NIREC

Efficient Removal and Recycling of Nitrogen from Organic Waste as Fertiliser

COOP-CT-2006
Contract Number 033130

Periodic Activity Report

Period I+II (Full Duration)

Accomplished by

IFA-Tulln
Dept. of Environmental Biotechnology

Responsible Persons:
DI Dr. Werner Fuchs
DI Frank Waeger
DI Thomas Wirthensohn
DI (FH) Reinhold Waltenberger

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1 Section 1 – Project objectives and major achievements during the reporting period

1.1 Project objective(s)

The technical objectives of the project are to develop a new sustainable technology for nutrient recovery and recycling from anaerobic digesters, which concurrently enhance the anaerobic digestion process. It also aims at the maximum valorization of all residuals and to convert them into marketable products, with standard quality specifications. NIREC will develop, combine, scale up and test the different components and techniques of the processes to obtain a totally integrated solution. When the solid part of the anaerobic digester effluent is composted, the liquid part is recycled and the valuable compounds are sold, this process targets for a zero emission solution. The technical program contains 8 Work Packages (WP), each addressing the main technological aspect. It starts with the pre-treatment of the substrate devoted for anaerobic digestion; another major activity is the development of a technical solution allowing stripping the ammonium directly in front or out of the anaerobic digester and it deals with the emerging odor emission from a waste treatment plant. Furthermore a legal/economic WP is included, dedicated to strengthen the acceptability of the developed process, and to fortify the potential end-users´ position. The proposed work will be fulfilled in a framework of advanced management. Laboratory work will be carried out to develop new technical solutions. The results will be used to design a pilot unit integrating all aspects investigated. After construction and start-up, a comprehensive evaluation with the pilot unit will be performed at a SME. The project has an important process dissemination and exploitation component including a strategy for market introduction assured by legal and economic assessment and evaluation of the results. The cooperation between 4 SME and 1 end-user is beneficial for all SME partners involved. Moreover 5 RDT performers contribute, all working on a European level.

Strategic objectives

- nitrogen recycling out of the liquid anaerobic digestion residuals
- enhancement of anaerobic digestion technology with respect of biogas output and biogas quality
- design of custom-made compost quality out of the solid anaerobic digestion residuals
- process the liquid digested residuals in order to recycle them on site and achieve direct discharge quality
- establish a standard for odour emission control

1.2 Summary of the work performed for the first period

- **WP 0 Management and follow up**
  Partners involved:
  - Coordinator IFA Tulln–UT,
  - Task manager: SESA

- **WP 1 Pre-treatment technologies of possible input materials in an anaerobic digestion plant**
  Partners involved: GIRO, CHRIS, CLE, GROSS
  - pre-treatment experiments in laboratory scale

- **WP 2 Nitrogen removal directly from the anaerobic digester**
  Partners involved: IFA, SESA, CHRIS, GROSS
  - most effective method to transform nitrogen compounds into soluble ammonia
  - investigation of the impact of nitrogen on the anaerobic process

- **WP 3 Separation technology for most dry solid residues and liquid residues with low organic matter.**
  Partners involved: MONZA, SESA, CLE
  - solid/liquid separation with a centrifugal extractor and a thickener
  - optimization of operating parameters

- **WP 4 Stripping and liquid residuals management.**
  Partners involved: IFA, SESA, CHRIS, MUP, GROSS
  - precipitation experiments in laboratory scale
  - development of a stripping unit in half technical scale
  - mechanical removal of solids at a pilot scale plant

- **WP 5 Solid anaerobic residues treatment, with special interest in value adding by creating a defined fertiliser product**
  Partners involved: MONZA, SESA, MUP
  - experiments of composting with various concentrations of digestate

- **WP 6 Best operational parameters of plant (bio filter) for minimized ammonia and odour emission**
  Partners involved: TUHH, SESA, CHRIS, GROSS
  - experiments with lab scale scrubbers using various acids
  - treatment of off gases from the composting process with a combination of scrubbers and biofilters

- **WP 7 Analysis of market acceptance and of legal framework for the further use of the solid, liquid and gaseous residues deriving from the anaerobic digestion**
  Partners involved: UNIVE, CLE, MUP
  - economic researching
  - legal researching
  - market study

- **WP 8 Exploitation and Dissemination activities**
  Partners involved: SESA, CHRIS, MUP, CLE, GROSS, IFA, UNIVE, GIRO, MONZA, TUHH
  - exchanges of personal from the RTD partners to the SME partners

2 Section 2 – Work package progress of the period

2.1 Introduction - general description

The project NIREC started on the 1st of Oct. 2006. The kick off meeting was held from Oct. 12 - 13 at IFA Tulln. The first quarterly meeting took place in Hamburg from the May 23 -25. Due to the complexity of the tasks involved in the development of the whole digestion process the proposed project could only be successfully accomplished by a combined effort of specialists in their specific sector with the extensive support from experienced research institutions. The development of the proposed improvements required several interactive activities as described below.

The first period of the project was started with a slight delay from several partners, since the EC funding arrived not earlier then June, 2007, and pre-financing was not possible for a several partners. Therefore a delay of three month was granted by the EC. A change in the consortium had to be made as well. Avicola from Romania was not able to join the project and was replaced by Clenergy/Slovakia. Clenergy is a distributor of environmental technology in the field of anaerobic digestion, focussing on Slovakia, Czechia, Poland, Hungary and Serbia. Clenergy is obviously not only a substitute, but a significant improvement for the consortium.

The 1st period was devoted to research and innovation related activities for optimisation of the single components of the system, representing the different levels of innovation. These were pre-treatment of the substrate, removal of nitrogen before or in the digester and the treatment of the digested liquid and solid residues. The latter with a focus on the control of odour emission.

- Comparison of the bioavailability of various substrates with several different pre-treatment approaches with respect of biogas output in an anaerobic digestion process. Ultrasound, chemicals (bases), heat and pressure were applied

- Development of an ammonium removal technology directly out of the anaerobic digester or in a side stream of the anaerobic digester by implementing a strip unit to the reactor
- Solid/liquid separation of the digested residues focusing on the characterization and production of a solid fraction to be composted. Experiments were carried out with screw press, vibration sieve, decanter, thickener and microfiltration
- Pretreatment of the liquid digested residues after separation as conditioning before the ammonia is stripped out and desorbed afterwards. This pretreatment emphasized on three parameters, which are critical for further treatment: (i) total solids, (ii) pH and dissolved (iii) CO_2

The tests on bioavailability were conducted by GIRO in batch tests. The use of sodium hydrogen and heat were the prior approaches. At IFA a small scale test plant was assembled for stripping before the digester; another one was built for stripping of the digested effluent. Experiments with filter technology (micro filtration, reverse osmosis) were conducted on a major scale plant at a farm in Styria/Austria. Monza worked on the separation of solids and liquids, in collaboration with SESA. A centrifuge and a thickener were rented for pilot scale experiments. The size of the experiments allowed to test the developed solutions and prototypes under practical conditions and to provide feedback information to the other work packages at an early stage.

The 2nd period was devoted to the scaling up of the improved technologies developed in period 1. Based on the experience developed in period 1 in each specific subtask the most promising technology was selected and further investigated in the larger scale. For this purpose several technical scale or pilot plants were operated by the process partners. These plants comprised:

- a high pressure reactor for thermal disintegration (WP 1)
- a half technical scale stripping plant (WP 2 and WP 4)
- a 2 step (microfiltration / reverse osmosis) filtration plant for liquid residues treatment (WP 4)
- a pilot membrane bioreactor for liquid residues treatment (WP4)
- pilot composting plants (WP 5)

Based on the existing situation at one of the project partners two alternative scenarios with implementation of the most convenient of the developed technologies were established. For these alternative scenarios a complete and detailed analysis of cost and benefits as well as environmental impact were performed.

In addition and to support the companies with the implementation of the proposed processes, the legal framework, i.e. the relevant regulations addressing biogas technology, discharge of liquid effluents and production as well as quality standards organic fertilizers were analysed and compiled.

2.2 Work package list / overview

In Table 1 the work packages of the whole project are listed including the lead contractors, the start and end date.

Table 1: Work package list – full duration of the project

Work-package No[1]	Workpackage title	Lead contractor Short Name [2]	Person-months[3]	Start month[4]	End month[5]	Deliv-erable No[6]
0	Management and follow up	IFA	5.5	1	27	
1	Pre treatment	GIRO	16	1	14	1, 2
2	Anaerobic digestion	IFA	36.5	5	25	3, 4, 5, 6
3	Separation	MONZA	14.5	1	12	7
4	Stripping/Liquid residues	IFA	41	5	25	8, 9, 10
5	Solid digested residues	MONZA	20.5	6 19	11 25	11, 12, 13
6	Gaseous emission	TUHH	26.5	9	18	14, 15, 16
7	Legal framework/Economic Market analysis	UNIVE	14.5	16	25	17, 18, 19
8	Exploitation and dissemination	SESA	8.5	23	27	20, 21
	TOTAL		183.5			

2.3 Deliverables list

The table below shows the list of the deliverables and when they were submitted.

Table 2: Deliverable list - full duration of the project

[1] Workpackage number: WP 1 – WP n.

[2] Short name of the contractor leading the work in this workpackage.

[3] The total number of person-months allocated to each workpackage.

[4] Relative start date for the work in the specific workpackages, month 0 marking the start of the project, and all other start dates being relative to this start date.

