LIFE Project Number

<LIFE05 ENV/DK/000153>

TECHNICAL FINAL REPORT

Reporting Date

<29/02/2008>

LIFE PROJECT NAME

<Utilisation of ash from incineration of wastewater sludge (bio ash) in concrete production>

Data Project

Project location	Denmark
Project start date:	<01/06/2005>
Project end date:	<30/11/2007>
Total Project duration (in months)	<30> months
Total budget	705.493€ (ref. amendment of 27/07/2007)
EC contribution:	303.745€
(%) of total costs	43
(%) of eligible costs	50

Data Beneficiary

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2. LIST OF KEY-WORDS AND ABBREVIATIONS

AWS	Avedøre Wastewater Services = Spildevandscenter Avedøre I/S. A cooperation among 10 municipalities operating 1 WWTP. The beneficiary partner for BioCrete.
Beton	The Danish word for concrete.
Bio ash	Ash from the incineration of sludge from (urban, biological) WWTP's (incineration at approx. 850^0C). Red bio ash or iron bio ash: The bio ash from a WWTP using an iron precipitant for the removal of phosphorus. Avedøre WWTP, Lynetten WWTP and normally also Damhusåen WWTP use an iron precipitant. Light bio ash or aluminium bio ash: The bio ash from a WWTP using an aluminium precipitant for phosphorus removal. As part of the BioCrete project (Task 3) a batch of light bio ash (060821) was produced at AWS by the incineration of dewatered sludge from Damhusåen WWTP, which had been operated using an aluminium precipitant for half a year.
BioCrete	Bio ash+Concrete. The acronym for the present LIFE project.
Dates	Dates are frequently shown using the year-month-day 6 digits numerical system, e.g. 8. July 2006 = 060708.
DS/EN 206-1	Concrete - Part 1: Specification, performance, production and conformity. The standard is used when producing concrete. The Danish national regulations are called DS 2426: Concrete - Materials - Rules for application of EN 206-1 in Denmark.
DS/EN 450-1	Fly ash for concrete - Part 1: Definition, specifications and conformity criteria.
DTI	Danish Technological Institute. The consultant for BioCrete.
ECN	Energy Research Centre of the Netherlands. Sub-contractor for DTI
Environmental class:	Or Exposure class. A way to classify the different environmental impacts to which concrete structures are being exposed. Passive class (P) is for example concrete which is for 'indoor' purposes and not exposed to freezing and chemical attacks. In Denmark there are 4 different classes, P (passive), M (moderate), A (aggressive) and E (extra aggressive).
Fly ash	The residue from coal fired power plants (incineration at approx. 1300^0C).
Leachate	Water which has percolated through contaminated material. In this context, leachate is the water arising from leaching tests where concrete specimens or crushed concrete are exposed to water under standardised test conditions.

Lynetten	The WWTP with the incinerator for sludge from both LYNIS WWTP's.
LYNIS	Lynettefællesskabet I/S. A cooperation among 8 municipalities operating 2 WWTP's: Lynetten and Damhusåen. A partner of BioCrete.
Mix design	A list of the ingredients (the "recipe") used for the production of a specific batch of concrete. The preferred unit for each ingredient is kg/m^3. The most important ingredients: Cement(C), Fly ash, Bio ash, water(W), plasticizers, filler and aggregates.
P08, P12 etc.	The acronym for concrete of environmental class P and a compressive strength of more than 8, 12 etc. MPa. A similar notation is used for the other environmental classes, e.g. M30 and A35.
Pozzolanic	An inorganic material (typically as a dry powder) is said to have a pozzolanic effect if it – just like cement – reacts with water to create an 'inorganic glue'. Pozzolanic materials may be naturally occurring, e.g. some clays of volcanic origin, and consist of silicium or silicium-aluminium containing materials. For further details, definitions are given in EN 197-1:2001.
Reuse	In this project the words "reuse" and "use" are synonyms. In wastewater circles and also environmental law "reuse" is common practise, while "use" sounds more logical for the end-user, e.g. the concrete producer.
RGB	Red-Green-Blue. A colour model based on additive colour primaries. The equipment measures the distribution of red, green and blue and expresses the results numeric.
Setting time	A standardised parameter (EN 196-3) to quantify the the strength development of concrete
SCA	The Danish acronym for AWS.
SEM	Scanning Electron Microscopy.
UNICON	Unicon A/S. A company with a great number of concrete producing factories, e.g. Avedøre (close to the AWS WWTP), Ejby and Hedehusene. A partner of BioCrete.
WDXRF	Wavelength Dispersive X-ray fluorescence (spectrometry).
WWTP	Wastewater treatment plant.

3. EXECUTIVE SUMMARY

A demonstration project has been conducted on full scale reuse of ash from incineration of wastewater sludge (bio ash) in concrete during the period June 2005 to November 2007. The project was conducted in partnership between two wastewater utilities –

Lynettefaellesskabet (LYNIS) and Avedoere Wastewater Services (AWS) - in the Copenhagen area and the concrete manufacturer, Unicon Ltd. Tests on concrete were conducted by Danish Technological Institute (DTI) with some of the environmental leaching tests in co-operation with Energy Research Centre of The Netherlands (ECN).

In most European countries a green tax of about 50 € per ton has to be paid for residues (e.g. bio ash) disposal on landfills. Thus, there is an economical driver for any kind of a sustainable reuse.

The utilisation of bio ash in concrete production was successfully demonstrated at full-scale for a fluidised bed incinerator (at AWS). During the project period 1.900 t of bio ash (corresponding to 45% of the production) was reused in plastic concrete. The bio ash has a relative uniform composition, and the typical content of bio ash in bio ash concrete is approx. 50 kg/m^3. The direct use of bio ash from a multiple hearth furnace (at LYNIS) turned out not to be feasible due to big and uneven grain sizes. Tests in the laboratory with milling of this ash showed positive results for the concrete production, pointing at this pre-treatment as a necessary and adequate step.

The practical handling of dry bio ash has not resulted in negative surprises. This issue is not trivial and not predictable as dust emissions during loading of transport vehicles as well as clogging problems for withdrawal from silos potentially can result in extra costs.

The idea to use bio ash for concrete production is inspired by the fact that fly ash from coal-fired power plants is a very useful ingredient in concrete, and therefore the technical characterization of bio ash has focused on a comparison with fly ash as well as fly ash concrete.

Bio ash is not as valuable as fly ash. Bio ash shows no (or very little) pozzolanic effect and cannot replace part of the cement in the mix designs. However, bio ash functions very well as a small particle size filler, which can replace up to half of the fly ash in the mix designs. This has been demonstrated for most concrete exposure and strength classes.

Bio ash concrete has a reddish colour especially when using iron bio ash. The colour is distinguishable from ordinary grey concrete, and this might be a problem if the bio ash concrete is to be used for visible structures. The maximum amount of bio ash which can be used in order to avoid the colour problem is estimated to be 5-10 kg/m^3 concrete when using iron bio ash and approx. 40 kg/m^3 when using aluminium bio ash.

The environmental impact of bio ash concrete is considered to be very limited after an evaluation based on standardized leaching tests on concrete specimens or crushed concrete. Although the concentration of a number of heavy metals is higher in bio ash, there is no difference between the concentrations of heavy metals in the leachates from bio ash concrete and from reference concrete with no bio ash.

Dissemination activities will continue through the networks of the participants, by future articles and conference papers, and by maintaining the home page www.biocrete.dk.

4. INTRODUCTION

Fly ash from coal-fired power plants has been used for decades in large quantities by the concrete industry as a partial replacement of cement. This has reduced the need for land filling as well as reduced the consumption of fossil fuels and natural resources for cement production and thereby also reduced CO_2 emissions.

