PhD course in «Chemical and energetic technologies»

XXVI cycle

UNIVERSITÀ DEGLI STUDI DI UDINE

Energetic conversion of organic fraction of municipal solid waste by anaerobic codigestion with sewage sludge

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Introduction:

The Anaerobic Digestion (AD) process

The AD process - microbiology

Organic Macro molecules

Anaerobic biomass

Hydrolysis ⇩

Soluble monomers

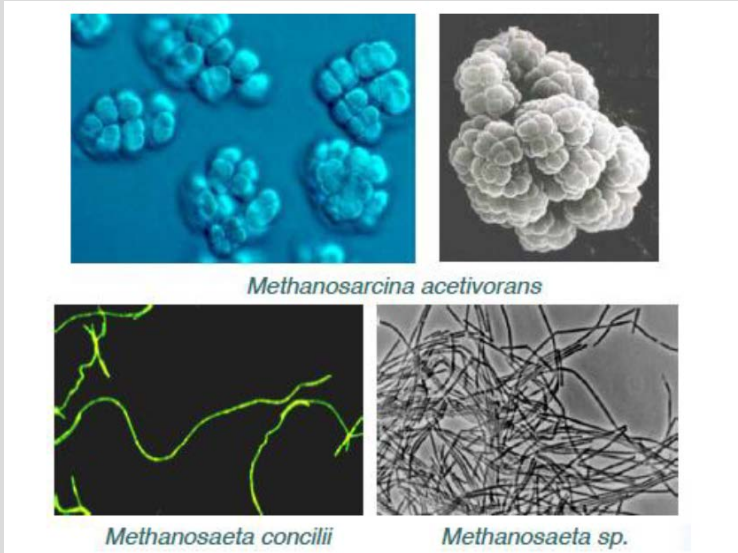
Acidogenesis ⇩

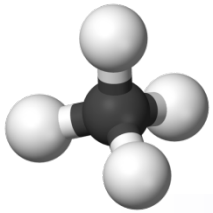
Organic Acids

Acetogenesis ⇗⇘

Acetic Acid | H_2, CO_2

Mhetanogenesis ⇩ ⇩



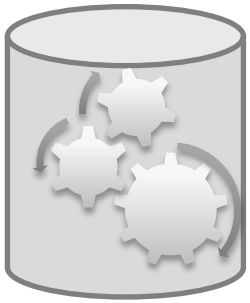


BIOGAS ➡

Methane	**55-65%**
CO_2	35-45%

The sewage sludge AD in WWTP

SEWAGE SLUDGE



BIOGAS

DIGESTATE

Process aims:

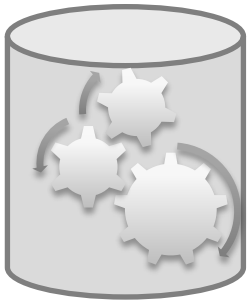
- **Substrate stabilization**
- **COD reduction**
- **Odour control**

Liquid fraction: to WWTP

Solid fraction

The AD as renewable energy source

ORGANIC SUBSTRATES



BIOGAS 1. CHP

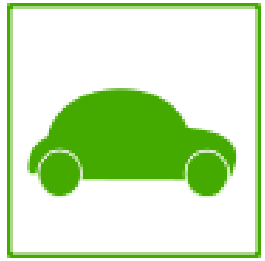
DIGESTATE 2.

Process aims:

- **Substrate stabilization**
- **COD reduction**
- **Odour control**
- **Energy recovery**

Liquid fraction: to WWTP

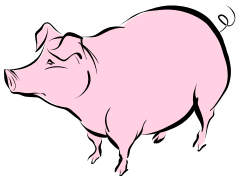
Solid fraction: to agriculture 3.



Available substrates to AD process

Typical organic substrates:

- Sewage sludge
- Manure



New organic substrates:

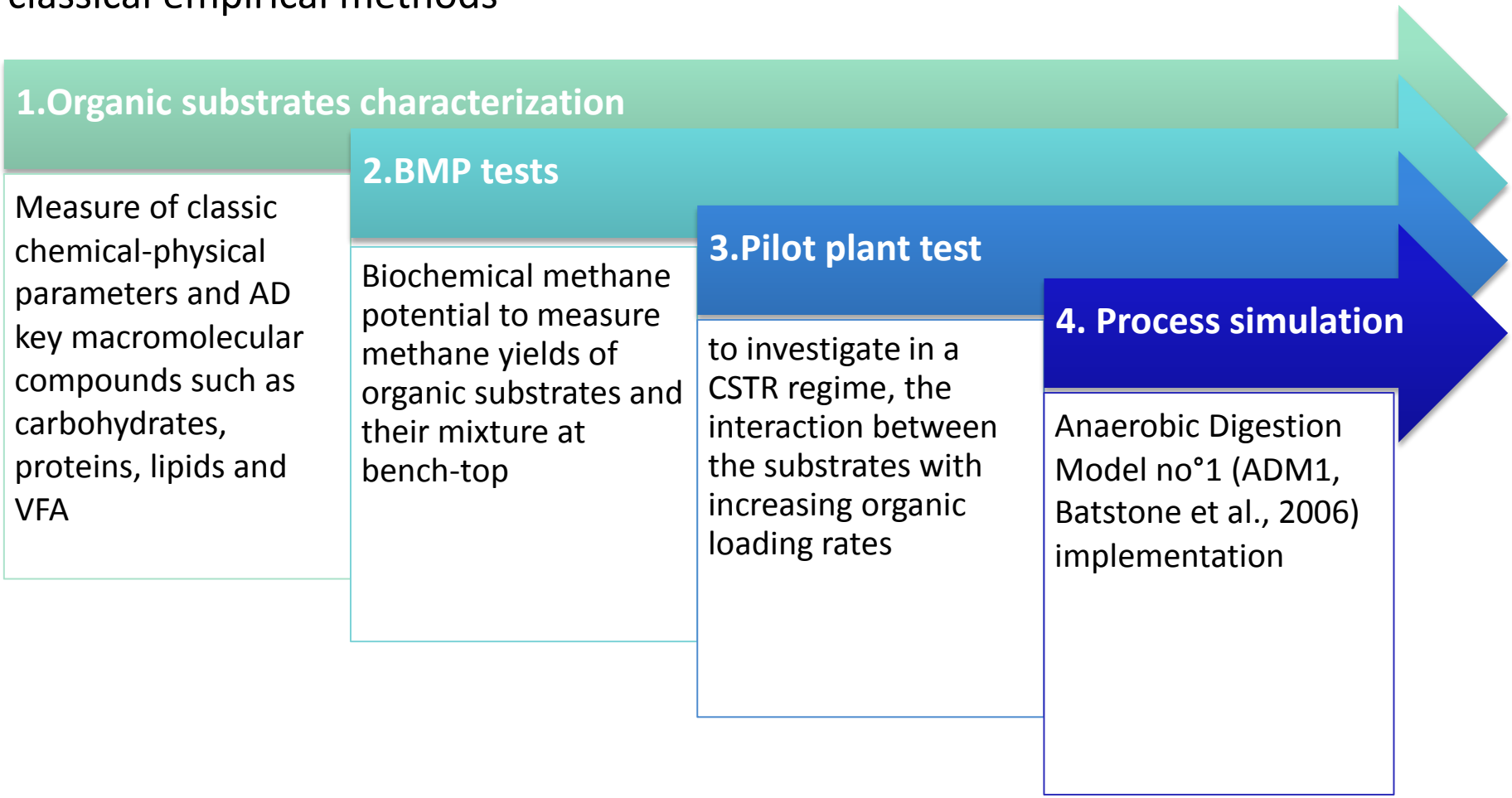
- Industrial wastewater
- Organic waste from industrial process
- Organic waste from agricultural production
- **Organic fraction of municipal solid waste (OFMSW)**
- Energy crops

Anaerobic Codigestion (AcoD): treatment of different organic substrates simultaneously

The PhD research project

The PhD research project

A new approach to optimize the anaerobic digesters up-grade by the design of an innovative protocol, based on biochemical process equations rather than on classical empirical methods



Udine WWTP

AMGA(CAFC)

The AD unit inside AMGA (CAFC) WWTP

WASTEWATER LINE

PRIMARY CLARIFIER

AS REACTORS

SECONDARY CLARIFIER

SEWAGE SLUDGE

SEWAGE SLUDGE LINE

MESOPHILIC AD UNIT

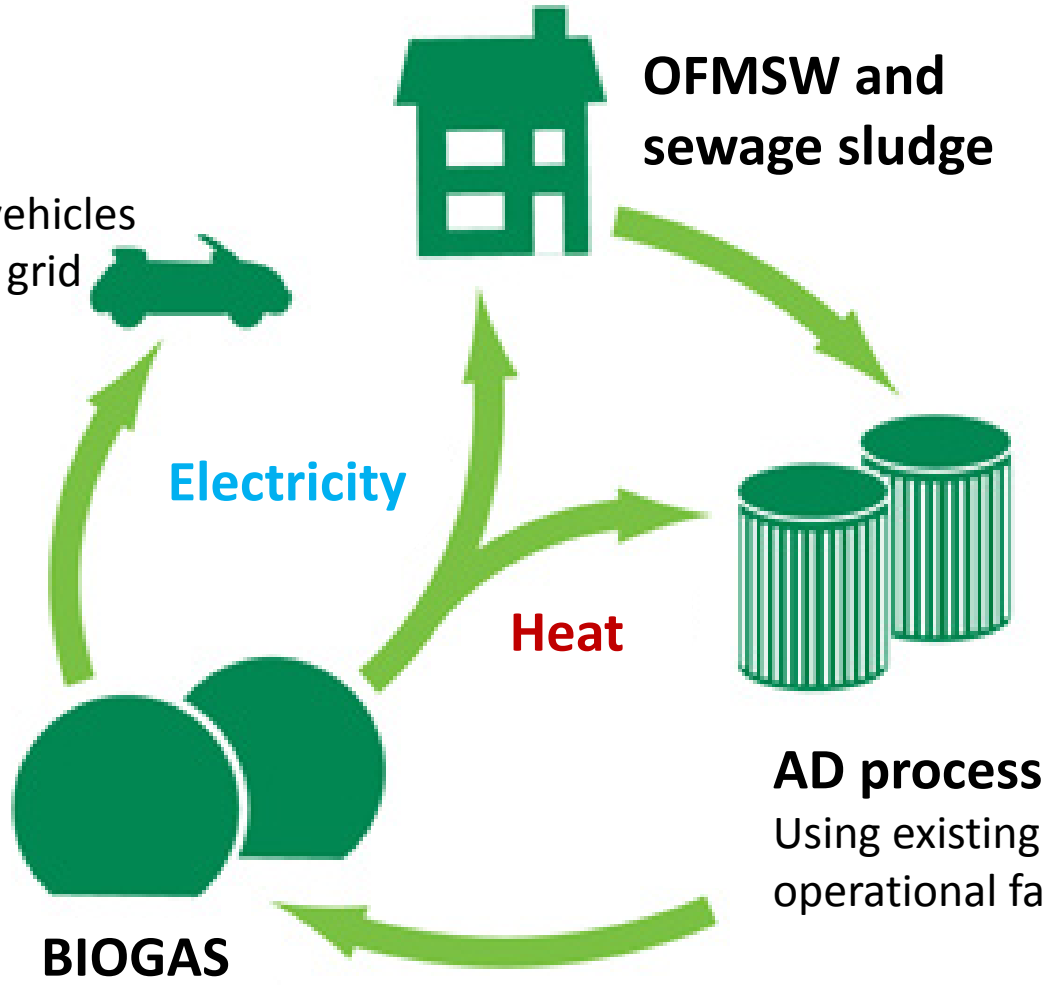
THICKENER

Spare treatment capacity

The AcoD solution

Synergy between WWTP and the organic waste treatment

Biomethane
Fueling stations for vehicles
or connection to gas grid



AD process inside WWTP
Using existing reactors and
operational facilities

The PhD research project

Phase 1

1.Organic substrates characterization

Measure of classic chemical-physical parameters and AD key macromolecular compounds such as carbohydrates, proteins, lipids and VFA

2.BMP tests

Biochemical methane potential to measure methane yields of organic substrates and their mixture at bench-top

3.Pilot plant test

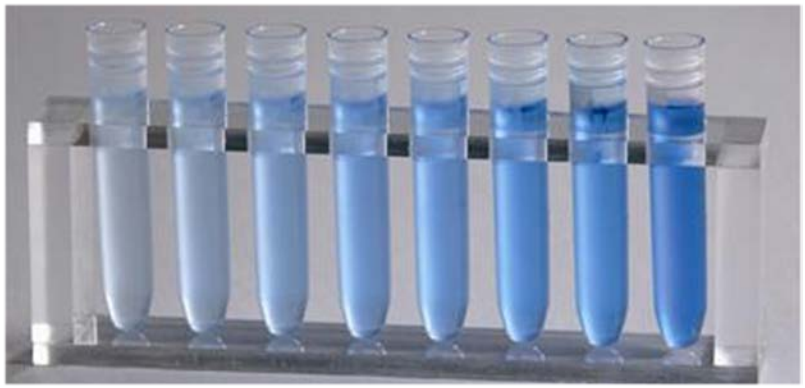
to investigate in a CSTR regime, the interaction between the substrates with increasing organic loading rates

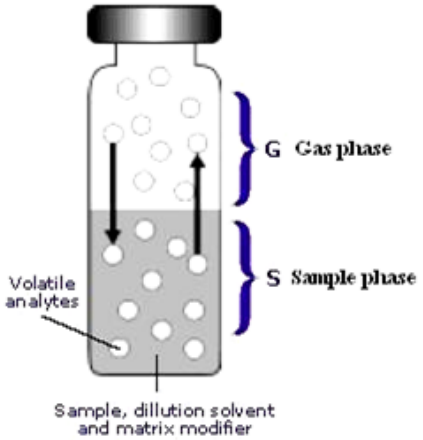
4. Process simulation

Anaerobic Digestion Model no°1 (ADM1, Batstone et al., 2006) implementation

Key AD parameters analysis

- TS,VS, COD_{TOT}, $COD_{S,}$ TKN, NH_4^+, pH, ALK
- Carbohydrates (Dubois's method)
- Proteins
- Lipids (gravimetric analysis)
- VFA (GC-MS)





Organic substrates characterization

1 ➢ Sewage sludge from thickener

AD unit monitorig

Sewage sludge

↓

Chemical-physical analysis

↓

Macromolecular compounds analysis

Digestate

↓

Chemical-physical analysis

Biogas

↓

Biogas production and methane concentration

Source selected OFMSW samples

- Source selected OFMSW (SS-OFMSW): selection criterion was fixed to conciliate minor distance to WWTP and higher quality waste, to avoid AD unit maintenance problems and to obtain the maximum biogas production.

