Process design of WWTP anaerobic digestion biogas upgrade to Compressed Natural Gas (CNG) for applications in public transportation

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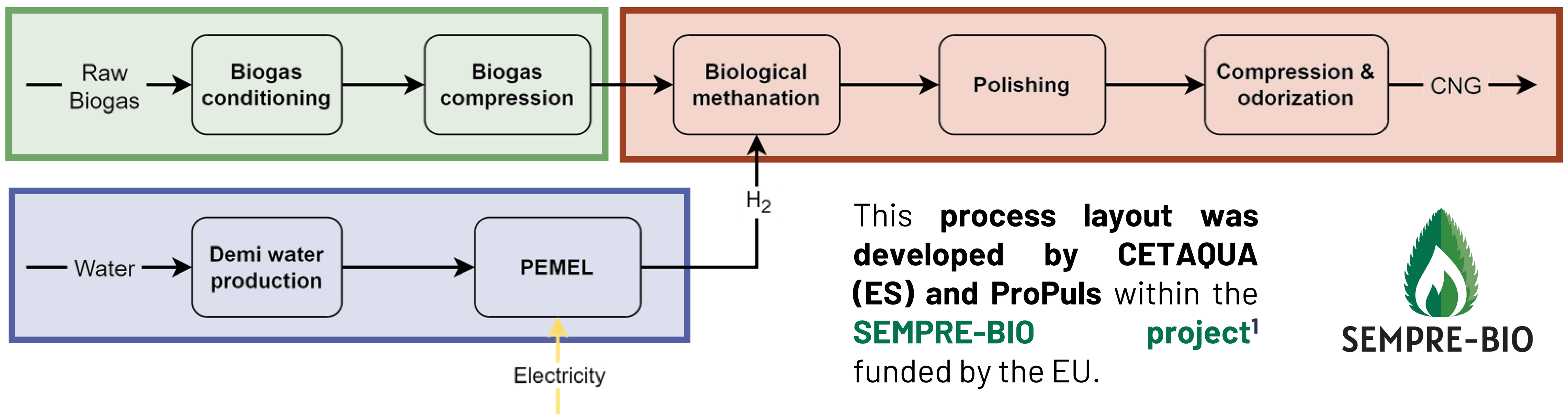
INTRODUCTION

Biogas production is an effective solution to protect air, water, and soil by **recycling organic waste streams into renewable energy**, while simultaneously **reducing GHG emissions**. Novel and cost-effective biomethane production solutions must be found to maximize the carbon utilization in the feedstock. The main **challenges** are:

1. **decrease** investment and operational **costs**
2. **optimize feedstock supply** and use
3. identify **alternative and cheaper feedstocks**
4. **improve** plant **efficiency** and operations
5. increase and monetize co-benefits from the **commercialization of side-products**.

OVERVIEW AND PROCESS DESCRIPTION

This study deals with designing, modelling, and evaluating key performance indicators for an efficient full-scale biogas-to-biomethane plant using an innovative combination of **bio-methanation** and proton exchange membrane **water electrolysis**.



This **process layout was developed by CETAQUA (ES) and ProPuls** within the **SEMPRE-BIO project**[1] funded by the EU.