Ash from incineration of wastewater sludge (bio ash) which is typically land filled today has a potential for use in concrete in the same way as fly ash is currently used.

Full scale production of bio ash concrete is already taking place in Denmark, but in very limited quantities. In order to promote a more extensive utilization of bio ash concrete the following barriers for an extensive utilization of bio ash concrete are addressed in this project:

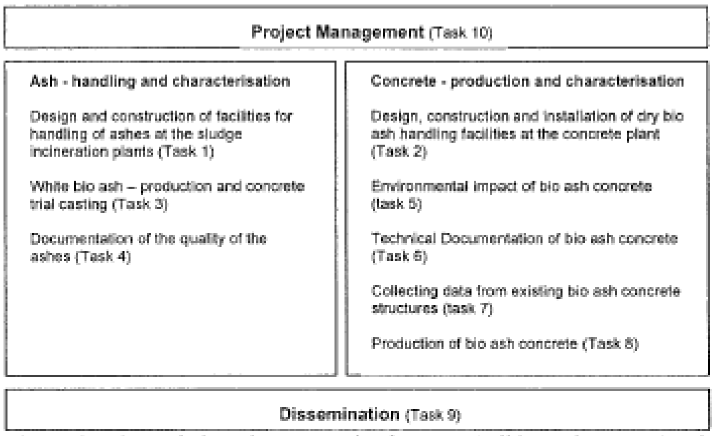
- Lack of documentation of the environmental impact in particular with respect to leaching of heavy metals from the bio ash concrete (Task 5).
- Lack of documentation of the technical properties of the bio ash (Task 4).
- Lack of documentation of the properties of fresh and hardened bio ash concrete (Task 6, 7 and 8).
- Need for a structured dissemination of existing know-how on bio ash concrete (Task 9).
- Ash handling facilities at the bio ash plants as well as the concrete plants to accommodate the bio ash in a dry form (Task 1 and 2).

The disposal of bio ash is a latent environmental problem, as the heavy metal of the bio ash can probably not be contained within the landfill boundaries forever. Landfill disposal of the bio ash also means use of space, which is considered a limited resource in most European countries.

Demonstrating that bio ash can be used in an environmental sustainable way in the production of concrete means that bio ash will go from waste to a valuable raw material. It will result in a reduced use of landfill space, the save of energy and reduction of CO_2 emissions overall. The latter two benefits are the results of the possible substitution of Portland cement by bio ash, thus reducing the energy consumption and CO_2 emission from the Portland cement production.

5. LIFE-PROJECT FRAMEWORK

The conduct of the project has been composed by 10 individual tasks, as shown below.



Three tasks focus on the ashes and five tasks on the concrete whereas the two general ones on Project Management and Dissemination are cross cutting.

The first phase of the project consisted of establishment of equipment needed for the surveys on the wastewater treatment plants (Task 1) and the concrete production plants (Task 2), respectively. The second phase included analysis and testing of bio ash and bio ash concrete.

An overview of the tasks, deliverables and reference to reporting is shown in the Table below.

	Task	Deliverable	End Date planned / realized	Reference reporting (all included in Appendix 2)
1	Design and construction of facilities for handling og ashes at the sludge incineration plant	Ash outlets installed and tested at WWTPs LYNIS and AWS	01/04/2006 May 2006	Final Task 1 report
2	Design and construc-tion of facilities for handling og ashes at the concrete production plant	Final project plan handling facilities installed and tested at the concrete plant	01/03/2006 July 2006	Final Task 2 report
3	White bio ash – ash production and concrete trial casting	Memo: "Chemical composition of European bio ashes" Report: "Bio ash concrete – Some implications of substituting Al for Fe in bio ash"	01/10/2006 Dec. 2007 Jan. 2008	Appendix in Final Task 3 report Final Task 3 report, title modified to "White bio ash – ash production and concrete trial casting"
4	Documentation of the quality of the ashes	Report: "Variations in Chemical and Physical Properties of Bio Ash for Use in Concrete" Product Standard: "Bio ash for use in concrete" (draft)	01/09/2007 Nov. 2007	Final Task 4 report, title modified to "Bio ashes from Lynetten and Avedøre waste water treatment plant – documentation of ash proporties" Included in Handbook as appendix to Final Task 9 report
5	Environmental impact of bio ash concrete	Report: "Leachability of heavy metals from bio ash concrete"	01/09/2007 Oct. 2007	Final Task 5 report, title modified to ""Environmental impact of bio ash concrete"
6	Technical document-tation of bio ash concrete	Report: "Durability of bio ash concrete" Report: "Setting time and strength development of bio ash concrete"	01/12/2007 Jan. 2008	Final Task 6 report, combined to 1 document and title modified to "Technical documentation of bio ash concrete"
7	Collecting data from existing bio ash concrete construc-tions	Report: "Field performance of bio ash concrete"	01/01/2007 May 2007	Final Task 7 report, title modified to "Collecting data from existing bio ash concrete construction(s)"
8	Production of bio ash concrete	Report: "Existing production data on bio ash concrete" Report: "Production of bio ash concrete"	01/12/2007 Feb. 2008	Final Task 8 report; existing production data on bio ash concrete is included as chapter 2 herein.
9	Dissemination programme of results	Handbook: "Guideline for use of bio ash concrete" in English and in Danish Project website platform operational	01/12/2007 Jan. 2008 Dec. 2005	Separate documents as appendix to Final Task 9 report www.biocrete.dk
10	Project management	Progress reports to the commission Final report to the commission	01/12-2007 Jan. 2008	Submitted on time as separate documents Final Task 10 report This document

The project was divided in 2 overall phases:

1) Establishment of equipment (Task 1 and 2)and
2) Production and envestigations of bio ash concrete and white bio ash (Task 3 – 8).

Subtasks 8.1 to 8.3 were added to the program in order to describe activities on obtaining permits from the authorities, the reuse of AWS bio ash, and the pre-treatment of LYNIS bio ash, respectively.

The dissemination (Task 9) and management (Task 10) has taken place synchronously with the phases. The organigram from the application is shown below. A task coordinator for each task has been appointed from the beneficiary, partners or consultants, and data for the project participants and key persons (latest version) are shown in Appendix 1.

Some delays have occurred within the project. For phase 1 of the project, which included investments in equipment. A reason for the minor delay compared to the planned dates can be explained by some hesitation by the partners until the signed agreement was received by the Commission by 16 November 2005. For the other deliverables, the dates for realization refer to the reporting of the individual tasks. In most cases, interim results have been available before, have been discussed at the joint meetings for the project participants and have influenced decisions underway for managing the project.

With submission of the final technical and financial reports within 3 months after the project end date the overall time plan is regarded as in compliance with the common provisions.

The project was carried out in cooperation between Spildevandscenter Avedøre I/S (Avedoere Wastewater Services, AWS) as beneficiary, and UNICON and Lynettefællesskabet I/S (LYNIS) as partners. Danish Technological Institute (DTI) were consultants with focus on laboratory testing and assessment of environmental and technical properties of the bio ash concrete as well as acting as Assistant Project Coordinator. The Energy Research Centre of the Netherlands (ECN) conducted, as sub-contractor to DTI, the tank leaching tests as part of the environmental investigations in Task 5. A direct agreement with AWS, UNICON and LYNIS has governed DTI's involvement in the project.

LYNIS and AWS own and operate the two largest sludge incinerators in Denmark, respectively, and the three corresponding WWTPs serve a population of about a 1.2 mil.