Substrates pre-treatment

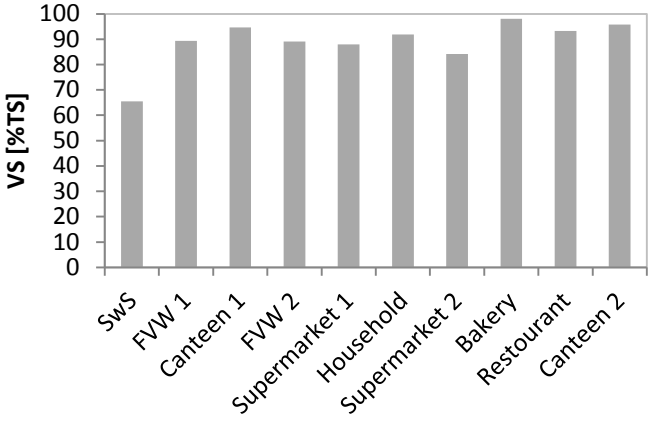
Grinding

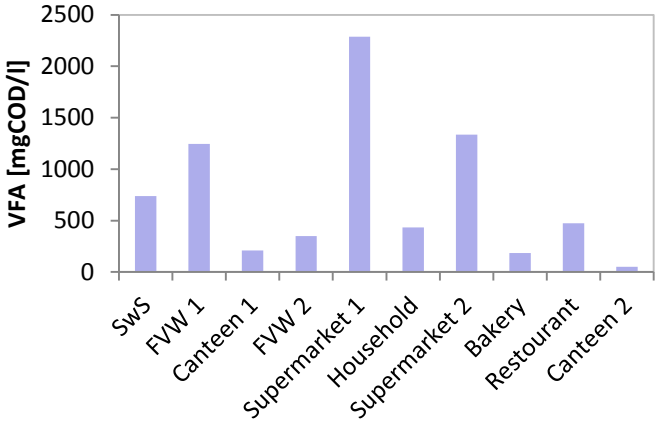
Dilution 5%TS

Shredding

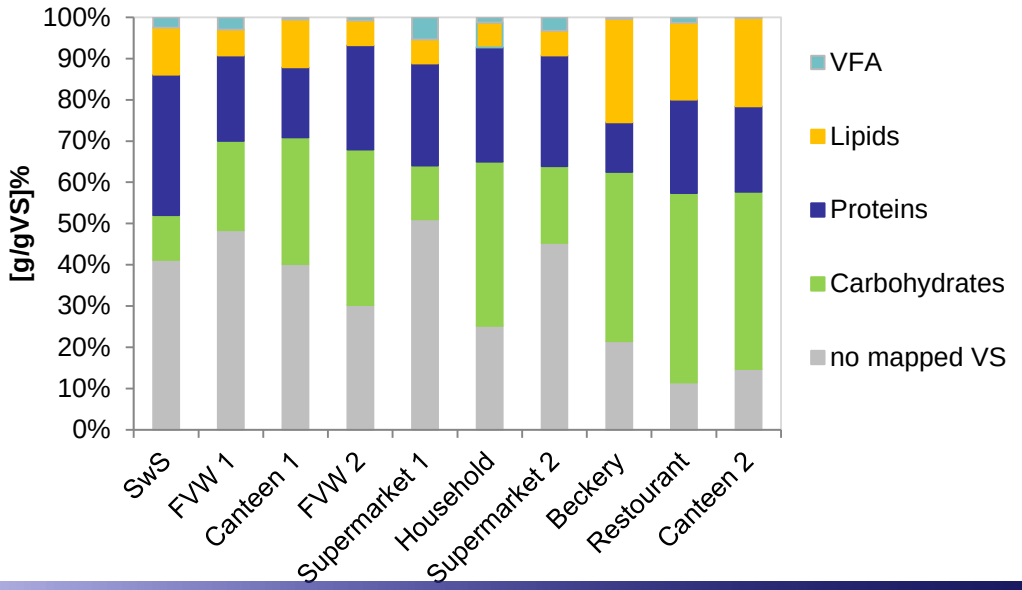
Characterization results

Substrates sampled:
SwS
Fruit&vegetable wastes (FVW1)
Canteen1
Fruit&vegetable wastes (FVW2)
Supermarket1
Household
Supermarket2
Bakery
Restourant
Canteen2





VS mapping



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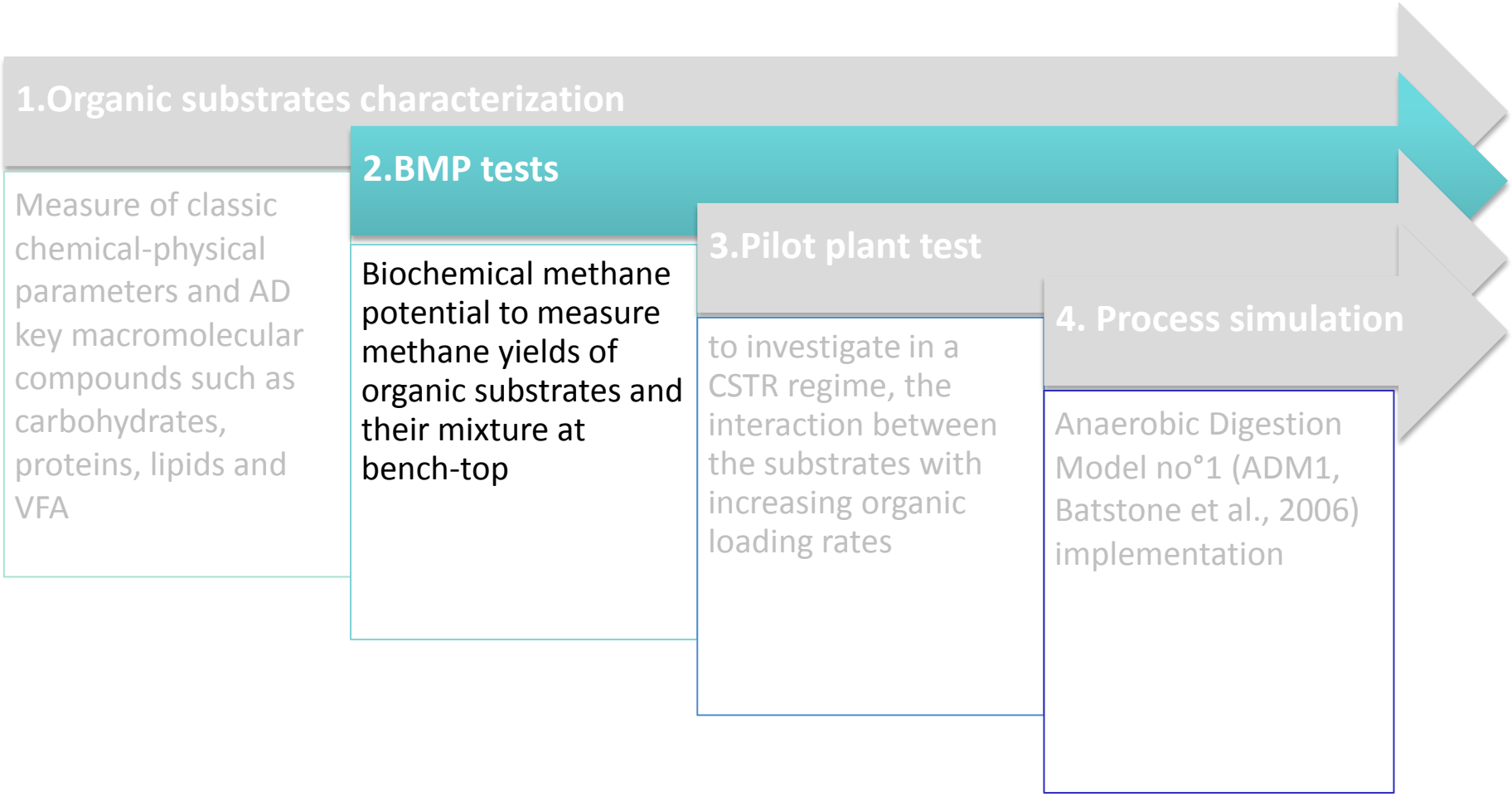


BMP tests

2

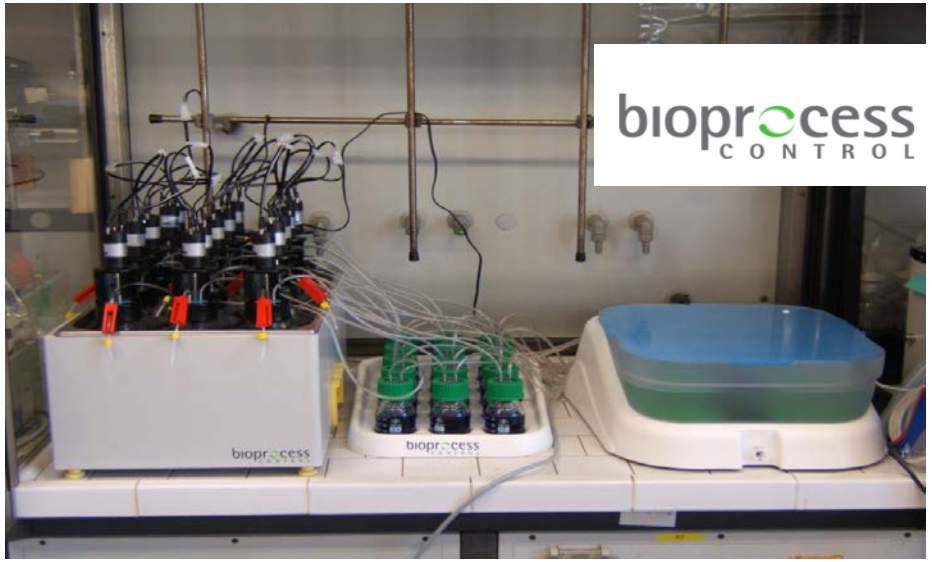
BMP tests are influenced by:

- inoculum characteristics (source, storage, activity);
- the gas measurement system (volumetric or manometric methods);
- the operational conditions (reactor volume, temperature, mixing system, trial duration);
- the chemical operational conditions (headspace gas, pH and alkalinity adjustment, mineral medium)
- the **inoculum to substrate ratio (ISR)**

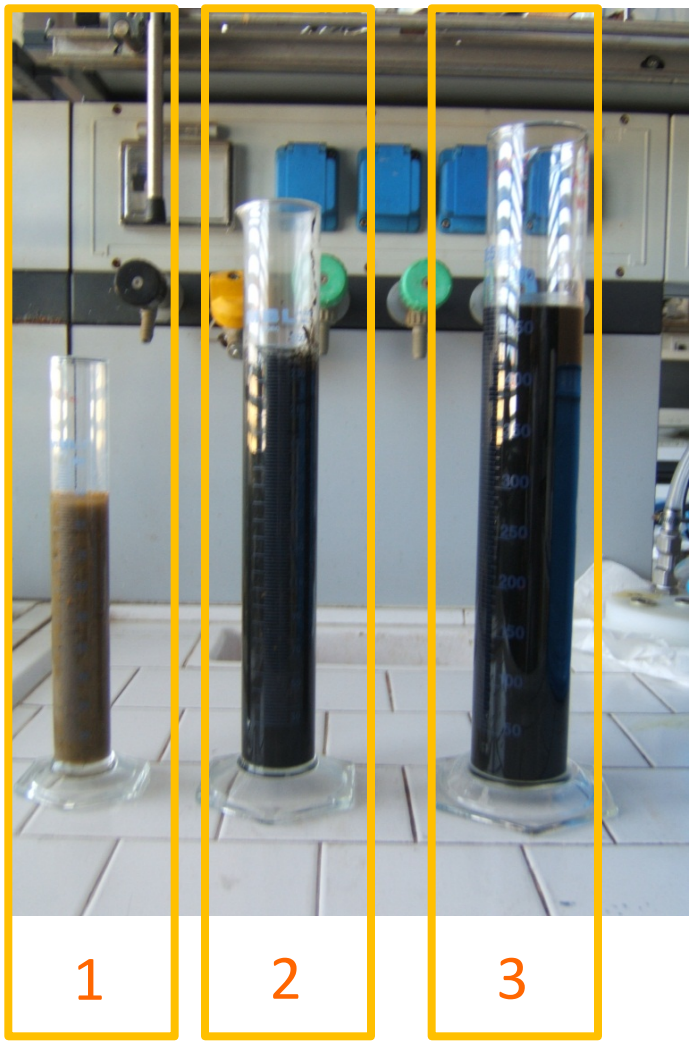
BMP tests performed on:

- Sewage sludge at different ISR;
- SS-OFMSW (gVS/gVS);
- Sewage sludge and SS-OFMSW mix in codigestion regime.

