EPFL

Design Project - SIE 2019

ENOIL BIOENERGIES

Evaluation of CO_2 Sources for the Microalgae Production

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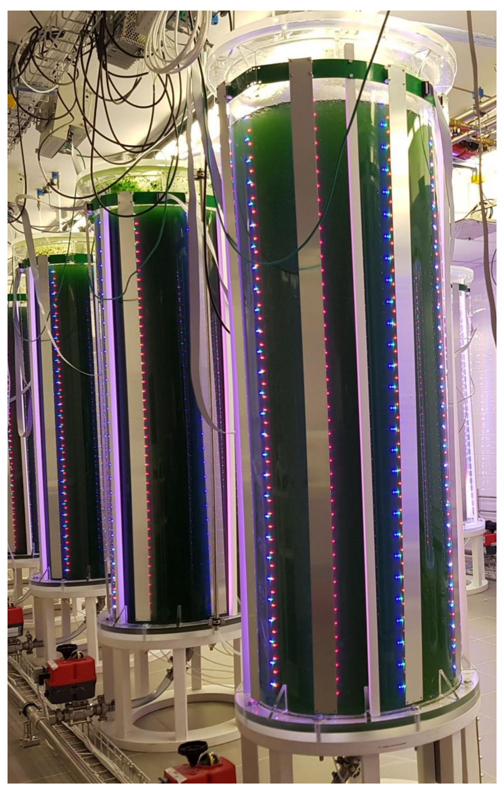
Context (1)

Enoil Bioenergies SA is planning to develop 1500 photo-bioreactors of 1m³ for the cultivation of *Spirulina platensis* for nutritional purpose. The algae farm will be located in Charrat (VS). The current source of CO_2 for the lab-scale algae farm is under the form of capsules.



OBJECTIVES

✓ Find an alternative to the current CO_2 source

✓ Integrate emissions of an other facility to perform CO_2 sequestration

✓ Identify a separation process to isolate CO_2 form the feed gas

✓ Design the separation process for the case study

Methodology (2)

- Literature review : Study different CO_2 sources and separation processes
- Analysis of the case study : amount and purity of CO_2 requirement
- Evaluation of the CO2 source fitting the case study
- Selection of the separation process fitting the requirements by comparing operational costs, energy needs and commercial availability
- Adaptation of the selected separation process

Results: Separation Process Comparison (4)

Biogas

↓

Gas cleaning — Removal of impurities; siloxane, H_2S, NH_3, Cl^- and H_2O

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CO_2 & CH_4 — CO_2 Separation

→ PSA | Membrane | MEA | Cryogenic distillation

CO_2 Requirements

- Composition : 99% CO_2, 1% CH_4
- Amount :105'000 Nm³/year
- Recovery : 87.5%

PSA (Pressure Swing Adsorption):
CO_2 gets adsorbed to the surface of a selected porous material and will be regenerate by lowering the pressure.

Membrane:
Relatively simple mechanism acts like a sieve, that separates the feed-gas by using the different kinetic diameter of CO_2 (3.4 Å) and CH_4 (3.8 Å).

MEA (Monoethanolamine Absorption):
Chemical absorption on MEA. CO_2 dissolved in MEA solution due to exothermic reversible reaction between weak acid (CO_2) and a weak base (MEA).

Cryogenic distillation:
Energy intensive process, yet has high potential for the future. It utilizes the different boiling/sublimation points of the compounds of the feed-gas.

Parameters	Unit	PSA	Membrane	MEA	Cryogenic
Purity	%	≥99	98	≥99	≥99
Recovery	%	98	-	90	96
Cost	\$/ton CO_2	50-60	10-20	52-77	-
Energy	kWh/kg CO_2	0.2	0.041	1.1	0.5
Commercial availability	-	High	Medium	High (for flue gas)	Low

High purity and recovery rate with high commercial availability → **PSA** is selected

Conclusion (6)

- The biogas produced from WWTP in Martigny is selected as the CO_2 source because of its close location to the future algae farm and high CO_2 content.
- The gas separation utilizing PSA on Zeolite 5A enables to achieve the CO_2 requirement.