UNICON is the largest ready-mixed concrete manufacturer in Denmark with concrete production facilities covering all regions of Denmark. One of their plants in the Copenhagen area has on an experimental basis manufactured and delivered limited amounts of bio ash concrete primarily for indoor structures (dry, non-aggressive environments). UNICON has a strong position on the ready-mixed concrete market in Norway and Sweden, and has recently been included in the Italy-based Cementir group. Cementir has considerable Portland cement and concrete production activities in e.g. Italy and Turkey.

DTI has well-equipped laboratories with substantial experience in testing and evaluating concrete with industrial waste materials as supplementary material (often cement substitutes). The experience includes leading the now finalised large project "Green concrete" sponsored by the Danish Ministry of Science, Technology and Development.

ECN is an international capacity in the field of leaching of heavy metals from concrete.

6. TECHNOLOGY

Like fly ash from coal fired power plants the bio ash was expected to be able to substitute a part of the cement in concrete mix designs. The project final results indicate, alas, that bio ash has very little, if any, pozzolanic (cement-like) effect, and there has not been a reduction of the cement content in the mix designs for the produced bio ash concrete.

The bio ash, however, is useful as a partial substitute for the fly ash in the concrete mix designs. For all concrete exposure and strength classes, up to half of the fly ash content has been replaced by bio ash with good results, the bio ash thus showing a good filler effect. The content of bio ash in the produced bio ash concrete has been in the range 20 – 70 kg/m^3.

The particle size distribution for AWS bio ash is somewhat coarser than for cement and fly ash, although these 3 materials look alike (except for the colour). It was only possible to use the AWS bio ash for the production of bio ash concrete, while the LYNIS bio ash was to lumpy, slaggy and coarse grained to be useful. The difference is due to the different types of incineration plant: At AWS the incineration takes place in a fluidized bed oven and at LYNIS in a multiple hearth oven – at 850 ^{0}C in both cases.

If grinded, the LYNIS bio ash can be used for concrete production just like AWS bio ash.

Compared with fly ash, bio ash has a very high content of phosphorus and calcium due to the abundance of these two elements in wastewater sludge. The typical P_2O_5 content of bio ash is 20 weight% or more compared to approx. 0.5% or less in fly ash. The very high content of total phosphorus did raise questions concerning the long-time durability and other technical issues such as strength development. However, the project results indicate no such problems.

Towards the end of the project period a certain dislike for the project purpose was experienced. Some scientists at the conference in Canada (as well as some early political signals in Denmark) find it advisable to recover phosphorus from bio ash, phosphorus being an essential element for life and being a limited resource.

At the two WWTP’s (LYNIS and AWS) outlet systems for dry ash have been finalized, and they are now in operation. Before that the ash from the incinerators was humidified and handled and land filled as wet bio ash. Now the ash handling systems are in place, and the bio ash can be transferred in a dry state on trucks for transport directly to the ash silo at the concrete production plants.

At the concrete production plants, facilities for receiving the bio ash have been established at 3 plants (Hedehusene, Avedøre and Ejby) in the Copenhagen area.

The current operation of this new equipment has demonstrated that the handling of dry bio ash can be done without technical problems, i.e. very few dust problems, easy transfer from WWTP ash silo to truck and from truck to concrete plant silo as well as efficient weighing and dosage of bio ash for the production of the ready-mixed bio ash concrete.

The new dry ash outlet at AWS. 060530.

7. PROGRESS, RESULTS

A final report has been elaborated for each task, see Appendix 2. In the following sections a short summary is given for each task

Task 1: Design and construction of facilities for the handling of ashes at the sludge incineration plant

Before the start of the project, the ash handling at both WWTPs consisted of systems for wetting / moisturing the ash prior to transport in open trucks to landfill disposal area within the WWTP area. For re-use in concrete it is necessary to keep the ash in dry condition as a powder.

The design, construction and establishment of dry ash outlets at AWS WWTP as well as at LYNIS (Lynetten WWTP) were completed early 2006. The operation of this equipment is satisfactory with only minor ash dust problems.

The equipment used is based on conventional screw conveyors, a flexible load bellow fitting to the openings in dry powder transportation van and connection tubes to air suction ventilators to ensure a dust free working environment outside the closed system.

For the fluidised bed ash (AWS WWTP) the ash handling has been relatively unproblematic without unforeseeable clogging problems, etc. For the multiple hearth ash, some initial difficulties were solved by installation of a 10 mm sieve.

The transfer of a batch (typically 20 – 25 t) of dry bio ash from the ash silo to the powder transportation van is programmed to be automatic. Thus, the transfer is handled by the van driver himself, and the presence of local WWTP personnel is not necessary. The load bellows sensor which registers when the van is full, functions very well by giving a signal to stop the screw conveyor and to close and elevate the load bellows. In general, the operation of the ash outlets is unproblematic.

There are only minor problems with respect to dust in the air or spilled ashes on the floor – very small when compared to the former normal operation of transfer of wetted ash to open trucks. Thus, the working environment has improved significantly.

Illustrative pictures are included in the Task 1 report.

The total (eligible) cost of the 2 dry ash outlets was approx. 130.000 €. This is less than expected in the grant agreement budget; therefore a budget modification has been requested and accepted (070727) transferring funds from cost category “equipment” to cost category “consumables”.

Task 2: Design and construction of facilities for the handling of ashes at the concrete production plant

By August 2006 UNICON finished the establishment of the facilities for the reception of bio ash at the concrete production plant at Ejby, and it was now possible to receive bio ash in silos at 3 plants (Hedehusene, Avedøre and Ejby) in the Copenhagen Area . One plant is situated less than 1 km from the WWTP and all are within less than 50 km from the WWTPs. This is a favourable situation concerning transport costs, which may not apply for all WWTPs in Europe with incineration.

The facilities at the plants do function very well (handling bio ash from AWS), and the limiting factor for the production of bio ash concrete has been the day to day demand. The strategy of involving 3 plants increased the flexibility for using the the bioash.

The behaviour of powders, such as cement and bio ash, in screw coveyors and silos cannot always be predicted but has to be tried at full scale. This was therefore essential for bio ash as a new product. No negative surprises were experienced with the bio ash.

The cost of the installed equipment (a.o. screw conveyor and computer system) was approx. 65.000 €, as expected in the budget.

Task 3: White bio ash – ash production and concrete trial casting

Bio ash concrete has a reddish colour due to the content of red iron bio ash, and this is a problem if the bio ash concrete is going to be used for visible structures simultaneously with ordinary grey concrete. Although being an esthetical problem, only, this is important for many consumers and therefore also for the market value. Because Lynetten WWTP as well as AWS WWTP uses an iron precipitant (JKL) for the precipitation of phosphorus, both sludge incineration plants produce red iron bio ash. Thus, it was planned to produce a “white” aluminium bio ash in order to evaluate the consequence for the colour and the different test parameters in Task 4, 5 and 6.

According to the plans a batch of approx. 12 t of aluminium bio ash has been produced by changing to an aluminium precipitant at Damhusåen WWTP for half a year and afterwards incinerating approx. 150 t of sludge cake at the AWS incineration plant. This aluminium bio ash is not “white”, however much lighter (and brownish) than the normal red iron bio ash, and has therefore been renamed to “light bio ash”.

In the Final report for Task 3, test results for this light bio ash and for AWS red bio ash have been compared, and further the quality of the corresponding two types of bio ash concrete have been discussed. The title of the report has been modified from the title in the proposal, however, the content describes the same activities and results. The included colour photos visualize the difference between concrete with no bio ash, with light bio ash and with red bio ash, respectively. Additional quantification of colour and reflectance was measured in laboratory – no significant change was observed over a period of 18 weeks; data have been reported in Appendix 3 to final report for Task 3 (In Danish). This deliverable is in excess to the proposal.