[5] Relative end date, month 0 marking the start of the project, and all ends dates being relative to this start date.

Del. no.[7]	Deliverable name	WP no.	Lead participant	Nature[8]	Dissemination level [9]	Delivery date[10] (project month)
D1	Best pre-treatment technology in laboratory scale	1	GIRO	R	**PP**	12
D2	Verification of the parameter set up for pre-treatment found in the laboratory in half technical scale	1	GIRO	R	**RE**	12
D3	Best strategy for conversion of organic fixed nitrogen into soluble NH4-N	2	IFA	R	**PP**	10
D4	Best strategy for recovering the nitrogen directly out of the anaerobic digester	2	IFA	R	**RE**	12
D5	Best half technical method for recovering nitrogen out of the anaerobic digester	2	IFA	p	**RE**	18
D6	Process parameters for optimized anaerobic digestion under ammonia concentration	2	IFA	R	**RE**	22
D7	Best separation technology for separating anaerobic digested residues	3	MONZA	R	**PP**	9

[6] Deliverable number: Number for the deliverable(s)/result(s) mentioned in the workpackage: D1 - Dn.

[7] Deliverable numbers in order of delivery dates: D1 – Dn

[8] Please indicate the nature of the deliverable using one of the following codes:

R = Report

P = Prototype

D = Demonstrator

O = Other

[9] Please indicate the dissemination level using one of the following codes:

PU = Public

PP = Restricted to other programme participants (including the Commission Services).

RE = Restricted to a group specified by the consortium (including the Commission Services).

CO = Confidential, only for members of the consortium (including the Commission Services).

[10] Month in which the deliverables will be available. Month 1 marking the start of the project, and all delivery dates being relative to this start date.

D8	Best laboratory method for the conditioning of the liquid digested residues	4	IFA	R	**pp**	12
D9	Best half technical scale method for stripping and recovery of nitrogen out of the conditioned liquid digested residues	4	IFA	P	**RE**	22
D10	Optimized operational parameter of the pilot membrane filtration plant for excess liquid treatment	4	IFA	P	**PP**	22
D11	Best combination of process parameters so that a desired level of stability of the composted product may be achieved	5	MONZA	R	**RE**	8
D12	Effects of adding recovered N to both compost and the solid digested residue	5	MONZA	R	**PP**	22
D13	Best overall strategies for treatment of solid residues	5	MONZA	R	**RE**	22
D14	Find out the best operation parameters for the scrubbers	6	TUHH	R	**PP**	12
D15	Find out the best operation parameters for the bio filters	6	TUHH	R	**PP**	12
D16	Customize an electronic nose with the best suited sensors for osmogenic emissions of composting plants	6	TUHH	P	**RE**	15
D17	Comparison of technologies of recovery and recycling of Nitrogen from waste versus Nitrogen fertiliser produced by the traditional chemical industry under an economic point of view	7	UNIVE	R	**PU**	20
D18	Study on the treatment costs of the different steps within the NIREC process	7	UNIVE	R	**PU**	20

D19	Guidelines for new disposal concepts valid for all Member States	7	UNIVE	R	**PU**	22
D20	Plan for using and disseminating knowledge (draft version)	8	SESA	R	**PU**	12
D21	Plan for using and disseminating knowledge (final version)	8	SESA	R	**PU**	24

2.4 List of milestones

Work package/Milestones	**Project month**	**Done**
Work package 1		
M 1: Definition of the best pre-treatment technology	13	☑
Work package 2		
M 2: Best conversion strategy for organic fixed nitrogen into soluble ammonia	13	☑
M 3: Development of recovering process for nitrogen directly out of an anaerobic digester	15	☑
Work package 3		
M 1: Best separation method for digestate	15	☑
Work package 4		
M 5: Identification of the most suitable conditioning technology for the treatment of the liquid digested residues	25	☑
Work package 5		
M 6: Customized compost quality	25	☑
Work package 6		
M 7: Assessment of best operation conditions for a scrubber and a bio filter	18	☑
Work package 7		
M 8: Data analysis of related costs and benefits	25	☑

2.5 Progress towards objectives

In the following the achievements of the work packages within the two periods are described in detail. The report tells which partners were involved in the single work packages, which work progress was achieved and the conformity with the proposed time schedule.

2.5.1 Work package number 1 (WP1): Pre-treatment of substrates

Start month: 1

Participants Short Name:

- GIRO
- GROSS

2.5.1.1 Objectives of WP 1

According to the proposed technical programme, WP 1 is devoted to the comparison of the bioavailability of various substrates with several different pre-treatment approaches with respect of biogas output in an anaerobic digestion process.
The task focuses on:

- The selection of pre-treatments and operation conditions,
- The effect of the selected processes on the behaviour of ammonia and solubilization of solid wastes,
- The effect of the selected processes in the anaerobic biodegradability.

The chosen pre-treatments to accelerate the process and improve the anaerobic digestion were an ultrasonic disintegration, a thermal hydrolysis and a thermochemical treatment.

2.5.1.2 Description of work performed

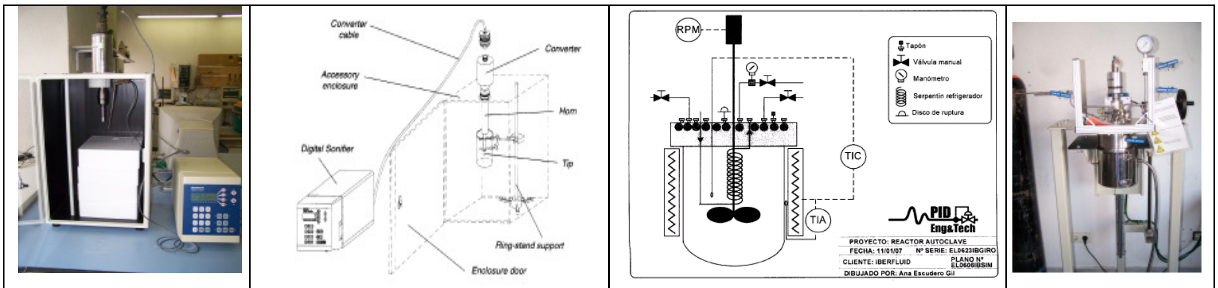
Task 1.1: Pre-treatment experiments in laboratory scale

In the first part of the work package one (period I), pre-treatment experiments at lab-scale were realized. It included:

(I) Set up of the equipments (ultrasounds and temperature equipments; see figure 1).

(II) Development of the pre-treatments protocols.

(III) Determination of anaerobic biodegradability of the pre-treated wastes.



a. ultrasound disintegrator **b. high temperature and pressure reactor**

Figure 1. Scheme of ultrasound (a) and thermochemical equipments.

As a substrate, meat waste was chosen as a substrate with high N-content and in agreement to project partner GROSS who is running a biogas plant with slaughter house waste. Meat wastes are characterized by its consistency, with a high content on protein and fat beside some inert fraction of hair and bones. Although the configuration of a biogas plant must encounter pre-treatment processes for sterilization of the raw material, because the anaerobic fermentation is a management alternative included in the animal by-products regulations, these pre-treatments also must be applied to increase the bioavailability of the high solid protein and fat content of these wastes.

Solid poultry (PouW) and pig wastes (PigW) were obtained from two industrial slaughterhouses (Catalonia, Spain). They were minced, homogenized and liofilizated before characterization. Analytical determinations for volatile solids (VS), total and soluble chemical oxygen demand (COD_S, COD_T), total nitrogen (TN), total ammonia nitrogen (TAN), fat content and volatile fatty acids (VFA) were done. Protein concentration was estimated from organic nitrogen content.

The ultrasound disintegration was realized with a digital sonifier with pulse duration adjustable, 5-40ºC operating temperature and 10-100% amplitude setting. Different dilutions of waste (1:5, 1:10 and 1:20) were done. All mixtures were treated at constant energy power (200W) and 19-20 kHz, and at three exposition periods (from 1 to 3 minutes). The best operation conditions were 1:5 waste dilution, 2 minutes of exposition time at constant energy power of 200W and 19-20 kHz for ultrasound disintegration.

The thermochemical experiments were performed in an autoclave with adjustable temperature and pressure (232ºC and 151 bar are maximum temperature and pressure, respectively). The assays were done at ambient pressure and the reaction time was fixed in 10 minutes at three different temperatures 120º C, 100º C and 80º C. A fixed volume of KOH solution was selected and mixed with 500 g of waste to reach three different ratios of alkali to waste (0.025, 0.05 and 0.1 g_{alkali}/gVS_{Waste}). In order to avoid dilution factor, the KOH solution was prepared at three different molarities. For this treatment, the best conditions were 120ºC, 10 minutes of reaction time and 0.025g_{alkali}/gVS_{Waste}.

Related to thermal pretreatment, the yield increment for the PigW is 25% and 41% after the pasteurization (70ºC & 60 min) and the 133ºC treatment (133ºC & 3 bar &

20 min), respectively. In the case of the PouW, the increment is negligible (1%). The observed yield improvement for the pig waste is related to the increase of the biodegradable fraction although there was no observed change in the protein to fat ratio after both pretreatment (pasteurization and 133ºC).

