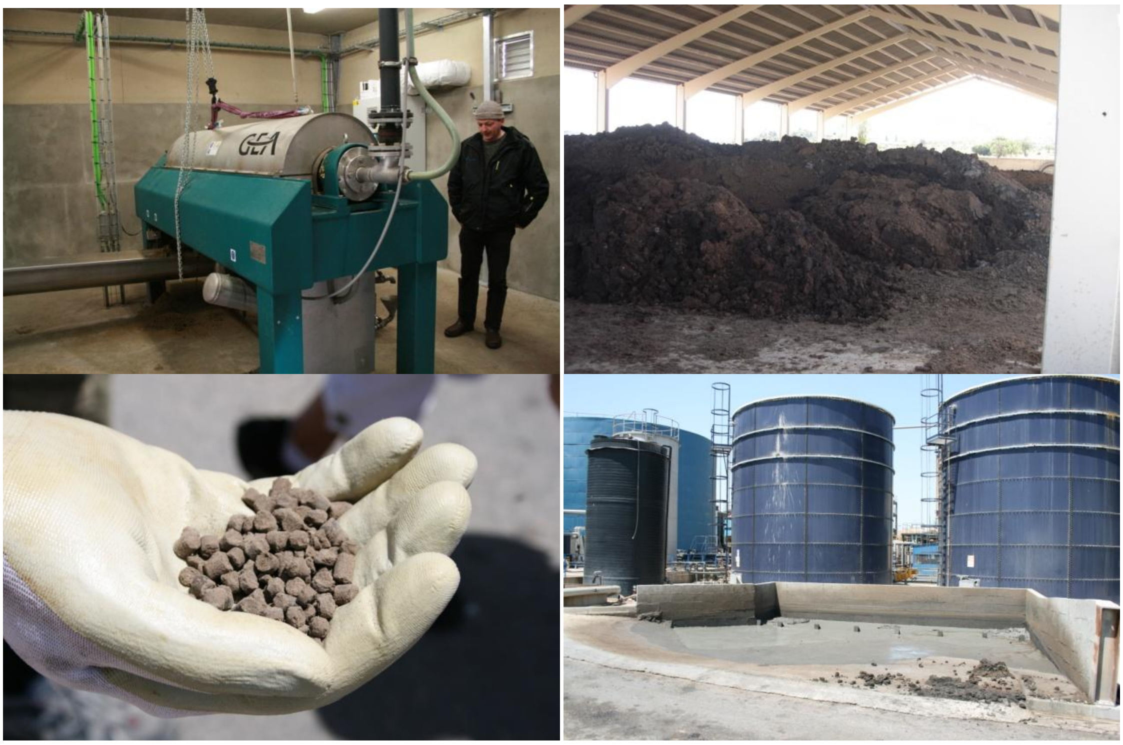
Manure Processing Activities in Europe - Project reference: ENV.B.1/ETU/2010/0007

END AND BY-PRODUCTS FROM LIVESTOCK MANURE PROCESSING

- general types, chemical composition, fertilising quality and feasibility for marketing



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Technical Report No. III to the European Commission, Directorate-General Environment

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Title	End and by-products from livestock manure processing - general types, chemical composition, fertilising quality and feasibility for marketing Technical Report No. III to the European Commission, Directorate-General Environment, Manure Processing Activities in Europe - Project reference: ENV.B.1/ETU/2010/0007
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Front page photos	Upper left: Decanter centrifuge for after-digestion separation of digestate. Upper right: Composting of separated solid fraction of slurry in roofed store. Lower left: Dried and pelletized separation fraction from biogas plant. Lower right: Reception facilities at biogas plant.
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PREFACE

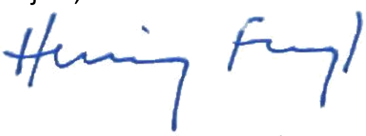
Manure processing is presently a subject that enjoys considerable attention in the EU due to the ongoing revision of the Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs (BREF), as well as due to current efforts to implement policies and legislation on EU and Member State level, for instance concerning renewable energy targets, targets for reducing the loss of plant nutrients to the environment, targets for reduction of greenhouse gases, and targets for manure handling in agriculture in relation to legislation about water protection and manure surpluses in livestock intensive areas.

This report is dealing with types, amount and qualities of end and by-products from livestock manure processing as well as its feasibility for marketing. There are presently especially three types of manure processing products being marketed at considerable volume, and a few more could gain importance if the interest in manure processing continues to grow. However, the market is suffering under lack of infrastructure, discredited qualities of the products, and lack of transparent and acknowledged regulation.

The report is prepared for the European Commission, Directorate General Environment, as part of the implementation of the project “Manure Processing Activities in Europe”, project reference: ENV.B.1/ETU/2010/0007. The Report includes deliverables related with Task 3 concerning description of end and by-products.

We greatly acknowledge all livestock manure experts, who kindly shared their data with us.

Tjele, 28 October 2011



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EXECUTIVE SUMMARY

- Based on Foged et al. (2011), it is suggested to classify end and by-products from livestock manure processing in 11 major groups of liquid and solid end and by-products according their chemical composition, content of plant nutrients, etc. This classification does not include biogas.
- Digestate is, with more than 88 million tonnes, by far the end or by-product that is produced in largest amounts in the EU, while the produced amount of biogas (from livestock manure and co-digested substrates) is estimated at 5,857,033 million m^3 at 65% methane content.
- A large number of datasets on the chemical composition of end and by-products were gathered via survey. These are available via the web page http://agro-technology-atlas.eu/endandbyproducts.aspx.
- As regards qualities of end and by-products from livestock manure processing, the following is highlighted:
    - The possible dry matter percentage obtainable through mechanical processing is averagely 26.9 % (ranging from 16 to 36%).
    - Liquid fractions have the relatively highest ratio between mineralised (NH_4-N) and organic N (N minus NH_4-N) and enable high efficient fertilising of growing crops.
    - Heavy metals like “Copper” (Cu) and “Zinc” (Zn) are especially more concentrated in the end and by-product groups “Manure compost” and “Dried manure and pellets”. This is not caused by the treatment process itself (no heavy metals are added during the process), but it is an effect of the processes causing removal of especially water and organic matter, wherefore metals in these end and by-products become relatively more concentrated. Also, the mentioned processes do not concentrate nitrogen and phosphorus in the same scale of heavy metals, as these nutrients are partially lost in the process (nitrogen is for instance lost as ammonia (NH_3) and nitrous oxide (laughing gas, N_2O) during composting). Similarly for biogas plants the quality of the digestate is a mirror of the quality of the substrates the biogas plant is fed with. Therefore, if the quality of the digestate is to be regulated, the most obvious and natural way to do this is via regulation of the products that are anaerobically digested (inputs to the plant).
- The fertilising value of end and by-products is correlated with their content of bio-available plant nutrients; mainly nitrogen and phosphorus, and secondarily potassium, magnesium and sulphur. Organic matter is not valued by conventional crop production farmers, but by private garden owners, wine yards, and alike. Splitting nitrogen and phosphorus in different fractions is generally beneficial as this enable balanced fertilisation in accordance with many crops’ needs.
- How the quality of end and by-products is assessed depends on the perspective they are seen from. An organic farmer, for instance, would not appreciate combustion ashes, where majority of the nitrogen is lost, while this is seen as a strong advantage for a poultry farmer in a high livestock dense region. Some fertiliser companies would see products with higher concentrates of phosphorus as interesting alternatives to depleting conventional resources.
- There are only three categories out of 11 groups of end and by-products that currently gather the attention of the market, namely “Separation solids”, “Manure compost” and “Dried manure and pellets”. This is due to their suitability for marketing as well as to the amounts currently produced. Other four groups of products (“Thermal and chemically treated manure”, “Digestate”, “Ash and charcoal” and “Manure concentrates”) are in principle also relevant for marketing, but the two first mentioned groups consists of rather voluminous products, wherefore transport costs normally would outweigh their fertilising value, and the other two mentioned product groups are currently only produced in marginal amounts. “Ashes and

charcoal" and "Manure concentrates" are the most interesting, as they potentially could be used for production of mineral fertiliser or mineral feedstuffs.

- End and by-products are relatively new on the market, and national legislation applicable to them is mainly based on EU directives, which are transposed into national law with different interpretation and varying results. Market operators are in doubt about classification of manure as waste or non-waste and limit values for content of heavy metals. Market operators are interested in possibilities for lawful conversion and upgrading of livestock manure via processing into products that could be marketed as mineral fertilisers or constituents thereof.
- For other market commodities the EU has introduced product classification and grading systems, in order to ensure a transparent price setting and the definition of qualities. This is, for instance, the case for beef carcasses, vegetables and many more. A similar product classification and grading system could be set up for end and by-products from livestock manure processing. Market operators would be obliged to label their products and prices accordingly. Another infrastructural measure to ease market activities is the establishing of published statistics on market prices for manure processing products in different parts of the Union. This would benefit livestock manure processing by making clear where best prices can be obtained.
- Due to associated logistics challenges, end and by-products have a market price that is considerably lower, but anyway linked to the market prices for mineral fertilisers.
- The economical optimal use of the biogas is case-specific and must be determined by feasibility studies and via management of each individual biogas plant.

1: BACKGROUND

A considerable increase in manure processing has taken place in EU Member States in the last 15 years, a development that has been triggered by still higher demands and focus on reduction of greenhouse gases, recycling of waste and biosecurity aspects, while a tightening enforcement of environmental provisions is becoming a more and more serious reality for livestock producers along with the structural development with increase of livestock unit sizes in most Member States of the Community. Particularly in intensive livestock areas of the EU, such as the Netherlands, Belgium (Flanders), France (Brittany), Denmark, and Italy (North), manure processing is incited in order to deal with surpluses, i.e. frequent occurrence of more than 170 kg nitrogen in livestock manure per ha available for the livestock farms.

The background for this is development has much to do with policymakers' higher and higher awareness of manure processing as a measure, whereby they can achieve several of these policy goals via one single measure.

Biogas production is a good example of this: Via anaerobic digestion of the slurry at a large pig farm with 25,000 ton slurry produced annually (equivalent to around 1,075 sows + feeding of the pigs for slaughter), there can annually be

- recycled 25,000 ton x 4.31[1] kg N/ton x 10% = 10,775 kg N more in the crop production via a higher bio-availability of the nitrogen after anaerobic digestion; the consequent save in mineral fertilisers is estimated at least 10,000 € (based on Foged (2010));
- produced around 450,000 m^3 biogas, which as renewable energy is equivalent to around 2.9 MWh or about 30,500 litres of fuel oil;
- made a CO_{2e} emission reduction of around 1,399 ton (based on own biogas feasibility calculation model); and
- ensured sanitation of the manure, with highest effect in thermophile biogas plants (Birkmose et al., 2007).

Politicians have an interest to use this "manure processing measure" even further. A good example of this is the Danish election coalition of social democrats and social peoples' party, who on 24 June 2011 proclaimed that they wish to introduce a demand for manure to be processed, and that land spreading of un-processed slurry shall be prohibited. In the Flanders there is introduced compulsory manure treatment of livestock farms' manure surpluses.

There are no doubts that there is a wish to see the development in manure processing over the last 10 years to continue.

However, manure processing will only have beneficial effects in case the nutrients in end and by-products are used efficiently in crop production, or in other ways disposed of in a sustainable way. For instance, in some parts of the EU the most important advantage of manure processing is that nutrients are concentrated and more easily can be exported from surplus areas to areas with lower nutrient pressures and that the N/P ratio of products is changed so that it better fits N/P ratio of crops needs. This is particularly relevant for phosphorus that becomes the limiting nutrient in intensive areas, also in Member States that benefit from derogation under the nitrates directive such as the Netherlands.

[1] This is the typical content of nitrogen in pig slurry.

2: METHODOLOGY

2.1: Types and amounts of end and by products

The estimated amounts presented in this report are based on a survey, described by Foged et al. (2011), in which experts from most EU Member States provided information about amounts of livestock manure that currently is being processed with the technologies listed in Annex A.

The consultant has roughly estimated the relative mass flow of each processing type, and by multiplying this with the amounts of processed livestock manure, calculated estimated amounts of end and by-products.

The end and by-products were classified in 11 groups of products with similar chemical characteristics. The grouping was suggested by Foged et al. (2011).

The classification of the products in relatively few groups is of major importance for a market to function in relation to price setting, because classification systems, statistics, and traders overview of the market are easier to establish for a few than for many commodities. The following table shows a big overlap between qualities of the solid fraction from different livestock manure separation technologies (here alone exemplified with the dry matter content for two different slurry separation technologies, meaning that having 10 different solid fraction types on the market just would confuse much more than necessary).

Table 2.1: % dry matter (DM) in separation solids. There is a bigger variation within than between technologies.

	Minimum	Average	Maximum
Screw pressing	16,0	24,8	34,3
Sieves	20,0	25,0	30,0

For the present being, there is therefore little justification of marketing solid fractions of livestock manure according to the technologies they were produced by, and likewise with other end and by-products.

Section 3 is dealing with end and by-products, with focus on the plant nutrients and other metals that it contains. Biogas is treated separately.

2.2: Qualities of end and by products

Experts were encouraged to register qualities of end and by products for the used livestock manure processing technologies. 46 datasets were collected – reference is made to Annex B concerning the specific parameters in the datasets.

A typical feature for the datasets collected via the survey was that they were based on slurry separation and anaerobic digestion, and that the qualities mainly were described by DM, N and P. Hence, literature studies were performed in order to gather datasets for other technologies and/or to investigate parameters to describe the content of heavy metals, etc.

Another source of data was Kumac Mineralen in the Netherlands, who had several detailed analyses of relevance, due to its participation in a pilot project set up by the Netherlands government in order to investigate the possibilities for production of mineral concentrates from livestock manure (Velthof, 2009)

The resulting datasets are placed at the web page http://agro-technology-atlas.eu/endandbyproducts.aspx[2].

2.4: Feasibility of marketing

The above mentioned classification of end and by-products is an essential pre-condition for the further assessment of their relevance on the crop fertiliser market.

