COMPARISON OF ONE-STAGE AND TWO-STAGE FERMENTATION PROCESS OF FOOD WASTE

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Bio2Energy

Progetto finanziato con il contributo determinante dell'accordo di programma MIUR-Regione Toscana DGRT 1208/2012-Accordo di programma quadro MIUR-MISE-Regione Toscana DGRT 758/2013 PAR FAS 2007-2013 - Linea d'azione 1.1 Bando per il finanziamento di progetti di ricerca fondamentale, ricerca industriale e sviluppo sperimentale realizzati congiuntamente da imprese e organismi di ricerca in materia di nuove tecnologie del settore energetico, fotonica, ICT, robotica e altre tecnologie abilitanti connesse bando FAR-FAS 2014

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- Biohydrogen production from the fermentative stage
- Anaerobic performances of **One** and **Two-stage** digestion processes?

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- Terms of comparison of the scenarios

3. RESULTS

4. CONCLUSIONS

INTRODUCTION

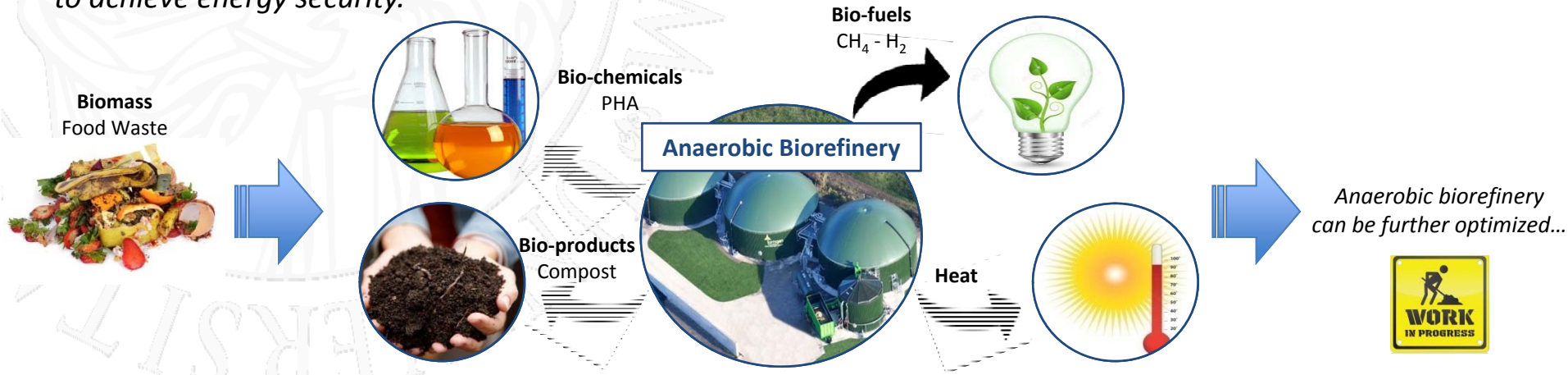
ANAEROBIC BIOREFINERY

Definition of Biorefinery (*European Commission, 2017 - COMMISSION STAFF WORKING DOCUMENT on the review of the 2012 European Bioeconomy Strategy*)

*"Integrated biorefineries, which use processing technologies to fractionate **biomass and biological waste streams, to produce food, feed, bio-based materials and fuel/energy** in an integrated manner, are critical infrastructures for enabling the cascading use of biomass."*

Anaerobic biorefiney concept (*Sawatdeenarunat et al., 2016*)

*"The anaerobic biorefinery is one of the biorefinery concepts, in which **AD** serves as a **centerpiece** to produce high-value, but low volume products (i.e., **chemicals** and drop-in **biofuels** to enhance economic viability of the system) and high-volume but low value products (i.e., **heat**, **electricity**, and conventional transportation biofuels) to achieve energy security."*



INTRODUCTION

BIOHYDROGEN PRODUCTION FROM THE FERMENTATIVE STAGE

Why Hydrogen production in anaerobic digestion?

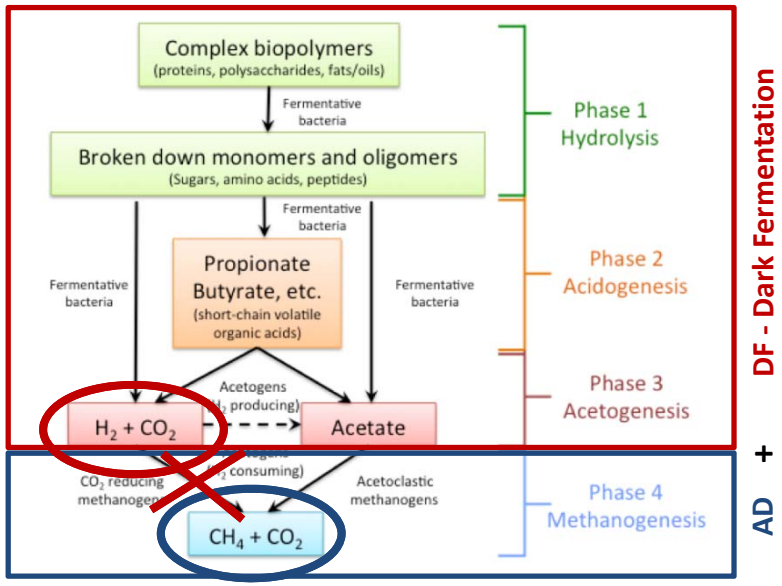
H_2 is considered one of the cleanest energy sources and its **energy density per mass (122 kJ g^{-1}) is 2.5 times compared to fossil fuels** (*Abdallah et al., 2016*). It could be used to produce electricity through fuel cells.

