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Improving hydrogen biomethanation in a CSTR reactor fed with primary sludge: (preliminary) results of a pilot-scale test

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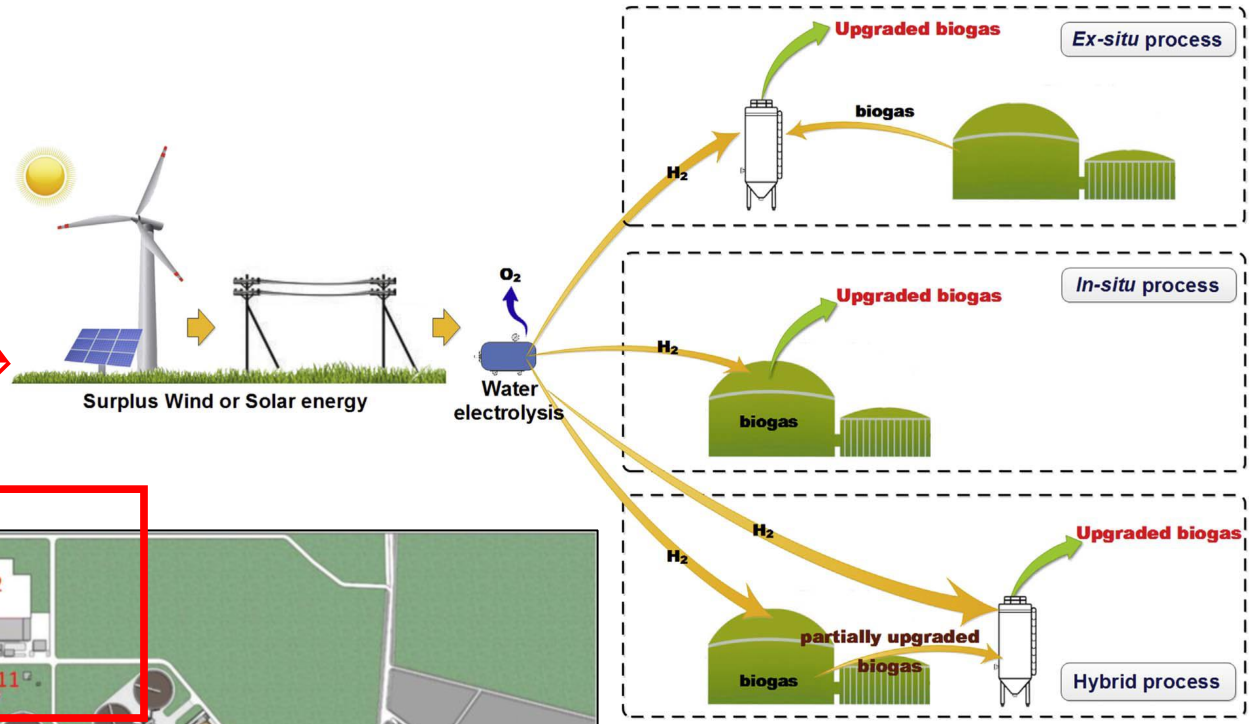
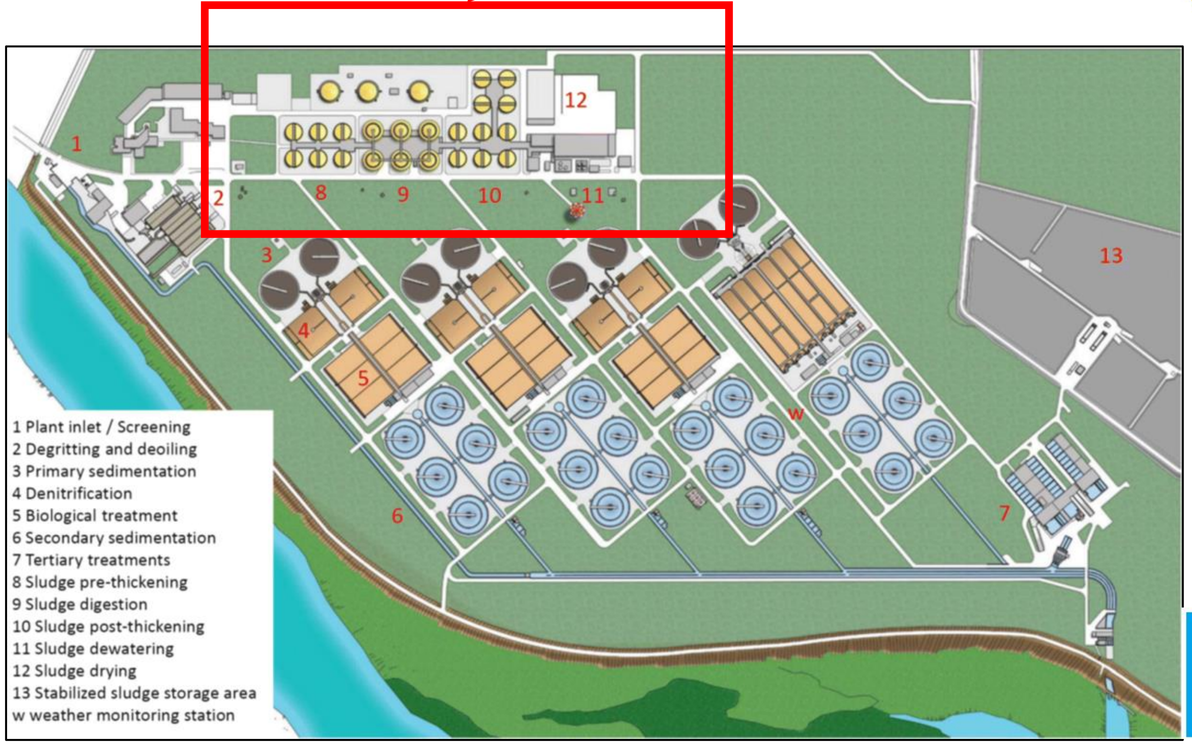
Hydrogen biomethanation

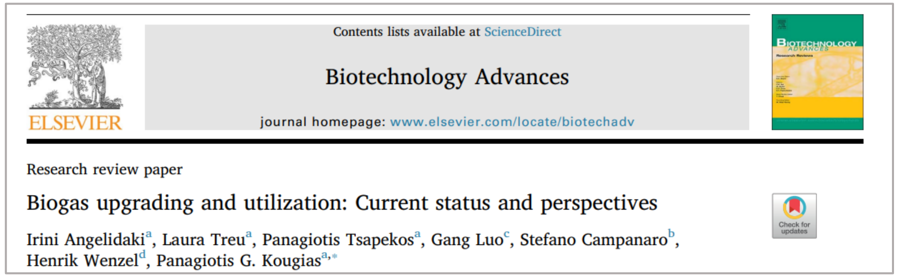


Goal:

- Storage and transformation of excess renewable energy
- Alternative process to upgrade biogas to biomethane
- Optimization of the anaerobic digestion process due to the hydrogen biomethanation exothermic reaction



