The Twenty-Sixth International Conference on Solid Waste Technology and Management
Philadelphia, PA, USA 27-30 March 2011

Biohythane production from the organic fraction of municipal solid waste: improving existing anaerobic digestion plants

C. Cavinato*, D. Bolzonella°, F. Fatone°, P. Pavan*, F. Cecchi°

*University Ca' Foscari of Venice * and University of Verona °*

EU FP7 VALORGAS (ENERGY.2009.3.2.2)

Second generation biofuels

Anaerobic digestion of the organic fraction of MSW is a well established and reliable technology in Europe

5 Year Development	1991-1995	1996-2000	2001-2005	2006-2010	1991-2010
# of plants installed	15	44	52	73	184
plants/y	3.00	8.80	10.40	14.60	9.20
capacity installed (t)	194,000	1,117,500	2,077,950	2,246,450	5,635,900
capacity installed (t/y)	38,800	223,500	415,590	449,290	281,795
average size of plant (t/y)	12,933	25,398	39,961	30,773	27,266

Source: De Baere et al 2010

Anaerobic digestion of the organic fraction of MSW is a well established and reliable technology in Europe

5 Year Development	1991-1995	1996-2000	2001-2005	2006-2010	1991-2010
# of plants installed	15	44	52	73	184
plants/y	3.00	8.80	10.40	14.60	9.20
capacity installed (t)	194,000	1,117,500	2,077,950	2,246,450	5,635,900
capacity installed (t/y)	38,800	223,500	415,590	449,290	281,795
average size of plant (t/y)	12,933	25,398	39,961	30,773	27,266

