More than 12 years of experience with commercial anaerobic digestion of the organic fraction of municipal solid wastes in Switzerland

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Abstract: In Switzerland, the first anaerobic digestion plants for the treatment of organic fraction of municipal solid waste (OFMSW) were built in the early 90-ies. By the end of 2005, 15 commercial full size plants will treat yearly about 100'000 tons of source separated biogenic waste. In addition, there is a large number of agricultural and municipal codigestion plants. Data on performances, yields and utilisation of the products are given on 7 Kompogas-plants (horizontal plug flow design), 2 Dranco-plants (vertical plug flow reactor), 1 BRV-plant (horizontal, rectangular reactor; not completely mixed), 1 Valorga-plant (vertical completely mixed design) and 1 ROM-plant (mixed sequential batch reactors). The horizontal design shows considerable advantages in comparison with the vertical one, causing less clogging and sedimentation problems. One ton of Swiss mixed biogenic waste will produce between 90 and 150 m^3 biogas in a well working plant, depending mainly on substrate properties. The sequential batch plant is more sophisticated than simple solutions and shows high yields at high loading rates, at higher energetic and economic costs, though. There are plants heated by the lignified overflow of waste screening which sell over 600 kWh energy per ton for driving cars. Kompogas has developed a new generation of digesters that treat one ton of OFMSW for only 30-50 € (excl. land price). Now, biogas from OFMSW is an approved, cost-effective and environmentally safe technology.

Keywords: biogas car, comparison, digestion, economy, full size, fuelling, OFMSW, operation, organic fraction of municipal solid waste, process technology, running parameters, gas yield

Introduction

Ducellier and Isman (*1955*) started to build first solid waste batch digesters in northern Africa and France already before world war II. Their experience led to the first „Swiss“ solid waste digesters, which were built in Rwanda 1982 (*Edelmann et al., 1983*). The plant consisted of three unheated, rectangular batch-reactors of 20 m^3 each covered by a plastic membrane with gas storage in an extra balloon. This installation supplied the energy to cook the meals of a large agricultural school for over ten years until the time of the civil war in Rwanda.

In Switzerland itself, the development of Dranco, Valorga and BTA-plants happening abroad was followed with interest in the 80-ies. However, solid waste digestion had not yet a high priority. At the end of the 80-ies, many large composting plants had been built mainly for the treatment of wastes from gardens and landscape. TVA (*Schweizerische Bundesbehörden, 1990*), i.e. a new law on the treatment of waste, suggesting the recycling of the different separately collected waste fractions whenever possible, as well as a congress on solid waste digestion in Basel *(ANS; 1989)* led to an increased interest on the possibilities of OFMSW-digestion. Especially the fact that also kitchen wastes started to be collected separately at that time, caused odour problems in composting plants and hence civil protests from their neighbourhoods. W. Schmid, an important Swiss contractor, decided to develop his own, privately financed digestion process which was named later "Kompogas". Furthermore, different research projects started in the early 90-ies, such as a feasibility study of OFMSW-digestion (*Edelmann et al., 1991*), digestion of silage and other agricultural solid waste in the Anacom process (*Baserga et al., 1994*), two step/two phase digestion of OFMSW (*Edelmann et al., 1999*) or the construction of a large (heated) pilot plant for the batch codigestion of agricultural and municipal wastes similar to the Rwanda-plant (*Membrez, 1998*).

The construction of full size plants was not easy at the beginning due to the fact that composting in commercial plants had a head start of about ten years. Therefore, the philosophy was to propagate first combined plants for composting and digestion (*Edelmann and Engeli, 1992*). Later, the insight into the advantages of AD resulted in legal changes in Canton Zurich requiring by law to take advantage of renewable energy whenever technically and economically feasible (Kanton Zürich; 1983, 1994). This caused an improved situation for AD. At the same time, works started in order to find solutions for non-urban regions also, such as codigestion of OFMSW in digesters of municipal sewage treatment plants (*Edelmann et al., 2000*) or in agricultural codigestion plants.

Today, regions such as Basel or the Italian part of Switzerland, which were placing much emphasis on composting, are opening up to AD also. Actually, more than a dozen large plants for AD of OFMSW are operating in Switzerland and several plants are under construction or in planification. In addition, a considerable number of agricultural and municipal codigestion plants have been built during last decade (*Swiss Biogas Forum, 2005*). This paper focuses on the commercial Swiss plants for AD of the organic fraction of municipal solid waste.

Technologies used in Switzerland

Besides agricultural and municipal codigestion of OFMSW, industrial digestion plants with technologies of BRV, DRANCO, KOMPOGAS, ROM and VALORGA are operated in Switzerland. Here, a short overview is given on the general features of the technologies, the process developments as well as on bottlenecks.

BRV: BRV built one plant, i.e. the Allmig plant already in 1994. It's a thermophilic horizontal digester, which shows plug flow characteristics to some extent. Because the horizontal cylinder was protected by a patent of KOMPOGAS, the BRV-reactor was built with a rectangular cross section. This shape has the disadvantage that it is not possible to stir the content with a longitudinal axis equipped with lateral arms, such as used by KOMPOGAS: The stirring had to be managed with four transversal axes, a fact which causes a mixing for and backwards in flow direction hampering an ideal plug flow of the substrate (cf. Figure 1).

Because there was still a certain feeling of insecurity regarding solid waste digestion at that time, the owner of the plant wanted to realise only a small plant investing mainly into a large fully enclosed composting plant. So the Allmig plant is not equipped neither with liquid/solid separation after digestion nor with re-inoculation. Therefore, the relatively wet digester output, which is not mixed – as recommended - with old, but with fresh composting material, limits the treating capacity of the digester: If too much (wet) material is digested, the compost may become too wet for an appropriate aerobic treatment, a fact which makes an optimal reactor loading impossible.

The plant worked without any major problems – at relatively low loading rates – until spring 2005. Then there was an incident: After having modified the software for operation of composting and digestion, the automated operation was started again just before the weekend. By mistake, the operator programmed 57 minutes of digester feeding and 3 minutes of rest instead of the contrary, with the effect that the reactor was mechanically overloaded. Because the safety devices did not respond, there resulted an overpressure that expanded the whole digester. For repair the digester had to be emptied and opened. On this occasion it was realised, that there was quite a lot of sediment inside the reactor. One reason might be the fact that parts of the frame for sediment discharge, transporting the sediment at the flat bottom of the reactor towards a screw for exportation (cf. Figure 1), were broken.

DRANCO: Two DRANCO-plants were built by Alpha Nidau AG in 1998 and 1999 in Central and Western Switzerland, respectively. Typical for the Dranco process is a vertical thermophilic plug flow reactor including re-inoculation of the fresh material with digested slurry. The DRANCO-process ("DRy ANaerobic COmposting") was already developed in the 80-ies with an excellent scientific follow up by the research group of W. Verstraete and L. de Baere in Belgium (*de Baere et al., 1986*).

The substrate is fed at the top of the cylindrical reactor and exported at the bottom. First, for the export of the output there was a mobile frame for discharge at the digester bottom. Plants built more recently export the digested slurry through a conical funnel (45°) at the bottom. This solution seems to be problematic especially with substrates containing also fibrous wastes from gardens, such as collected normally in Switzerland: Both Swiss plants worked just a few months in 2004 because of clogging problems, which caused long interruption periods for repair. Clogging seems to happen especially in plants with a relatively wide reactor diameter in comparison with its height. In the “Aarberg”-plant (Figure 2), actually the feeding diet was changed to more easily degradable, well chopped material. However, because of quicker acidification, this led to a reduction of the loading rate. In addition to the clogging, the Aarberg-plant lost a significant amount of gas at the transition from cylinder to roof, which prolonged the time-out for repair works.

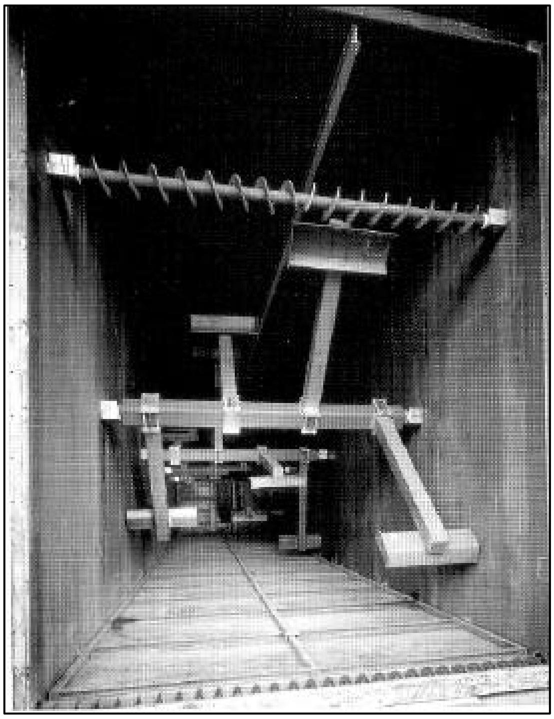

Figure 1 (left): View from the gable end into the open BRV-digester: transversal stirring axes, sediment removal frame

Figure 2 (right): The Aarberg DRANCO-plant: vertical design

KOMPOGAS: Since 1990, KOMPOGAS-plants were erected at 9 sites in Switzerland and at 13 sites abroad in Europe and overseas. The KOMPOGAS technology consists of a horizontal, cylindrical digester for thermophilic plug flow digestion stirred gently at intervals by a longitudinal axis. A part of the digested slurry is used for mashing and inoculation of the fresh material fed into the reactor.

Most of the different plants differ somewhat from each other, because there has been a continuous process of process development. Except three digesters made out of concrete, the Swiss reactors are steel constructions; at actual steel prices as well as for large reactor volumes it seems to be more reasonable to use concrete for reactor construction, though. At the beginning, the reactors were placed inside buildings (Figure 3). In order to save building area, the substrate was moved over several floors for sorting out unwanted items, chopping, screening and eventual storing in a underground bunker. Today, the process is optimised and reduced to its indispensable parts: the reactors are placed outside (Figure 4) and pre- and post-treatment are placed on one level in a (inexpensive) hall equipped with a biofilter. However, this configuration needs some additional space. Some new plants feeding gas into the public pipeline use the lignified sieve overflow for heat production, what increases the amount of gas to be sold.

All Swiss KOMPOGAS-plants work(ed) without any major problems. However, it has to be stressed, that it is important to feed an appropriate mixture of wastes. This may be for example a mixture of easily degradable kitchen, food and industrial wastes combined with wastes from the gardens including also small lignified particles, such as collected normally in Switzerland. Outside Switzerland, some KOMPOGAS-plants operate also with wastes, which are not source separated. In Kempten, Germany, a KOMPOGAS-plant was run nearly exclusively with protein-rich food wastes first. There, inhibition occurred due to high ammonia concentrations. In other plants very high proprionate concentrations were observed without significant inhibition, though. The horizontal design with an agitation only right-angled to flow direction, guarantees a very good plug flow behaviour, as long as the substrate shows a total solids content, which is high enough (>~20%). Therefore, an appropriate re-inoculation of the fresh material is necessary in order to impede acidification and exportation of the methanogenic biocenosis. The KOMPOGAS-process runs very stable: The horizontal design seems to be advantageous regarding clogging and sedimentation as well as referring to optimal degasification of CO_2 effected efficiently by the lateral arms for agitation.

Figure 3: The "Samstagern"-plant is located in an industrial zone inside a building (centre) of several floors, equipped with biofilters.

Figure 4: New modular KOMPOGAS-plants are put up outside, enclosing for waste air treatment just the parts producing bad odours.

ROM: The ROM-plant is composed of one hydrolytic vessel and three stirred anaerobic sequential batch reactors, which run at thermophilic temperature. The Frauenfeld-plant is the first anaerobic ROM-plant; today, the number of the methanogenic reactors has been reduced to 2. The fresh substrate undergoes a hydrolysis and is pumped batchwise through the rectangular methanogenic vessels (Figure 5). This prevents short circuits and guarantees optimal hygienic conditions. There are connections between all vessels allowing re-inoculation as well as providing different options, should an intervention be necessary. The ROM-plant is capable of handling a wide variety of substrate combinations with total solid contents from liquid up to ~35% TS.

Figure 5: The four vessels of the ROM-sequential batch plant conjoined by a sophisticated piping (located inside a building).

Figure 6: The VALORGA-plant of Bernex, Geneva: A cylindrical digester with a volume of 1000 m^3 treats easily digestible wastes on a composting plant.

VALORGA: The only VALORGA plant was built in 2000 in Bernex treating OFMSW of Geneva (Fig. 6). The thermophilic digester is a large vertical cylinder which is completely mixed by blowing gas through valves at the reactor bottom. In 2003/04 however, the operation was stopped for ~8 months because of large quantities of sediments (sand, gravel etc.) in the lower part of the reactor, hampering the function of the mixing equipment and reducing the active volume of the digester significantly. The reactor had to be opened and emptied with devices suited for heavy duty applications.

Overview on the performance of Swiss commercial plants

Table 1 shows plant operation data of the Swiss commercial biogas plants referring to the year 2004. No data are available yet on the new KOMPOGAS-plants which started to operate in Jona (420 m^3) and Lenzburg (330 m^3) in 2005. Additional plants are under construction or planned in Ottenbach, Pratteln (Basel), Utzensdorf and near Locarno. By 2006, nearly 10'000 m^3 digester volume for AD of OFMSW will be available in Switzerland. Additional data on the Swiss plants (flow sheets, pictures etc.) can be found on www.biogas.ch/anlagen.htm and www.kompogas.ch/en/.

Site	Design	Vol. [m^3] (reactors)	Waste [t FS/a]	Gas Yield [m^3brut/a]	Energy [MWh/a]	Gas/Vol [m^3/m^3*d]	LR (OS) [kg/m3.d]	Gas/OS [l/kgOS]	Gas/FS [m^3/t]
Rümlang	KOMPOGAS	454 (2)	8'460	1'234'831	7'162	7.5	12.3	608	146
Allmig, Baar	BRV	500 (1)	3'150	284'000	1'647	1.6	4.1	376	90
Bachenbülach	KOMPOGAS	812 (3)	13'577	1'565'361	9'079	5.3	11.0	480	115
Samstagern	KOMPOGAS	512 (2)	9'377	893'944	5'185	4.8	12.0	397	95
Otelfingen	KOMPOGAS	780 (1)	13'814	1'639'904	9'511	5.8	11.6	495	119
Niederuzwil	KOMPOGAS	790 (2)	11'399	1'043'286	6'051	3.6	9.5	381	92
Aarberg *	DRANCO	800 (1)	785	83'000	481	0.3	0.6	441	106
Frauenfeld	R.O.M.	178 (4)	4925	618'000	3'584	9.5	18.2	523	125
Villeneuve *	DRANCO	800 (1)	~4'000	193'000	1'119	0.7	3.3	201	48
Volketswil	KOMPOGAS	290 (1)	~7'500	461'000	2'674	4.4	17.0	256	61
Bernex, Genf *	VALORGA	1'000 (1)	4'750	344'000	1'995	0.9	3.1	302	72
Oetwil am See	KOMPOGAS	740 (1)	10'366	1'192'000	6'914	4.4	9.2	479	115

Table 1: Plant operation data of Swiss commercial biogas plants in 2004. *): plants were out of order for several months in 2004 due to clogging and/or sedimentation problems. Energy/a: estimated with 5.8 kWh/m^3 gas; OS = organic substance: estimated with 24% OS of fresh substance (FS)

The amount of gas produced per ton of waste depends on different factors, such as amount of waste available, i.e. loading rate, composition of the waste (shares of kitchen and garden wastes) and process technology. The productions of normally running plants vary between about 90 and nearly 150 m^3/t of fresh substrate (Table 1, right). Despite of a very high loading rate, KOMPOGAS Rümlang shows the highest yield per ton of waste (146 m^3/t). This is the oldest plant with a balanced, well adapted biocenosis and operated with a lot of experience. The main reason for the high yield is the addition of fats and oils depending on the share of garden wastes. A significant amount of oil addition is not typical for the other plants resulting in lower yields. Kompogas Volketswil, on the other hand, seems not to be run optimally: If the data provided by the private operator are correct, this plant is overloaded (estimated LR: 17 kg OS/m^3.d). Overloading seems also to be probable – even if less than the postulated 7'500 tons were fed - because a relatively poor gas composition has been reported (higher share of CO_2 in the gas freed by hydrolysis; reduced methanogensis).

The loading rates in table 1 are just estimated (assumptions: TS of the waste: 30%, OS of TS: 80%, i.e. OS = 24% of FS). In Rümlang, OS may be a bit higher due to addition of fatty products, what would reduce the gas yield per kg of OS and increase the LR to some extent, respectively. Nevertheless, it can be said that optimal loading rates for KOMPOGAS-plants are in the range of about 12 kg OS/m^3.d. The ROM-plant, on the other hand, is capable of managing a LR of over 18 kg OS/m^3.d with a high gas yield due to the local separation of acidification and methanogenesis. The specific daily production of 9.5m^3/m^3 reactor is high because of the volume reduction achieved by 2-stage digestion. The yearly energy productions may be not 100% accurate, because they were just calculated with a mean energy content of 5.8 kWh/m^3 biogas.

Utilisation of the products

Table 2 shows the year of construction and the amount of energy sold by the commercial Swiss biogas plants. Electricity, heat and car gas as well as "Energy/t" refer to the amount of energy sold to third parties, i.e. surplus energy after deduction of the plants own needs and losses due to efficiency factors. Gas for cars is cleaned and sold at local KOMPOGAS-fuelling stations (Rümlang, Bachenbülach, Otelfingen) and/or fed into the public gas pipelines (Bachenbülach; also in Samstagern, where the gas cleaning devices, however, were not in use in the year 2004).

Site	Design	Start	**Vol.** [m^3] (reactors)	**Waste** [t/a]	**Gas Yield** [m^{3}brut/a]	**Electricity** [MWh/a]	**Heat** [MWh/a]	**Car Gas** [MWh/a]	**Energy/t** [kWh/t]
Rümlang	KOMPOGAS	1992	454 (2)	8'460	1'234'831	1'090	162	496	207
Allmig, Baar	BRV	1994	500 (1)	3'150	284'000	387	(410)		123
Bachenbülach	KOMPOGAS	1994	812 (3)	13'577	1'565'361	-		8'602	634
Samstagern	KOMPOGAS	1995	512 (2)	9'377	893'944	1'106			118
Otelfingen	KOMPOGAS	1996	780 (1)	13'814	1'639'904	2'117		471	187
Niederuzwil °)	KOMPOGAS	1997	790 (2)	11'399	1'043'286	1'729			152
Aarberg *)	DRANCO	1998	800 (1)	785	83'000	61			78
Frauenfeld	R.O.M.	1999	178 (4)	4'925	618'000	424			86
Villeneuve *)	DRANCO	1999	800 (1)	~4'000	193'000	446			112
Volketswil	KOMPOGAS	2000	290 (1)	~7'500	461'000	598			80
Bernex, Genf *)	VALORGA	2000	1'000 (1)	4'750	344'000	457			96
Oetwil am See	KOMPOGAS	2001	740 (1)	10'366	1'192'000	1'094			106

Table 2: Data of Swiss commercial biogas plants in 2004. Electricity = produced in a cogenerator and sold to the local electricity network, Heat = heat sold to external users, Car gas = energy fed into public gas pipelines or sold for fuelling cars at the plant itself. Energy/t = energy sold. *): plants were out of order for several months in 2004 due to clogging and/or sedimentation problems. °): one of the two reactors was stopped and broken down in late autumn to give room for a new, larger reactor.

After experiments with a smaller pilot plant in 1992 the first KOMPOGAS digester with a volume of 160 m^3 started to produce gas in Rümlang. Likewise at different other sites, this plant was extended later by an additional digester (290 m^3). The second Swiss biogas plant was built by BRV in Baar (Canton Zug). This was originally a composting plant with odour problems. Because AD was new at that time, it was recommended by "arbi" to construct a combined plant with a share of 60% AD and 40% composting. Nevertheless, the uncertainty about solid waste digestion led to a solution with only around 20% AD. Allmig treats about 18'000 tons of organic material per year and it uses all AD surplus heat for heating the fully enclosed composting hall, which is aerated by 40'000 – 70'000 m^3 of air per hour. The preheating of this air is a big advantage since there is no condensation inside the building and therefore significantly less corrosion of the machinery as compared to conventional enclosed composting plants. The heat amount is given in parenthesis because it's sold internally "from digestion to composting".

The KOMPOGAS-plant of Bachenbülach was extended by additional digesters also. Originally, the gas was used for cogeneration. Today, the whole gas production is cleaned and fed into the public gas pipeline, thus showing the best cost/benefit rate. Therefore in 2004, Bachenbülach was able to sell net 634 kWh methane per ton of waste treated. This is over three times more than the energy sold by the other plants producing electricity by cogeneration: These plants sold between ~100 and 207 kWh/t, at higher prices per kWh for electricity, though. Despite of the fact, that with well designed commercial AD-plants practically no odour problems exist and that some KOMPOGAS-plants are located within industrial zones in the neighbourhood of other commercial buildings (Figure 3), the selling of the cogeneration waste heat is not an easy thing: Only KOMPOGAS Rümlang is able to sell heat to a large car repair shop nearby. Some plants, such as ROM, have a high requirement for on-site power for the biogas plant itself and/or the subsequent post-treatment of the products (production of high quality composts), what reduces the amount of energy sold externally.

Selling cleaned gas becomes ever more interesting: The full energy content of the gas may be used, a fact which produces less waste heat, i.e. less energy loss. The biogas cleaning step needs less than 10% of the biogas energy content (different technologies). Today, on the Swiss market there is a large fleet of different cars and commercial vehicles, modified for biogas use, that are available. The additional investment for upgrading the car is paid back soon by the cheaper price of biogas in comparison to conventional fuel. The network of fuelling stations is growing fast, because biogas cars show the lowest environmental impacts of automotion (cf. www.kompogas.ch/en/).

After liquid/solid separation, compost is produced by an aerobic post-treatment, which lasts between 10 days and several weeks depending on the desired compost quality and the process technology, respectively. The ordinary compost quality, i.e. for application in agriculture, is supplied free of charge to the farmers. Some plants provide even machinery for compost application gratis. However, higher qualities, i.e. longer post-treatment and mixtures with other substrates, may cost. The liquid part of liquid/solid separation shows a very good quality including a high nutrient content (*Edelmann, 2002*) and is given to farmers for irrigation and fertilisation purposes. As such it is certified for the cultivation of "bio-products". Today, in Switzerland the agricultural application of sewage sludge has been forbidden due to undesired compounds, such as hormones etc.. This seems to have a positive effect on the market for composts and liquid fertilisers.

For urban sites, where agricultural land to bring out the liquid is missing, a technology for complete cleaning of the liquid phase by nitrification/denitrification and membrane technology has been contrived (*ibidem*). At the same time, KOMPOGAS has developed a technology to clean the water by aquaculture, i.e. by growing algae, fish, crabs, salads and vegetables inside greenhouses using waste heat and CO_2 of cogeneration and treating the water in a succession of ponds, where the nutrients are converted into new, saleable biomass (*ibidem*).

Economy, ecology and energy pay back factor

At the beginning of OFMSW-digestion, the treatment of one ton of biogenic waste had cost as much as about 120 €. In the late 90-ies, expenses came down to less than 100 €/t for KOMPOGAS-plants (*Edelmann, 2002*). Today, KOMPOGAS has developed a new generation of plants with annual treating capacities ranging from 4'000 to 20'000 tons (by steps of 4'000 tons). The waste is delivered at ground level inside a hall and the reactor is heated by the lignified fraction withheld by the sieve while working up the waste. This procedure increases the usable gas share. The treating costs in a large KOMPOGAS-plant (including all costs of construction and technology, such as gas line, biofilters or liquid/solid separation, but except the price for land acquisition) have now decreased to 30 to 50 €/ton depending on country and local conditions. For smaller plants or plants treating unsorted garbage, the costs may be somewhat higher (*W. Schmid, 2005*).

In Switzerland, very detailed life cycle assessments (LCA) of the different technologies to treat OFMSW have been established. Biogas overtopped clearly composting, incineration or combined technologies. If positive side effects, such as averting impacts of mineral fertiliser productions, are taken into account, the impacts of AD become negative, i.e. there are less environmental costs than benefits. In addition, biogas from OFMSW digestion shows the very best LCA of a all renewable (and non renewable) energies (*Edelmann, 2002*).

With data of the LCA mentioned above, the energy pay back factor for the Rümlang KOMPOGAS-plant has been calculated (*Edelmann, unpublished*): The ratio of energy production versus total energy need for operation and energetic pay back of the energy investment for construction and future demolition is 5.3 to 1. A new, simplified plant with cogeneration will reach a factor of ~8 and a plant for feeding biogas into the gas network may reach values significantly higher than 10, a fact, which implies an energetic pay back time of all past and future energetic investments within 2-3 years of operation.

To sum up, it can be stated, that today AD of OFMSW is a reliable and approved technology for the treatment of biogenic wastes. It closes ecological cycles and is environmentally safe. It costs less than competing technologies and reveals an excellent efficiency freeing the solar energy bound within the chemical bindings of biomass. Now, the data from full size practical plants are here. They just have to be communicated to the politicians and decision makers!

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