Task 1.2: Experiments in half technical scale

Task 1.2 was postponed to period II. In this task, a medium scale experiment with a high pressure reactor was realized. Temperature and pressure pre-treatment technology were evaluated in terms of bio-availability and biogas production at lab scale. The high pressure pre-treatment or hydrostatic pressure treatment was evaluated at semi-industrial scale with a hyperbaric reactor (figure 2), in order to preserve the maximum methane potential of slaughterhouse waste. The residue used was pig waste from an industrial slaughterhouse.
The samples (500 g) were vacuum packed in a watertight and flexible container, in order to ensure small quantities of air (less than 10%). Experiments were done in triplicate at different pressures (200, 400 and 600 MPa) for 15 minutes at room temperature, with a hyperbaric reactor (NH Hyperbaric 6000/120 wave model) located in CENTA (Cabrills, Girona, Spain), a specialized research center in meat industry development. The temperature was regulated from 10-12ºC to 30-35ºC. The cooling final phase was instantaneous after the pressure was released.

Figure 2. High pressure reactor (NC Hyperbaric 6000/120 wave model)

The solubilization and the $N-NH_4$ to TN ratio did not increase in all cases. Although there were not significative differences between protein and lipid concentrations before and after of pre-treatment, a change in the methane potential was observed due to higher protein degradation.

2.5.1.3 **Work progress and conformity with the time schedule**

- **Period I**

Experiments with ultrasonic disintegration, thermal and thermochemical pre-treatment were realized in the first period. This task 1.1 needed an extension by three months of the second period to provide more time for ending laboratory scale experiments.

The mayor steps of work were as follows:

Month 0-2: searching of bibliography and information related to solid wastes and pre-treatment processes. Selection of slaughterhouse wastes as example of complex organic waste.

Month 2-4: characterization of wastes collected in slaughterhouses and equipments´ set up.

Month 4-7: realization of the different ultrasound and thermochemical experiments and biodegradability assays with the untreated wastes.

Month 7-12: determination of biodegradability assays with the ultrasound and thermochemical treated wastes.

Month 13: realization of the thermal pre-treatments experiments. Determination of biodegradability assays with the thermal treated wastes.

Month 14-15: determination of biodegradability assays with the thermal treated wastes.

- **Period II**

Experiments with high pressure reactor were realized in the second period.

The mayor steps of work were as follows:

Month 13: bibliography and information searching related to high pressure pre-treatments. Final step of lab scale experiment related to the thermal and pressure pretreatment.

Month 14: experimental part development and characterization of the raw and pre-treated samples.

Month 14-15: determination of anaerobic biodegradability of the raw and pre-treated wastes.

Deliverables submitted

D 1: Best pre-treatment technology in laboratory scale - ☑ 19.02.2007

D 2: Pre-treatment process in half technical scale - ☑ 26.06.2008

2.5.2 Work package number 2: Anaerobic digestion

Start month: 5

Participants Short Name:

- IFA
- GROSS
- MUP

2.5.2.1 **Objectives of WP 2**

The goal of WP 2 is the development of an ammonium removal technology directly out of the anaerobic digester or in a side stream of the anaerobic digester.
The specific objectives of this task are to find out:

- The best strategy for conversion of organic fixed nitrogen into soluble NH_4-N.
- The best strategy for recovering the nitrogen directly out of the anaerobic digester.
- The best half technical method for recovering nitrogen out of the anaerobic digester.
- The process parameters for optimized anaerobic digestion under high ammonia conditions.

2.5.2.2 **Description of work performed**

In order to determine the effects of high ammonia concentrations on the anaerobic digestion (AD) process several experiments had to be done.
Due to the fact that nitrogen is organically bound when it enters the anaerobic fermenter the fastest and most effective method to transform those nitrogen compounds into soluble ammonia had to be evaluated.
Further on the impact of nitrogen on the anaerobic process was investigated. As a result the best conditions for anaerobic digestion of organic wastes and by-products should be figured out.
To be able to overcome the inhibitory effects of ammonia one option is to remove nitrogen out of the fermenter. Therefore a steam-stripping-plant in laboratory scale was built up which is able to remove ammonia directly out of the substrate.

Task 2.1: Conversion of organic fixed Nitrogen into soluble NH4-N

The technical objective in Task 2.1 is to find out the fastest possible transformation from organic fixed Nitrogen into soluble NH4-N.
Therefore laboratory trials on ammonia release with different enzyme pretreatments and specialized microorganisms were carried out. *Clostridium sticklandii* a microorgamism which is able to perform the stickland-reaction (the amino group cut off from the amino acid) was chosen. In comparison to 40% conversion of fixed nitrogen into soluble ammonia achieved without addition of special microorganisms 60% could be obtained with *Clostridium sticklandii* after 7 days. The addition of

special hydrolytic enzymes resulted just in a shorter lag-phase but not in a higher ammonia yield.

In comparison to the specific hydrolyses performed in the laboratory the actual situation at the Grossfurtner plant was observed. According to chemical analysis most of the organically bound nitrogen is set free as ammonia in the first reactor of the full scale plant. In close cooperation with the technician at the plant who provides all necessary data a detailed mass balance will be set up.

Task 2.2: Removal of Nitrogen directly form the anaerobic digester

The technical objective in task 2.2 is to find out a possibility to reduce the ammonium content within the reactor or in a side stream.

After determining the necessary parameters for anaerobic digestion under high nitrogen concentrations and the possible ways to convert organically bound nitrogen into removable ammonia nitrogen in the first period of this project the focus was put on the removal technologies in the second period.

Steam stripping of ammonia was chosen as method for nitrogen removal out of the fermenter because of the high efficiency of steam as ammonia stripping media (compare to WP 4). To gain detailed data about the process a first laboratory steam-stripping facility was built up. Due to the high efficiency and the high temperature in the column no raise in the pH and increase of the surface for mass transfer by packings within the column is necessary. That is important because the packings would be blocked by the high amount of solids in the substrate immediately.

Figure 3: First nitrogen removal trials in laboratory.

Starting from laboratory scale steam stripping (batch systems below 1 l volume), as shown in figure 1, the process was scaled up to continuous stripping system with a throughput of 20 l/h. All together 3 concepts for nitrogen removal were tested to find out the most suitable solution. Beside steam and air stripping, flash evaporation turned out to be the most promising technology in order to removal rates, process stability and energy consumption.

On basis of the laboratory and pilot scale results a technical feasibility study and a complete process scheme was developed. Further on as a follow-up of the project a demonstration plant for nitrogen removal and recovery will be constructed at the GROSSFURTNER AD plant by summer 2009.

Task 2.3: Limitation of the anaerobic digestion by ammonia inhibition

The technical objective in task 2.3 is to find out the maximum ammonium concentration in the anaerobic digestion reactor without inhibiting the biological degradation process.
Therefore several batch degradation and continuously driven anaerobic reactors were operated with different substrates, organic loading rates and of course different nitrogen concentrations. The results show that at lower nitrogen concentration higher the methane yields and the COD reduction rates due to the better performance can be reached. According to those results it can be expected that to obtain good results in anaerobic digestion the total Nitrogen concentration in the anaerobic reactor should be kept below 5 g/l.

Interrelation with other work packages
WP2 interrelates with WP1 and WP4

2.5.2.3 **Work progress and conformity with the time schedule**

Task 2.3:

Month 1-2:	Literature studies
Month 2:	Test setup for batch degradation
Month 3-5:	Evaluation of the limitation of the anaerobic digestion by high ammonia concentrations in batch degradation experiments.
Month 5-12:	Anaerobic degradation experiment continuous laboratory fermentation under different conditions.

Task 2.1:

Month 5:	Searching for microorganisms that are able to convert organic fixed nitrogen into ammonia nitrogen.
Month 5-12:	Investigation of the conversion of organic fixed nitrogen into ammonia nitrogen in laboratory
Month 15-18:	Investigation of the conversion of organic fixed nitrogen into ammonia nitrogen as well as at the full scale plant of Grossfurtner.
Month 18-25:	Feasibility study and a process scheme design for flash-evaporation steam stripping at Grossfurtner.

Task 2.2:

Month 8-15:	Developing steam stripping systems for the removal of nitrogen out of the substrate for the test attempts.

The work within Task 2.1: is already completed and the deliverable was submitted by the end of November 2007.

Task 2.3: Limitation of the anaerobic digestion by ammonia inhibition was treated earlier than it was proposed because of the need to find a suitable concentration of ammonia to be set in the fermenter. That data is necessary for defining the requirements and minimum performance of the nitrogen removal system.
As a compensation for starting earlier with task 2.3, the work on task 2.2 has been postponed and was just started. It will be done intensively in the following project year.
Task 2.3 was started earlier than scheduled (projectmonth1 instead of 5) to be able to compensate eventually appearing delays.

Deliverables submitted
D 3: The Best Strategy for Converting organic fixed Nitrogen into soluble Ammonia Nitrogen - ☑ 04.12.2007
D 4: Best strategy for recovering the nitrogen directly out of the anaerobic digester - ☑ 20.08.2008
D 5: Best half technical method for recovering nitrogen out of the anaerobic digester - ☑ 19.12.2008
D 6: Process parameters for optimized anaerobic digestion under ammonia concentration - ☑ 31.10.2007

2.5.3 **Workpackage number 3: Solid-liquid separation of the digested residue**

Start date: Month 1
Participants Short Name

- MONZA
- SESA

2.5.3.1 **Objectives of WP 3**

According to the proposed technical programme WP 3 is devoted to carry out a solid/liquid separation of the digested residues focusing on the characterization and production of a solid fraction to be composted and a liquid fraction to be nitrogen stripped.

