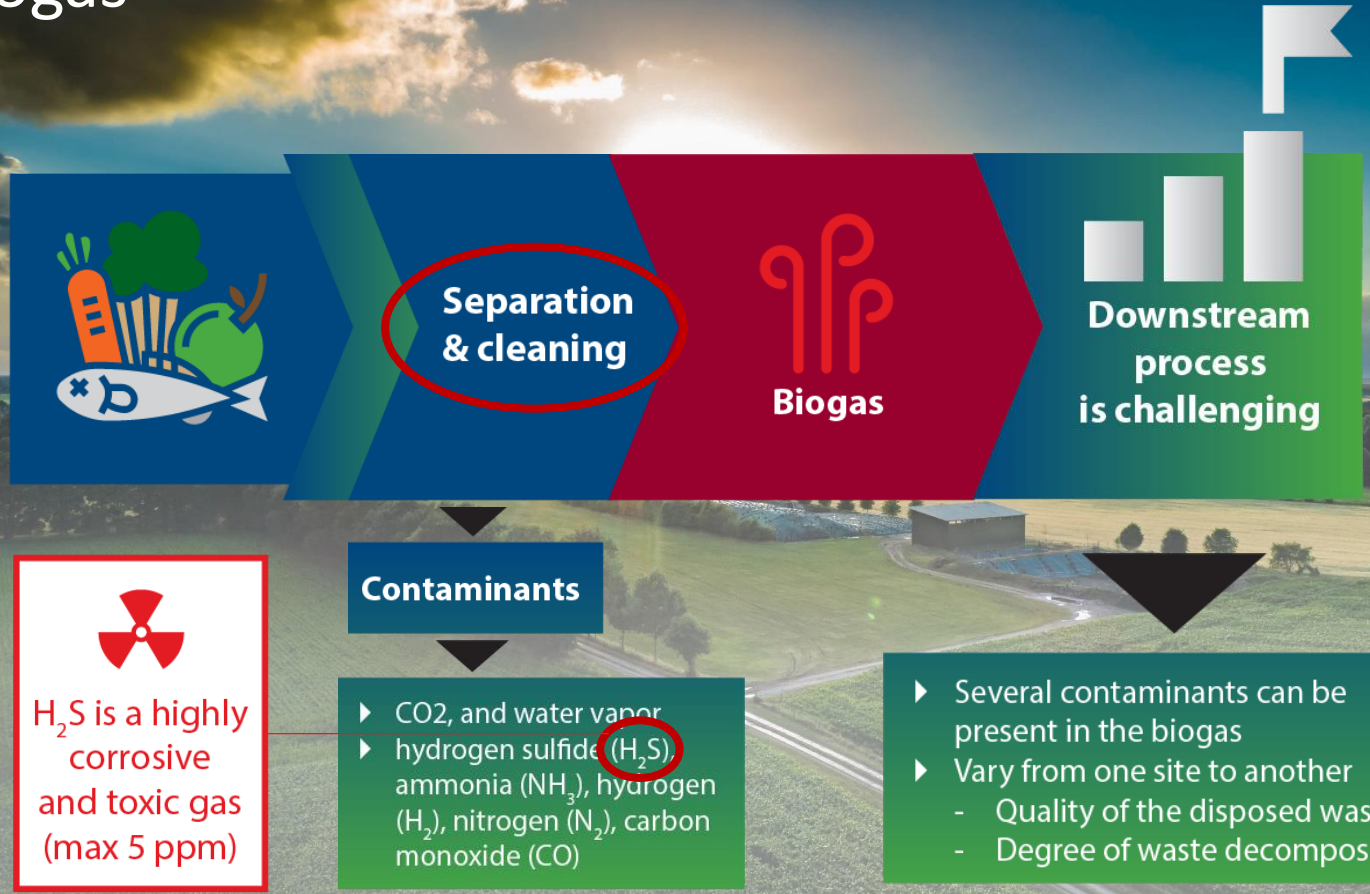
Biogas Production

Biogas


Separation & cleaning
Biogas
Downstream process is challenging
Contaminants
H_2S is a highly corrosive and toxic gas (max 5 ppm)
CO2, and water vapor
hydrogen sulfide (H_2S), ammonia (NH_3), hydrogen (H_2), nitrogen (N_2), carbon monoxide (CO)
Several contaminants can be present in the biogas
Vary from one site to another
- Quality of the disposed waste
- Degree of waste decomposition

Biogas Composition

- Composition of biogas depends on several factors
  - Main influencers:
    - source (feed) composition
    - pH

Reduce the heating value of the gas + Corrosive and toxic

	Unit	Landfill gas	Natural gas[1]
CH_4	%vol.	35-65	87
CO_2	% vol.	15-50	1.2
H_2O	% vol.	0-5	-
N_2	% vol.	5-40	0.3
O_2	% vol.	0-5	-
H_2	% vol.	0-3	-
CO	% vol.	0-3	-
H_2S	ppm_v	0-300	1.5
NH_3	ppm_v	0-5	-
HalHC[2]	ppm_v	20-200	-
VOC[3]	mg/m^3	0-4500	-
Siloxanes	mg Si/m^3	0-50	-
C2+[4]	%vol.	-	12

[1]North sea
[2]Halogenated hydrocarbons (Cl^-/F^-)
[3]Volatile organic compounds
[4]Higher hydrocarbons

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Biomethane Specifications

- Specifications for some countries for injecting biomethane into the grid or use it as a vehicle fuel

Specification	Country			
	Brazil	Sweden	Switzerland	Netherlands
CH_4 (%)	>90	97	>96	>80
Wobbe Index (MJ/m^3)	46.5-53.5	44.7-46.4	47.9-56.5	43.46-44.41
CO_2 (%)	<3	<3	<4	<6
H_2O (mg/m^3)	-45ºC (dew point)	<32		<32
H_2S (mg/m^3)	<10	<15.2	<5	<5
O_2 (%)	<0.8	<1	<0.5	<0.5