Recommendations

➢ The gas cleaning step for removing impurities such as H_2S, NH_3, siloxane, needs to be further developed before implementation

➢ The comprehensive cost analysis should take place between three parties (Enoil, separation technology provider and CO_2 source industry) to meet the specific needs of the algae farm in Charrat

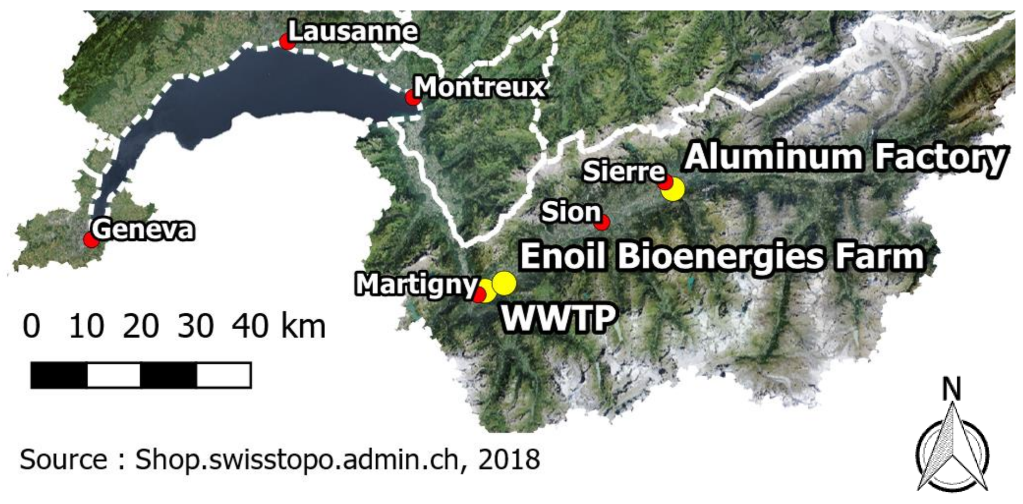
➢ The production of waste should be considered for a better management and ensure the future algae farm to be sustainable

➢ Feeding the algae with bicarbonate can be considered especially if flue gas is considered in the future

CO_2 Source Selection (3)

The table shows the composition of the different CO_2 source considered. The maximum tolerated value is the toxicity threshold or Swiss regulatory limit.

Compound	Units	Typical Flue gas	Biogas WWTP	Atmosphere	Max tolerance	Negative effects
N_2	%	65-80	0.2-0.6	78.084	-	None
O_2	%	2-10	0,1-0,5	20.946	75	Inhibition
H_2O	%	5-20	1–5	<1 - 5	-	None
CO_2	%	7-15	35-45	0,0408	5	Toxicity
CH_4	%	-	55-65	1.75E-04	1	Explosion
H_2	ppmv	-	<0,5	0,55	-	None
H_2S	ppm	-	100-1'000	traces	5	Inhibition
NH_3	ppm	-	100	traces	27	Inhibition
CO	ppmv	-	<0,1-0,3	0.2	30	Toxicity
Siloxanes	mg/m³	-	0-41	-	0	Toxicity
Total Cl^-	mg/m³	-	0-2,2	-	-	Lysis of cells



Source : Shop.swisstopo.admin.ch, 2018

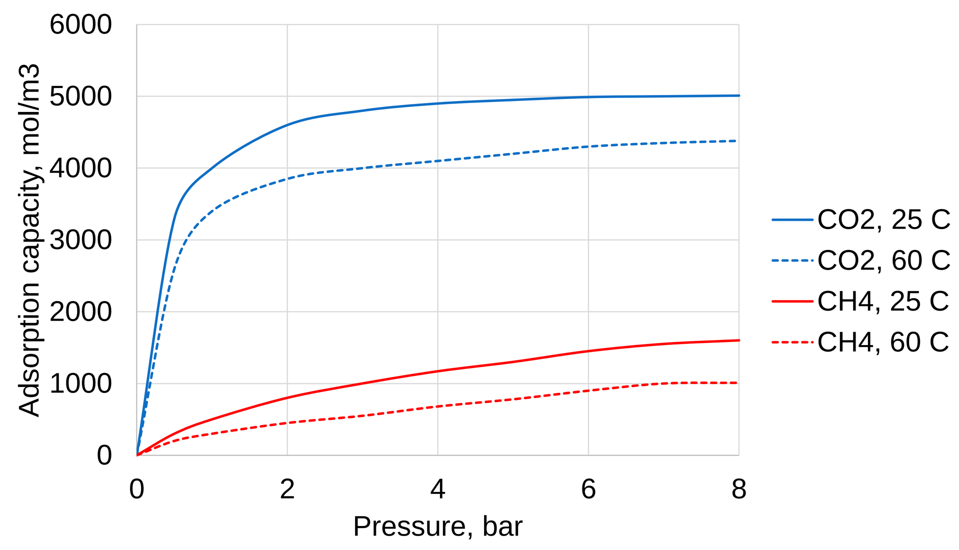
🟡 : Location of CO2 sources 🔴 : Nearby cities

Selected source:
WWTP Martigny – Biogas

- Composition :40%CO_2, 55%CH_4
- Impurities : ~5%
- Production : 300'000 Nm³/year
- Discharge : 35 Nm³/h
- Pressure : 4.5 bar
- Temperature :40-45°C
- Distance :6 km

