From a Municipal Biowaste Treatment Plant to a Biorefinery: An Italian case study

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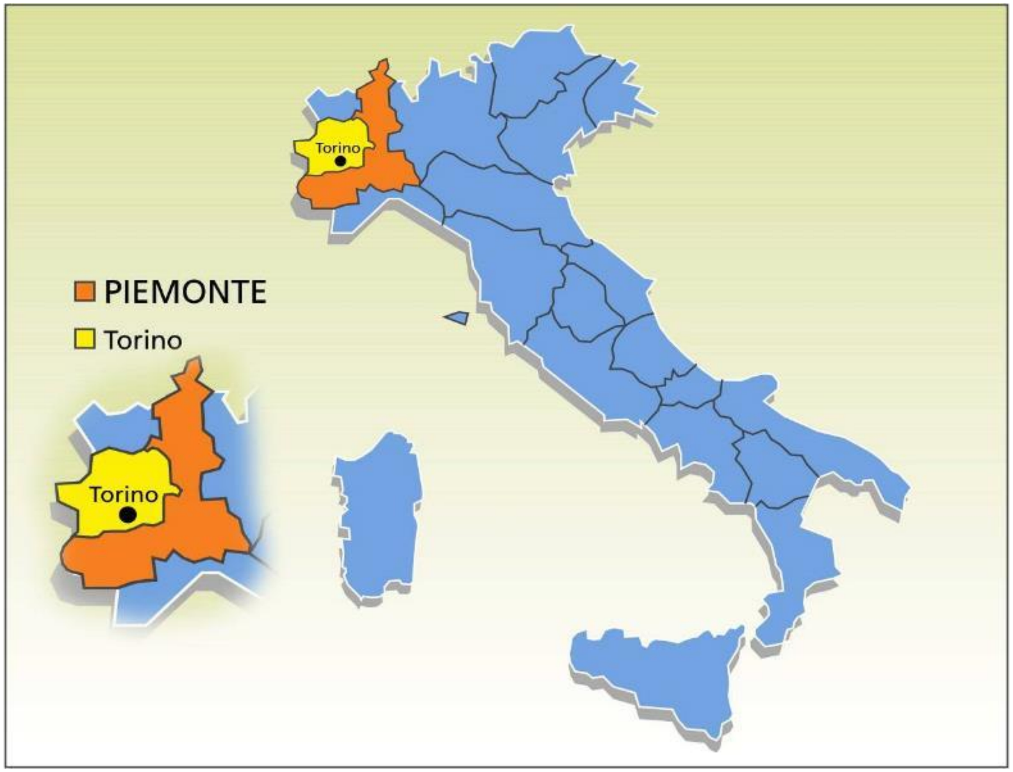
Case Study: Cooperation between Acea and University of Torino

Objective: turning a modern existing municipal biowaste treatment plant into a biorefinery producing thermal and electric power from biofuel, and value added chemical products for multiple use.

Products: measurable results that can be demonstrated, transferred and replicated in any urban environment of this world.

ACEA Group

ACEA is a modern Italian multi-utility company, which currently provides services for municipalities, private companies and citizens. In more than 150 years the company has continued its growth and the current Group operates on three main services: environment, water and waste water, energy.



ACEA Pinerolese Industriale SpA is a corporation, whose shareholders are 47 Municipalities.

ACEA Pinerolese Industriale S.p.A.: a multi utility system

Environmental services: management of the entire system through collecting of Municipal Solid Waste (MSW) and treatment. The collecting services is applied directly at 150.000 inhabitants (twice those in Gela) living in 47 municipalities placed in the south west of Turin province close to the French border. The treatment service is applied to a wider area roughly 800.000 inhabitants (more than in the provinces of Caltanissetta and Agrigento).

Natural Gas Distribution: 650 km grid, 24 municipalities 85*10^6 Sm^3 NG distributed on 35.000 final connection's point.

Water and waste water services: 61 municipalities for 200.000 inhabitants. 116 waste water treatment system. Clean water grid extended for circa 2.000 km, 850 km for the waste water network.

