D2.23 KPIs Eco-Cement Project

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SUMMARY

About 5% of global carbon dioxide emissions originate from the manufacture of cement and industrial waste is now a global concern causing environmental harm. Solutions to both these problems are being researched: one solution is Eco-Cement, which will use valuable 'waste' resources from industry and sequester carbon dioxide as part of its production process. The main objective of the Eco-Cement project is to develop a biomimetic technology for enzyme based microbial carbon precipitation through the reuse of industrial waste in order to produce an eco-cement, which has minimal negative impacts to the environment.

Eco-Cement has the potential to replace Ordinary Portland Cement (OPC), in certain markets, as an environmentally sustainable cement. Besides lower CO2 emissions, Eco-Cement also has the potential to be a more cost efficient cement as a result of having lower production costs and fewer costly waste streams to dispose of.

To ensure that these potentials are reached to their fullest ability, key performance indicators (KPIs) are defined and measured. Environmental and energy KPIs will be used in the life cycle assessment (LCA) performed in Work Package 5 (WP5), in which the environmental impact of the Eco-Cement process will be compared to OPC. Energy KPIs will also be of use in WP6, where they will impact on running costs of novel Eco-Cement plants. Economic KPIs will be used in WP6 to evaluate the most suitable markets for Eco-Cement. Performance KPIs will be used in WP3 and WP4 to refine each aspect of the Eco-Cement process in order to achieve the most effective and efficient process possible, both in terms of the biomimetic process to produce Eco-Cement and of the mechanical properties of concrete made from Eco-Cement.

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ACRONYMS

CKD Cement Kiln Dust

GGBS Ground granulated blast-furnace slag

KPI Key Performance Indicator

kWh Kilowatt hour

LCA Life Cycle Assessment/Analysis

MFA Material Flow Analysis

MJ Megajoule (million joules)

OPC Ordinary Portland Cement

WP Work Package

1. INTRODUCTION

A great deal of environmental problems are caused by civilisation viewing processes as inherently linear, and any heterogeneous side products as waste, even if they contain valuable materials. Most processes and activities are considered only in terms of inputs and wastes, with only single desired outputs being defined. Little or no consideration is given to the possibility that one process's “waste” is another's input. **'Systems thinking'** attempts to consider these possibilities, however, by trying to take account of all possible connections and impacts of inputs and outputs in order to close all 'linear' processes into cyclic systems with no waste streams.

EU policies are directed at reducing the negative environment impact of human to sustainable levels. The objective of the Eco-Cement project is to produce a biocement with comparable strength to OPC, using wastes from the cement and food industry, lower production costs and no negative environmental impacts.

With such a broad range of objectives under the Eco-Cement project (strength, waste use, lower costs and environmental impact) a **'systems-thinking'** approach must be used in the development and analysis of the Eco-Cement process. Industrial 'wastes' will be re-appropriated as inputs for the Eco-Cement process, with the Eco-Cement process itself producing no wastes, merely inputs for other processes.

This may involve, for example, using biological processes to treat water arising from our Eco-Cement process by growing aquatic plants in a bio-reactor, using the biomass in another activity and recycling the cleaned water in the Eco-Cement process. Depending on the quantity of ammonium by-product arising from our process we may have to develop a process for capturing it as crystals, which can be collected and sold to another industry that uses them. This may involve de-watering and drying an ammonium salt solution using waste heat from the OPC plant.

1.1 Systems Thinking

Rather than tradition methods of analysis, which look at 'things' in isolation with a view to breaking them down into their constituent parts in order to understand them, systems thinking focuses on how that ‘thing’ interacts with the constituent parts of the system of which it is a part. This is described as the process of viewing systems in a holistic manner understanding how things influence one another within a whole.[1] Professor Jay Forrester is credited with developing this concept at MIT in 1956[2].

Rather than react to a problem in a system with an isolated, specialised solution (that may itself cause more unintended consequences), system thinking would evaluate the entire system in order to eliminate the problem from occurring in the first place.