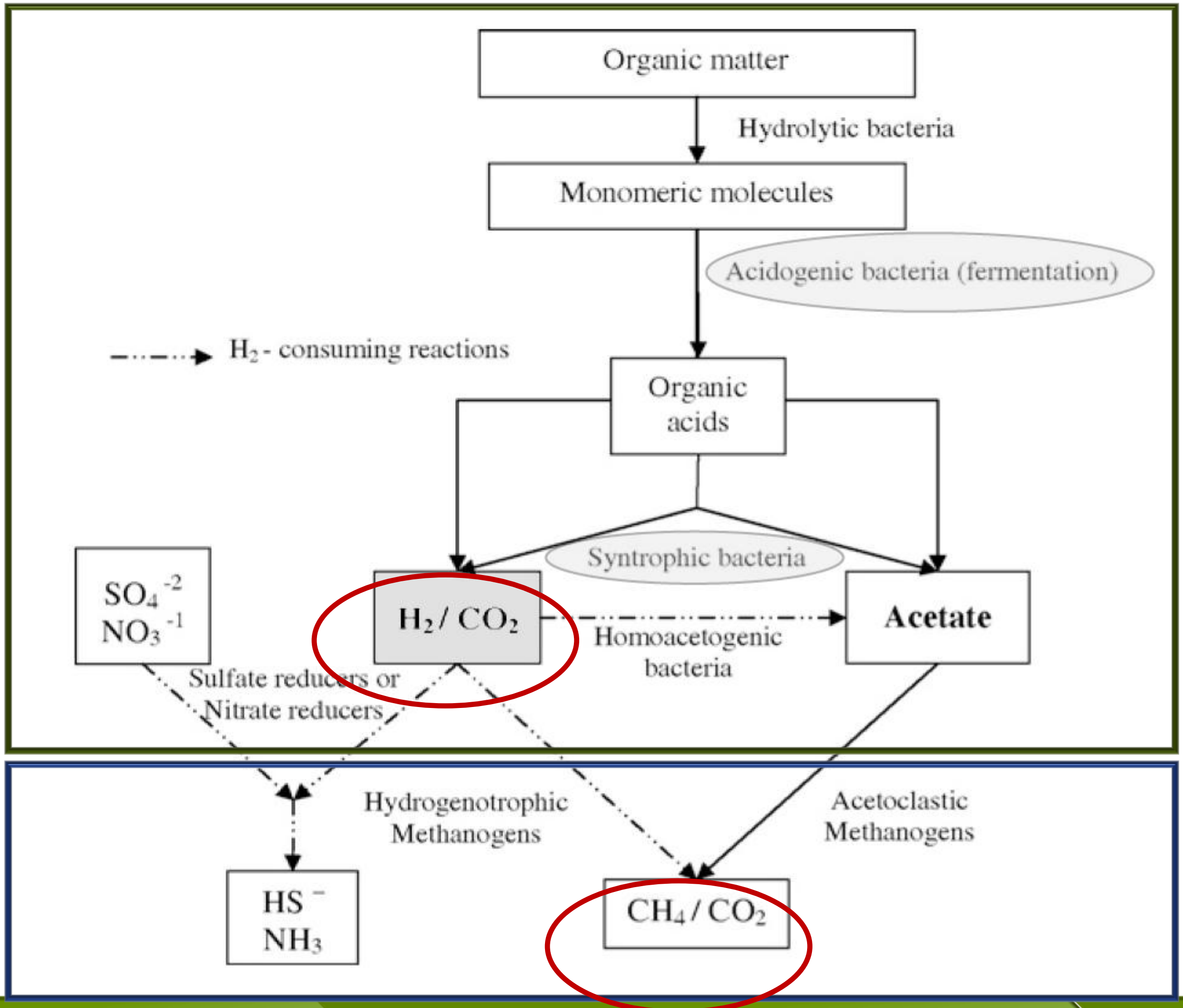
Source: De Baere et al 2010

So far, main drivers for this success have been:

✓ **the implementation of separate collection of biowaste: this allows for the treatment of material characterized by a high biogas potential (up to 160-170 m^3 biogas per tonne of raw material) and the production of a digestate of good quality**

✓ **the subsidies for renewable energy (EU 202020)**

A step forward for the improvement of the common anaerobic digestion process is the two-phase process in thermophilic conditions: in such a way we optimize the bioreactor operation and both hydrogen and methane can be produced