The constraints, challenges and possibilities for the marketing was analysed in several steps. Initially a number of experts, employed in companies that already trade end and by-products from manure processing, i.e. market operators, were consulted, using the following list of questions:

1. Identification of customers
   - 1.1. Customers of these products are clearly identified? Are well-established marketing channels? How would you improve the identification of customers?
   - 1.2. Which kind of customers do you have (farmers, gardening, organic fertilizer company, public works, composting plants, other)? What percentage of each one?
2. Characteristics of the end products / market requirements
   - 2.1. What features / properties should these products have to be accepted by customers? Have costumers any special requirement?
   - 2.2. Do clients ask for a guarantee on the supply and/or require a minimum volume/weight of product? Is this a problem for the sales?
   - 2.3. What do you consider to be the key points to assure customer loyalty?
   - 2.4. What other socio-economic aspect has an impact on the sales / demand for this type of fertilizer products? (E.g. chemical fertilizer cost, regulation on agriculture, etc.).
   - 2.5. Which is the average price of the product you sell?
   - 2.6. How important is the sale of these products in your trading account? It is important for the viability of the company?
3. Legislative framework
   - 3.1. Is the current legislative framework adequate? It favours or hinders the marketing of these products? How flexible is the current legislation?
   - 3.2. What legislative actions or which aspects of its application (control, procedure, etc.) should be modified to boost the market of this kind of fertilizer?
4. Comments (any comments or suggestions you wish to add)

Other issues were raised, for instance about logistically challenges in relation to interaction with buyers.

The following persons were consulted:

- KomTek (company specialised in composting and trade with biomasses), Hans Peter Fyhn, http://www.komtek.dk/, hp@komtek.dk, Mob. +45 2222 2542
- Kumac Mineralen (has developed own manure treatment plants, from where they sell a liquid nitrogen fertiliser and a solid separation fraction), Henry van Kaathoven, http://www.kumac.nl, info@kumac.nl, Mob. +31 6 5380 4386

[2] The website will be used as a portal for communication of results of more projects that are managed by Agro Business Park

- VCM Mestverwerking (deeply embedded in the manure processing industry in the Flanders, and recently organiser of a conference about marketing of end and by-products), Frederik Accoe, http://www.vcm-mestverwerking.be, frederik.accoe@vcm-mestverwerking.be, Mob +32 4 9373 5319
- FERVOSA, Manlleu, Catalunya, Spain, (Centralized composting plant, Darius Sancho
- Sodemasa, Zaragoza, Spain (Manure management company), Christian Siegler
- TRACJUSA, Juneda, Catalunya, Spain (Thermal drying plant with AD + evaporation + thermal drying), Antonio Badia
- GUASCOR, Spain (Company owner of some thermal drying plants with NDN + evaporation + thermal drying), Pedro Royo
- MACASA-LABIN, Igualada, Catalunya, Spain (Company that produces organic fertilizer), Juan Mateu
- Energy-farming (a consortium of 8 anaerobic digestion plants that has taken the initiative to market dried/pelletized digestate and manure towards the retail market, for instance shops selling fertilizers for private gardeners, and towards the worldwide market (for instance Asia, ...)), Dirk van Eersel, +32(0)493787061, dirk@energy-farming.be

Section 6 includes the consultant's summary from these consultations, and as well the result of further analyses.

It is emphasized that the consultant by marketing understands trade over longer distances and typically via retailers or other market operators, and not alone between neighbouring farmers and alike in the local municipality.

3: TYPES AND AMOUNTS OF END AND BY-PRODUCTS

The main groups of end and by-products from livestock manure processing are listed in Table 3.1, while section 3.2 discusses biogas.

3.1: Liquid or solid end and by-products

There are 11 major types of end and by-products, and table 3.1 also show the estimated amounts that are currently produced in EU Member States.

Table 3.1: Types and amounts of end and by-products from livestock manure processing in EU. The amounts are based on estimates of number of manure processing installations in EU Member States and the amount of livestock manure they process (Foged et al., 2011).

Code	Short name: Type	Index number of technology(s), that resulted in the end or by-product (index according Annex A)	Amounts, 1,000 tonnes per year	Comments to the indicated amounts
Separation				
1	**Separation solids**: Livestock manure solids, typically with a dry matter content of around 25% and rich in phosphorus and nitrogen.	1-10	4,855	One of the most used separation processes is natural settling (Foged et al., 2011), for which Frandsen (2011) informs that the solids weigh 8% of the initial weight. However, other separation processes are generally slightly more efficient; this is why we assume that separation averagely results in 10% of the initial weight as solid fraction. It is further assumed that both processed livestock manure[3] and other products[4] contribute to the production of solid fraction. Other products would in this connection especially be the product of flocculation.
2	**Separation liquids**: Liquid fraction, typically with dry matter content around 2% and with a relatively high content of nitrogen and	1-10	43,692	In accordance with the above, it is estimated that 90% of the treated amounts ends in the reject liquid fraction.

[3] "Livestock manure" means "raw", i.e. not previously processed/treated livestock manure.

[4] "Other" means by or end products of livestock manure that is already processed, and / or other organic wastes.

Code	Short name: Type	Index number of technology(s), that resulted in the end or by-product (index according Annex A)	Amounts, 1,000 tonnes per year	Comments to the indicated amounts
	potassium.			
Additives and other pre/1st treatments				
3	**Thermal and chemically treated manure**: Products that mainly have different pH or bacteriological characteristics, while the dry matter content and the content of plant nutrients remain unchanged (except where sulphuric acid is used; this leads to an increased content of sulphur). The technologies used to produce Thermal and chemically treated manure are typically standalone technologies. Thermal and chemically treated manure is looking the same, has the same structure, and it not like most other end and by-products fractions of the processed input products.	11-14	7,473	The input amount is the same as the output amount, except from the additive amount, which is marginal.
Anaerobic digestion				
4	**Digestate**: Product with a lower dry matter content and a higher share of mineralised nitrogen than the undigested raw livestock manure.	15-16	88,039	Around 55% of the substrate is livestock manure, while the remaining part is constituted by other products[5], mainly organic wastes from the food industry, and energy crops like maize silage[6]. Digestate would normally have a

[5] Other products means end products of livestock manure that is already processed, and / or other organic wastes

[6] Digestate from purely energy crops (maize silage and similar) are not included in the figures.

Code	Short name: Type	Index number of technology(s), that resulted in the end or by-product (index according Annex A)	Amounts, 1,000 tonnes per year	Comments to the indicated amounts
				weight of ~99% of the weight of the input substrate, while the biogas would weigh less than 1% of the input substrate weight.
Treatment of the solid fraction				
5	**Manure compost**: Products with a relatively high content of dry matter, organic matter and nutrients, but with a significant moisture content (i.e. typically >40%, but down to 15%), such as the products of composting.	17-19	3,253	The majority of these products are resulting from conventional composting. Only a few % is produced by vermicomposting or biodrying. Slightly less than half of the composted matter is raw livestock manure. It is assumed that the other substrates that are composted especially are separation solids as well as bulking material (to facilitate the oxidization), such as straw and peat. The loss of carbon during composting is often more than 50% (see for instance Andersen et al., 2010), and a big share of the nitrogen and water is also lost. It is therefore assumed that the compost weight is 50% of the weight of the input substrate.
6	**Dried manure and pellets**: Products with low moisture content (< 10%) and high concentrations of dry matter, organics and nutrients, such as the products of thermal drying or pelletizing. Relative concentration values of nutrients and organic matter depend of the processes which precede the drying.	20-21	967	It is assumed that the livestock manures and other products that are dried, in some cases combined with pelletizing, have a content of 30% dry matter before the drying process and 87% afterwards.
7	**Ashes and charcoal**: Products	22-24	124	It is assumed that ashes from

Code	Short name: Type	Index number of technology(s), that resulted in the end or by-product (index according Annex A)	Amounts, 1,000 tonnes per year	Comments to the indicated amounts
	with high dry matter content but without or with very low organic matter content, such as ashes from combustion or charcoal from pyrolysis. These kinds of products will have very low or null concentration of nitrogen.			combustion represent 25% of the initial livestock manure dry matter weight, and that all combusted livestock manure is chicken manure of deep litter type with 44% dry matter. Foged et al. (2011) did not find any commercial installations for gasification or pyrolysis of livestock manure.
Treatment of the liquid fraction				
8	**Filter water**: Water with minimal amount of organic matter, that technically (not legally) is clean enough to be disposed of in the nature, or used as irrigation water;	26-29, 33-34	1,732	These products originate from ultra filtration, reverse osmosis, and ozonizing, and could also come from vacuum evaporation. It is assumed that the liquid weight amounts to 60% of the initial treated amounts of livestock manure and other.
9	**Manure processing effluents**: Manure processing effluents with some content of organic matter;	35-41	6,080	Effluents with low content of nitrogen, but still some organic matter (much higher than the end product form Microfiltration, Ultrafiltration, and Reverse Osmosis). These products mainly derive from nitrification-denitrification.
10	**Manure concentrates**: Material with minimal amount of organic matter, with a high nitrogen, magnesium or phosphorus fertilising value;	26-29, 33-34, 31, 39-40	1,154	These would result from nitrogen stripping, struvite and calcium phosphate precipitation as well as from air scrubbing. They also results from filter processes. The largest proportion is currently the result of concentration by vacuum evaporation (technology index 29).
Air cleaning (as part of manure processing plant)				

Code	Short name: Type	Index number of technology(s), that resulted in the end or by-product (index according Annex A)	Amounts, 1,000 tonnes per year	Comments to the indicated amounts
11	**Air cleaning sludge**: Air cleaning sludge	43-45	-	The amounts are marginal.

Wet oxidation (technology index 25) is never used as a terminal process, therefore not generating any end or by-product.

Constructed wetlands (technology index 42) do not produce any end or by-products.

3.2: Gaseous end and by-products / biogas

While section 3.1 deals with captured solid and liquid fractions of end and by-products from livestock manure processing, biogas is another major product, although it does not contain any plant nutrients or other metals.

Foged et al. (2011) reported that biogas plants treats 88 million tonnes of manure and other, and that 30% is pig slurry, 21% cattle slurry, 4% deep litter from cattle, while 44% is constituted by other products, for instance separation solids. In the following chapters we assume that "other" is constituted by separation solids, although in practice it would include many different types of substrates that are co-digested with livestock manure, for instance energy crops, sludge from municipal waste water treatment plants and agro-industrial waste.

The biogas yield depend on many factors, for instance the hydraulic retention time, whether there are one or two stage digestion, temperature regime, etc. Some typical figures for the biogas yield are shown in the following table.

Table 3.2: Estimated biogas yield from anaerobic digested livestock manure and other in EU Member States.

Type substrate	Amount, %	Amount, 1,000, tonnes	1,000 ton volatile solids (VS)	m^3 methane per ton volatile solids (VS)
Pig slurry	30	26,631	1,065	290
Cattle slurry	21	18,708	1,048	210
Cattle deep litter	4	3,741	958	250
Other, here assumed to be solid separation fraction	44	38,957	7,791	390
Total	100	88,039	10,862	3,807,071 million m^3

The equivalent amount of biogas with 65% methane content is 5,857,033 million m^3. Some conversion factors to energy equivalents are shown here - http://www.balticbiogasbus.eu/web/about-biogas.aspx.

Other gaseous products, not useful in economic terms, but existing are: ammonia, N_2O (nitrous oxide), and N_2 (nitrogen gas). Flotats et al. (2011) has for various manure processing technologies estimated the production of such gases. Evaporation of ammonia is both harmful for the environment and a loss of valuable nitrogen. Nitrous oxide is a very harmful greenhouse gas, having a greenhouse effect that is equivalent to 320 times that of CO_2. Nitrogen gas is harmless and a normal constituent of the air we breathe.

4: CHARACTERISTICS OF END AND BY-PRODUCTS

Annex B holds tables with the chemical composition of the 12 suggested groups of end and by-products. There are in total 130 datasets.

The datasets, which for the majority originates from research projects, do not include specific parameters like “Suspended matter” in liquid fractions or “Cadmium” (Cd), which are seldom analysed.

Other end and by-products that are seldom analysed include “Air cleaning sludge”, for which no analyses were found. The interest to analyse products is probably much related with their amounts and feasibility for marketing.

However, we have gathered average analysis results in Table 4.1, which gives a unique overview of qualities of end and by-products from livestock manure processing. Some lessons we can learn from the table are:

- The possible dry matter percentage obtainable through mechanical processing is averagely 26.9 % - (varying from 16 to 36%).
- Liquid fractions have the relatively highest ratio mineralised (NH_4-N) / organic N (N minus NH_4-N); therefore they are most suitable for high efficient fertilising of growing crops.
- Heavy metals like “Copper” (Cu) and “Zinc” (Zn) are more concentrated in “Manure compost” and in “Dried manure and pellets”. This is not caused by the treatment process itself (no heavy metals are added during the process), but rather an effect of the processes causing removal of especially water and organic matter and consequently concentration if these metals. However, the mentioned processes do not concentrate the main plant nutrients, the nitrogen and the phosphorus, in the same scale as heavy metals, because they are partially lost in the process – part of the nitrogen is for instance lost as ammonia (NH_3) and nitrous oxide (N_2O) during composting. This is also the case for biogas plants, where the quality of the digestate is a mirror of the quality of the input products of the biogas plant. Therefore, if the quality of the digestate is to be regulated, the most natural way to do this is via regulation of the products that are anaerobically digested.
- It is emphasized, that, while Table 4.1 on the one hand gives rather unique information about the chemical composition of end and by-products, it has its shortcomings: the number of analyses behind the figures are in some cases too few to draw any conclusion and should be interpreted as indications only. Also, some of the groups are rather heterogeneous – this is for instance the case for the group of “Manure concentrates”, which are based on technologies as different as for instance nitrogen stripping and struvite precipitation.

Table 4.1: Overview of average composition of 11 specified groups of end and by-products form livestock manure processing. See details in Annex B. No Analyses were found for Air cleaning sludge.