1 http://en.wikipedia.org/wiki/Systems_thinking [Last Accessed 2013_3_29]
2 http://www.thinking.net/Systems_Thinking/Intro_to_ST/intro_to_st.html [Last Accessed 2013_3_29]

1.2 Applied Systems Thinking

A number of approaches and frameworks have been developed for applying the ideas of systems thinking to man-made processes :

Cradle to cradle[3]: Is an approach which aims to mimic natures processes, viewing materials as nutrients circulating in healthy safe metabolisms that don't produce waste.

The Natural Step[4]: (developed in Sweden in 1989) sets out system conditions for sustainability under four conditions derived from the first two laws of thermodynamics, as these set the limiting conditions for life on earth. These laws are that all matter that will ever exist is here now and that disorder increases in closed systems. As the earth is a closed system with respect to matter, the overall aim of **The Natural Step** is to eliminate the destruction of nature and the build up of mined substances and chemicals.

Industrial Ecology[5]: is a scientific framework for understanding industrial systems through the flow of energy and materials at different levels. **Industrial Ecology** is multidisciplinary, with aspects from engineering, economics, sociology, toxicology and the natural sciences encompassed.

Industrial Symbiosis[6]: is part of the field of **Industrial Ecology** and it involves the collaboration of traditionally distinct industries in order to achieve a competitive advantage thanks to physical exchange of materials, energies and wastes.

1.3 Measuring Sustainability.

There are a number of tools available to frameworks seeking to achieve sustainability. These tools measure and assess different aspects of systems.

Material Flow Analysis, **MFA**, (also known as Substance Flow Analysis) investigate physical-equilibrium-based energy and material flows. The underlying principles of **MFA** are mass balance and systems thinking, which combine to give the full picture of the different inputs, uses and outputs of a given material or energy through interconnecting systems over a given time. [7]

Life Cycle Assessment/Analysis (**LCA**) also examines material flows based on mass balance ans systems thinking, however focus is put on the potential environmental impacts of single products or processes, rather than mapping the flow of a material or energy through interconnecting systems. [8]

LCA does not, however, offer definitive answers in its assessments of a process or product. This is because while a LCA focuses on one product or process, that product or process may be made up of many others. LCAs need to have well defined and realistic impact categories, in

[3] http://mbdc.com/ [Last Accessed 2012_03_29]
[4] http://en.wikipedia.org/wiki/The_Natural_Step [Last Accessed 2012_03_29]
[5] http://en.wikipedia.org/wiki/Industrial_Ecology [Last Accessed 2012_03_29]
[6] http://www.eoearth.org/article/industrial_symbiosis [Accessed 2013_03_29]
[7] Ayers, Robert and Leslie. 2002. The Handbook of Industrial Ecology. Edward Elgar publishing ltd.
[8] Ayers, Robert and Leslie. 2002. The Handbook of Industrial Ecology. Edward Elgar publishing ltd.

order to take account of the possible positive and negative side effects of sub processes and products. Interpretation also involves assessing the completeness and consistency of data elements used and the sensitivity of the data to possible changes, all in terms of the initial scope and method of study.

In order to ensure that data is relevant in LCA, and systems thinking in general, Key Performance Indicators (KPI) must be defined. KPIs are crucial, measurable variables in projects whose interpretation define the outcome of the project. They are the values that are make up and determine impact categories in LCA. They will be discussed in the following section.

1.4 Deliverable 2.23 Key Performance Indicators

The purpose of this deliverable is the identification of the key performance indicators that will be used in future work packages, to verify the results of the technologies that will be applied.

The objective of the Key Performance Indicators (KPIs) is to control and maximize the Eco-Cement efficiency in the whole industrial process. KPIs should be clearly linked to the strategy, i.e.; the things that matter the most. The KPIs allow tracking progress and gaining relevant insights to help manage and improve performance. They should be primarily designed to empower employees and provide them with the relevant information to learn. This in turn should improve the decision making process and lead to improve performance. These measures are used to set goals or rules, to objectively access the achievement of these goals, and to provide feedback on any unwanted variance between achievements and goals. Individual KPIs must be specific enough to give useful and insightful data about the project, but the KPIs as a whole should be broad enough that all relevant, and interconnecting, aspects of the project are monitored.

KPIs for the Eco-Cement project can be broken down into four categories.