1^{st} phase reactor

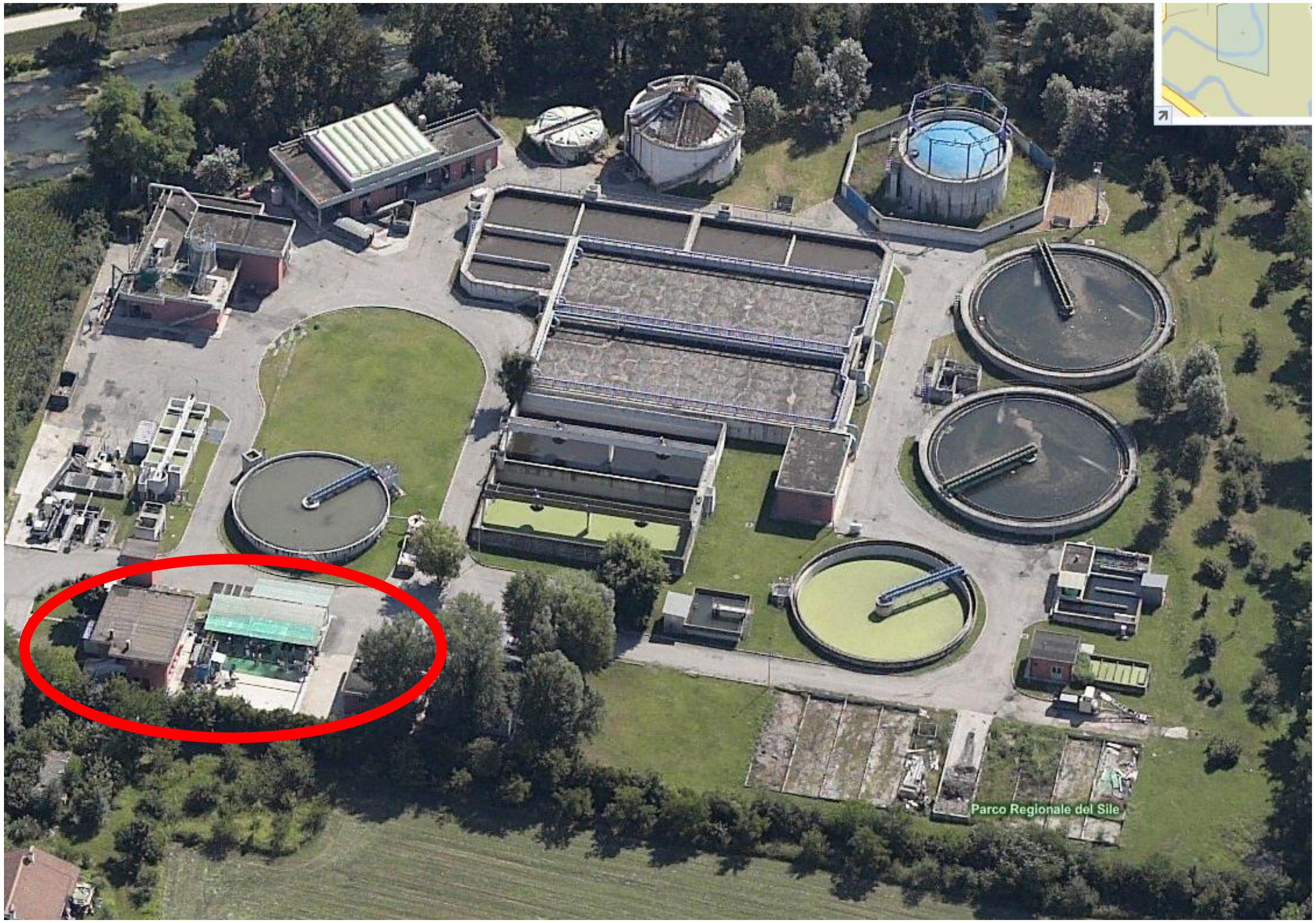
2^{nd} phase reactor

Hydrogen and methane can be collected and used separately or mixed to produce (bio-)hythane

The overall energy content of the mixture is lower than biogas itself but:

- ✓ **The addition of even small amounts (10% or lower) of hydrogen to biogas extends the lean flammability range significantly while the flame speed is faster**
- ✓ **The CO_2 emissions are decreased as less CH_4 is produced and replaced by H_2**

The research activity was carried out in Treviso WWTP experimental hall



CSTR

T = 55° C

V= 0.2 m^3

V= 0.8 m^3

	Run I	Run II	Run III
HRT 1phase (d)	3.3	3.3	3.3
HRT 2 phase (d)	12.6	12.6	12.6
OLR 1 phase (kgVS/m^3d)	16	21	14
OLR 2 phase (kgVS/m^3d)	4.2	5.6	3.7

Università Ca'Foscari Venezia

SUBSTRATE: BIOWASTE FROM SEPARATE COLLECTION

	units	average	min	max	S.d.
TS	g/kg	242,9	145,3	304,7	71,3
TVS	g/kg	179,5	150,0	220,9	40,13
TVS	%TS	73,8	61,5	88,4	10,6
COD	g/kg	217,2	151,9	273,6	41,02
TKN	mgN/kg	5738	2178	8436	2280
TP	mgP/kg	198,7	140,7	250,0	39,6

	units	average	min	max	S.d.
pH		7,51	7,31	7,69	0,16
TS	g/kg	22,87	22,31	23,38	0,46
TVS	g/kg	13,38	13,03	13,70	0,35
TVS	%TS	58,48	57,72	59,21	0,61
TKN	mgN/kg	0,50	0,48	22,40	0,02
TP	mgP/kg	0,06	0,06	0,07	0,01

INOCULUM FROM THE WWTP FULL SCALE ANAEROBIC DIGESTOR

Performances in Run I and II

First stage (H_2)

RUN I

parameter	u.m.	AV	SD
GP	m^3/d	0,45	0,11
GPR	m^3/m^3d	2,26	0.55
SGP	l/kgTVS	136,82	35,30
H_2	%	37,06	8,57
SHP	l/kgTVS	51,16	11,81

RUN II

parameter	u.m.	AV	SD
GP	m^3/d	0,24	0,03
GPR	m^3/m^3d	1,22	0,17
SGP	l/kgTVS	59,97	6,68
H_2	%	34,00	3,36
SHP	l/kgTVS	20,44	3,36

Second stage (CH_4)

RUN I

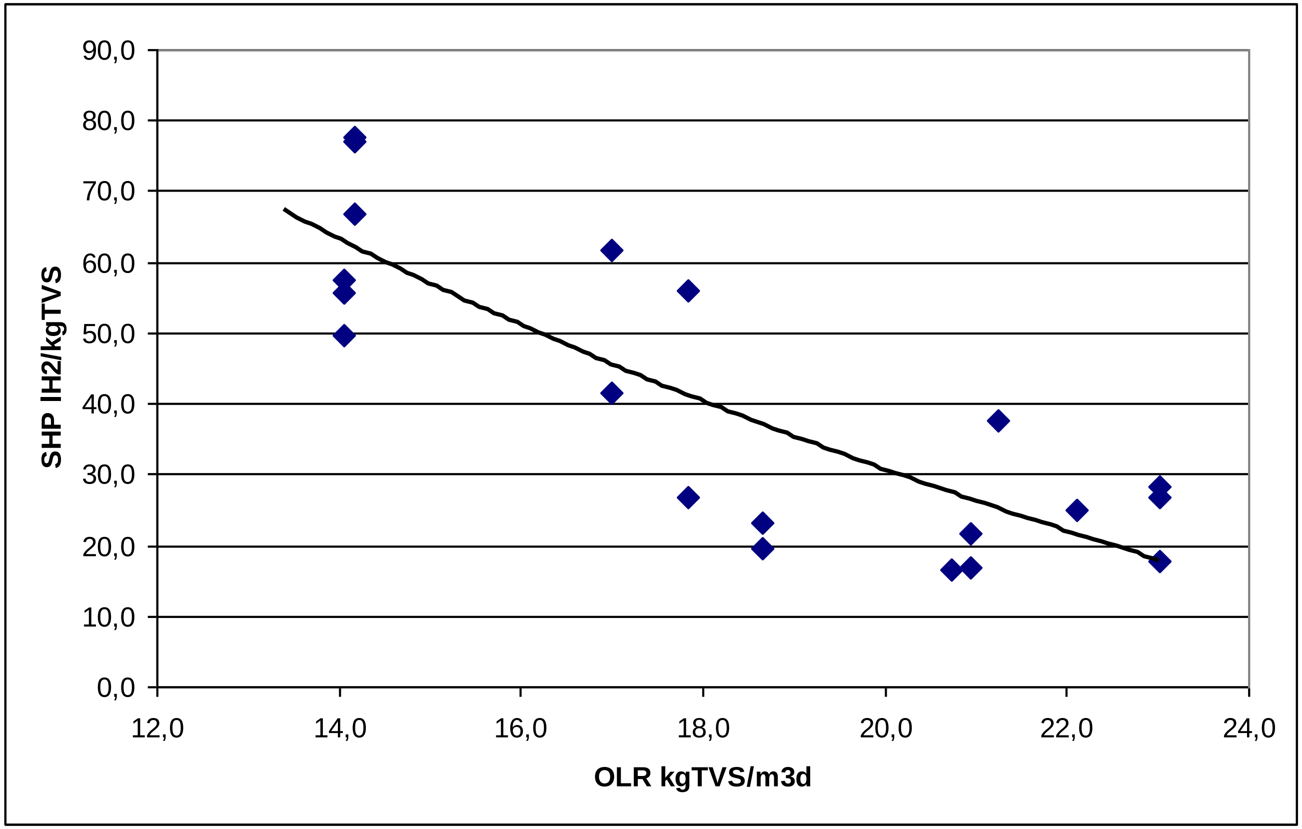
parameter	u.m.	AV	SD
GP	m^3/d	1,03	0,10
GPR	m^3/m^3d	2,71	0,27
SGP	m^3/kgTVS	0,64	0,09
CH_4	%	64,93	2,21

RUN II

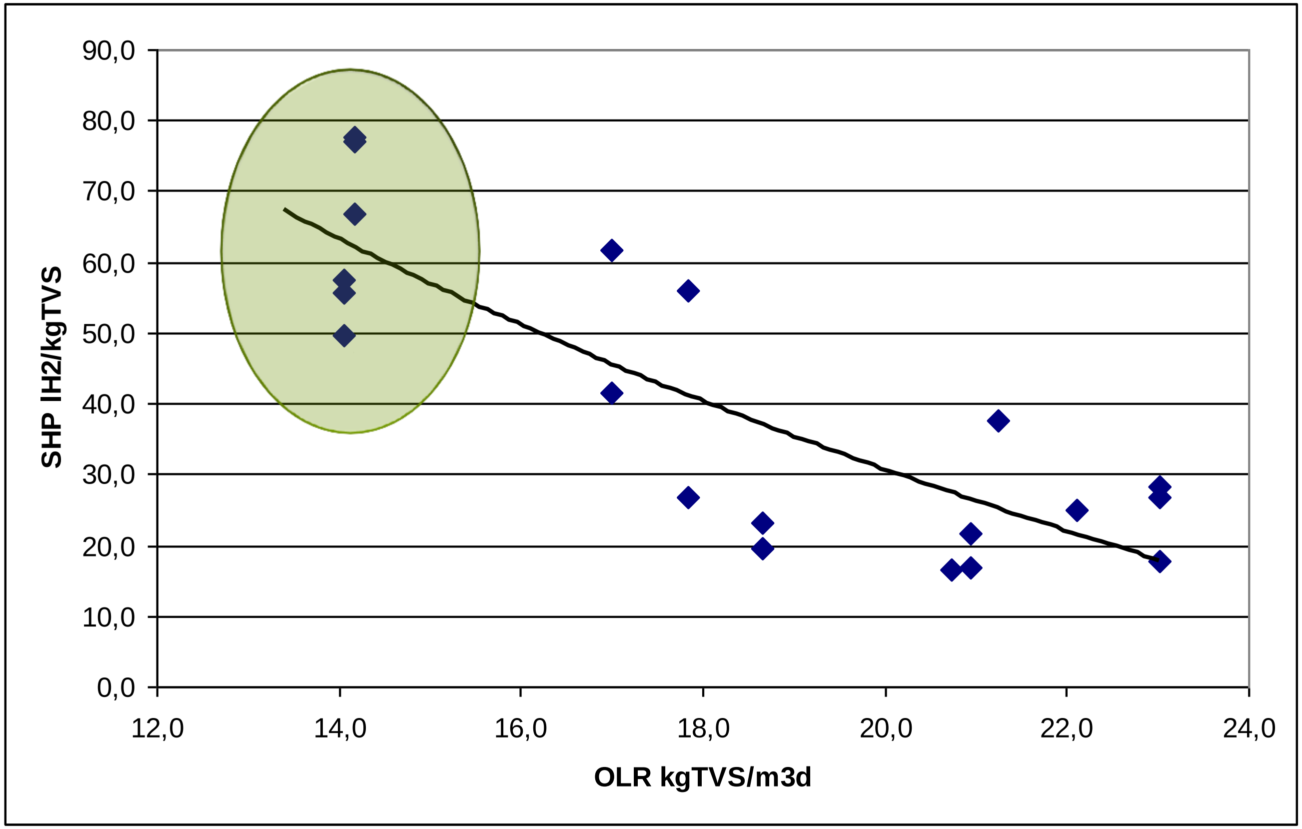
parameter	u.m.	AV	SD
GP	m^3/d	1,27	0,22
GPR	m^3/m^3d	3,35	0,58
SGP	m^3/kgTVS	0,63	0,12
CH_4	%	65,38	1,80

Università Ca'Foscari Venezia

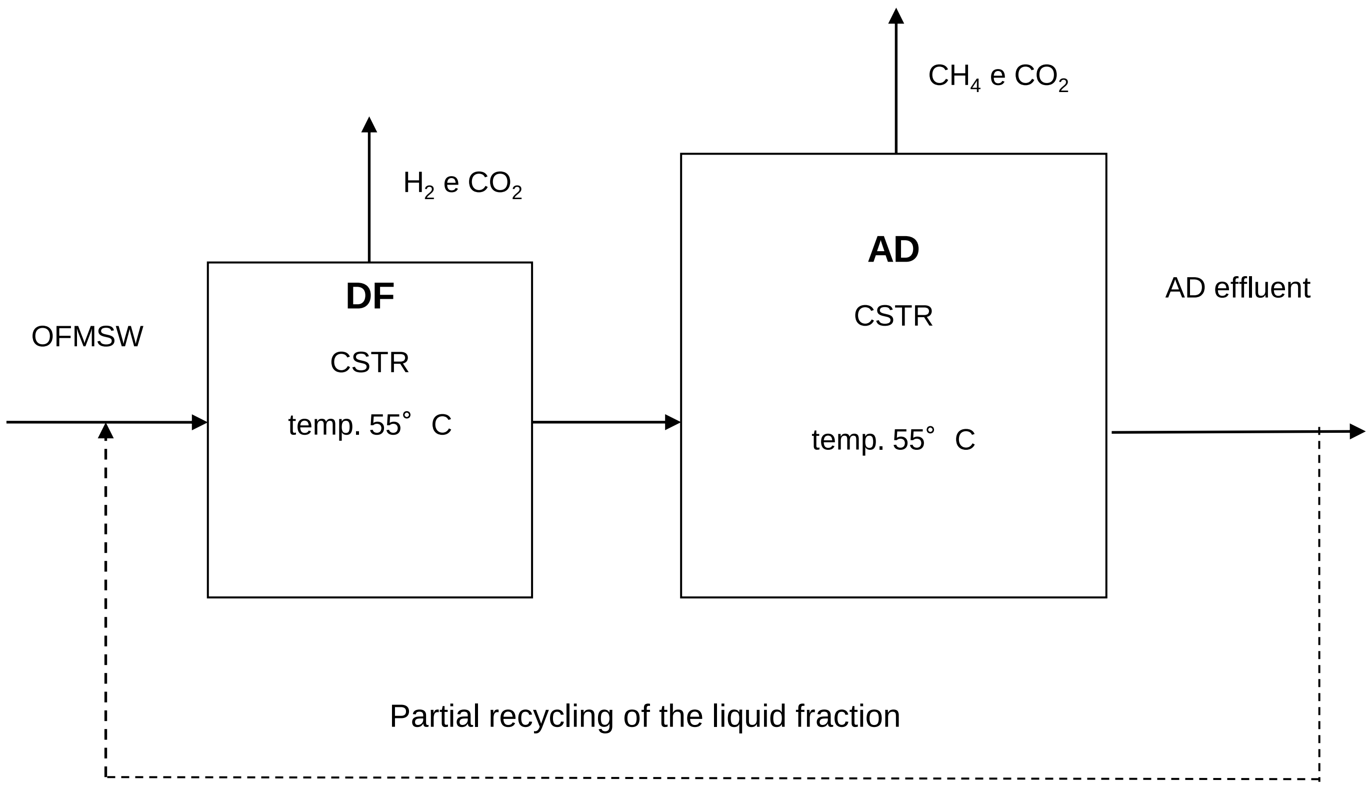
Results of Run I and II suggested to decrease the applied OLR to the first reactor and improve pH through the partially recycling of the second reactor



Results of Run I and II suggested to decrease the applied OLR to the first reactor and improve pH through the partially recycling of the second reactor



pH control at 5.5 without the addition of external chemicals



Run III

parameter	u.m.	AV	SD
GP	m^3/d	0.62	0.07
GPR	m^3/m^3d	3.0	0.06
SGP	l/kgTVS	170	0.1
H_2	%	33	5.2
SHP	l/kgTVS	65	6.3

1st reactor

2nd reactor

parameter	u.m.	AV	SD
GP	m^3/d	2.2	0.05
GPR	m^3/m^3d	3.0	0.05
SGP	m^3/kgTVS	0.62	0.1
CH_4	%	65	4.3

Run III

parameter	u.m.	AV	SD
GP	m^3/d	0.62	0.07
GPR	m^3/m^3d	3.0	0.06
SGP	l/kgTVS	170	0.1
H_2	%	33	5.2
SHP	l/kgTVS	65	6.3

1st reactor

2nd reactor

parameter	u.m.	AV	SD
GP	m^3/d	2.2	0.05
GPR	m^3/m^3d	3.0	0.05
SGP	m^3/kgTVS	0.62	0.1
CH_4	%	65	4.3

bio hythane mixture obtained

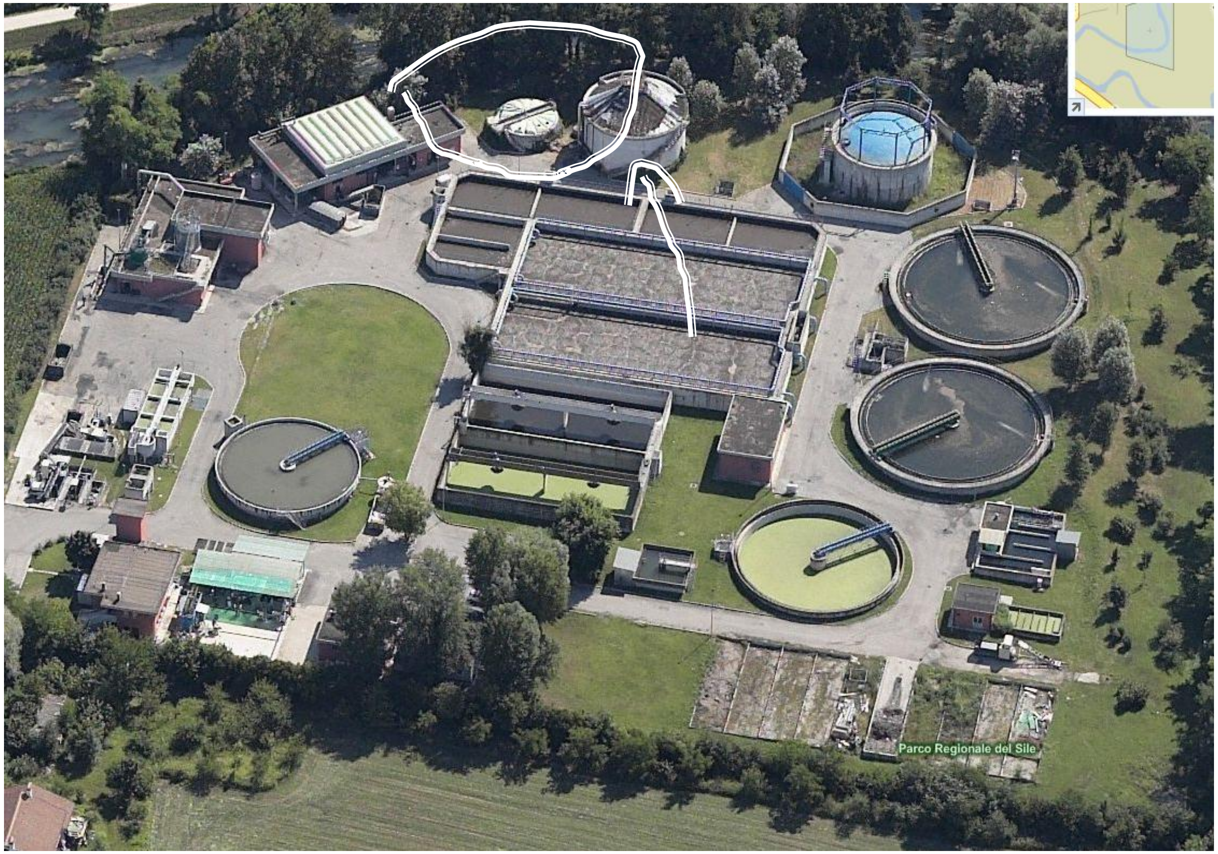
	m^3H_2/d DF	m^3CO_2/d DF	m^3CH_4/d DA	m^3CO_2/d DA	m^3gas/d	$\%H_2$	$\%CH_4$	$\%CO_2$	GPR [m^3gas/m^3d]	SGP [lgas/kgVS]
RUN I										
Average	0,168	0,285	1,337	0,722	2,512	6,7	53,2	40,1	2,6	779
S.d.	0,041	0,070	0,134	0,072	0,317	-	-	-	0,3	98
Min	0,097	0,165	1,053	0,569	1,884	5,2	55,9	38,9	2,0	584
Max	0,225	0,381	1,471	0,795	2,872	7,8	51,2	40,9	3.0	890
RUN II										
Average	0,083	0,161	1,665	0,882	2,791	3,0	59,7	37,4	2,9	661
S.d.	0,012	0,023	0,286	0,151	0,472	-	-	-	0,5	111
Min	0,075	0,145	1,257	0,665	2,142	3,5	58,7	37,8	2,2	507
Max	0,107	0,207	2,053	1,087	3,454	3,1	59,4	37,5	3,598	818
RUN III										
Average	0,220	0,408	1,411	0,740	2,779	7,9	50,8	41,3	2,9	980
S.d.	0,055	0,103	0,185	0,097	0,439	-	-	-	0,5	154
Min	0,179	0,333	1,280	0,672	2,464	7,3	51,9	40,8	2,6	869
Max	0,283	0,525	1,541	0,809	3,158	9,0	48,8	42,2	3,3	1113

	H_2 energy content (kcal/kgVS)	CH_4 energy content (kcal/kgVS)	Total energy content (kcal/kgVS)
Run I	135	3,760	3,900
Run II	51	3,575	3,600
Run III	203	4,750	4,900

	H_2 energy content (kcal/kgVS)	CH_4 energy content (kcal/kgVS)	Total energy content (kcal/kgVS)
Run I	135	3,760	3,900
Run II	51	3,575	3,600
Run III	203	4,750	4,900

Full scale implementation of the bio-hythane approach in a WWTP: economical considerations

Full scale implementation of the bio-hythane approach in a WWTP: Economical considerations



Parameter	Units	Value
OFMSW flowate	t/d	20
Refuses from sorting line	t/d	5
TS influent	t/d	4
TVS influent	t/d	3
Overall SGP	m^3/kgTVS	0.98
overall biogas production	m^3/d	3147
hydrogen production	m^3/d	249
overall energy produced	kWh/d	8341

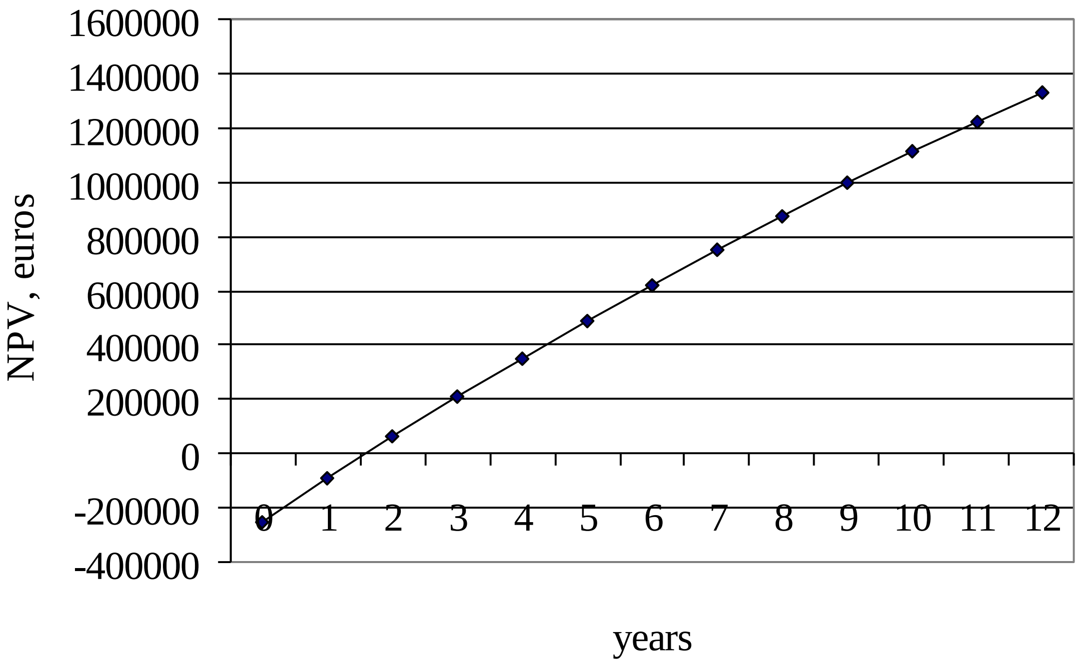
(*) in this simulation, for simplicity, no benefits coming from sewage sludge digestion are considered, and also the further energy recovery from the surplus of heat coming from CHP is added

Actualisation index: *i = 5,3% - 1,8% = 3,5% (bank index – inflation index)*

For a generic year n, the NPV is given by:

$$N.P.V._n = -Co + (bn - cn)\frac{(1{,}035)^n - 1}{(1{,}035)^n * 0{,}0035}$$

NPV of the approach proposed
(in the Italian scenario for renewable energy)



The choice of both a two-phase and thermophilic system clearly boosts the economics

Take home messages

Dark fermentation in the first reactor was optimised without any reagent addiction for pH control and without any previous treatment of inoculum

Recirculation of rejected wastewater after anaerobic digestion from the second was sufficient to keep the process at ideal condition for hydrogen production (pH around 5.5)

The highest yield in terms of H_2 production was obtained at the lower loading condition, with a maximum specific hydrogen production of 73.8 $lH_2/kgTVS_{fed}$ for an applied OLR of 14 $kgTVS/m^3$ per day

The second reactor maintained its typical yield of some 0.65 $m^3/ kgTVS_{fed}$

The economical feasibility for this process implementation at full scale was also analysed