#	Name	%	Kg/ton						Mg O_2 / liter			**Gram/ton**									
		DM	N	NH4-N	P	K	C org	VS	Susp. mat.	BOD	COD	Mg	Ca	Na	Cd	Cu	Zn	**Hg**	**Pb**	**Cr**	**Ni**
1	Separation solids	26.9	7.62	3.68	4.70	3.00		174.4				3. 31	5.19	0.8		35.48	137.12				
2	Separation liquids	2.86	3.30	3.14	0.46	2.90	63.55	11.67	11.70	6.54	108.22	108.8	37.03	0.67	0.01	8.43	24.44		0.01	0.20	0.29
3	Thermal and chemically treated manure	6.55	2.47	1.18	0.92	2.56	6.62	22.32				0.71				52.25	220				
4	Digestate	5.00	3.25	2.43	0.73	2.72	42.63	36.13		31.85		394	2184	954	0.02	9.00	74		0.70	2.50	2.60
5	Manure compost	46.93	13.88	4.04	6.92	12.62		434.94				8.97	30.87		0.10	58.20	212.51	0.02	6.54	4.24	3.18
6	Dried manure and pellets	87.39	57.83	23.26	22.22	43.26	550	574.52				5.54	12.09	7400	0.82	183.6	1119	0.03	11.04	8.76	12.26
7	Ashes and charcoal	97.08	19.26		38.83	42.81	392.9	681.38				9.75	62.47	13.43	2.43	274.3	965	1	10.72	27.1	32
8	Filter water	0.14	0.20	0.17	0.04	0.24		1.43				0.16	1.75	0.04	0.01	0.01	1.14		0.01	0.01	0.01
9	Manure processing effluents	3.95	1.51	0.04	1.14	1.94		4.44	0.44	0.08	1.26					1.51					
10	Manure concentrates	6.02	7.25	9.51	0.50	6.52	0	15.93				403.7	106.8	1.57	0.01	2.53	12.23		0.01	0.01	0.571
11	Air cleaning sludge	-	-	-	-	-	-	-				-	-	-	-	-	-	-	-	-	-

5: FERTILISING QUALITIES OF END AND BY-PRODUCTS

5.1: Plant nutrients and some factors of importance for crop fertilisation

Fertilising of crops is especially dealing with the following plant nutrients

- Nitrogen – the primary plant nutrient, in livestock manure present in organic and mineral (ammonium/NH_4^+) form. The nitrogen bound to organic substances in the livestock manure is released with the decomposition of the organic matter, up to 2-3 years after spreading on the field, and therefore also in periods where there are no crops on the field, or where plants do not uptake plant nutrients. After release, the nitrate is converted to ammonium via microbes, which binds to water and, at the same time is quite volatile/easily evaporates. Nitrogen is often lost to the aquatic environment and that is of concern of the EU's Nitrates Directive (91/676/EEC).

  The nitrogen field effect, also called the bio-availability, describe the amount of nitrogen in mineral fertiliser that has the same effect on the crop yield as 100 kg nitrogen in livestock manure.

  Given the above, the most secure fertilisation effect is ensured by spreading products containing the highest share of mineralised/ammonium nitrogen as possible at periods where the crops needs the fertiliser, and ensures it is not volatilized during spreading.

- Phosphorus – the second most important plant nutrient. Phosphorus is especially incorporated into organic matter. When released from organic matter in livestock manure, the phosphorus goes into a complex soil pool, and will gradually become available to the crop on the field for several years after the phosphorus application.
- Potassium – generally important for all crops. Potassium is dissolved in the liquid phase of livestock manure.
- Magnesium – is required more by some crops than other, for instance potatoes and sugar beets have a higher demand for Mg-fertilising than, for instance, pulses like peas and beans.
- Sulphur – is required as fertiliser in highest amounts by nitrogen fixating crops like peas and alfalfa, which have to produce sulphur-containing amino acids from fixated nitrogen. Rape seed also has a higher demand for sulphur than other crops, especially due to its special composition of amino acids in the protein.

While it is well known that the value of the nitrogen as plant fertiliser largely depends on its bio-availability and therefore on its ratio mineralised / organic bound nitrogen, it is more or less assumed that spread amounts of phosphorus, potassium, magnesium and sulphur fertilisers are sooner or later taken up by crops, i.e. they are fully bio-available.

It is often said that soil quality benefits from organic structural material, by making the soil more porous and water binding and thus enable higher yields, but the proof for this seems vague, and in any case there are no proof of buyers' willingness to pay extra for this organic structural matter, as long as buyers are conventional crop farmers, growing field crops like cereals and alike. Others, like for instance private garden owners and wine yards are willing to pay for organic structure material in the form of compost.

A general advantage of several livestock manure processing technologies is the splitting up of the main plant nutrients, nitrogen and phosphorus, over different fractions whereby a more precisely balanced fertilising is enabled, both in relation to crops needs and to the legislative requirements.

More indirect qualities of fertilisers are related with their requirements to the spreading equipment and the storage size and quality.

5.2: The impact of processing on livestock manures' fertilising value

Summing up from the previous section, the fertilising value of end and by-products is correlated with its content of bio-available plant nutrients; mainly nitrogen and phosphorus, and secondarily potassium, magnesium and sulphur. Organic structure material is not valued by conventional crop production farmers, but by private garden owners, wine yards, and alike. Splitting nitrogen and phosphorus in different fractions is generally beneficial. Indirect characteristics of fertilisers are their requirements for specific spreading equipments and storage size and quality. The following Table 5.1 provides an analysis of the 11 defined groups of end and by-products against these factors.

Table 5.1: Analysis of defined groups of end and by-products against their fertilising value factors.

Code	Short name	Fertilising value in relation to unprocessed livestock manure
1	Separation solids	▪ Bioavailability: Unchanged for phosphorus, but probably only around 30-45 % (i.e. around halved) for the total nitrogen, because it is the organic bound nitrogen that follows the solid fraction. If the separation efficiency is low, then there would not be any change of the nitrogen bioavailability. ▪ Organic structure material: This is concentrated in the separation solids. ▪ Splitting of nutrients: The separation solids contain normally around 80% of the phosphorus and 20% of the nitrogen, but separation efficiencies vary. ▪ Spreading equipment: Can be spread with conventional solid manure spreaders. ▪ Storage requirement: Optimal storage happens in closed containers to avoid ammonia volatilization and nitrates leaching.
2	Separation liquids	▪ Bioavailability: The bioavailability of the nitrogen is improved, and comparable with that of nitrogen in mineral fertiliser, i.e. above 90% ▪ Organic structure material: Very low. ▪ Splitting of nutrients: Yes, normally it holds around 80% of the nitrogen and 20% of the phosphorus. ▪ Spreading equipment: Can be spread with conventional slurry spreaders – however application directly into the soil or under the leaves is more important due to the high share of volatile, mineralised nitrogen – alternatively, acidification in storage / during spreading could be used as a measure to reduce the risk of volatilization. ▪ Storage requirement: Like conventional slurry – however, floating

Code	Short name	Fertilising value in relation to unprocessed livestock manure
		layer /cover on the tank even more important due to the high share of volatile nitrogen - alternatively acidification in the storage.
3	Thermal and chemically treated manure	▪ Bioavailability: Normally no change, but some additives especially binds the volatile mineralised nitrogen, wherefore its share is relatively higher and so is the bio availability. ▪ Organic structure material: No change. ▪ Splitting of nutrients: No change. ▪ Spreading equipment: No change. ▪ Storage requirement: No change.
4	Digestate	▪ Bioavailability: According Foged (2010) from 17-30 % higher, most in cattle slurry, but if the baseline is a high bioavailability, then probably 10% improvement. ▪ Organic structure material: Around 10% of the carbon (dry matter) is oxidised during the anaerobic digestion, and the digestate is much more liquid and homogenous than slurry. Therefore the content of organic matter is lower than before treatment. ▪ Splitting of nutrients: No. ▪ Spreading equipment: No change – however application directly into the soil or under the leaves is more important due to the high share of volatile, mineraliser nitrogen – alternatively acidification in storage / during spreading. ▪ Storage requirement: No change – however, floating layer /cover on the tank even more important due to the high share of volatile, mineraliser nitrogen – alternatively acidification in the storage.
5	Manure compost	▪ Bioavailability: No references found, but probably lower bioavailability of the nitrogen, because the volatile part tends to evaporate and the rest remains in organic form. ▪ Organic structure material: Relatively improved: The dry matter content is increased during composting (water evaporates), and often it is used to mix the manure with some organic material, for instance peat, to facilitate the oxidation. ▪ Splitting of nutrients: No – however, much of the nitrogen disappear due to leaching and evaporation during the process, why the N:P relation is reduced. ▪ Spreading equipment: Can be spread with conventional solid manure spreaders. ▪ Storage requirement: Final produced compost need to be stored on tight platforms. According to some EU member states' legislation, it can be kept in simple field heaps, at least for a limited period.
6	Dried manure	▪ Bioavailability: Considering the dried manure and pellets typically are

Code	Short name	Fertilising value in relation to unprocessed livestock manure
	and pellets	made from separation solids, the bio-availability of the nitrogen is probably only around 30-45 % (i.e. around halved), because it is the organic bound nitrogen that follows the solid fraction. ▪ Organic structure material: Concentrated in dried manure and pellets. ▪ Splitting of nutrients: Can be alike separation solids - normally around 80% of the phosphorus and 20% of the nitrogen, but highly dependent on previous treatments (e.g. acidification, nitrification-denitrification). ▪ Spreading equipment: Can be spread with conventional mineral fertiliser spreader. ▪ Storage requirement: No specific requirements.
7	Ashes and charcoal	▪ Bioavailability: In general, all or large parts of the nitrogen, especially the most volatile and mineralised part, disappear in the process. The bio-availability of the remaining nitrogen in charcoal is not sufficiently investigated, but is probably dependent on factors like temperature and oxygen supply during the pyrolysis. ▪ Organic structure material: Burned away in ash. ▪ Splitting of nutrients: Yes, much nitrogen converted to di-nitrogen (N_2). ▪ Spreading equipment: Ashes would not be spread alone, but incorporated in other fertilisers. Charcoal can be spread with conventional mineral fertiliser spreader. ▪ Storage requirement: Open container.
8	Filter water	▪ Bioavailability: N/A – very low content of N. ▪ Organic structure material: N/A – very low content. ▪ Splitting of nutrients: N/A – very low content of nutrients. ▪ Spreading equipment: It could be led to a constructed wetland. ▪ Storage requirement: None, or only intermediate tank – typically disposed off along with production.
9	Manure processing effluents	▪ Bioavailability: N/A – low N content, although higher than in filter water. ▪ Organic structure material: N/A – low content, although higher than in filter water. ▪ Splitting of nutrients: N/A – low content of nutrients, although higher than in filter water. ▪ Spreading equipment: Would be spread via fertigation or as liquid manures. ▪ Storage requirement: Like liquid manure, but less requiring of cover

Code	Short name	Fertilising value in relation to unprocessed livestock manure
		or floating layer.
10	Manure concentrates	▪ Bioavailability: High – similar to mineral fertilisers. ▪ Organic structure material: Extremely low. ▪ Splitting of nutrients: To a very high extent (N, P, Mg – dependent on product). ▪ Spreading equipment: Conventional mineral fertiliser spreaders. Ammonia water shall be spread with special equipment and require injection into the soil, to limit ammonia emissions. ▪ Storage requirement: Low volume, open containers for dry forms, and sealed/closed containers for ammonia water, which is very volatile.
11	Air cleaning sludge	N/A – this group of end and by-products are typically led back to the process stream, and not used for fertilising.

The characteristics of these products can be seen from different perspectives. An organic farmer, for instance, would not appreciate ashes, where majority of the nitrogen is lost, while this is seen as a strong advantage for a poultry farmer in a high livestock dense region. Some fertiliser companies would see products with higher concentrates of phosphorus as interesting alternatives to depleting conventional resources.

6: FEASIBILITY OF MARKETING OF END AND BY-PRODUCTS

The following sections contain the compiled observations from consultation of experts in trade of end and by-products from livestock manure processing. The main factors of relevance in relation to trade are the fertilising quality (the issues mentioned in the previous chapter), legal issues, market mechanisms, and technological challenges.

Biogas is dealt with in section 6.6.

6.1: Relevance for marketing

In previous chapters we have classified end and by-products in 11 different groups. The following table explains which of those groups is relevant for marketing:

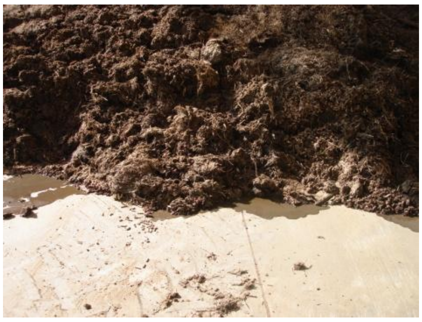
Table 6.1: Relevance of marketing end and by-products.

Code	Short name	Relevance for marketing	Explanation	Examples of potential buyers
1	Separation solids	✓	▪ This is a relatively concentrated form of P, often with 5-10 kg P / ton, produced with the purpose of exporting it away from the farm or the region, where there is excess livestock manure, particularly phosphorus in the manure, in relation to the crop production area. ▪ Composting before trade would be an option to make the product more stable – prepared for transport.	▪ Composting plants ▪ Biogas plants
2	Separation liquids	-	▪ Voluminous and volatile. Too expensive to transport out of the farm.	▪ Own or neighbours fields
3	Thermal and chemically treated manure	(✓)	▪ Generally, the thermal and chemically treated manure is voluminous and in most cases done to benefit the livestock farmer's own crop production economy or to help him obtaining an environmental permit. An exception form that is pasteurisation, which has the purpose to enable export of	▪ Own fields ▪ Farms abroad

Code	Short name	Relevance for marketing	Explanation	Examples of potential buyers
			livestock manure from livestock dense areas to another Member State.	
4	Digestate	(✓)	▪ Digestate is voluminous as raw slurry and not suited for longer transports. However, regional biogas plants often serve as re-distribution centres for livestock manure (within 30 km).	▪ Crop production farmers in the local area
5	Manure compost	✓	▪ Compost has a relatively high dry matter percentage and is a stable product; it is therefore suited for longer transports. The composting is often done with the purpose to market livestock manure products.	▪ Garden owners ▪ Wine growers ▪ Horticulturists
6	Dried manure and pellets	✓	▪ The same explanation as for compost, while dried and pelletized products of course are even more concentrated and stable.	▪ Crop producers worldwide
7	Ashes and charcoal	(✓)	▪ Very concentrated and easy to trade. ▪ However, the brackets are due to the fact that there, even in a European perspective are small amounts produced, and there are few relevant buyers, especially for ash products.	▪ Ashes: Mineral fertiliser component producers ▪ Charcoal: Crop production farmers
8	Filter water	-	▪ Low content of plant nutrients.	▪ Own or neighbours fields
9	Manure processing effluents	-	▪ Low content of plant nutrients.	▪ Controlled wetlands
10	Manure concentrates	(✓)	▪ Very concentrated and easy to trade. ▪ However, the brackets are due to the fact that there, even in a European	▪ Mineral fertiliser component producers ▪ Crop producers, if

Code	Short name	Relevance for marketing	Explanation	Examples of potential buyers
			perspective are small amounts produced, and few relevant buyers.	they have required spreading technology available
11	Air cleaning sludge	-	▪ N/A – this group of end and by-products are typically led back to the process stream, and not used for fertilising.	▪ N/A

There are out of 11 groups of end and by-products only three that presently gather the attention in relation to marketing, namely separation solids, compost and dried manure and pellets, due to their suitability for marketing as well as the currently produced amounts. Other four products (Thermal and chemically treated manure, Digestate, Ash and charcoal and Manure concentrates) are principally also relevant for marketing, but the two first mentioned are rather voluminous, wherefore transport costs normally would outweigh the value of the end or by-product, and the other two mentioned products presently produced only in marginal amounts.



Picture 1: Separation solids from cattle slurry to be composted – here from USA.

Picture 2: The separation solids are mixed with wood chips (small) and put in windrows under roof, and turned frequently.

Picture 3: Final compost, in this case used as bedding material for dairy cows.

Of the groups that are indicated with a conditional marketing potential, i.e. marked with brackets in the table above, we would especially emphasize, that the most concentrated forms: Ashes and charcoal and Manure concentrates are the most interesting. They could potentially be used in the industry, for instance for production of mineral fertiliser and mineral feedstuffs, in case the legislation would make this possible.

6.2: Fertiliser qualities

Typically livestock manures are traded only on basis of their type and amount, and analyses on nitrogen content are used for verifying their quality and for reporting the trade to the authorities, in case there are no official default/standard values for livestock manure excretion. The content of phosphorus and potassium is of concern as well, but it does not influence the price setting. Magnesium and sulphur is not known to be of interest in trades of livestock manures. The bio-availability of the plant nutrients has no importance for the price setting, and is considered connected to the type of the livestock manure.

The market for end and by-products of manure processing is much less developed than the market for (raw) livestock manures, but it is assumed largely that there are similarities in the way these markets would function in relation to price setting and community/national legislation governing the trade.

This means that it is important to group end and by-products in a relatively few classes with specified characteristics, for instance a standard for separation solids, where default values for dry matter, nitrogen and phosphorus content are laid down, so that prices for individual batches can be set in relation to a market price for the default quality.

Table 6.2 shows a proposal for default values of dry matter, N and P content of the three most market-ready types of end and by-products.

Table 6.2: Proposal for default values of dry matter, N and P content of the three most market-ready types of end and by-products.

End and by-product	Dry matter, %	Nitrogen, kg/ton	Phosphorus, kg/ton
Separation solids	27	8	5
Manure compost	47	14	7
Dried manure and pellets	87	19	39

6.3: Community legislation governing marketing end and by-products

In this chapter, some important aspects in relation to trade of end and by-products of livestock manure processing related to community legislation are presented.

6.3.1: Lawful ways to use livestock manure and processed fractions thereof

According to the Nitrates Directive (91/676/EEC), livestock manure and its processed fractions, as well as chemical fertilisers, shall be used as fertiliser for crops in accordance with their needs. The livestock owner is responsible for the manure management, including its correct storage, until it is spread on fields as fertiliser. The obligation can be transferred to another legal person, to whom manure is sold; in this case amount and quality of sold manure have to be reported to the relevant authorities, together with clear identification of buyer and seller. The measures included in the action programme established under the Nitrates Directive are mandatory within designated Nitrate Vulnerable Zones (NVZ) and voluntary outside those zones.

Regulation 2003/2003, governing the marketing of mineral fertilisers, establishes that marketed mineral fertilisers cannot contain organic nutrients of animal or vegetable origin. According to the BelFertil association (Jaeken, 2011) of Belgian and Luxembourg mineral fertiliser producers, production of mineral fertilisers on basis of processed organic material may also be problematic in practice, because it leads to odour problems, contamination with heavy metals, colouring of the products, and risks of self-explosions.

6.3.2: Requirements for sanitation

Regulation (1069/2009/EC), laying down health rules as regards animal by-products and derived products not intended for human consumption, defines manure as a category II product, and so are the processed parts of it as well.

According to the above mentioned Regulation, if livestock manure or processed manure are traded between Member States, they must have been treated at least 70°C for 60 minutes in an approved biogas, composting or technical plant.

It is accepted that raw manure as well as processed manure products are used as fertiliser on the fields without sanitation within the member state, and on the condition that it has not been processed on a waste treatment plant[7].

Concentration of the livestock production in some areas has led to a larger focus on the amount of heavy metals in the livestock manure, at least concerning pig production, where feed additives containing copper and zinc are used.

The concentrations of heavy metals are typically increased by livestock manure processing. Hsu and Lo (2001) found that the concentration of Cu, Mn and Zn increased 2.7 times during the composting of a solid separation fraction of pig slurry, due to the chemical processes during composting.

Also, several manure processing technologies concentrates the dry matter of the livestock manure, including the metals and the non-volatile part of the solids. This is for instance the case with combustion, drying and evaporation technologies, as well as the aeration technologies such as composting. The metals are generally bound chemically to the organic/solid part of the manure, wherefore also separation technologies will concentrate the heavy metals in the solid phase.

Elevated levels of heavy metals have toxicological effects on the ecosystems. High levels of heavy metals in soil can be toxic to crop plants, and can be taken up by crops and cause human health problems. High levels of heavy metals in manures can lead to accumulation in the soil to which they are applied. This could lead to longer-term problems for crop yields and safety.

The Sewage Sludge Directive (86/278/EEC) sets limit values heavy metal concentration in soils and in sludge used for fertilisation, but the directive is not regulating application of livestock manure or processed manure fractions.

As a consequence of the described situation, several Member State have introduced own regulations to avoid contamination of soils with heavy metals derived from livestock manure application. Most focus is on regulating the spreading of compost. However, the situation makes it difficult for the market operators, who need to understand each country's regulations.

6.4: Market mechanisms

The EU has for other market commodities introduced product classification and grading systems in order to ensure a transparent price setting and the definition of qualities. This is for instance the case for beef carcasses, for vegetables and many more. A similar product classification and grading systems could be set up for end and by-products from livestock manure processing, so to make market operators labelling their products and prices accordingly.

Another measure to ease market activities are the establishing of published statistics on market prices for manure processing products in different parts of the Community. This would make clearer where best prices can be obtained.

While the default qualities could be determined for the entire EU, the market prices would be varying considerably from region to region, especially for the products that depend on regional marketing.

A general feature for the market with end and by-products form livestock manure processing is that it heavily depends on supply and demand, where the demand especially is correlated with the prices on mineral fertilisers, which again depend on the energy prices to produce them. Figure 6.1 shows that fertiliser prices have been steadily growing in the last decade. On the other hand, the supply highly

[7] Article 2.2 and 2.2.b of the Waste Framework Directive (2008/98/EEC): 2.2. The following shall be excluded from the scope of this Directive to the extent that they are covered by other Community legislation: (b) animal by-products including processed products covered by Regulation (EC) No 1774/2002, except those which are destined for incineration, landfilling or use in a biogas or composting plant;

varies from region to region and highly depends on the livestock concentration in a particular area, as well as on the legislation in force.

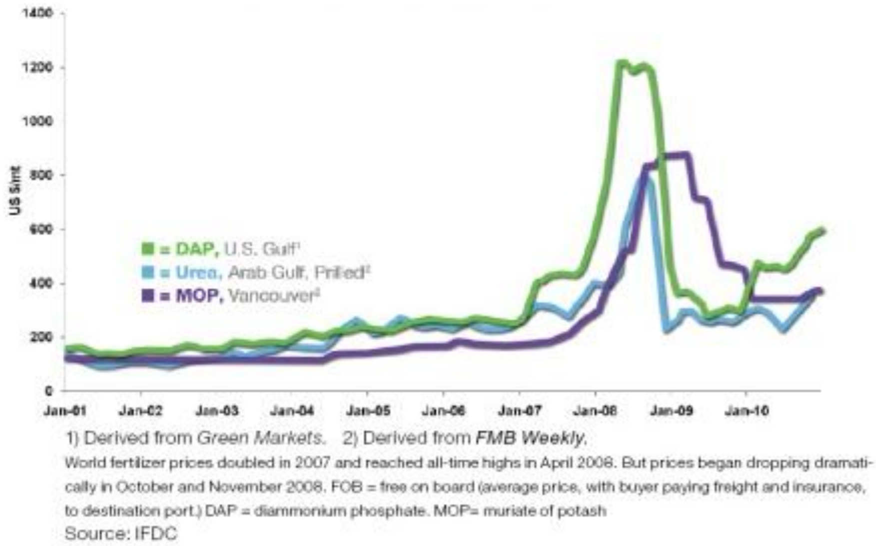


Figure 6.1: Development in fertiliser prices on the World market (FOB, bulk). Monthly averages January 2001 to December 2010.

6.5: Technological challenges

The technological challenges deal with the logistical handling of end and by-products. Due to the relatively high content of volatile nitrogen, the liquid fractions (except Filter water and Manure processing effluents) require to be kept in closed containers or tanks with tight cover; alternatively they could be treated with acid in order to bind the ammonia.

Separation solids have often a dry matter content of less than 30%, which is typically the limit for seepage; therefore they shall normally be kept in watertight stores, preferably also with cover as it soon starts composting, whereby large amounts of methane and ammonia, as well as some laughing gas are released. Logistics handling of the separation solids must in this case ensure a quick transport to biogas plants in order to limit emissions to a minimum.

Compost ends up with a stable product, but it is often made on basis of products that have less than 30% dry matter; in such cases, it is important to store them on watertight and drained concrete surfaces, to prevent water contamination. Generally all air emissions (ammonia, methane and laughing gas), which are rather large, should be collected during composting as well as during other aeration processes.

Some products are easier to store – this is for instance the case with ash and charcoal.

Transport vessels have generally the same requirements as the storage vessels, to avoid seepage and emissions. Acceptable transport costs are of course heavily correlated with the nutrient concentration of the end and by-product, wherefore ash and charcoal is more relevant for long transports.

Spreading equipment must in some cases be specially designed for spreading end and by-products – this is the case for Manure concentrates, for instance ammonia water.

6.6: Market considerations for biogas

Probably the main part of the biogas that is produced in the EU is used for generation of electricity, simply due to the fact that subsidies most often are linked to the electricity sales price.

The subsidies for biogas based electricity range from 0 (zero) for instance in Estonia, up to around 27 c€ per kWh in Italy and Germany; in some countries the subsidisation is in the form of an established green certificate system, for instance in Poland.

Some countries offer investment support, but generally the funds are limited and in any case of less importance for the economy of a biogas plant than the support for the operational costs via the electricity price. Especially Sweden supports indirectly biogas production via support to use of biomethane in the transport sector.

Generally, the main part of the biogas that is converted to electricity is only converted with an efficiency of around 40%, while the rest 15-25% of the energy is used in the process and 35-45 % is excess heat. The heat is often not utilised due to lack of possibilities for that (no heat consuming activities nearby), and due to sufficiently high income from sale of electricity in countries with a highly subsidised electricity price.

Probably future markets for biogas are those where the energy can be used efficiently, and therefore the preferred use would be (prioritised order):

1. Use for local heat (or cooling) production, replacing use of natural gas at for instance district heating plants.
2. Use in the transport sector via pipelines/gas grids and containers, preferably without upgrading to natural gas qualities[8], which with current known technologies is rather costly.
3. Conversion to electricity.

The economical optimal use of the biogas is case-specific and must be determined by feasibility studies for each biogas plant when it is being planned. The economical optimal use of the biogas is not always the environmentally or socio-economically optimal use.

[8] The quality of natural gas follows certain standards. Natural gas contains app. 30% more energy per volume unit than biogas.

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8: ABBREVIATIONS AND ACRONYMS

ABP	Agro Business Park A/S
AU	Animal Unit. Danish coefficient that expresses the nutrient load of livestock. 1 AU = 100 kg N in livestock manure ex. storage = app. 36 produced slaughter pigs from 32 to 107 kg.
BAT	Best Available Technique, as defined in Directive 2008/1/EEC
BREF	Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs
Ca	Calcium - the conversion factor from CaO to Ca is 0.7146.
CO_2	Carbon Dioxide
CPH	Combined Heat and Power
DG ENV	European Commission, Directorate-General Environment
DM	Dry matter
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
GIRO	GIRO Centre Tecnològic
IED	Industrial Emissions Directive 2010/75/EEC
IPPC	Integrated Pollution Prevention and Control, as defined in Directive 2008/1/EEC, now replaced by the Industrial Emissions Directive 2010/75/EEC
IRPP	Intensive Rearing Pigs and Poultry
IRR	Internal Rate of Return
K	Potassium - the conversion factor from K_2O to K is 0.8301.
Laughing gas	Nitrous oxide, N_2O – a greenhouse gas with a climate impact that is around 300 times that of CO_2
LSU	The livestock unit, abbreviated as LSU (or sometimes as LU), is a reference unit which facilitates the aggregation of livestock from various species and age as per convention, via the use of specific coefficients established initially on the basis of the nutritional or feed requirement of each type of animal (see table below for an overview of the most commonly used coefficients). The reference unit used for the calculation of livestock units (=1 LSU) is the grazing equivalent of one adult dairy cow producing 3 000 kg of milk annually, without additional concentrated foodstuffs. See also http://epp.Eurostat.ec.Europa.eu/statistics_explained/index.php/Glossary:Livestock_unit_(LSU).
MBE	Morsø BioEnergy
Mg	Magnesium - the conversion factor from MgO to Mg is 0.6031.
MS	Member State of the European Union
N	Nitrogen
Na	Sodium - the conversion factor from Na_2O to Na is 0.741839763.
NVZ	Nitrate Vulnerable Zone, as defined in Directive 676/91/EEC
OU	Odour Units

P	Phosphorus – the conversion factor from P_2O_5 to P is 0.436681223.
VS	Volatile solids

ANNEX A: "LONG-LIST" OF CONSIDERED MANURE PROCESSING TECHNOLOGIES

Index	No.: Livestock Manure Treatment Technology	Stand alone	Combined
	10: Separation		
1	10A Coagulation-Flocculation		✓
2	10B Electrocoagulation		✓
3	11 Separation by grate		✓
4	12 Separation by screw pressing	✓	✓
5	13 Separation by sieves	✓	✓
6	14 Separation by filter pressing	✓	✓
7	15 Separation by centrifuge	✓	✓
8	16 Air Flotation		✓
9	17 Separation by drum filters	✓	✓
10	18 Natural settling separation		✓
	20: Additives and other pre/1st treatments		
11	21 Acidification of liquid livestock manures	✓	✓
12	22 pH increasing (liming)	✓	✓
13	23 Temperature and pressure treatment	✓	✓
14	24 Applying other additives to manure	✓	✓
	30: Anaerobic treatment		
15	31A Mesophilic anaerobic digestion	✓	✓
16	31B Thermophilic anaerobic digestion	✓	✓
	40: Treatment of the solid fraction		
17	41 Composting of solid livestock manure or solid fractions of liquid livestock manure	✓	✓
18	41A Vermicomposting	✓	✓

Index	No.: Livestock Manure Treatment Technology	Stand alone	Combined
19	42 Biodrying	✓	✓
20	43 Thermal drying		✓
21	44 Pelletizing		✓
22	45 Combustion		✓
23	46 Thermal gasification		✓
24	47 Pyrolysis		✓
25	48 Wet oxidation		✓
	50: Treatment of the liquid fraction		
26	51 Microfiltration		✓
27	52 Ultra filtration		✓
28	53 Reverse osmosis		✓
29	54A Concentration by vacuum evaporation		✓
30	54B Concentration by atmospheric evaporation		✓
31	55 Ammonia stripping and absorption		✓
32	56 Carbon dioxide stripping		✓
33	57 Electro-oxidation		✓
34	58 Ozonizing		✓
35	59A Aerobic digestion (aeration)	✓	✓
36	59B Autothermal aerobic digestion (ATAD)	✓	✓
37	60 Nitrification-denitrification (conventional)		✓
38	61 Partial nitrification - autothrophic anammox denitrification		✓
39	62A Struvite (magnesium ammonium phosphate) precipitation		✓
40	62B Calcium phosphate precipitation		✓
41	63 Algae production on liquid manure substrates		✓
42	64 Constructed wetlands		✓

Index	No.: Livestock Manure Treatment Technology	Stand alone	Combined
	100: Air cleaning (as part of manure processing plant)		
43	101 Air scrubbing		✓
44	102 Air biofiltration		✓
45	103 Bioscrubing (Aerobic biofilter)		✓

ANNEX B: CHEMICAL VALUES OF END AND BY-PRODUCTS

The following tables show examples of chemical composition of end and by-products from livestock manure processing. The references for the individual datasets are listed under each table – in some cases reference concerns only the number and sizes of the livestock manure processing installations in question and chemical values are provided from other sources.

The shown values are to be considered as examples; they illustrate the chemical composition for relevant parameters, as well as the variation in the composition. The references must be consulted in each case in order to clarify for instance the analysis method and the exact technologies that were used to produce the end or by-product.

The data is also accessible at http://agro-technology-atlas.eu/endandbyproducts.aspx.

Annex B.1: Separation solids

Table B.1: Examples of qualities of separation solids[9]*.*

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
Fibre fraction	36.00		11.6		4		7		2																																1
Solid fraction from a mechanical separator	28.33		11.8		5.4		6.9		3.9				212.3								4.8		8.1		0.80				93.9		282.6										2
Bioenergie-Region Südoldenburg pig slurry solid fraction	27.50	28	9.8	10.1	3	3.3	6.9		3.2				190								4.8		4.1						14.1		115.8										3
Solid fraction pig manure	28.80																																								4

9 The signs '≥' means the parameter value is like ('=') or larger ('>') in case there is also indicated a less-than value ('<').

Used units are:

- % for dry matter (DM)
- kg per ton for macro elements (N (meaning total N), NH4-N, P, K, organic C, Mg, Ca, Na), volatile solids (VS) and suspended matter
- gram per ton for trace elements (Cu, Zn, Hg, Pb, Cr, Ni)

The parameter Volatile solids (VS) is only a relevant parameter for solid fractions. Biologic oxygen demand (BOD), chemical oxygen demand (COD) and suspended matter is only relevant for liquid fractions.

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
Fibre fraction	22.00	32	3.8	5.1	2	3	1.3	2.9	2																																5
Solid fraction	19.00		5.1				1.4						15.1																												6
Fibre fraction	25.00		4.5		2		1.2		2																																7
Fibre fraction	36.00		11.8		5.6		13		2.3																																8
Solid fraction	16.00		6.5				6.3						13.2																												9
Solid Fraction (20% inflow)	20.00		2.2				3.5		5.8				15																												11
Bioenergie-Region Südoldenburg pig slurry solid fraction	27.90	34.3	8.2	8.5	3	3.2	2.6	3.4	3.2	3.4			250	420							1.49	2.16	4.25	4.31					24.7	28.2	77.3	96									12
Fibre fraction	20.00	30			2.8	6.9			1.5	3.72			178	276															10	42	20	231									774

References:

- 1: Birkmose.T. (2010): Status over anvendelsen af gylleseparering i Danmark. maj 2010. Danish Agricultural Advisory Service. Aarhus. Denmark. The number of installations and treated amounts includes various types of mechanical separation (such as centrifuge, screw pressing and band filer separation) following the flocculation. We have not been able to divide these technologies.
- 2: Gerard Velthof, Alterra Wageningen UR. (2009) Report: Kunstmestvervangers onderzocht . Tussentijds rapport van het onderzoek in het kader van de pilot Mineralenconcentraten;
- 3: Brauckmann University of Osnabrück; data from test in July 2011 GEA and Spallek. Further information on www.bioenergie-suedoldenburg.de. In practice the Spallek centrifuge is used.

- 4: vcm inquiry (2010). VITO BBT study manure processing (2007); Only the nitrification-denitrification facilities that separate pig or cattle manure as a first step are counted here; in addition: 6 anaerobic digestors use separation by centrifuge for post-treatment of their digestate. We cannot distinguish between different separation technologies. Therefore they are all counted as centrifuge (= most often used technique).
- 5: Birkmose.T. (2010):
- 6: Rico. C.. García. H.. Rico. J.L. (2011). Physical–anaerobic–chemical process for treatment of dairy cattle manure. Bioresour. Technol. 102. 2143-2150.; These values of solids and nutrients concentration have been obtained at lab scale through a coagulation-flocculation separation process of dairy cattle manure.
- 71: Birkmose.T. (2010): Status over anvendelsen af gylleseparering i Danmark. maj 2010. Danish Agricultural Advisory Service. Aarhus. Denmark.;
- 8: Some of these centrifuge installations use coagulation/flocculation as pre-treatment - however we do not know how many!
- 9: Unpublished data; There is only a decanter centrifuge for the separation of manure in Cantabria. It is a Pieralisi Baby2. Installed in the pilot plant for I+D+i purposes. The centrifuge receives the liquid fraction of dairy manure separated by screw
- 10: Report authored by F. E. de Buisonjé and R.W. Melse Wageningen UR Livestock Research; Input type: Co-digested cattle slurry. Pig slurry and Cattle slurry
- 11: Brauckmann University of Osnabrueck; Data from test in July 2011. For details see www.bioenergie-suedoldenburg.de. Average and max. In practice of screw process are mainly used with cattle slurry. There are no data available
- 12: E-mail/Oral Communication (Luis Ferreira); (Oral communication with L. Ferreira)

Annex B.2: Separation liquids

Table B.2: Examples of qualities of separation liquids.

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
Liquid fraction from a rotary press with flocculant (Vanotti, et al. 2009)	1.38		1.41		1.19		0.17						5.21		1.21		3.032		7.89										2		3										1
Liquid fraction from a screw pressing (Magrí and Flotats, 2000)	2.65		2.67		1.62		1.05		1.03				16.6		22.10				18.74									0.02	15		128				0.007		0.4800		0.2200		2
Liquid fraction from a screening (Westerman and Bicudo, 2000)	0.96		1.33		0.96		0.36		1.04				5.78		6.42				7.64		0.11		0.263		0.23				9		11										3
Liquid fraction from a inclined screen (Chatain, et al. 2001)															11.05				20.14		0.168		0.488		0.14				12		7										4

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
Liquid fraction from a screew pressing (Magrí, 2007)	2.54		3.43		2.59		0.72		1.65				15.3		17.70		10.05		30.07		0.302		1.095																		5
Influent to RO	2.31		3.61		3.42			0.005	3.63												371		56.5		0.938				0.032		0.16										6
Influent to RO	2.05		3.75		3.62			0.005	3.82												256		20		0.858					0.01	49.9										7
Influent to RO	1.99		3.81		3.6		0.014		4.13												203		24		0.845			0.01	0.241		0.339					0.01		0.01	0.3		8
Influent to RO	1.85		3.61		3.26		0.009		3.49												179		102		0.83					0.01		0.01									9
Influent to RO	1.53		3.28		2.9		0.005		3.26												175		105		0.772					0.01		0.01									10
Influent to RO	1.61		2.91		2.66		0.005		2.68												256		49.7		0.71			0.01		0.01		0.01				0.01		0.01	0.359		11
Influent to RO	1.87		3.12		3.06		0.005		3.01												263		110		0.745					0.01		0.01									12
Influent to RO	2.37		4.35		4.29		0.005		4.32												287		138		1.03			0.01		0.01	0.198					0.01		0.01	0.355		13
Influent to RO	2.64		5.98		5.64		0.01		4.58												184		54.6		1.09					0.01	0.01										14

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
Influent to RO	3.15		6.54		6.36		0.014		4.71																1.12																15
Influent to RO	2.48		5.46		5.01		0.008		4.37																1.02																16
Influent to RO	2.46		5.67		5.41				5.17																0.972																17
Liquid fraction	1.4		2.3	2.9			0.3		1.9																																18
Liquid fraction from a screening (Radis-Steinmetz. et al. 2009)	2.81								1.26										50.55		0.0162				0.20				35		41										19
Rotary press with flocculant	1.3815		1.414		1.19		0.17						5.209		1.212		3.032		78.85										2.01		2.91										20
Bioenergie-Region Südoldenburg pig slurry liquide fraction	2.7		2.9	5.4			0.4		3.4												0.18		0.64						14.1		32.5										21
Screening	2.81								1.26										505.5		0.0162				0.20		0.02		35		41.2					0.007	0.48		0.22		22

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
Screw pressing	2.65		2.671		1.619		1.049		1.028				16.6		22.1				187.44										15		128										23
Screw pressing	2.49		3.434		2.59		0.722		1.652				15.3		17.7		10.05		300.72		0.302		1.095																		24
Screening	0.96		1.327		0.963		0.355		1.037				5.7792		6.421				76.42		0.11		0.263		0.23				8.5		11.2										25
Inclined screen	1.4959		0.729		0.359		0.19		0.38						11.05				201.36		0.168		0.488		0.14				12		7										26
Liquid fraction pig manure	3.4		3.9	6.2			0.56		4.52												0.12																				27
Liquid fraction	3.2	4.2	2	2.8	3	4.2	0.2	1	2																																28
Liquid fraction	2		0.9	1.2			0.08												14.3																						29
Liquid fraction	3.5		2.8	4			1		2																																30
Liquid fraction	2		4	4.8			0.2		1.9																																31
Liquid fraction	2.9		3.4	4.7			0.8		3.2																																32
Liquid fraction	1.5		0.8	1.3			0.1												15.4																						33

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
Liquid Fraction (80% inflow)	5		2.2				1		5.8				3																												34
Bioenergie-Region Südoldenburg pig slurry liquide fraction	3.8	3.9	3.03	5.3	3.2	5.4	0.95	1	3.46	3.6			19.6	20							0.56	0.6	1.15	1.2					12.5	12.9	35.2	39									35
Liquid Fraction	2.66	21	1.94	5.8	2.97	3.8	0.66	2.88	3.48		47.7	79.4																													36

References:

- 1: VANOTTI M.B., SZOGI A.A., MILLNER P.D., LOUGHRIN J.H. (2009). Development of a second-generation environmentally superior technology for treatment of swine manure in the USA. Bioresource Technology 100, 5406–5416.; pH was 7.8 and the electrical conductivity 13.7.
- 2: MAGRÍ A., FLOTATS X. (2000). Biological treatment of the liquid fraction of pig slurry in a sequencing batch reactor. In: 2nd International Symposium on Sequencing Batch Reactor Technology, vol. 2, pp. 132-135, Narbonne (France).; pH was 7.7 and the electrical conductivity 12.9.
- 3: WESTERMAN P.W., BICUDO J.R. (2000). Tangential flow separation and chemical enhancement to recover swine manure solids, nutrients and metals. Bioresource Technology 73, 1-11.; pH was 8.3.
- 4: CHASTAIN J.P., VANOTTI, M.B., WINGFIELD, M.M. (2001). Effectiveness of liquid-solid separation for treatment of flushed dairy manure: a case study. Applied Engineering in Agriculture 17, 343-354.;
- 5: MAGRÍ A. (2007). Modelling the biological treatment of the liquid fraction of slurry for the removal of nitrogen, Universitat de Lleida.; pH was 8.0 and the electrical conductivity 18.2.
- 6: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20090625. Liquid phase from dissolved air flotation.
- 7: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20090805. Liquid phase from dissolved air flotation.
- 8: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20090909. Liquid phase from dissolved air flotation.

- 9: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20091006. Liquid phase from dissolved air flotation.
- 10: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20091113. Liquid phase from dissolved air flotation.
- 11: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20091208. Liquid phase from dissolved air flotation.
- 12: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100203. Liquid phase from dissolved air flotation.
- 13: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100311. Liquid phase from dissolved air flotation.
- 14: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100419. Liquid phase from dissolved air flotation.
- 15: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100617. Liquid phase from dissolved air flotation.
- 16: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100713. Liquid phase from dissolved air flotation.
- 17: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100827. Liquid phase from dissolved air flotation.
- 18: Birkmose.T. (2010): Status over anvendelsen af gylleseparering i Danmark. maj 2010 . Danish Agricultural Advisory Service. Aarhus. Denmark.; The number of installations and treated amounts includes various types of mechanical separation (such as centrifuge. screw pressing. and band filer separation) following the flocculation. and we have not been able to divide these technologies.

- 19: RADIS-STEINMETZ R.L., KUNZ A., DRESSLER V.L., DE MORAES-FLORES E.M., FIGUEIREDO-MARTINS A. (2009). Study of metal distribution in raw and screened swine manure. Clean 37, 239-244.; pH was 7.2.
- 20: VANOTTI M.B., SZOGI A.A., MILLNER P.D., LOUGHRIN J.H. (2009). Development of a second-generation environmentally superior technology for treatment of swine manure in the USA. Bioresource Technology 100, 5406–5416.;
- 21: Brauckmann University of Osnabrück; Data from test in July 2011 GEA and Spallek. Further information on www.bioenergie-suedoldenburg.de In practice the Spallek centrifuge is used.
- 22: RADIS-STEINMETZ R.L., KUNZ A., DRESSLER V.L., DE MORAES-FLORES E.M., FIGUEIREDO-MARTINS A. (2009). Study of metal distribution in raw and screened swine manure. Clean 37, 239-244.; pH was 7.81 and the electrical conductivity 13.67.
- 23: MAGRÍ A., FLOTATS X. (2000). Biological treatment of the liquid fraction of pig slurry in a sequencing batch reactor. In: 2nd International Symposium on Sequencing Batch Reactor Technology, Narbonne (France), vol. 2, pp. 132-135.; pH was 7.20.
- 24: MAGRÍ A. (2007). Modelling the biological treatment of the liquid fraction of slurry for the removal of nitrogen, PhD Thesis. Universitat de Lleida.; pH was 7.70 and the electrical conductivity 12.9.
- 25: WESTERMAN P.W., BICUDO J.R. (2000). Tangential flow separation and chemical enhancement to recover swine manure solids, nutrients and metals. Bioresource Technology 73, 1-11.; pH was 8.01 and the electrical conductivity 18.18.

- 26: CHASTAIN J.P., VANOTTI, M.B., WINGFIELD, M.M. (2001). Effectiveness of liquid-solid separation for treatment of flushed dairy manure: a case study. Applied Engineering in Agriculture 17, 343-354.; pH was 8.30.
- 27: vcm inquiry (2010). VITO BBT study manure processing (2007); Only the nitrification-denitrification facilities that separate pig or cattle manure as a first step are counted here; in addition: 6 anaerobic digestors use separation by centrifuge for post-treatment of their digestate. We cannot distinguish between different separation technologies. Therefore they are all counted as centrifuge (= most often used technique).
- 28: Birkmose.T. (2010)
- 29: Rico. C.. García. H.. Rico. J.L. (2011). Physical–anaerobic–chemical process for treatment of dairy cattle manure. Bioresour. Technol. 102. 2143-2150.; These values of solids and nutrients concentration have been obtained at lab scale through a coagulation-flocculation separation process of dairy cattle manure.
- 30: Birkmose.T. (2010): Status over anvendelsen af gylleseparering i Danmark. maj 2010 . Danish Agricultural Advisory Service. Aarhus. Denmark.;
- 31: Some of these centrifuge installations use coagulation/flocculation as pre-treatment
- 32: Birkmose.T. (2010): Status over anvendelsen af gylleseparering i Danmark. maj 2010 . Danish Agricultural Advisory Service. Aarhus. Denmark.;
- 33: Unpublished data; There is only a decanter centrifuge for the separation of manure in Cantabria. It is a Pieralisi Baby2. installed in the pilot plant for I+D+i purposes. The centrifuge receives the liquid fraction of dairy manure separated by screw.
- 34: Report authored by F. E. de Buisonjé and R.W. Melse Wageningen UR Livestock Research; Input type: Co-digested cattle slurry. Pig slurry and Cattle slurry
- 35: Brauckmann University of Osnabrueck; Data from test in July 2011. For details see www.bioenergie-suedoldenburg.de. Average and max. In practice of screw process are mainly used with cattle slurry. There are no data available.
- 36: Information provided by Sergio Piccinini and different papers authored by Sergio Piccinini et al.; Considerations about plants size -Number of plants 100 kW (considered farm-size): 49 / Average power engine 28 kW-Number of plants 101-500 kW (considered farm-size): 61 / Average power engine 283 kW.

Annex B.3: Thermal and chemically treated manure

Table B.3: Examples of qualities of Thermal and chemically treated manure.

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
Acidified pig slurry	5.54		4.31		3.21		0.96		2.35																																1
Fly ash added to pig manure (10% fly ashes/manure), 12 days after addition	3.97		1.04056		0.85		0.2382		0.99647		3.4539										0.41288								55		195										2
Fly ash added to pig manure (20% fly ashes/manure)	13.59		1.05539		0.77		0.78822		1.0872		9.7848										1.00566								49.5		245										3
Hydrogen cyanamide additive to pig slurry (2,4 L - 50% dilution - per m3 of slurry)	5		0.77		0.553								33.5																												4
Micro-Aid additive to pig slurry (0,22 kg per m3 pig slurry)	4.7		0.66		0.52								30.46																												5
Pasteurized digestate	6.5		7				1.7		5.8				3																												6

References:

- 1: Information from the companies BioCover and InFarm; The technology is reducing the pH of the slurry by adding sulphuric acid to the slurry. while the slurry still is in the stable system. Reducing the pH from app. 7.5 down to 5.0 prevents the mainpart of the ammonia to volatilize.
- 2: Vincini, M., Carini, F., Silva, S. (1994). Use of alkaline fly ash as an amendment for swine manure. Bioresource tecnology, 49: 213-222.; pH: 8.9, Mn: 227, Fe: 242

- 3: Vincini, M., Carini, F., Silva, S. (1994). Use of alkaline fly ash as an amendment for swine manure. Bioresource tecnology, 49: 213-222.; pH: 9.3, Mn: 199, Fe: 1345
- 4: H2S emission decreased to 0. Significant increase of total N in slurry, and significant increase of ammonia emissions. Source: Patni, N.K. (1992). Effectiveness of manure additives. The Centre for Food and Animal Research. Agriculture Canada, Otawa (Onta; pH: 7.0
- 5: Significant decrease on N-NH3 emissions. No effect on H2S emissions. Source: Patni, N.K. (1992). Effectiveness of manure additives. The Centre for Food and Animal Research. Agriculture Canada, Otawa (Ontario), Canada. ; pH: 7.0
- 6: Report authored by F. E. de Buisonjé and R.W. Melse Wageningen UR Livestock Research; Pasteurization (70 C. 1 hour) Input type: Co-digested pig and cattle slurry No information about size was provided.

Annex B.4: Digestate

Table B.4: Examples of qualities of digestate.

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
Digested slurry	2.8		5		4		0.9		2.75																																1
Codigestate (pig and cow slurry+organic waste) (Bernal et al. 2011)	1.5	12.7	0.6	4.9	0.4	3.5	0.08	1.24	0.85	3.13	5.8	70.5	8.5	97.3			1.2	62.5			67	721	192	4176	66.00	1842	0.01	0.02	1	17	8	140			0.1	1.3	01	4	0.05	2.6	2
Digestate	6.63		3.02				1.05		3.79																																3
treatment residue	3.4		2.1		1.3		0.3		2.9				2.6																												4
Digested	2.98		3.87		2.96		0.8		2.87		51.6																														5

References:

- 1: Jørgensen. P.J. (2009): ‘Biogas – green energy ; PlanEnergi and Researcher for a Day. Faculty of Agricultural Sciences. Aarhus University. Research Centre Foulum. Denmark.; Our references do not divide the number of plants in mesophilic and thermophilic installations. In this case we have placed them all at mesophilic istallations because most plants are mesophilic Input amounts and types are pure estimates.
- 2: Bernal, P., Alburquerqeu. J.A., Bustamante, M.A., Clemente, R. (2011). Guia de utilización agrícola de los materiales digeridos por biometanización. CESIC; pH was between 5.6 and 8.2 and the electrical conductivity between 5.2 and 30.8.
- 3: Information collected from Latvia Biogas Association. Farmers Parliament. Plant operators. Ministry of agriculture. Rural Support Service; Analysis results for digestate: Total Nitrogen in dray matter - 3.02%; K in dry matter - 3.79%; P in dray mattre - 1.05%; Butryc acid - 0.11%; lactic acid - 0.14%. Ph - 7.67 LLU farms Vecauce.
- 4: according to the information given in the biogas association yearbook The treatment residue analysis from one installation used for research purposes (cattle slurry + silage)
- 5: Information provided by Sergio Piccinini and different papers authored by Sergio Piccinini et al.; Considerations about plants size -Number of plants 100 kW (considered farm-size): 49 / Average power engine 28 kW -Number of plants 101-500 kW (considered farm-size): 61 / Average power engine 283 kW

Annex B.5: Manure compost

Table B.5: Examples of qualities of manure compost.

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
Compost from codigested cow slurry + organic wastes (Giro, 2010)	22	31.2	6.6	9.7	0.65	2.82	1.17	4.80	1.32	4.06			167	257													0.02	0.125	7.48	16.224	28.6	113.26	0.00	0.016	0.66	8.736	1.32	4.68	1.10	2.808	1
Compost form a centralized composting plant of cow manure (Juncasa, Catalunya, Spain)	88.9		26.3144		3.0226		15.3797		46.8503				531.622								13.9573		52.9844				0.18		38.227		369.824		0.02		1.78		4.45		5.33		2
Compost from a drying plant (NDN + Evaporation + Drying + Composting) (Langa	63.2		21.24		9.72		12.42		7.02				1341.736								8.64		14.58				0.00		93.9		282.6		0.00		0.00		0.00		0.00		3

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	Corg ≥	Corg <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
de Durero Plant)																																									
Compost-Cow manure (Fervosa, Spain)	51.2		11.9296		3.9936		5.1712		10.6496				290.304								4.3008		25.0368				0.15		135.168		268.288		0.07		21.50		10.75		6.66		4
Compost	33.05																																								5
Compost	28.86																																								6
Compost	57		7.5				2.6		5.8				22																												7

References:

- 1: Giro CT (2010) Characterisation of codigested compost. Data not published; pH was between 7.3 and 8.6 and the electrical conductivity between 2.25 and 3.34.
- 2: Gerard Velthof, Alterra Wageningen UR. (2009) Report: Kunstmestvervangers onderzocht . Tussentijds rapport van het onderzoek in het kader van de pilot Mineralenconcentraten;
- 3: Gerard Velthof, Alterra Wageningen UR. (2009) Report: Kunstmestvervangers onderzocht . Tussentijds rapport van het onderzoek in het kader van de pilot Mineralenconcentraten;
- 4: pH was 8.87 and the electrical conductivity 6.36.
- 5: Agencia Residus catalunya; Input type is in reference of medium size installations with 51% of substrate different of manures. such as sewage sludge and other organic waste
- 6: Agencia Residus catalunya; Input type is in reference of medium size installations with 51% of substrate different of manures. such as sewage sludge and other organic waste

- 7: Report authored by F. E. de Buisonjé and R.W. Melse Wageningen UR Livestock Research; Input type: Pre-dried poultry manure and solid manures/ solid fractions with non-manure additives (straw. gypsum. etc.) No information about size was provided. Compost produced: 60% of the input

Annex B.6: Dried manure and pellets

Table B.6: Examples of qualities of dried manure and pellets.

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
Pellets from a thermal drying process (VAG SL)	84,23		58,85		40,82		13,89		36,02				561,03																248,32		1687,53										1
Pellets from a thermal drying process (TRACJUSA)	81,43		61,38		41,08		14,32		40,34				562,68								1,02		2,92		14796,88			1	210,48		1747,53		0,03		4,07		8,51		6,52		2
Dry product (dust) from a thermal dryer plant (DDP Alcarras)	90,90		68,72		4,64		18,65		29,42				547,22								0,99		4,64					0.64	142,71		673,57					18		9		18	3
Dried product form a RO plant	83.52		23.7		6.5		20.9		15.3				600.2								14.6		28.7		3.40				133		368.8										4
Pellets	90		70				40		70		550																														5
Pellets	90		70				40		70		550																														6
Pellets (30% of the input)	90		40				13.1		24.9				70																												7
Pelletized end product	82.14	86	59	66			12	16	37	45			670	680																											8
Solid dried fraction. Often pelletized.	84	95	50	60			13	17	35	50			540	636																											9

References:

- 1: Data provided by GIRO Centre Tecnològic
- 2: pH was 6.8 and the electrical conductivity 65.8.
- 3: pH was 7.6 and the electrical conductivity 37.
- 4: Gerard Velthof, Alterra Wageningen UR. (2009) Report: Kunstmestvervangers onderzocht . Tussentijds rapport van het onderzoek in het kader van de pilot Mineralenconcentraten;
- 5: Consejería de Agricultura y Medio Ambiente de Castilla-la Mancha. Dirección general de Calidad y Sostenibilidad Ambiental. Servicio de Residuos;
- 6: Consejería de Agricultura y Medio Ambiente de Castilla-la Mancha. Dirección general de Calidad y Sostenibilidad Ambiental. Servicio de Residuos;
- 7: Report authored by F. E. de Buisonjé and R.W. Melse Wageningen UR Livestock Research; No information about size was provided.
- 8: There are: 3 installations: anaerobic digestion+separation by centrifugue+thermal drying+pelletizing and 3 installations with the diagram: separation by drums filters+NDN+thermal drying+pelletizing.
- 9: Pedro Esteban Turzo; Average tons treated by this technology are less than 50000 but is belonging to facilities treating averages amounts of 110000 tons/year of pig manure - Information elaborated based on information provided by Perdo Esteban - government of Castilla Leon

Annex B.7: Ashes and charcoal

Table B.7: Examples of qualities of ashes and charcoal.

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
Biochar from poultry litter (broiler) (Agblevor et al. 2010)	97		16.78	23.09			16.8	25.9	56.5	75.9	226.98	327.3	454.7	562							11.6	18.8	57.3	86.4	14.80	20.3	3.00	4	0.08	0.16	0.08	0.13							32.00	53	1
Biochar from poultry litter (starter turkey) (Agblevor et al. 2010)	96		17.47				13		32.2		521.95		754								7.9		43.7		5.20		2.00		0.05		0.08								31.00		2
Biochar from chicken litter (Ro et al., 2010)	96		26.59				16.51		65		398.40		806.4																												3
Biochar from swine pig (Ro et al., 2010)	96.6		31.49				69.07		24.73		489.76		829.79																												4
Ash (7% of the input)	99.8		0.14				91.7		2.5																																5
Bottom ash from combustion of chicken																												0.5	848		480			1	2.7		36.5		27.4		6

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
deep litter																																									
Fly ash from combustion of chicken deep litter																											2.66		523.06		4344			1	18.73		17.78		16.55		7

References:

- 1: Agblevor, F.A., Beis, S., Kim, S.S., Tarrant, R., Mante, N.O. (2010). Biocrude oils from the fast pyrolysis of poultry litter and hardwood. Waste Management, 30: 298- 307; Figures udner organic carbon are total carbon.
- 2: Agblevor, F.A., Beis, S., Kim, S.S., Tarrant, R., Mante, N.O. (2010). Biocrude oils from the fast pyrolysis of poultry litter and hardwood. Waste Management, 30: 298- 307; Figures under organic carbon are total carbon.
- 3: Ro, K. S., Cantrell, K. B., Hunt, P.G. (2010). High-temperature pyrolysis of blended animal manures for producing renewable energy and value-added biochar. Ind. Eng. Chem. Res., 49: 10125-10131; Figures under organic carbon are total carbon.
- 4: Figures under organic carbon are total carbon.
- 5: Report authored by F. E. de Buisonjé and R.W. Melse Wageningen UR Livestock Research; Input type: Dry Poultry manure (60% dry matter) No information about size was provided. Ash produced: 7% of the input
- 6: Provided by KEM http://www.kem.dk, from a plant in the UK;
- 7: Provided by KEM http://www.kem.dk from a plant in the UK;

Annex B.8: Filter water

Table B.8: Examples of qualities of filter water.

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
Permeate from RO	0.026		0.02		0.017			0.005		0.005											0.78		2.39			0.005			0.018		0.06										1
Permeate from RO		0.2	0.036		0.037			0.005		0.005											0.219		0.728			0.005				0.01	19.7										2
Permeate from RO		0.2		0.02	0.012			0.005		0.005											0.113		4.1			0.005				0.01		0.01									3
Permeate from RO	0.06			0.02	0.014			0.005		0.005												0.01	0.41			0.005				0.01		0.01									4
Permeate from RO		0.2		0.02	0.0133			0.005		0.005											0.174			0.01		0.005		0.01		0.01		0.01				0.01		0.01		0.01	5
Permeate from RO		0.2	0.03		0.019			0.005		0.005											0.329			0.01		0.005				0.01		0.01									6
Permeate from RO		0.2	0.02		0.019			0.005		0.005											0.291		6.52			0.005		0.01	0.07			0.01				0.01		0.01		0.01	7
Permeate from RO		0.2	0.061		0.061			0.005		0.005												0.01	1.15			0.005				0.01		0.01									8
Permeate from RO		0.2	0.059		0.059			0.005		0.005																0.005															9
Permeate from RO		0.2	0.105		0.097			0.005		0.005																0.005															10

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
Permeate from RO	0.02		0.109		0.096			0.005		0.005																0.005															11
Permeate from RO		0.2	0.03		0.029			0.005		0.005											0.177		1.87			0.005		0.01		0.01	0.038					0.01		0.01		0.01	12
After ion exchange		0.2		0.02		0.001		0.005		0.005												0.01	0.299			0.005		0.01		0.01	0.023					0.01		0.01		0.01	13
After ion exchange		0.2		0.02		0.001		0.005		0.005											0.063		1			0.005				0.01		0.01									14
After ion exchange	0.02			0.02	0.008			0.005		0.005												0.01	0.33			0.005				0.01		0.01									15
After ion exchange		0.2		0.02		0.001		0.005		0.005											0.276		1.87			0.005		0.01		0.01		0.01				0.01		0.01		0.01	16
After ion exchange		0.2		0.02	0.001			0.005		0.005												0.01	0.01			0.005				0.01		0.01									17
After ion exchange		0.2		0.02	0.049			0.005		0.005											0.305		0.86			0.005		0.01		0.01		0.01				0.01		0.01		0.01	18
After ion exchange		0.2	0.026		0.03			0.005		0.005												0.01	10			0.005				0.01		0.01									19
After ion exchange		0.2		0.02	0.003			0.005		0.005																0.005															20
After ion exchange		0.2	0.045		0.015			0.005		0.005																0.005															21

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
After ion exchange		0.2	0.026		0.011			0.005		0.005																0.005															22
Permeate form a RO plant	0.07		0.5		0.4		0.01		0.2				0.2									0.01		0.01	0.05					0.01	0.05										23
Permeate form a UF plant	1.28		3.3		3.04		0.08		3.3				3.8									0.01		0.01	0.80					0.01	0.6										24
Permeate (water): 75%	0.9		0.4				0.03		2.5				0.3																												25

References:

- 1: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20090625
- 2: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20090805
- 3: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20091006
- 4: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20091113
- 5: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20091208
- 6: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100203
- 7: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100311
- 8: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100419
- 9: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100617
- 10: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100713
- 11: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100827
- 12: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20090909

- 13: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20090909
- 14: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20091006
- 15: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20091113
- 16: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20091208
- 17: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100203
- 18: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100311
- 19: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100419
- 20: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100617
- 21: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100713
- 22: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100827
- 23: Gerard Velthof, Alterra Wageningen UR. (2009) Report: Kunstmestvervangers onderzocht . Tussentijds rapport van het onderzoek in het kader van de pilot Mineralenconcentraten;
- 24: Gerard Velthof, Alterra Wageningen UR. (2009) Report: Kunstmestvervangers onderzocht . Tussentijds rapport van het onderzoek in het kader van de pilot Mineralenconcentraten;
- 25: Report authored by F. E. de Buisonjé and R.W. Melse Wageningen UR Livestock Research; Input type: Veal calf slurry and LF pig slurry No information about size was provided.

Annex B.9: Manure processing effluents

Table B.9: Examples of qualities of Manure processing effluents.

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
Rotary press with flocculant + DN_N (2 tanks) + P precipitation (full scale)	0.9725		0.239		0.043		0.035						1.722		0.326		0.038		0.79										0.13	0.26											1
Rotary screen + intermittent aeration + Lagoon (full scale)							0.0425								0.24		0.12		1.33										4.1	1.33											2
Screen pressing + SBR (lab scale)	0.286		0.017		0		0.115		0.589				0.71		0.07				0.293										1.8	4.1											3
Centrifugation + SBR (full scale)			0.029		0.0064		0.022								0.32		0.093		0.356										0	0.36											4
Effluent nitrification-denitrification	0.60	0.8	0.255		0.11		0.15						2.33		1.22				0.6	4.2																					5
Sludge (after dewatering): 15%	25		7				6.5		3.3				13																												6

References:

- 1: VANOTTI M.B., SZOGI A.A., MILLNER P.D., LOUGHRIN J.H. (2009). Development of a second-generation environmentally superior technology for treatment of swine manure in the USA. Bioresource Technology 100, 5406-5416.;
- 2: BICUDO J.R., SVOBODA I.F. (1995). Effect of intermittent-cycle extended-aeration treatment on the fate of carbonaceous material in pig slurry. Bioresource Technology 54, 53-62. ; pH was 9.71 and the electrical conductivity 6.32.
- 3: MAGRÍ A., FLOTATS X. (2000). Biological treatment of the liquid fraction of pig slurry in a sequencing batch reactor. In: 2nd International Symposium on Sequencing Batch Reactor Technology, Narbonne (France), vol. 2, pp. 132-135, ; pH was 8.00 and the electrical conductivity 5.40.
- 4: TILCHE A., BORTONE G., MALASPINA F., PICCININI S., STANTE L. (2001). Biological nutrient removal in a full-scale SBR treating piggery wastewater: Results and modelling. Water Science and Technology 43, 363-371.; pH was 8.20 and the electrical conductivity 3.70.

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- 6: Report authored by F. E. de Buisonjé and R.W. Melse Wageningen UR Livestock Research; Input type: Veal calf slurry and LF pig slurry No information about size was provided.

Annex B.10: Manure concentrates

Table B.10: Examples of qualities of Manure concentrates.

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
Ammonia Water from pig slurry Stripping/Absorption process (pilot plant)					20	42					0.001	0.006																													1
Concentrate from RO	4.52		6.31		5.93			0.005	6.3												661		104		1.96				0.045		0.2										2
Concentrate from RO	3.57		6.47		6.29		0.009		6.61												443		39.7		1.45					0.01	51.3										3
Concentrate from RO	3.59		6.41		5.77		0.023		7.1												362		48.1		1.49			0.01	0.052		0.197					0.01		0.01	0.55		4
Concentrate from RO	3.69		6.23		5.79		0.014		6.47												333		174		1.49					0.01		0.01									5
Concentrate from RO	3.21		6		5.57		0.009		6.22												333		204		1.56					0.01		0.01									6
Concentrate from RO	3.65		6.01		5.78			0.005	5.92												541		104		1.54			0.01		0.01		0.01				0.01		0.01	0.676		7
Concentrate from RO	3.917		6.43		6.18			0.005	6.12												678		222		1.57					0.01		0.01									8
Concentrate from RO	3.401		5.79		5.72		0.007		5.52												441		211		1.51			0.01		0.01	0.232					0.01		0.01	0.488		9
Concentrate from RO	3.47		7.38		7.2		0.014		6.05												245		67.2		1					0.01		0.01									10
Concentrate from RO	4.71		9.6		9.31		0.019		7.15																2																11
Concentrate from RO	4.35		9		8.36		0.013		7.49																1.69																12
Concentrate from RO	4.09		9.06		8.53		0.016		8.09																2																13
Concentrate from a UF plant	3.53		6.7		6.4		0.2		7.8				13.5										0.2		1.90				0.4		0.9										14

Name	DM ≥	DM <	N ≥	N <	NH4-N ≥	NH4-N <	P ≥	P <	K ≥	K <	C org ≥	C org <	VS ≥	VS <	Susp. mat. ≥	Susp. mat. <	BOD ≥	BOD <	COD ≥	COD <	Mg ≥	Mg <	Ca ≥	Ca <	Na ≥	Na <	Cd ≥	Cd <	Cu ≥	Cu <	Zn ≥	Zn <	Hg ≥	Hg <	Pb ≥	Pb <	Cr ≥	Cr <	Ni ≥	Ni <	Reference
Concentrate from a RO plant	4.11		5.6		3.4		0.5		3.7				27.8								0.2		0.9		0.80				27.3		81.6										15
Mineral NK-concentrate	3.5		7				0.18		9.13				1.4																												16
Solid phase	28		12				7		4.6				21																												17
Solid phase	23																																								18

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- 6: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20091113
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- 9: Samples taken and analysed by WUR. Informed by Kumac Mineralen; Sampled 20100311
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- 16: Report autohred by F. E. de Buisonjé and R.W. Melse Wageningen UR Livestock Research;
- 17: Report autohred by F. E. de Buisonjé and R.W. Melse Wageningen UR Livestock Research;
- 18: Pedro Esteban Turzo; Elaborated based on information provided by Pedro Esteban - government of Castilla Leon

ANNEX C: CONSULTATIONS CONCERNING END AND BY-PRODUCTS

The following tables summarise key points concerning the issues listed in section 2 – methodology.

Company: Kom-Tek (Denmark) Expert: Hans Peter Fyhn Date: 7 July 2011	Specialised in composting and trade with manure biomasses Product: Solid separation fractions, compost, livestock manures
1.1: Customers of these products are clearly identified? Are well-established marketing channels? How would you improve the identification of customers?	Many customers contact us. We make a little advertisement in agricultural magazines, and have also been present at Agromek, the major Danish agricultural fair.
1.2: Which kind of customers do you have (farmers, gardening, organic fertilizer company, public works, composting plants, other)? What percentage of each one?	Farmers, crop producers
2.1: What features / properties should these products have to be accepted by customers? Have costumers any special requirement?	Customers demand declaration of the chemical content of plant nutrients.
2.2: Do clients ask for a guarantee on the supply and/or require a minimum volume/weight of product? Is this a problem for the sales?	Not really, but many customers return
2.3: What do you consider to be the key points to assure customer loyalty?	A good deal
2.4: What other socio-economic aspect has an impact on the sales / demand for this type of fertilizer products? (E.g. chemical fertilizer cost, regulation on agriculture, etc.).	-
2.5: Which is the average price of the product you sell?	We only trade separation solids (apart from different types of livestock manures). Currently the farmer pays for the transport, around € 13 per ton. Our business is based on payments from the producers of the separation solids. The price is lower than the value of the content of plant nutrients, and this is due to the higher logistics costs than for mineral fertilisers.
2.6: How important is the sale of these products in your trading account? It is important for the viability of the company?	Yes, our company depends on trade with separation solids together with compost and livestock manures.
3.1: Is the current legislative framework adequate? It favours or hinders the marketing of these products? How flexible is the current legislation?	The animal by-products regulation hinders us in use of the separation solids for composting together with other products.
3.2: What legislative actions or which aspects of its application (control, procedure, etc.) should be modified to boost the market of this kind of fertilizer?	-
4: Comments (any comments or suggestions you wish to add)	

Company: Kumac Mineralen (Netherlands) Expert: Henry van Kaathoven Date: 11 July 2011	Has developed own manure treatment plants Product: A liquid nitrogen fertiliser and a solid separation fraction
1.1: Customers of these products are clearly identified? Are well-established marketing channels? How would you improve the identification of customers?	We sell the liquid concentrate to nearby crop producers, especially to potato growers, who with this fertiliser can boost their yields, also because they can apply the concentrate on top of the 170 kg N/ha for livestock manure. We pay biogas plants for taking the separation solids.
1.2: Which kind of customers do you have (farmers, gardening, organic fertilizer company, public works, composting plants, other)? What percentage of each one?	Farmers, biogas plants.
2.1: What features / properties should these products have to be accepted by customers? Have costumers any special requirement?	That we can prove the fertilising effect, and help farmers with special equipment needed for spreading the liquid concentrate.
2.2: Do clients ask for a guarantee on the supply and/or require a minimum volume/weight of product? Is this a problem for the sales?	No.
2.3: What do you consider to be the key points to assure customer loyalty?	Benefit for customers.
2.4: What other socio-economic aspect has an impact on the sales / demand for this type of fertilizer products? (E.g. chemical fertilizer cost, regulation on agriculture, etc.).	-
2.5: Which is the average price of the product you sell?	-
2.6: How important is the sale of these products in your trading account? It is important for the viability of the company?	In our gross accounts we currently pay for the disposal of the products, but their fertilising value should rather give us an income.
3.1: Is the current legislative framework adequate? It favours or hinders the marketing of these products? How flexible is the current legislation?	The main problem for us is to be able to market the liquid concentrate as mineral fertiliser, but we have on a test basis got a two-years permission from the Commission to do so. We have very exceptionally got environmental authorities approval to dispose of the Manure processing effluents (50% of incoming slurry amounts) in the nature, after it has been demineralised.
3.2: What legislative actions or which aspects of its application (control, procedure, etc.) should be modified to boost the market of this kind of fertilizer?	It should be possible to refine livestock manure through processing to mineral fertilisers.
4: Comments (any comments or suggestions you wish to add)	

Company: VCM Mestverwerking (Belgium) Expert: Frederik Accoe Date: 12 July 2011	Deeply embedded in the manure processing industry in Flanders, and recently organiser of a conference about marketing of end and by-products Product: N/A
1.1: Customers of these products are clearly identified? Are well-established marketing channels? How would you improve the identification of customers?	Different customer for different products: It seem like products with high organic content is having some interest from wine growers and alike, while mineral fertiliser component companies sees a perspective in, and has already started using concentrated products as raw material.
1.2: Which kind of customers do you have (farmers, gardening, organic fertilizer company, public works, composting plants, other)? What percentage of each one?	See above.
2.1: What features / properties should these products have to be accepted by customers? Have costumers any special requirement?	Wine growers and alikes demands the organic matter, while fertiliser component producers especially see products as replacement for current major phosphorus sources.
2.2: Do clients ask for a guarantee on the supply and/or require a minimum volume/weight of product? Is this a problem for the sales?	-
2.3: What do you consider to be the key points to assure customer loyalty?	-
2.4: What other socio-economic aspect has an impact on the sales / demand for this type of fertilizer products? (E.g. chemical fertilizer cost, regulation on agriculture, etc.).	Price on alternative products
2.5: Which is the average price of the product you sell?	-
2.6: How important is the sale of these products in your trading account? It is important for the viability of the company?	In Belgium livestock manure processing must happen with the part of the livestock manure that cannot be used lawfully as fertiliser on own farm – therefore many farmers are dependent on the possibility to market end and by-products.
3.1: Is the current legislative framework adequate? It favours or hinders the marketing of these products? How flexible is the current legislation?	Many would see it as an advantage if livestock manure could be processed and refined into mineral fertiliser or components thereof.
3.2: What legislative actions or which aspects of its application (control, procedure, etc.) should be modified to boost the market of this kind of fertilizer?	Regulation 2003/2003.
4: Comments (any comments or suggestions you wish to add)	-

Company: TRACJUSA. (Juneda, Catalunya, Spain) Expert: Antonio Badia Date: 07/07/11	Thermal drying plant (AD+ Evaporation+ Thermal Drying) Product: Pellets
1.1: Customers of these products are clearly identified? Are well-established marketing channels? How would you improve the identification of customers?	Costumers aren't well identified and market channels are non-existence. It is necessary a strong commercial action to get in touch with potential customers. The first contact is difficult but then, as our product is of good quality, becomes easy.
1.2: Which kind of customers do you have (farmers, gardening, organic fertilizer company, public works, composting plants, other)? What percentage of each one?	75% agriculture (most to tree fruit) / 25% horticulturist /a little to public works (road, etc.)
2.1: What features / properties should these products have to be accepted by customers? Have costumers any special requirement?	High content of organic matter and nutrients (our product has 60-65% of organic matter and N:P:K = 4:4:6, and is well accepted) Long term stability. During pellet formation it is necessary to add some water, this limit the storage time to a maximum of 3 months.
2.2: Do clients ask for a guarantee on the supply and/or require a minimum volume/weight of product? Is this a problem for the sales?	We try to offer a good service and guaranty the supply
2.3: What do you consider to be the key points to assure customer loyalty?	Supply at the right time and fertilizer advising
2.4: What other socio-economic aspect has an impact on the sales / demand for this type of fertilizer products? (E.g. chemical fertilizer cost, regulation on agriculture, etc.).	Chemical fertilizer costs together with the fuel cost
2.5: Which is the average price of the product you sell?	Pellet 40 – 55 €/t / Dried product: 25-30€/t
2.6: How important is the sale of these products in your trading account? It is important for the viability of the company?	The principal income of the plant is the electricity sold to the grid and taxes for manure treated (farmers pay 2-3 €/t). Sales of pellet only represents 1.5 – 2.0%
3.1: Is the current legislative framework adequate? It favours or hinders the marketing of these products? How flexible is the current legislation?	It is not adequate. It is not possible to register some products Concentrations of Cu and Zn are the main limiting parameters.
3.2: What legislative actions or which aspects of its application (control, procedure, etc.) should be modified to boost the market of this kind of fertilizer?	Product characteristics less restrictive, and easier procedure to register
4: Comments (any comments or suggestions you wish to add)	--

Company: GUASCOR (Spain) Expert: Pedro Royo Date: 09/07/11	Owner of some Thermal drying plants (NDN+ Evaporation + Thermal Drying) Product: Dried product
1.1: Customers of these products are clearly identified? Are well-established marketing channels? How would you improve the identification of customers?	It is not easy to identify customers. We try to contact young open mind farmers with high fertilizer requirements. Difficulties are due to the higher cost of management of this kind of products. Especial machinery is required, which means an increase in the cost to be offset by a lower price of the product sold.
1.2: Which kind of customers do you have (farmers, gardening, organic fertilizer company, public works, composting plants, other)? What percentage of each one?	80% young farmers with high amount of cropland 20% management companies of organic wastes and organic fertilisers
2.1: What features / properties should these products have to be accepted by customers? Have costumers any special requirement?	Absence of others organic wastes (bio solids, MSW, etc.) High content of macronutrients (N and P). They don't paid attention to other compounds (micronutrients)
2.2: Do clients ask for a guarantee on the supply and/or require a minimum volume/weight of product? Is this a problem for the sales?	Constant composition and provision at the right time
2.3: What do you consider to be the key points to assure customer loyalty?	Quality of the product: composition, stability and homogeneity along the time
2.4: What other socio-economic aspect has an impact on the sales / demand for this type of fertilizer products? (E.g. chemical fertilizer cost, regulation on agriculture, etc.).	Formation of the farmers would be an important point to introduce this kind of products. They will appreciate the quality of those products
2.5: Which is the average price of the product you sell?	Dried product: 20 – 40 €/ton
2.6: How important is the sale of these products in your trading account? It is important for the viability of the company?	Not really important
3.1: Is the current legislative framework adequate? It favours or hinders the marketing of these products? How flexible is the current legislation?	Correct, except the content of certain heavy metals (e.g. Zn that is coming from feed)
3.2: What legislative actions or which aspects of its application (control, procedure, etc.) should be modified to boost the market of this kind of fertilizer?	--
4: Comments (any comments or suggestions you wish to add)	--

Company: FERVOSA. (Manlleu, Catalunya, Spain) Expert: Darius Sancho Date: 10/7/11	Centralized composting plant Product: Compost
1.1: Customers of these products are clearly identified? Are well-established marketing channels? How would you improve the identification of customers?	Costumers aren't well identified. In certain cases we use the same channels as chemical fertilisers. Compost and other organic products, live in the ambiguity between waste and fertiliser product of quality Association among composting plants could improve commercialization.
1.2: Which kind of customers do you have (farmers, gardening, organic fertilizer company, public works, composting plants, other)? What percentage of each one?	It is not possible to plan the production, so costumers depend on the amount and quality of the products produced in on year. More or less we have: ▪ 70% farmers ▪ 15% public works ▪ 10% organic fertilisers companies ▪ 5% gardening
2.1: What features / properties should these products have to be accepted by customers? Have costumers any special requirement?	Macronutrients (N and P) But also stability and physical properties: density, moisture content, impurities, etc., source of the waste used to produce the compost
2.2: Do clients ask for a guarantee on the supply and/or require a minimum volume/weight of product? Is this a problem for the sales?	We don't have any problems with guarantee of supply, we have enough stock
2.3: What do you consider to be the key points to assure customer loyalty?	Good quality of the product and the assistance but price is still the major factor
2.4: What other socio-economic aspect has an impact on the sales / demand for this type of fertilizer products? (E.g. chemical fertilizer cost, regulation on agriculture, etc.).	Major factors affecting sales/purchase of fertilisers are the harvest prevision and its price. If fertiliser planning is done at the correct time, more organic fertiliser is used. When no prevision is done, chemical fertiliser is most used, because nutrients are quicker available to plants.
2.5: Which is the average price of the product you sell?	Fervo-64: 6 €/t Fervo Manure: 15 €/t (Compost from manure) Fervo-Humus: 24 €/t
2.6: How important is the sale of these products in your trading account? It is important for the viability of the company?	It is not important in our trading account (5%). But we consider as a strategic factor to the future
3.1: Is the current legislative framework adequate? It favours or hinders the marketing of these products? How flexible is the current legislation?	Regulation are enough, the problem is the control of the regulation. There is a lot of non-registered organic products (eg. digested from AD) that disturb and distorts the market and the prices..
3.2: What legislative actions or which aspects of its application (control, procedure, etc.) should be	More control and fines to the non registered products. Promotion of the registered products and information

modified to boost the market of this kind of fertilizer?	to the end users (fertiliser characteristics, fertiliser plans, etc.)
4: Comments (any comments or suggestions you wish to add)	Awareness of the landowners of the scarcity of the land that is necessary to preserve. Change of mind: from short term benefit to long term vision.

Company: MACASA- LABIN (Igualada, Catalunya, Spain) Expert: Juan Mateu Date: 05/05/2011	Company that produces organic fertilizer Costumer: He purchase manure products. compost, ammonia water, etc., to produce organic fertilizers
He usually gets paid to use organic waste in his process. He will change his mind and paid some money (1/2 of the nutrient market price) if the product has: ▪ Constant composition (nutrients, moisture content, organic matter stabilization...) ▪ Free of heavy metals and other pollutants ▪ High (enough) concentration of nutrients (principal factor to define the price) ▪ Can be managed as a real product (without limiting of storage, any odour, etc.)	

Company: Energy-farming, Belgium Expert: Dirk van Eersel Date: 13 July 2011	Consortium of 8 anaerobic digestion plants Product: Has taken the initiative to market dried/pelletized digestate and manure towards the retail market, for instance shops selling fertilizers for private gardeners, and towards the worldwide market (for instance Asia, ...)
1.1: Customers of these products are clearly identified? Are well-established marketing channels? How would you improve the identification of customers?	We have identified some customers, but marketing is a continued effort.
1.2: Which kind of customers do you have (farmers, gardening, organic fertilizer company, public works, composting plants, other)? What percentage of each one?	Farmers and farmers' cooperatives in Belgium and abroad.
2.1: What features / properties should these products have to be accepted by customers? Have costumers any special requirement?	Price
2.2: Do clients ask for a guarantee on the supply and/or require a minimum volume/weight of product? Is this a problem for the sales?	-
2.3: What do you consider to be the key points to assure customer loyalty?	Price
2.4: What other socio-economic aspect has an impact on the sales / demand for this type of fertilizer products? (E.g. chemical fertilizer cost, regulation on agriculture, etc.).	Price on alternative products
2.5: Which is the average price of the product you sell?	Much less than production costs and less than the actual value of the containing plant nutrients. Livestock farmers pay us to get rid of their manure.
2.6: How important is the sale of these products in your trading account? It is important for the viability of the company?	Our company's only business – therefore vital.
3.1: Is the current legislative framework adequate? It favours or hinders the marketing of these products? How flexible is the current legislation?	The main problem is unclear and even changing rules in EU Member States for content of heavy metals.
3.2: What legislative actions or which aspects of its application (control, procedure, etc.) should be modified to boost the market of this kind of fertilizer?	Uniform and clear rules /demands for chemical composition of manure pellets throughout the EU. Guaranteed maximum price on heat for drying manure and digestate.
4: Comments (any comments or suggestions you wish to add)	-

Company: SODEMASA (Zaragoza, Spain) Expert: Christian Siegler Date: 18/7/11	Public company. (Environmental management company)
1.1: Customers of these products are clearly identified? Are well-established marketing channels? How would you improve the identification of customers?	It's typically mouth by mouth propaganda, as hardly an established market structure can be found. Internet, like a nutrient's trade could help. Or direct advertisement at Farmer's organisations (associations etc.).
1.2: Which kind of customers do you have (farmers, gardening, organic fertilizer company, public works, composting plants, other)? What percentage of each one?	Land farmers (fruit tree orchards) are clients, but some fertilising company has shown general interest.
2.1: What features / properties should these products have to be accepted by customers? Have costumers any special requirement?	Contents of nutrients, dry matter and heavy metals. Dry products are more efficient to transport, and better to handle.
2.2: Do clients ask for a guarantee on the supply and/or require a minimum volume/weight of product? Is this a problem for the sales?	No specific dry matter is demanded, nutrient contents should be known, and also the heavy metal contents.
2.3: What do you consider to be the key points to assure customer loyalty?	See. 2.2.
2.4: What other socio-economic aspect has an impact on the sales / demand for this type of fertilizer products? (E.g. chemical fertilizer cost, regulation on agriculture, etc.).	As general as it is, but it's good for all marketing: The client has to be convinced that the product improves his business. More yield or quality for the same or cheaper prices.
2.5: Which is the average price of the product you sell?	At the moment it's not commercialised, the client comes and picks it up.
2.6: How important is the sale of these products in your trading account? It is important for the viability of the company?	Economic feasibility is not depending on this, but it would improve the global balance. Least goal is to not have further costs. It's not the main purpose of the treatment plant to commercialise the solid fraction.
3.1: Is the current legislative framework adequate? It favours or hinders the marketing of these products? How flexible is the current legislation?	--
3.2: What legislative actions or which aspects of its application (control, procedure, etc.) should be modified to boost the market of this kind of fertilizer?	--
4: Comments (any comments or suggestions you wish to add)	--

Manure processing is presently a subject that enjoys considerable attention in the EU due to the ongoing revision of the Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs (BREF), as well as due to current efforts to implement policies and legislation on EU and Member State level, for instance concerning renewable energy targets, targets for reducing the loss of plant nutrients to the environment, targets for reduction of greenhouse gases, and targets for manure handling in agriculture in relation to legislation about water protection and manure surpluses in livestock intensive areas.

This report is prepared for the European Commission, Directorate General Environment, as part of the implementation of the project "Manure Processing Activities in Europe", project reference: ENV.B.1/ETU/2010/0007. The Report includes deliverables related with Task 3 concerning description of end and by-products.