The conclusion is that the colour problem is significantly reduced when using the light aluminium bio ash, and that this light bio ash technically at least is just as good as the red bio ash.

Based on the colour evaluations, the limit for no adverse colour effect seem to be a max addition of 20 – 40 kg light bio ash per m^3 concrete and only 5 – 10 kg/m^3 for red bio ash.

In other words; seen from the concrete producer it is an advantage to use light bio ash based on aluminium precipitants. Seen from the WWTP, the situation is more complex. At several WWTPs throughout Europe, aluminium based precipitants are used already so bio ash from these plants are expected to contribute less with the colouring. At other WWTPs using iron-based precipitants it may or may not be more expensive to shift to aluminium based precipitants, as prices on chemicals may vary much from one country to another. In Denmark, the iron based precipitants are cheaper and it is not considered cost-effective to shift to aluminium based only for the reason to produce light rather than red bio ash. More information on the actual chemical costs is included in appendix 2 to the Final Task report 3.

It became more costly to produce the light bio ash than expected due to the necessity for a longer period using aluminium precipitant. The extra cost for using an aluminium precipitant and for incinerating the produced sludge cake amounted to approx. 60.000 € during this experimental period of the project.

A memo “Chemical composition of European bio ashes” is included as Appendix 1 to the Final report for Task 3. The data obtained from questionnaires to contact persons and institutes represents bio ashes from WWTPs in The Netherlands, Germany, Switzerland, France UK and Denmark. Data included plants producing iron bio ash as well as aluminium bio ash.

The chemical composition of the 17 samples of European bio ash is quite uniform and consistent. With respect to the abundant elements, phosphorus is an important component, typically, the level is 15 – 24 weight percent as P_2O_5. The levels of the more important heavy metals also seem to be quite consistent, mercury being the only exception. In general, sludge incineration plants produce a primary ash with < 0.1 mg/kg mercury and remove mercury from the flue gas in a second stage. However, in some cases the mercury containing secondary ash or residue is disposed of together with the primary ash.

Task 4: Documentation of the quality of the bio ashes

6 samples of bio ash from LYNIS as well as from AWS have been collected in 200 kg drums during 2006 and have been analysed at DTI. Sub-samples from 3 of the 6 LYNIS samples have been milled to a smaller particle size prior to most analysis, see Task 8.3, as this turned out to be a necessary pre-treatment. Also, the light bio ash (Task 3) has been sampled (AWS 060821) and included in the test programs. Approximately 30 chemical, physical and mineralogical parameters have been analysed.

As it is expected that bio ash can act as a substitute for fly ash in concrete mix designs, part of the analytical program was inspired by the analytical parameters defined in EN 450-1 “Fly ash for concrete”.

In the final Task 4 report, results are summarised from the comprehensive characterisation of chemical composition, physical proporties and morphology. Analytical details are included as appendix in electronic version, only (175 pp.), and are also available from the web-site.

The memo “Quality control parameters of bio ash – property limits” as well as an example of a “Product Standard”, which basicly refer to the same issue on limit values for the composition of bio ash, are integrated into the handbook “Guideline for use of bio ash concrete” (Task 9)..

LYNIS bio ash primarily being a ‘bottom ash’ from a multiple hearth incinerator oven is more coarse grained with slag-like particles than the AWS bio ash, which is a ‘fly ash’ from a fluidized bed incinerator oven. AWS bio ash and milled LYNIS bio ash exhibit similar properties with respect to EN-450-1 parameters, although the LYNIS bio ash is somewhat inferior with a higher content of loss on ignition and chloride. Bio ash consists of bigger and more porous and edged particles than fly ash.

In general, the bio ash quality fulfils the EN-450-1 parameters for fly ash. Few exceptions are chloride and setting time in LYNIS bio ash, and 90 days activity index demand in AWS bio ash. It should be stressed that this is not a formal problem as bio ash is not a fly ash after the definition in DS/EN 450-1. Bio ash can therefore still be used in concrete according to DS 2426 (the national application document for the European concrete standard EN 206).

The quality of the bio ash from LYNIS as well as from AWS is quite constant during the year.

The obtained data suggests that the bio ashes investigated can only be expected to have minor pozzolanic effect if used as a cement replacement in concrete.

In the long term, the bio ashes are not expected to have specific negative effects on the durability of concrete evaluated on the basis of their chemical and mineralogical composition .

In the short term, the bio ashes are expected to influence the proporties of fresh concrete evaluated on the basis of their particle size distribution, irregular shape and internal porosity, In particular, the workability might be negatively affected.

Task 5: Environmental impact of bio ash concrete

The environmental impact of bio ash concrete was evaluated using a method of characterization (defining 3 categories of residues) described in the Danish ministerial order No. 1635 of 13. December 2006 “Recycling of residues and soil for construction works” and compared with a similar characterization of a reference concrete with no bio ash.

Thus, according to the ministerial order, the present characterization is based upon a European leaching test method prEN 12457-3 (June 1998), and the leachate has been analyzed for 19 heavy metals: Ag, <u>As</u>, <u>Ba</u>, Bi, <u>Cd</u>, Co, <u>Cr</u>, <u>Cu</u>, <u>Hg</u>, <u>Mn</u>, Mo, <u>Ni</u>, <u>Pb</u>, Sb, Se, Sn, Tl, V, <u>Zn</u>, and in the ministerial Order the underlined 10 metals are attributed with leachate limit values which define residue category.

In the proposal, also investigation of phosphorous was planned but since this parameter is not included in the above Ministerial order, it was not considered relevant for the investigations and therefore not conducted.

Further, in order to simulate behaviour of fresh (i.e. not carbonated) as well as aged (i.e. carbonated) concrete, the concrete samples have been tested after no exposure to carbon dioxide as well as after 1 – 2 months of exposure to carbon dioxide.

In this way 6 different bio ash concrete samples have been tested, and in total 20 leachates have been analyzed.

Comparison between bio ash concrete and reference concrete: For all heavy metals and for not carbonated as well as carbonated concrete samples there is no significant difference between the concentrations in the bio ash concrete leachate and the reference concrete leachate. This is the case although the concentration of some heavy metals (Bi, Cu, Hg, Pb, Se and Zn) is approximately ten times higher in bio ash as in cement and as in fly ash.

Category characterization (category 1 is the best): No metal exceeds category 3. Chromium (Cr) corresponds to category 3. Barium (Ba) also corresponds to category 3 if the concrete sample is not carbonated, but to category 1 when carbonated. Mercury (Hg) probably corresponds to category 1, but the analytical detection limit was too high in order to be sure. The remainder 7 metals correspond to category 1.

Thus, because of chromium (and barium) the bio ash concrete corresponds to a category 3 residue – but the same is the case for the reference concrete!

Two leaching tests (bio ash + reference) according to a Dutch Standard method show leachate heavy metal concentrations far below the category 1 limit values.

The overall conclusion is that the use of bio ash for concrete production has very limited environmental impact.

Task 6: Technical documentation of bio ash concrete

Based on studies of concrete mix designs with various content of fly ash and bio ash, UNICON recommends not to replace more than 50% of the fly ash by bio ash. Thus DTI has produced higher class (P20, M30 and A35) concrete specimens using 3 AWS bio ashes and 3 milled LYNIS bio ashes in mixes with approx. 40 kg/m^3 bio ash and 40 kg/m^3 of fly ash, as well as reference specimens with fly ash only (60 – 80 kg/m^3).