In specific the WP3 focuses on the characterization of different machineries performing solid/liquid separation of the digested residue in terms of:

a) Throughput and mass balance
b) Quality of solid fraction to be composted
c) Quality of liquid fraction for a further nitrogen stripping and/or to be depurated

The technical work carried out consisted in the section and testing of suitable equipments on several batches of digestate in order to perform the solid/liquid separation.

Performances were evaluated running the devices at different operational conditions.

The quality of the separated solid and liquid phases were characterized by means of lab analyses.

Step followed to get the scope were:

I) Literature surveys

II) Run trials for the solid/liquid separation of digestate through two different machineries at different operating conditions

III) Sampling the solid and the liquid fractions produced during the trials for lab analyses

IV) Data elaboration

V) Deliverable 7 compiling

2.5.3.2 **Description of work performed**

The work was started through investigations in literature to seek descriptions of treatment technologies and machineries performing the solid/liquid separation on sludge similar to the one produced at SESA anaerobic digestion plant.

Through a confrontation with SESA staff and in order to meet the plant needs, two machineries of two different suppliers were chosen for tests on the digestate: Pieralisi FP 600 2RS/M centrifugal extractor and Huber Rotamat thickener.

Both the machineries were hired on purpose for the trials and also considering the need for SESA plant to purchase in a next future a device able to treat the exceeding amount of digestate produced and not recirculated in the composting biocells

Solid/liquid separation tests were carried out at SESA plant in two different periods: in January 2007 trials with the centrifuge; in March 2007 trials with the thickener.

During the trials the first step was the identification of the polyelectrolyte. To this aim, some lab test were done on different poly products to assess the flocculation performance on SESA digestate.

Experimental trials started with running the machineries taking confidence with their potentiality, then operating parameters were optimized on the digestate and on the effect to be produced: the drier solid fraction as possible. Samples on the digestate, solid and liquid fractions were taken and analysed at SESA internal laboratory.

In order to evaluate the performances of the machineries tested, the attention was focused on treatment capacity, mass balance and yields of the solid/liquid separation; lab analyses were carried out on the output materials.

In particular, for the solid fraction after separation the following parameters were tested to assess its suitability for composting: dry matter content, Volatile Solid content, Total Nitrogen and Ammonia, C/N.

Concerning the liquid fraction after separation parameters investigated are: Dry matter content, Total Nitrogen and Ammonia, COD.

The operating conditions tested on the centrifuge were adjusted by the technician and selected considering the optimization of the clarification of liquid. The parameter on which trials were based was mainly the polyelectrolyte use and some minor variations on the digestate throughput.

For the thickener trials the operating conditions were adjusted by the operator given the features of material/sludge to be treated. In particular, the settings were selected taking into account that the machinery can process up to 400 Kg of dry matter/h, that is to say for the SESA digestate, showing a d.m. content around 5-6%, a maximum throughput of 6-8 mc/h.

Besides, in order to have a quite clarified liquid, the thickener cannot be run without polyelectrolyte. For this reason, different kind of polyelectrolytes were preliminary tested (sedimentation test) in laboratory to single out the polyelectrolyte showing the best flocculation of the digestate.

MONZA staff elaborated analytical outcomes and drafted the deliverable 7 and finalised it after having shared, discussed and agreed it with SESA staff.

As far as the choice of purchasing, the plant manager can use the information produced in this experimental trials. Both the devices tested seem to have pros and cons, that can become key issue given the priorities decided by the plant manager.

The Table below summarizes outcomes and results produced in the experimental trials carried out with the two machineries, giving evaluations about the performances proved:

Parameter	u.m.	***Thickener***	***Decanter centrifuge***
Polyelectrolyte	yes/no	-	+
Treatment Capacity	mc/h	=	=
Mass Balance	%	+	-
Dry Matter content	%	-	+
C/N ratio	%	-	+
Nitrogen content	% w:w	+	-
COD	mgO_2/kg	+	-

+ preferable, - not preferable, = similar performances

Polyelectrolyte: the poly helps with the flocculation that is to say a better separation of solids towards the solid fraction and a higher clarification of the liquid fraction. Actually there are many poly products on the market suitable for different kind of materials/sludges. As polyelectrolyte is a cost for the plant manager, the benefit coming from the flocculation must justify the expense. All the polyelectrolytes tested were found not performing an optimized flocculation on the SESA digestate. The trials with and without polyelectrolyte showed similar/comparable performances in terms of solids splitting, that is to say that the Pieralisi - showing to be able to run also without polyelectrolyte - is preferable.

Treatment capacity: it has to be considered as positive a higher treatment capacity as it allows the plant to manage a higher amount of digestate. According to the technical sheets, it evicts the centrifugal extractor can treat up to 12mc/h while no information is reported for the thickener. Actually the real treatment capacity depends on the features of the material to be processed, so empiric data produced during the trials have to be considered as more reliable then the ones reported in the technical sheets. In the tests run, at the operating condition chosen – optimizing the performances on the solid/liquid separation in terms of quality of the output materials - the two machineries showed similar performances, namely a treatment capacity around 6 mc/h. The maximum yearly treatment capacity for both machineries assess at about 16.800 t/y corresponding at 14,6% of the total digestate produced at SESA plant.

Mass Balance: the splitting yield was considered preferable when more solid fraction is produced. In general the liquid fraction is a cost as it needs to be treated in a waste water treatment plant, while the solid fraction can easily undergoing composting. Under this standpoint, the machineries tested showed a splitting capacity significantly different: Huber thickener is preferable as it produces a lower amount of liquid fraction (30% liquid mass against the 93% by the decanter centrifuge).

Dry matter content: all solid samples produced with the centrifuge stay above 25% d.m. which is conventionally the limit between a palable material which can be easily handled with a mechanical front end loader and a pumpable material which only can be sucked with pumps and treated as a liquid/like. On the other hand all solid samples from the thickener lie in the range of the pumpable area (<25% d.m.). A palable material is more suitable for the “handling” in terms of transport, mixing operations and loading of biocells with the composting mix. The solid fraction produced by the centrifugal extractor is preferable respect the sludge-like solid from the thickener.

C/N ratio: is and important parameter for the composting mix definition, as its optimisation allows to maximise biological reactions kinetics. The typical C/N value in the composting starting mix stays at 25-30. in the solid fraction produced by both the machineries C/N values are lower and assessed around about 4 for thickener and 9 for the centrifugal extractor. This means that both solids need to be mixed with a lighter, dry, carbon source and bulky material like garden waste before composting, but this is particularly addressed for the Huber solids that shows a pumpable features, poor in carbon which needs to counterbalance with a very dry and sucking material.

Nitrogen: Total Nitrogen behaviour are monitored in order to optimize its removal from fraction to be depurated and/or disposed, in particular, ammonia it's a limiting factor affecting technologies and costs for its cleaning in WWTPs. Under this point of view reduction of nitrogen in the liquid fraction is desirable. Huber thickener proves to be more efficient in the nitrogen reduction

COD: is typically used to measure the organic substance load in waste water and is used for setting treatment requirements (limits) in discharge permits. It is also useful in process monitoring (incoming loads, concentration) and process control in waste water plants. In tests run, Huber thickener proves to be more efficient in the COD reduction in the separated liquid.

2.5.3.3 Work progress and conformity with the time schedule

Months 1-3: Collecting information about machineries performing solid liquid separation, experimental design of trials
Month 4: tests on the centrifuge, sampling
Months 5-6: tests on the thickener, sampling, lab analyses.
Month 6-9: data elaboration, deliverable compiling, discussion and refining

Work is in line with the proposed time frame; no deviation occurred for WP3. The activities were carried out from October 2006 to March 2007.

The draft of deliverable no. 7 was delivered at the end of June 2007; then it was shared and discussed with partners involved in the work, namely the SESA staff. Final version of Deliverable 7 final was delivered at mid-term meeting in Este (PD-I).

Deliverables submitted

D 7: Report on Solid/liquid separation of effluent from anaerobic digestion-
☑ 31/10/2007

2.5.4 Workpackage number 4 "liquid residues management"

Start date: Month 4

Participant short name:

- IFA-UT
- SESA
- CHRIS

- MUP
- GROSS

2.5.4.1 Objectives of WP 4

The liquid digested residues after separation should be pre-treated and conditioned for further treatments. Considering a zero emission plant, the goal is to obtain direct discharge quality and/or recycling of the generated wastewater streams within the plant. To reach these goals, ammonia stripping, membrane technology and membrane bioreactor technology were investigated.

2.5.4.2 Description of work performed

WP 4 consists of 3 subtasks, task 4.1 was started in month 4 and the results were handed in with Deliverable 8. Tasks 4.2 and 4.3 were started in month 10 and were continued until month 25, when Deliverables 9 and 10 were handed in. For task 4.2 a stripping unit was set up in laboratory scale at IFA Tulln, for task 4.3 microfiltration and reverse osmosis were applied in half technical scale at a biogas plant in Styria (A) and a membrane bioreactor (MBR) pilot plant at the premises of the project partner S.E.S.A. in Este (I) was started up. Although MBR-technology was not explicitly mentioned as a part of Task 4.3, it was considered as a perfect possibility to investigate the performance of a combined biological and membrane treatment for anaerobic digestate effluent.