1) <u>**Environmental KPIs**</u>

Environmental KPIs indicate the environmental impacts of the Eco-Cement process. This includes the emissions of gases, heavy metals and non metals but will also need to take into account the emission of waste water. Environmental KPIs also monitor the degree of waste recycling involved in the Eco-Cement process. These KPIs can be measured against industrial values for ordinary Portland cement (OPC). These KPIs will be determined in WP3 and WP4 and will be used the life cycle assessment (LCA) performed in WP5 and will ultimately be the measure of the environmental sustainability of Eco-Cement over OPC. It is expected that emission KPI values for the Eco-Cement process will be significantly lower than those for the OPC process, while the recycling KPI values will be at least as high as those for the OPC process. Our objective is no negative environmental impact from the Eco-Cement process.

2) <u>**Energy KPIs**</u>

Energy KPIs indicate electrical and fuel energy use from the Eco-Cement process, against those of the OPC industry. Energy KPIs for the Eco-Cement process will be determined in the LCA in WP5, as they impact on the environmental KPIs, and will be used in WP6 and WP7, as values promotable in marketing strategies, as they impact on the running costs of cement plants. It is expected that energy KPI values for the Eco-Cement process will be significantly lower than those for the OPC process, especially the values describing fuel use.

3) **Process and Performance KPIs**

Process and Performance KPIs indicate the efficiency of the biomimetic process and the physical properties of the Eco-Cement based concrete. Process KPIs will not have industrial equivalents as there is no current biomimetic industrial process to measure them against. The values for these KPIs will be determined on an ongoing basis in WP3, with changes to the process being implemented as values are determined, in order to make the Eco-Cement process as efficient as possible. Performance KPIs will be measured against standard performance ranges of OPC based concrete. Values for performance KPIs will be determined in WP3 and WP4.

In general, the values for the process and performance KPIs are expected to be as high as possible. The exceptions are the KPIs **5.1.6**, Additives/Eco-Cement [kg/kg], and **5.2.4**, Time to Cure to Final Strength. The value of KPI **5.1.6** is expected to be as low as possible, indicating little or no need for costly additives to improve the properties of the Eco-Cement. The value of KPI **5.2.4** is expected to similar to the industrial value for OPC, indicating that Eco-Cement has similar workability to OPC.

4) **Economic KPIs**

Economic KPIs indicate the financial aspects of the Eco-Cement process against those of the OPC industry. Production cost and capability, as well as investment requirements will be determined. These KPIs will determined in WP6 and will be used in both WP6 and WP7 as promotable measures of the economic benefits and limits of the Eco-Cement process. It is expected that economic KPI values for the Eco-Cement process will be significantly lower than those for the OPC process, as cheap wastes and far less energy intensive processes are used.

While the most relevant work packages have been pointed out in the above descriptions, in truth all the KPIs impact on all the work packages. Economic KPI values can impact on WP3 and WP4, calling for less expensive, but possibly less well performing materials to be used for marketability reasons. Environmental and energy KPI values may be in balance with process and performance KPI values, as improved performance may come at the expense of more energy or more emissions. All the KPIs impact in some way on WP6 and WP7, with better KPI values resulting in more inherent marketability of the Eco-Cement. Ultimately, no KPI value can be evaluated, or improved, in isolation from any other.

2. ECO-CEMENT PERFORMANCE INDICATORS: ENVIRONMENTAL

2.1 CO_2 Emissions

The primary environmental indicator considered will be the CO_2 emissions per unit of cement. The environmental KPIs of the Eco-Cement process will be given values during the LCA performed in WP5.

These can be split into two types:

2.1.1 Tonne CO_2 / Tonne cement

This is the total amount of CO_2 (in tonnes) per tonne of cement produced. This includes all aspects of cement production (raw material extraction, transport, processing) up to the “gate”. Industrial averages vary for OPC, based on the processing method used.
Methods range from the wet process, which supplies “wet” material to the kiln requiring a lot of excess heat energy to bring achieve calcination temperature, to the “dry with preheater and precalciner” process, which through heat recycling and pre-processing reduces the overall energy and CO_2 cost. The values for the tonne CO2 / tonne cement for each of these processes will be used for sensitivity analysis in the LCA performed in WP5.