WWTP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Research review paper

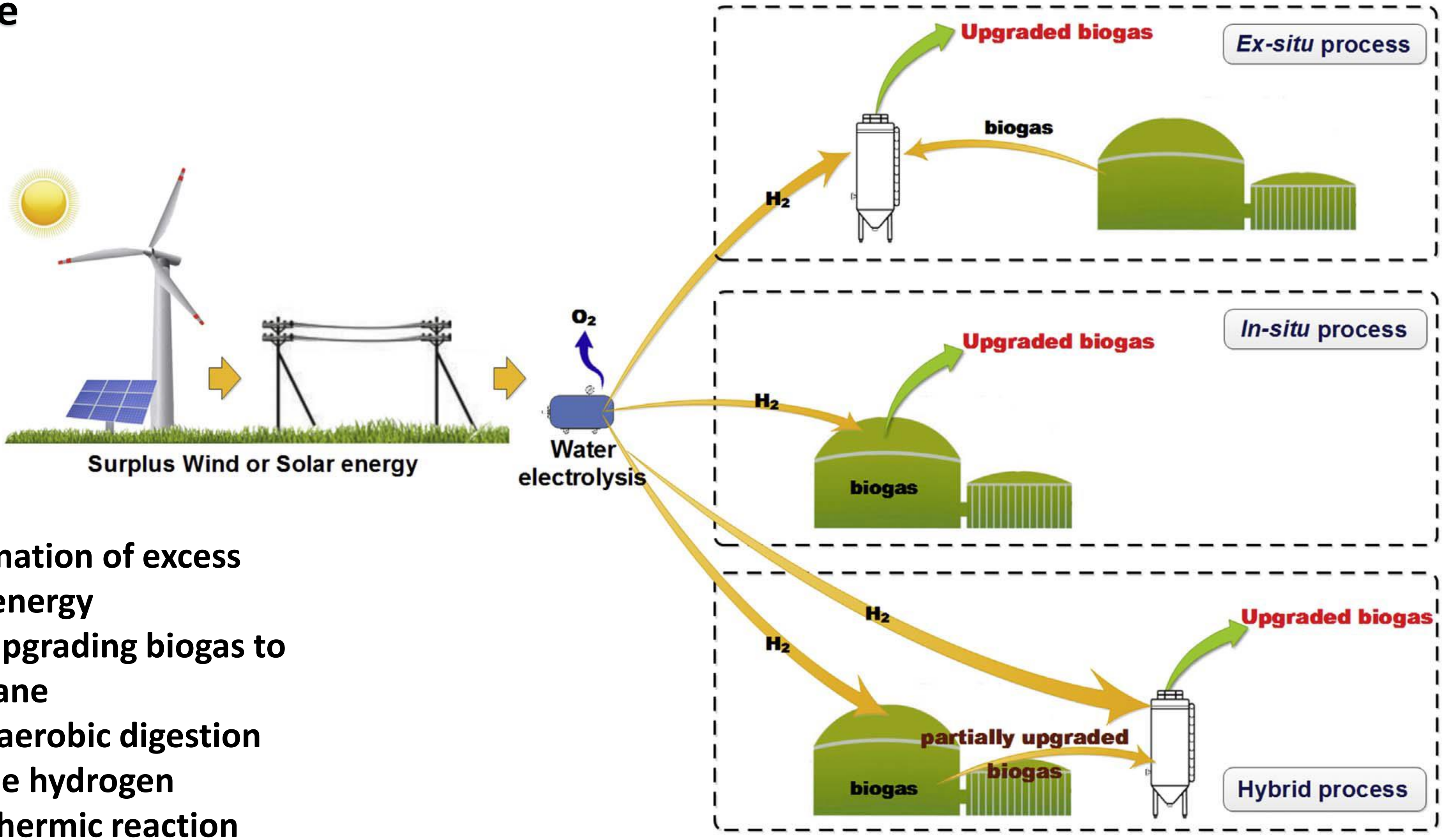
Biogas upgrading and utilization: Current status and perspectives

Irini Angelidaki[a], Laura Treu[a], Panagiotis Tsapekos[a], Gang Luo[c], Stefano Campanaro[b], Henrik Wenzel[d], Panagiotis G. Kougias[a,*]

HOW?

Power to Gas
Power to Methane

Hydrogen biomethanation

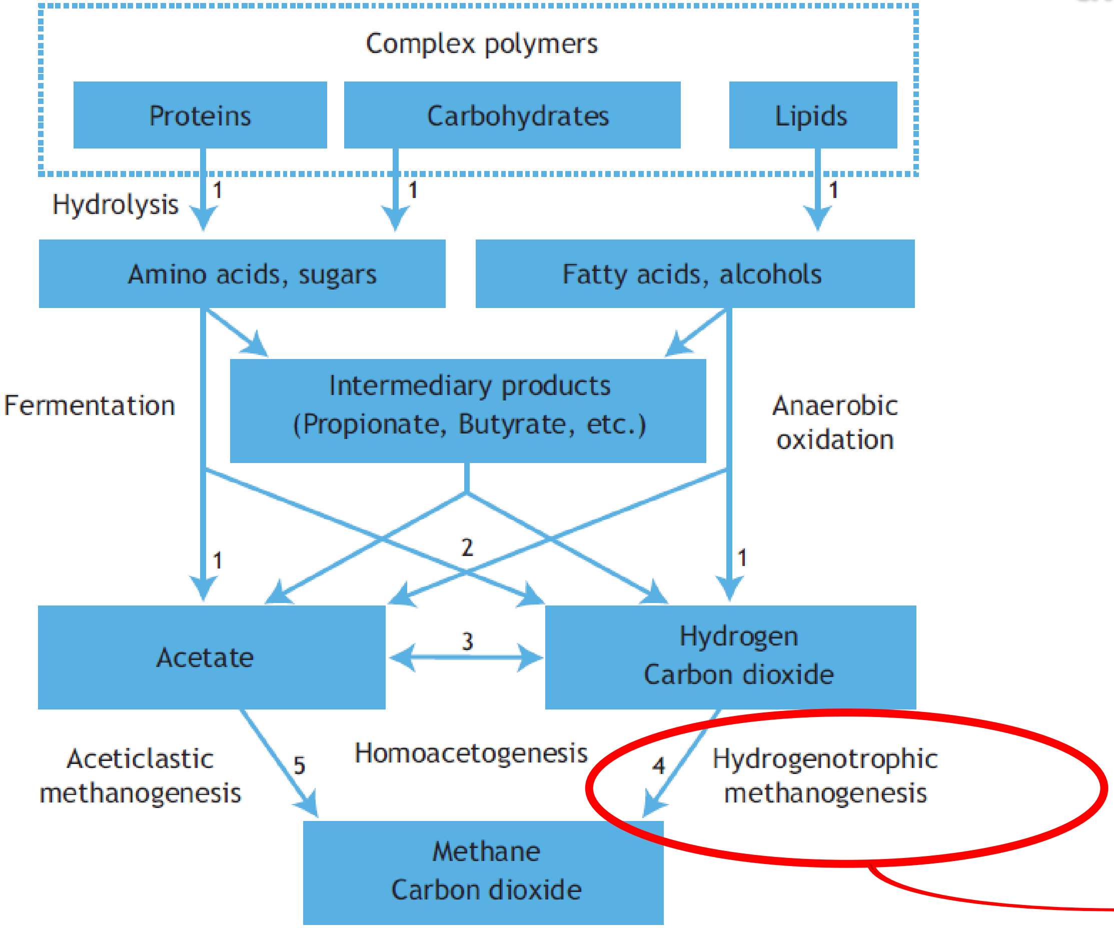


Goal:

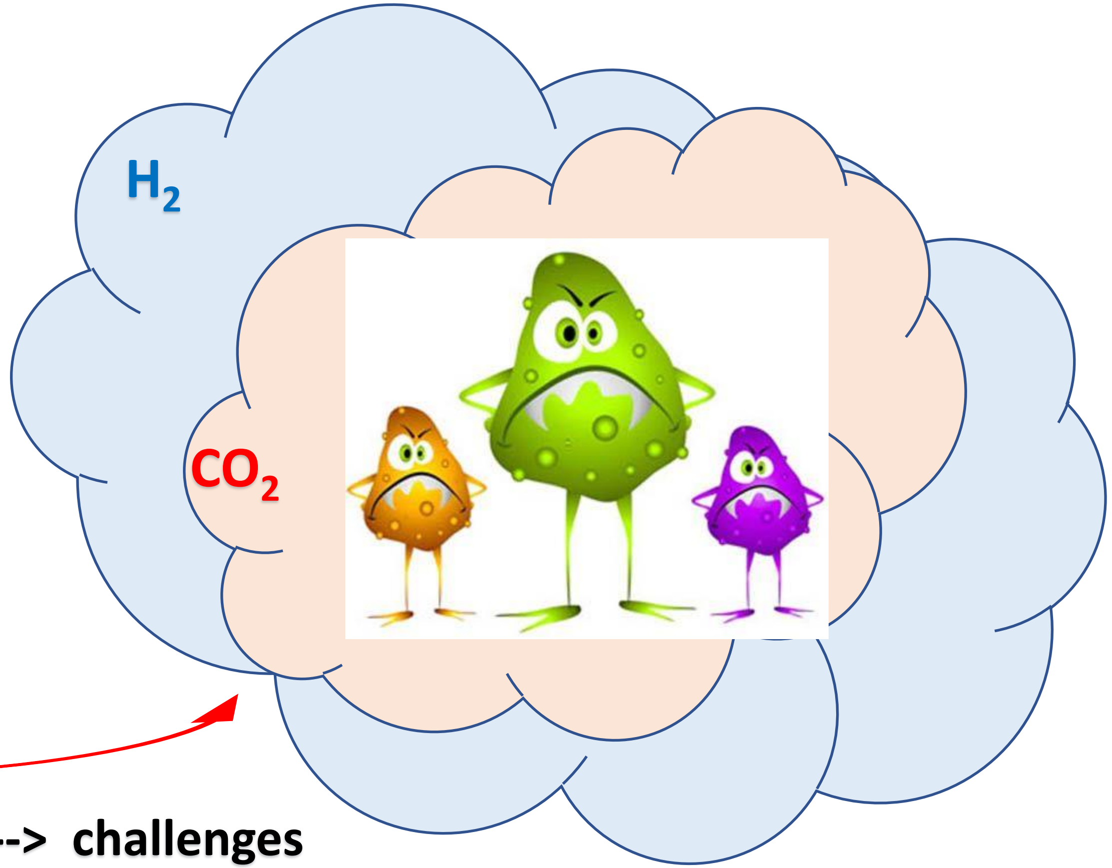
- **Storage and transformation of excess renewable energy**
- **Alternative process for upgrading biogas to biomethane**
- **Optimization of the anaerobic digestion process due to the hydrogen biomethanation exothermic reaction**

HOW?

H_2 biomethanation < -- > exothermic reaction catalysed by hydrogenotrophic methanogenic archaea



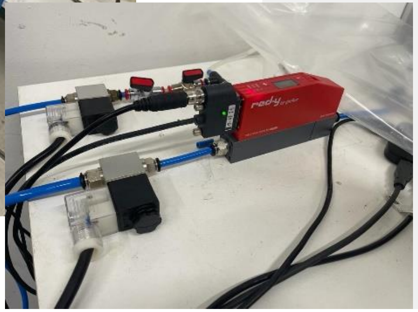
$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O \quad \Delta H° = -164.9$ kJ/mol

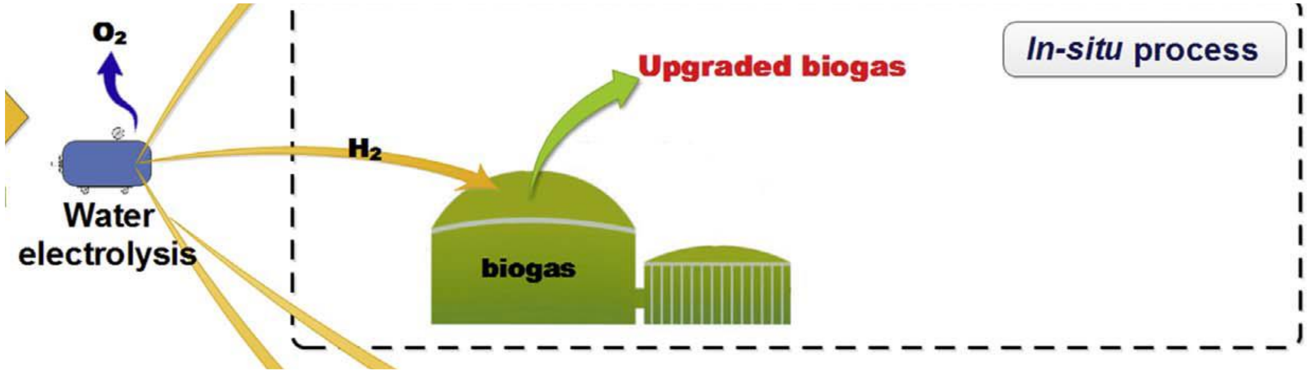


Limiting factors <--> challenges

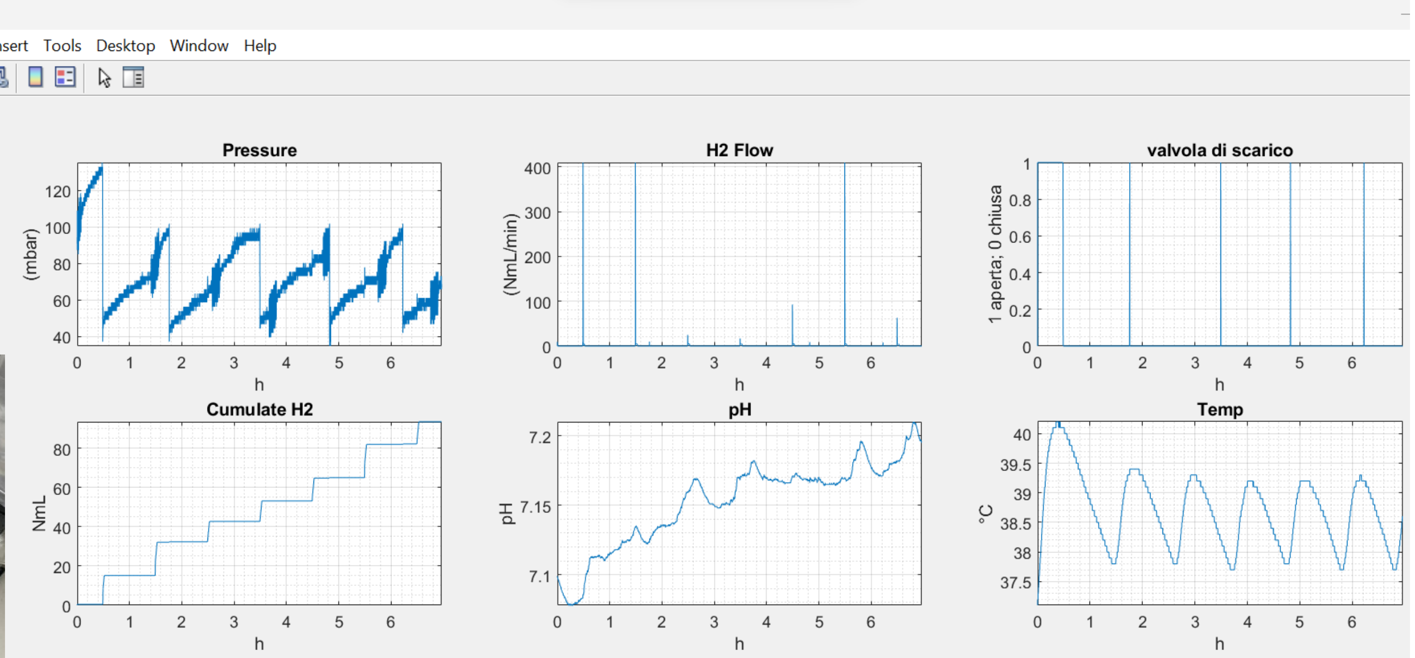
- pH increase due to the bicarbonate consumption could inhibit Hydrogenotrophic Methanogenesis
- H_2 partial pressure increase could inhibit VFAs oxidation
- Poor gas-liquid H_2 mass transfer (low solubility)
- Effective applicability of the in-situ process at full scale (existing reactors: kLa)

In this work:



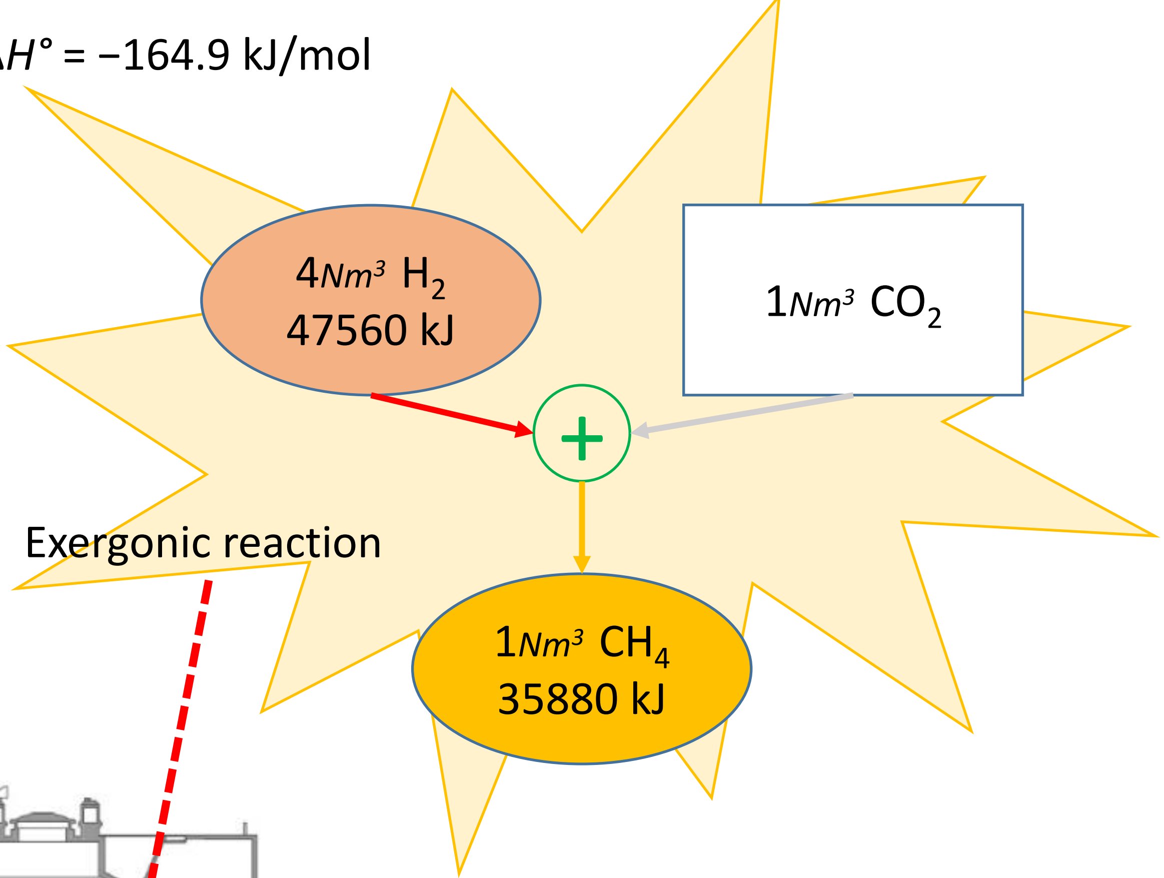


- In-situ H_2 biomethanation process energy assessment
  - A.D. pilot scale test with preliminary results



Energy assessment

$4H_2 + CO_2 \rightarrow CH_4 + H_2O \quad \Delta H° = -164.9$ kJ/mol

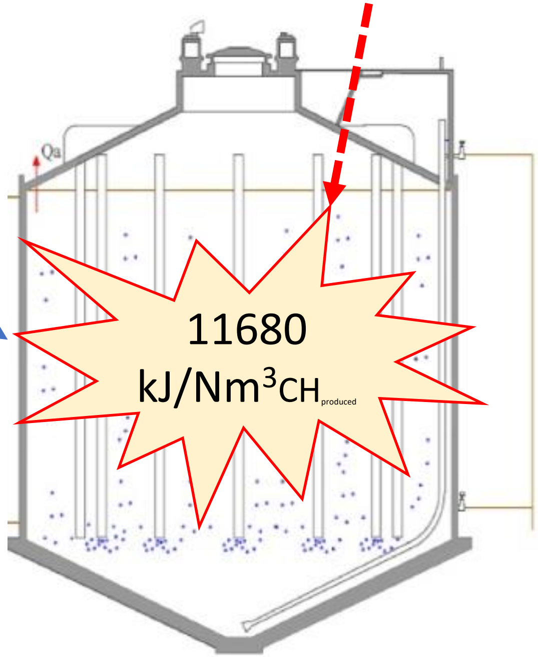


HYPOTHESIS:

- lower heating value of H_2: 11,890 kJ/m3
- TS of the sludge: 4%, VS/TS ratio 0,74
- boiler efficiency η: 0.9
- Sludge specific heat capacity C: 4.18 kJ/kg/◦C
- ambient temperature: 15°C
- Heat transfer digester walls k: 0,8 W/m²/°C
- volume and surface digester → radius to height ratio: 1:1

HEATING

Primary s. → 38 °C



Boiler η=90%

PS and WAS parameters obtained from the elemental composition analysis.

	PS	WAS
VS raw formula	$C_{10.6}H_{18.2}O_{4.1}N$	$C_{6.8}H_{11.8}O_{3.2}N$
COD/VS (g O_2/g VS)	1.76	1.49
Theoretical biogas production (Nm^3/kg VS)	1.06	0.96
Theoretical methane production (Nm^3/kg VS)	0.62	0.52

Primary s. biodegradability: 50%

H_2
26,4
Nm^3/d

15,9 m^3 biogas
58% CH_4
42% CO_2

CO_2 theoretically available
6,6 Nm^3

+

Exergonic reaction

1 m^3
Primary s.
3% V.S.

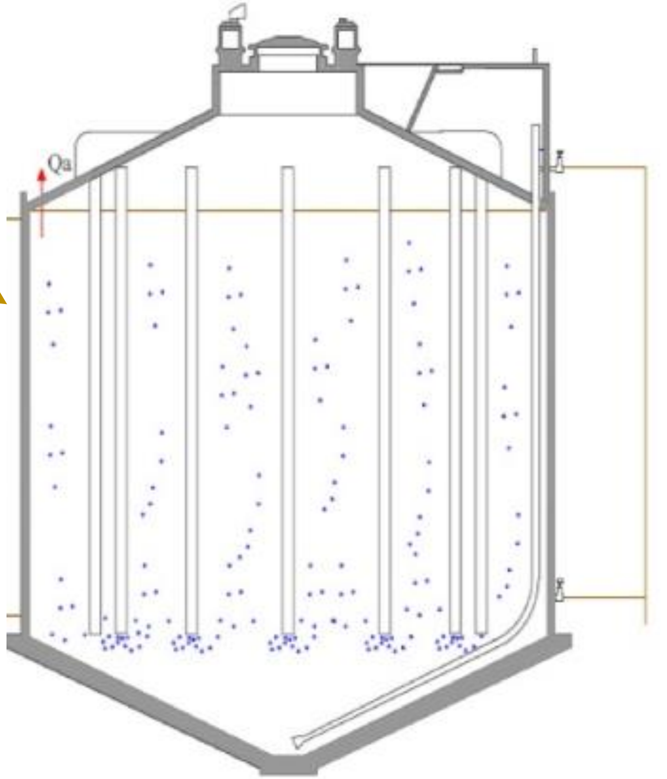
smat gruppo

19%

81%

HEATING 38 °C - 96,3 MJ

Boiler η=90%



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A modelling approach for the assessment of energy recovery and impact on the water line of sludge pre-treatments

Giuseppe Campo [a], Alberto Cerutti [a], Mariachiara Zanetti [a], Margherita De Ceglia [b], Gerardo Scibilia [b], B Vai alla pagina 1 ino [a,*]