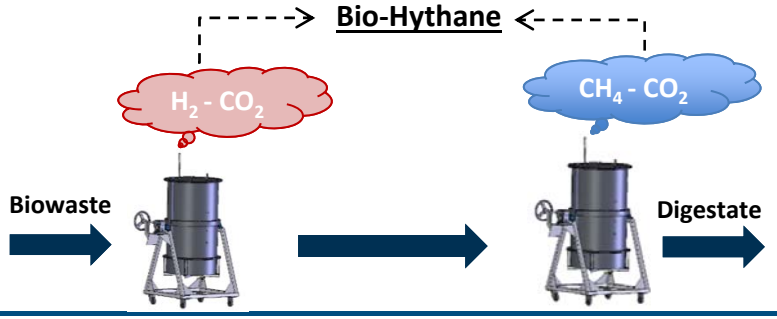
What dark fermentation is?

DF is the first agidogenic step of AD where fermentative bacteria (e.g. *Clostridium perfringens*) break down **organic matter into primarly H_2, CO_2 and soluble metabolic products** (*Ghimire et al., 2015*).

The two-stage process:

DF can be implemented in a two-stage process where, in the second step, methanogenic bacteria convert the spent organic effluent from the first stage into CH_4 and CO_2 gas (*Ariunbaatar et al., 2015*). **Enhancement of the total biogas production** (*Lee et al., 2010*). The two gas flow could be used either by itself or mixed together in a mixture that simulates the composition of **Hythane**.

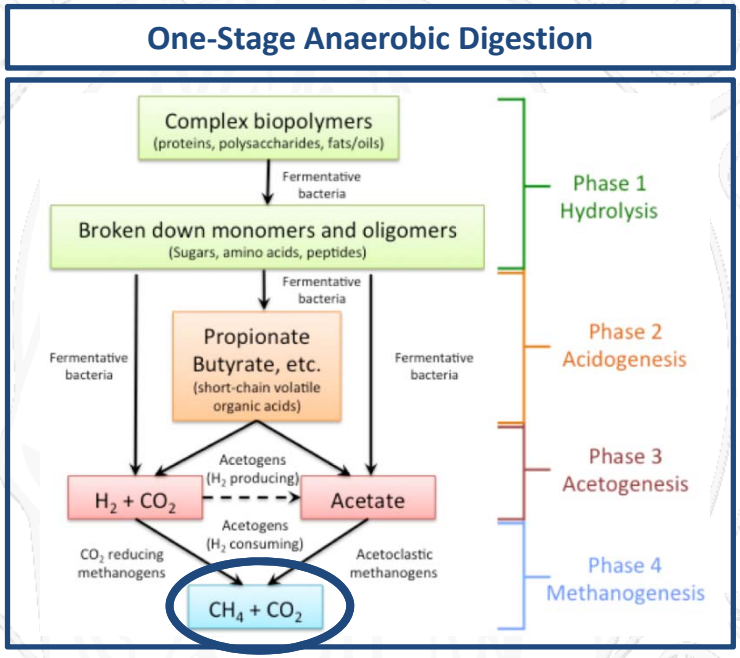


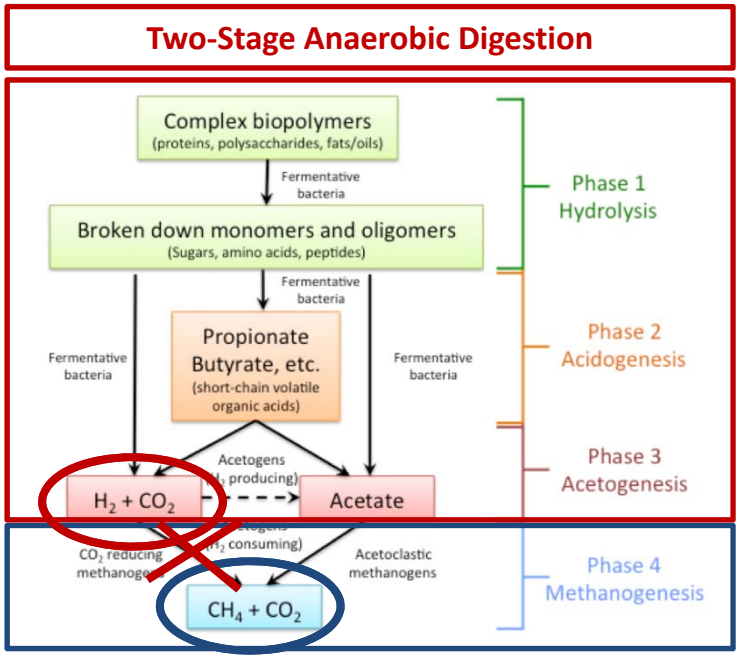


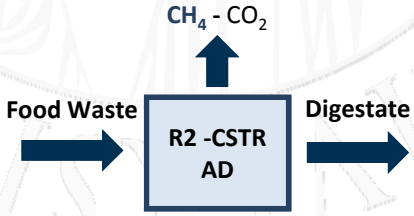
INTRODUCTION

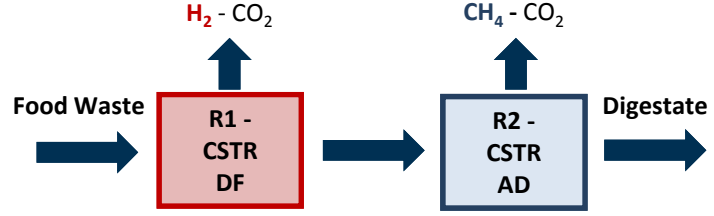
RESEARCH QUESTION:

WHICH PROCESS BETTER VALORISE THE ANAEROBIC DIGESTION OF FOOD WASTE?