Task 4.1: Best conditioning technology of the effluent stream and evaluation of recycling options

A wide variety of tools and procedures was investigated and optimized in order to prepare and refine the crude anaerobic digester effluent for further purification. According to the requirements of the subsequent technology (i.e. membrane separation, stripping, MBR, and recycling) the best and most straight-forward technology was worked out.

Precipitation experiments were done in laboratory scale, for stripping a half technical scale unit was developed, regarding parameters such as packaging material, height, volumes, temperature, pH and comparison of air versus steam. The experiments for mechanical solid removal were done at a pilot scale, located at a 500 kW biogas plant.

Task 4.2: Best NH3 Stripping technology for waste water containing high suspended solid

To find out best stripping technology for nitrogen removal experiments were carried out in bubble reactors and a packed column that was built at the premises of the IFA Tulln. To optimize parameter setting for a maximum removal of ammonia, a multitude of trials were carried out varying the parameters with the main influence on stripping efficiency:

- pH
- Temperature
- Alkalinity

Removal rates of up to 80% and more can only be achieved economically when packed columns are applied. Nowadays, to determine optimal flow conditions the producers of carrier material often supply software for the dimensioning of the column. Hence, optimization on carrier material and column parameters can be determined by using the mentioned software. Furthermore practical experience from operators showed that, independent on the carrier material used, the content of suspended solids in the liquid entering the column should not succeed 500 mg/L.

Figure 4: Stripping plant

For ammonia removal via stripping directly from anaerobic sludges (SS > 5 g/L) a different technology was developed (see WP 2).

Task 4.3: Membrane filtration of residual effluents

Operation of a membrane pilot plant (microfiltration and reverse osmosis) that was erected at an agricultural Biogas plant in Styria (A) was optimized in terms of suspended solids management and improvement of membrane performance. In parallel additional experiments were carried out in the lab scale to compare performance of submerged membranes with an external cross flow filtration device. In this context also different membrane materials with varying pore sizes were tested.

Figure 5: Reverse osmosis unit of 2 step membrane filtration plant

Finally, to optimize effluent quality from the reverse osmosis, experiments were carried out on the possible treatment by ion-exchange. Different materials, i.e. commercial strong acidic ion-exchange materials and natural zeolithe, were investigated with focus on their exchange capacity for different constituents (in particular ammonium) and as well regeneration and long term stability.

Figure 6: External filtration unit of the membrane bioreactor plant

Start up of the membrane bioreactor pilot plant at S.E.S.A. was followed for 3 months. The faced diffciulties of denitrification due to a disadvantageous ratio of COD to TKN were further investigated in parallel laboratory scale test plant that was established at the premises of IFA. This test plant was operated for 8 months until the end of the project.

2.5.4.3 **Work progress and conformity with the time schedule**

The mayor steps of task 4.1 were as follows:
Month 4 - 10: Mechanical removal of solids from anaerobic digester
Month 4 - 10: Chemical removal of solids, colloids and ions
Month 4 - 10: pH setting by use of chemicals or stripping
Month 4 - 10: CO_2 removal by use of chemicals or stripping

The mayor steps of task 4.2 were as follows:
Month 9 - 13: Stripping of ammonia in bubble reactors
Month 10 - 20: Air stripping of ammonia with a packed column
Month 21 - 22: Steam stripping of ammonia with a packed column

The mayor steps of task 4.3 were as follows:
Month 11 – 14: Start up of the membrane bioreactor pilot plant at S.E.S.A plant
Month 14 – 15: Construction of laboratory scale membrane bioreactor (MBR) at the premises of IFA Tulln
Month 16 – 25: Operation of the laboratory scale MBR
Month 16 - 20: Supervising of the microfiltration and reverse osmosis pilot plant at a biogas plant in Styria/AUT
Month 20 - 22: Ultrafiltration and microfiltration tests in pilot scale
Month 22 -23: Ion Exchange Experiments

Of WP 4's tasks, the first, 4.1, was due by end of September and Deliverable 8, which summarizes the results of task 4.1 was handed in. These data are the necessary groundwork for 4.2 and 4.3, where further treatment was investigated.

For task 4.2 and 4.3 the setups and first experiments already started in period I. The main work was done in period II. The work of WP 4 was well within time regarding the modified (3 months extension) schedule.

D 8: Report on best laboratory methods for the conditioning of the liquid digested residues - ☑ 31/10/2007
D 9: Report on best half technical scale method for stripping and recovery of nitrogen out of the conditioned liquid digested residues - ☑14/10/2008
D 10: Report on optimized operational parameter of the pilot membrane filtration plant for excess liquid treatment - ☑ 14/10/2008

2.5.5 **Workpackage number 5: Solid residues treatment**

Start date: Month 5
Participant Short Name:

- MONZA
- SESA
- MUP

2.5.5.1 **Objectives of WP 5**

The objective of WP 5 is to treat solid residues after separation in an effective way, so that the end product is a fertiliser of high quality "

- Task 5.1: has the scope to optimize the composting process for the digested residues
- Task 5.2. aim is to investigate effects of adding N recovered in WP 4 to both compost and the solid digested residue. Technical work will be performed through lab analyses in order to assess effects of addition of N recovered in WP 4 on N concentration and type (which influences its loss and plant availability), depending on the added amount and duration of storage/composting.
- Task 5.3 focuses the research on the use and valorisation of digested residue in agricultural applications. Different kind of organic fertilisers, as reciped in task 5.2 are applied onto soils and evaluated in particular assessing the need to assess N distribution into the soil eventual N leachation in the groundwater.

2.5.5.2 Description of work performed

According to the proposed technical programme, WP 5 is meant to assess anaerobic residues treatment, with specific interest in value adding by creating a defined fertilizer product. The production of an organic-mineral Nitrogen fertilizer based on compost as the organic nitrogen source should join the advantages of compost (enhancement of soil fertility) with those of a readily available Nitrogen source, useful for increasing crop yields and soil fertility in general. A further possible advantage is represented by the fact that the leaching potential of the free mineral nitrogen fraction could be reduced due to the bounding activity of humus and humus-like compounds which characterize a high quality compost.

In particular WP 5.2 and WP 5.3 are aimed to develop an experimental activity performed on the production of a set of organic-mineral fertilizers best fitting with the current regulation and on the assessment of the fertilizers behaviour after application, in particular their leaching potential in common soils.

Task 5.2 Organic mineral fertilizers production

For the preparation of the organic-mineral fertilizers, three different compost lots were produced. Sesa provided for the raw materials an for the composting experimental design as it reflects the company typical process. Compost production was carried out at Christiaens Group site in Horst (NL) using two pilot plants 2 cubic meter each.

Final compost label	Digestate (% w:w)	Solid Digested Residue (% w:w)	Compost (% w:w)	Green waste (% w:w)	Liquid mineral Nitrogen (L)[1]
K1	39		13	47	5
K2		40		60	6
K3	35		15	50	

[1]NH_4NO_3 (total N title, 18%)

K1 and K3 were produced according to a similar starting mix (digestate + compost + green waste) except for the addition of mineral Nitrogen in K1 mix; after the composting process, final compost batches showed comparable features under all the considered parameters, probably due to an important Nitrogen evaporation rather than conversion into an organic form during composting.

On the other hand K2 (produced from a starting mixture comprising SDR, green waste and mineral Nitrogen) resulted in comparatively higher organic Carbon, TKN, NO_3^-, NO_2^- concentrations, and a lower NH_4 content (one tenth of K1 and K3). For these reasons, the subsequent fertilizers production was simplified and based on 2 different types of compost (K3-like and K2).

The criteria for the production of a set of fertilizers was mainly based on reference standard for organic-mineral Nitrogen fertilizers as fixed by the Italian law 217/06 (attachment 1 par. 6.1), which require:

- minimum total Nitrogen content of 12% (by weight)
- minimum organic Nitrogen content of 1%
- minimum organic Carbon content of 7.5%.

On the purpose of producing a law compliant Organic-Mineral Fertilizer (from now on referred as "OF"), compost K3 and compost K2 were mixed with a solid mineral N fertilizer (Hydro® NH_4NO_3, total N concentration 26% in weight). The choice of such a fertilizer was due to:

1) the presence of Mineral Nitrogen in the same form (NH_4^+) as that recovered from Liquid Digested Residue
2) the presence of NO_3^-, whose behaviour description in soil was one of the scopes of the research
3) the need to maximize the overall mineral N concentration for reducing dilution effect during OF production, with particular regard to organic N from compost

After production, the OFs were immediately charged on the experimental reactors for the subsequent lysimetric tests. The following table summarizes the OFs produced.

Composition			Characterization		
Label	Compost % (%D.M.)	NH_4NO_3 %	Organic C (%)	TKN (%)	Organic N (%)
OF1	56 (50)	44	6.85	12	0.49
OF2	80 (49)	20	9.89	6	0.7
OF3	58 (2)	42	13.99	12	1.0
OF4	57 (8)	43	18.34	12	1.0

Relative Carbon, Nitrogen and moisture content of compost made it difficult to prepare fertilizers compliant to law requirement.
It was first chosen to stress total Nitrogen concentration in OF1 and Organic Carbon in OF2.

Then, in order to get a fully compliant set of OFs, compost used for OF3 and OF4 preparation was previously dried (in oven, overnight) in order to increase its specific organic N contribution; it was finally possible to produce two "fully compliant" organic-mineral fertilizers.

Task 5.2 Organic mineral fertilizers application onto soil and N dynamics evaluation trough lysimetric tests and Task 5.3 valorisation of digested residues

A battery of experimental reactors were built in order to simulate soil plots on which performing the leaching tests. Each reactor consisted in a PVC pipe 55cm high with a

diameter of 25cm. The bottom end of the pipe was leant on a wire mesh covered with a disposable fabric sheet, in order to prevent ground particles fall down to the leaching collection system. Each reactor was filled with a some 40cm soil layer and amended with proper amounts of Nitrogen according to the experimental design.
Two standard Nitrogen loads were chosen, one being assumed from the Nitrates Directive indication (170 kgN/ha), the other – theoretically suitable for non vulnerable soils - being arbitrarily decided to stress the experimental conditions and point out exogenous Nitrogen behaviour into soils (1,000 kgN/ha).
The experiments consisted in the simulation of medium-heavy rainfall events in the reactors according to average Milan rainfall events during the most rainy season. To do so, the meteorological data (kindly from Regional Environment Agency, ARPA) over a 4-year period were elaborated, and typical October rain events of 20mm were taken as a reference.
Over the experimental period, 4 rain events were simulated at given frequencies on the reactors using tap water; after each rain event, on-site measurement of temperature and soil pH were taken, and all the leachate released from the bottom of the reactor was collected, weighted and sampled for nitrogen lab investigation.
At the end of the experimental period, samples of soils were taken from the 10cm top and bottom layer of each reactor, and further characterised.
Three sets of trials were planned and performed along the experimental campaign.
The first trial consisted in a lysimetric test on three pipes under the following conditions:

Label	Type of fertilizers	Nitrogen load kg/ha
MIN1	Hydro®	1,000
Blank 1	None	0
K2	Compost K2	1,000

The trial was performed over a 4 week period, simulating 4 rain events (1 every 7days). Aim of the trial was to evaluate possible differences in the behaviour of fertilizers applied at heavy loads with respect to unfertilised soil.

The second trial was aimed at describing, under the same experimental conditions (rain events frequencies), the behaviour of Nitrogen when added to soils within maximum concentrations allowed by Nitrates Directive (170 kgN/ha), including a set of two different Organic Fertilisers (OF1, OF2).
Three independent replicates were organised for each Organic Fertilizer for the assessment of standard deviation and variability coefficients. This trial was aimed at simulating real conditions on vulnerable areas, introducing OFs as Nitrogen source.

According to high water evaporation which occurred in the first and second trials (50-75% of water added), and in order to enhance relative differences among the tests, a third trial was planned to assess OF3 and OF4 behaviours in which rain events were compressed in time (1 event every 3-4 days) and a 1,000 kgN/ha was used as Nitrogen load.

Three independent replicates were organised for each Organic Fertilizer (OF3 and OF4) for the assessment of standard deviation and variability coefficients. This trial was aimed at simulating stressed conditions, possibly applicable just in non-vulnerable areas.

As far as OF leaching assessment tests are concerned, a high experimental variability was found along the trials, with particular reference to

- soil characterisation, which revealed strong differences in Carbon and Nitrogen concentrations among the samples, with respect to exogenous Nitrogen supplied to the lysimeters, and water drainage potential
- external conditions (i.e. environment temperature and relative humidity), which changed along the trials according to seasonal weather conditions, thus influencing parameters such as water evaporation, Nitrogen metabolism.

The abovementioned conditions made it scarcely possible to trace specific Nitrogen behaviours along each lysimeter back to univocal Nitrogen applications, either in terms of Nitrogen load or chemical form. In particular, no significant peculiar behaviour characterised (either in positive or in negative direction) any of the Organic-mineral Fertilisers produced along the project.

2.5.5.3 **Work progress and conformity with the time schedule**

- **Organic-mineral Fertilizers formulation and production and application tests trough lysimetric trials**

The mayor steps of work were as follows:
Month 16-17: Literature background data collection, trials experimental design for compost production at Christiaens (NL)
Month 17-20:Experimental activity, compost production (3 trials) at Chris, sampling, lab analyses
Month 17-19:Literature background data collection, OF production and trials experimental design for lysimetric trials
Month 19-25:Experimental activity, implementation of mineral, compost and OFs application on to soil and leachation tests, sampling and lab analysis
Month 21-26:data elaboration and discussion
Month 26-27: deliverables compiling, discussion and refining

Lysimetric trials (WP 5.3) were finished in October and lab analyses were ready by the first half of November, so that deliverable was executed with 4 weeks months delay.

Deliverables submitted

D 12: Report on effects of adding recovered N to both the compost and the solid digested residues – ☑ delivered at the final meeting in Horst on 28/10/2008

D 13: Report on best overall strategies for treatment of solid residues – ☑ delivered at the final meeting in Horst on 28/10/2008

2.5.6 **Workpackage number 6**

Start month: 1

Participants Short Name:

- TUHH
- SESA
- CHRIS

2.5.6.1 **Objectives of WP 6 "Gaseous emissions"**

The gaseous emission produced during the pre-treatment, the anaerobic digestion and the composting step should be cleaned by acidic absorption and bio-filtration

2.5.6.2 **Description of work performed**

In order to find the best operation parameters for a waste gas treatment system to remove ammonia emissions from the exhaust air of a composting process various investigations have been carried out during the first year of this project.

In a set of experiments with lab scale scrubbers various scrubbing liquids have been tested with regard to their ammonia removal efficiency from ammonia enriched gases. As scrubbing liquids acids such as HNO_3, H_2SO_4, and H_3PO_4 have been used as well as water. All the acids showed very good removal efficiencies up to a pH of around 8. The water reached the pH of 8 nearly immediately after start up and proved not to be very efficient for the reduction of ammonia emissions. During a continuous treatment of the ammonia enriched air with HNO_3 and pH value of the scrubbing liquid changes very rapidly between pH 4 and 8. Accordingly this pH range is not suitable for regulation purposes of an acidic scrubber with regard to the pH. In continuous operation it should be run at pH values below 4. H_3PO_4 scrubbers might even be run at pH values around 7. Due to economical reasons is the best option for a scrubbing liquid with respect to the ammonia removal.

The lab scale experiments were varified in bench scale within a composting trail. A set of 6 composting reactors have been filled with a biowaste mixture provided by SESA. The off gases emitting during the composting process were treated with a combination of scrubbers and biofilters. Water and H_2SO_4 were used as scrubbing liquids, and the biofilter were filled with the coarse fraction of the matured compost after screening. Like in the lab scale experiments before, the ammonia was successfully removed from the gas phase using H_2SO_4. When using only water still relatively high ammonia concentration were emitting from the biofilter. Both devices can act as sources for ammonia (buffer effect). Whereas the removal of the ammonia did not result in a significant reduction of the odour, with the acidic scrubber sometimes also acting as an odour source.

In first tests H_2SO_4 has already been applied to the waste gas treatment system of the SESA plant. The promising results showed very low ammonia concentrations emitting from the biofilter.

For monitoring the gaseous emissions of the composting process and for assessing its efficiency, an electronic nose (Pen 2, Fa. Airsense Analytics GmbH, Schwerin, GER) has been available, which was suitable to analyse the emissions with the help of a sensor array consisting of 10 metal oxide sensors. Not all 10 sensors showed to be equally able to reflect the development of the odour concentration in the gas. With the help of several experiments the most suitable sensors could be identified. As ammonia proved to be an important issue with regard to the emissions of the SESA plant, the ammonia sensitive sensor is essential for such a monitoring device. Beside this one, 2 other sensors were found to be suitable. One had a high sensitivity to the odorous substances present within the waste gas, the other was showing quite a good correlation with the olfactory odour concentration. This sums up to a number of 3 from 10 sensors to equip an e-nose with to roughly monitor the efficiency of the biofilter at the SESA plant, which should significantly reduce the cost for such a device. For further sensor specifications please contact Airsense Analytics GmbH.

Nevertheless, investigations revealed, that it was not possible to tell a biofilter failure by analysing the signal pattern of the sensors in the radar plot diagram. But the intensity of the signals of selected sensors on the other hand indicates the strength of odorous emissions. This will help assessing the emissions of the biofilter with regard to their odour related impact. Even though it is yet not possible to determine an olfactory odour concentration by analysing the signals of the sensors. Anyway, to really described the performance of the treatment process and to use the data for process control, further improvements to such a monitoring device have to be made. One option would be to combine different sensor types within the same device other than different sensors of the same type like in the Pen 2. Other suitable gas sensors might be detectors based on ion mobility, electro chemistry, photon emission or photon ionisation.

2.5.6.3 **Work progress and conformity with the time schedule**

All work has been completed.

Deliverables submitted

D 14: Find out the best operation parameters for the scrubbers - ☑ 18/01/2008
D 15: Find out the best operation parameters for the bio filters - ☑ 19/02/2008

D 16: Customize an electronic nose with the best suited sensors for osmogenic emissions of composting plants - ☑ 20/08/2008

2.5.7 **Work Package number 7: "Legal Framework and Market Analysis"**

Start month: 7
Participants Short Name:

- UNIVE
- SESA
- CLENERGY

2.5.7.1 **Objectives of WP 7**

According to the NIREC programme, Work Package 7 consists of:

- the analysis and assessment of how the juridical framework could enhance the dissemination of the technologies studied within the NIREC,
- the analysis and assessment of the economic and environmental cost-benefits added value coming from the adoption of the technologies studied within the NIREC.