SEMPRE-BIO
CETAQUA CENTRO TECNOLÓGICO DEL AGUA

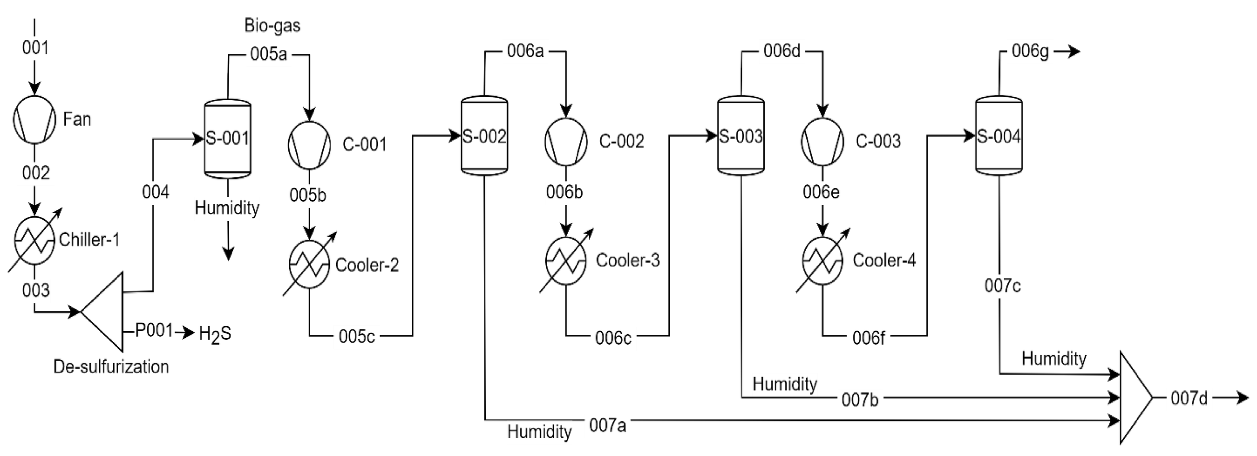
1. RAW GAS PRETREATMENT AND COMPRESSION

Feedstock: biogas from **Baix Llobregat Waste-Water Treatment Plant (WWTP)** (Barcelona, Spain)[2]

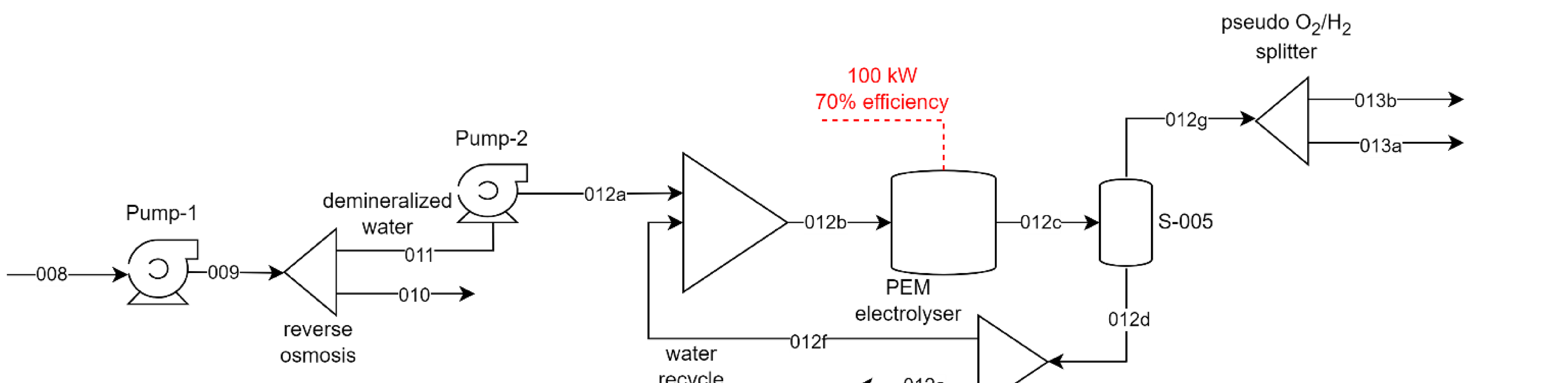
Size of feedstock: **370 Nm³/h biogas**

Composition: CH_4/CO_2 molar ratio of 1.87, 1.5 mol% nitrogen, and traces of H_2S

ASSUMPTIONS:
- Chilling to 5°C
- 99.99% H_2S removal efficiency
- **Compression to 8 bar for methanation**