The overall industrial average for OPC is **0.67 Tonnes CO_2 / Tonne Cement** [9]

2.1.2 Tonne CO_2 / Tonne Processed Material

This is the total CO_2 emissions of the processing stage only.
For Eco-Cement, this will be the emissions associated with the production and pre-processing of (non-recycled ?) raw materials, such as the urea, protein and Ca^{2+} source .
For OPC, this will be the CO_2 emissions from clinker production only

The overall industrial average for OPC clinker is **0.858 Tonnes CO_2 / Tonne Clinker** [10]

2.2 Contaminants

Cement can contain contaminants arising from the additives and fuels used during production. Two types will be considered, heavy metals and organic compounds.

[9] Calculated from the values for absolute cement production (report 311b) and gross CO_2 production (report 312a) in 2010, reported on the GNR website: http://www.wbcsdcement.org/GNR-2010/index.html [Last accessed 2013_3_26]
[10] Weighted average gross CO2 (excluding CO2 from electric power) emission per tonne clinker in each region in 2010 reported on the GNR website (report 321): http://www.wbcsdcement.org/GNR-2010/index.html [Last accessed 2013_3_26]

2.2.1 Heavy Metals

This is amount of heavy metals produced as by-product in cement production.
This cannot be expressed as a percentage of cement, as any percentage will be very low and multiple metals may be present in different amounts. In addition, a percentage will not be a clear representation of where in the cement process the metals arise, if they are released as waste or bound in set cement, or if they can have a measurable effect on the environment.
Eco-Cement may use industrial wastes that contain heavy metals as toxic by-products of the original industrial process.
OPC production can result in the presence of heavy metals such as nickel, zinc, lead, aluminium, copper, chromium and others, with the amounts varying greatly, according to factors such as fuel type used and limestone purity. [11]

2.2.2 Non-Metals

This is amount of non-metal contaminants produced as by-product in cement production. As with **2.2.1**, Heavy Metal Contaminants, this cannot be usefully expressed as percentages.
Cement production can result in non-metal contaminants such as ammonia, polycyclic aromatic hydrocarbons (PAHs), halogens, cyanide, volatile aromatic hydrocarbons and others. As with heavy metal contamination, **2.2.1**, the amounts of non-metal contaminations can vary greatly according to fuel used, purity of limestone and other factors[11]

2.3 Waste Water

This is the volume of contaminated waste water produced by the cement process, per tonne of cement. Most water used during the OPC process is lost by evaporation during the heating stages and therefore is not considered contaminated. However significant amounts of contaminated water can arise during the quarrying of limestone. Waste water values are under reported for OPC, however some sources put average waste water emissions from OPC at **702 litres per tonne of cement.** [12]

2.4 Waste recycling

The amount of waste recycled will be evaluated under two headings, according to their use as either fuel or additives to improve properties of the cement.

[11] Achternbosch, M. *et al*. "Heavy Metals in cement and concrete resulting from the co-inceration of wastes in cement kilns with regard to the legitimacy of waste utilisation", Umwelt Bundes Amt, 2003.
[12] Marceau, M. I. *et al*, "Life Cycle Inventory of Portland Cement Manufacture", Portland Cement Association, 2006, table 25a, pg 28. Storm run off (from the plant) is omitted.

2.4.1 Waste used as Process Fuel

This is the percentage of thermal energy obtained from waste material.
The cement industry currently uses fossil fuels, fossil waste fuels and biomass fuels in the following percentages:

	Fossil Fuel	Fossil Waste* Fuel	Biomass** Fuel
%	87.7	2.9	9.4

Table 2.1 Percentage distribution of fuels used in cement manufacture.[13]

* Waste Tyres etc.

** Bioethanol etc.

2.4.2 Waste used as Additives

This is the percentage, by weight, of waste used as additives in the cement process.
Eco-Cement aims to use waste streams as sources of urea, protein and calcium ions.
OPC can make use of recycled cement kiln dust (CKD), Ground-granulated blast-furnace slag (GGBS) and other wastes to reduce the proportion of clinker in the final cement mix. OPC can use from 0 – 95% waste material in blends. [14]

[13] Calculated from the values for thermal energy consumption by fuel type in 2010 (report 319), reported on the GNR website: http://www.wbcsdcement.org/GNR-2010/index.html [Last accessed 2013_3_26]
[14] Moya, J. *et al*. “Energy Efficiency and CO2 Emissions- Prospective Scenarios for the Cement Industry”, JRC Scientific Reports, 2010, pg 37

3. ECO-CEMENT PERFORMANCE INDICATORS: ENERGY

Energy usage indicators can be split into two types, electrical and fuel, but total energy use will also be considered.