2.5.7.2 **Description of work performed**

Task 7.1: Comparison of technologies of recovery and recycling of Nitrogen from waste

According to the proposed technical programme of the NIREC project, task 7.1 is devoted to the comparison of technologies of recovery and recycling of Nitrogen from waste versus Nitrogen fertiliser produced by the traditional chemical industry under an economic point of view. Nevertheless, in order to avoid any overlappings with task 7.2 (Deliverable 18) and following the growing concern for environmental issues throughout society, task 7.1 has mainly focussed on the analysis of different management options for digester effluent from an environmental point of view, outlining the environmental benefits having monetary impact and the externalities.

In specific the task has focussed on the following topics:

- Assessment of different management options for digester effluent outlining the environmental and economic benefits, when compared with an existing integrated composting and anaerobic digestion plant and with the traditional Nitrogen fixation process via the "Haber-Bosch" process.
- Analysis on the feasibility of fertiliser production with recovered Nitrogen from waste by outlining the strength and weakness points and the money-saving synergetic effects.

In particular, the study has been developed by the following steps:

1. Definition of different scenarios as outlined from the project research activities.
2. Calculation of the input and output fluxes and of the nitrogen mass balance and quantification of the consumption of resources for the management systems of digested effluents investigated in the project.
3. Analysis on the outlined nitrogen recycling, recovery and removal strategies under an environmental and economic point of view by using methodology from environmental impact assessment (EIA).
4. Drawing up of some general conclusions on the subject of environmental impacts from the production of fertilizers from waste.
5. Development of final economic-environmental considerations in order to set up and describe a qualitative matrix about private and social-environmental costs and benefits.

Task 7.2: Economic evaluation of the treatment strategies pointed out in the NIREC project

This operative unit (Task 7.2) worked together with other groups of research who faced with technical and biological subjects, and analyzed the economic feasibility and the profitability of investment into innovative and integrated experimental activities. These processes have to solve the problem of Nitrogen in the field of AD.

The purpose of our study is to provide useful information to *optimize the management of anaerobic digestion and integrated productions*. The analysis is carried out in experimental enterprises dealing with *the treatment strategies pointed out in NIREC Project*.

In particular, we focused our attention on the innovative technologies AFTER THE ANAEROBIC DIGESTION PROCESS; these activities aim at a more rational handling of solid, liquid and gaseous wastes coming from biodigestion.

The purpose of the business analysis of data related to NIREC experimentations, is to evaluate the profitability in investing in new technologies, and to appraise the possibility of integration between AD, composting line and sale of enriched compost.

Data were collected through a particular method of management control. We analyzed each operational function of an enterprise dealing with waste handling in order to find out a reference model.

This model should allow to compare traditional management to the application of new methodologies experimented in NIREC Project, in terms of economic weight.

Therefore, economic data, referred to traditional process of anaerobic digestion (AD) and to digestate composting, have been compared to economic data obtained in the experimental phases of the project.

Data related to traditional process have been collected with a specific *form* in order to have a synthetic *description* of the experimental plant, *investment* and *production costs*.
On the basis of the collected data, we can provide a reference model able to show separately the weight of public contribution and the potentialities of private activities providing value added to their own products and services.
We intend to investigate specific investment costs of new technologies for each experimental step (from WP3, WP4 and WP5). Beside the costs, we also analyse *revenues*, with commercial production and *project externalities*.
These data allow us to set a COST/BENEFIT ANALYSIS of the experimented technologies, and to define GUIDELINES FOR FEASIBLE INVESTMENTS in the chain of the anaerobic digestion.
After setting the surveying form, a spreadsheet for data elaboration (matrix) has been prepared.
This matrix has been used for comparing costs of different productive models:

- traditional model of AD (SCENARIO 0);
- experimental model of AD with ammonia stripping at different levels of the traditional process and with integration to the compost chain (SCENARIO 1 and SCENARIO 2).

Finally, the study produced, for each scenario:

6. INPUT-OUTPUT RELATION among the main factors of production, gross output and revenue pointed out by INDEX OF TECHNICAL AND ECONOMIC EFFICIENCY (OPERATING GROSS MARGIN);;
7. CASH FLOWS IN THE MEANING OF NET PRESENT VALUE (NPV), AND INTERNAL RATE OF RETURN (IRR); these parameters allow to compare different kind of alternative investments and to valuate the Payback Period (PBP);
8. RECLASSIFIED BALANCE SHEET, with social and environmental costs and benefits highlighted.

Task 7.3: European Legal framework regarding anaerobic digested residues

Legal researching has started beginning with the legal survey of the horizontal EU rules that could affect NIREC technologies:

I) environmental impact assessment rules
II) IPPC rules
III) Air emission rules with specific reference to odorous emissions

EU rules have been compared with the relevant national implementation in the States involved as NIREC Partners and some other Eastern Europe Countries:

i) Italy; ii) Austria; iii) Germany; iv) Spain; v) Netherlands; vi) Slovakia; vii) Czech Republic; viii) Poland; ix) Republic of Serbia

The above mentioned EU rules have been collected and analysed with reference to the relevant applicability to AD plants and activities, considering that, as a general concept, AD plants being waste treatment/management plants:

a. are likely to be subjected to EIA under EU rules
b. are likely to be subjected to IPPC rules and relevant BREF documents
c. are likely to cause pollutions emissions with particular regard to odorous nuisance or contamination

The research followed these basic assumptions and investigated if:

a. AD plants are subjected to EIA under EU rules and, as a consequence, to the relevant national EIA rules
b. AD plants are subjected to IPPC under EU rules and, as a consequence, to the relevant national IPPC rules and to the relevant technical directives on BAT
c. There are EU rule regarding odorous emissions, to be applicable also to waste treatment plants or to specific industrial sectors and if national rules consider such emissions with specific legal measures and remedies

Legal researching has gone on with the legal survey of the specific EU rules that could affect NIREC technologies, i.e. waste management rules, with specific regard to AD technologies and/or organic waste flow, and superficial and underground water protection, with specific regard to nitrate pollution control.

EU rules have been compared with the relevant national implementation in the States involved as NIREC Partners and some other Eastern Europe Countries:

ii) Italy; ii) Austria; iii) Germany; iv) Spain; v) Netherlands; vi) Slovakia; vii) Czech Republic; viii) Poland; ix) Republic of Serbia

The work has focused on legal requirements for solid residues of AD to be used for agronomic purposes, having regard to quality standards of accepting soils and of spreading materials.

2.5.7.3 **Work progress and conformity with the time schedule**

The research activities have been performed and finalized in compliance with the time schedule of NIREC.

The results of each tasks are pointed out in these deliverables:
→ Task 7.1 in *Deliverable 17*
→ Task 7.2 in *Deliverable 18*
→ Task 7.3 in *Deliverable 19*

Deliverables submitted
D17: Comparison between technologies of recovery and recycling Nitrogen from waste and Nitrogen produced by traditional chemical industry from an economic point of view - ☑ 18/09/2008
D18: Cost study: treatment costs of the different steps within NIREC process - ☑ 18/09/2008
D19: Guidelines for new disposal concepts valid for all Member States - ☑ 18/09/2008

2.5.8 **Workpackage number 8 "Exploitation and Dissemination"**

Start month: 1
Participants Short Name:

- All partners

2.5.8.1 **Objectives of WP 8**

Task 8.1 Exploitation of results:

- define marketing actions for the commercial exploitation of the project results such as patenting, licensing, results diffusion activities, negotiations with possible external partners and end-users.
- organize technical training of SMEs personnel

Task 8.2. Dissemination of results:

- marketing and dissemination actions to other European SMEs belonging to the waste-treatment sector

2.5.8.2 **Description of work performed**

All partners have started with their dissemination activities in period I. The SME and in particular the RTD partners have presented project results to the wider public on several occasions (see dissemination report).

An important issue was the exchange of knowledge and know-how within the consortium. For this purpose beside numerous bi-/trilateral meetings several exchanges of personal from the RTD partners to the SME partners have been conducted to train the SME personal or to provide input from the practical side to the researchers:

- IFA has sent scientific personal to SESA (Liquid residues management), MUP (N-stripping) and GROSS (Improvement of Anaerobic digestion, N removal)
- MONZA has sent scientific personal to SESA and CHRIS (Solids digestion/Composting)
- TUHH has sent personal to SESA and CHRIS (Gaseous emissions)
- SESA personal was working at TUHH (Gaseous emissions)
- CHRIS personal was training personal at SESA (Solids digestion/Composting)
- UNIVE is working in close co-operation with SESA and IFA (Costs-Benefits Analysis)

Several SME partners have already integrated output of the project in their product portfolio and have direct benefit from the project with regard to new business activities or improvement of their current business. Details on the exploitation of the developed technologies/processes are described in the “Dissemination report”.

2.5.8.3 **Work progress and conformity with the time schedule**

Dissemination and exploitation activities are followed throughout the project and are in line with the proposed time schedule.

Deliverables submitted

D20 Plan for using and disseminating knowledge (draft version) - ☑ 20/08/2008
D21 Plan for using and disseminating knowledge (draft version) - ☑ 20/03/2009

2.6 Deviations from the work programme

A general deviation is caused by the fact of the delayed project start (see Section 3 consortium management). The kick off meeting was held in the beginning of October 2006 with the prospect that the contract will be signed immediately and the starting date was fixed with 1.10.06. However the finalisation of the contract caused a delay of 7 months. Due to administrative issues some institutions were not able to start with mayor practical work before the signing of the contract. This caused a delay in the starting off the project. This issue was discussed intensively at the 6-month meeting. It was agreed to keep the old starting date for those institutions which had already expenses in the respective time period. However; the EC was asked to grant an extension of period I. This was accepted by the EC and period I was extended by 3 months. The delay required some rearrangements in the work packages but including those 3 months most of the time is already regained. Nevertheless still some smaller delays with regard to the foreseen plan exist. The rearranged time schedule is presented in Fig. 1 (last page).