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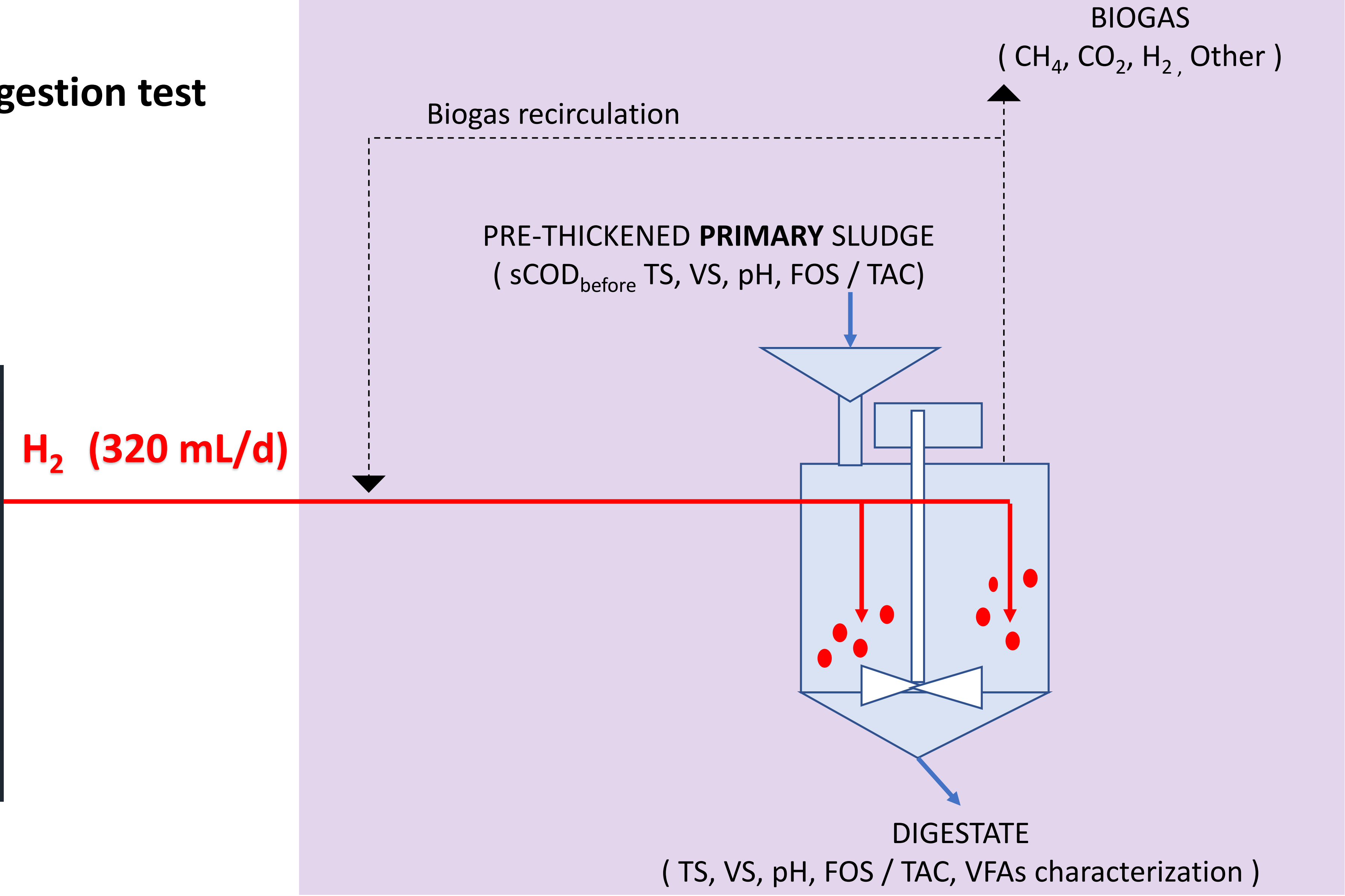
Pilot scale test

Materials and Methods

Semicontinuous digestion test

Electrolyser

10 L C.S.T.R. MESOPHILIC DIGESTER – HRT 20 days



Materials and Methods

Average elemental composition of the PS used in the study.

	N (%)	C (%)	H (%)	O (%)
TS	4.568	41.819	6.048	46.994 (*)
FS	<DL	0.546	0.253	ND

FS, fixed solids (TS – VS); DL, detection limit; ND, not determined
(*) The oxygen amount was calculated as 100 minus the sum of the amounts of C, N, H.

Substrate: **Primary** sludge

Ruffino B., et al; Energy Conversion and Management; 223 (2020)

$$tCOD = \frac{8(4n + a - 2b - 3d)}{(12n + a + 16b + 14d)} as \left(\frac{gCOD}{gC_nH_aO_bN_d} \right) = 1{,}65\ \frac{g\ O_2}{g\ VS}$$

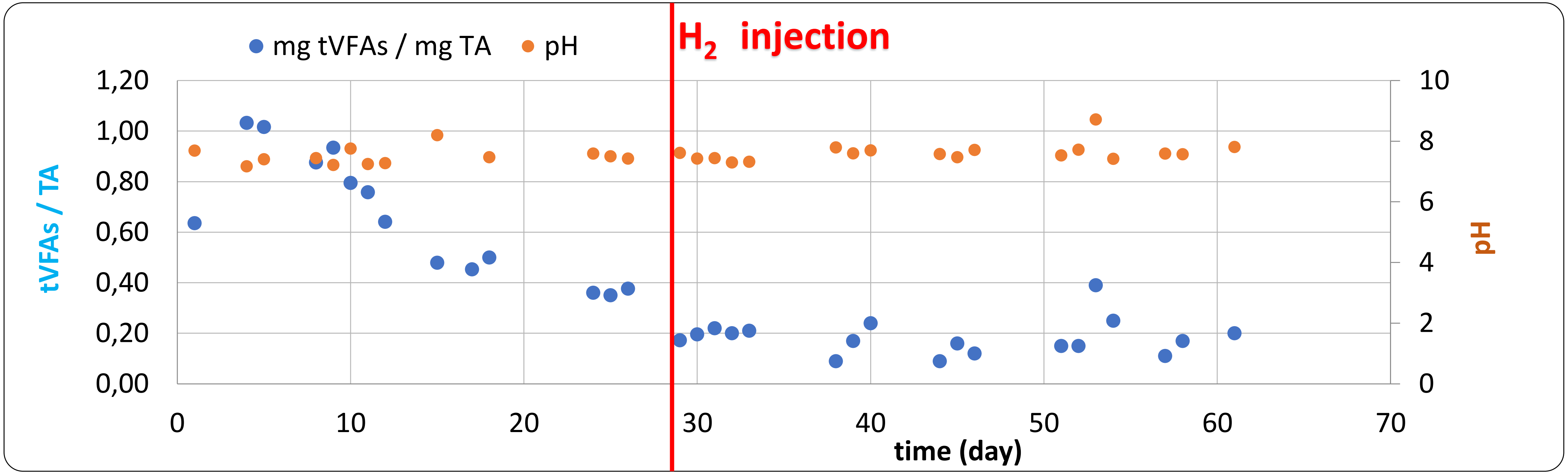
$$\frac{{}_sCOD}{{}_tCOD} = 5\ \%$$

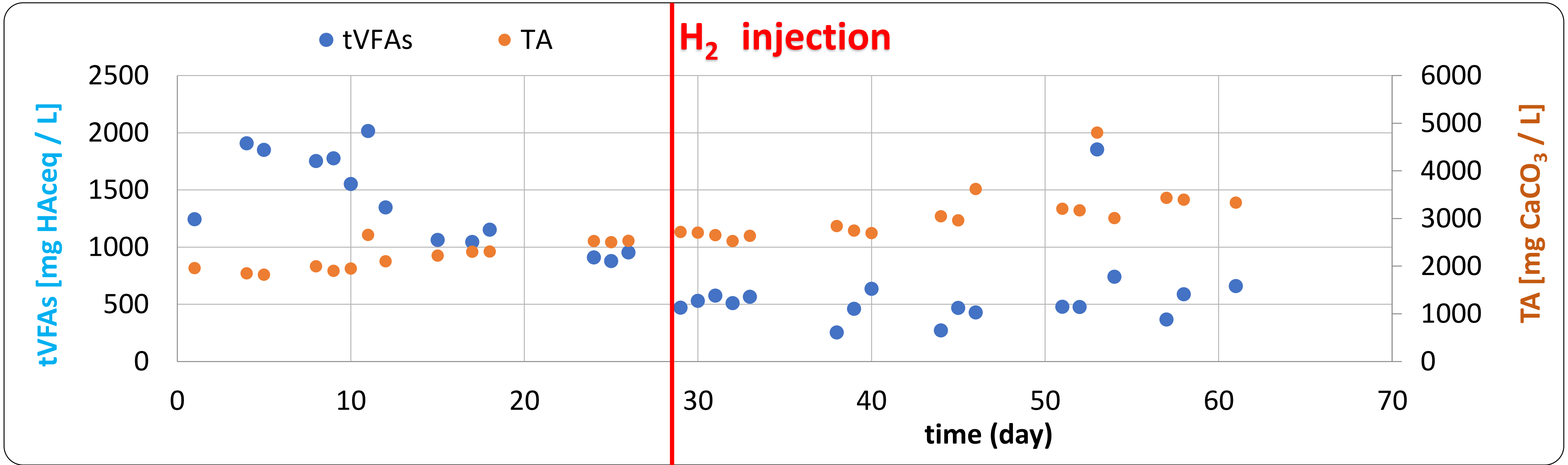
Castiglione Torinese SMAT WWTP 2,300,000 e.p.

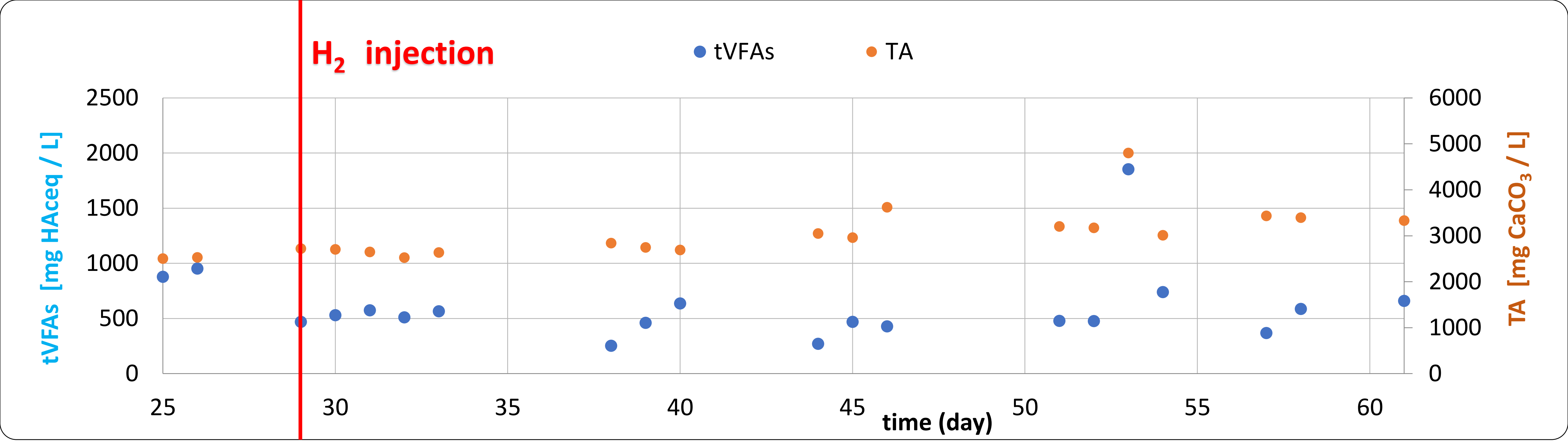
Sludge line:
from pre-thickeners
to digesters