Treatment of biogas:
-Removal of H_2O, H_2S, CO_2, O_2, N_2

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Case Study

Biogas Cleaning and Upgrading Process

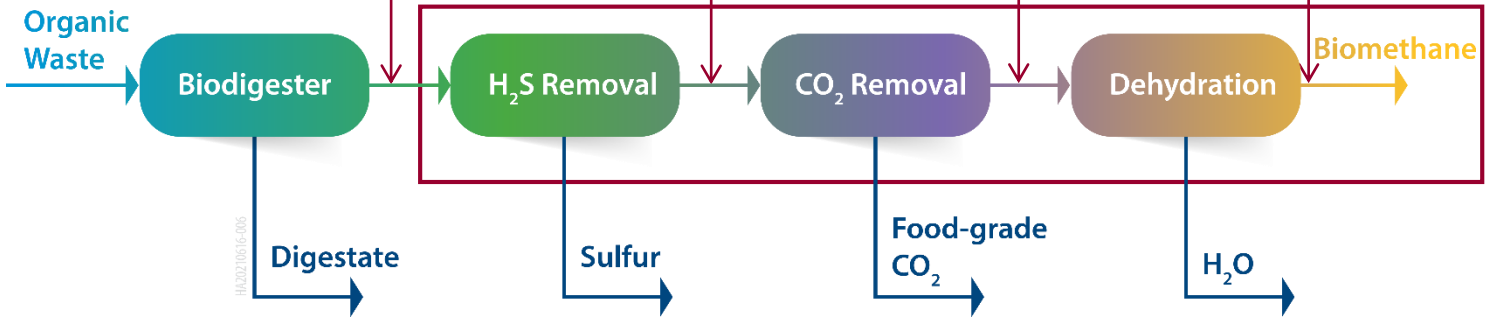
- Biogas composition during the process

Flow	1500Nm³/h
Temp.	35˚C
Pressure	3.0bar
CH_4	60mol %
CO_2	39.8mol %
H_2S	0.2mol %
H_2O	Sat.

Flow	1500Nm³/h
Temp.	35˚C
Pressure	2.9bar
CH_4	60mol %
CO_2	39.8mol %
H_2S	4ppm
H_2O	Sat.

Flow	1500Nm³/h
Temp.	35˚C
Pressure	2.8bar
CH_4	96.5mol %
CO_2	2.3mol%
H_2S	4ppm
H_2O	Sat.

Flow	1500Nm³/h
Temp.	35˚C
Pressure	2.7bar
CH_4	97.6mol %
CO_2	2.4mol %
H_2S	4ppm
H_2O	23mg/Nm³