The milling was conducted as a sample pretreatment as it turned out in early 2006 that it was not possible to produce bio ash concrete of an acceptable consistency, when using LYNIS bio ash, see further description in subtask 8.3. The milling took place in the laboratory ofAalborg Portland; no costs for this has been charged to the project. The milling solved the problem and the tests were conducted as described in the proposal – in this way representing bio ash from multiple hearth furnace after such pretreatment.

These concrete specimens were tested for long-term durability (freeze-thaw resistance and shrinkage) and strength development (Setting time and compressive strength after 2, 7, 28 and 56 days) as well as heat development and compressive strength.

There were no significant differences between bio ash concrete and reference concrete with respect to freeze-thaw resistance, shrinkage and compressive strength. The setting time is higher for the bio ash concrete.

Overall the concrete mixes had similar properties regarding durability and strength development, with the only major difference being the later setting time indicated in the heat development test. It was possible to obtain satisfactory fresh concrete properties with both types of bio ash, although the mix designs had to be modified to compensate for the bio ashes higher water demand. All concrete mixes were modified with higher paste content and/or higher super plasticizer dosage and a 50-50 percent mix of fly ash and bio ash, in order to obtain satisfactory fresh concrete properties.

It is concluded that it is acceptable to produce bio ash concrete of higher exposure and strength classes. The high content of total phosphorus does not seem to have a negative effect on the concrete quality.

Task 7: Collecting data from existing bio ash concrete construction(s)

Two structures with bio ash concrete and of a considerable size have been identified and investigated. The first was in connection to a demo bridge with concrete of a high strength class concrete and established in 2002, the second was a filling around a water basin / stormwater detention pipe with concrete of lower strength class and established in 2004. The concrete qualities have been examined and estimated with respect to compressive strength, chloride penetration, cracks, carbonation, air voids and particle characterization a.o. by using different types of microscopy.

The bioash concrete of the demonstration bridge showed all the signs of being a healthy durable concrete. The microstructure does not show any significant defect originating from the plastic or hardened state of the concrete, i.e. it is properly placed and cured concrete of adequate composition.

The bio ash concrete around the the water basin is generally in good condition and based on the microscopy analysis the compressive strength is estimated at around 20 MPa. The concrete has a high water to cement ratio, and areas of increased porosity due to short plastic cracks originating from the first few hours from placements are observed.

From the microscope examinations no pozzolanic effect has been observed, and a strength contribution from the bio ash is most likely due to a filler effect.

The overall conclusion is that the analyzed concrete with bio ash is as durable as "ordinary comparable concrete".

As all Danish bioash concrete the investigated concretes are still young, less than 5 years of age, and consequently it has not been possible to evaluate their long-term durability performance. However, there are no signs that the long-term durability will develop any different than expected for comparable conventional concrete.

Task 8: Production of bio ash concrete

During the past 5 years UNICON has produced approx. 40.000 m^3 bio ash concrete mainly of the classes P08 and P12 using approx. 2.200 t of AWS bio ash, the typical use of bio ash thus being approx. 50 kg per m^3 of bio ash concrete. A milestone of 400.000 m^3 bio ash concrete was not obtainable, because the LYNIS bio ash was/is too lumpy to be used, and because the current demand was lower than expected.

The bio ash concrete mixing properties and quality has been acceptable; however some (minor) drawbacks must be mentioned:

1) Concrete with bio ash demands more water and/or plasticizer than concrete without bio ash to achieve the same workability (or consistency). 2) To maintain the strength level, it will often be necessary to add more cement (e.g. to retain the W/C-ratio). 3) Bio ash concrete consistency might be more sticky, i.e. more difficult to get out of the trucks.

In the used bio ash concrete mix designs not more than 50% of the fly ash has been replaced by bio ash. In order to increase the use of bio ash, the concrete production plants have experimented with 100% as well as 70% replacement, however with little success: The concrete workability and/or strength is not acceptable. Thus, a maximum of 50% replacement of fly ash by bio ash has been confirmed.

Pre-testing of bio ash concrete of higher classes has shown acceptable quality for P20, M30, A35 and E40 concrete containing 22 – 45 kg/m^3 of bio ash (as well as 22 – 45 kg/m^3 of fly ash).

The reddish colour of iron bio ash concrete is distinguishable from the 'normal' grey concrete, if the content of red bio ash is higher than 5-10 kg/m^3. The lighter brownish colour of aluminium bio ash concrete is distinguishable at approx. 40 kg/m^3. Thus, for visible structures the maximum use of bio ash will often be limited by the possible colour problem, and not by the technical quality of the concrete.

The overall conclusion is that bio ash from AWS, i.e. the ash from a fluidized bed incinerator, can be used for concrete production for many purposes, and in a European perspective it will possible to use bio ash concrete as an important part of the total amount of concrete produced.

The 2 report deliverables mentioned in the proposal has been integrated into 1 report attached in Appendix 2, Final report for Task 8.

Subtask 8.1: Permits from the municipal authorities

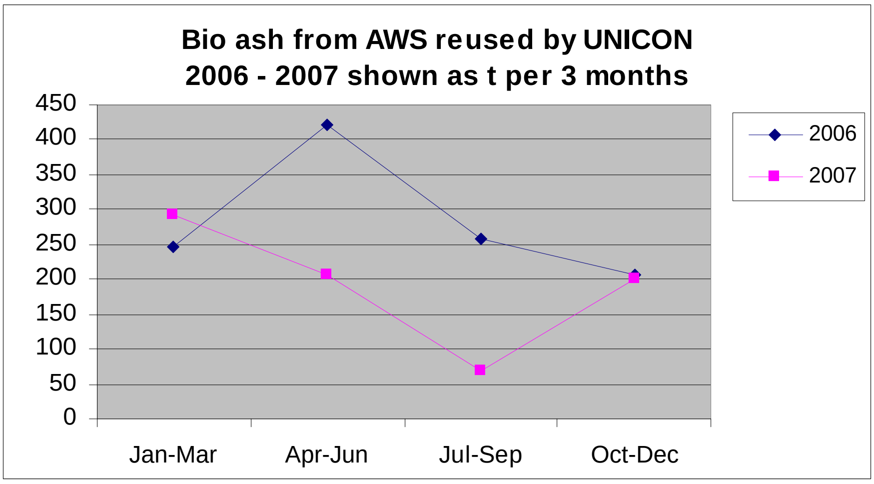
In order to (re)use bio ash for the production of bio ash concrete, the sludge incineration plant needs a permit from the municipal authority. Thus, AWS as well as LYNIS did receive permits from the Hvidovre and Copenhagen municipal authorities, respectively. However, the permits were granted for the project period only, and must now be renewed for future reuse. Based on the promising results from the environmental impact studies (Task 5), it is expected that it will be possible to obtain such extended permits.

The concrete production plants also need permits for the use of bio ash, and are also expected to be able to obtain extended permits. Further, based on the promising technical project documentation activities (Task 4, 6, 7 and 8) it is expected that a temporary consent of using bio ash for concrete production in DS/EN 206-1 and DS 2426 can be prolonged.

A 'Material Safety Data Sheet' for AWS bio ash has been worked out; see Appendix 3 (in Danish).

Subtask 8.2: Amounts of bio ash from AWS reused by UNICON

Since the establishment of the a dry ash outlet at AWS January 2006, there has been a current transfer of bio ash from AWS to UNICON concrete production plants in the Greater Copenhagen area, from 1 plant in the beginning and to 4 plants ultimo 2007. In total approx. 1.900 t, corresponding to 45% of the AWS bio ash production. The amounts per 3 months are shown in the figure below. It is noticed that the demand for bio ash was smaller in 2007 than in 2006, however at the same level early 2006 and late 2007.