Primary sludge samples
Thickened from 2,5 to 3,1% TS

Results: Process stability

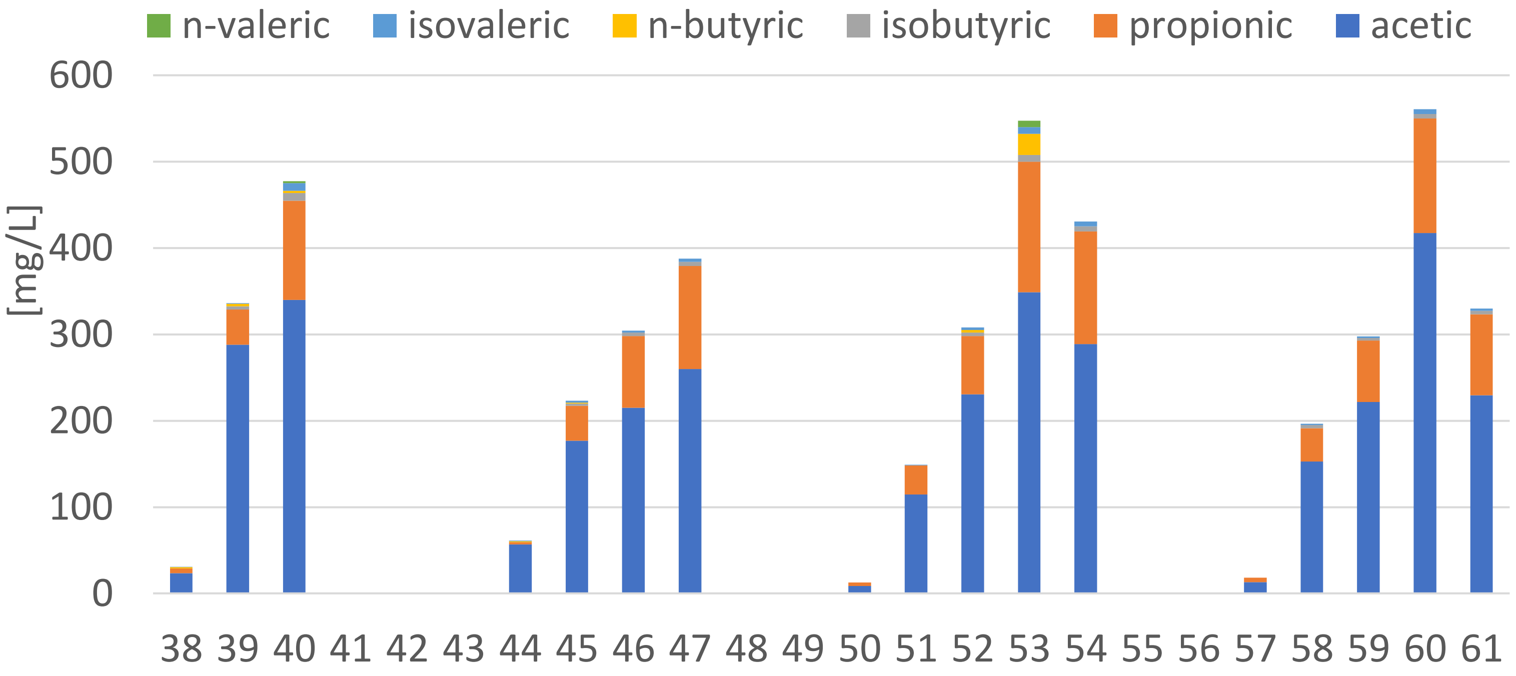




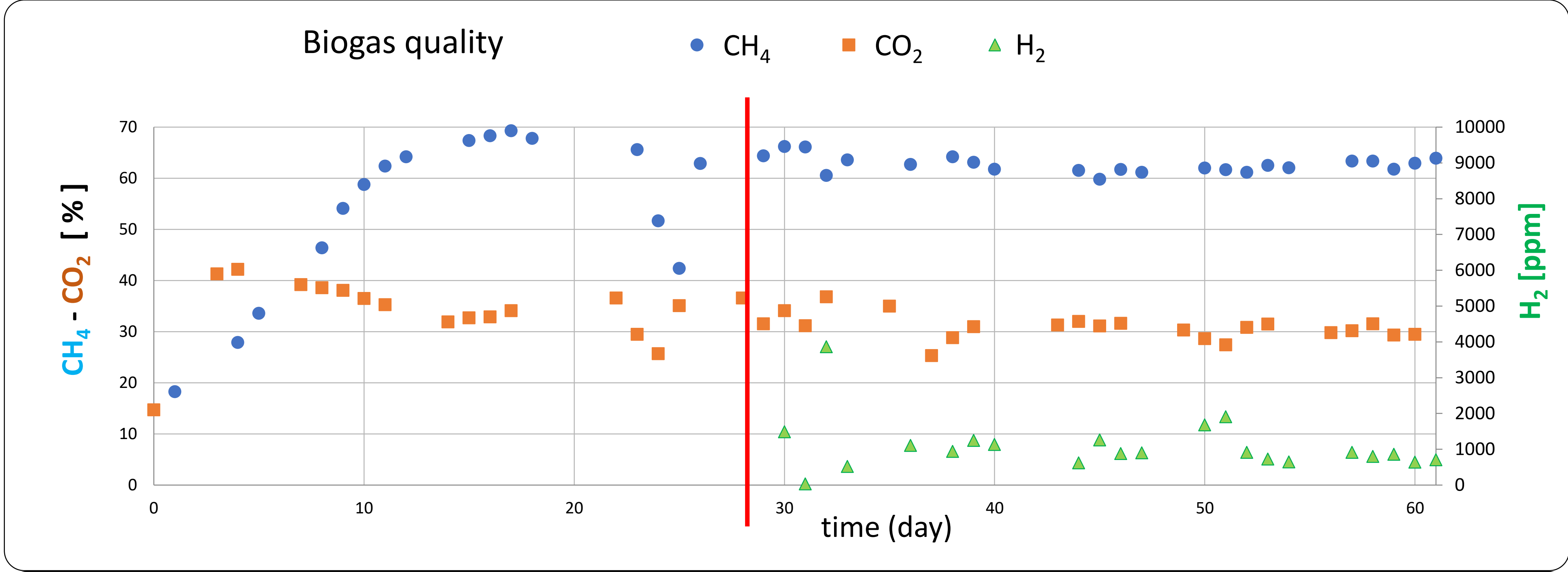


VFAs characterization and quantification

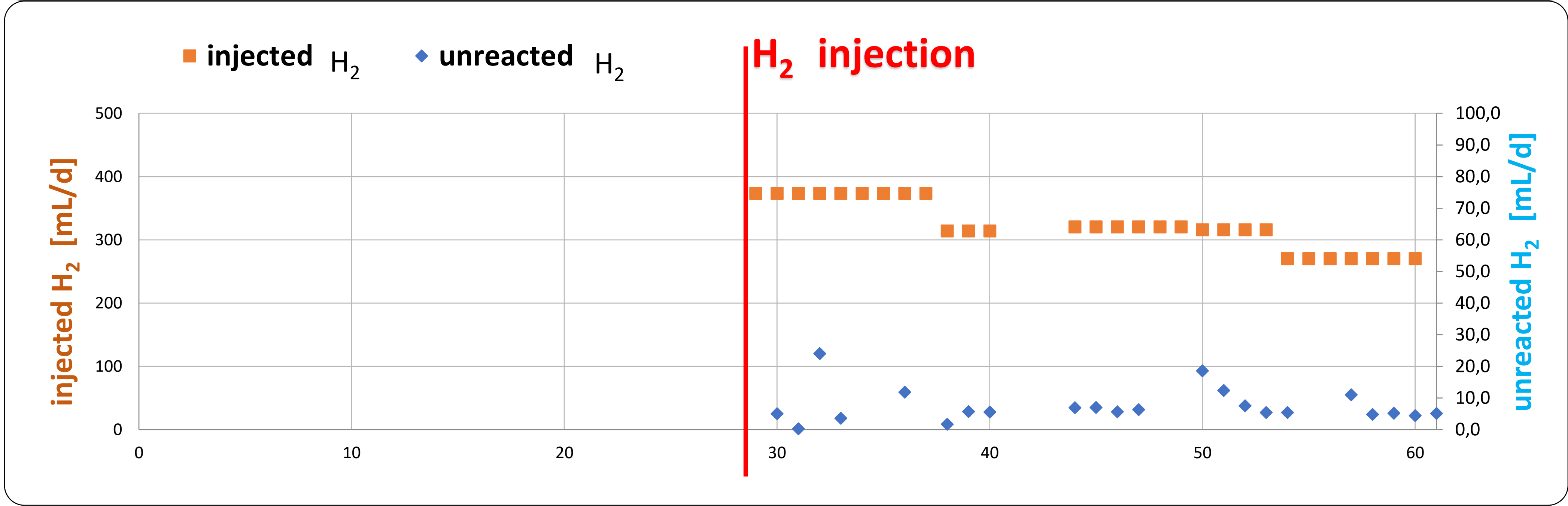
lighter species accumulation during the week which were degraded during the weekend when the primary sludge was not fed



Results
Biogas production



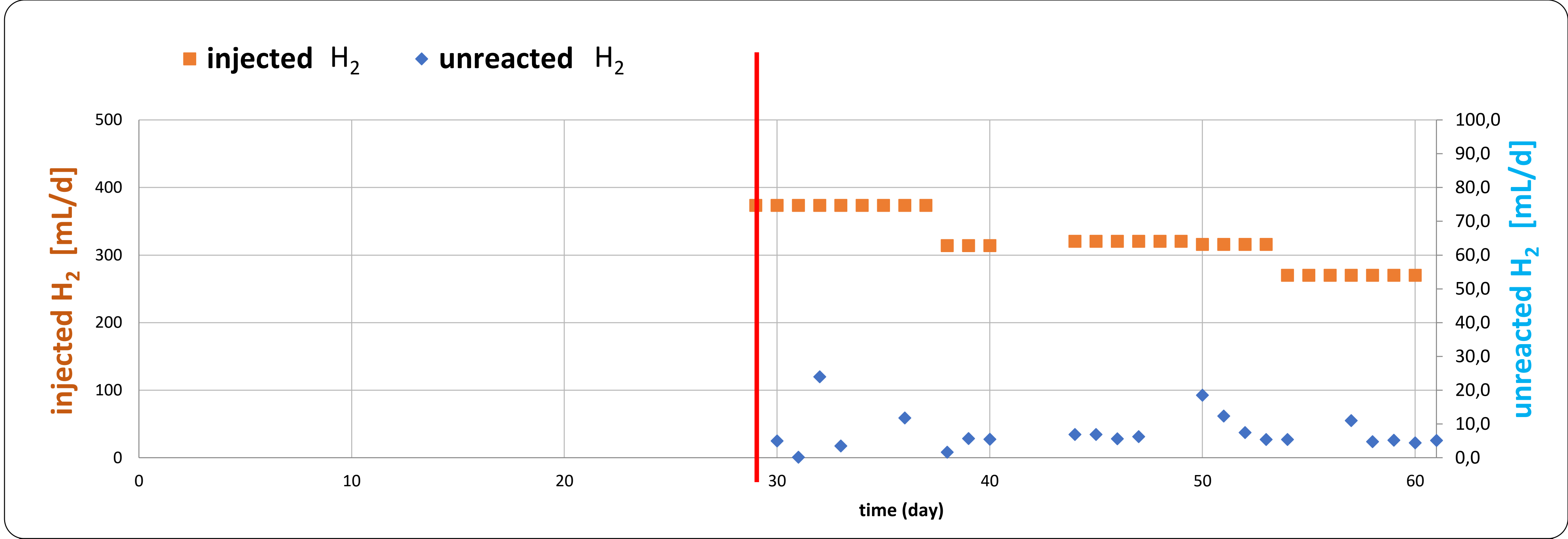
Injected H_2 is on average the 5% that stoichiometrically could react with the CO_2 produced