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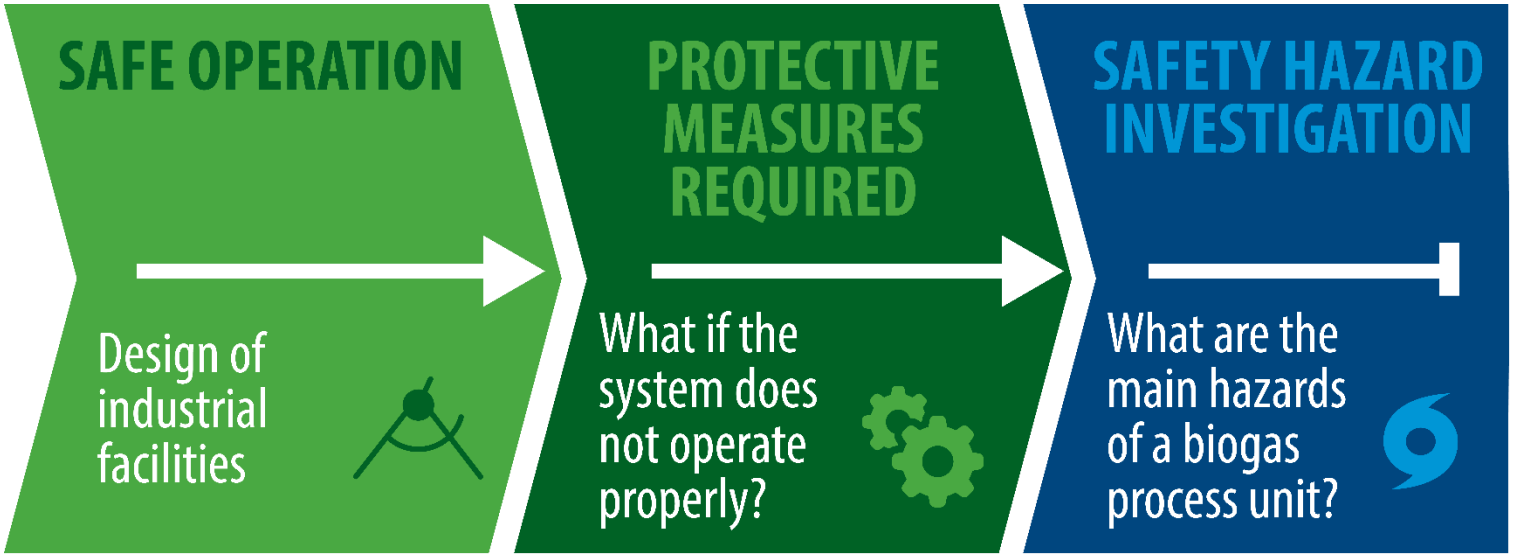
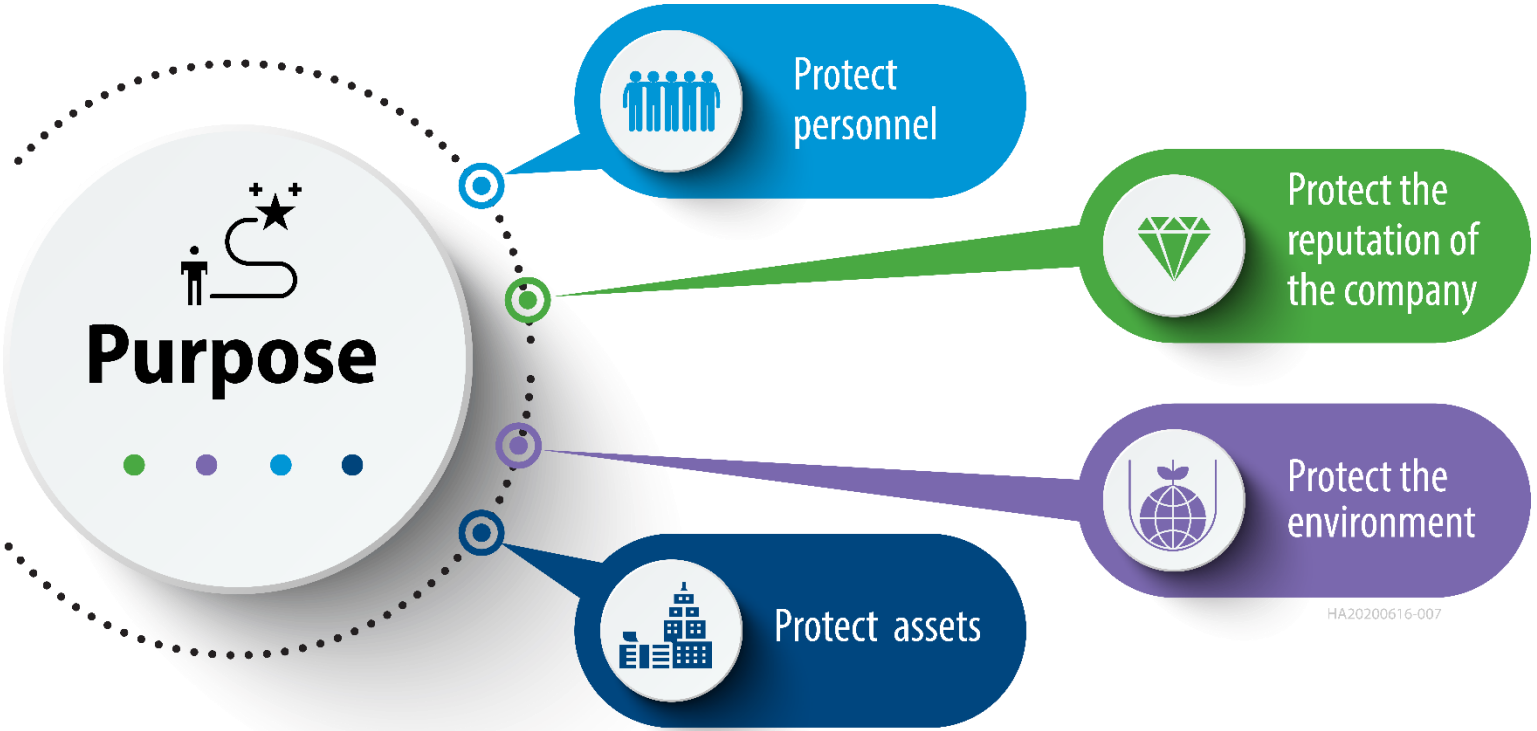
Safety Hazard Investigation

Safety Hazard Investigation



Safety Hazard Investigation



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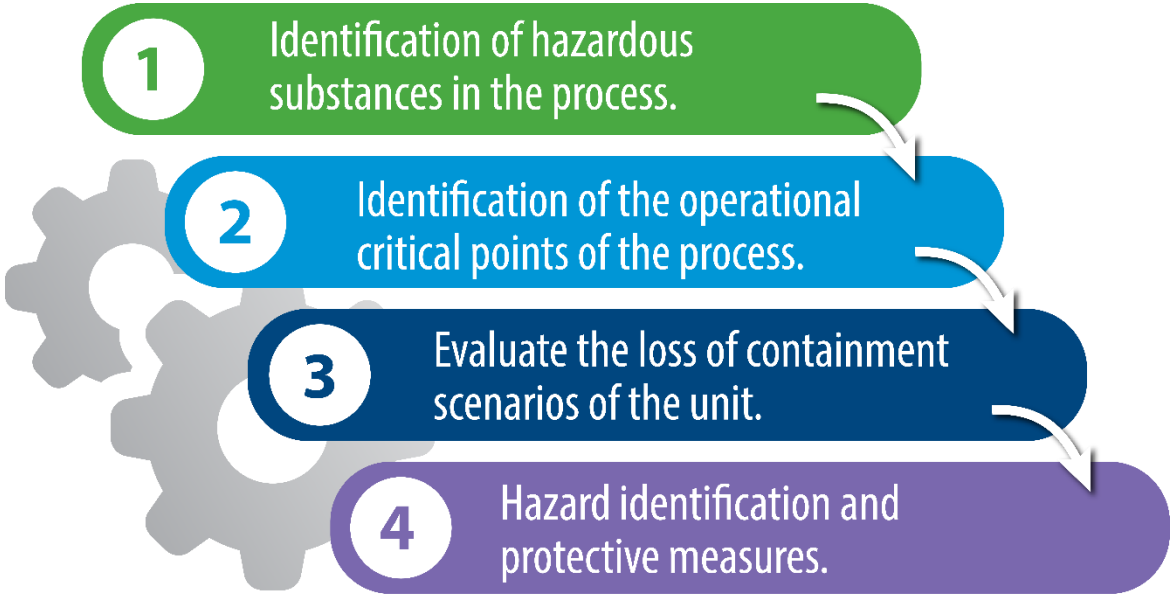
Methodology