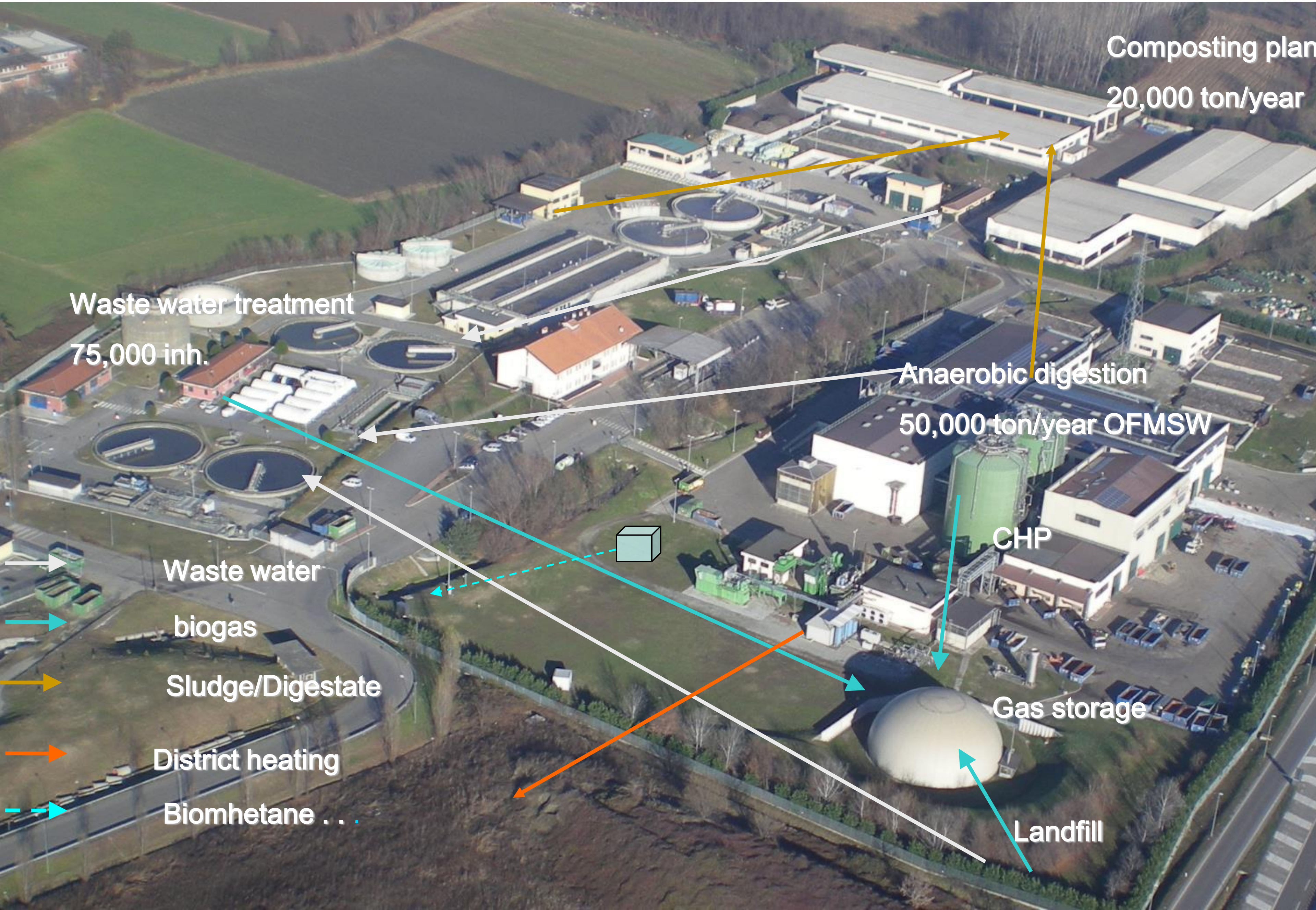
Energy services: *Acea Pinerolese Energia S.r.l.* sells natural gas and electric energy to private sector on the national market