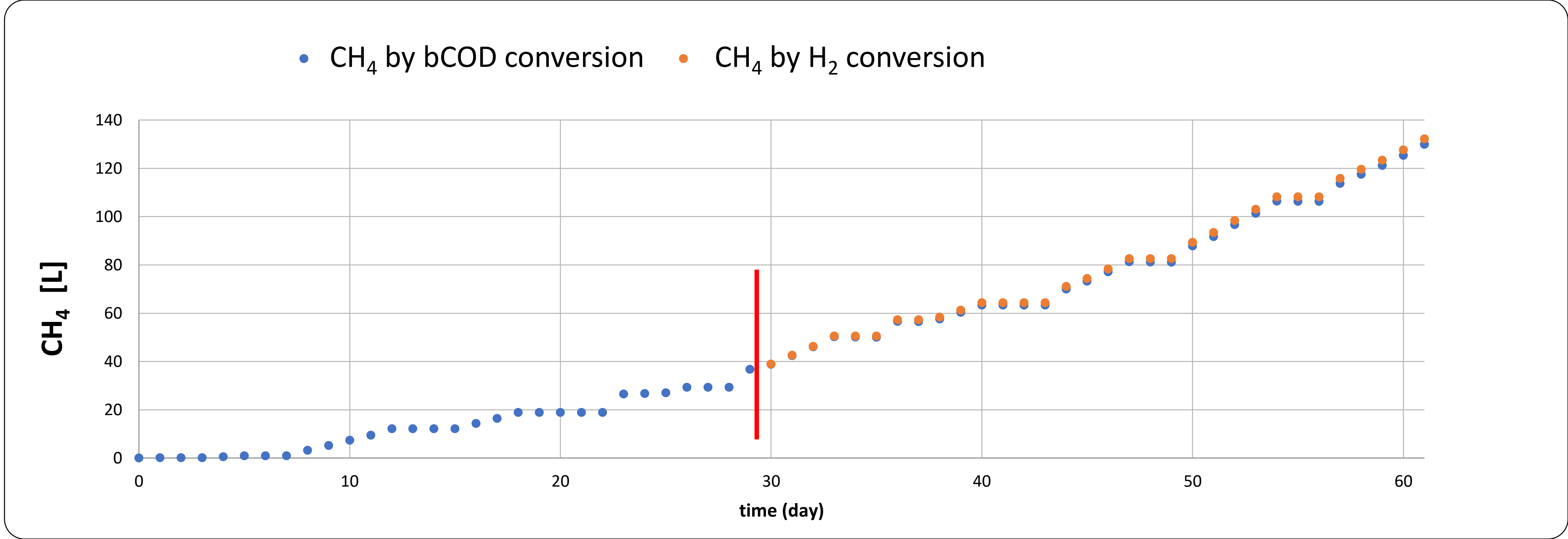


Conversion rate of H_2 in CH_4 99%

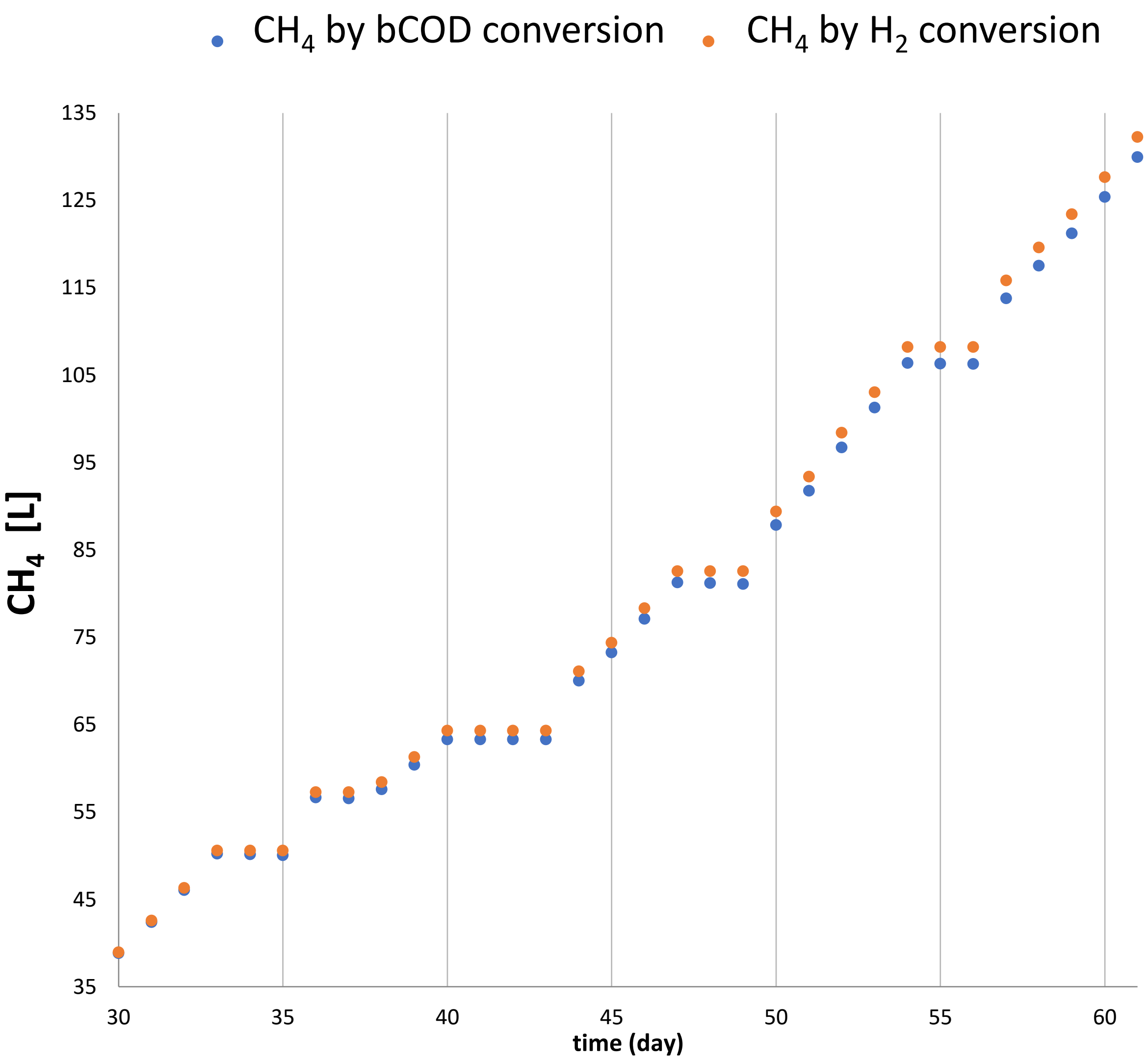
Results

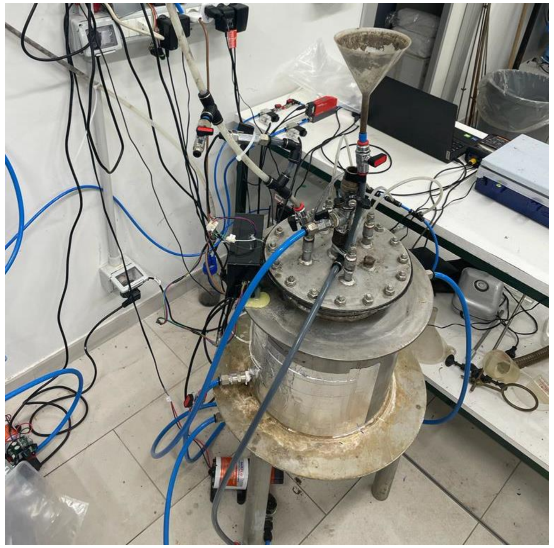
Methane cumulative production





Hydrogen biomethanation contributes for the 2% to the methane production increase





Conclusions

- The in-situ hydrogen biomethanation process has a positive effect in a lower thermal energy consumption;
- The pilot scale test conditions allowed a conversion rate of H_2 in CH_4 of 99%. However, in order to understand the system limiting factors, increasing steps of H_2 flow rate should be investigated;
- Experimental data (VFAs characterization) could be elaborated with the Anaerobic Digestion Model 1 to predict process inhibitory factors

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Thank you for your attention!

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