MATERIALS AND METHODS

SUBSTRATE AND INITIAL INOCULA

Substrate:

Food waste (FW) is a highly desirable feedstock for anaerobic fermentation due to its **high carbohydrate content**, **biodegradability and availability** (*Cavinato et al., 2012, De Gioannis et al., 2013*).

Food waste was manually sorted from the organic fraction of municipal solid waste collected in a Tuscan municipality (Italy) by means of a kerbside collection system. In order to obtain a slurry with a total solid (TS) content suitable to wet fermentation, the sample was treated in a food processor, sifted with a strainer (3 mm diameter) and mixed with tap water.

Inoculum 1 to start-up – IN1:

Activated sludge collected from the aerobic unit of a municipal wastewater treatment plant was used as inoculum for the fermentative reactor. Activated sludge were **heat treated at 80°C for 30 minutes prior to set-up with the aim of selecting only hydrogen producing bacteria** while inhibiting hydrogenotrophic methanogens (*Alibardi and Cossu, 2015*). Tests were carried out when the inoculum temperature reached mesophilic conditions.

Inoculum 2 to start-up – IN2:

The seed sludge used in the methanogenic reactor was collected from an **anaerobic reactor treating the organic fraction of municipal solid waste (OFMSW)** and cattle manure.

	TS (% w/w)	TVS (% w/w)	pH
IN1	2.1 ± 0.2	1.5 ± 0.1	7.1 ± 0.0
IN2	2.9 ± 0.1	1.8 ± 0.1	8.2 ± 0.1
FW	5.7 ± 0.1	4.3 ± 0.1	3.8 ± 0.0

MATERIALS AND METHODS

ANALYTICAL PARAMETERS

Parameters	Acquisition method	Frequency
pH	Metter Toledo probes (± 0.01)	Continuous
Temperature	Metter Toledo probes (± 0.1°C)	Continuous
Gas production	Volumetric counters (± 0.07 l)	Continuous
Gas storage	10 l Multilayer foil bags	Continuous
Gas quality (H_2, CH_4, N_2, O_2, H_2S, CO_2)	Gas-Chromatography, 3000 Micro GC INFICON	Daily
VFAs	Gas-Chromatography, 7890B Agilent	Daily
TS (substrate and digestates)	APHA, 2006	Daily
TVS (substrate and digestates)	APHA, 2006	Daily
Total Alkalinity	Titration, Martín-González et al., 2013	Daily
Partial Alkalinity (bicarbonate) – 5.75	Titration, Martín-González et al., 2013	Daily
Intermediate Alkalinitiy (VFAs) – 4.3	Titration, Martín-González et al., 2013	Daily

Alkalinity

Reactors

Volumetric counters

VFAs

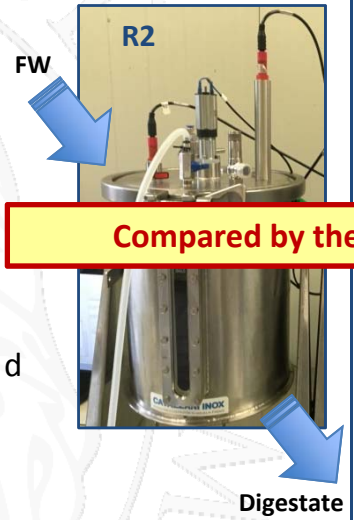
pH and temperature probe

MATERIALS AND METHODS

EXPERIMENTAL SET-UP

Run1 - One-Stage Anaerobic Digestion

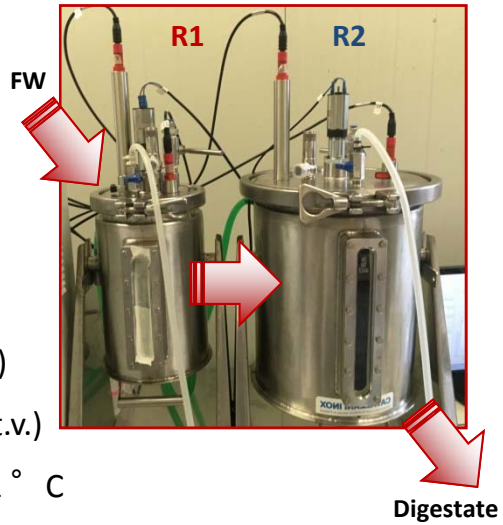
- **Feeding:** daily
- **OLR R2:** 2.5 kgTVS/m^{3}d
- **HRT R2:** 17 d
- **Volume R2:** 12 l (w.v.), 19 l (t.v.)
- **Temperature R2:** 37.0 ± 0.1 ° C
- **Duration:** 42 d (25 d unsteady st., 17 d steady st.);



Compared by the same OLR in R2

Run 2 - Two-Stage Anaerobic Digestion

- **Feeding:** daily
- **OLR R1:** 14.2 kgTVS/m^{3}d
- **OLR R2:** 2.5 kgTVS/m^{3}d
- **HRT R2:** 13 d
- **Volume R1:** 3 l (w.v.), 6 l (t.v.)
- **Volume R2:** 12 l (w.v.), 19 l (t.v.)
- **Temperature R1:** 37.0 ± 0.1 ° C
- **Temperature R2:** 37.0 ± 0.1 ° C
- **Duration:** 26 d (13 d unsteady st., 13 d steady st.);



Temperature was constantly kept at mesophilic conditions by a jacket where warm water heated up by thermostat was continuously recycled.

pH in R1 was **set at 5.5** and controlled through NaOH 2M solution addition. Previous studies found 5.5 to be the optimum pH for hydrogen production (*Chinellato et al., 2013*).