BMP tests were carried out in triplicate.



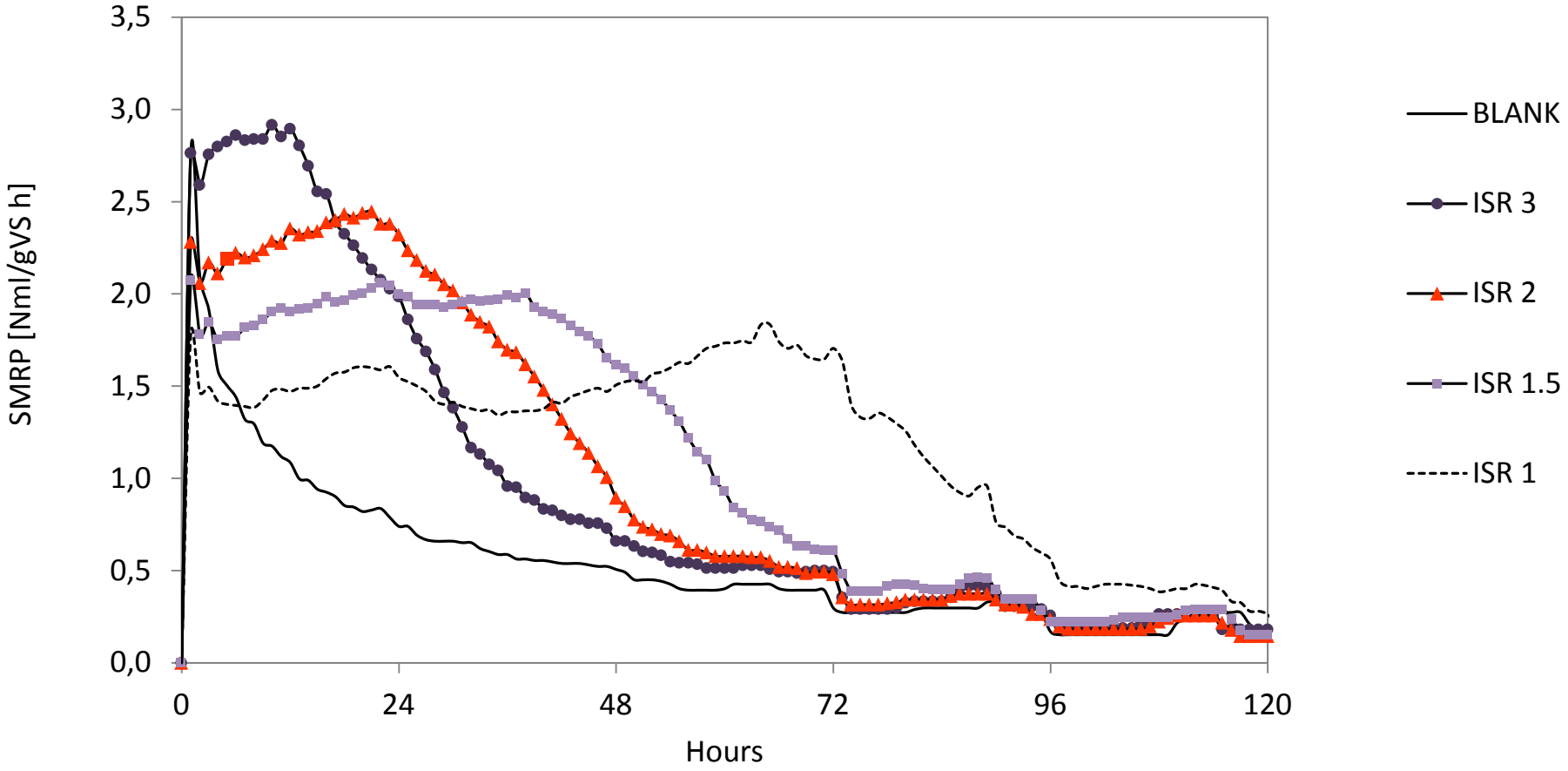
BMP tests



1. SS-OFMSW at 5%TS
2. Sewage sludge
3. Inocula

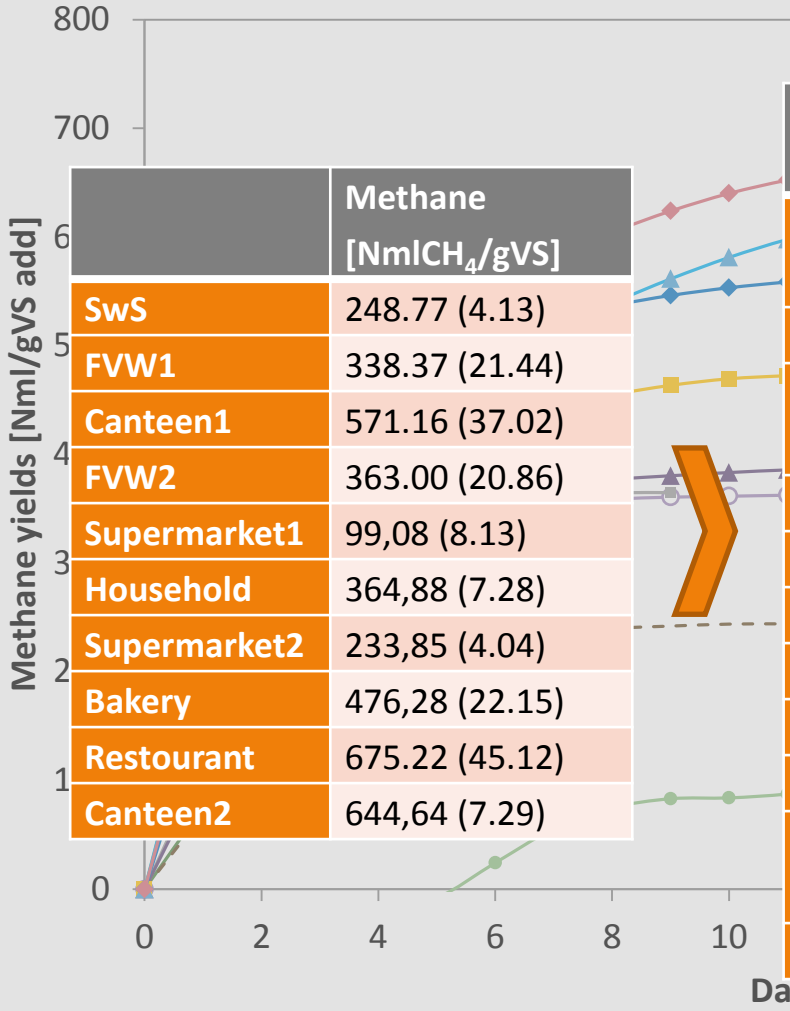
BMP tests results

Specific Methane Rate Production (SMRP) of SwS at different ISR



BMP tests results

BMP of mono-substrates

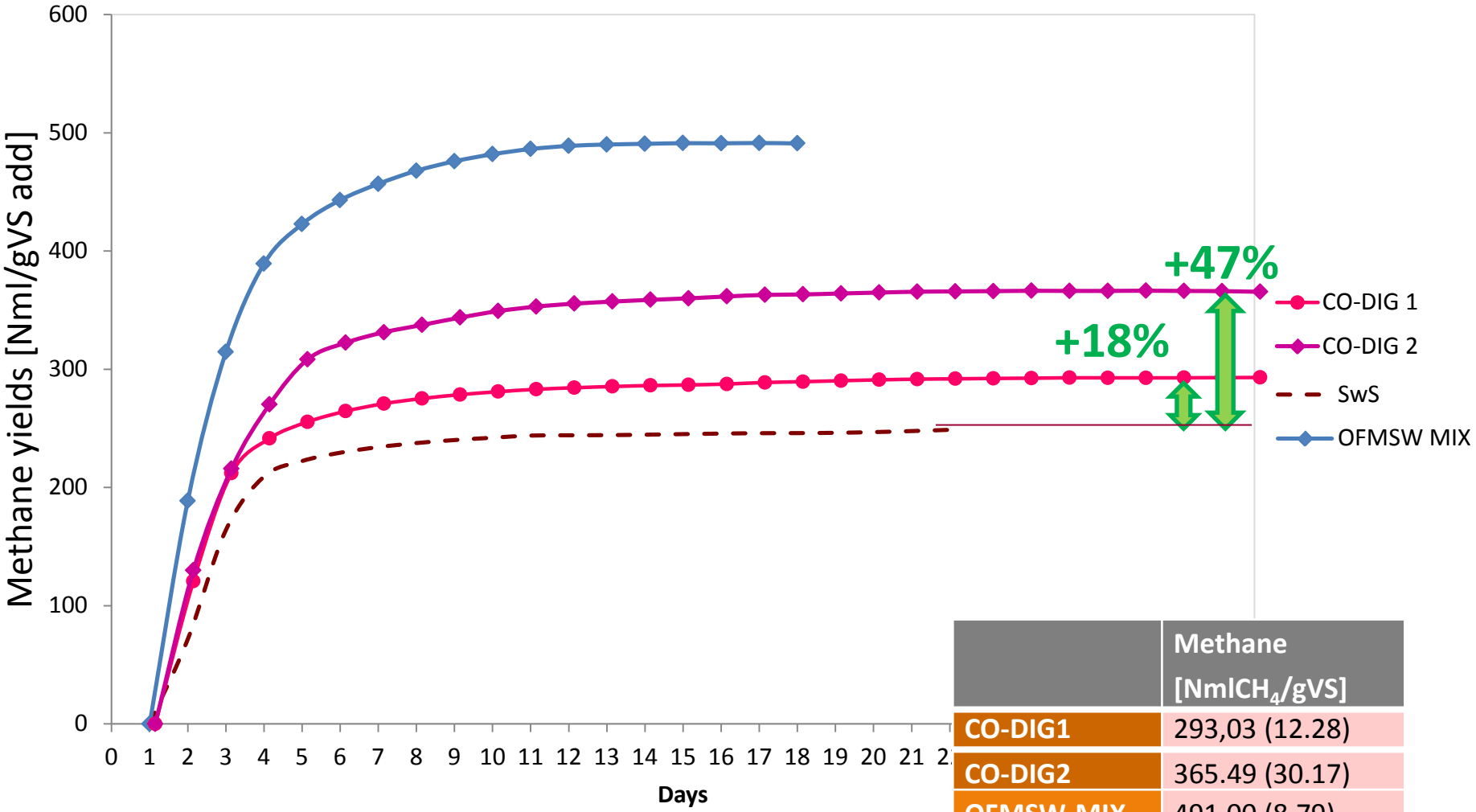


	Methane [$NmlCH_4/gVS$]
SwS	248.77 (4.13)
FVW1	338.37 (21.44)
Canteen1	571.16 (37.02)
FVW2	363.00 (20.86)
Supermarket1	99,08 (8.13)
Household	364,88 (7.28)
Supermarket2	233,85 (4.04)
Bakery	476,28 (22.15)
Restourant	675.22 (45.12)
Canteen2	644,64 (7.29)

Organic substrates	BMP [$mlCH_4/VS$ add]	References
Household waste	456	Zhang et al. 2012
	472	Cho et al., 1995
Restaurant waste	430	Liu et al., 2009
	390	Neves et al.2008
FVW	352	Jiang et al. 2012
OFMSW	382	Ponsa et al. 2011
	300-570	Davidsson et al. 2007
	353	El-Mashad and Zhang, 2010
	186-222	Owens and Chynowet., 1993
	360	Shanmugam and Horan, 2009
	525	Lissens et al., 2004

BMP tests results

BMP of mixed substrates in AcoD regime



	Methane [NmlCH$_4$/gVS]
CO-DIG1	293,03 (12.28)
CO-DIG2	365.49 (30.17)
OFMSW-MIX	491,00 (8.79)