- Approach used in the study case:



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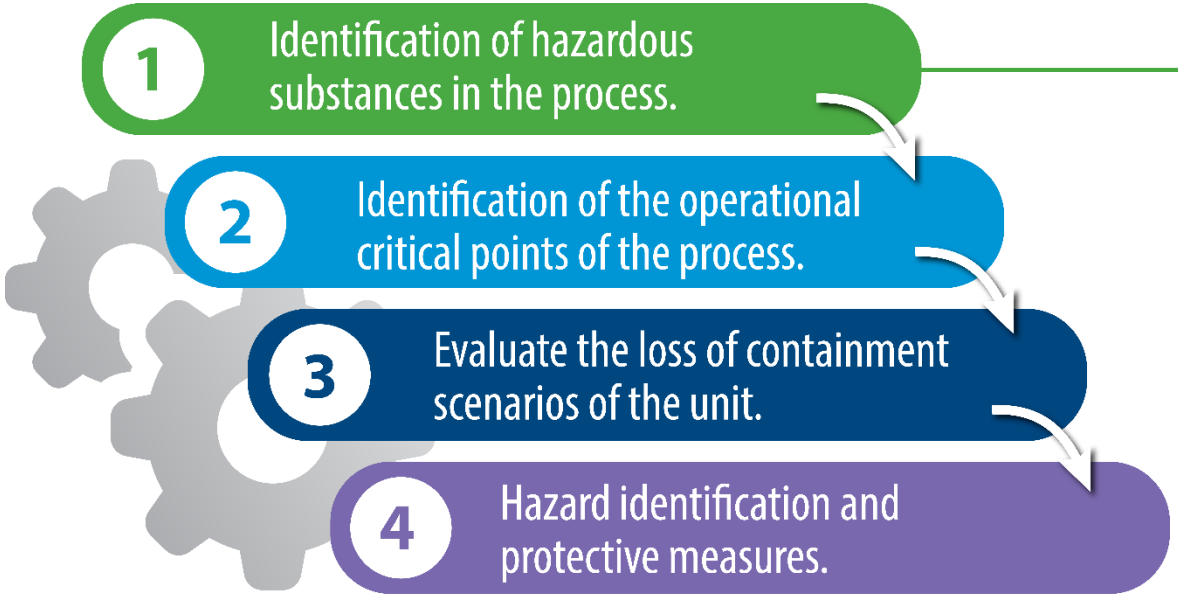
Methodology

- Approach used in the study case:



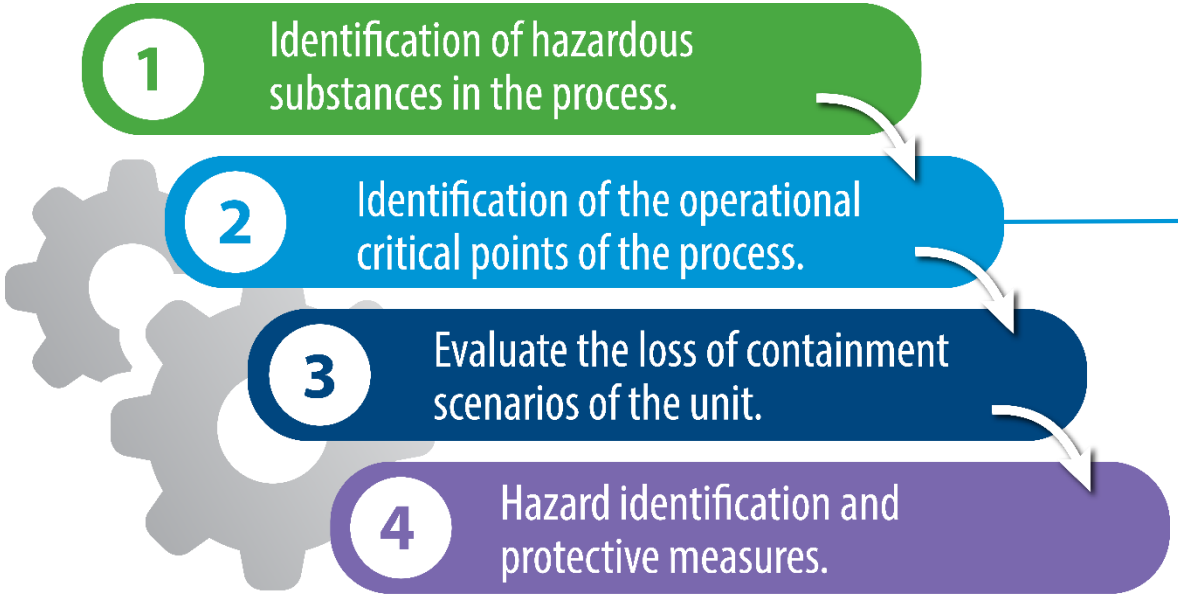
STEP 1:

Identify all the substances involved

Identification of the hazardous properties of the substances involved in the biogas process

Methodology

- Approach used in the study case:



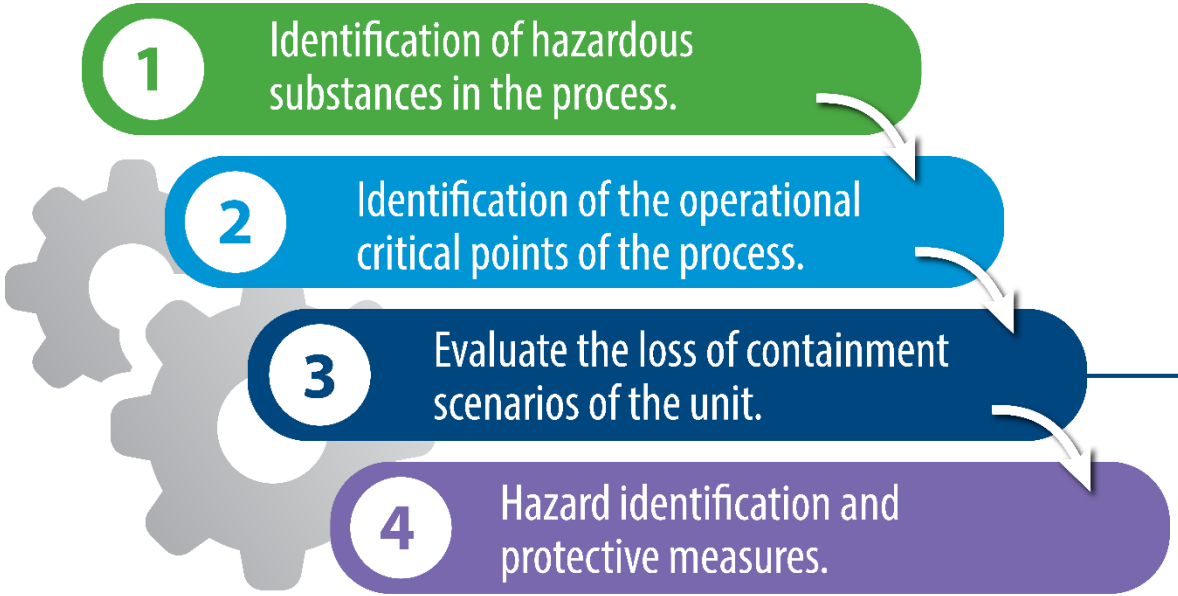
STEP 2:

Operating conditions & stream's composition are evaluated.

Most critical points (e.g. high temperatures/pressures).

Methodology

- Approach used in the study case:

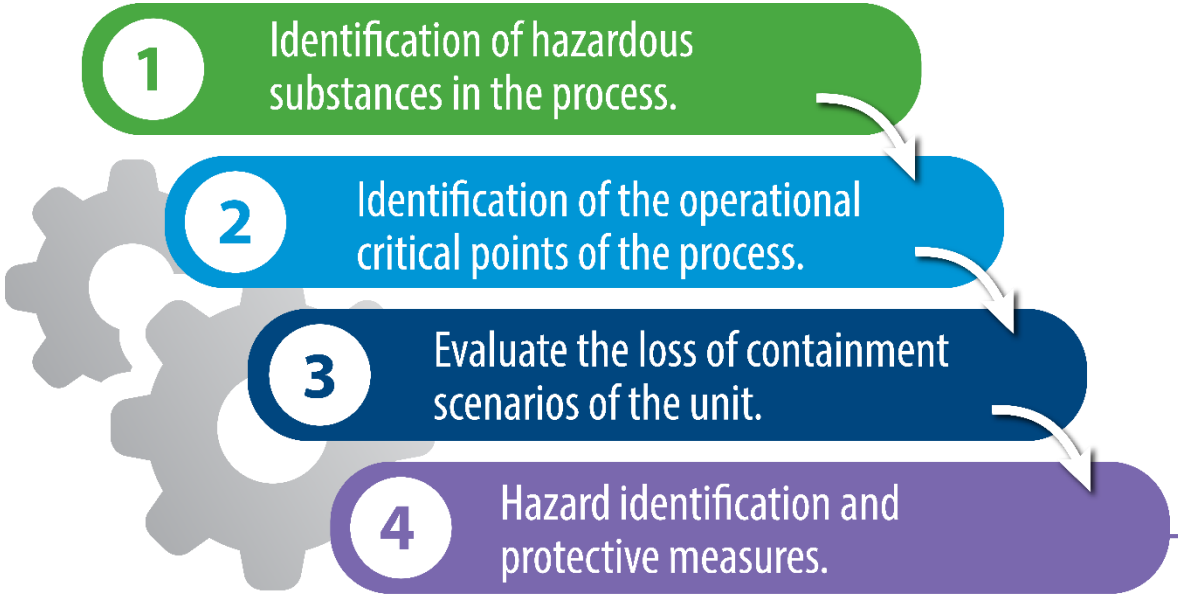


STEP 3:

STEP1+ STEP 2 = loss of containment events

Methodology

- Approach used in the study case:



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STEP 4:

Equipment type.

The impact of hazards on health, safety, continuity of operations, and asset preservation is the basis to provide prevention, protection, and other safety measures.

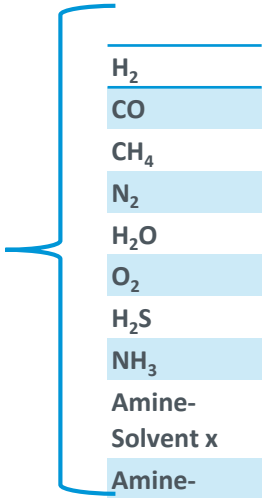
Results

Safety Hazard Investigation – Analysis and Results

- STEP 1: Identification of hazardous substances

Composition of streams

Identify all substances



H_2
CO
CH_4
N_2
H_2O
O_2
H_2S
NH_3
Amine-Solvent x
Amine-Solvent y

GHS

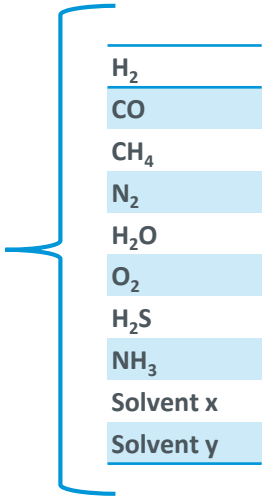
Safety	Health
H2, CO, CH4, H2S, NH3	H2S, NH3, Amine-Solvent
Flammable gases (H2, CO, CH4, H2S, NH3) Oxidizing gas (O2)	Acute Toxic (CO, H2S, NH3) Skin corrosion/ irritation (NH3, Amine-Solvent) Eye damage/ irritation (Amine-Solvent) Reproductive toxic (CO, Amine-Solvent) Specific Target organ toxicity, simple exposure/repeated exposure (H2S / CO)