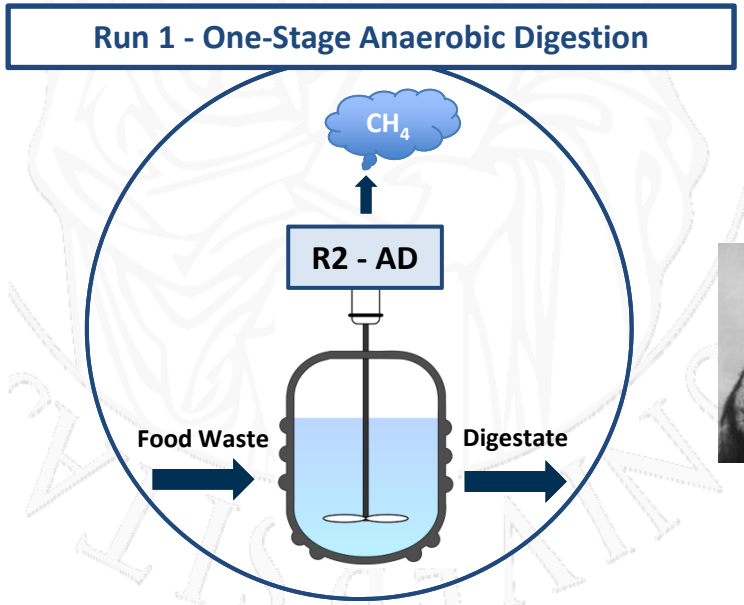
Steady state was performed for one whole HRT when AI/AP ratio was below 0.3 (*Martín-González et al., 2013*).

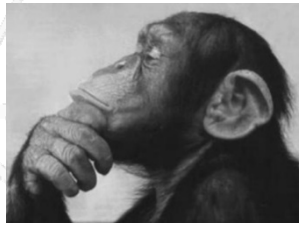
MATERIALS AND METHODS

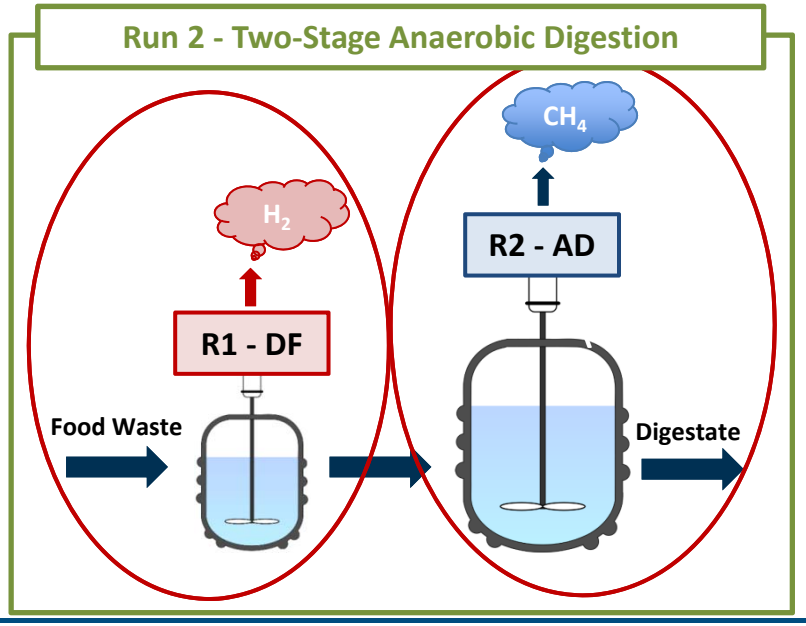
TERMS OF COMPARISON OF THE TWO SCENARIOS

The two steady phases of the two runs were compared by means of:

- ✓ **Volatile solids removal efficiency (%):** $\eta_{TVS} = \frac{TVS_{IN} - TVS_{OUT}}{TVS_{IN}} \times 100$
- ✓ **Specific Gas Production – SGP ($Nl_{biogas}/kgTVS_{IN}$ d)**
- ✓ **Methane and Hydrogen content in biogas (%)**