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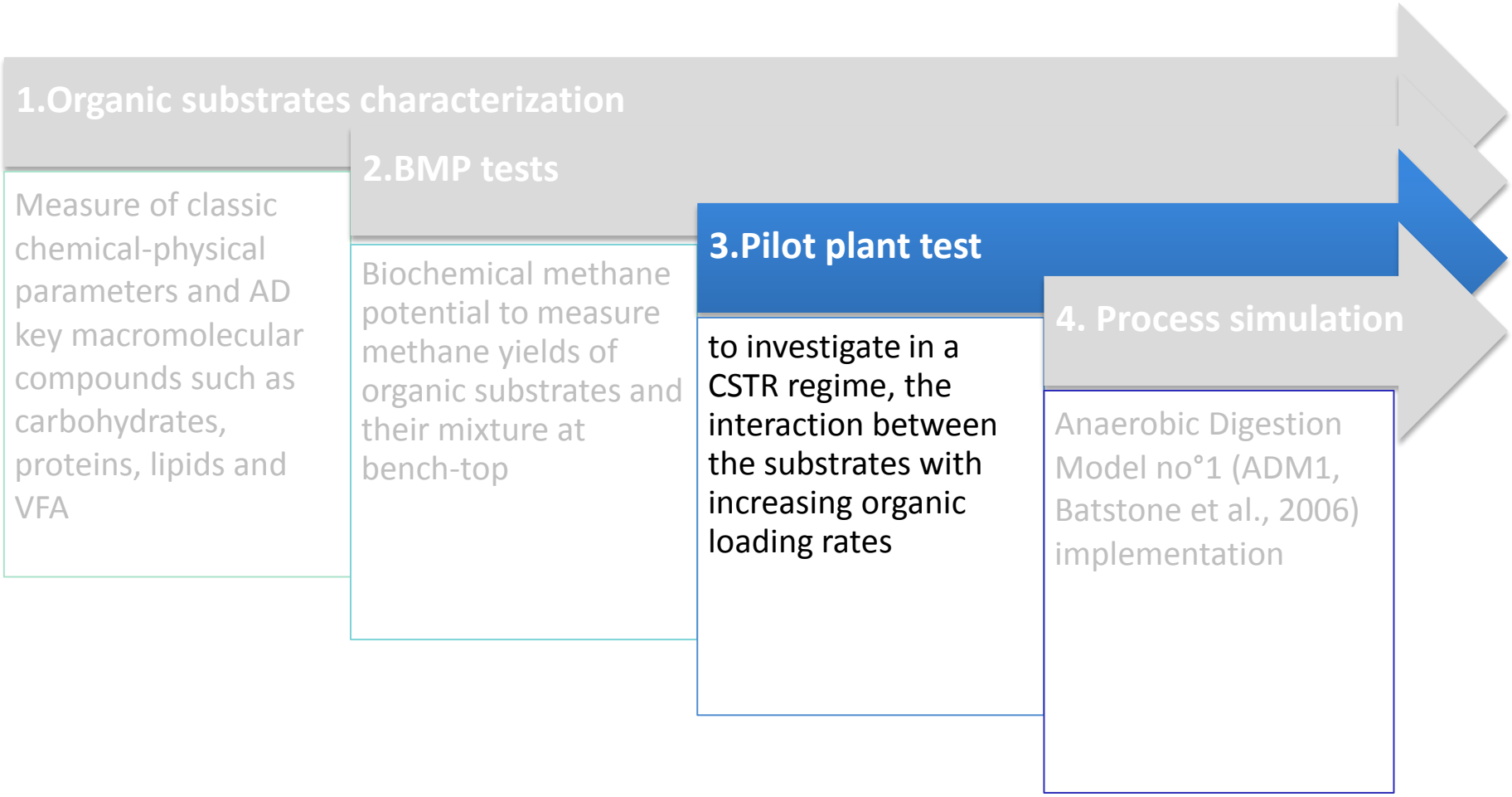
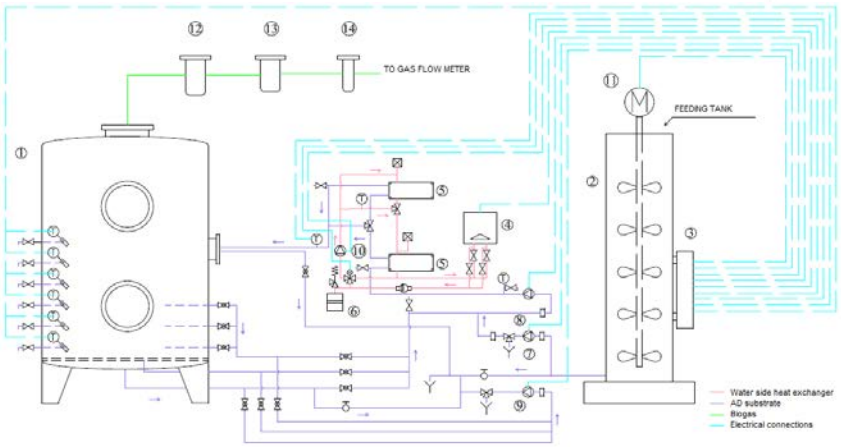
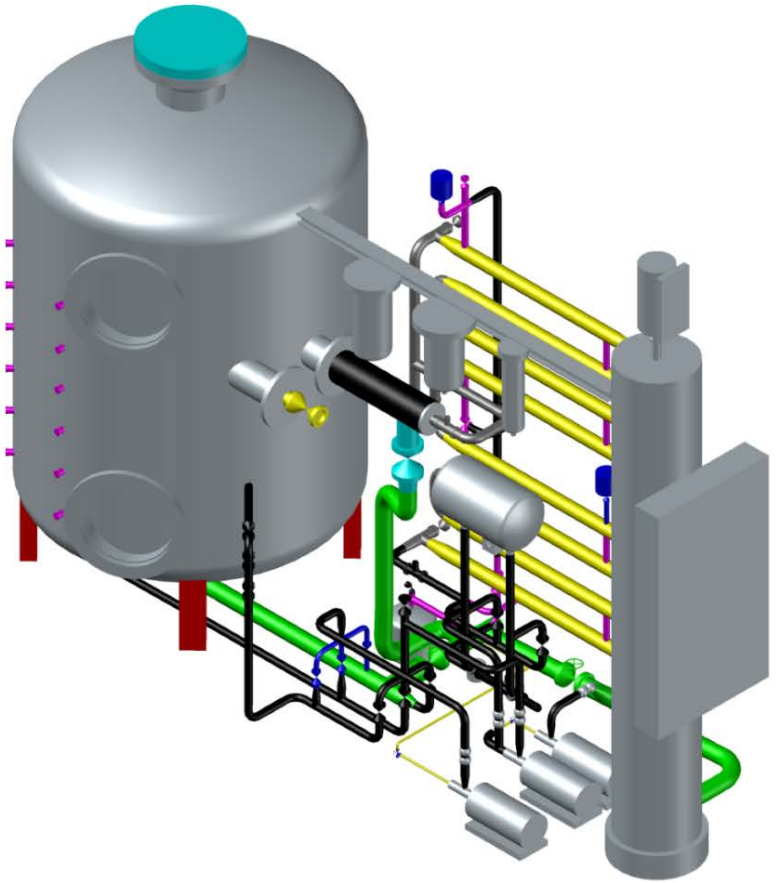


3 *Design and building of the pilot plant of 2.3 m^3*

The pilot plant is designed to implement the AD process in a 1:1000 scale respect the AD existing unit in Udine WWTP. The pilot plant is formed by 3 sections:

- Substrates pre-treatment;
- AD unit;
- Biogas line.





Pilot plant configuration

Substrates pre-treatment

Biogas line

AD reactor

Feeding tank

Experimental procedure

SUBSTRATES:

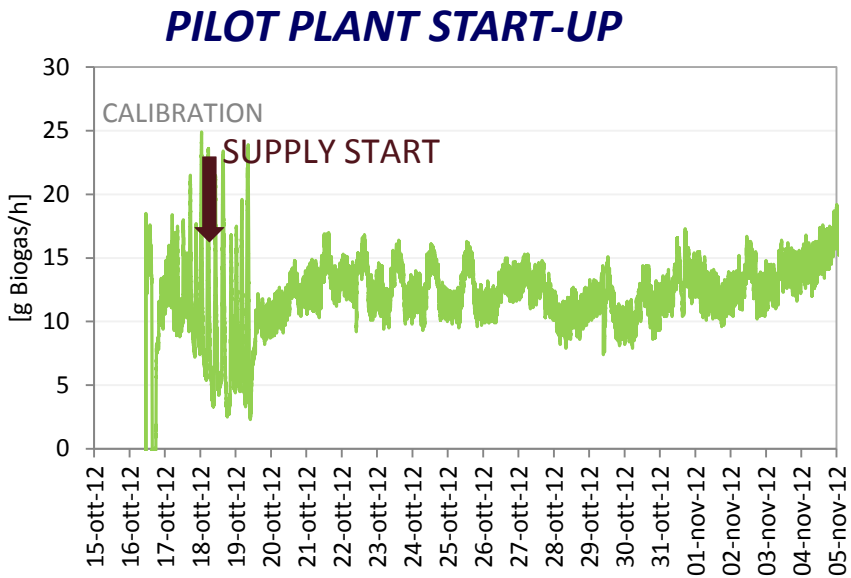
- SS-OFMSW: **canteen** and in a **friut and vegetable market wastes;**
- SwS: was drown by the Udine WWTP thickener;
- Inoculum: used for the start-up, was from the full-scale mesophilic AD unit digestate of Udine WWTP.
- Treated wastewater to dilute substrate mixture.

The experiment was conducted through six different stages with an increasing organic load.

- ***Pilot plant start-up***: pilot plant digester was inoculated with 1.8m^3 of biomass.

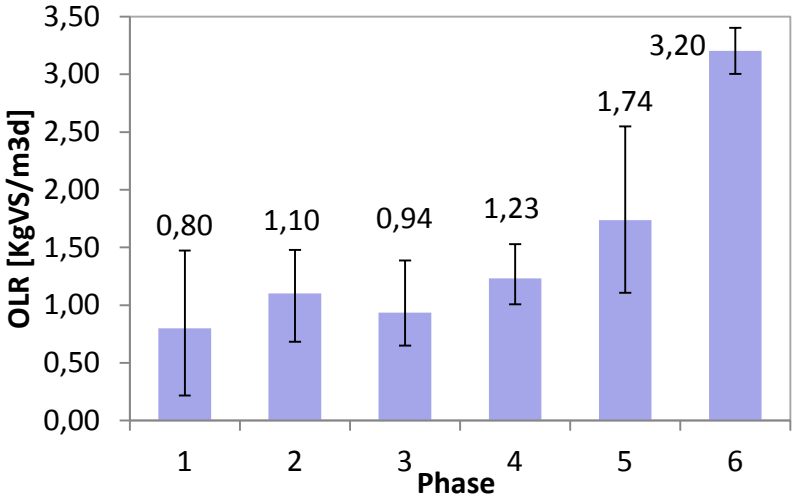
- ***Phase 1***: sewage sludge digestion HRT=24.3d;

- ***Phase 2 to 6***: AcoD of sewage sludge and SS-OFMSW increasing OLR and decreasing HRT to 20 days.



Experimental procedure

- OLR ramp



Substrates percentages (weight based) in the feed during the experimental phases.

Phase	1	2	3	4	5	6
SwS	100%	90,9%	90,9%	66,7%	66,7%	41,3%
SS-OFMSW	-	1,5%	3,0%	11,1%	16,7%	29,3%
Treated wastewater	-	7,6%	6,1%	22,2%	16,6%	29,4%

- Parameters monitoring

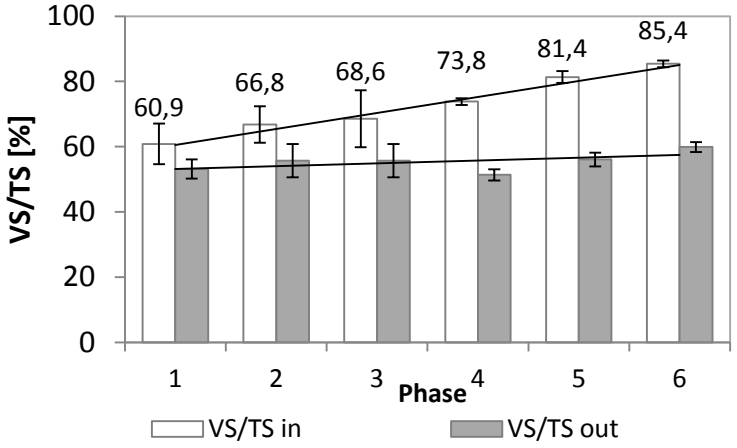
The experimental pilot plant test was characterized by intensive parameters monitoring in order to control the process and establish its efficiency.

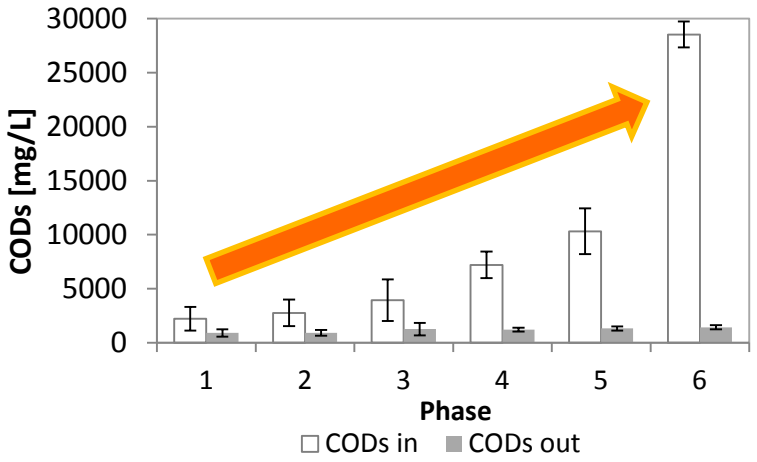
Chemical-physical parameters analysed in each sample point.