3.1 Total kWh / Tonne cement

This is the total amount of electrical energy in kilowatt hours, kWh, per tonne of cement produced. This includes all aspects of cement production (raw material extraction, transport, processing) up to the "gate", as well as the energy from burning fuels.
Industrial averages vary for OPC based on the processing method used. As with **2.1.1**, CO2 tonne / Tonne Cement, the minimum and maximum values will be used for sensitivity analysis in the LCA performed in WP5.

The overall industrial average for OPC is **859 kWh / Tonne Cement** [15]

3.2 kWh / Tonne cement

This is the total amount of electrical energy in kilowatt hours, kWh, per tonne of cement produced. This includes all aspects of cement production (raw material extraction, transport, processing) up to the "gate", but does not include the energy from burning fuels.

The overall industrial average for OPC is **108 kWh / Tonne Cement** [16]

3.3 MJ / Tonne Processed Material

This is the total amount of fuel energy in megajoules, MJ, used in the processing stages only.
For Eco-Cement, this will be the energy used during the production and pre-processing of raw materials, such as the urea, protein and Ca^{2+} source.
For OPC, this will be the energy used in clinker production only and can vary widely as the wet process requires more fuel, for directly heating wet raw material to calcination temperature, than the more energy efficient dry process, which recycles heat onto dry raw material.

The overall industrial average for OPC clinker is **3580 MJ / Tonne Clinker** [17]

[15] Thermal energy consumption from fuels per tonne clinker (report 319), divided by clinker-to-cement ratio (report 3213), plus weighted average electric energy consumption per tonne cement (report 3212), reported on the GNR website: http://www.wbcsdcement.org/GNR-2010/index.html [Last accessed 2013_3_27]
[16] Weighted average electric energy consumption per tonne cement in each region over time in 2010 reported on the GNR website (report 3212): http://www.wbcsdcement.org/GNR-2010/index.html [Last accessed 2013_3_26]
[17] Thermal energy consumption from fuels (report 319)reported on the GNR website: http://www.wbcsdcement.org/GNR-2010/index.html [Last accessed 2013_3_27]

4. ECO-CEMENT PERFORMANCE INDICATORS: PROCESS

Process KPIs will be used to evaluate and improve each aspect of the Eco-Cement process. These will be measured in WP3.

4.1 g $CaCO_3$ / l

This is the amount in grams, g, of calcite ($CaCO_3$) per litre, l, of Eco-Cement solution (microbe, growth solution, urea, Ca^{2+} source). This is a measure of the efficiency of the overall Eco-Cement process.
It is expected that a minimum of 33g/l will be required to make a cement of similar strength to OPC.

4.2 g $CaCO_3$ / kg Final Packaged Product

This is the amount in grams, g, of calcite ($CaCO_3$) produced per kilogram, kg, of the final packaged product. The finalised production process will impact on this KPI, and this KPI in turn will impact on the cost of the final product. If the final product needs to be sold either very very concentrated to ensure sufficient biomass survives transport, or very dilute to ensure sufficient nutrients accompany the microbe, then the value of this KPI will decrease.
A low value will imply a larger amount of packaged product will be required for a given amount of calcite to be formed.

4.3 Biomass/time production

This is the amount of biomass grown per hour. This is a measure of the effectiveness of the revalorised waste used as growth media (yeast extract, lactose mother liquor etc.).

4.4 Urea/(time*biomass)

This is the rate of urea consumed per unit of biomass. This is a measure of the urease activity of the *S. Pasteurii* microbe under Eco-Cement conditions.

4.5 Ca^{++} /biomass

This is the demand of calcium ions per unit of biomass. This is a measure of the calcite production ability of the microbe.

4.6 Additives/Eco-Cement

This is the amount of additives used per kg of Eco-Cement, to improve physical performance properties, if needed. Possible additives include activated clays, silicates and rice husks.