Annual turnover 2015: € 133.126.959

Net profit: € 1.274.628 ,

Distributed to shareholders: € 1.167.250

ACEA Waste Treatment Plant



Incoming Material

Organic fraction

SS-OFMSW

- *Households*
- *SC-OFMSW*
- *Restaurants*
- *Canteens*
- *Markets*

AD-line

Green waste

- *Green public area*
- *Domestic green waste*

Composting line

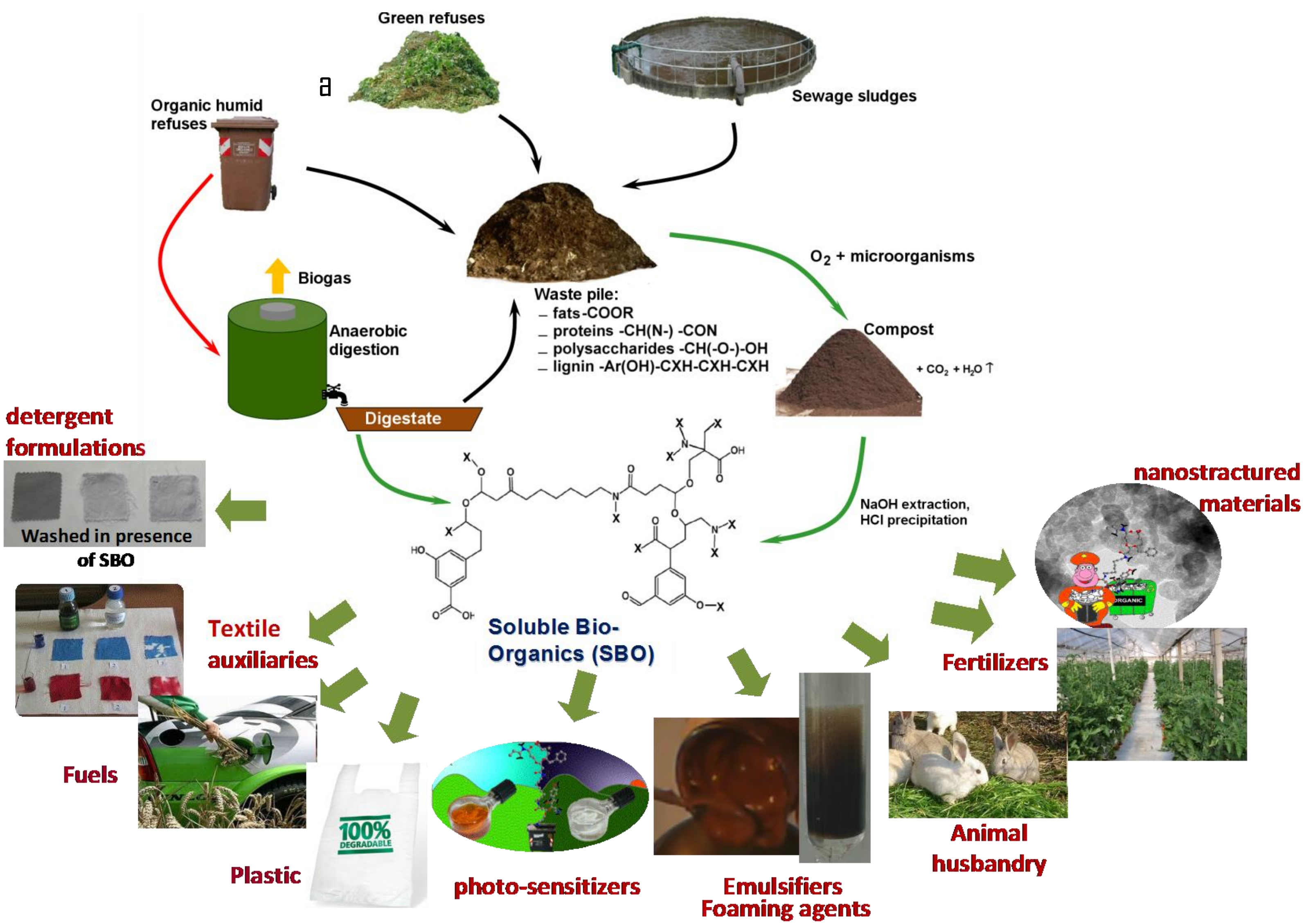
Production Figures

		2013
A.D. Line	OFMSW	49.940 ton
Composting Line	Green waste (domestic and public)	11.500 ton
Products	Biogas from digester (AD)	4.300.000 m^3
	Biogas from landfill	4.400.000 m^3
	Digestate sludge A.D.	4.950 ton
	FloraWiva Compost	5.300 ton
Energy	Electric power produced,	14,6 GWh
	Thermal power produced	16.0 GWh
	Electric power plant consumption,	8,6GWh
	Thermal power plant consumption,	3,7 GWh
	Thermal power grid consumption,	2,8 GWh
	Electric power to netwok	6,0 GWh

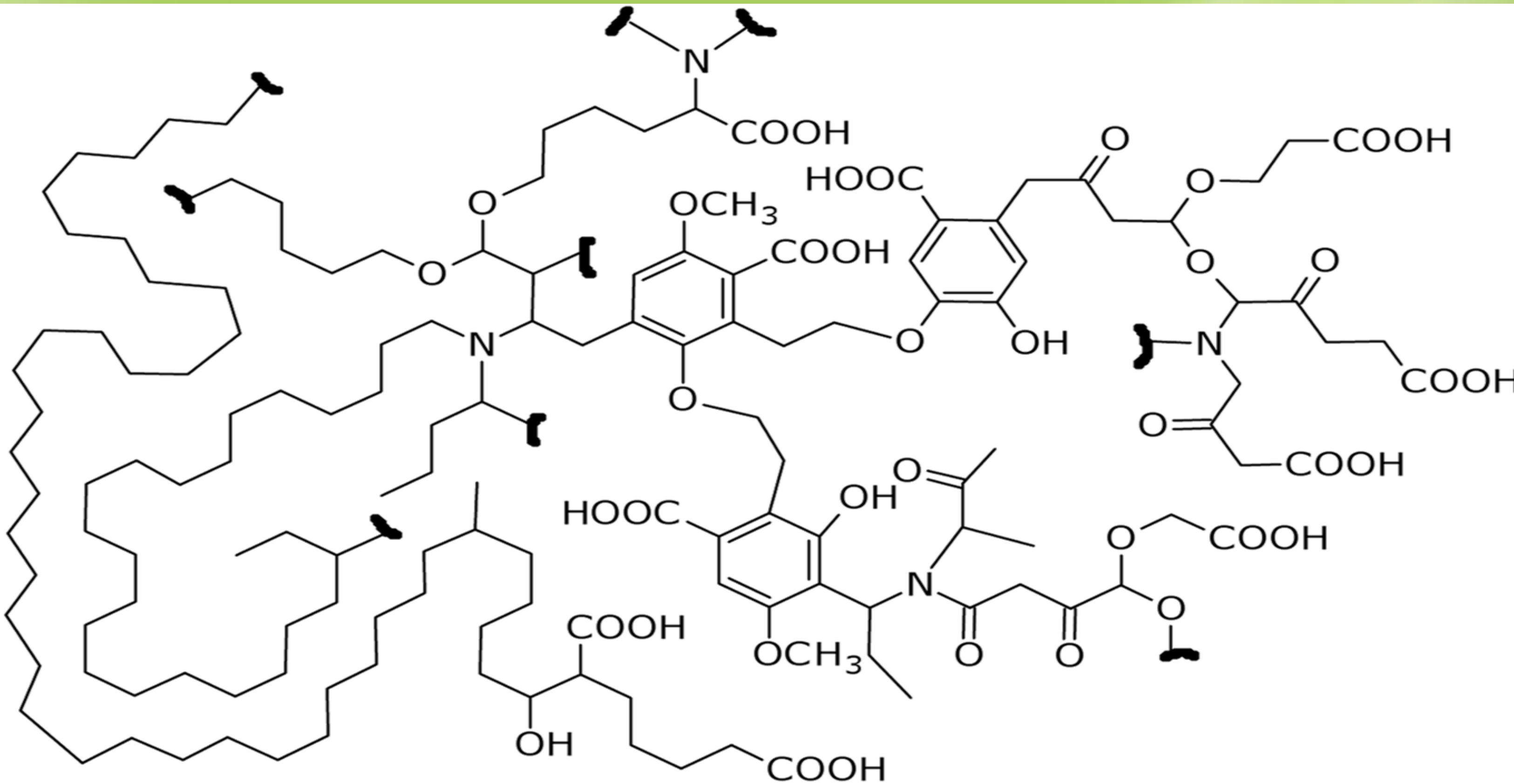
Process Cost covered in nearly equal parts by tipping fees, and by biogas and power sales

Process and Products R&D

Urban biowaste sources and bio-based products



Reason for multiple uses of hydrolysates



Virtual representation of molecular fragment for soluble hydrolysates of fermented municipal biowastes fitting analytical data for mixtures of molecules with different molecular weight (35-400 kDa) and different content of C types and functional groups, bonding mineral elements bond contained in the pristine biowastes.