Subtask 8.3: Pre-treatment of bio ash from LYNIS

Early 2006 it was experienced, that the coarse grained and lumpy nature of LYNIS bio ash gave some handling problems by the transfer of the ash from the transportation van to the silo at the concrete production plant. This problem was solved by installing a bow sieve between the ash silo and the new screw conveyor at LYNIS.

However, we faced a real problem for the project, when it turned out that it was not possible to produce bio ash concrete of an acceptable consistency, when using LYNIS bio ash. For the time being it would not be possible to reuse the LYNIS bio ash for the production of concrete.

In order to obtain bio ash samples with an acceptable particle size distribution, it was decided to pre-treat the LYNIS bio ash by milling. This was done in order to produce ash samples which could be used for the studies, analysis and characterization defined in the test programs for task 4, 5 and 6. Thus, the content of 3 drums (with approx. 200 kg LYNIS bio ash samples of 060726, 060825 and 061125) were milled (to “50% < 20 µm”) at Aalborg Portland, and these milled samples were included in the test programs.

In this way, the commitments to the project for investigating the feasibility of bio ash from multiple hearth furnace was met. Costs for the milling in the laboratory are not included in the budget and accounting, thus witnessing a strong commitment from the partners to the project.

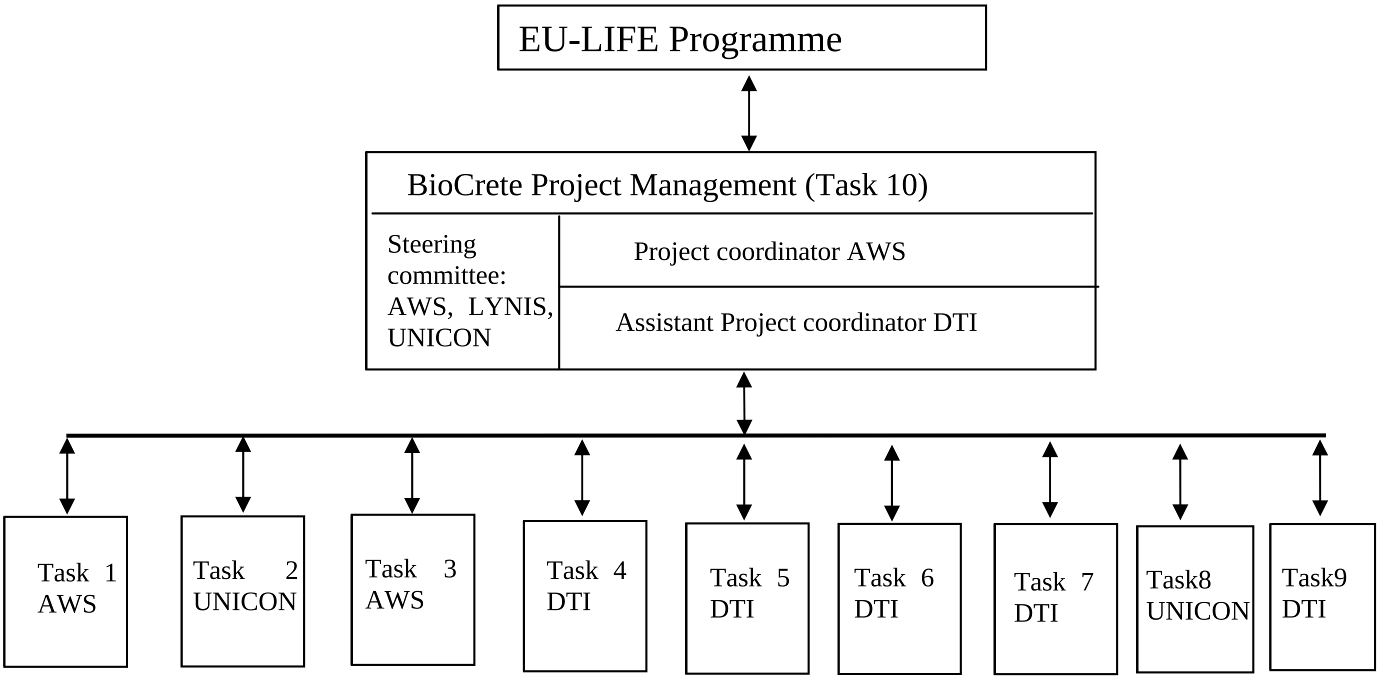
It turned out that the milled LYNIS bio ash has bio ash concrete properties very similar to the AWS bio ash. LYNIS has not yet decided whether full scale milling equipment shall be established at the sludge incineration plant.

Task 9: Dissemination programme of results, see chapter 8

The final report for Task 9 summarises dissemination activities and includes a note on “after LIFE communication plan”.

Task 10: Project management, see also chapter 5

A project organisation, as described in the application, was established and maintained throughout the project period, see the figure below.



The figure gives an overview of which organisations held the responsibility for conduct of the individual tasks. A list of contact details for the key-persons in the participating organisations are included in Appendix 1.

The Steering Committee included a representative from each of the partners (AWS, LYNIS and UNICON) with the beneficiary representative as Chairman. Together with the EU-LIFE Programme, the partners provided the funding for the project.

The partners contracted DTI as a consultant to conduct the majority of the investigations; some of the environmental envestigations were sub-contracted from DTI to ECN in the Netherlands.. The project participants (partners + consultant) met regularly – in total 9 meetings were held in the project period. Minutes (in Danish) are available from the meetings. The meeting venues took place on rotation in order to visit the wastewater treatment plants and the laboratories for the bio ash concrete investigations.

For practical reasons all Steering Committee meetings were held in connection to the joint meetings among the project participants. In these cases, the Steering Committee met first in order to clarify any matters of interest for the partners, only, and hereafter the project participants met to discuss the progress of all the tasks. The Steering Committee members had in this way dual functions as the same persons were also representatives in the joint project participant meetings. A major input from the Steering Committee was the preparation of agreements between the partners and DTI and the partners in between, respectively. Both agreements were signed 4 November 2005 and have been submitted to the Commission as appendix to the Mid-term Report.

Progress- and mid-term reports were prepared and submitted to the Commission according to the contract.

8. DISSEMINATION ACTIVITIES AND DELIVERABLES

Activities and Output presented per tasks

A final report has been elaborated for each task (Task 1 – 10), see Appendix 2.

Task 1. The new dry ash outlets at AWS WWTP (see picture on page 10) and Lynetten WWTP were installed early 2006. The two WWTP's have approx. 5000 and 1500 visitors per year, respectively.

Task 2. The handling facilities at UNICON, Ejby concrete production plant were finalized mid 2006. Approx. 100 visitors per year.

Task 3. The "Memo: Composition of European bio ashes" (Appendix 1 in Final report for Task 3) has been sent December 2007 with thanks to the 10 'active' European contributors to the data in the memo. The implications of substituting the iron by aluminium are discussed in the Final report for Task 3, and were also presented by Dan Kjersgaard at the conference in Canada.

Task 4. The documentation, including the variation of bio ash properties is presented in the Final report for Task 4, and was also presented by Claus Pade at the conference in Norway. A memo concerning "Quality controls parameters of bio ash – property limits" has been integrated into the Guideline – Handbook (Task 9) and can also be downloaded as a separate document from the website www.biocrete.dk under Task 4.

Task 5. The leachability of heavy metals from bio ash concrete is presented in the Final report for Task 5 , and preliminary results on similar specimens were presented by Jørn Bødker at the conference in Switzerland.

Task 6 - 8. The documentation is available in the corresponding task reports in appendix 2. Further dissemination of the results will be along with the completed project.

Task 9. The list of dissemination activities is shown in Appendix 5.1 and one of the conference papers (Moncton, Canada) is included as Appendix 5.2.

With reference to the dissemination activities foreseen in the proposal for this task and as commented by Monitoring Team, the status is:

- preparation of a guideline on implementation and use of bio ash concrete: reported as deliverable in English and Danish; see Appendix 4.1 and 4.2.

- publication of the guideline in English and in Danish at a project website: same documents as above

- distribution of hard copies of the Handbook / guideline to all Danish municipalities and to other relevant parties of the Danish building and construction sector: this will be limited to the municipalities in the greater Copenhagen area and not the whole country due to the location of WWTPs with sludge incineration, and to associations representing the Danish building and construction sector shortly after submission to the Commission.

- preparation and presentation of documents to CEN/TC 104 "Concrete and Related Products": during 2008, it will be evaluated how it is advisable and possible to revise relevant concrete standards based on the project results, e.g., DS 2426, DS/EN 206-1 and contact to the standard committee CEN/TC 104 “ Concrete and Related Products”. This is in accordance with the Task 9 description and part of the After-LIFE dissemination plan.

- advising of the municipals affiliated to both LYNIS and AWS on how to update their instruction on tenders for construction of new building: this is included in the Handbook / Guideline and the municipalities affliliated to both LYNIS and AWS,are all in the Greater Copenhagen area.

- publication of articles in Danish as well as in English international journals and trade journals: 3 papers have been published in Danish journals and 3 presentations were given at international conferences, see appendix to Final Task 9 report also presented as Appendix 5.1 to this Final Technical Report. The presentations given at conferences and seminars can be downloaded from the website..

- conduction of a kick-off seminar for stakeholders and potential end-users bio ash and bio ash concrete: this was conducted at DTI 5 October 2006 with 3 papers being presented.

- presentation of the project at the meeting in the European Ready Mixed Concrete Organisation: folders of the BioCrete Project were on display

- launching of the project website: the website www.biocrete.dk was launched early 2006 from which a general description is given and documentation from Task reports and separate appendix documents can be downloaded. The website is updated by DTI.

In addition to this, an early presentation of the BioCrete was given at the EU-LIFE seminar on 13 October 2005 as part of a crosscutting event with presentation of newly granted LIFE projects in Denmark.

"From ash to concrete". A poster on the LIFE BioCrete project and a small 'bridge' of bio ash concrete slabs at the AWS exhibition hall. 080117.

9. EVALUATION AND CONCLUSIONS

9.1 Project Implementation

Management

The project management has gained from a good continuity for most of the key persons in the project and a structure, which was maintained throughout the project period. Regular meetings with written minutes and follow-up actions have contributed to the project coherence and transparency. The facility "Monitoring Team" has functioned well at the advisory level on how to manage a number of questions arising during the project period.

Partnership agreements had been prepared in advance of the project application and were signed 4 November 2005 shortly after the project approval by the Commission . Copies of the agreements have been submitted to the Commission as appendix to the Mid-term report. No disputes have occurred between the partners.

The problems encountered have mainly been of a technical character, which has led to the need of adjustment of the timing of the activities. A major technical problem encountered was the finding that the bio ash from the multiple hearth incinerator at Lynetten WWTP was not feasible for the concrete production due to the grain structure. With respect to the project, this was managed by laboratory scale pre-treatment by milling in order to enable the testing of concrete characteristics according to the contract. However, the full-scale application for this type of bio ash could not be conducted.

The partnership between two wastewater utilities and a concrete producing company in combination with a specialist institution on a consultant basis brought the very different worlds of wastewater treatment and concrete production together. This partnering and the close cooperation gave added value in terms of getting an insight and understanding of the conditions of operating within these two worlds.

Technical and commercial application

The technical and commercial applications are likely to be directly transferable to other European countries. The results of the survey included in Task 3 show a quite uniform and consistent chemical composition of bio ashes form incineration of sludge at urban wastewater treatment plantswith one heavy metal (Mercury, Hg) as an exception. Still, tests on a local bio ash are needed for evaluating the feasibility for concrete production.

The economical feasibility will for transport conditions be locally depending on the distance between incinerator and concrete producing facility. In this project, the transport was kept within 25 km. If land filling is the alternative for disposal of the ash and if green taxes apply, such as in Denmark, the saving of these costs can make the use in concrete economic feasible.

The approvals by environmental authorities as well as product standardisation organisations are limiting factors for future continuous application. However, the tests conducted in the project show very limited environmental impact. Despite some increased heavy metal concentrations in bio ash in comparison to cement and fly ash, no significant difference in the quality of test leachates could be observed. The major limiting factors are believed to be the colouring aspect, which may be relevant for some visible structures, as well as the market conditions for the various classes of concrete.

Comparison against the project-objectives

The objective of the project to remove technical barriers for the utilisation of bio ash in the production of concrete, and at the same time to reduce the amount of waste disposal has been met.

Five barriers were identified.

• <u>Lack of documentation of the environmental impact in particular with respect to leaching of heavy metals from the bio ash concrete</u>. This documentation has been provided (Task 5) by conducting leaching tests according to a standardised European method supplied with other tests and comparisons with reference concrete without bio ash. The overall conclusion is that the use of bio ash for concrete production has very limited environmental impact.

• Lack of documentation of the technical properties of the bio ash. This documentation has been provided (Task 4) by comprehensive investigations of different bio ashes for chemical composition, physical proporties and morphology. The bio ashes can only be expected to have minor pozzolanic effect if used as a cement replacement in concrete. In the long term, the bio ashes are not expected to have specific negative effects on the durability of concrete but in the short term, the workability might be negatively affected.
• Lack of documentation of the properties of fresh and hardened bio ash concrete. This documentation has been provided (Task 6, 7 and 8) covering both comprehensive laboratory investigations as well as practical experiences from full-scale implementation. The bio ash from fluidised bed oven is considered acceptable for direct use in bio ash concrete, whereas bio ash from multiple hearth furnace requires pretreatment by milling.
• Need for a structured dissemination of existing know-how on bio ash concrete. By conducting this demonstration project, a significant step forward has been taken in terms of dissemination of know-how on bio ash concrete. Several dissemination activities (Task 9) have been conducted within the project period and the current final reporting also provides valuable information for both stakeholders at WWTPs with sludge incineration, at concrete producers and for regulatory authorities.
• Ash handling facilities at the bio ash plants as well as the concrete plants to accommodate the bio ash in a dry form. These were established at full scale (Task 1 and 2) and the equipment has worked satisfactorily after some initial modifications.

On this basis, the project-objectives are considered as being met

Dissemination activities

In addition to a kick-off seminar October 2006 in Denmark, the project has been presented at 4 conferences (Switzerland, Spain, Canada and Norway, plus 1 more already scheduled for June 2008 in Sweden), 3 articles have been prepared and in addition to this distribution of folders at seminars, introduction given at courses, a display at the AWS exhibition facilities, which annually receives about 5,000 visitors, and finally a project website: www.biocrete.dk which in 2007 has received 58 external hits in Danish and 72 external hits in English.

In particular the conference presentations have led to some follow-up communications with other end-users having an interest in reuse of bio ash.

The future

The reuse of AWS bio ash for concrete production is expected to continue and hopefully increase to 100 %. However, investigations of alternative means of reuse will also be conducted in case the market situation results in less demand for bio ash in concrete.

The present standard approving the use of bio ash in concrete as well as the permit from the local environmental authorities for reuse of the bio ash in concrete production are temporary documents. It is expected that the documentation provided from this project will answer the open questions. The renewal of the permits from the environmental authorities as well as the confirmation of the use of bio ash in concrete production standards is in progress.