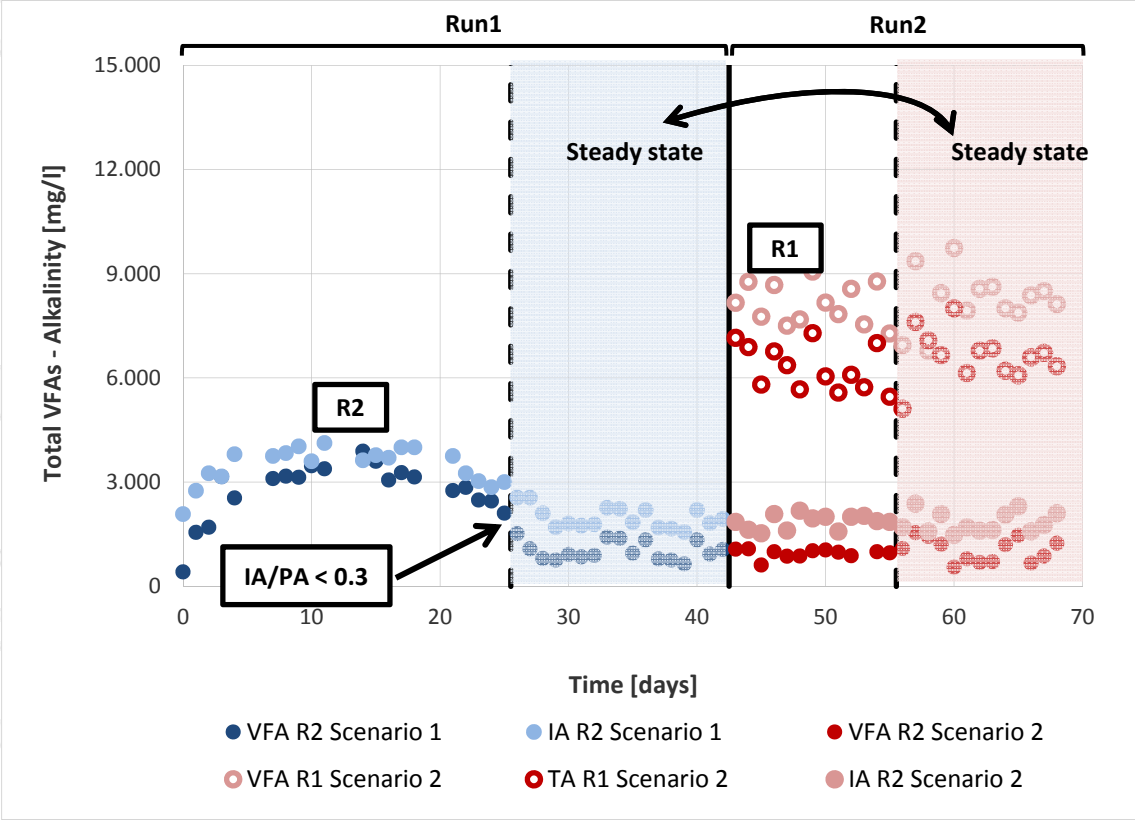




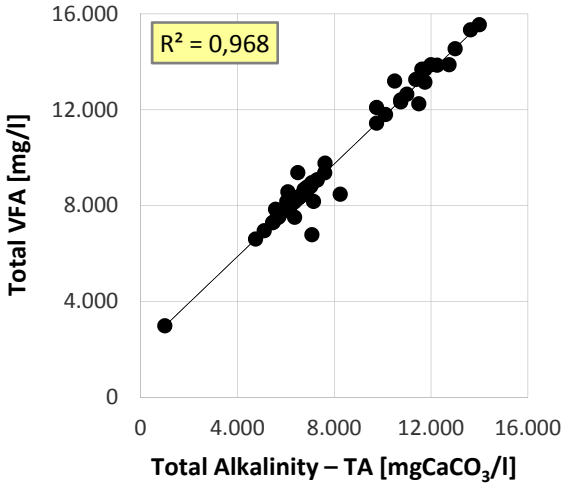
RESULTS

VOLATILE FATTY ACIDS AND ALKALINITY

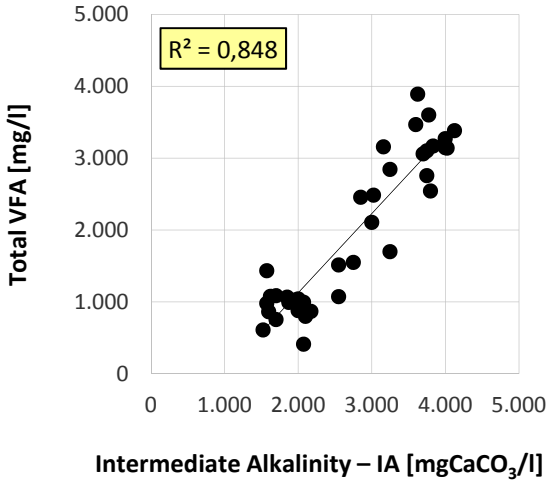
- ✓ Linear relationship **VFA - Total Alkalinity (TA)** in the fermentative reactor (**R1**)
- ✓ Linear relationship **VFA - Intermediate Alkalinity (IA)** in the methanogenic reactor (**R2**)