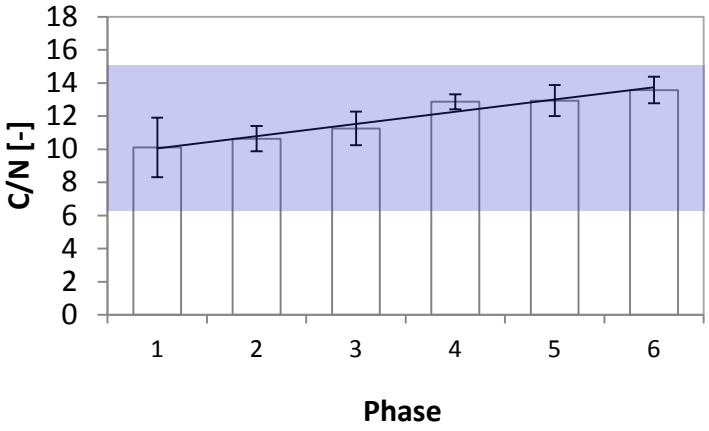
Sample point	Feeding tank	AD reactor	Discharging pump
Parameters	pH	pH	pH
	TS,VS	Alkalinity	TS,VS
	Soluble COD	FOS/TAC	Soluble COD
	TKN	VFA	TKN
	Ammonia		Ammonia
	Sulphates		Sulphates
	Phosphorus		Phosphorus
	C,N		Heavy metals

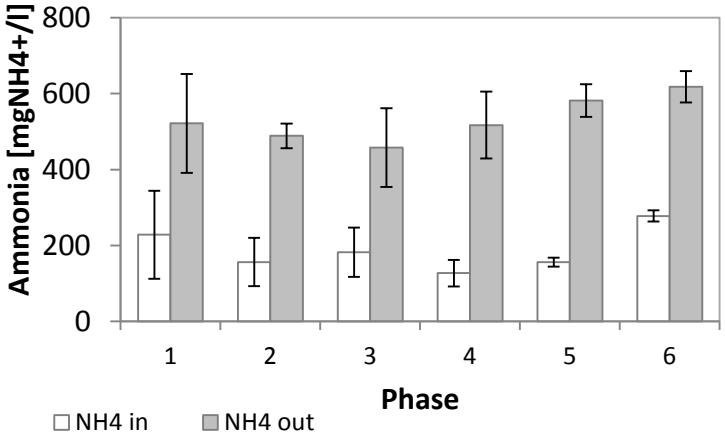
Pilot plant results

Parameters for substrates characterization



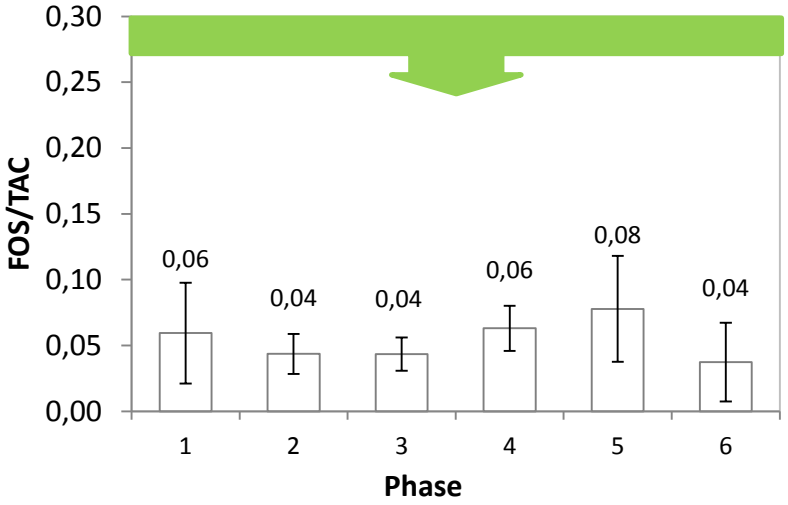


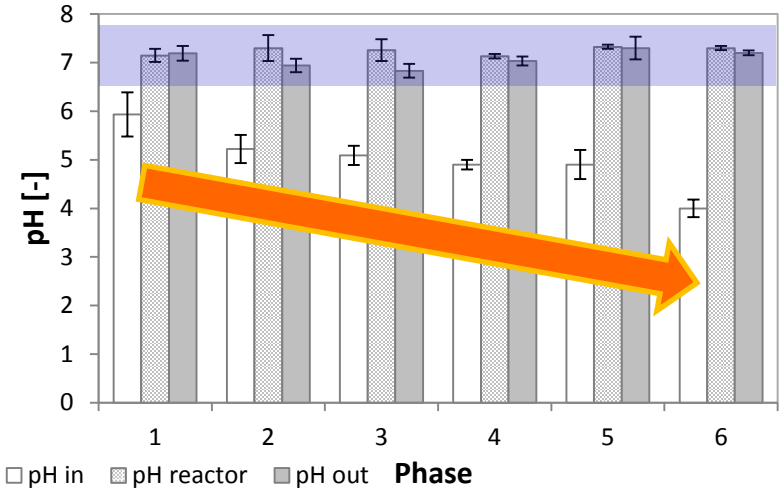




Pilot plant results

Control parameters

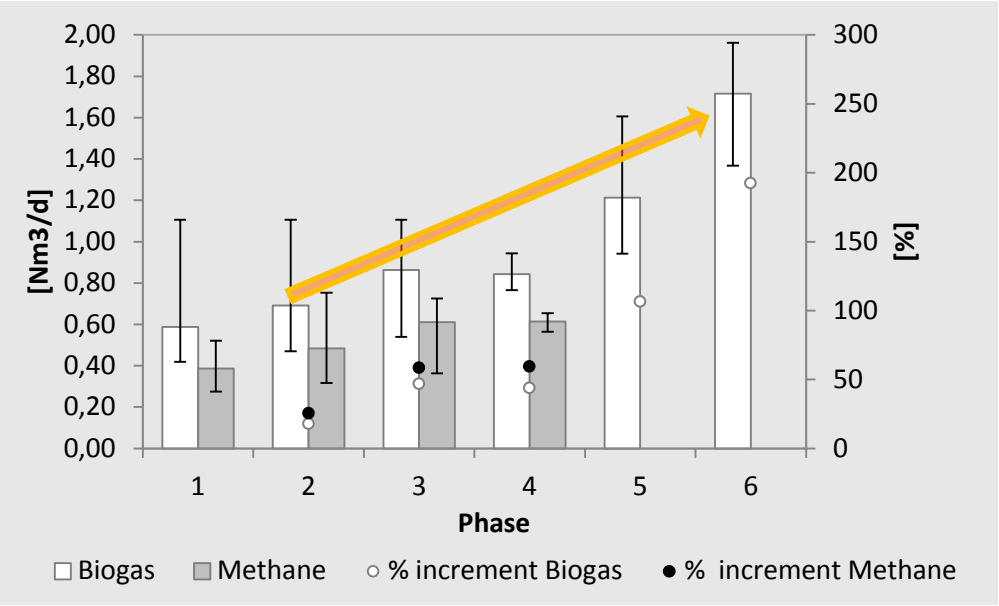


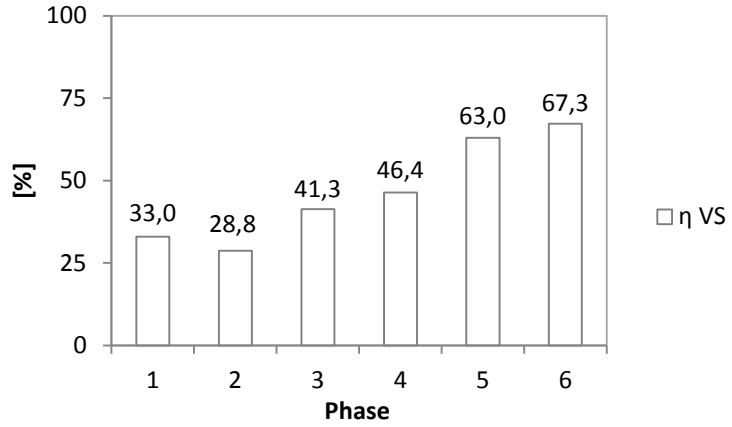


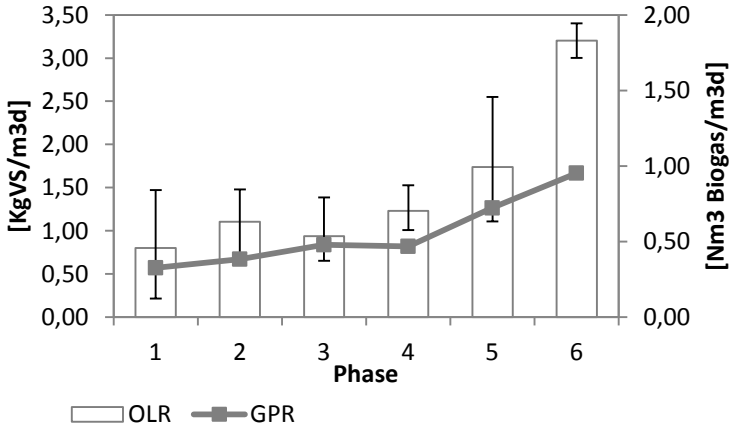
Sample point		Phase					
AD reactor		**1**	**2**	**3**	**4**	**5**	**6**
ALK	[$mgCaCO_3/l$]	1447,9	1578,6	1453,4	1323,3	2088,5	2764,7
		(289,5)	(145,9)	(133,8)	(253,3)	(600,5)	(161,3)
VFA	[mgCOD/l]	21,8	30,2	11,5	3,0	5,1	4,1
		(8,2)	(16,7)	(5,1)	(2,8)	(4,8)	(2,7)

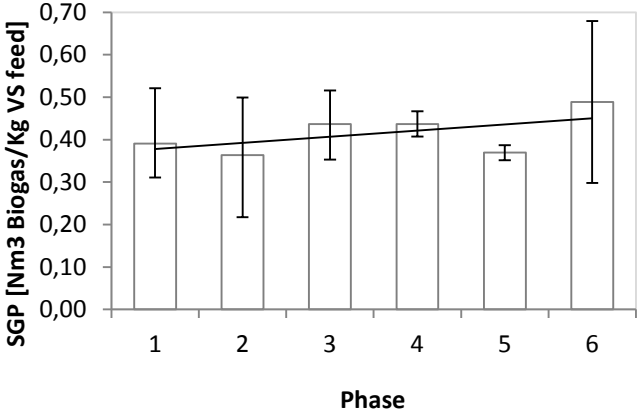
Pilot plant results

Efficiency parameters









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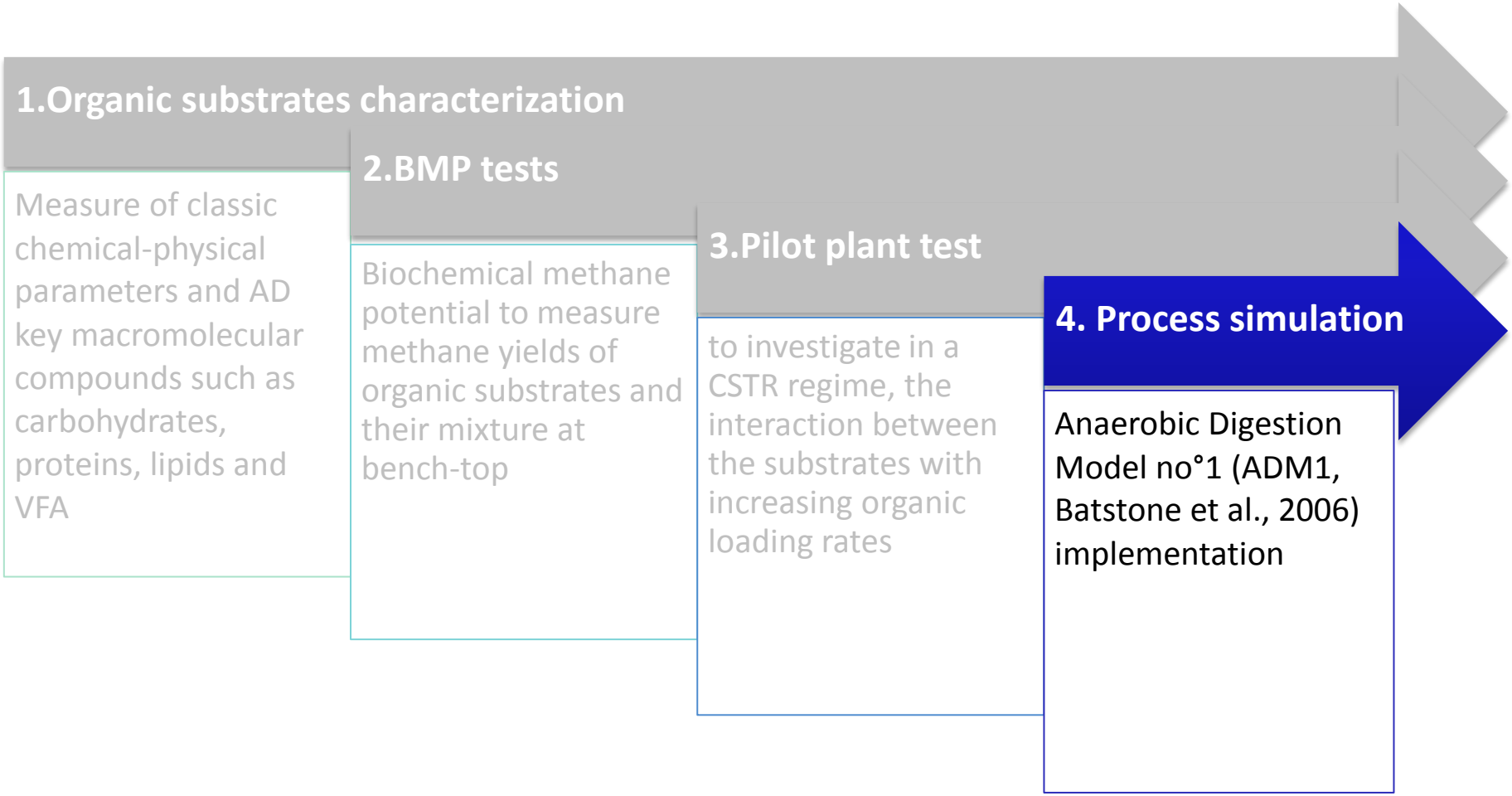


Process simulation

4

Mathematical modeling of the anaerobic digestion process by ADMno°1

Mathematical model — ***ADM1 _Anaerobic Digestion Model no°1 (2002, IWA)***

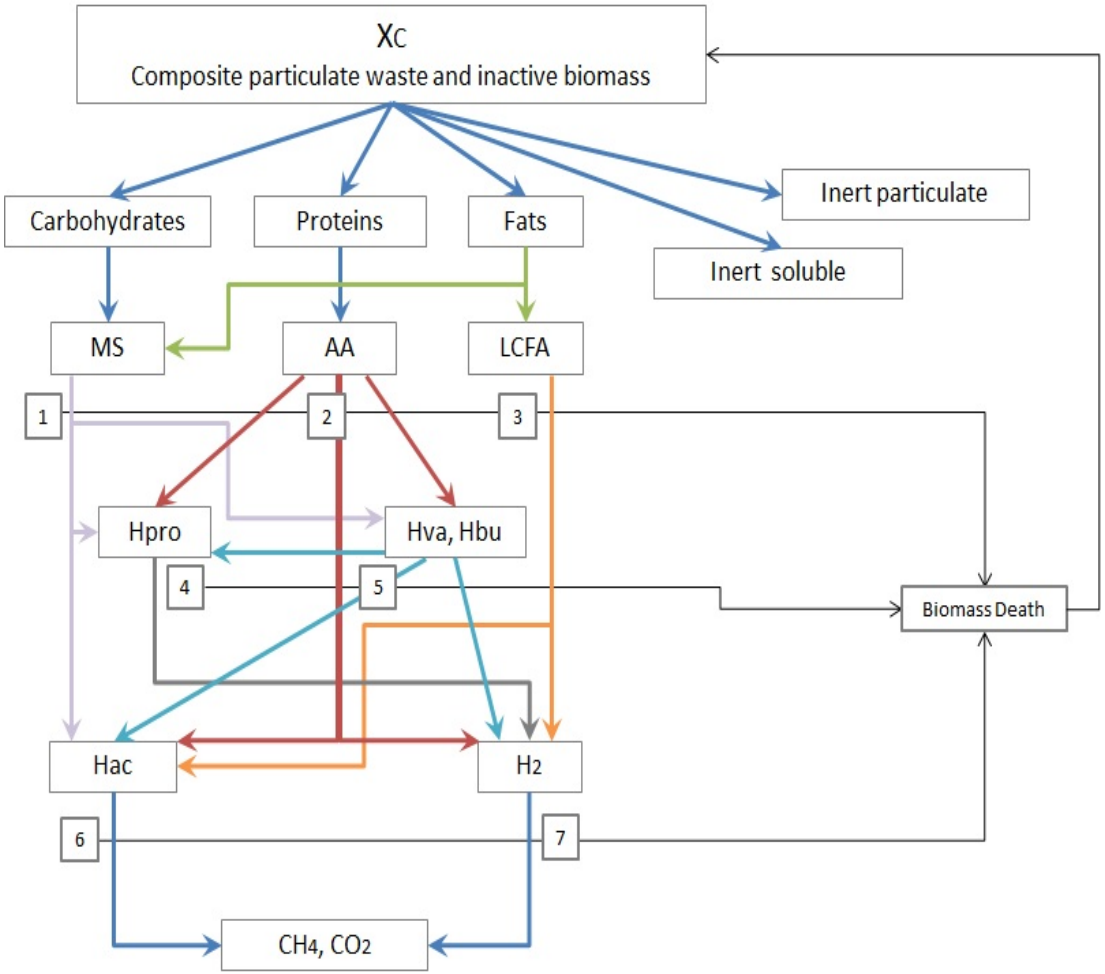
Equations to describe biochemical and chemical-physical process

Simulation of behaviour of biomass inside the AD reactor in different scenarios

Optimize digesters design and the operative conditions

Experimental procedure

ADM no° 1 (Batstone et al. 2002) Implementation



A. ADM1 with Copp interface for ASM1
B. ADM1 modified (without Xc parameter)

GPS-X

Hydromantis

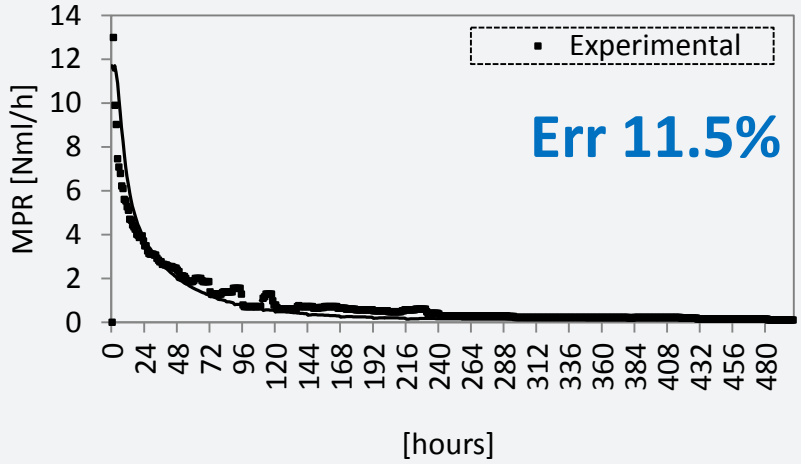
AQUASIM 2.1

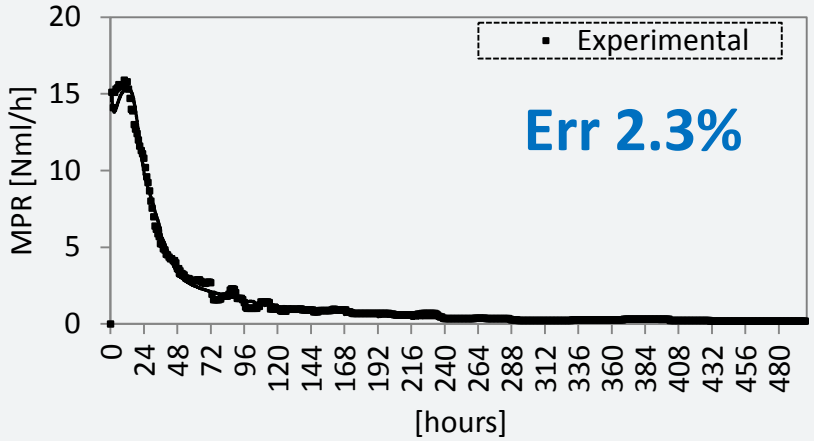
Biochemical processes implemented in ADM1 (adapted from Batstone et al., 2002) 1.Acidogenesis from sugars; 2. Acidogenesis from amminoacids; 3. Acetogenesis from LCFA; 4. Acetogenesis from propionate; 5. Acetogenesis from butyrate and valerate; 6. Acetoclastic methanogenesis; 7. Hydrogenotrophic methanogenesis. MS=monosaccarides; AA=amminoacids; LCFA=long chain fatty acids; Hva=valeric acid; Hbu=butyric acid

Simulation results for full-scale AD unit with sewage sludge

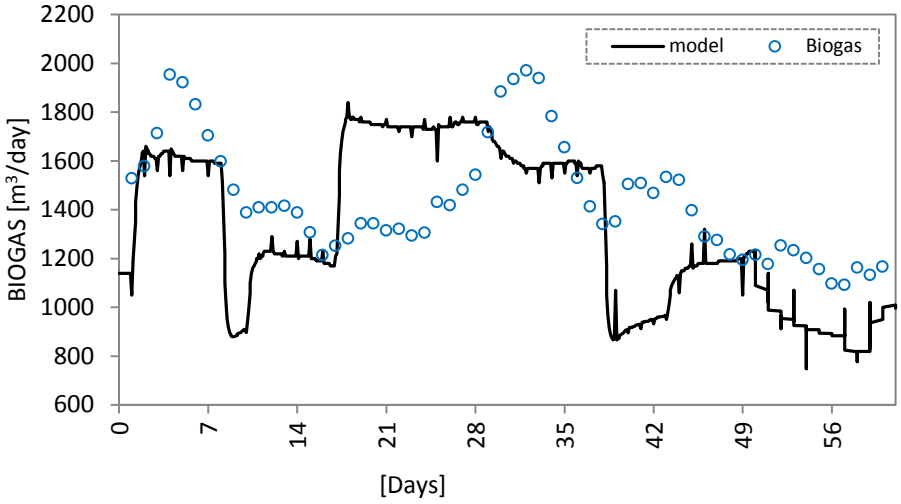
ADM 1 (A)

BMP

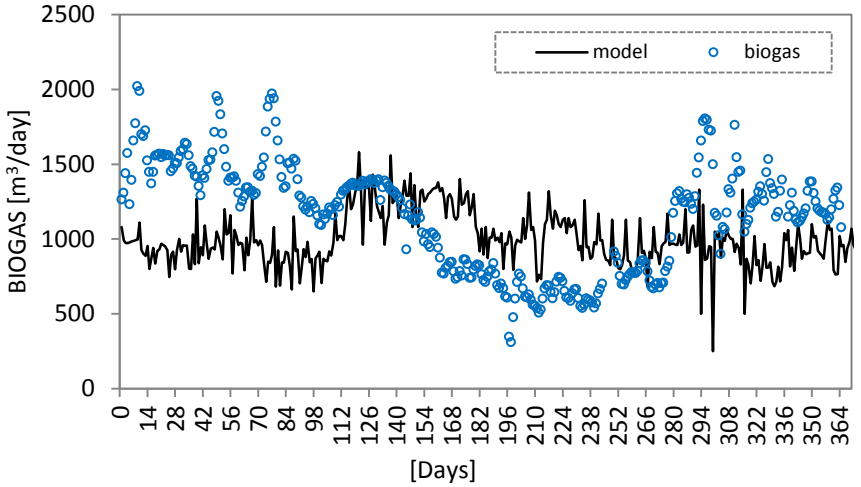




Err 17.8% [0.3÷40.2]



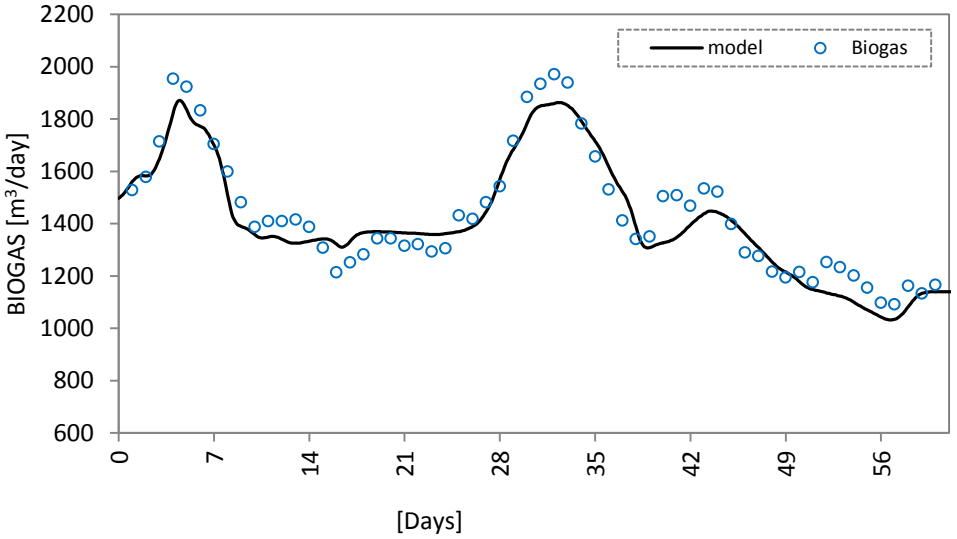
Err 35.5% [0.2÷227.9]



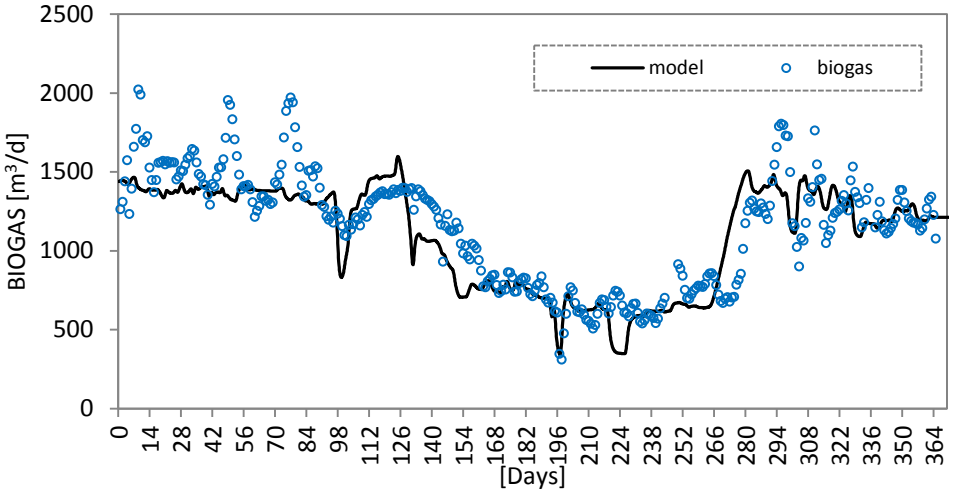
Simulation results for full-scale AD unit with sewage sludge

ADM 1 (B)

Err 5.0% [0.1÷12.5]

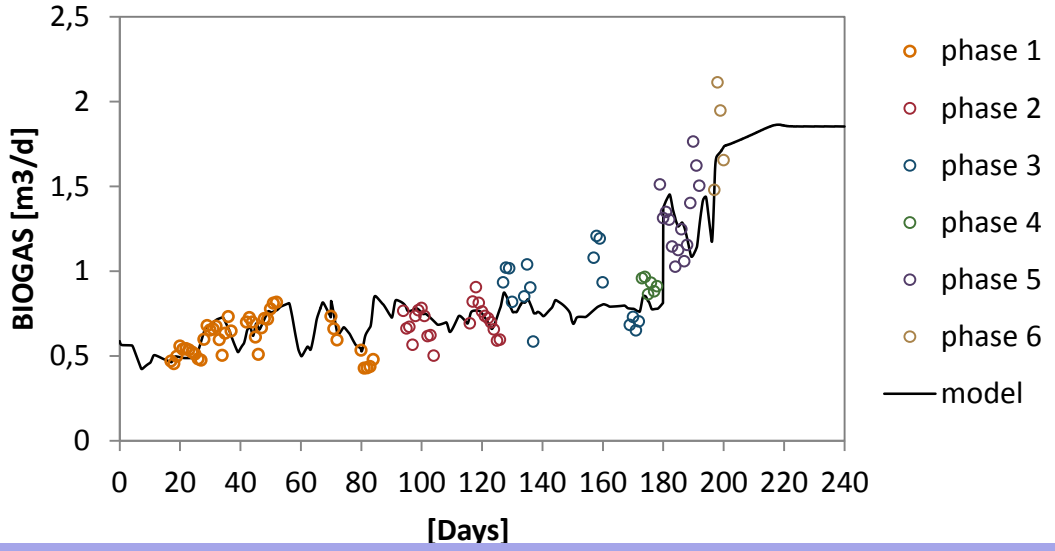


Err 13.0% [0.4÷71.8]

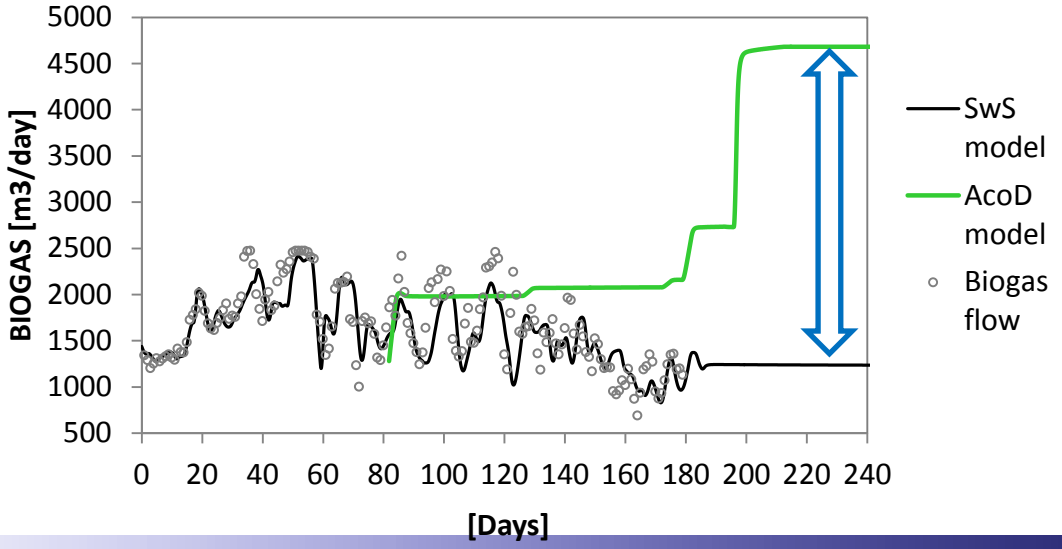


Simulation of pilot plant and full-scale up-grade to AcoD

Pilot Plant: Simulation of the experimental phase



Full scale reactor: Simulation of SwS and up-grade to AcoD



Feasibility study of AcoD plant up-grade

AcoD in WWTP

Two scenarios were hypothesized:

- **Scenario 1**:AcoD of SwS and SS-OFMSW in AD WWTP reactor to deplete the spare treatment capacity;

- **Scenario 2**: AcoD of SwS and OFMSW in AD WWTP unit in existing reactor and in a new one, to treat the amount of OFMSW received by the Udine waste treatment plant

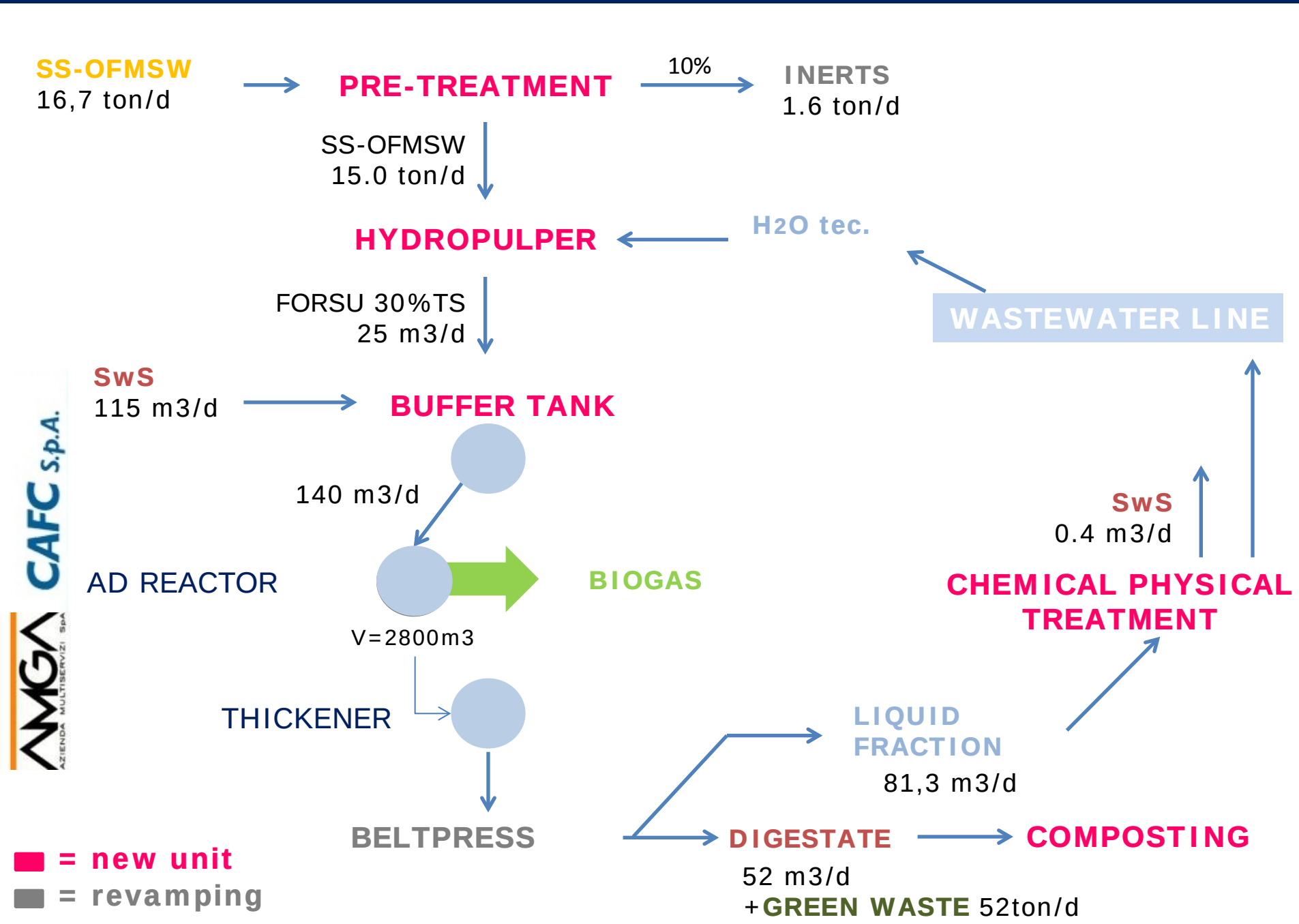
AMGA AZIENDA MULTISERVIZI SpA CAFC S.p.A. net

AcoD reactors
Process wastewater treatment

OFMSW pre-treatment
Composting

Sinergy between WWTP and waste treatment plant

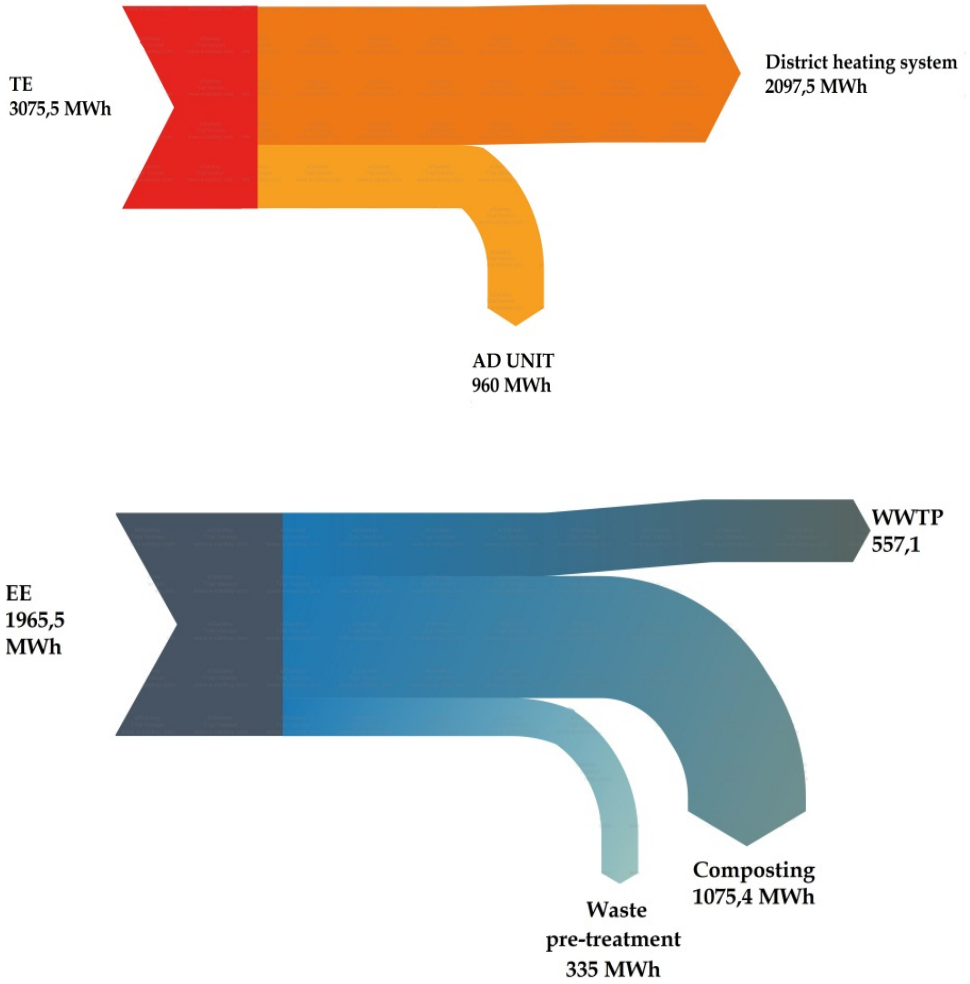
SCENARIO 1


SS-OFMSW
16,7 ton/d
PRE-TREATMENT
10%
INERTS
1.6 ton/d
SS-OFMSW
15.0 ton/d
HYDROPULPER
H2O tec.
WASTEWATER LINE
FORSU 30%TS
25 m3/d
SwS
115 m3/d
BUFFER TANK
140 m3/d
AD REACTOR
BIOGAS
V=2800m3
SwS
0.4 m3/d
CHEMICAL PHYSICAL TREATMENT
THICKENER
LIQUID FRACTION
81,3 m3/d
BELTPRESS
DIGESTATE
COMPOSTING
52 m3/d
+GREEN WASTE 52ton/d
= new unit
= revamping

Scenario 1

Operative conditions		
HRT	20	[d]
Volume	2800	[m^3]
Qin	140	[m^3/d]
Qin_SwS	115	[m^3/d]
Qin_OFMSW	25	[m^3/d]
TS_in	7,8	[%]
OLR	3,3	[KgVS/m3d]
Q Biogas	3640	[m^3/d]

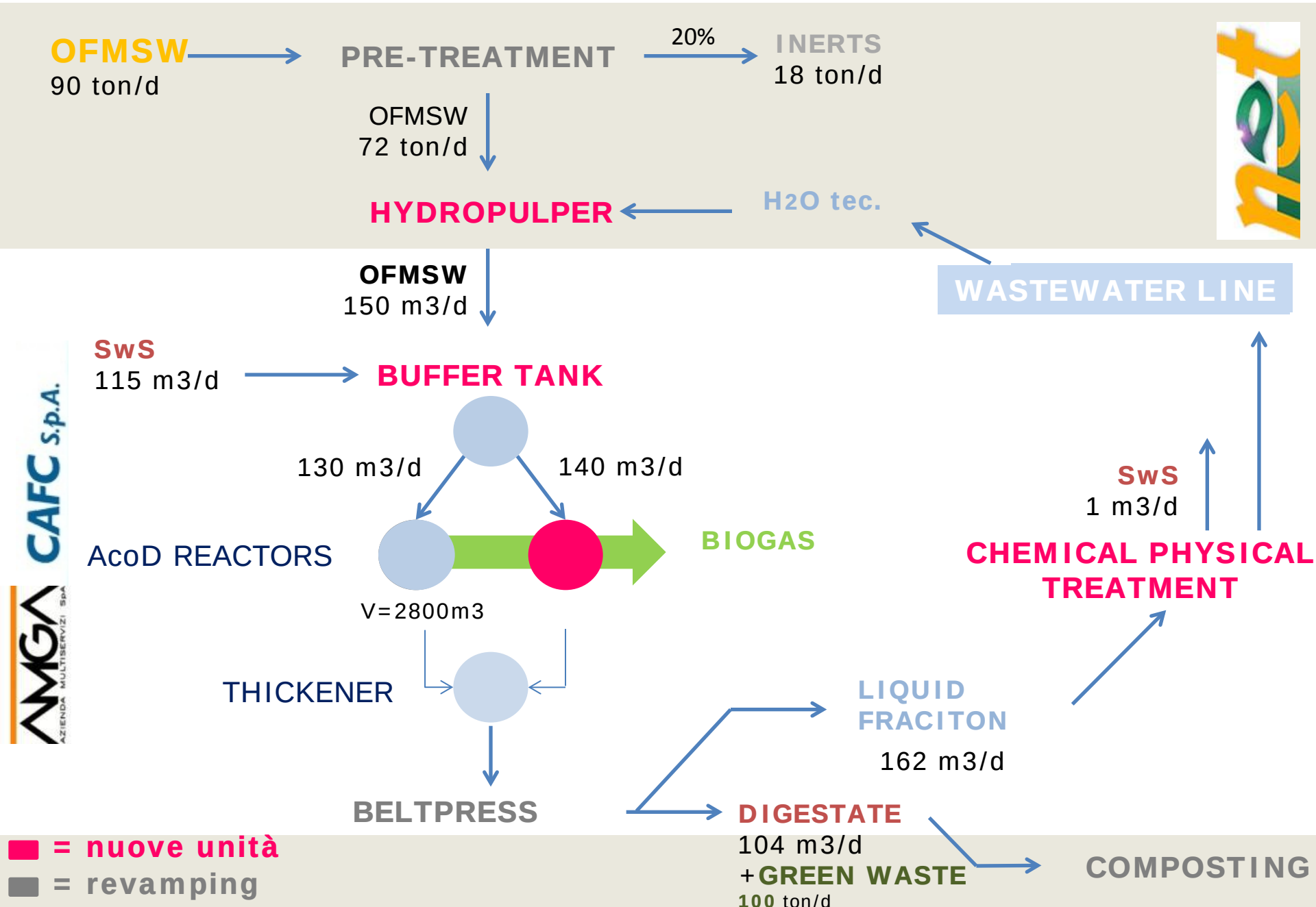
Energetic Balance [MWh/y]



Scenario 2

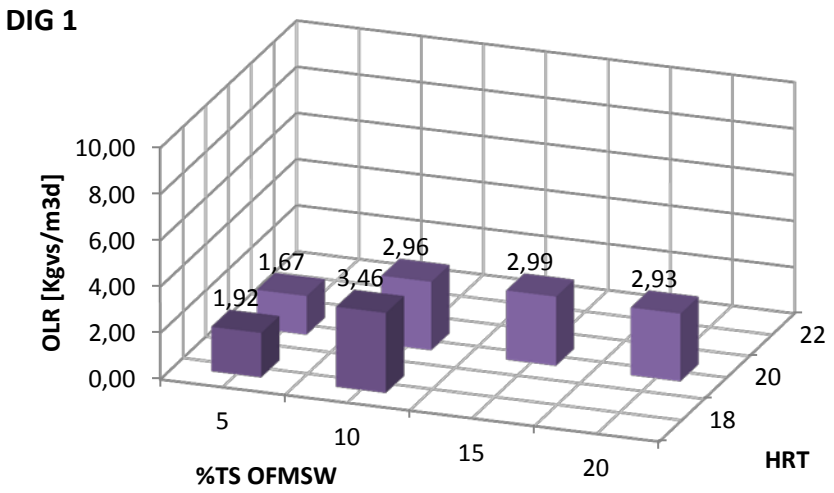
Sinergy between WWTP and waste treatment plant

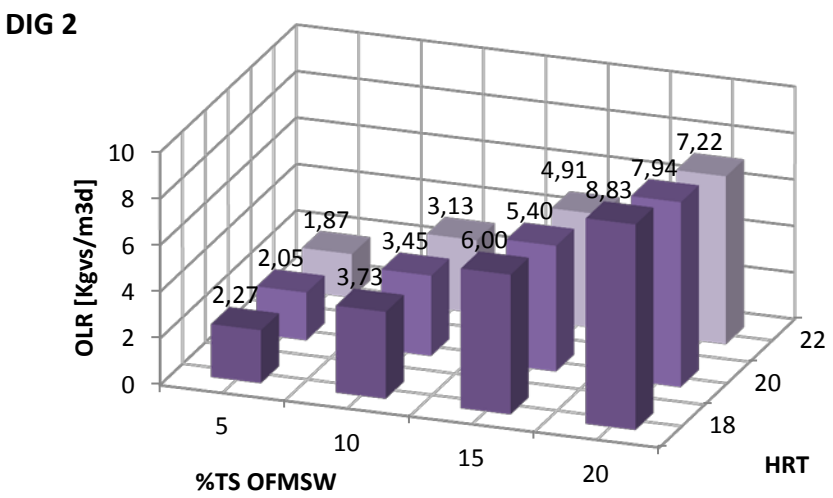
SCENARIO Integrated waste and wastewater treatment hub



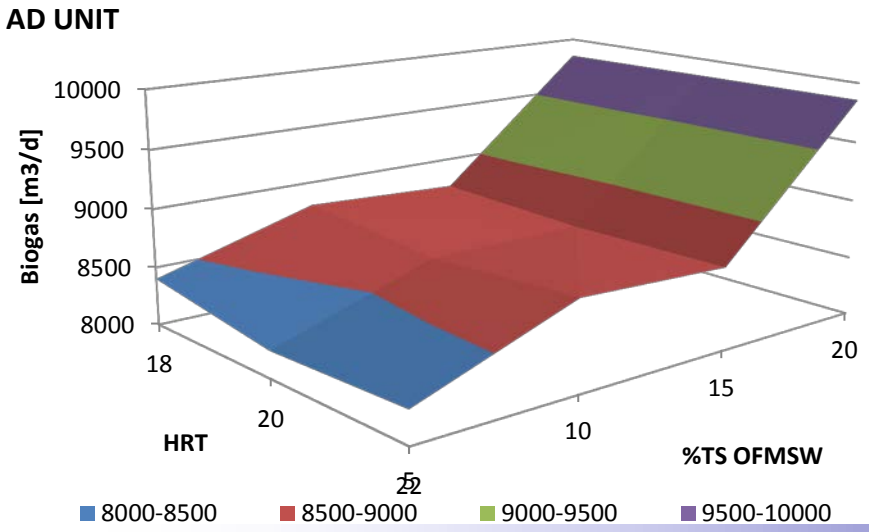
Scenario 2

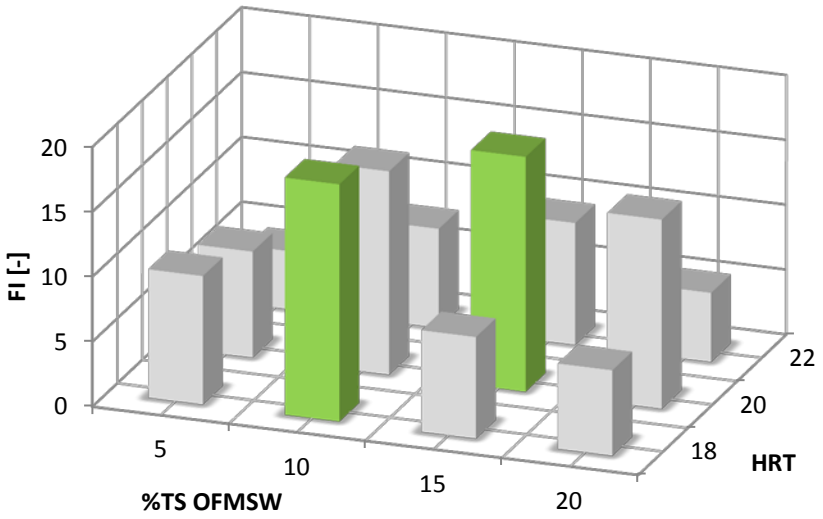
OLR conditins tested in simulation for digester 1 and digester 2





Simulated biogas production for the whole AD unit



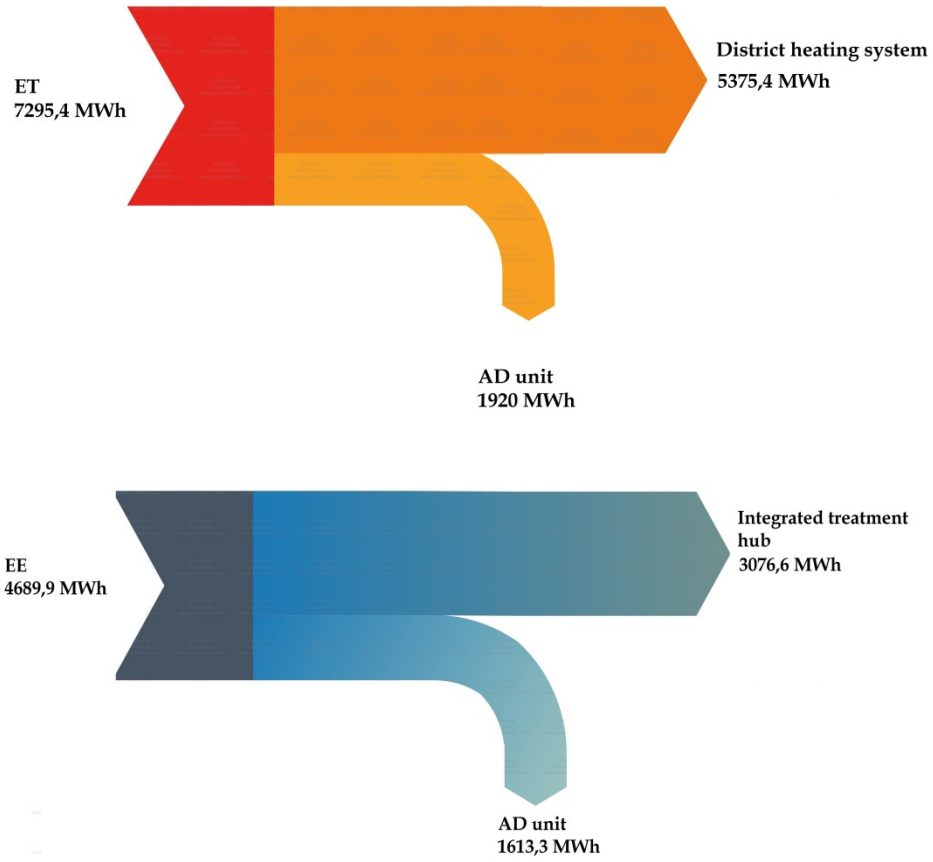


Scenario 2

Operative conditions

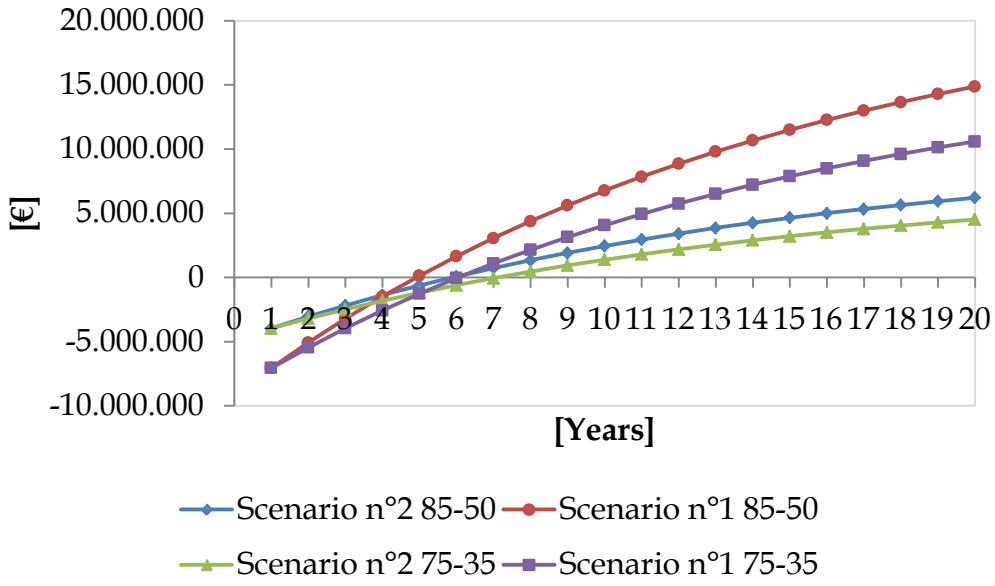
	DIG 1	DIG 2	
HRT	20	20	[d]
Volume	2800	2600	[m^3]
Qin	140	130	[m^3/d]
Qin_SwS	90	30	[m^3/d]
Qin_OFMSW	50	100	[m^3/d]
TS_in	7,2	12,2	[%]
OLR	3,3	5,4	[$KgVS/m^3d$]
Q Biogas	3420	5265	[m^3/d]

Energetic Balance [MWh/y]



Scenarios comparison

	Scenario n°1	Scenario n°2	
Investment	3960,00	7040	[K€]
Expenses	436,42	1283,71	[K€/year]
Revenues	1537,01÷1773,89	3598,82÷4198,82	[K€/year]
NPV	4735,47÷6477,98	11039,14÷15425,06	[K€]
PB	7÷5	6÷4	[years]
IRR	20÷25	24÷30	[%]



Conclusions

This protocol can be defined as follow:

- Deep **substrate characterization** has to be focalized on macromolecular compounds analysis (carbohydrates, proteins, lipids and VFA) and chemical-physical parameters analysis are mandatory to evaluate the substrate for AD process This step implies high lab efforts and a **standardized methodology** for complex substrate is necessary.

- **BMP tests** allow to understand the biomass performance in substrates degradation and to highlight potential inhibition phenomena. The operative conditions of BMP trials are still under discussion in the scientific community. However complying with the most recent guidelines, comparable results can be obtained

- **Pilot plant experimentation** is fundamental to understand the AD process performance under dynamic organic loading conditions. In case of non-conventional substrates or non-conventional operative conditions pilot plant test is mandatory.

- **ADM1 modeling** allows to test different HRT and OLR scenarios and to define the best operative conditions. ADM1 requires a **lot of experimental data** and the quality results is strictly linked to substrate characterization. When the ADM1 is calibrated, it can be used in a very wide field of operations: numerous operative scenarios can be tested.



The project

"Energetic conversion of organic fraction of municipal solid waste by anaerobic codigestion with sewage sludge"

POR FESR 2007-2013
OBIETTIVO COMPETITIVITA' REGIONALE E OCCUPAZIONE
Friuli Venezia Giulia

Unione Europea FESR

Ministero dello Sviluppo Economico

REGIONE AUTONOMA FRIULI VENEZIA GIULIA

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Thanks for attention

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Ing. Valentina Cabbai