Final Design: PSA (Pressure Swing Adsorption) (5)

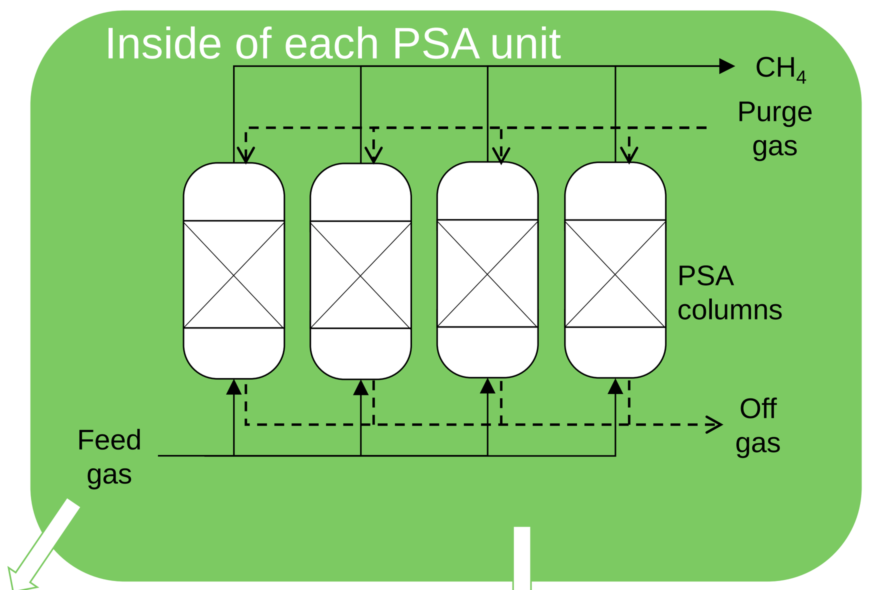
PSA mainly consists of four phases; (1) Pressurization (2) feed (3) blow-down, and (4) Purge. The performance of PSA relies on the capacity of adsorbent materials. The study by Augelletti et al.(2017) demonstrates **Zeolite 5A** to be a potential adsorbent for our case. Their PSA units were considered for our case.

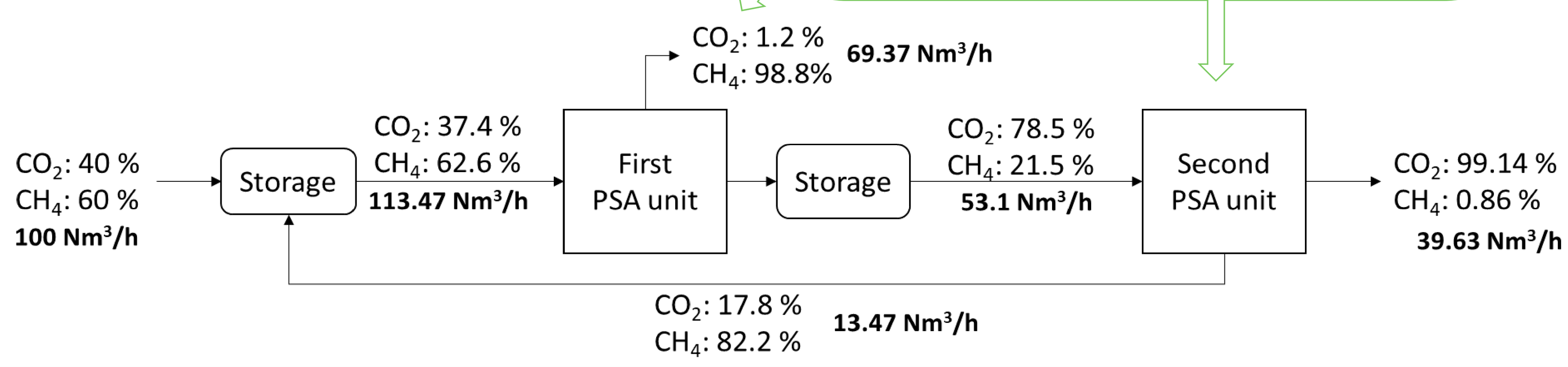


Zeolite 5A Equilibrium adsorption isotherm

To ensure high purity and recovery rate, a **double PSA units systems** are evaluated. **Each unit consists of 4 columns.**

	First PSA	Second PSA
Column length	1.5 m	1 m
Column diameter	0.4 m	0.31 m
Column porosity	0.36	0.36
Pressure feed	6 bar	6 bar
Phase (1)	170 s	110 s
Phase (2)	190 s	130 s
Phase (3)	170 s	110 s
Phase (4)	190 s	130 s





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