R1 – Fermentative reactor

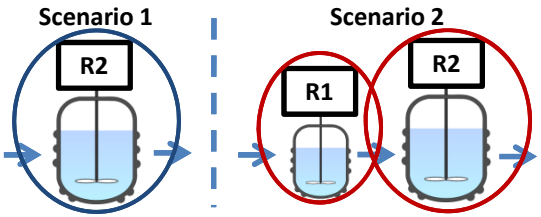


R2 – Methanogenic reactor



RESULTS

VOLATILE FATTY ACIDS

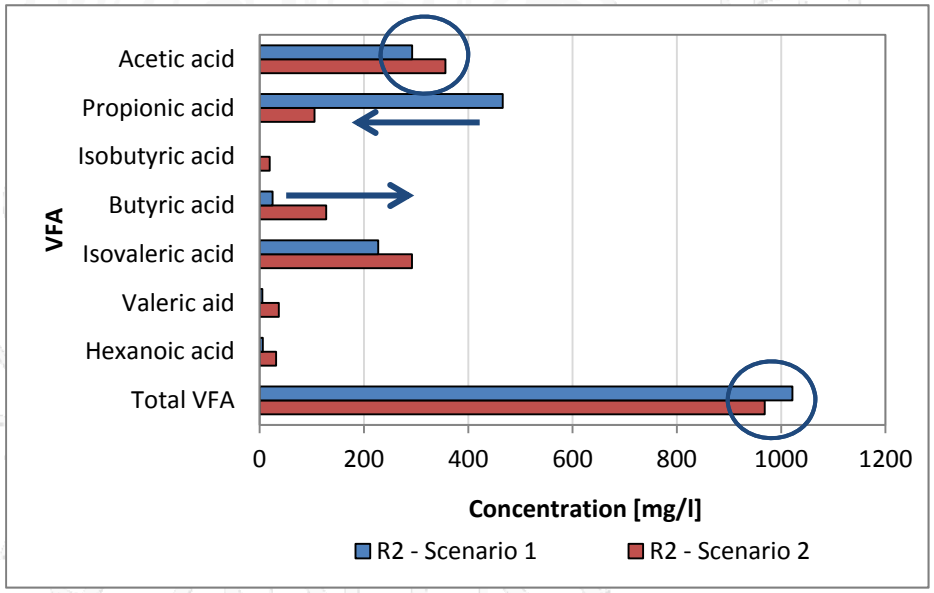


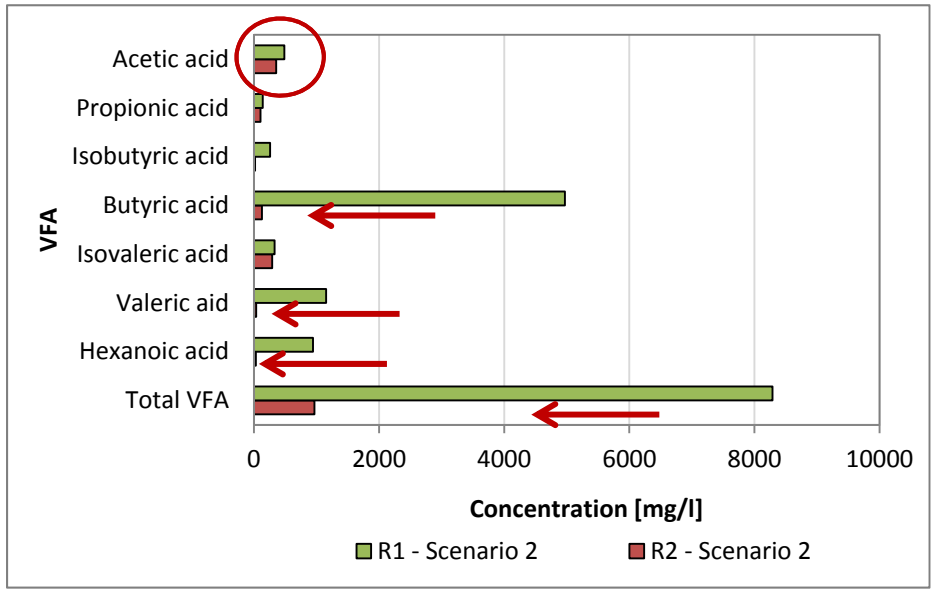
Comparison between VFA in R2 during Scenario 1 and 2:

- ✓ Total VFA concentration was almost steady during Scenario 1 and 2
- ✓ Decrease of propionic acid
- ✓ Increase of acetic and butyric acid

Comparison between VFA in R1 and R2 during Scenario 2:

- ✓ Butyric, valeric and hexanoic acid were degraded in R2;
- ✓ Acetic, propionic and isovaleric acids were almost stable