4.7 Cost saving for the Recommended medium

This is the ratio of the cost of revalorised waste against standard (industrial) medium. This is a measure of the costs saved by using industrial wastes. While this value should be as high as possible, the benefits of using cheap industrial waste will have to be weighed against possible negative effects on environmental, process and physical performance KPIs.

5. ECO-CEMENT PERFORMANCE INDICATORS: PERFORMANCE

These are the KPIs which measure the physical performance of concrete made with Eco-Cement. These KPI's will be measured in WP3, used in planning the industrial trial in WP4 and disseminated as part of WP7 as data for promoting the Eco-Cement product and process.

5.1 Compressive strength

Compressive strength is a standard performance test for concretes. Compressive pressure is applied to concrete cylinders until failure is achieved. Strength is measured in N/mm^2 and is measured as the concrete cures, usually after 3, 7 and 28 days.
OPC concretes can have compressive strengths from from 14 to over 120 N/mm^2.

Average values for of OPC used in residential buildings are **20-35 MPa** [18]

5.2 Tensile Strength

Tensile strength is the maximum stress a material can withstand while being pulled and stretched before failing. Concretes do not have very high tensile strength and usually require reinforcement for applications requiring tensile strength.

Average values for tensile strength of unreinforced OPC are in the range of **2 – 5 MPa** [19]

5.3 Flexural Strength

Flexural strength is the measure of a materials ability to resist failure in bending, and has applications in pavements.

OPC has flexural strengths in the range of **3.9 – 5.1 MPa** [20]

5.4 Time to Cure to OPC Strength

The time to cure to OPC strength is the amount of time it takes cement to reach the equivalent strength of fully cured OPC (35 MPa).

OPC is expected to be fully cured by **28 days**.

[18] http://www.cement.org/tech/faq_strength.asp [Last accessed 2013_3_26]
[19] http://www.engineeringtoolbox.com/concrete-properties-d_1223.html [Last accessed 2013_3_26]
[20] http://www.cement.org/tech/faq_strength.asp [Last accessed 2013_3_26]

5.5 Depth of Cementation

One of the possible applications of the Eco-Cement process is the consolidation of loose sand and soil. For this purpose, a KPI measuring the depth of penetration achieved by a sample of Eco-Cement solution will be needed. This KPI can be measured under different application conditions, such as spray, manual pump and electric pump. According to V. Whiffin's thesis, a cementation depth up to 170mm may be possible. [21]

[21] Whiffin, V. "Microbial CaCO3 Precipitation for the production of Biocement", PhD Thesis, 2004, pg 130.

6. ECO-CEMENT PERFORMANCE INDICATORS: ECONOMICAL

Economic KPIs will measure the economic performance of Eco-Cement and the alternative cements so that comparisons can be made. They will be calculated in WP6 after the Eco-Cement process is finalised in WP3 and WP4.

6.1 Cost

This is the total cost, in euros, to buy one tonne of cement.
The aim of the project is to produce Eco-Cement with a production cost approximately 27% less that of OPC.

The average cost of OPC is **€200 / tonne** [22]

6.2 Tonnes Cement/Year

This the production capacity, of cement, in tonnes per year for a single factory.

The average production capacity of an OPC cement plant is **890,000 Tonnes / Year** [23]

6.3 Investment Costs Per Tonne / Annum

This is the estimated investment cost per annum for one tonne of cement.
Costs can vary according to the total amount of cement produced per annum.

A typical OPC factory producing 1 million tonnes p.a. costs approximately **€170 per Tonne / Annum** [24]

[22] https://www.build4less.ie/product_info.php?products_id=311 [Last accessed 2013_3_26]
[23] Absolute production volume of cement (report 311b) divided by 930 (number of plants included in survey), reported on the GNR website http://wbcsdcement.org/GNR-2010/index.html [Last accessed 2013_3_27]
[24] "Development of State of the Art-Techniques in Cement Manufacturing: Trying to Look Ahead" CSI/ECRA-Technology Papers, Annex II, pg 99