Most feasible short term applications: agriculture and anaerobic digestion





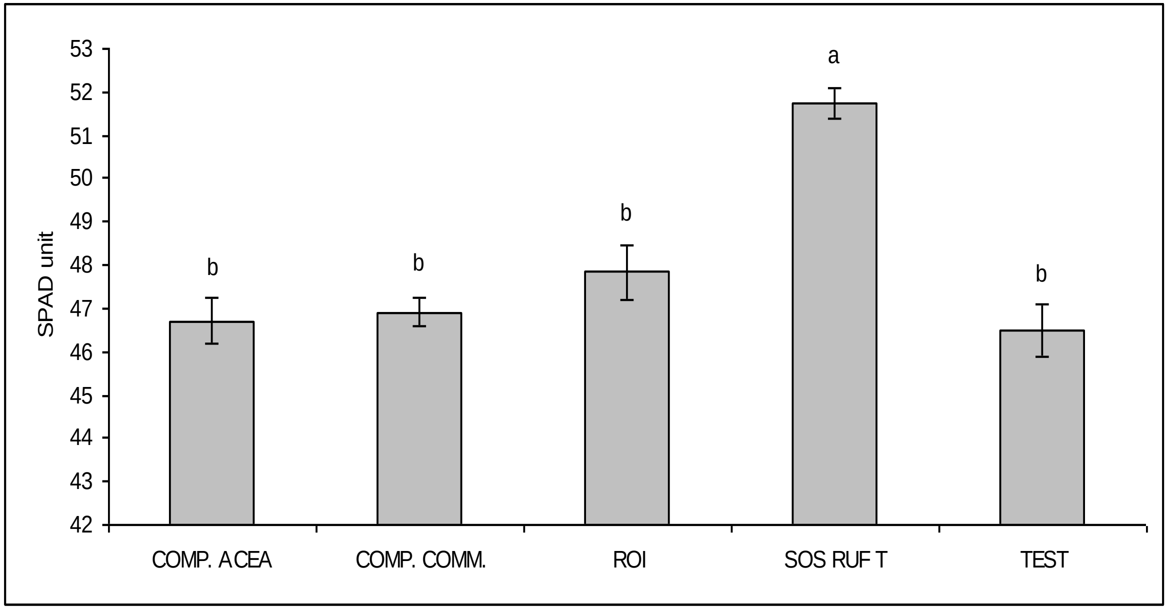




Compost Acea (CVD T 110)
ROI (CVD T 110)
Compost commerciale
SOS RUF T (CVD T 110)

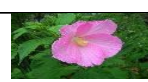
Enhanced Chlorophyll Content

In leaves of tomato plant grown at Gambuzza farm in Punta Secca (RG) on soil treated with Acea compost hydrolysate (SOS RUF T) compared to pristine compost (COMP.ACEA) and other commercial materials



Enhancement of leaves chlorophyll content accompanied by **higher plant growth**, **earlier fruit ripening** and **increased fruit productivity**. This effect is likely to result from **enhanced plant photosynthesis rate**. For **green pepper** cultivation, **90 % higher plant productivity** in soil treated with only 140 kg ha^{-1} Acea compost hydrolysate. This are rather low doses compared to 2000-3000 ton ha^{-1} for other organic fertilizers based on compost or animal manure

Crop production increments (w/w %) relative to control by hydrolysates of food waste anaerobic digestate (D), compost (CV) of vegetable matter (V) from private and public gardening, compost (CVD) of mixed D and V, compost (CVDS) of mixed D, V and sewage sludge (S), and from as collected post harvest tomato plants (TP). For rapeseed, % reduction of plant lesions due to Leptosphaeria maculans.

Plant		CVDS	CVD	CV	D	TP
Tomato Lycopersicon[2]		20	20	20		
Tomato Micro Tom[5]		46		1	16	
Pepper[3]			66			
Maize[4]		120				
Bean[7]						77-278[a]
Radish[6]						0
Wheat[5]		10		9	9	
Tobacco[5]		6		0	0	
Euphorbia[8a]		233			117	
Lantana[8b]		430			235	
Hibiscus[9]				15[b]	25[b]	
Oilseed rape[11]		56[c]			42[c]	

Effect of compost hydrolysates (SBO) on anaerobic digestion processes

Anaerobic Digestion.
A virtuous cycle: improving biowaste anaerobic digestion by hydrolysate isolated from the composted digestate.

Product In-house use

Main issues:

- **enhancing the biogas CH_4/CO_2 ratio**
- **reducing ammonia in the digestate**

Process Scheme

Organic humid fraction (OHF) $\Rightarrow$ biogas + digestate $\Rightarrow$ compost $\Rightarrow$ SBO

OHF + SBO (0.05-2 %) $\Rightarrow$ **4 % more biogas + no ammonia production**

Norg $\Rightarrow N_{NH4} \Rightarrow N_2$

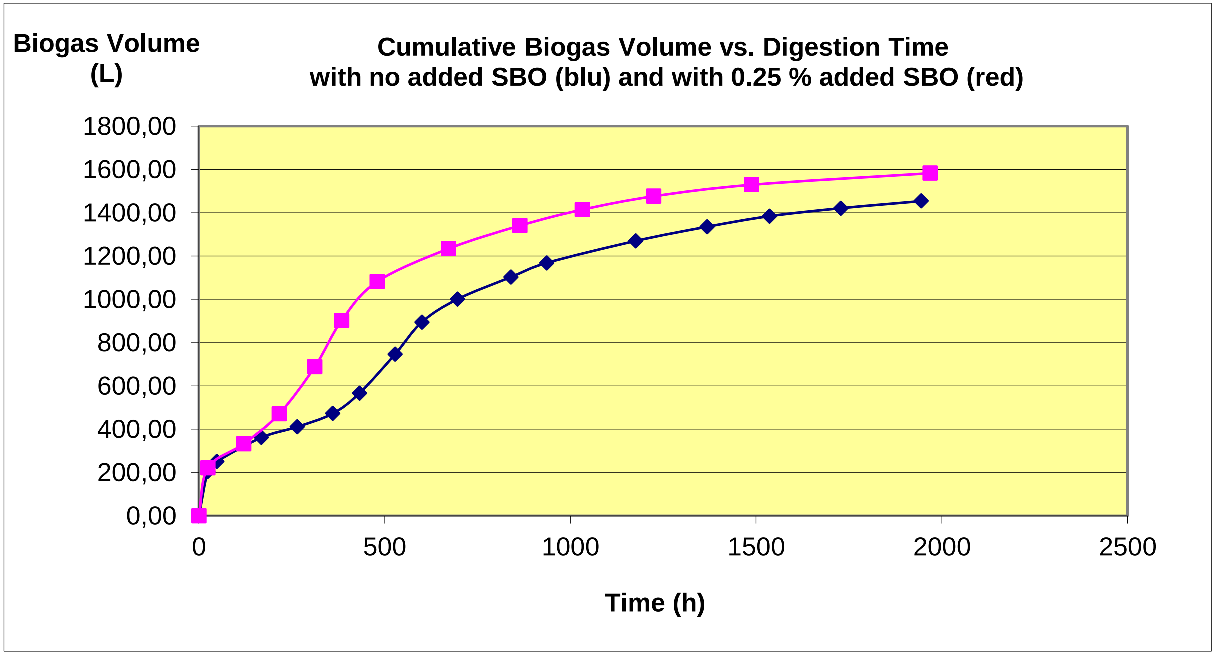
enhanced oxidation of ammonia to elemental nitrogen by hydrolysate, leading to ammonia abatement = 83-133 % of the total ammonia initially present in the feed slurry and the produced amount during fermentation in absence of hydrolysate

Hydrolysates (SBO) modulators of the anaerobic fermentation of the organic humid fraction of urban refuse

Reduction of the digestate ammonia content

	No added hydrolysate	0.25 % added hydrolysate
Ammonia N in (g)	109.8	65.4
Ammonia N out (g)	197.1	3.4
(N out-N in)/Nin %	80	- 95

Increase of biogas production



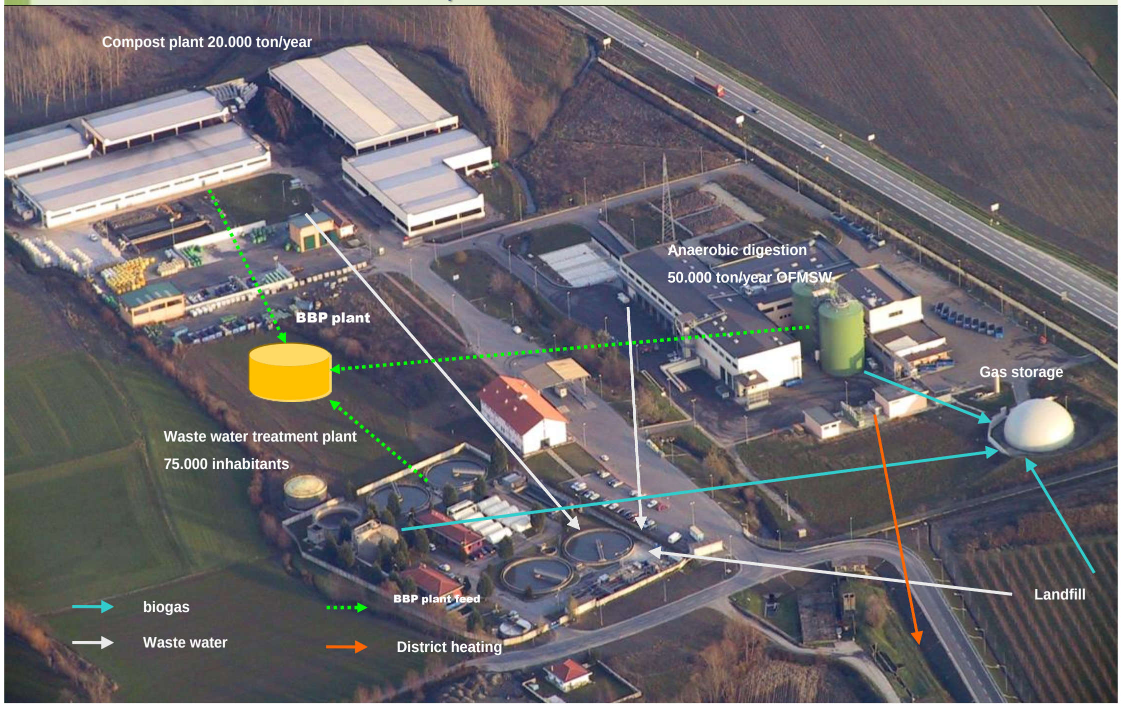
Economic Impact of Biogas Production Technology Assisted by Compost Hydrolysate. The Acea Pinerolese case study

	Amount, ton/yr	**N $(NH)_4$ abatement cost, €/yr**	**Facility capital cost**
Organic humid fraction slurry feed to bioreactors	100,000		
N$(NH)_4$ amounts in feed	126		
N$(NH)_4$ amounts in digestate	156		
N$(NH)_4$ production	30		
N$(NH)_4$ abatement by 0.05 % added hydrolysate	25		
Required hydrolysate	50	**5,000-25,000**	**200-300 k€**
Cost of N$(NH)_4$ abatement by conventional technology, 1.4 €/kg		35,000	1-2 million €

Advantages of hydrolysate assisted vs conventional technology

- **5000-30000 €/yr lower operational cost**
- **5-10 fold lower capital cost**
- further potential benefits from hydrolysate sales for other uses

Case Study: Integrating the bio-based products (BBP) plant into Acea Pinerolese urban wastes treatment plant in Pinerolo (TO). Energy and material flow among the four compost, anaerobic digestion, waste water treatment and landfill current plant sections and the new virtual BBP production unit.



Plant integrating fermentation and compost chemical hydrolysis will start July 2018 processing 2000 compost t/yr and yielding 200-800 t/yr hydrolysate

Virtuous cycle

1. Organic humid fraction to anaerobic digestion reactors.
2. Digestate + green wastes to composting
3. Compost to hydrolysis facility (**yellow cylinder in Figure**) producing the hydrolysate
4. Hydrolysate to biogas production reactor

Results

Enhanced biogas production and digestate with reduced ammonia content

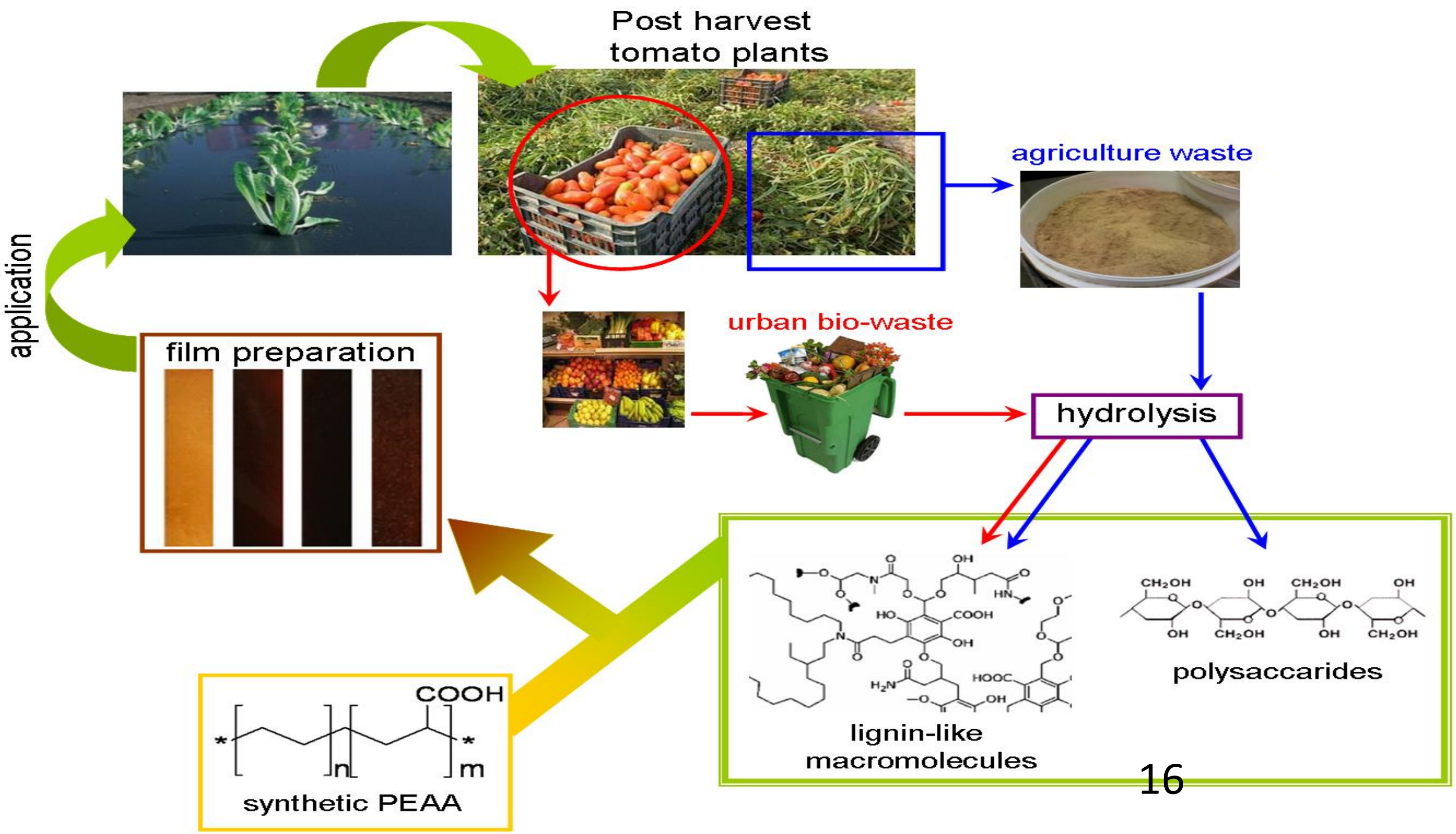
In-house use = No market risk.

The Biochemical-Chemical Integrated Plant operating July 2018 will allow

Moving Forward with Limited Risk

1. Produce hydrolysate in excess of amount needed for in-house use
2. Run marketability tests in real operational environment for hydrolysate use in agriculture. Produce formulates for specific plant effects
3. Scale up hydrolysis facility according to agriculture market assessment results
4. Invest in further R&D to develop new products

Example: mulch films with enhanced mechanical strength and reduced cost



Variability of hydrolysates and sourcing biowaste composition

Sourcing biowaste (SB)	SB		Hydrolysate	
	C %	C/N	C %	C/N
Raw food waste (RFW)	40.6	31.2	64.6	9.2
Digestate D15	31	9.7	54.0	7.2
Digestate D28	16.2	20.2	48.7	8.3
Compost D28 and gardening residues (GR)	32.1	14.0	53.5	8.4
Compost RFW-GR 90	32.5	9.1	54.0	8.3
Compost RFW-GR 110	26.9	10.0	47.9	7.6
Compost D15+GR+sewage sludge (SS) 110	21.8	10.4	49.1	7.5
Compost GR270	11.6	12.9	42.5	12.2
CompostGR360	7.9	11.8	42.0	11.1
Mean and sd as % of mean value	24.5 ± 44.4 %	15.5 ± 45.3 %	50.7± 13.5 %	8.9 ± 19.1 %

Compared to sourcing biowastes, hydrolysates have higher C content and lower compositional variability.

Hydrolysates (SBO) are rich both in organic and in mineral elements, which can make them competitive with current commercial fertilizers.

Table 2. Analytical data for SBO according to Montoneri et al (2011a)

SBO	pH	Volatile Solids, w/w %[a]	C, w/w %[a]	N, w/w %[a]	C/N
FORSUD	6.4	84.6	45.07 ± 0.12	7.87 ± 0.12	5.73
CVD	8.8	71.7	37.51 ± 0.04	4.89 ± 0.03	7.67
CVDF	8.2	72.7	35.47 ± 0.09	4.34 ± 0.17	8.17
CV	8.2	72.1	38.25 ± 0.09	4.01 ± 0.03	9.54
CVF	8.7	72.2	37.35±0,38	4.80±0,07	7.78

	Mineral elements: Si, Fe, Al, Mg, Ca, K, Na as % w/w;[1] Cu, Ni, Zn, Cr, Pb, Hg as ppm[a]												
	Si	Fe	Al	Mg	Ca	K	Na	Cu	Ni	Zn	Cr	Pb	Hg
FORSUD	0.36	0.16	0.78	0.18	1.32	9.15	0.39	100	27	185	11	44	0.23
	±0.03	±0.00	±0.04	±0.01	±0.05	±0.06	±0.01	±1	±1	±4	±0	±2	±0.01
CVD	2.49	0.88	0.60	0.93	4.70	3.76	0.17	249	97	427	27	99	0.26
	±0.04	±0.02	±0.06	±0.02	±0.08	±0.07	±0.01	±2	±2	±2	±2	±1	±0.01
CVDF	0.92	0.53	0.44	0.49	2.59	5.49	0.15	216	71	353	30	75	0.45
	±0.03	±0.02	±0.02	±0.01	±0.03	±0.04	±0.01	±1	±0	±3	±1	±1	±0.02
CV	2.55	0.77	0.49	1.13	6.07	3.59	0.16	202	92	256	19	85	0.15
	±0.01	±0.04	±0.04	±0.06	±0.38	±0.21	±0.01	±4	±1	±1	±1	±1	±0.02
CVF	2.45	0.83	0.48	1.00	4.88	3.54	0.17	255	79	457	21	93	0.36
	±0.01	±0.01	±0.03	±0.01	±0.14	±0.02	±0.01	±2	±1	±8	±1	±2	±0.04

	C types and functional groups[b] concentration as mole fraction of total organic C												
	Af	NR	OMe	OR	OCO	Ph	PhOH	PhOY	COOH	CON	C=O	Af/Ar	LH
FORSUD	0.43	0.10	0.04	0.10	0.03	0.10	0.02	0.01	0.07	0.09	0.01	3.3	9.3
CVD	0.41	0.07	0.00	0.15	0.04	0.12	0.03	0.03	0.10	0.03	0.02	2.3	5.2
CVDF	0.31	0.08	0.00	0.20	0.07	0.16	0.06	0.02	0.09	0.01	0.00	1.3	5.3
CV T230	0.37	0.07	0.00	0.14	0.04	0.13	0.05	0.02	0.12	0.01	0.05	1.8	3.6
CVF	0.37	0.03	0.05	0.17	0.05	0.14	0.04	0.03	0.12	0.00	0.01	1.8	4.9

[a]Concentration values referred to dry matter: averages and standard deviation calculated over triplicates.

[b]LH = liphophilic to hydrophilic C ratio; liphophilic C = sum of aliphatic (Af), aromatic (Ph), methoxy (OMe), amide (CON), ammine (NR), alkoxy (RO), phenoxy (PhOY) and anomeric (OCO) C atoms; hydrophilic C = sum of carboxylic acid (COOH), phenol (PhOH) and ketone (C=O) C.

Bio Chem Energy

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Effects of different hydrolysates on different plants

Major differences are exhibited by hydrolysates obtained from digestate (DH) versus composts (CH), rather than by hydrolysates obtained from different composts (CV, CVD, CVDF, CF).

Effects' differences depend on plant species

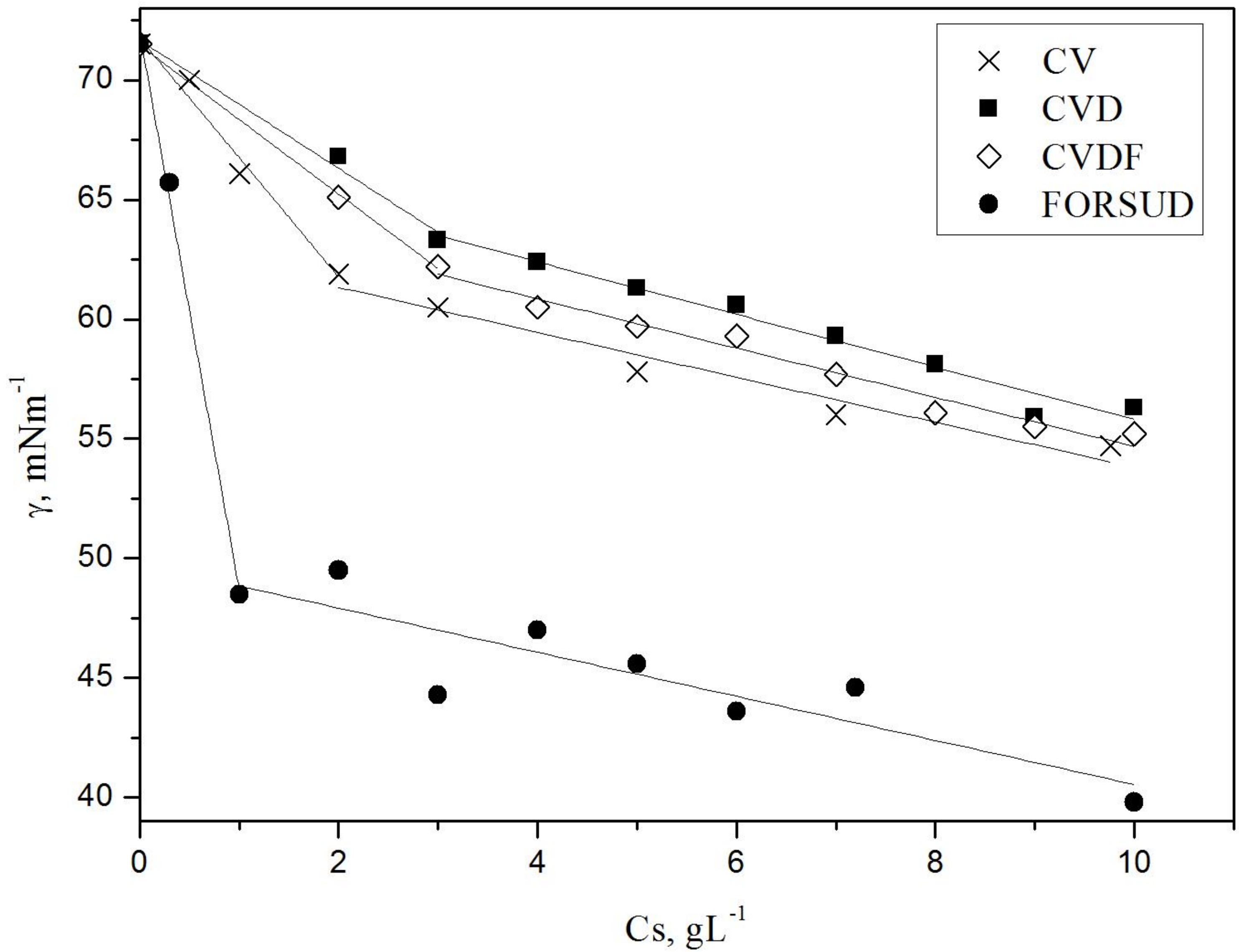
Examples:

On Euphorbia, DH > CVDFH

On Tomato, CVH > DH

On Hybiscus, DH = CVH

Effects of different hydrolysates from digestate (FORSUD) and composts (CV, CVD, CVDF) on water surface tension

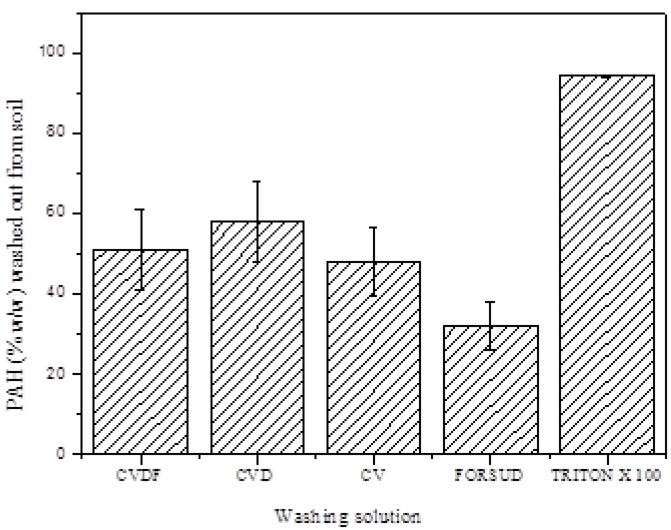


Hydrolysates Performance in Other Applications

Hydrolysates from digestate yield composite mulch films with better mechanical performance than compost hydrolysates

Hydrolysates from digestate enhance ammonia production in anerobic fermentation, while compost hydrolysates reduce digestate ammonia content

Hydrolysates from compost are more efficient than hydrolysates from digestate in removing PAHs from soil by soil washing



Coping with variability of biowastes due to seasonal and geographical differences

The availability of biowastes from different sources allows obtaining a wide range products that can be tailored to specific applications.

The variability of the hydrolysates chemical composition as a function of the sourcing materials allows to make mixtures to obtain end products with constant reproduceable specifications and performance.

Final assessment to be achieved by prototype plant operating in July 2018 at the Acea site. It will process biowastes collected over the four yearly season, and from Italy, Greece and Cyprus. The process will operate in continuous mode, which allows continuous monitoring of process and products yield and quality.

Regulatory Requirements

Based on chemical composition, sourcing material and production process, the hydrolysates fall well into the category of fertilizers according to the Italian legislation (DL 29 aprile 2010 n. 75). Thus, product registration in the Italian Fertilizers Registry from the Ministry of Agriculture is feasible.

Moreover, the University of Torino has demonstrated the efficacy and safety of the hydrolysates for use in agriculture and in rabbits and pigs diet.

References:

1. Biagi D, Gasco L, Rosato R, Peiretti PG, Gai F, Lazzaroni C, Montoneri C, Ginepro M, Anim Feed Sci Tech 2016, 214, 66-76.

2. Montoneri E, Efficacy of alkaline extract from municipal biowaste compost as piglets feed additive, 2011, unpublished report.