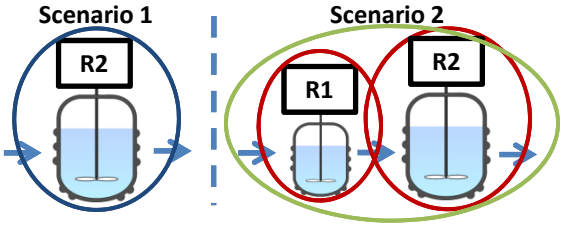


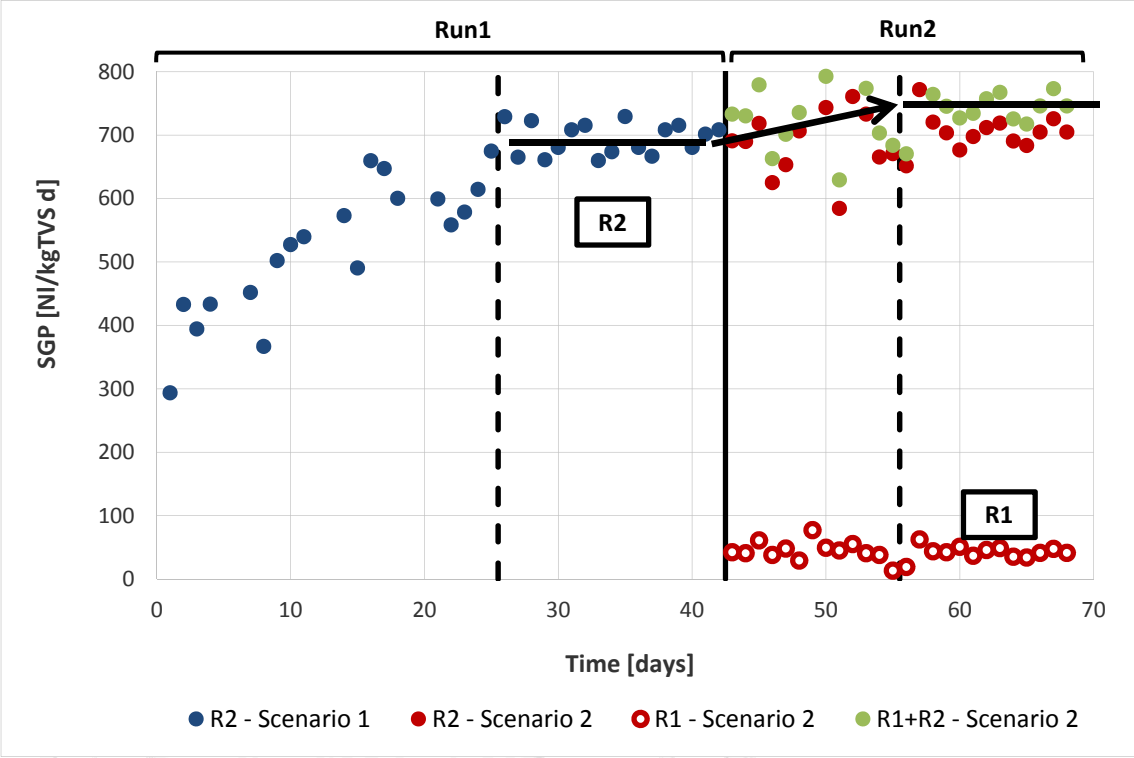


Comparison between mean values

RESULTS

BIOGAS PRODUCTION AND QUALITY





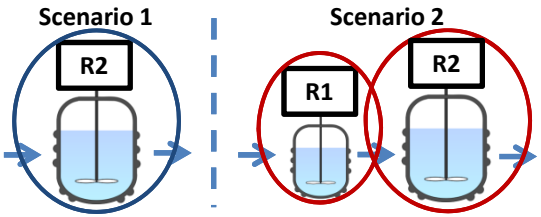
Scenarios	SGP [NL/kgTVS d]	GPR [NL/lr d]
R2 – Scenario 1	694.4 ± 24.6	1.74 ± 0.06
R2 – Scenario 2	704.6 ± 28.5	1.77 ± 0.05
R1 – Scenario 2	43.1 ± 12.8	0.61 ± 0.18
R1 +R2 Scenario 2	747.7 ± 37.4	2.39 ± 0.21

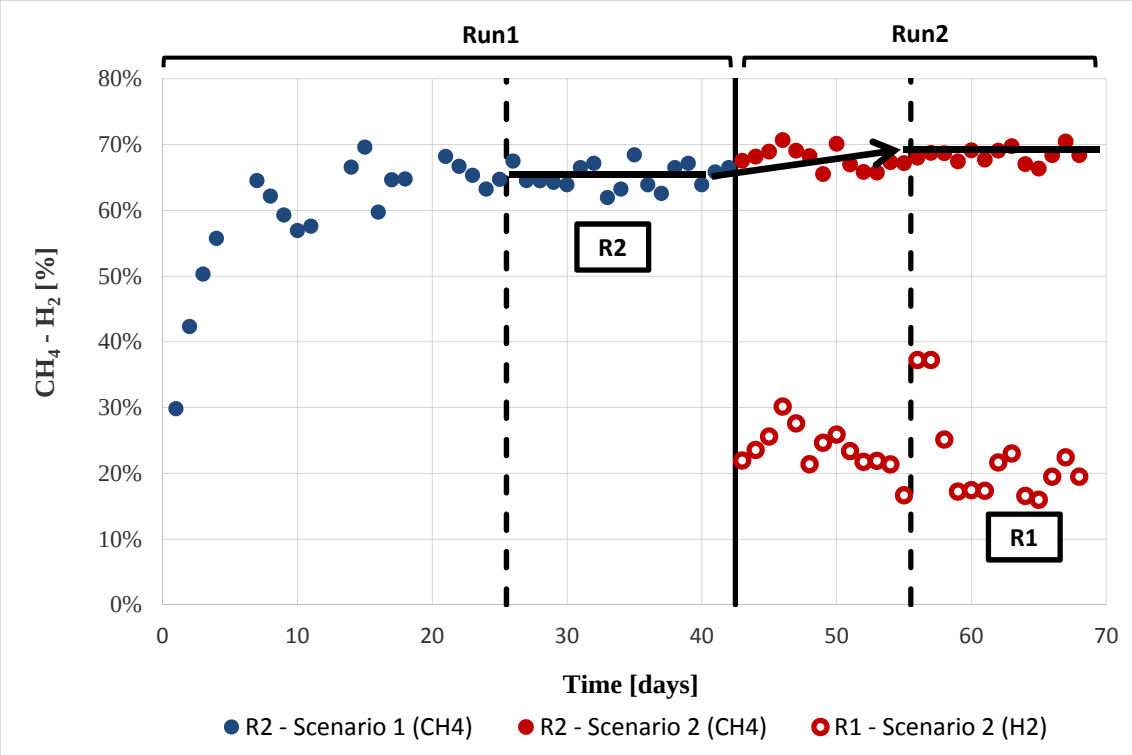
✓ **Scenario 2:** increase in biogas production