H_2, CO, CH_4, H_2S, NH_3, O_2

STEP 1: Identification of Hazardous Substances

Composition of streams

Identify all substances



H_2
CO
CH_4
N_2
H_2O
O_2
H_2S
NH_3
Solvent x
Solvent y

GHS

Environment
H2S, NH3, Amine-Solvent
Hazards to aquatic environment (H2S, NH3, Solvent x, y)

H_2S, NH_3, Solvents

STEP 2: Identification of Operational Critical Points

1.H_2S Removal Absorber	• Flammable gases (H_2S and Biogas) • H_2S is fatal if inhaled (Health) and it is toxic to aquatic life (Environmental).
2.Recirculation of solvent + CO_2 to the CO_2 stripper	• The solvents can cause severe skin irritation and damage to eyes Harmful to aquatic life
3.CO_2-absorber	• CO2 clean biogas. The biogas contains mainly methane which can form explosive mixture with air if a leak occurs
4.H_2O-absorber	• Dried biogas. The biogas contains mainly methane which can form explosive mixture with air if a leak occurs

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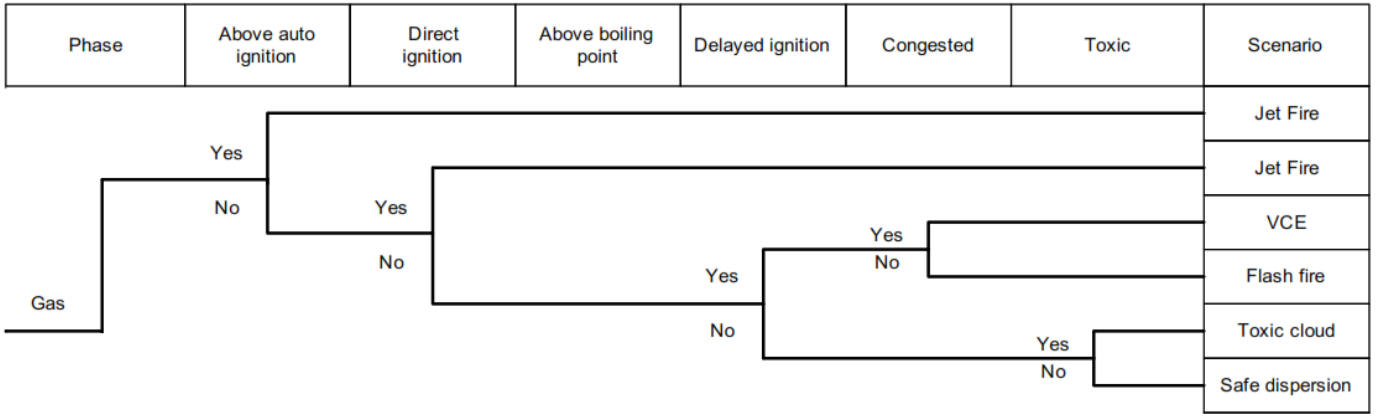
STEP 3: Evaluate the Loss of Containment Scenarios of the Unit

- Event tree analysis



>> liquid releases of the solvents >> pools that can contaminate the soil and/or aquatic life

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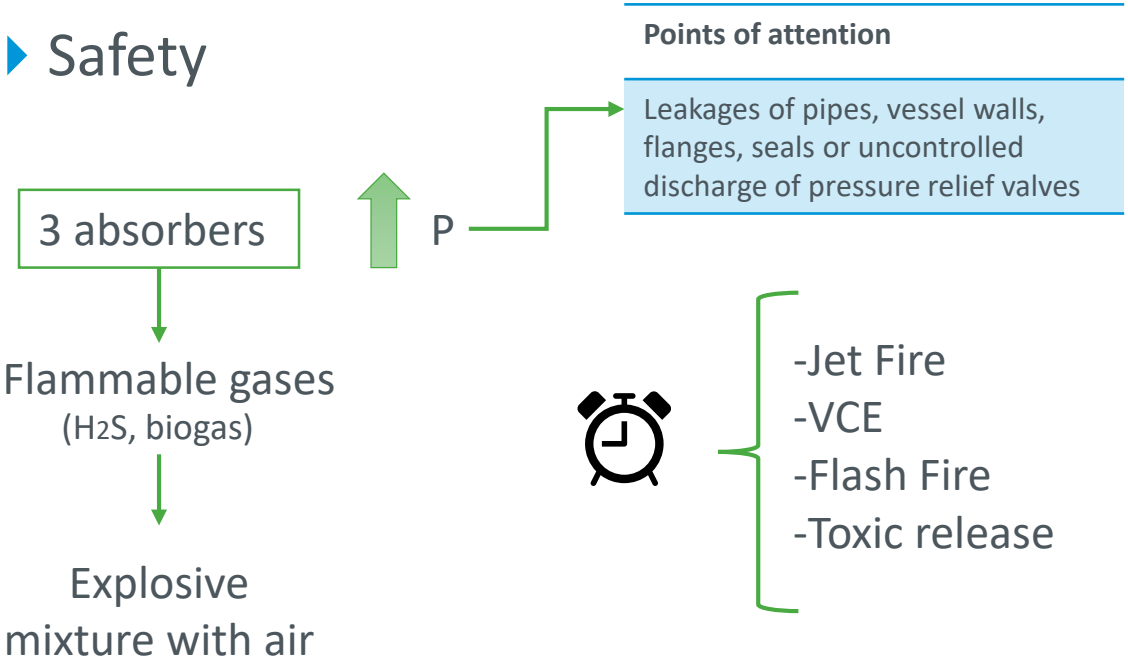
STEP 4: Hazard Identification and Protective Measures