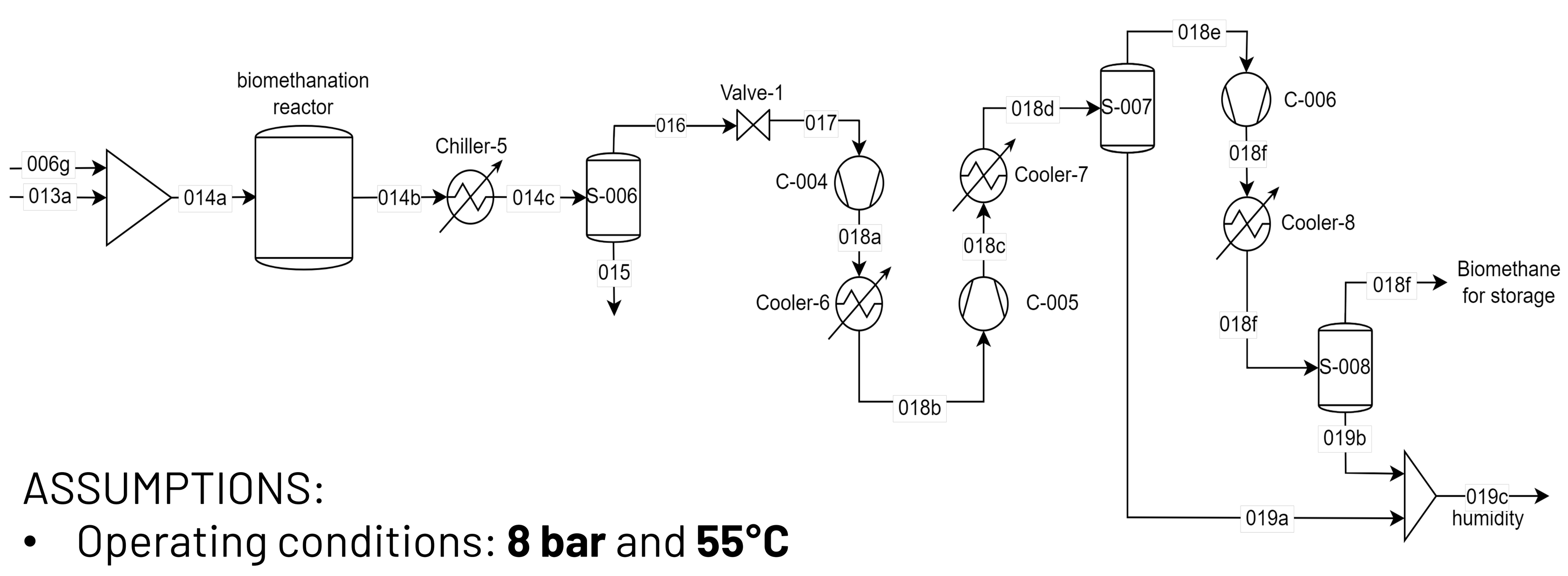
2. PEM ELECTROLYSER



$$H_2O_{(l)} \rightarrow H_{2\,(g)} + O_{2\,(g)}$$

ASSUMPTIONS:
- Simplified model retrieved from the literature[3]: only water splitting reaction is considered
- **1.6 MW overall capacity (three stacks of 550 kW)** and **70% efficiency**
- H_2O feed rate is regulated to achieve the **H_2 production required** by the methanation stoichiometry (**0.16 g H_2/ g biogas**)
- Conversion is tuned based on the assigned capacity and efficiency

3. BIO-METHANATION

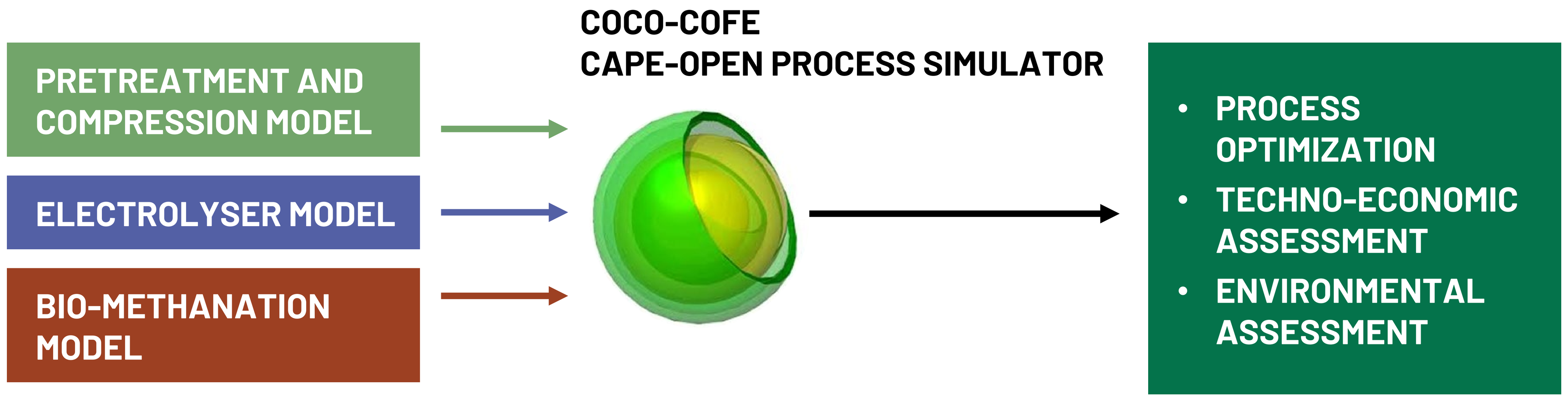


ASSUMPTIONS:
- Operating conditions: **8 bar** and **55°C**
- Reactor is modelled as a **fixed conversion reactor**, where enzymes catalyse the conversion of hydrogen and carbon dioxide into methane according to reaction:

$$CO_2 + 4\,H_2 \rightarrow CH_4 + 2\,H_2O$$

- Conversion of 98.5% for the limiting reactant (i.e., CO_2)
- **Biomethane is compressed to 250 bar for storage** as CNG

4. FLOWSHEET DEVELOPMENT AND COMING STEPS



- The sub-models are integrated in **COCO-COFE simulation environment**
- The simulation provides the **mass and energy balance for the process**
- The obtained **results** will be used as a **starting point to perform an economic and environmental assessment** (in progress)

5. RESULTS

KPI	Specific value	Unit of measure	Absolute value	Unit of measure
H_2 production in PEMEL	0.077	kg/kg H_2O	39.2	kg/h
O_2 production in PEMEL	0.609	kg/kg H_2O	310.9	kg/h
Electricity demand for PEMEL	24.18	MJ/kg biomethane	1.6	MW
Biomethane production	0.588	kg/kg raw biogas	**325**	**Nm³/h**
Biomethane purity	**97.200**	**vol%**		
Electricity demand for biogas compression	0.414	MJ/kg biomethane	28.81	kW
Electricity demand for biomethane compression	0.760	MJ/kg biomethane	50.40	kW
Overall electricity consumption	25.392	MJ/kg biomethane	**1690.03**	**kW**
Overall cooling duty	1.222	MJ/kg biomethane	81.05	kW
Refrigeration duty	0.596	MJ/kg biomethane	39.47	kW

HIGHLIGHTS

- **Increased CH_4 productivity by 53%** with respect to the CH_4 content in raw biogas
- The **process yields high-purity biomethane** (>97 vol% CH_4) from a medium-concentrated feedstock (65 vol% CH_4)
- O_2 production can be valorised (e.g., oxyfuel combustion for steam generation)
- The major electricity consumption is still associated with the PEMEL unit (24.2 MJ/kg CH_4), which does not depend on the considered storage pressure.

REFERENCES

1. SEMPRE-BIO HEU project. https://sempre-bio.com/
2. https://www.acciona.com/projects/wwtp-baix-llobregat/?_adin=0896179978
3. Wang, Y., Pang, Y., Xu, H., Martinez, A., Chen, K.S., 2022. http://dx.doi.org/10.1039/D2EE00790H

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