SGP = + 7.7%

RESULTS

BIOGAS PRODUCTION AND QUALITY



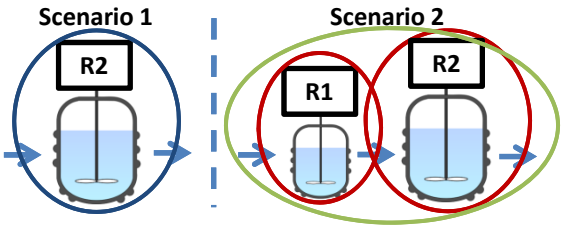


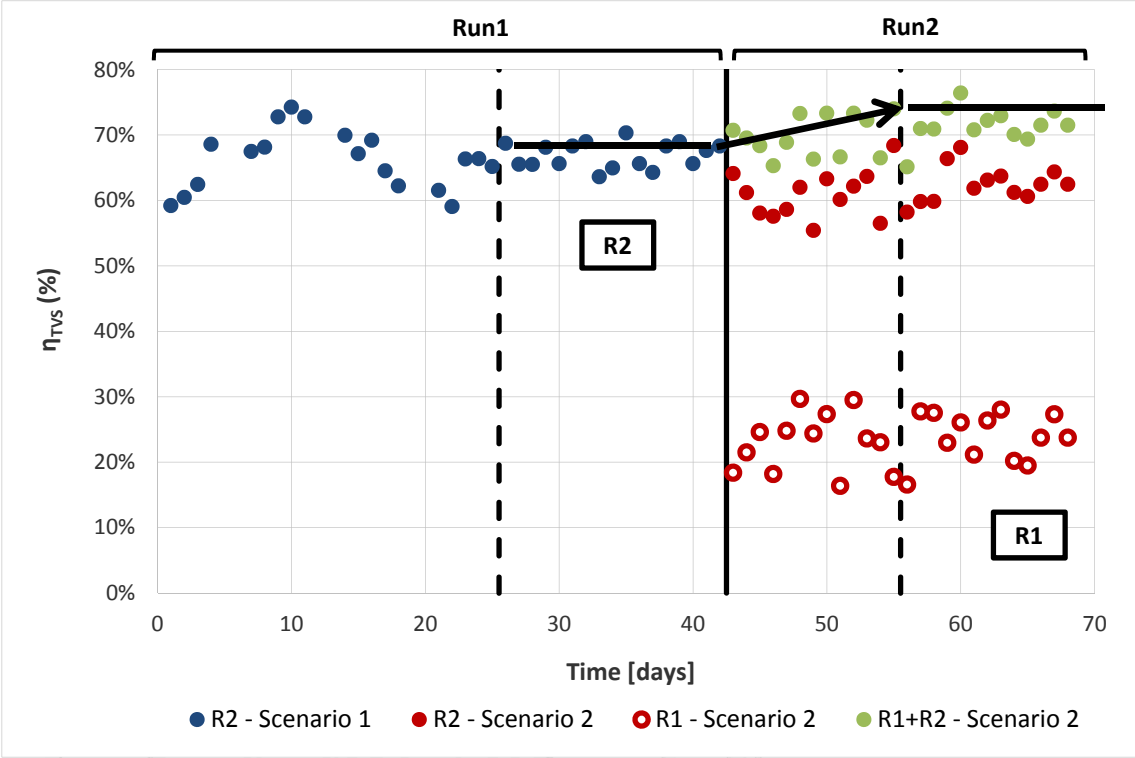
Scenarios	H_2 [%]	CH_4[%]
R2 – Scenario 1	-	65.2 ± 1.9
R2 – Scenario 2	-	68.4 ± 1.1
R1 – Scenario 2	22.9 ± 5.5	-

- ✓ **Scenario 2:** increase in methane content — **CH_4 = + 3.2%**
- ✓ **Scenario 2:** hydrogen rich biogas in R1 — **H_2 = 22.9%**

RESULTS

VOLATILE SOLIDS REMOVAL EFFICIENCY





Scenarios	η_{TVS} [%]
R2 – Scenario 1	67.0 ± 2.0
R2 – Scenario 2	23.5 ± 4.0
R1 – Scenario 2	62.5 ± 2.7
R1+R2 – Scenario 2	71.5 ± 2.7

✓ **Scenario 2:** increase in volatile solids removal

η_{TVS} = + 6.8%

CONCLUSIONS

COMPARISON BETWEEN ONE-STAGE AND TWO-STAGE ANAEROBIC PROCESSES

- ✓ Higher biogas production
- ✓ Higher methane content in the methanogenic reactor and a hydrogen rich biogas in the fermentative one
- ✓ Higher volatile solids degradation

RESEARCH QUESTION:

WHICH PROCESS BETTER VALORISE THE ANAEROBIC DIGESTION OF FOOD WASTE?

These first results allow to conclude that:

The Two-stage process is a valuable system to valorise food waste

Further analysis carried out with other OLR and HRT will be performed in order to confirm these preliminar findings and to evaluate better process conditions.

Thanks for your attention!

COMPARISON OF ONE-STAGE AND TWO-STAGE FERMENTATION PROCESS OF FOOD WASTE

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