- Safety



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STEP 4: Hazard Identification and Protective Measures

New studies	• HAC • F&G detection study • QRA, consequence modelling
Detection	•Flammable, flame or heat detectors near potential release sources with alarms •Provide air inlet of building with gas detectors •H2S gas detectors (mobile and fixed)
Inherent safety measures	• Sufficient distance between fuel source and potential ignition source • Open space, ventilation (VCE dispersion)
Extra measures	• Provide lightning conductors on buildings to reduce potential ignition • Emergency shutdown systems (jet fire) • Fire water to cool down impinged equipment/piping

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STEP 4: Hazard Identification and Protective Measures

Health

-Solvents

Corrosive/irritant to skin and can cause eye damaged/irritation

-H_2S

High exposures: shock, convulsions, inability to breath, rapid unconsciousness, coma, and death.

Points of attention

Exposure is possible due to leakage of equipment, failure of equipment, uncontrolled drainage, maintenance performed on contaminated equipment

STEP 4: Hazard Identification and Protective Measures

PPE	• Complete PPE (special requirements for H_2S service)
Procedure and controls	• Information on working spaces where H2S gas is/might be present • Training • Maintenance procedures
Safety systems	• Ventilation systems that remove gas from work spaces (explosive-proof due to H_2S)
Extra measures	• Safety showers and eye wash facilities • Provide shielding near potential spray release sources

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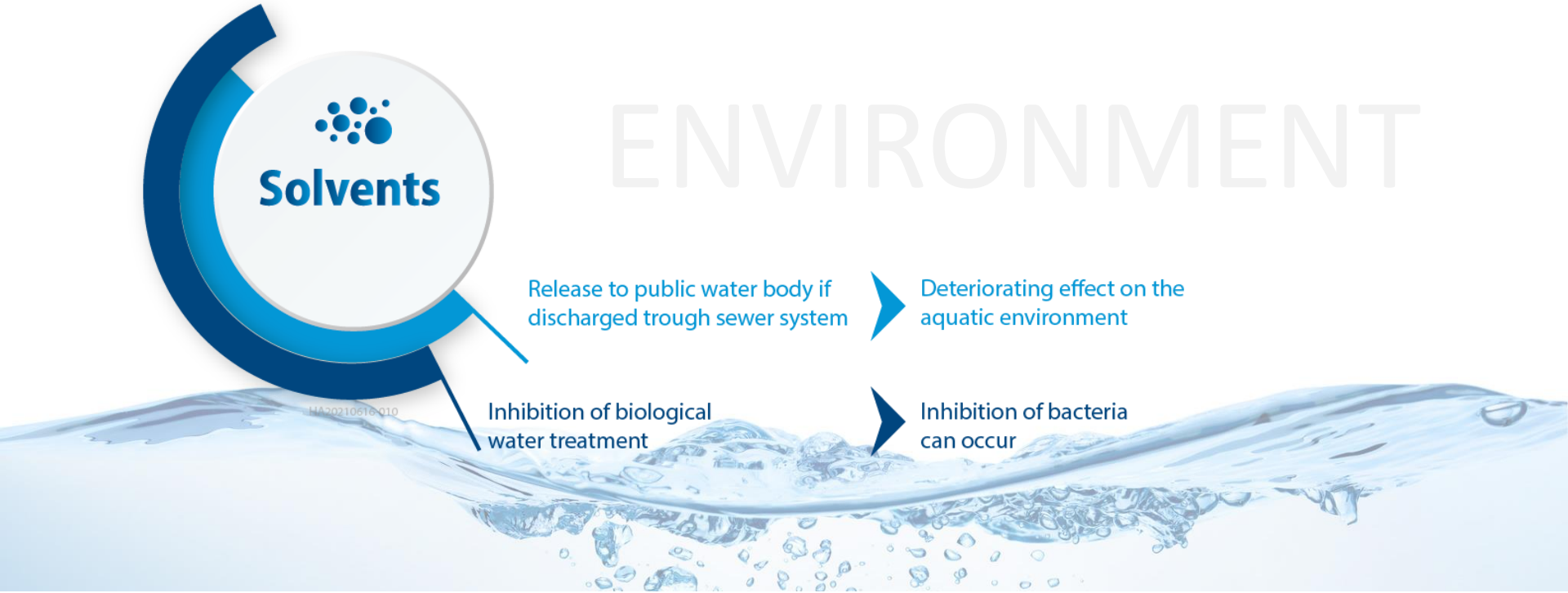
STEP 4: Hazard Identification and Protective Measures