In the kick-off meeting it was decided that the contribution by the SME partners to the single workpackages will be re-arranged. In particular Christiaens (CHRIS) will put its focus on composting whereas Machowetz&Partner (MUP) will be more concerned with anaerobic digestion and stripping. This change has no impact on the overall work programme and output of the project.

In workpackage 1 task 2.1 (pre-treatment experiments at the half technical scale) was postponed to period II. This is in line with the general idea of the project to evaluate different technologies at the small scale and later, in period II, to test the most promising ones in the larger scale

In workpackage 2 it was found more convenient with regard to straightforwardness to swap the sequence of Task 2.1 “Conversion of organic fixed Nitrogen into soluble NH4-N and Task 2.3 “Limitation of the anaerobic digestion by ammonia inhibition”. The reason is that it is more necessary to find out the inhibitory ammonia level first to decide which ammonia concentration are allowed in the anaerobic digester as a basement to evaluate different technologies for ammonia removal with regard to their efficiency but also to their technological impact.

In workpackage 7 “Legal framework/Economic market analyses” the work was refocused. The initial description of work was very general. It was decided to concentrate the work on issues strictly related to the developed technologies which will give the involved SMEs the necessary backup to disseminate their technologies. As well with regard to legal framework a complete EC wide survey was found to be too ambitious. It was decided to compare EU regulations will be compared with the relevant national implementation in the States involved as NIREC Partners, which are Italy; ii) Austria; iii) Germany; iv) Spain; v) Netherlands; vi) Slovakia.

For the delivery of the final documents a number of questions addressing financial and particular audit issue occurred. Therefore it took longer to compile the necessary documents from all partners and a corresponding request was sent to the EC to extend the period for reporting from 45 to 90 days. This was agreed by the EC.

3 Section 3 – Consortium management

The participating SMEs and the RTD partners of NIREC formed a consortium which comprises 5 companies and 5 research institutions in Europe. It was the goal of the chosen management structure to profit from the individual expertise of the participating institutions while maintaining an effective decision making and controlling process.

IFA-UT (project management) together with SESA (technical management) assured the synergy of the consortium. It was their task to exchange the results obtained according with the proposed program and to receive the feedback for the execution and development of the goals of the projects. All communication tasks with the EC were in the responsibility of the management.

A mayor problem derived from the fact that the contract negotiations took longer than foreseen as described before. This caused some confusion as some partners started their work from the very beginning and some others had to wait or were not able fully start their activities until the contract was signed. Due to the grant of 3 extra months for period I by the EC these problems were widely overcame and the foreseen work programme was completed within time.

One change in the consortium had to be made after project start. AVICOLA, a Rumanian company did not join the project. In particular they had problems to understand the funding system of CRAFT projects. In the end they were substituted by CLENERGY who entered the contract at the same terms, reading work duties and funding, as the initial partner. As a supplier for environmental technology, focussing on anaerobic digestion, CLENERGY not only has a broad economic background, but also an insight into the markets in central- and eastern Europe. Therefore this change can be considered an advantage. CLENERGY joined the consortium by the end of Period I and it took part already in the mid-term-meeting, although the official start of their work was 01.01.08, the beginning of period II.

Several meetings, a kick off and quarterly meeting as well as several smaller meetings, were held to provide all partners with information and to discuss the current status of the project and the obtained results. During these meetings the necessary co-ordination of the interactions, clarification of uncertainties, organisation of exchange of researchers, and agreement on the methodologies and strategies, were made. The minutes of meetings are available and are also submitted to the EC.

- The kick-off meeting was organised by IFA and held in Tulln/AUT, Oct 12-13, 2006. It was the first time, that all partners were physically assembled. The character and tasks of a CRAFT project was explained by the representatives of the EC, Marc Taquet-Graziani and Carlo Mancini. The workpackages were accurately defined. The minutes of the meeting were written by IFA Tulln.

- The 6 month meeting was organised by TUHH and held in Hamburg/GER May 24-25, 2007. The payment of the EC was just received after delays in the beginning, therefore the 6 month meeting was perfect to fully start the project and make minor readjustments.

- The mid term meeting was held in Este/ITA Oct. 17-18, 2007. A review on the 1st period was made as well as the defining of the next steps in the 2nd period. A major issue was the reporting after the 1st period.

- The 3rd meeting was held in Mollet del Vallès (Barcelona), Spain, from 8th – 9th Feb., 2008. Reporting for period was discussed. Necessary arrangements and clarifications for the final 6 months of work were made

- The final meeting took place in Horst, the Netherlands, 27th – 28th Nov., 2008. Beside the presentation of the work performed, focus was set on future/follow-up activities and dissemination. As well administrative issues were discussed in detail. All minutes of meetings are up-loaded on CIRCA.

Beside the general meetings listed above several smaller mainly bilateral meetings were held between partners working within the same work package. Also a highly active exchange of personal was done as outlined before (see Workpackage number 8 “Exploitation and Dissemination”).

In general, the most time consuming work within management was related to administrative issues. Problems related to the technical work were mainly solved within the partners collaborating on a single work package itself or through discussion during the general assemblies. All in all, the occurring difficulties were all solved in a friendly and cooperatively atmosphere and no mayor problems occurred in the consortium management.

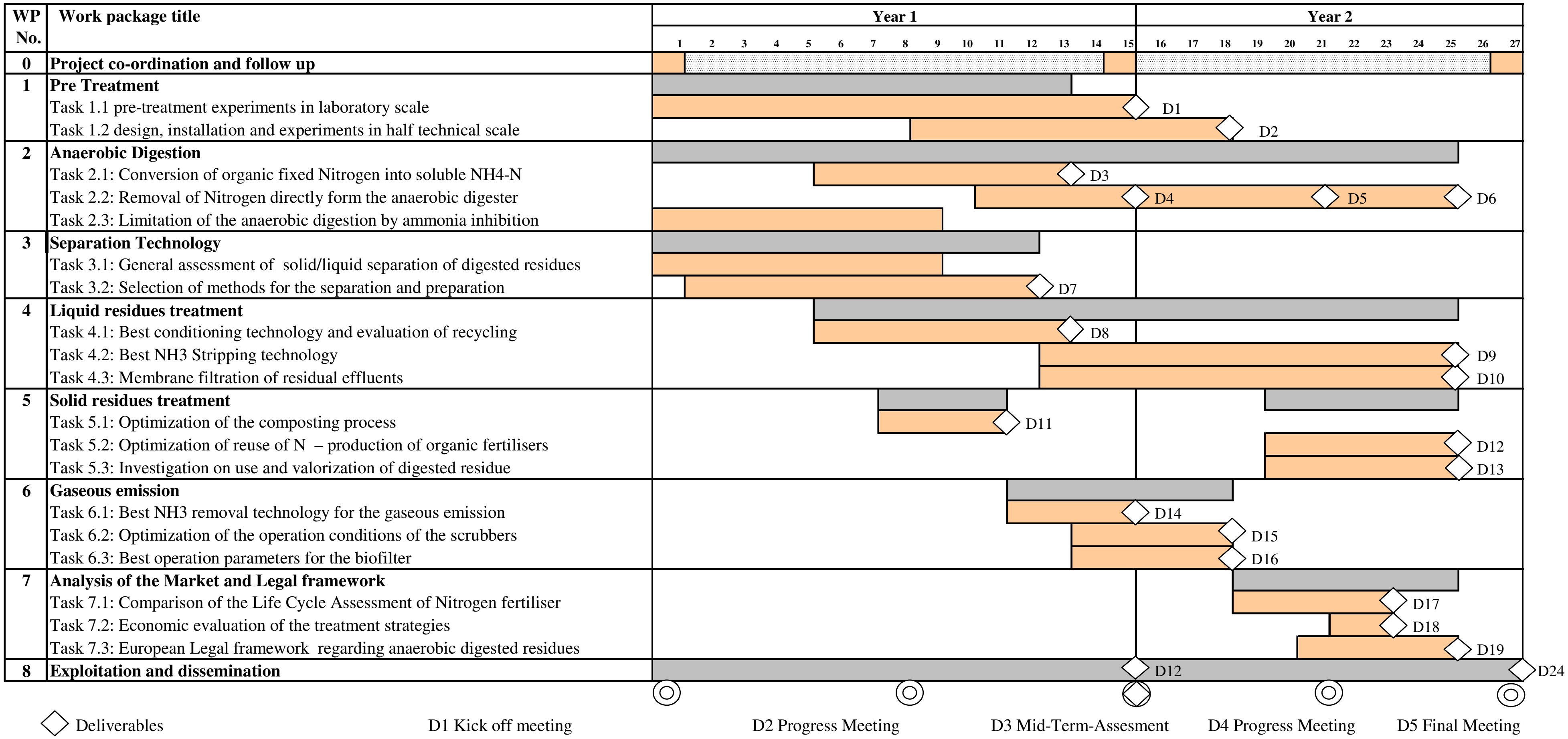


Figure 4: Time schedule of the NIREC project