The binding and immobilisation of phosphorus (P) into the concrete matrix is an issue, which is debated in the technical-scientific community. P is considered a limited resource at the global level. Already today, there are techniques available for recovery of P from sludge or bio ash, however, only implemented to a limited extent with the current low prices on recovered P-product. Since the P-content in bio ash is not considered a benefit, a possible future increase in P-recovery is not expected to cause a problem for the use of bio ash in concrete.

The reuse of LYNIS bio ash in concrete will not begin in the near future. A change of the type of incinerator is under consideration, so in this period no investments in e.g. milling equipment will be made. In case a new fluidised bed incinerator will be installed, reuse in concrete production will again be an option.

9.2 Analysis of long-term benefits

Environmental benefits

Based on the investigations prior to this project, a certain contribution with a pozzolanic effect from the bio ash was expected and thereby an ability to replace some of the cement for concrete production. Such an effect could not be demonstrated and there will not be a saving in the resources for the production of cement.

Concerning heavy metals leaching from bio ash concrete – even after crushing of the concrete simulating the life circle of the produced concrete – the environmental impact is considered neutral as there is no significant difference compared to reference concrete without bio ash.

Seen as a resource, the bio ash does contribute positively since fly ash and other ingredients commonly used in concrete production are becoming scarce. Bio ash is therefore a very useful material for the concrete producing industry.

The most common practice of disposing bio ash from incinerators at WWTPs is by land filling. This takes place in accordance with the EU Directive 99/31/EF of 26/04/1999, in Denmark implemented by order no. 650 of 29/06/2001. With a reuse of the bio ash, this will extend the lifetime of existing landfill sites bio ash and prolong the time needed for establishing new ones. This is considered a significant benefit, as establishing new landfills is both costly and often troublesome due to public resistance against this type of land use.

Long-term sustainability

The prevention from land filling is a significant benefit for the wastewater utilities. Seen in a context of environmental accounting, e.g., by the so-called EDIP method, the impact parameter “slag and ashes” will be reduced from about 3 % to zero of the average person entire load for this parameter. This is considered a significant benefit.

Producing bio ash concrete has the consequence that the phosphorus in the bio ash will not be available for (future) recovery. This can be considered to be a problem.

Bio ash can replace some of the fly ash and/or filler material in concrete mix designs, thus inducing some possible cost savings. For the time being, UNICON has not tried to quantify this saving.

In countries where the land filling of bio ash is subject to green taxation, there is a direct saving by reuse. In Denmark, this tax is currently 375 DKK (about 50 €) per ton. In countries with a similar taxation, this is considered a major economic driver.

The impact on social benefits is considered marginal. One issue could be that it is more encouraging to recover bio ash as a product for further environmental safe use in society than to put it into a landfill with no beneficial use.

The decision from the WWTP owners whether Al-based precipitants will be used for phosphorous removal instead of Fe-based precipitants is expected to be taken for other reasons than reducing the colour impact on the bio ash concrete. The Al-based bio ash will reduce the colour problem, however, depending on the local market price of the chemicals (precipitants) this may not be cost-effective. Al-based precipitants are used at several WWTPs throughout Europe already for other reasons, such as control of certain microorganisms in activated sludge, however, the sustainability of Al- versus Fe-based precipitants can also be a subject for discussion due to normally more energy-intensive production of Al-products.

At present, the bio ash concrete is only used at large scale in the lower concrete classes, however, has a potential for uses in higher classes, which will expand the market. It is, however, a consideration for the concrete producers whether this step will be taken as the necessary product standardisation procedures is time and resource demanding.

Replicability, transferability

A high replicability is expected due to the relative uniform character of bio ash from urban WWTPs across Europe. This project demonstrates the reuse in concrete and provides a substantial documentation by a high number of both technical tests of concrete quality as well as environmental impacts by well-established leaching tests. This can be of direct use by other utilities and concrete producers in order to replicate this technology. Still, it is advised to make new tests with the specific bio ash in question and the specific concrete production plant.

Some interest to the project has been shown from similar WWTPs in Europe with sludge incineration, which appears from the willingness to contribute to the questionnaire survey on chemical composition of bio ashes (part of Task 4) and from e-mail correspondence with the Project Coordinator. A follow-up contact will be taken to this network in order to make the results from the BioCrete project available.

Innovation

The reuse of bio ash in concrete production is considered a novel practice, however, not an invention applicable for patenting. The project has demonstrated that use of the bio ash as an ingredient is possible and feasible and only requires addition to the existing recipes for the concrete. The remaining process technology for concrete production has not been changed.

At the organisational level, a co-operation is required between the wastewater utilities and the concrete producer. A new aspect of such a co-operation is the change of roles that the utilities become a supplier instead of an end-user and vice-versa for the concrete producer. This is not considered as a problem and only adds a new development to the Public-Private-Partnership concept.

Innovation in sludge incineration technology, such as using pyrolysis technology, may lead to other characteristics of the bio ash due to higher process temperatures. Probably, this may bring the characteristics closer to fly ash and thereby stimulate pozzolanic behaviour. Sludge pyrolysis is currently being investigated within the ongoing EU-FP6 project NEPTUNE (www.eu-neptune.org) and a contact to this project is already existing.

10. AFTER-LIFE COMMUNICATION PLAN

The BioCrete web-site (www.biocrete.dk), from which the project key deliverables will be available is a major dissemination platform.

The handbook “Guideline for use of bio ash concrete” (in English and in Danish) will be the basis for future dissemination in general. The technical final report (with the exception of Chapter 11) will also be disseminated to stakeholders with a specialist background. Here, the contacts established during the survey of the composition of ashes in other European countries will be used as a network.

Direct attention to the BioCrete project results will be made by direct contacts to the municipalities in the Greater Copenhagen area with a hard-copy of the handbook and link to the web-site.

Papers and articles: Relevant national and international conferences and journals will be considered for presentation of the project results. An article for the Danish specialist journal “Dansk Beton”, is planned to be published in the spring 2008. Further the paper "The use of sludge incinerator ash in the production of concrete" will be presented at “XXth Symposium on Nordic Concrete Research and Development” organised by Nordic Concrete Research in Bålsta Sweden, 2008-06-08.

Revision of standards: During 2008 it will be evaluated how it is advisable and possible to revise relevant concrete standards based on the project results, e.g. DS 2426, DS/EN 206-1 and contact to the standardisation committee CEN/TC 104 “Concrete and Related Products”.

Future studies: At the present time the experiences from the project are used to investigate the use of bio ash in earth moist (or zero slump) concrete for concrete goods.

The website will be updated by DTI on a regular basis.

11. APPENDICES

Appendix 1	“Data for participants and key persons”
Appendix 2	Appendices with a Final Report for each Task (Task 1 – 10): Appendix 2.1 to Appendix 2.10
Appendix 3	“Material Safety Data Sheet” for AWS red bio ash (in Danish)
Appendix 4	“Bio ash in concrete – a guideline”. In English (Appendix 4.1) and in Danish (Appendix 4.2)
Appendix 5.1	“List of dissemination activities”
Appendix 5.2	The paper “The reuse of bio ash for the production of concrete. A Danish case study”, presented by Dan Kjersgaard at the IWA Specialist Conference on Wastewater Biosolids, Moncton, New Brunswick, Canada. 24-27 June 2007.
Appendix 6	“Layman’s Report” In English (Appendix 6.1) and in Danish (Appendix 6.2)

12. LAYMAN’S REPORT; SEE APPENDIX 6.1 AND 6.2