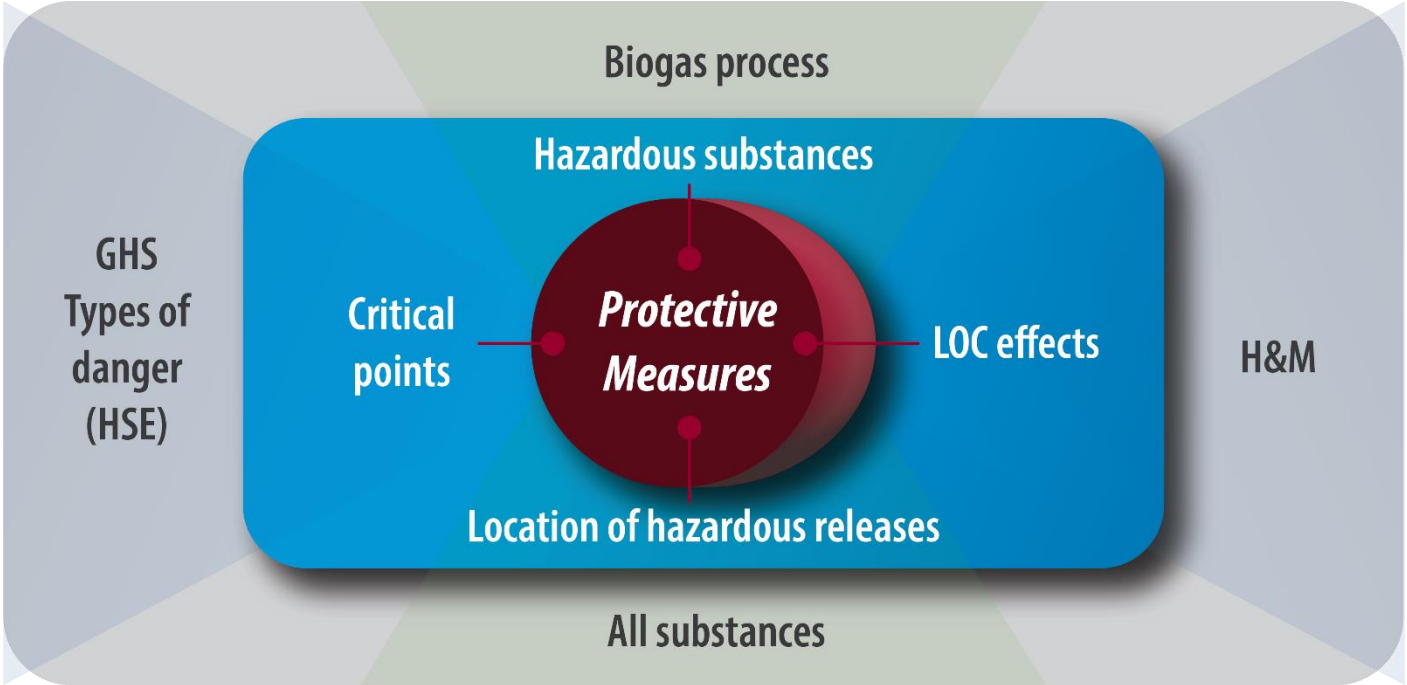


STEP 4: Hazard Identification and Protective Measures

- Protective measures:
  - Separate closed drainage system
  - Liquid tight floors under process equipment
  - Fire water catch basin to retain fire water runoff from process equipment and storage tanks

Conclusion

Conclusion


Biogas process
Hazardous substances
GHS
Types of
danger
(HSE)
Critical
points
Protective
Measures
LOC effects
H&M
Location of hazardous releases
All substances
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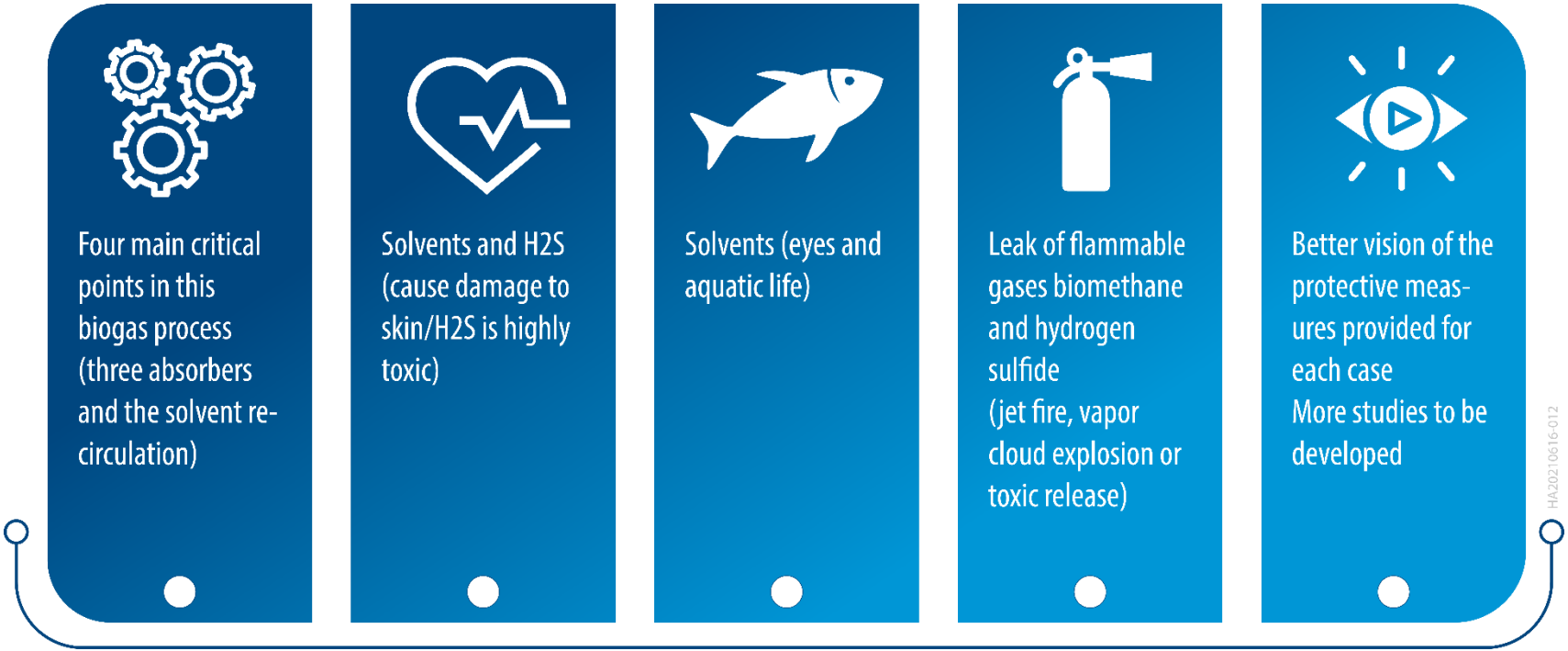
Conclusion – Case Study



Questions