7. LIST OF KPIS AND METRICS

Nº	KPI	METRIC	OPC
Environmental KPIs			
1	Tonne CO2 / Tonne Cement	Tonne/Tonne	0.67 t/t
2	Tonne CO2 / Tonne Processed Material	Tonne/Tonne	0.85 t/t
3	Heavy Metals	micrograms	n/a*
4	Organic Compounds	micrograms	n/a*
5	Waste Water	Litres/Tonne	702 l / t
6	Waste Used as Process Fuel	Percent	12.3%
7	Waste Used as Additives	Percent	0-95%
Energy KPIs			
8	Total kWh / Tonne Cement	KWh/Tonne	859 kWh / t
9	KWh (Electric) / Tonne Cement	KWh/Tonne	108 kWh / t
10	MJ / Tonne Processed Material	MJ/Tonne	3580 MJ / t
Process KPIs			
11	g CaCO3 / l	g/l	n/a*
12	g CaCO3 / kg Final Product	g/kg	n/a*
13	Biomass / Time Production	kg/hour	n/a*
14	Urea/(Time*Biomass)	kg/(hour*kg)	n/a*
15	Ca2+/Biomass	kg/kg	n/a*
16	Additives/Cement	kg/kg	n/a*
17	Cost Saving for the Recommended Medium	€/€	n/a*
Performance KPIs			
18	Compressive Strength	MPa	20-35 MPa
19	Tensile Strength	MPa	2-5 MPa
20	Flexural Strength	MPa	3.9-5.1 MPa
21	Time to Cure to OPC Strength	Days	28 Days
22	Depth of Cementation	mm	n/a*
Economic KPIs			
23	Cost	€/Tonne	€200 / t
24	Tonnes Cement / Year	Tonne/Year	890,000 t / a
25	Investment Cost Per Tonne/Annum	€/Tonne/Year	€170 / t / a

Table 7.1 List of KPIs, Units and corresponding values for OPC.

* No corresponding value for OPC

8. CONCLUSION

The KPIs presented within this document are used across a range of work packages in the Eco-Cement project. Environmental KPIs are what will be determined and assessed in the LCA that will be performed in WP5. Energy KPIs will be also be determined and assessed in the LCA performed in WP5, but they will also be disseminated in WP6 and WP7 as selling points of the Eco-Cement process, along with the performance KPIs. Process KPIs, calculated in WP3 and WP4, will be used to ensure the Eco-Cement process is at its most effective.

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Additives in Cement

- Moya, J. *et al*. "Energy Efficiency and CO2 Emissions- Prospective Scenarios for the Cement Industry", JRC Scientific Reports, 2010, pg 37

Price of Cement:

- https://www.build4less.ie/product_info.php?products_id=311 [Last accessed 2013_3_26]

Investment cost of Cement Plant

- "Development of State of the Art-Techniques in Cement Manufacturing: Trying to Look Ahead" CSI/ECRA-Technology Papers, Annex II, pg 99

Cement Mechanical Properties

- http://www.cement.org/tech/faq_strength.asp [Last accessed 2013_3_26]
- http://www.engineeringtoolbox.com/concrete-properties-d_1223.html [Last accessed 2013_3_26]
- Whiffin, V. "Microbial CaCO3 Precipitation for the production of Biocement", PhD Thesis, 2004, pg 130.

10. ATTACHMENT

6.1 Deliverable review report

Date		Venue	
Reviewer			
Company			

6.2 Technical result of the deliverable

Deliverable covers the topic specified in the title					
Yes		Partly		No	

Technical contents are relevant to ECO-CEMENT and to the WPs					
Yes		Partly		No	

Presented results in the deliverable are of high value					
Yes		Partly		No	

Technical sound of the deliverable					
Good		Regular		Bad	

Described work in the deliverable follows a clear methodology					
Good		Regular		Bad	

Please add your comments on the content and the technical results of the deliverable. Please comment the problems, if any.

Comments:

6.3 Length, structure and presentation of the deliverable

Adequate length of the deliverable					
Good		Regular		Bad	

Deliverable organization is appropriate					
Good		Regular		Bad	

Presentation of the deliverable clear and concise					
Good		Regular		Bad	

Please add your comments on the length, the structure and the presentation.

Comments:

5.4 Rating for the deliverable

Please provide a rating for this deliverable from 5 (excellent) to 1 (very poor): ____

Deliverable is							
Accepted		Accepted with revisions		Rejected unless modified as suggested		Rejected	

Comments: