Baseline Report for the Aggregate and Concrete Industries in Europe

ECO-SERVE Network, Cluster 3: Aggregate and Concrete Production

June 2004

DANISH TECHNOLOGICAL INSTITUTE

ERGO Engineering Geology Ltd.

Franzefoss

The Icelandic Building Research Institute

NCC

SUMMARY AND CONCLUSIONS

This baseline report includes state-of-the art covering ongoing European and national research, as well as the economic, environmental, political and societal issues for optimum management of aggregate resources and production of concrete with limited environmental impact. The report includes input from Cluster 3 members on the current research in their national R&D projects in this field. It will serve as a consensus fundament for identifying future research needs and a link to the next report of this cluster on the Best Available Technology. The report covers aggregate and concrete production, construction and demolition waste, standardisation and future research needs in these sectors.

Aggregates

The aggregate part discusses sustainability in the aggregate production industry in relation to mineral resources. It is concluded that natural sand and gravel resources are being depleted in Europe and the trend is towards using more of crushed and manufactured aggregates as well as recycled material. Conflicts due to land use for quarrying are common all over Europe and the need for long term planning is a pressing social, economical and political issue. The importance of mass balance and need to reduce surplus materials is emphasised and the focus should be on no-waste production in the aggregate industry. The energy consumption for aggregate production is relatively small, compared to the energy consumption for the production of concrete, but the transport of aggregates from quarry to customer has large energy impact and is increasing in general in Europe.

Key figures on aggregate production in Europe are presented and discussed. It is difficult to obtain correct figures due to different terminology and definitions between countries. Nevertheless, the figures show that the average production in Europe in the year 2000 was some 6.9 tonnes per capita, exceeding the amount of all other minerals produced in the EU. Information on where to obtain statistics regarding European aggregate production is also listed in the report. The uneven distribution of resources and the cross-boarder transport of materials is underlined by the fact that annual production figures vary from 2 to 16 tonnes per capita, while the trade balance figures vary from 13 million tonnes net export to 10 million tonnes net import.

A list of recent and on-going research and current practice in the field of aggregate in Europe is presented. The information includes web-links and publications where more detailed information can be obtained.

Concrete

It is generally recognised that concrete production is a complex topic when it comes to sustainability issues, partly because various constituents/materials are involved and partly because sustainable concrete production may be defined in many ways. In this baseline report focus is placed on 3 areas, namely:

1. Reduction of clinker content into cement by means of using supplementary materials or blended cement.
2. Use of waste materials in concrete production as a substitute for natural non-renewable materials.
3. Improved working environment with the introduction of Self-Compacting Concrete (SCC), reducing the noise and vibration impact on the concrete workers.

The basics behind these technologies are described and reference is made to some important recent European R&D projects in these areas.

The broad picture of sustainable concrete production is that item 1 above is being implemented all around Europe, which is mainly a result both of the cement industry being forced to improve their environmental profile and possibly reduce their production costs. Furthermore, there are economical benefits by reducing the cement content in concrete. The change from pure Portland cement to blended cement is clearly reflected in the cement production figures.

The details and use of supplementary materials differ significantly from country to country, depending on national traditions and availability of materials. The concrete traditions in each European country are most often reflected in the national codes and standards in terms of cement types and minimum cement content. With the introduction of European codes and harmonised standards these traditions are getting easier to compare through the National Application Documents. Therefore, it could be expected that experiences obtained in one country could be more easily adopted in other countries in the future since a reference is available.

The second item is somewhat connected to item 1 since some supplementary materials (e.g. fly ash) are waste products from other industries. A more general substitution of main concrete constituents due to reuse of waste water/slurry and reuse of crushed construction and demolition waste is still under development and the implementation across Europe is characterised by the fact that some countries are far ahead while others are still considering.

The implementation of SCC is another issue that is expected to be increasing significantly across Europe. There are still some technical problems that need to be solved before it can be accepted as a well-proven technology. However, its implementation is being secured by the construction industry having a clear incentive of increased productivity as a bonus for improving the working environment. On the other hand, it should be kept in mind that future SCC-design should not compromise other sustainability issues of concrete in the desire of improving construction productivity.

Materials recycling

The issue of recycling concrete – from demolition of buildings or from construction materials surplus – and using recycled aggregates from construction and demolition waste (C&DW) for construction purpose, has been increasingly focused during the last decades. This has been partly from the viewpoint of environmental waste handling, partly as a means of saving natural resources. The resource saving potential is limited, however, as it has been calculated that on a European scale, even a full utilisation of recyclable aggregates will account for maximum 10 % of the annual consumption of aggregates. On a local or National scale – depending on the specific resource availability and waste-handling situation – the impact may be bigger. For this reason a lot of research and practical development in production technology as well as materials utilisation has been undertaken in many European countries, and generally it can be said that this today is more or less a state-of-the-art technology. A main limitation so far has been the lack of standardisation. There is, however, work in hand to have these materials implemented in the European standards for materials and structures, and to make easy-to-use specifications. Several RILEM committees have played a key role in these efforts.

Challenges for future research

The report concludes with a technological foresight for the aggregate and concrete industries, and with a discussion on how the future needs could be met by targeted research.

Being mature industries with a civilisation-long history, these industries will hardly be expected to undertake major leaps in development. Having a great environmental and societal influence, however, these sectors will need to continuously consider new technological options, and any improvement or development will immediately have significant impact on society.

Probably the most urgent needs in the near future will be to comply with increasing requirements and expectations concerning sustainability and environmental profile, relating to e.g. the consumption of resources, emissions and pollution, waste generation, use of energy and public health issues. It is a major challenge to meet these requirements while keeping up a profitable production of some of the most needed and consumed materials in the modern society.

A number of specific research topics are finally summarised under the four headings: (i) concept development, (ii) production technology, (iii) basic materials knowledge, (iv) application technology of materials.

CONTENTS

1 INTRODUCTION

This baseline report is the first deliverable (3.1.1) of Cluster 3 "Aggregate and Concrete Production" of the ECO-SERVE Network. It relates to subtask 3.1 ”Baseline report” according to the Work Plan dated February, 2002.

Following the introduction, three chapters (nos. 2, 3 and 4) are devoted to sustainability issues concerning aggregate and concrete production, and recycling. Finally, the baseline report contains standardisation issues in Chapter 5, recommendations for further research in Chapter 6 and finally a list of references in Chapter 7.

The baseline report is written by the following working group appointed by the principal contractors of Cluster 3 (Table 1.1):

- Torbjörn Muhr, cluster co-ordinator, NCC, Sweden
- Swein Willy Danielsen, Franzefoss Pukk, Norway
- Edda-Lilja Sveinsdottir, IBRI, Iceland
- Børge Johannes Wigum, ERGO, Iceland
- Þorbjörg Hólmgeirsdóttir, ERGO, Iceland
- Dorthe Mathiesen, DTI, Denmark
- Claus V. Nielsen, DTI, Denmark

However, the input and comments received from all the cluster members are greatly acknowledged.

1.1 Background and scope

The ECO-SERVE Network is financed from the European Commission under the 5th Framework Program. Reference is made to www.eco-serve.net. Table 1.1 shows the members of Cluster 3.

Cluster 3 ”Concrete and Aggregate production” is a one out of 4 cluster within the network. Other clusters deal with wastes as secondary fuels and raw materials for cement production, production and application of blended cements, and pavement production and design, respectively (Figure 1.1). Furthermore, ECO-SERVE contains an activity named Task 2 crossing over the clusters in its effort to describe and formulate environmental indicators. Reference is made to the reports produced by the clusters and Task 2.

When establishing the network, it was decided to join the concrete and aggregate industries across Europe into one cluster in an effort to contribute to a reduction in the environmental impact of their activities and to aim at a sustainable development[a] in this combined business sector. Such development should be coupled with industrial demands on improved productivity and societal needs for the development of harmonised technology for durable structures of high quality.

[a] Several definitions of sustainable development exist. The most used being the one of the Brundtland Commission (The World Commission, *Our Common Future*, 1987), reading "a development that meets the need of the present without compromising the ability of future generations to meet their own needs."

Participant		Organisation name	Contact	Abbreviated	Country
Activity Code	No				
REC	3	DTI, Danish Technological Institute	Mathiesen, Dorthe	DTI	DK
IND	6	Franzefoss Pukk AS	Danielsen, Svein Willy	Franzefoss	NO
REC	10	IBRI, Icelandic Building Research Institute	Sveinsdottir, Edda Lilja	IBRI	IS
IND	33	NCC AB - Roads	Muhr, Torbjörn	NCC	SE
IND	19	CTG S.p.A. (Italcement S.p.A./Ciments Francais)	Di Mauro, Giovanni D	CTG	I
HES	23	Universita' degli studi di Roma "La Sapienza"	Bonifazi, Giuseppe	DIC	I
IND	24	EKET - Hellenic Cement Research Center Ltd.	Charoula, Malami	EKET	GR
REC	25	ERGO Engineering Geology Ltd.	Wigum, Boerge Johannes	ERGO	IS
REC	26	SINTEF - The Foundation for Scientific and Industrial Research	Hansen, Einar Aassved	SINTEF	NO
HES	27	National Technical University of Athens	Founti, Maria	NTUA	GR
IND	28	Sandvik Rock Processing AB	Hedvall, Per	Sandvik	SE
IND	29	Umbria Filler S.r.	Marchione, Philipp	Umbria	I
IND	31	Björgun ehf	Kristjansson, Sigurdur	Bjorgun	IS
IND	34	Dragados Obras y Proyectors SA	Pena, Fidel	Dragados	E
REC	35	Consejo Superior de Investigaciones Científicas	Andrade, Carmen	CSIC	E
IND	37	Damiani Costruzioni S.r.l	Potena, Claudia	DC	I
REC	38	Research and Development Center for Concrete Industry	Ambramowicz, Marian	CEBET	PL
HES	40	Luleaa University of Technology	Ronin, Vladimir	LTU	SE
EUA	49	UEPG, The European Aggregates Association	Bida, Jan	UEPG	EU
REC	50	Slovenian National Building and Civil Engineering Institute	Selih, Jana	ZAG	SI
REC	51	NGU, Geological Survey of Norway	Neeb, Peer	NGU	NO
EUA	52	ERMCO, European Ready Mixed Concrete Organisation	Biasioli, Francesco	ERMCO	EU
HES	60	Slovak University of Technology	Bajza, Adolf	STUBA	SK

Table 1.1 Members within cluster 3 (May 2004). The top-four are the principal contractors. REC = research center/institute, IND = industrial partner, HES = higher education institution, EUA = European Association.

The linking of Cluster 3 activities to the rest of the ECO-SERVE network and to the production line of building materials is illustrated in Figure 1.1.

The aggregate and concrete industry is presently facing a growing, public awareness relating to the environmental profile of their activities. With concrete being the most important construction material and with the annual aggregate production being of the order of 10 tonnes per capita throughout Europe, a major part of the environmental impact of the total building industry is related to these materials. The following figures illustrate the current situation of the building sector as to its importance for sustainable development[b]:

- 40 % of the total energy consumption is related to this sector (mainly through operation/heating/cooling).
- The sector uses globally 40 % of all produced materials.
- Approximately 40 % of the CO_2 emission can be related to buildings and constructions.
- Approximately 40 % of the global amount of waste comes from production and demolition of buildings and structures.

[b] Figures from a Nordic project on environmental indicators in the building sector http://www.nordicinnovation.net/article.cfm?id=1-834-251

- The sector uses approximately 40,000-50,000 different products, part of them containing substances harmful to health and safety.

Thus, the construction materials sector will also have to bear a great part of responsibility in fulfilling the OECD described necessity of reducing energy consumption and emission by a factor 4 within the next 10 years.

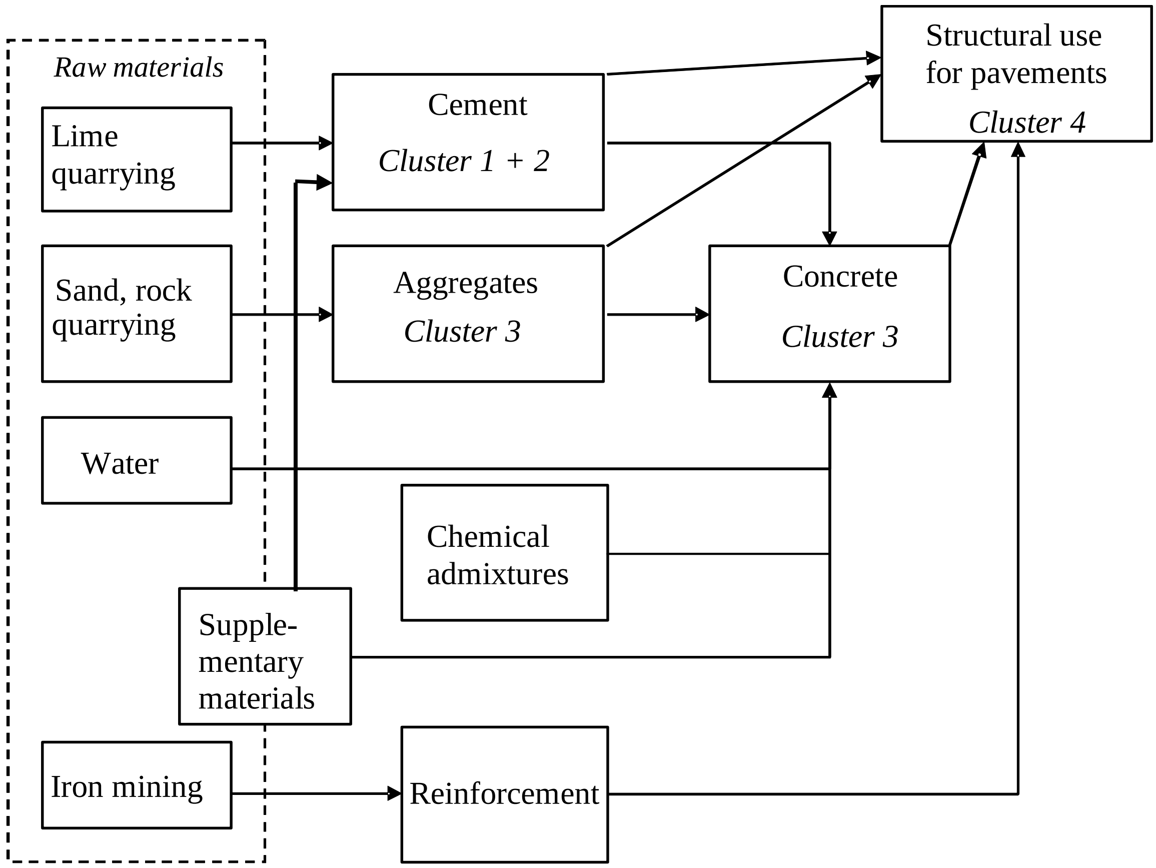

Figure 1.1 Constituents of concrete and its relationship with the ECO-SERVE Network clusters. Pozzolanas may be natural volcanic material or waste products from power plants.

In a recent paper from the EU (COM, 2001[1]) the following statement was made: "The global implementation of sustainable development requires more particularly: the design, development and dissemination of technologies making it possible to *ensure more rational use of natural resources, less waste production and a reduction in the impact of economic activity on the environment."*

In an OECD-report on sustainable development (OECD, 2001[2]) it is stated in a chapter on managing natural resources: "where appropriate, *encourage life-cycle, recycling, and materials-flow approaches to managing natural resources*. Before implementing mandatory recycling, however, ensure that neither total materials and energy flows, nor conditions in the anticipated markets for recycled products, would result in the costs of these programmes exceeding projected benefits."

The quotes given above show that sustainable development will be of major importance in government policies in the coming years and several EU member states have formulated policies aimed at securing environmentally sustainable industries. The ECO-SERVE Network will help to convert these policies into practical applications.

However, it should be noted that the above-mentioned quotes also reflect a holistic approach where the sustainable development should include all aspects throughout the life cycle of a building/construction. Hence, to obtain an overall sustainable construction the knowledge of the environmental impact of various material choices should be connected with the structural design in order to optimise its environmental profile. Sometimes diverging needs are encountered during this process, for instance the wish to make slender walls, saving building materials diverges with the wish to make energy efficient buildings, requiring thick walls.

Due to practical considerations in order to keep the ECO-SERVE project within plausible limits of time and funding, Cluster 3 is limited to deal with the production of aggregates and concrete (Figure 1.1).

The role of Cluster 3 is therefore to consider sustainability issues up to when the material is being implemented in a construction (building, road, bridge), i.e. during the first phase on the time axis below. The issue of reusing construction and demolition waste (C&DW) is also treated in this report since it is an essential aspect when considering sustainability in the aggregate industry. Therefore it could be said that the time axis of Figure 1.2 actually forms a closed loop after demolition due to the fact that a large part of the C&DW may be put back into the aggregate production.

The baseline report is limited to normal weight aggregates and concrete.

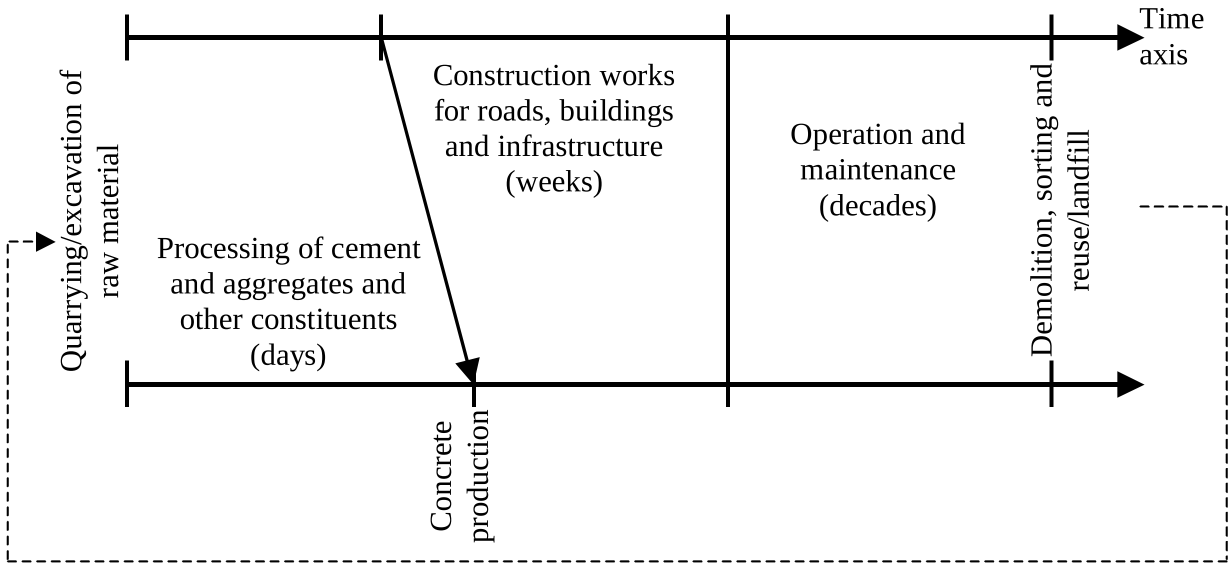

Figure 1.2 Illustration of life cycle phases for buildings and constructions. Upper time axis illustrates aggregates where the connection to the lower time axis indicates the part of aggregate production being applied in concrete production.

1.2 Objectives

1.2.1 Cluster 3

According to the ECO-SERVE network work plan for Cluster 3 dated February, 2002, the overall objective of Cluster 3 is to contribute to a reduction of the environmental impact of aggregate and concrete production making them more cost-effective, while improving or at least maintaining their required technical performance.

It is further, an objective to perform mapping activities in the field, i.e. establish an overview/inventory of stakeholders, record their views and obstacles towards environmentally friendly production technologies and to co-ordinate national and European research activities in the field.

1.2.2 Baseline report

An important step in reaching the overall objective of Cluster 3 is to create an overview (establish the baseline) of current practises and on-going research activities in the field of sustainable aggregate and concrete production. This is the aim of the present report.

The content of this report is prepared in close contact with the Cluster 3 members in order to cover all essential European questions when it comes to sustainable aggregate and concrete production as well as the associated economical, societal and political issues.

The baseline report is used as foundation for determining the Best Available Technologies in the field and, later on, for preparing guidelines on environmentally friendly concrete and aggregate production.

2 AGGREGATE PRODUCTION

In the past, aggregates[c] like sand and gravel have chiefly been quarried from natural resources, however an increasing amount is coming from crushed rock and the use of recycled material. Demolition waste, recycled concrete and material recovered during road repairs are also increasing. Further processing of aggregates is carried out by means of crushing, screening and washing.

Aggregates are a major constituent in the construction industry and are by far the most used material worldwide, second only to water. They are used in a range of different application fields, e.g. in concrete and mortar, where they account for about 70 % of the total volume, and in pavements, where they account for over 90 % of the total volume.

The aggregate industry is in general not a favourite amongst the public and e.g. environmentalists. The industry produces noise and dust, sites are often unsightly, changes to land are non-reversible, and high volumes of lorry traffic are associated with the industry. It may be said that, in some regard, the aggregate industry is facing an image problem all over Europe. New quarry applications are rejected on grounds of various environmental issues, and in some countries existing quarries only get a few years licence at a time. It is therefore safe to say that the aggregate industry is often unwanted; however, this is not the same as unnecessary. There is constant need for aggregates, both for repair of existing structures and for new construction work. It must also be born in mind that quarries cover small areas compared to cities and roads, and they are a condition for urban life.

Following is an account of sustainability issues, key figures on production and state-of-the-art covering recent and on-going research and current practice in the aggregate production sector, largely based on input from members at the Cluster 3 Workshop[d].

2.1 Sustainability in the aggregate production sector

Aggregate production is, by the strictest definition, non-sustainable, since aggregate resources are non-renewable. However, the term sustainability used in this context, can be used to characterise an aggregate production which is in an optimum balance with the geological resources used, as well as with the various kinds of physical and societal surroundings. Any exploitation of natural resources should give a maximum of added value to the society, without causing a need for re-deposition or pollution, or being in conflict with the CPD[e] (Danielsen & Ørbog, 2000[3]).

The sustainability issue has been on the agenda at a series of conferences over the past years. Europeans are realizing the importance to balance the needs of their economies and

[c] The European standard for aggregates (EN 12620:2002) states: "Aggregate is a granular material used in construction. Aggregate may be natural, manufactured or recycled." The most common natural aggregates of mineral origin are sand, gravel and crushed rock.
[d] Input from members' representative: see Table 1.1.
[e] The Construction Products Directive from the EU Commission.

societies for mineral raw materials against the need to protect the natural environment from unnecessary adverse impacts (Geological Survey of North Rhine-Westphalia, 2002)[4]. Many countries have expressed concerns about the sustainability of the aggregate resource, both in terms of tonnage remaining and also the land-use planning issues, due to the non-renewable character of natural aggregate resources. This is especially pronounced in regions facing a shortage of adequate local materials.

Quarrying and transport of materials have environmental impacts on the local neighbourhood and society, for instance with regard to noise, dust, pollution, and effects on biodiversity. Furthermore, there are land-use conflicts between quarrying and agriculture, recreation, building sites and archaeology, especially in densely populated regions. The aggregate production has often been characterised by inferior mass balance[f] (e.g. high percentages of surplus material). *The biggest challenge facing the aggregate industry will probably be to introduce resource management strategies to meet the environmental requirements while, at the same time, maintaining profitable day-to-day production, and even increase the level of industrialization.*

The sustainability issues that are most pressing in relation to the aggregate industry are

- *Mineral resources,*
- *Land use,*
- *Mass balance & surplus materials, and*
- *Energy consumption.*

It is very important to have a holistic view and not focus on one or few parameters.

Regarding sustainability in the aggregate sector, recycling and re-use of construction and demolition wastes has been thoroughly investigated in the past years (see Chapter 4).

2.1.1 Mineral resources

With natural sand/gravel resources being rapidly depleted all over Europe, the needs of the construction industry will have to be met increasingly from crushed/manufactured aggregates. For instance in Norway, with a traditional abundance of glaciofluvial sand gravel, the last 20 years have seen a marked transition from sand/gravel to crushed rock in the market: while in the 1980ies 50-60 % of the production value in the aggregate sector could be ascribed to natural sand/gravel the corresponding figure today is 20 % and decreasing.

Several countries are currently applying resource taxation and/or regulations, to limit the exploitation of scarce sand/gravel resources.

There have been drastic changes in how e.g. Swedish authorities deal with applications for new quarries. As a larger group of stakeholders have a say in the approval of new quarries, it is almost impossible to get approval for new quarries and it may even be

[f] Mass balance: to have a total balance between the size fractions produced and those that can be placed on the market.

difficult to prolong licences for current quarries. The main arguments for turning down new quarry applications in Denmark are environmental care, the non-reversible effects on landscape of the aggregate production and that the land has been planned for other use. The main argument for approval has been that the area is already planned as a resource for aggregate production. New quarries in Italy are only granted for a limited year's license, making it difficult for producers to invest in the necessary equipment. All this highlights the need for long term planning, including a resource strategy, to avoid conflicts, as the aggregate industry must maintain a good relationship with the society.

2.1.2 Land use

Most people rely on the commodity of the infrastructure for everyday life, however, very few, want to live next to a quarry. This causes conflicts regarding e.g. land-use, noise and dust. Simultaneously, the demand for new buildings and improved infrastructure is increasing. Part of the problem is that public authorities in many countries do not have an over-all resource strategy, where the long term need for and supply of crucial materials is balanced against other land use and preservation issues. Incorporated in such a strategy should also be possibilities to use a quarry after it has been closed, making the value of the area increase, e.g. for housing, industry, recreation areas and lakes.

2.1.3 Mass balance and surplus materials

One of the main challenges in aggregate production, especially when producing crushed aggregates from hard rock quarries, is to obtain a satisfactory "mass balance". Any excess fraction that has to be kept on stock – or even worse – deposited, creates an economic as well as an environmental problem. To meet a good mass balance is not only a question of production, but also the society's demand for products and their properties. A consequence of good mass balance is the extended lifetime of the resource. The Norwegian experience is that if quarries are well planned and the production is end-use oriented, surplus material is rarely a problem. Ultimately, no-waste production should be a goal within the aggregate industry.

However, the responsibility is not only to the producers'. Authorities need to formulate their view on how these issues are to be handled, and materials standards as well as materials research should take up a priority for using the whole range of aggregate sizes produced, not only limited, key size fractions.

The development in resource availability (chapter 2.1.1) strongly challenges the concept of mass balance. With a tendency in the market towards more fine crushed materials and a use of key size fractions, the percentage of e.g. minus 4 mm crushed sand from a hard rock quarry may be of the order of 30 %. At the same time, a technology of utilising such materials in e.g. concrete is not fully developed and implemented throughout Europe. A consequence is huge amounts of surplus, fine-grained materials. If e.g. 2,000 million tonnes of the total European aggregate production of 2,600 million tonnes are crushed hard rock materials, approximately 600 million tonnes will be in the size range < 4 mm – and probably at least half of this will have to be deposited, due to lack of application technology and market.

2.1.4 Energy consumption

The energy issue is a very complicated one, owing to an assortment of energy types used and various geological settings. It involves the aggregate production as well as the transport and the final application of the aggregates.

Aggregate plants are either fixed or mobile; fixed plants normally use electricity whereas mobile units run on fossil fuel. With regard to efficiency, comparison of these two types of plants is difficult. The type of energy used also depends much on the geological setting: producing aggregates from crushed rock requires more energy for processing than excavating sand and gravel. The latter, however, use more energy for transportation within the quarry itself. In Denmark, for instance, the production relies heavily on wheel loaders.

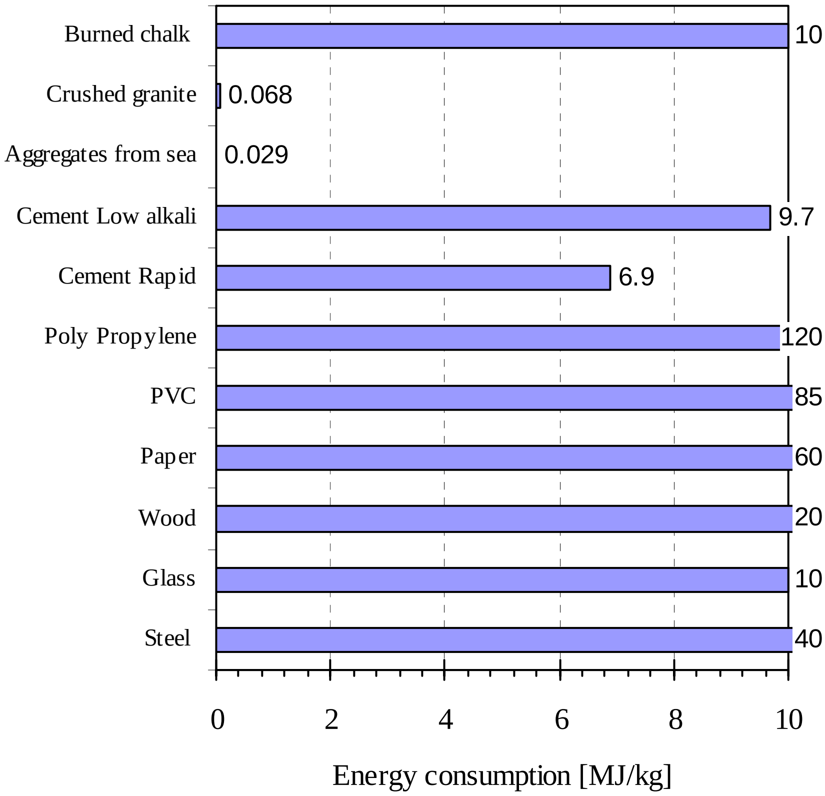

Figure 2.1 Energy consumption connected with production of different materials.[g] Note that wood,, paper and plastics include thermal values according to the normal LCA-principles. The numbers given at the columns indicate the value for each material.

[g] Data taken from Danish environmental databases.

The energy consumption per tonne of produced aggregates is relatively small compared to the energy consumption of other materials required for concrete production (Figure 2.1). Taking into account that the production of one m^3 of concrete typically requires about 2 tonnes of aggregates and 300 kg of cement the energy consumption associated with cement is still 20 times higher than that associated with aggregate production. Note that these figures do not include material transport to the concrete production plant.

When comparing the materials in Figure 2.1, it shall be taken into account, that one cannot compare the energy consumption for production of 1 kg of steel with 1 kg of cement. Focus should lie on the functional unit in which the materials are used, to compare the environmental impact from the material seen in a life cycle perspective. The illustration just gives roughly an idea of the energy consumption related to the first two phases of the life cycle (extraction and production) of different materials.

In many situations the greatest energy impact in the aggregate sector is linked to the materials transport – from the quarry to the customer, an increasingly important issue as more and more densely populated areas are running out of local materials supply, and land use conflicts in these areas show a tendency not in favour of quarrying.

2.2 Key figures of aggregate production in Europe

The aggregate industry in the 15 European countries that are members of the European Aggregate Association, UEPG[h], produced in the year 2000 some 2 620 million tonnes of sand, gravel and crushed rock, representing an EU average of 6.9 tonnes/capita. This total exceeds the total tonnage of all other minerals produced in the EU. Clearly, this is bound to have environmental impacts and it is our responsibility to optimise the use of this material. To illustrate the impact of this extraction, the quarrying of 2,000 million tonnes of aggregates a year over a 100-year period roughly corresponds to the lowering of the Netherlands by 2–3 m.

The industry has both economic and social impacts: the annual value of the raw material and processed products (aggregates) is 35,000 million € for these countries, and the industry directly employs 250,000 people.

An extensive overview of the production of aggregates (Sand & Gravel and Crushed Rocks) in Europe is provided in the report: Minerals Planning Policy and Supply Practices in Europe[5]. All figures in that report were extracted from the European Minerals yearbook Final Draft 1995.

The European Mineral Statistics 1997–2001 was published last year (2003)[6]. This new, enlarged, edition now includes production, export and import tables:

- By **individual country**: for the whole of Europe, including eastern Europe and Russia
- By **commodity** for the EU, EU applicants, Norway and Switzerland

[h] http://www.uepg.org

- For **primary aggregates** production and trade (sand, gravel and crushed rock).

2.2.1 Statistics of the European Aggregate Production Industry

Outlines of key figures of aggregate production are presented in the subsequent figures and tables. Figures are from the website of UEPG and the European Mineral Statistics 1997–2001. The production of aggregates in tonnes/capita in European countries in the year 2000 is presented in Figure 2.2 while the production of primary aggregates (sand, gravel and crushed rock) is presented in Table 2.1. Figure 2.3 shows the percentage distribution of the production of aggregates in European countries. The consumption of primary aggregates is listed in Table 2.2, while aggregates trade is presented in Figure 2.4. Some other sources of European statistics regarding aggregates are presented in Table 2.3.

A comprehensive statistical account of the European Aggregate Production Industry is given in the European Mineral Statistics 1997–2001, with the following quotation regarding the ambiguities of obtaining the "correct" figures of aggregate mineral production:

> *Aggregates suffer from the incompleteness of available production data and incompatibility of different countries' production statistics for this group…….*
> *Other problems are related to the terminology used by different countries. These can include such categories as:*

- *'Gravel and crushed rock' with no distinction between types of aggregate minerals*
- *'Building stone' that incorporates both crushed-rock aggregate and dimension stone*
- *'Limestone' and other purely petrologic descriptions with no indication of the construction/industrial use split*
- *'Sand' with no distinction between material for construction sand and special sand for industrial uses e.g. for glass*

The following text, also from the European Mineral Statistics 1997–2001, is on the Aggregate Production in Europe:

> *……… The majority of the EU member countries are self-sufficient in supply of aggregate minerals but while some, e.g. UK, produce approximately equal quantities of sand & gravel and crushed rock aggregates others are, for obvious geological and topographic reasons, deficient in one or the other. For example, Netherlands lacks resources suitable for the production of hard-rock aggregates while Austria, landlocked and without broad alluvial lowlands, is a net importer of sand and gravel. Simple statistical analysis, especially if only 'gross' national trade positions are examined, can be misleading: aggregates are low-cost minerals 'ex-pit' and are, as a result, sensitive to transport costs. They may be imported via a short cross-border route at lower cost than if they were carried a much greater distance within national borders.*

For countries bordering the North Sea production of marine-dredged sand and gravel is a significant part of supply. In the case of the UK this source amounts to approximately 23 million tonnes/year or 22 per cent of total UK production in 2001. Almost half of this tonnage is landed at foreign ports as exports. Crushed rock produced from onshore sites is also conveyed by sea from Norway and Scotland. Recycled and secondary aggregates have become an increasingly important part of supply, in response to environmental constraints on the production of primary (quarried) material. Such statistics as are available suggest that the proportion of national supply contributed by secondary material is greatest in the geographically smaller European countries where transport distances are less. In England these materials account for 20-25 per cent of total supply.

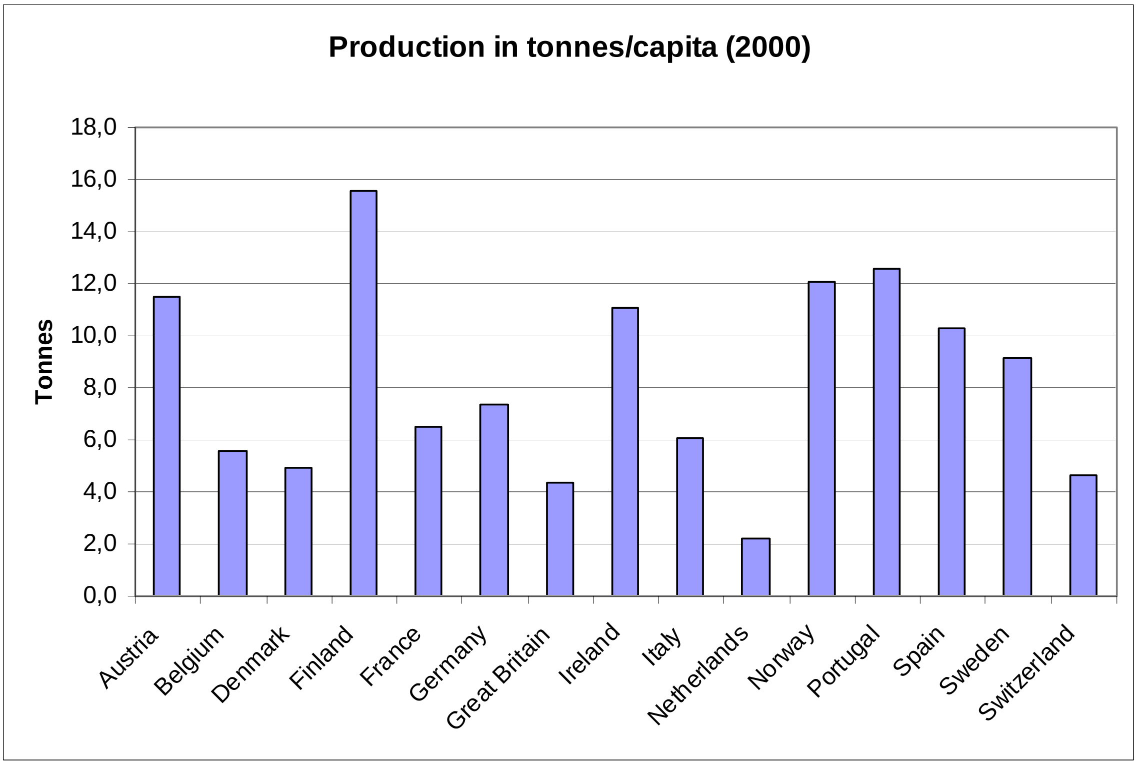

Figure 2.2 Production of Aggregates in tonnes/capita in European Countries in the year 2000. (Source: UEPG).

Table 2.1 Production of primary aggregates (sand, gravel and crushed rock) (Source: the European Mineral Statistics 1997–2001).

tonnes

Country		1997	1998	1999	2000	2001
Austria (e)	Sand and gravel	…	…	…	25 712 457	23 122 827
	Crushed rock	*24 400 000	*23 600 000	*25 000 000	23 818 614	22 445 635
Belgium (f)	Sand	2 804 547	(a) 9 234 452	(a) 9 390 019	(a) 10 407 187	*10 000 000
	Crushed rock (b)	31 212 851	32 368 250	36 838 157	38 326 885	39 604 958
Bulgaria	Sand and gravel	*3 600 000	*3 500 000	*3 500 000	*3 500 000	*3 500 000
Cyprus	Crushed rock	6 500 000	7 660 000	8 500 000	8 800 000	9 300 000
Czech Republic	Sand and gravel	16 311 299	14 567 328	12 617 011	12 218 945	11 916 192
	Crushed rock	19 697 795	17 810 245	17 775 006	18 304 260	20 301 407
Denmark	Sand and gravel	55 800 000	53 300 000	68 800 000	57 500 000	52 700 000
	Crushed rock	400 000	300 000	300 000	331 000	276 000
Estonia	Sand and gravel	1 900 000	2 400 000	1 800 000	2 100 000	2 300 000
	Crushed rock	…	…	…	2 300 000	1 800 000
Finland	Sand and gravel	…	…	44 000 000	(d) 80 000 000	…
	Crushed rock	…	…	36 000 000	…	…
France	Sand and gravel	164 950 000	167 000 000	173 760 000	180 570 000	172 764 000
	Crushed rock	182 500 000	189 710 000	200 950 000	218 670 000	218 604 000
Germany	Sand and gravel	374 500 000	359 200 000	369 400 000	343 200 000	324 200 000
	Crushed rock	102 866 000	108 971 000	154 039 000	144 805 000	136 606 000
Greece	Crushed rock	65 000 000	41 000 000	…	…	…
Hungary	Sand and gravel	24 880 908	22 428 395	22 613 058	29 696 007	32 242 756
	Crushed rock	3 938 500	4 738 200	5 257 300	5 137 500	5 827 674
Ireland	Sand and gravel	…	…	40 000 000	(d) 41 000 000	…
	Crushed rock	…	…	60 000 000	…	…
Italy	Sand and gravel	169 157 933	217 174 833	242 997 037	…	…
	Crushed rock	*48 900 000	48 954 868	60 528 842	…	…
Latvia	Sand and gravel	…	480 609	787 317	790 257	688 904
Lithuania	Sand and gravel	4 500 000	6 000 000	8 500 000	8 400 000	7 600 000
Netherlands	Sand and gravel	…	…	30 000 000	28 050 000	…
Norway	Sand and gravel	26 000 000	26 000 000	23 000 000	19 000 000	17 000 000
	Crushed rock	35 000 000	37 000 000	39 000 000	34 000 000	34 000 000
Poland	Sand and gravel (c)	61 616 000	64 192 000	71 196 000	73 588 000	62 534 000
	Crushed rock	23 175 000	28 006 000	30 324 000	27 661 000	25 593 000
Portugal	Sand and gravel	6 580 906	5 672 875	5 009 999	6 876 470	…
	Crushed rock	63 391 664	69 336 303	65 468 852	63 610 282	…
Romania	Sand and gravel	713 000	1 048 772	763 065	813 941	733 409
Slovakia	Sand and gravel	3 000 000	3 000 000	2 400 000	2 000 000	…
	Crushed rock	9 500 000	11 700 000	7 700 000	7 700 000	…
Slovenia	Sand and gravel	10 412 000	10 292 000	12 419 000	12 546 000	11 510 000
Spain	Sand and gravel	60 576 635	70 722 768	74 826 345	81 688 475	*90 000 000
	Crushed rock	…	…	222 600 000	302 000 000	…
Sweden	Sand and gravel	26 269 964	29 401 068	29 001 138	24 623 555	23 448 226
	Crushed rock	35 289 694	45 390 262	50 300 004	46 599 806	…
Switzerland	Sand and gravel	…	…	26 000 000	(d) 33 000 000	…
	Crushed rock	…	…	4 000 000	…	…
UK	Sand and gravel	98 383 000	98 315 000	100 953 000	101 622 000	101 397 000
	Crushed rock	133 787 000	131 716 000	132 598 000	130 307 000	133 759 000
EU30 Total		2 388 000 000	2 452 000 000	2 598 000 000	2 595 000 000	2 550 000 000

Note(s):

(1) So far as possible, these statistics include construction sands; gravel, pebbles, shingle and flint; crushed stone used for concrete aggregates, road stone and other construction use; granules, chippings and powders, listed under Prodcom codes 14211190, 14211210, 14211230, 14211250, 14211290

(2) Where official sources show more than one series for aggregates the higher series has generally been used in this compilation

(3) Where marine sands and gravels have been identified, these are included

(4) Information may be incomplete or absent due to reporting methods, confidentiality or lack of available information. All EU30 countries produce sand and gravel and crushed rock.

(5) Production from many small operations is not officially compiled. The minimum number of employees for which establishments are required to report production varies between different countries and can also vary from year to year within a country

(6) Quantities of sand from sand and gravel operations may be discarded due to low demand. This may or may not be included in the statistics

(a) Includes silica sand

(b) Including gravel, slag and tarred macadam

(c) Includes an estimate for small producers

(d) Includes crushed rock

(e) Sales

(f) Deliveries

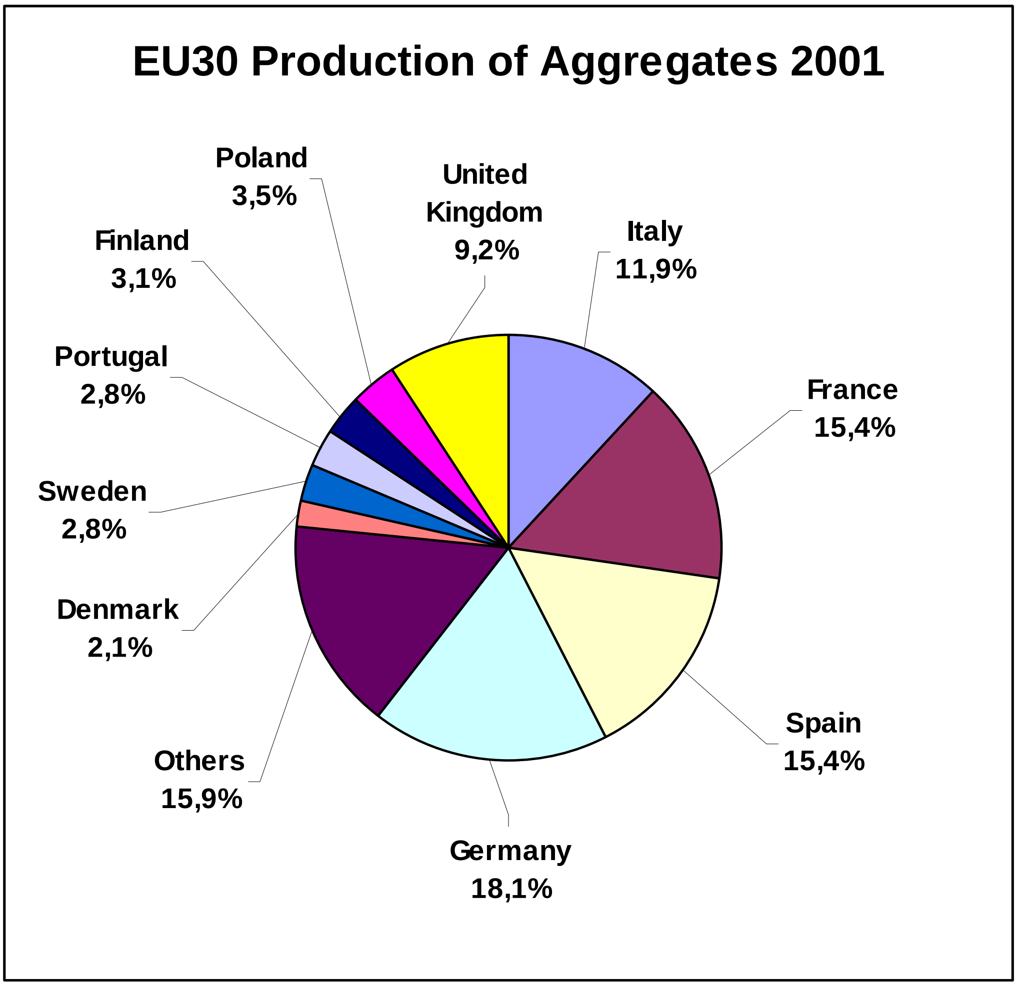

Figure 2.3 Production of Aggregates (2001) – Percentage Distribution. (Source: the European Mineral Statistics 1997–2001).

Table 2.2 Consumption of primary aggregates (sand and gravel and crushed rock) 2001 (Source: the European Mineral Statistics 1997–2001).

	Million tonnes		Million tonnes		Million tonnes
Austria	45.5	Greece	…	Portugal	71.0
Belgium-Luxembourg	57.0	Hungary	37.5	Romania	0.9
Bulgaria	3.5	Irish Republic	…	Slovakia	10.0
Cyprus	9.3	Italy	…	Slovenia	11.9
Czech Republic	31.9	Latvia	1.1	Spain	89.0
Denmark	54.0	Lithuania	8.3	Sweden	21.7
Estonia	4.2	Malta	…	Switzerland	39.0
Finland	80.0	Netherlands	39.0	Turkey	…
France	388.1	Norway	40.0	UK	222.7
Germany	454.7	Poland	88.7		

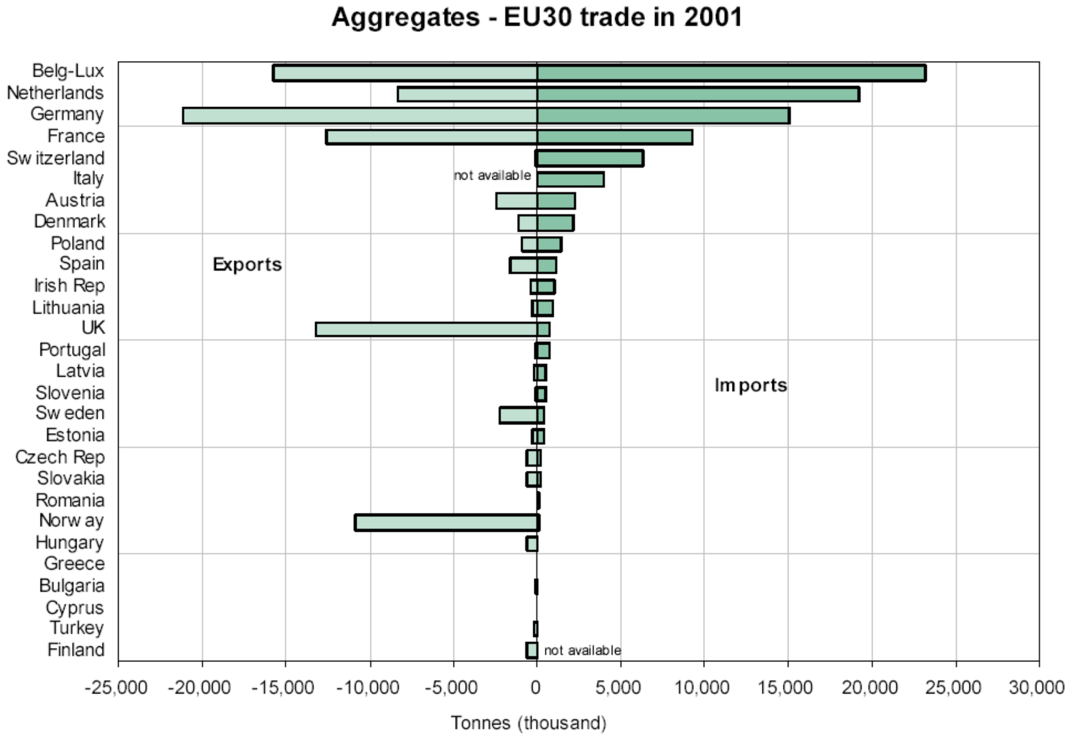

Figure 2.4 Aggregates trade in 2001.
(Source: the European Mineral Statistics 1997–2001).

Table 2.3 Some other sources of European statistics regarding aggregates.

The European Geological Data Catalogue (Geixs)	Geixs is a product of European Union of National Geological Surveys, and is a database for, among others, land use planners and minerals industries.	http://geixs.brgm.fr
National Geological Surveys	Some of the National Geological Surveys in Europe present annually an account of the national use of aggregates, e.g. Norwegian Geological Survey, NGU[7],[8] The British Geological Survey also conducts Aggregate Minerals Surveys (AM), at four-yearly intervals since 1973, provide an in-depth and up-to-date understanding of regional and National sales, inter-regional flows, transportation, consumption and permitted reserves of primary aggregates. The British Geological Survey has recently published the results of AM2001[9].	www.ngu.no
Directory of Mines and Quarries	In recent years the publication; the Directory of Mines and Quarries (DMQ), by the British Geological Survey, has been derived from a database called BritPits. The database holds information on the name of active mines and quarries, their geographic location, address, operator, mineral planning authority, geology, mineral commodities produced and end-uses	www.bgs.ac.uk/mineralsuk/data/britpits/home.html
United Kingdom Minerals Yearbook[10]	This presents comprehensive statistics, by year, on UK minerals production, consumption and external trade.	
Mineral Extraction in Great Britain from National Statistics (UK)[11]	Annual information is presented in Mineral Extraction in Great Britain from National Statistics (UK) covering all mines & quarries, except deep mined coal, for mineral extraction on Great Britain. Information is published, by mineral, at both county and region level. Government uses this information for land-use planning to ensure that the necessary mineral resources are available. It is also used in national accounts and to meet the obligations of an EU regulation.	

2.3 State-of-the-art covering recent and on-going research and current practice

In Table 2.4 a summary is given regarding on-going research and current practice in the field of aggregate in Europe. Sources of information have primarily been the members of Cluster 3 Workshop together with search at the internet, particularly from databases at www.cordis.lu and www.e-core.org.

It is not an easy task to collect such information ad to establish a complete overview. Consequently, the list is bound to be incomplete and some relevant projects may be missing. Emphasis has however been on organisations, projects and network dealing with topics related to:

- Aggregate-extraction & processing,
- Collection of Aggregate Statistics,
- Sustainable development of aggregate production
- The functionality and durability of aggregates production

Table 2.4 Overview over current R&D activities regarding aggregates

Aggregate extraction / Aggregate Statistics				
Name of Project/Network	**Type of project Time period**	**Main Topic/Objectives**	**Partners or Participating countries [Lead/contact Partner]**	**Web-links Publications**
SANDPIT	5th framework (EU) EVK3-CT-2001-00056	Overall objective to develop reliable prediction techniques and guidelines to better understand, simulate and predict the morphological behaviour of large-scale sand mining pits/areas and the associated sand transport processes at the middle and lower (offshore) shore face and also in the surrounding coastal zone.	Researchers and coastal zone managers from Denmark, France, Italy, Netherlands, Norway and Portugal.	**http://sandpit.wldelft.nl/mainpage/mainpage.htm**
The aggregate database at NGU	National Norway	NGU has during the last decades developed extensive databases for sand, gravel and crushed rock aggregates covering most of Norway.	**Geological Survey of Norway (NGU)**	**www.ngu.no/grusogpukk**
Raw Materials Policy and Supply Practices in North-western Europe		The regional reports handle the countries around The Netherlands, or bordering the North Sea: the German States Lower-Saxony and North-Rhine Westphalia, Belgium, the UK, Norway, Denmark and finally The Netherlands itself.	**Road and Hydraulic Engineering Institute (DWW)**	**www.international.bouwgrondstoffen.info/** 6 regional reports + summary report
Economic Minerals and Geochemical Baseline (EMGB) Programme	National UK	The aim is to increase the knowledge and understanding base of metallic, non-metallic and industrial mineral resources within the UK and overseas. Some issues including: • sustainable minerals development, commodity life-cycle analysis, the environment and mineral extraction • minerals and planning • provision of statistics on mineral production and trade for the UK and the world • developing new scientific research programmes related to mineral resources	**British Geological Survey**	**http://www.bgs.ac.uk/mineralsuk/aboutus/emgb.html**

Aggregate processing				
Name of Project/Network	**Type of project Time period**	**Main Topic/Objectives**	**Partners or Participating countries [Lead/contact Partner]**	**Web-links Publications**
Manu-factured sand for use in concrete	National Norwegian Projects 1990-recent	Various R&D projects regarding production and use of manufactured (crushed) sand in concrete.	Franzefoss, SINTEF and other industries in Norway	12,13,14&15
Crushing technology		Research regarding improvement of aggregates properties through crushing technology	Nordberg (Now Metso) Svedala (now part of Metso and Sandvik).	16,17, 18,19,20,21,22& 23
Production and Utilisation of Manu-factured Sand for Concrete Purposes	NORA (Nordic Atlantic Co-operation) 2003	A review of the present state-of-the-art knowledge regarding production and use of manufactured sand in Norway. In addition the current situation in Iceland and Greenland is evaluated in order to enable utilisation of these novel techniques. Description of Norwegian development in aggregate production and in concrete mix design. A new technology; the Rhodax crusher is presented and discussed.	**Hönnun Consulting Engineers, Iceland** S.W.Danielsen, Norway NIRAS Greenland A/S	www.honnun.is/sand 24
MINBAS R&D PROGRAM 2003-2005	National Sweden 2003-2005	One of the tasks of the program is optimisation of the production process from quarry to final product, for industrial minerals, aggregates and dimensional stone.		**www.minfo.se**
Utilising innovative rotary kiln technology to recycle waste into synthetic aggregate	BRITE/ EURAM 3 BRST985234 1998-2001	The aim is to use an innovative design of rotary kiln to provide a solution to two modem day dilemmas which confront both disposers of waste & users of natural aggregate for the production of concrete: 1. how to overcome the conflicting problems of dealing with the increasing amounts of domestic & industrial wastes &, at the same time, effect a reduction in the numbers of landfill sites being used for disposal 2. how to limit the use of irreplaceable natural resources & still satisfy the growing demand for aggregate.	**Sherwen Engineering Company Ltd.**	
LESS FINES Less fines production in aggregate and industrial minerals industry	5th framework (EU) GROWTH G1RD-CT-2000-00438 2001-2004	During the European annual production of 1.35 billion tons of blasted rock, around 20 % of the total production, is too fine to be used efficiently and therefore has to be put on waste dumps. The aim of the project is to reduce this amount of lost material by 50 % through the adaptation of the explosives and timing procedure to the natural breakage characteristic of the rock.	**University of mining and metallurgy, Austria**	

Sustainable development				
Name of Project/Network	**Type of project Time period**	**Main Topic/Objectives**	**Partners or Participating countries [Lead/contact Partner]**	**Web-links Publications**
		The Austrian Chamber of Commerce is running a campaign with WWF due to improve the image of the aggregates industry in the field of biodiversity.	**The Austrian Federal Economic Chamber**	steine@wko.at
Mining, Minerals and Sustainable Development (MMSD)	2002	Understanding how to maximize the contribution of the mining and minerals sector to sustainable development at the global, national, regional and local levels.	**International Institute for Environmental and Development**	www.iied.org/mmsd/ [25]
Enhanced utilisation of Danish resources	2001-2002 National Danish	To record the limitation and possibilities for preserving the Danish resources by the increased use of sea materials, recycled aggregate and aggregate with the lowest possible quality. A number of different scenarios were investigated and a pilot test of concrete containing aggregate not normally used for concrete was carried out.	**Danish Technological Institute and the Danish Nature and Forest Agency**	http://www.skovognatur.dk/raastof/generel/ressource.htm
LIFETIME Lifetime engineering of buildings and civil infrastructures	5th framework (EU) GROWTH G1RT-CT-2002-05082 2002-2005	To contribute to European and world-wide development of a more sustainable built environment. The Network will involve all key stakeholders of buildings and civil infrastructures, including mining, whose activities concern investment planning, design, facility management and maintenance, reuse and recycling. The network will focus on application of lifetime principles into these areas.	**Technical Research centre of Finland**	

Functionality/Durability of Aggregates/Applications				
Name of Project/Network	**Type of project Time period**	**Main Topic/Objectives**	**Partners or Participating countries [Lead/contact Partner]**	**Web-links Publications**
PARTNER	5th framework (EU) GROWTH G6RD-CT-2001-00624 2002-2006	To provide the basis for a unified European testing methodology to evaluate and classify the alkali reactivity of aggregates in concrete.	**Building Research Establishment (UK)**	www.partner.eu.com
Drawing-up of performance require-ments for sand and aggregates intended for cement-related applications	Belgian Regional Programme	Focusing on quality of aggregate in relation to the quality of the end product, i.e. concrete and mortar, can deteriorate in the long term for reasons that include impurities, aggregates that are sensitive to frost and alkali-silica reactions, aggregates with low mechanical resistance). Insufficient aggregate quality may cause damage and, in most cases, the structure is damaged deep down, i.e. in its load-bearing elements. Only demolition or costly repair techniques may be envisaged in such cases. Contraction of raw materials (sand, gravel etc.) and the breakthrough made by alternative aggregates (artificial aggregates, industrial residues, recycled aggregates) mean that this issue is more topical than ever.	**Belgian Building Research Institute** (**BBRI**)	
IAEG Commission Nr. 17 on Aggregates	IAEG project 1998-	Compilation of information on aggregates in a number of countries. To consider the investigation, categorisation, acquisition, preparation and testing of natural rock aggregates and to provide examples of the best ways of presenting this information to both the lay public and the construction industry	**Contact persons:** Lars Persson, SGU, Björn Schouenborg, SP	http://www.sgu.se/hotell/iaeg/iaeg_e.html
FARIN (**F**orum for **A**lkali **R**eaction **I**n **N**orway)	Norwegian Forum	FARIN is an independent Norwegian research forum for those interested in and involved with Alkali Aggregate Reactions (AAR) in concrete. Main objectives of FARIN is: • to acquire knowledge by research on alkali-silica reaction petrology, aiming to improved applied methods for testing aggregate from fundamental petrographical, mineralogical and geochemical points of view; • to spread acquired knowledge as publication in national and international periodicals, as well as contributions to official meetings and gatherings; • to serve as a national platform to coordinate research in the field and to promote and cooperation between parties with an interest. Forum meetings are planned thrice annually.	**Lead partner:** Hönnun hf Consulting Engineers	www.this.is/ergo/efarin
THE COURAGE PROJECT **Construction with Unbound Road Aggregates in Europe**	European Commission DG VII 4th Framework Programme	The COURAGE Project investigated the fundamental characteristics and mechanical behaviour of unbound granular materials used in pavement construction. In order to characterise the behaviour of granular materials, COURAGE draws on functional and simplified laboratory tests. This will enable the performance of such materials to be more rigorously understood. This in turn will assist in maximising the efficient use of unbound granular materials in road construction, improve consumption of currently wasted materials and provide increased reliability of pavement performance.	**Project Co-ordinator: The University of Nottingham, United Kingdom**	http://www.civeng.nottingham.ac.uk/courage/

3 CONCRETE PRODUCTION

3.1 Sustainability in the concrete production sector

In the Nordic network "Concrete for the Environment" completed in December 2003, one of the main activities was to reach consensus on the definition of a sustainable concrete structure, which can be used as a basis for further work in making concrete even more sustainable. The definition all the Nordic countries agreed upon read[i]:

> "*An environmentally sustainable concrete structure is a structure that is constructed so the total environmental impact during the entire life cycle, incl. use of the structure, is reduced to a minimum. This means that the structure shall be designed and produced in a manner, which is tailor-made for the use, i.e. to the specified lifetime, loads, environmental impact, maintenance strategy, heating need etc. This shall be achieved by utilising the inherently environmentally beneficial properties of concrete, e.g. the high strength, good durability and the high thermal capacity. Furthermore, the concrete and its constituent shall be extracted and produced in an environmentally sound manner.*"

This definition considers a concrete structure in its entire life cycle. The activities in ECO-SERVE and in this baseline report focus on the production phase of concrete only. However, the discussions of environmental issues should be seen in a holistic perspective, meaning that one has to take into consideration the entire life cycle when evaluating environmental issues and when comparing various solutions with respect to material choice and structural design.

3.1.1 Background

In the last two decades environmental issues in the concrete industry have been paid a lot of attention, aiming at reducing the total environmental impact of concrete structures to a minimum, without compromising on their performance. A lot of different tools have been developed in order to reduce the environmental impact of concrete and concrete structures and to promote the production of "green concrete". These tools and the technologies behind them vary considerably across Europe due to regional/national differences in legislation, market conditions and traditions in the construction industry.

The construction industry as a whole has suffered from an image of being dirty, noisy and polluting in the eyes of the public, especially when it comes to construction works with "heavy" construction materials such as concrete. This negative image needs to be reversed, which is being recognized by the industry. A lot of work is going on within the various European industrial associations resulting in the formation of environmental work groups and the publication of environmental declarations.

[i] Concrete for the Environment; www.nordicinnovation.net

More information is found on the individual web sites for these associations[j]. Also *fib*[k] recently published a report on “Environmental Effects of Concrete”.[26]

Another example is the British cement and concrete sector that have joined forces,[l] giving an overview of their efforts in promoting sustainable development. Furthermore, the American Concrete Institute currently has a working group formulating the sustainability goals for the North American concrete industry.[27]

Also in the Netherlands a lot of work has been done to improve sustainability of the concrete sector. For instance the Netherlands Concrete Society published a state of the art on concrete[28] including a country-by-country listing of the most important environmental aspects of concrete production.

During the last century concrete has developed into the most important building material in the world. This is partly due to the fact that concrete is produced from natural materials, available in all parts of the globe, and partly due to the fact that concrete is a versatile material, giving architectural freedom.

The production of concrete annually amounts to 1.5-3 tonne per capita in the industrialized world: this makes the concrete industry including all of its suppliers a major player in the building sector. Thus, improving the sustainability of the concrete industry automatically will lead to significant improvements in the building sector as a whole.

Since concrete consists of a number of various constituents (Figure 1.1) the environmental impact of concrete production is a complex mechanism partly governed by the individual impacts from each of these constituents and partly governed by the combined effect of the constituents when they are mixed together. The aggregate part of concrete normally accounts for 70-75 % of its volume and therefore the environmental issues of aggregate production strongly influence concrete production. Furthermore, cement production is associated with large energy consumption and CO_2 emissions. Thus, the sustainability of concrete as a material is strongly influenced by the cement industry and the aggregate industry. However, since concrete is most often reinforced by means of steel bars this material needs also be included in a total sustainability analysis. The amount of steel present in a reinforced concrete structure vary according to its purpose and the design conditions, but a rebar content of 200 kg per m^3 concrete is not unusual for non-prestressed structures. Comparing the energy consumptions for cement and steel production (Figure 2.1) it is seen that this figure gives energy consumptions for the steel production to be about 3 times as high as for the cement. This small example illustrates the need to keep the holistic perspective when considering sustainability.

[j] European Ready Mixed Concrete Organisation, www.ermco.org
International Bureau for Precast Concrete, www.bibm.org
European organisation of cement producers, www.CEMBUREAU.be
[k] International Federation for Structural Concrete, http://fib.epfl.ch
[l] www.ConCemSus.info where a 8-page pdf report may be downloaded.

In Figure 3.1 approximate CO_2 emissions are related to various production phases and materials of a prestressed hollow core slab based on Danish experiences.[m] The figures involve the emissions related to production of cement and prestressing steel plus emissions related to transportation and installation of slab together with demolition after completed service life. It can be seen that cement production contributes significant to the total CO_2 emission (about 55 %). However, if the carbonation of concrete (mainly taking place on concrete rubble after demolition) the CO_2 emissions released during calcination may be reclaimed. This contribution amounts to about 50 % of the CO_2 emissions during cement production, which may be counter balanced giving the negative contribution in Figure 3.1.

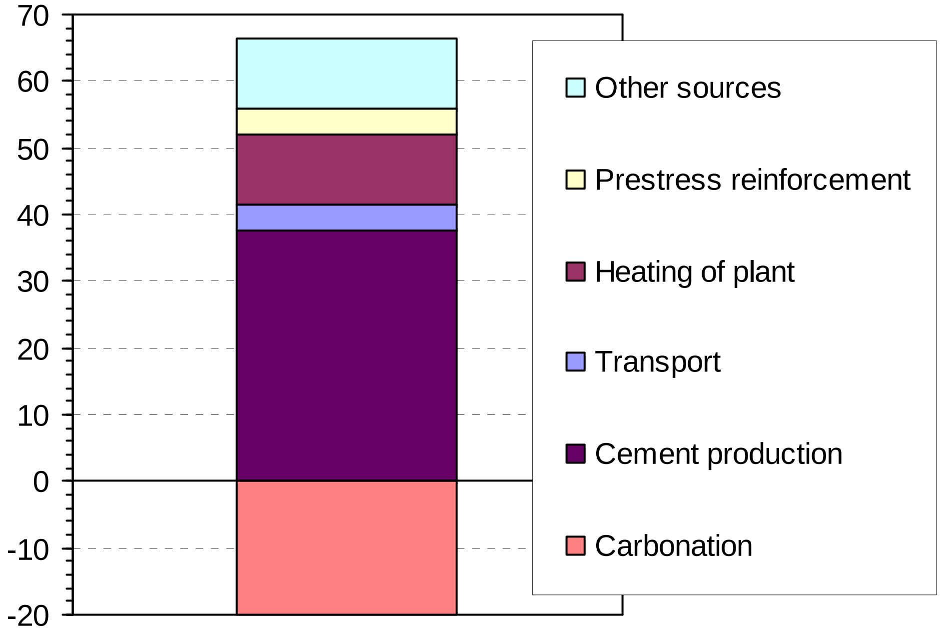

Figure 3.1 CO_2 emissions from production of prestressed hollow core slab.

In a recent *fib* report[29] on prefab concrete sustainability other LCA examples are provided together with an extensive literature list.

3.1.2 Overview

In Table 3.1 several topics regarding sustainability in concrete production are outlined. These topics are elaborated further in the following in order to provide the reader with an overview of the concrete production industry. It is generally accepted that most sustainability aspects of concrete production may be considered under one of these categories.

Category 1) mainly concerns the production and processing of raw materials for concrete production. Since this topic is treated by the aggregate part of this baseline report and from Cluster 1 and 2, it is not dealt with in the present chapter.

[m] Calculations taken from TESCOP project.

Table 3.1 Societal and economical issues associated with environmental impacts for concrete production.

Environmental impact category	**Societal issues**	**Economical issues**
1) Land-use and exploitation of natural resources (excavations, quarrying, ground water, lime stone). Mainly connected with the production of concrete constituents.	Recreation vs. industry. Planning of land-use. Utilisation of scarce resources.	Transport distances. Use of local materials vs. imported materials.
2) Waste products from concrete production (washing/mixing water, cement slurry, form oil, rejected concrete and excess production)	Land filling with the risk of leaching of heavy metals and hydrocarbons. Sorting and reusing.	Landfill taxes. Recycling into production. Demand from other industries.
3) Emissions and energy consumption (CO_2, SO_2, embodied energy throughout production, transport and construction)	Commitment to reduce greenhouse effect and to behave in an energy conscious manner.	Energy taxes. Up-to-date production equipment and methods.
4) Working environment (noise, vibrations, dust, accidents...)	Health problems.	Expenses for hospitalisation and sick leave. Automated production equipment and methods.

Category 2) is often dealt with by means of:

- Reusing waste generated from within the concrete production, e.g. washing water or rejected concrete batches.
- Reusing waste products from other industries, e.g. fly ash, slag, silica fume, waste glass, manufactured sand.

Category 3) is often dealt with by means of minimising the use of Portland cement clinker by:

- blending cement with supplementary cementitious materials such as e.g. fly ash, silica fume, slags, limestone etc. Blending during cement production or at the concrete plant depend on local traditions and level of technology. In some parts of the world addition of local supplementary materials, such as rice husk or bamboo fibers are added to concrete also.
- optimising the concrete mix design, so that its performance fulfils the specifications with the lowest possible clinker content in the concrete.

Finally, category 4) is often dealt with by improved automation of concrete batching and casting. However, this again may lead to societal side effects such as reductions in the labour force.

The use of fibre reinforced concrete also leads to improved working environment as the traditional reinforcement work involves extensive impact on the workers.

A relatively new way of improving the working environment for the concrete workers during casting is by using Self-Compacting Concrete (SCC), a high-performance concrete that flows into the formwork under its self-weight only, without the need for vibration and compaction.

All of the above-mentioned actions have obvious societal impact (Table 3.1).

The most popular tools for the authorities in order to implement environmentally friendly actions are economically based instruments such as landfill, energy and CO_2 emission taxes.

Landfill taxes are in effect in several countries together with mandatory recycling schemes[30]. Such schemes may include a general ban on land filling of certain materials and/or mandatory separation and sorting. According to OECD (2003) ten European countries currently apply landfill taxes.

Another instrument for the authorities to promote sustainability within the construction sector is environmental labelling schemes, where the construction is given a mark to indicate its impact on the environment. Such schemes are often associated with the energy performance of a building, i.e. its energy efficiency during operation and more seldom with the choice of its materials. As an example of a broader labelling scheme the LEED[n] system applied in Northern America may be taken. In the LEED system a building is given a number of points based on a long list of sustainability issues. Of course the energy efficiency of the building design has a large influence on the rating but, also recycling of waste products during construction and environmentally friendly material choices count.

Finally, it should be mentioned that sustainability issues in concrete production are often governed by simple short-term economical considerations such as:

- Changes in the production facilities being very costly, it takes time to adopt new technologies requiring alterations in mixing equipment, storage facilities and so forth. Furthermore, the manufacturer needs to establish documentation that the green choice of materials is in agreement with the standards and codes of practice, which may be costly.

- The competition on concrete is very focused on price. The costumers are not (yet) prepared to pay an increased cost for environmentally friendly concrete.

[n] Leadership in Energy & Environmental Design, www.usbgc.org

3.2 Key figures of concrete production in Europe

In order to assess the potential for environmentally friendly measures for the concrete industry, a few diagrams are created to quantify some basic figures of concrete production in Europe.

3.2.1 European ready-mixed concrete statistics

The annual ERMCO ready-mixed concrete industry statistics[o] gives information regarding the amounts of concrete being produced in Europe and the corresponding cement consumption. A small part of this information is illustrated on the following pages. The figures are taken from the ERMCO 2001 statistics, knowing that the 2002 figures have been published just before this report was finished. However, it has been decided to keep the 2001 figures since it has been estimated that the overall picture has only changed slightly from 2001 to 2002. Also bear in mind that most of the figures are reported/estimated from the members to ERMCO and therefore they are subject to a certain variation.

Figure 3.2 shows the production of ready-mixed-concrete (rmc) in 16 European countries. It is clearly seen that Germany, Spain and Italy represent a major part of the production followed by France and the U.K. Comparing Figure 3.2 and 3.3 shows that 55 % of the total rmc is produced by countries having 40 % of the population. Especially Italy and Spain are producing more rmc than their share of the population accounts for. Figure 3.5 also supports this fact.

These differences in concrete production per capita depend strongly on the building traditions, on the population density, on the economy and on the state of development in the various regions, as well as on the amount of large infrastructure projects that are taking place at a given time.

Figure 3.4 shows how the total concrete production figures are distributed into rmc, precast and site-mixed production methods. It is interesting to see that rmc and precast production add up to more than 80 % of the total production as applying environmental measures in concrete production is much easier when it is taking place under controlled production conditions compared with on-site concrete production.

[o] www.ERMCO.org

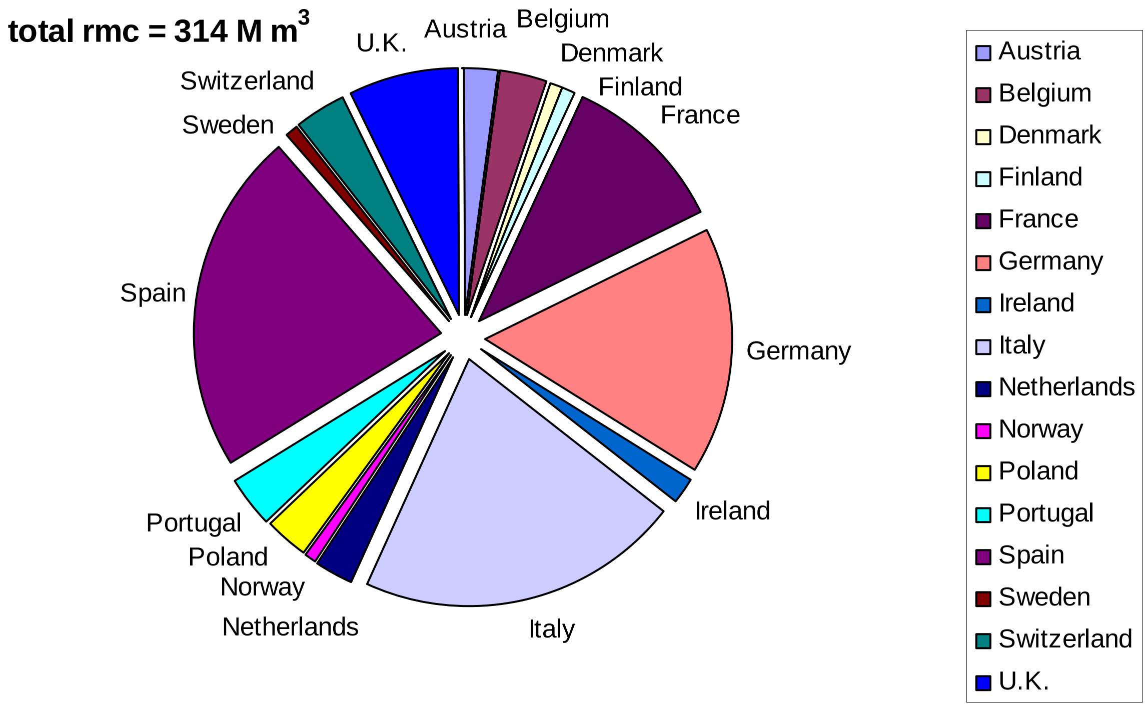

Figure 3.2 Production of ready-mixed concrete in 16 European countries. Source: ERMCO 2001 statistics.

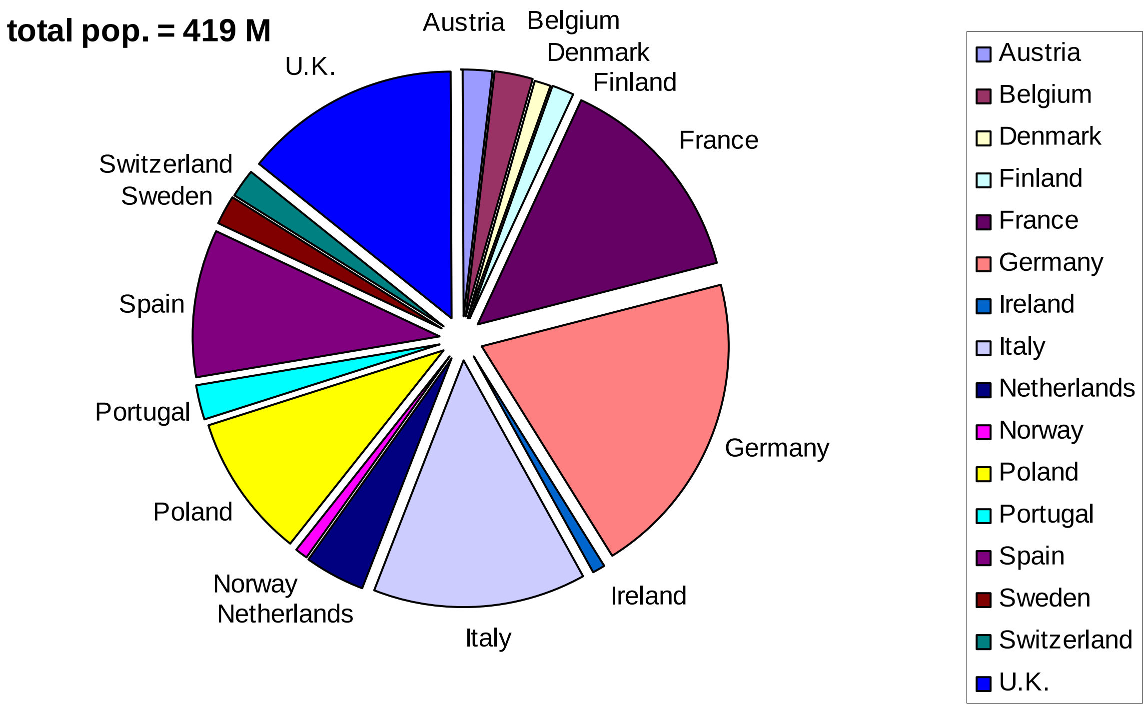

Figure 3.3 Population distribution.

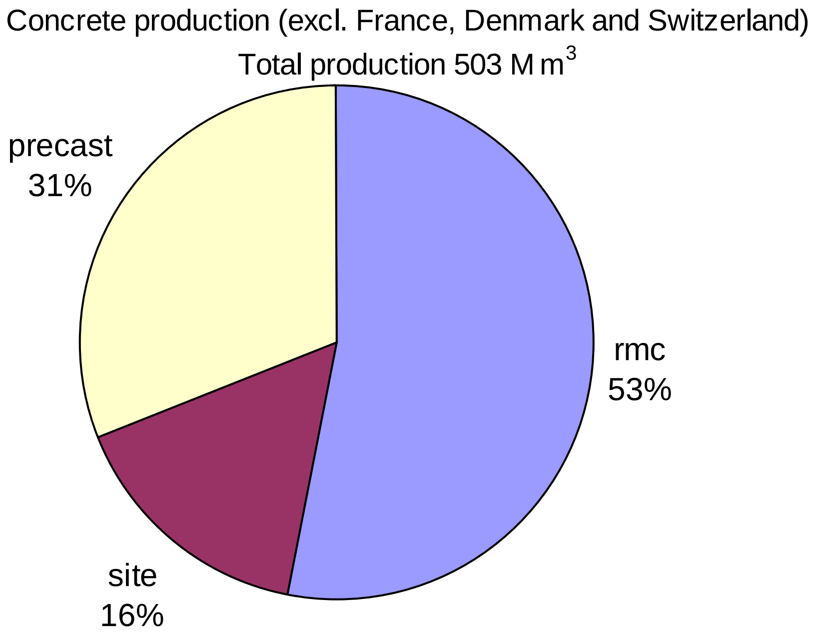

Figure 3.4 Total concrete production distributed on ready-mixed concrete, precast concrete and concrete produced on the building site. Note that data have not been reported from France, Denmark and Switzerland. Source: ERMCO 2001 statistics.

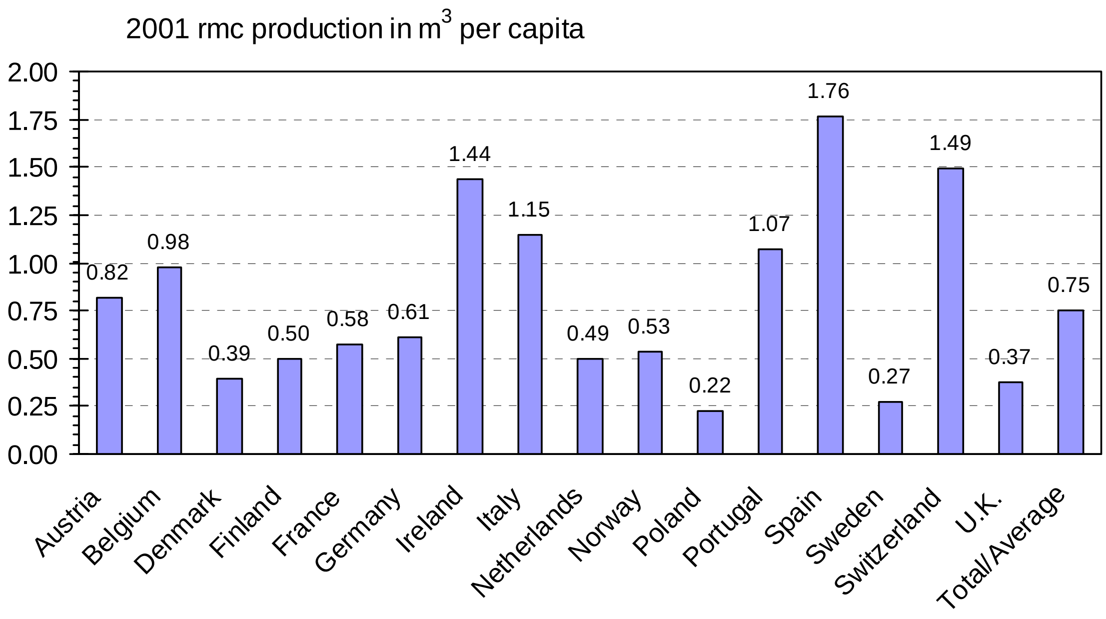

Figure 3.5 Annual ready-mixed concrete production per capita. Source: ERMCO 2001 statistics.

Taking the cement consumption reported by the various ERMCO members draws a similar picture as the concrete production (Figure 3.6 and 3.7). Again the countries having a high concrete production per capita also have high cement consumption.

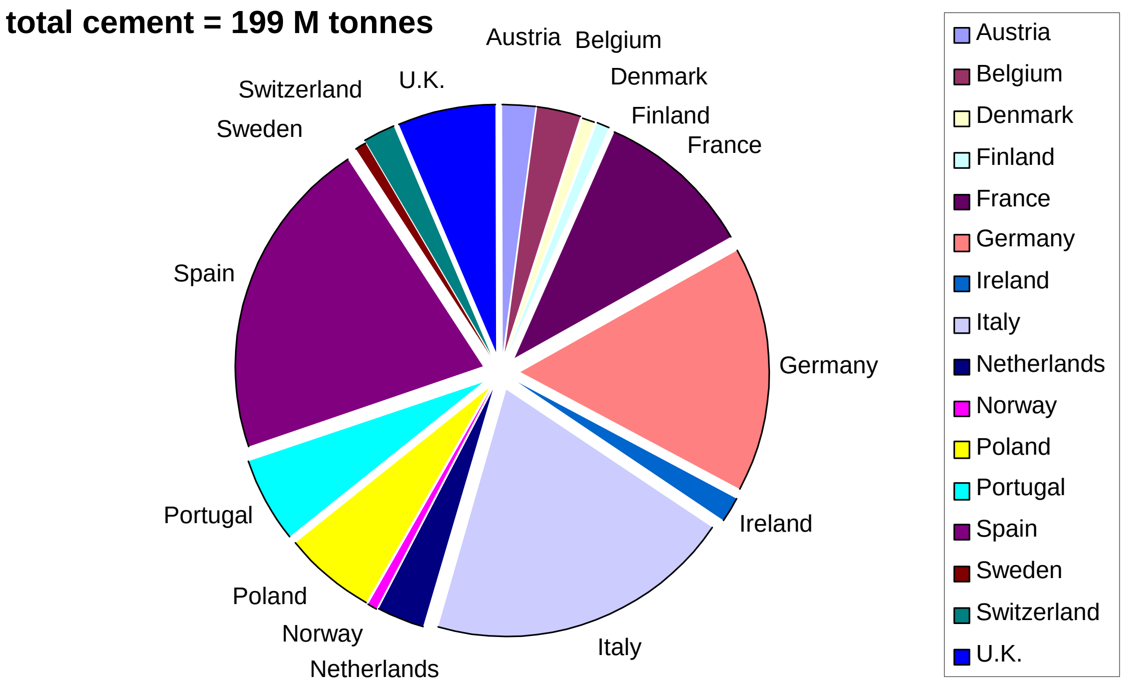

Figure 3.6 Total cement consumption in 16 European countries. Source: ERMCO 2001 statistics.

The annual cement consumption of almost 200 million tonnes Portland cement clinker equals an average of about 500 kg per capita. Since the production of 1 kg cement generates approximately 1 kg CO_2 emission this corresponds to 500 kg CO_2 annually per capita. The total CO_2 emissions per capita are listed on various web sites.[p] Comparing these total CO_2 emissions per capita with the cement consumption figures in Figure 3.7 it is seen that cement production counts for about 2-3 % in Scandinavia up to about 15 % in Spain and Portugal. These figures do not take the CO_2 uptake (carbonation) in the service life of a concrete structure and after demolition into account and therefore the numbers in that case would be slightly smaller (see also Figure 3.1).

[p] For instance via the UN on http://milleniumindicators.un.org

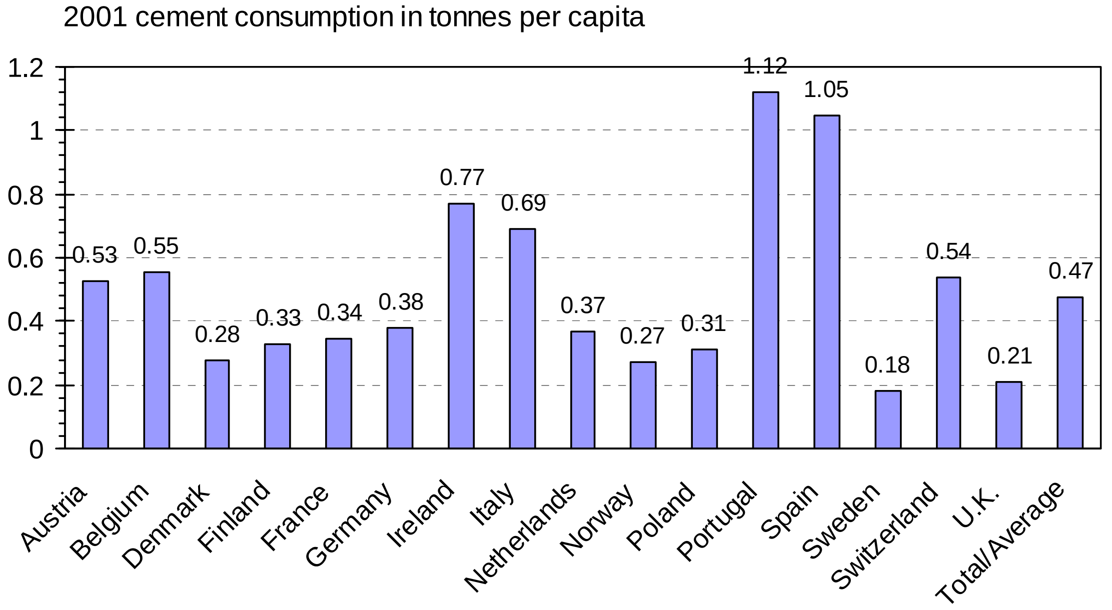

Figure 3.7 Total annual cement consumption per capita. Source: ERMCO 2001 statistics.

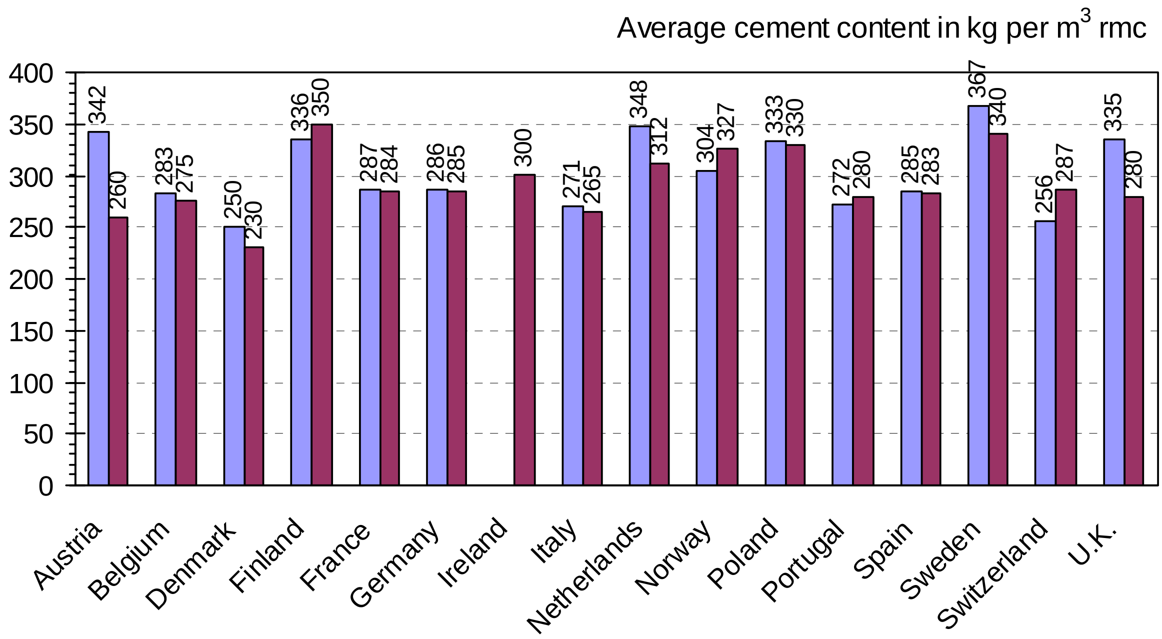

Figure 3.8 Cement dosages in the ready-mixed concrete industry. The blue columns represent reported cement consumption divided by the rmc production for each country. The purple columns represent the average cement dosage reported to ERMCO. Source: ERMCO 2001 statistics.

Figure 3.8 shows the amount of cement used to make one m^3 of ready-mixed concrete around Europe. Cement contents are ranging from 250 to 350 kg/m^3, rather moderate compared to the variations depicted in the previous figures, indicating that the cement consumption in ready mixed concrete production is on an adequate level. However, it is still possible to lower the cement content in some parts of Europe: due to the fact that the environmental impact of cement is the most important parameter with respect to energy consumption and CO_2 emission related to concrete, even small reductions in cement consumption would improve the environmental performance of concrete significantly. No distinction is made between the various cement types in the ERMCO statistics.

ERMCO statistics also include key figures on plant sizes and numbers, production methods, strength classes and turnovers.

3.2.2 European cement statistics

Cement is often taken as the main environmental indicator of concrete sustainability making it interesting to look into the cement statistics as well. From the European Cement Association CEMBUREAU[q] production figures are available for the EU in 2001. Here it is stated that the annual total cement production in the EU-countries amounts to 176 million tonnes, which is the same order of magnitude as the consumption stated in Figure 3.6 from the concrete manufacturers.

However, cement production differs significantly with respect to energy efficiency and CO_2 emissions throughout Europe[31]. The complexity is further illustrated by the fact that CEMBUREAU considers totally 27 types of cement grouped into 5 categories (CEM I-V) and 3 strength classes in accordance with EN 197-1:2001[32]. Figure 3.9 shows the total production of 176 million tonnes subdivided into strength classes, pure Portland cement (CEM I) and blended cements. The two most important cement types CEM I and CEM II cover about 33 and 50 % of the total production, respectively.

One obvious trend from Figure 3.9 is that the use of pure Portland cement (CEM I) is being taken over by blended cement, especially when it comes to strength class 32.5. Further considerations of the use of blended cements are undertaken in Cluster 2 in the ECO-SERVE network.

[q] www.CEMBUREAU.be

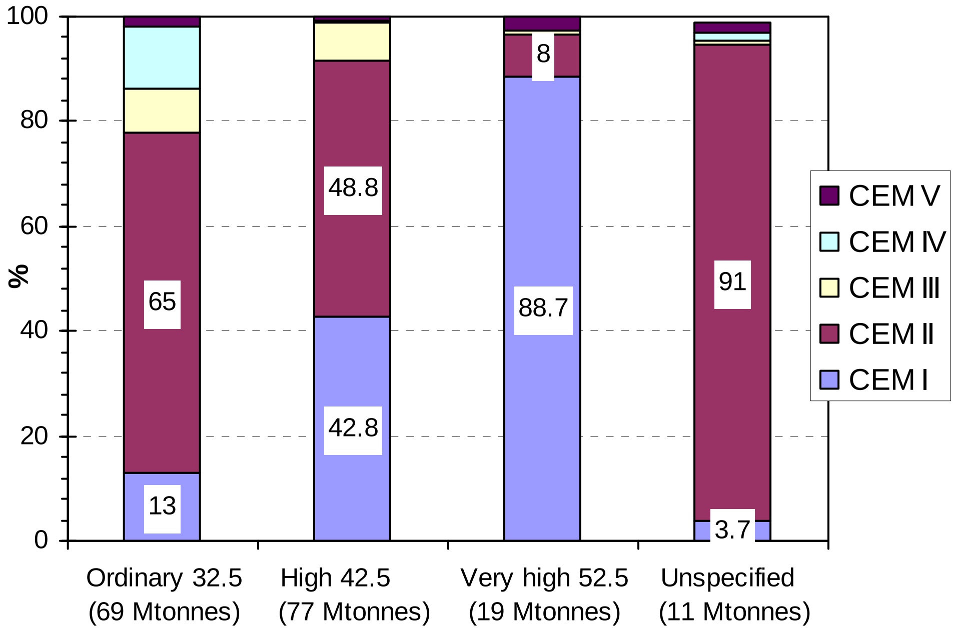

Figure 3.9 Cement production distributed on cement type and strength class. The numbers on the columns indicate the share of CEM I and CEM II within each strength class. Source: CEMBUREAU 2001 production figures.

3.3 State-of-the-art covering recent and on-going research and current practice

In this chapter an overview of the various technologies (technical instruments) used in Europe to produce sustainable (green) concrete is given, including instruments well-known and implemented in daily practice together with new and innovative instruments, which are included in the latest research and development work.

3.3.1 Reducing clinker content

Reducing clinker content in concrete is of major concern in order to improve the environmental performance of concrete. Many different sources estimate that approximately 1 kg of CO_2 is emitted to the atmosphere for each kg of cement produced. This is of course very much dependent on production methods and local conditions but it still underlines the fact that reducing clinker content in cement and or the cement content in concrete improve the environmental profile of concrete.

Josa et al (2004) present a life cycle inventory of cements in the EU. Data is presented obtained from several European cement producers from northern Europe. Here it is calculated that the CO_2 emissions per kg CEM I is 800-900 g while it is around 700 g per kg CEM II. For CEM III blastfurnace slag cement the clinker substitution is up to 66 % and therefore the CO_2 emission is reduced to less than one third compared with CEM I.

When evaluating the CO_2 emission from concrete products seen in a life cycle perspective it shall be mentioned that the previous calculations and life cycle assessments do not take into account the fact that concrete actually consume CO_2 during its service life and after demolition due to carbonation of cement paste. A recent Nordic project is looking into this area in order to find out to which degree this effect should be included in LCA-calculations[r] and to develop guidelines for including carbonation in calculations. Preliminary calculations performed in the context of this Nordic project indicate that the CO_2 uptake of carbonating concrete may represent up to half of the CO_2 emissions produced during cement production. This effect is visualised in Figure 3.1 where approximately 30 % of the total CO_2 emissions stemming from the production of a hollow core slab element is attributed to carbonation.

There are many different methods of reducing the clinker content in cement or the cement content in concrete many innovative possibilities are investigated in different research and development programs in Europe. The most commonly used technologies are:

- Use of supplementary materials at the concrete plant (fly ash, silica fume, blast furnace slag, limestone filler, sewage sludge ash, ashes from co-combustion and many other ashes which are more or less reactive)
- Use of blended cement (when Portland clinker is mixed with substituting materials).
- Optimising mix design

Furthermore, it is possible to use cement produced in a more environmental friendly manner, e.g. decreased use of non-renewable energy sources for cement production or using wastes as secondary fuel. These aspects are covered in Cluster 1 of the ECO-SERVE Network.

Use of supplementary materials

In the following a number of different materials are briefly described. These materials are being used or can be used as a supplement to the binder matrix in concrete: in most cases they allow to lower the cement content and in some cases to improve specific concrete properties. Some of the materials mentioned have pozzolanic effect in concrete and thereby contribute to the property development of the concrete, some are inactive fillers added with different purposes.

Fly ash and silica fume are pozzolanas contributing to development of the concrete properties (mechanical and durability properties). Their contribution is taken into account by using the k-value concept.[s] In the common European concrete standard EN 206-1 the k-value concept for using fly ash and silica fume together with CEM I cement is given. For instance a k-factor of 0.4 can be used when fly ash is added to concrete in combination with CEM I with strength class 42.5 or higher.

[r] "CO_2 uptake during the concrete life cycle" funded by the Nordic Innovation Centre.
[s] k = 1 means that 1 kg of supplementary material may substitute 1 kg cement in the water to cement ratio.

The k-values differ from one country to another, which is reflected in the different National Application Documents (Chapter 5). The k-value has a large influence on the pricing of a supplementary material. For instance, silica fume is often used with k = 2.0, meaning that the price of silica fume could in theory be twice that of cement. If the k-factor instead was 1.0 the situation would be completely different. When the degree of application of pozzolanas is evaluated in different countries, it is important to take into account the allowable k-factors together with the market price as well as the technical performance of the materials.

Fly Ash

Fly ash as a partial Portland cement replacement in concrete was firstly used in 1955 in the UK, where a 20 % replacement of cement with fly ash was used in the last part of the Lednock Dam construction[33].

The utilisation of fly ash has increased significantly since it was introduced in the construction sector in the middle of last century. According to ECOBA (European Coal Combustion Products Association) 39.95 million tonnes of fly ash were produced in 2001. The degree of utilisation of the fly ash was 46 % with the five major applications being concrete addition, cement raw material, blended cement, engineering fill, and structural fill. The 46 % utilisation degree however represents substantial differences among the European countries.

Even in the Scandinavian countries there are major differences in fly ash application. For instance in Denmark fly ash has been used to a large extent for about 25 years, and the entire volume of fly ash produced in accordance with the requirements in EN 450 is used primarily for concrete and cement production.

In Finland fly ash is only used in concrete (up to 80 kg/m^3) for indoor purposes and not where concrete can be exposed to freeze/thaw attacks.

In Norway fly ash is only used for production of blended cement (Standard cement FA[t]); in Sweden only a few concrete companies are using fly ash imported from Denmark.

In North America Canmet[u] has been working very strongly for many years to extend the knowledge of fly ash and high volume fly ash concrete. Canmet has organised a large number of international conferences on supplementary materials in concrete.

Fly ash is a pozzolan, i.e. it reacts with the calcium hydroxide formed by the Portland cement hydration to form calcium silicate hydrate, the main binder phase of concrete.

There are many investigations and many years of experience to document that replacing cement with fly ash improves the technical performance of fresh and/or hardened concrete. While fly ash will improve the workability of fresh concrete it also improves durability by decreasing the concrete permeability, and by mitigating expansion due alkali silica reaction and sulphate attack. The early strength of fly ash concrete is most

[t] CEM II/ A-V-42,5R, see www.norcem.no
[u] Canada Centre for Mineral and Energy Technology. More information is found on www.ecosmart.ca

often lower than that of corresponding pure Portland cement concrete, whereas the long-term strength is increased. The heat of hydration of fly ash concrete is low, making it well suited for mass concrete structures.

The EN 450 covers fly ash from coal burned power plants, but standardisation work is going on extending the EN 450 to involve fly ash derived from 20 % co-combustion with CO_2 neutral fuels. The draft prEN 450-1 section 3.2 states:

Fly ash: fine powder of mainly spherical, glassy particles derived from burning of pulverized coal, with or without co-combustion materials.

The performance of concrete containing co-combustion has been investigated. The Netherlands has carried out many different research activities in this field[34].

Silica Fume

Although already mentioned in the literature as a supplementary material for concrete in 1952, only within the last decade or two has silica fume found considerably use in concrete. The current annual world production of silica fume has been estimated to be between 0.5 and 1.0 million tonnes, i.e. the availability of silica fume is very limited compared to other types of supplementary materials, e.g. fly ash and granulated blast furnace slag. For availability and economic reasons (silica fume is more expensive than to FA and GBFS) silica fume can only be expected to have a limited effect as a clinker reducing supplementary material.

Silica fume is a pozzolan consisting of spherical "pure" SiO_2 particles of average diameter 0.5 micron. There are many investigations and many years of experience to document that replacing cement with silica fume improves the technical performance of fresh and/or hardened concrete. As a pozzolan silica fume reacts with the calcium hydroxide formed by the Portland cement hydration to form calcium silicate hydrate, the main binder phase of concrete, leading to a denser less permeable microstructure. Due to its high k-factor and small particle size, improving particle packing in concrete, silica fume increases the strength of concrete. Also, silica improves durability in terms of e.g. alkali silica reaction susceptibility and chloride ion penetration.

Granulated Blast Furnace Slag

GBFS has been used as a partial replacement of Portland cement for at least a century. The annual production of blast furnace slag in Europe in 1999/2000 was 56.4 million tonnes: of these 33.8 million (60 %) were granulated for use in blended cement or as supplementary material in concrete. Most countries not only Europe have a rather high rate of utilisation of blast furnace slag once it has been granulated. Germany, Belgium and the Netherlands have utilisation degrees above 80 %. It has been estimated that the CO_2-emission "of concrete" can be reduced to about 40 % by replacing 75 % of Portland cement with GBFS.

The hydration of blast furnace slag in combination with Portland cement is complex, but it is well documented that the concrete made with slag exhibits low heat of hydration, low permeability and improved durability in aggressive environments.

Limestone Filler
Limestone filler or powder has been used for cement and concrete production for many years. It has been found to increase workability and early strength, as well as to reduce the required compaction energy. The increased strength is found particularly when the powder is finer than the Portland cement particles.

Nowadays the limestone filler is of particular interest for Self Compacting Concrete (SCC) where the need for fine particles to obtain adequate flow properties is essential.

In France the fly ash sources are limited due to their energy situation (nuclear power plants) while very good limestone sources exist. Therefore, limestone filler is used to a large extent in SCC and for earth dry concrete and ready mixed concrete[35].

In the Netherlands the limestone filler consumption was 130,000 tonnes per year. Also UK, Italy and Spain use limestone filler for concrete applications and for production of blended cements.

Other ashes
Wastes from other industries are also considered as supplementary materials for concrete. In Denmark Sewage Sludge Incineration Ash (SSIA) has been investigated in the Center for Green Concrete[v].

SSIA is a residual product from burning of sewage sludge and the approximately produced amounts in Denmark are 10,000-15,000 tonnes pr. year. The SSIA is reactive in concrete but the degree of activity is depending on the different burning techniques used and the source of the sewage sludge. The SSIA produced nearby the big cities has different chemical composition from SSIA produced in the areas with a lower population density.

Compared to traditionally fly ash SSIA contains heavy metals and an ongoing Danish project[w] is dealing with investigations of the leaching behaviour of new types of concrete containing residual products from other industries.

Ashes from combustion of bio fuel are used in Sweden as a supplementary material for concrete in the exposure classes with the lowest level of limitations.

Metakaolin
Metakaolin is a highly reactive pozzolan formed by the calcination of kaolinite (China clay). Considerable CO_2-emission is associated with the production of metakaolin. This considered and also bearing in mind that metakaolin is rather expensive and that only a limited production is taking place it seems unlikely that metakaolin will be a source of positive environmental impact in connection with concrete production.

[v] www.greenconcrete.dk
[w] Funded by the Danish Environmental Protection Agency, Environmental project on concrete products, 2003-2005.

Glass filler
Recent Nordic investigations have shown that recycled glass ground to approximately same Blaine fineness as cement can be used as cement replacement. Danish investigations[36] under a national research project[x] showed that the reactivity factor for glass filler was lower than 0.5, the factor normally used for fly ash in Denmark. In a test series fly ash was replaced with glass filler and the concrete strength was found slightly lower than the reference concrete. All other concrete properties investigated were at the same level or better compared to the reference concrete. In particular the glass filler were evaluated as an interesting supplementary material for concrete containing white cement, because adding the glass filler does not affect the colour of the concrete visually.

Similar results were obtained in an Icelandic investigation carried out in 1998[37] where the replacement of up to 10 % of ground bottle glass did not affect the concrete strength and decreased the ASR in the concrete.

Use of blended cement

The utilisation of blended cement across Europe is increasing. For instance the average Portland clinker content in German cements was reduced from 85-86 % in 1997 to 80.6 % in 1999, and the German cement industry is increasing its effort to promote blended cement.

However, the use of blended cement is very much dependent on national traditions and the local/national conditions. In England and Denmark there are no traditions for the use of blended cement. In Denmark 90 % of all cement used for concrete is CEM I. This is attributed to the fact that there is a long tradition among the Danish concrete manufacturers to perform the blending at the concrete plant (using fly ash and/or silica fume). The main reason for this preference is a wish from the concrete manufacturers to maintain control over the various concrete constituents separately and thereby ensure a better production.

In the Netherlands GBFS cements are wide used, because of the need of finding alternative materials for cement production. Since GBFS needs grinding before adding it to concrete production it seems obvious to implement this material directly in the cement production.

Cement manufacturers worldwide are facing demands to reduce CO_2 emissions[y] and production of blended cement is one way of meeting these demands.

Cluster 2 of the ECO-SERVE network is dealing with blended cement. Further information on the issue can be found in their reports.

---

[x] Funded by the Danish Environmental Protection Agency, 2002-2003.
[y] In 1999 the major cement manufacturers formed a Cement Sustainability Initiative under the World Business Council for Sustainable Development (WBCSD) in order to promote research and development on cement production and sustainability, http://www.wbcsdcement.org

Cement production with decreased consumption of non-renewable energy resources

Almost half the CO_2 emission from cement production derives from fossil energy carriers consumed in the process. Therefore the use alternative or waste fuels for cement production, makes cement more environmentally friendly by preserving non-renewable energy resources and thereby also the concrete in which the cement is used. Cluster 1 of the ECO-SERVE network is dealing with this aspect and further information is found in their reports.

Optimising mix design

There are many design models for optimising the mix design composition of concrete. The purpose of developing these models are primary to be able to design concrete with specific properties and a specific service life, while at the same time reducing the cost of concrete to a minimum. In most countries the expensive constituent for traditional concrete is cement. So by optimising concrete from a financially point of view in most cases also result in optimising the environmental performance of concrete. But in some regions the aggregates are the most relevant part of the concrete cost making it a question of optimising constituents in order to bring the costs of the concrete to a minimum.

One way of optimising concrete composition is by optimising the aggregate composition in order to obtain dense packing of the aggregate particles minimising the need for binder and thereby for cement (e.g. the Danish modification of Linear Packing Density Model by Glavind 1993)[38]. Other models take into account all solid particles when calculating the optimal composition[39,40] (Compressive Packing Model). Other models used across Europe are: Feret, Thaulow, De La Pena, Particle Matrix Model etc.

Another way of reducing cement content in concrete is by a careful use of admixtures. The development of normal and high range water reducing admixtures has reduced the water demand in concrete significantly and thereby also the quantity of cement. Admixtures available on the market become more and more effective. However, the optimal use of water reducing agents is dependent on the price of the admixture and on the properties of concrete. The development and use of admixtures are still undergoing huge changes and it is expected that the major part of all concrete is containing admixtures in the future.

Optimising concrete composition may also lead to improved environmental performance if the environmental profiles of the constituents chosen for the concrete are carefully taken into account. A Danish LCA on a highway bridge build in green concrete showed a reduction of CO_2 emission of 26 % just by replacing the low alkali sulphate resistant cement (CEM I 42.5 (HS/EA/≤2))[z] typically used for that kind of structures with a rapid hardening cement (CEM I 52.5 (MS/EA/≤2)[aa]). The calculations were based on a service

[z] (HS/EA/≤2) means: HS: High sulphate resistant, C_3A content ≤ 5%; EA: Extra low alkali content, the acid-soluble alkali content ≤ 0,4 %; ≤2: The water-soluble chromate content ≤ 2 mg/kg)
[aa] (MS/EA/≤2) means: MS: Moderate sulphate resistant.

life of the bridge of 75 years[41]. This change of material was possible because there was no risk of sulphate attack and therefore it was allowed to choose moderate sulphate resistant cement. The CO_2 and NO_x emissions associated with the two types of cement are listed in the table below.

	CO_2 [kg CO_2 pr. tonne cement]	NO_x [kg NO_x pr. tonne cement]	Proportion of CO_2-neutral fuel [%]
Low alkali sulphate resistant cement	1158	8.9	6
Rapid® cement	834	3.4	18

Table 3.2 CO_2 and NO_x emissions from the two types of cement produced by Aalborg Portland.

3.3.2 Recycling of waste products in concrete

For concrete production the most relevant waste products to consider for reuse may stem from:

- Recovered aggregate washed out from fresh concrete (rejected batches, excess production) and reused as concrete aggregates.
- Washing water and water from saw cutting cleared from slurry and reused as mixing water.
- Construction and demolition waste (C&DW), i.e. hardened concrete rubble, masonry, tiles etc. The aspects regarding recycling of C&DW is dealt with in Chapter 4 and for concrete purposes in particular in Section 4.3.
- Other waste materials such as granulated rubber from car tyres, crushed glass from drinking bottles or stone dust from the quarry industry.
- Fillers with and without pozzolanic properties, i.e. supplementary materials. Note that these types of materials are treated under Chapter 3.3.1.

Reuse of water

During concrete production large amounts of water is used to wash mixing equipment, trucks and formwork. Washing water contains a certain amount of cement paste (slurry) and residuals from form oil that must be separated before reusing the water in the making of new concrete. The slurry may be used to substitute the fines in new concrete. Figure 3.10 shows how concrete slurry may be treated in concrete production.

It is also possible to collect and reuse rainwater from rooftops and pavements and add this to the sedimentation basin.

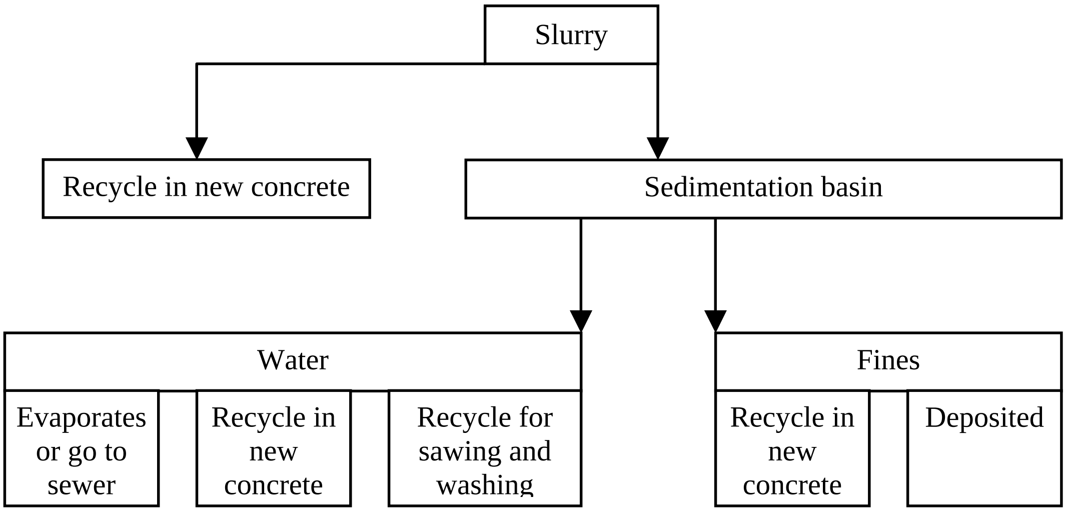

Figure 3.10 Treatments for slurry. Illustration taken from *fib* (2003b).

It is generally accepted to reuse wastewater in concrete production and the technologies are well known. This is supported by the fact that it is allowed to reuse water in concrete according to EN 206-1:2000[42]. The European standard for mixing water EN 1008:2002[43] gives a very detailed guideline for the process of determining whether recycled water is plausible for use in concrete. The step-by-step guideline may be found in Annex B of EN 1008.

The feedback from the Cluster 3 members in connection with the Workshop[bb] clearly gave the impression that water is reused in concrete production throughout Europe and that the level of utilisation is increasing. However, it is also acknowledged that there are still many production plants that need to update their recycling facilities.

However, there may be various contaminations that need to be considered before reusing or depositing the fines and the water. In Denmark the concrete industry has experienced contaminations from form oils (hydrocarbons), exceeding the threshold levels set by the authorities for polluted soil. However, it is questionable whether the soil threshold is applicable for concrete slurry. Furthermore, there is reason to doubt whether the existing leaching test methods are plausible.

These issues are currently being investigated in a Danish research project[cc] involving the Danish concrete industry. The contamination from hydrocarbons and its environmental impact are investigated. It is considered whether reusing the slurry in concrete production is plausible. By doing so it is anticipated that the oil residues are effectively confined in new hydration products. A preliminary conclusion from the project is that by changing from mineral to vegetable based form oil the amount of hydrocarbons analysed in the slurry is decreased to a very low level. The remaining hydrocarbons derives from the fuel

[bb] Held at Danish Technological Institute, February 2004.
[cc] Funded by the Danish Environmental Protection Agency, Environmental project on concrete products, 2003-2005.

used for the machinery and maybe still from the oils because some "vegetable" based oils are mixed with mineral based oils.

The member feedback from the Workshop showed that the above-mentioned problem is not recognised elsewhere in Europe - maybe because it has simply not been analysed yet.

3.3.3 Working environment

Self-compacting concrete (SCC)

The concrete industry is traditionally seen as a dirty and dangerous place to work. However, lately more focus has been put on the concept of self-compacting concrete (SCC) that needs not to be vibrated in order to flow into the formwork. This enables the contractors to omit a costly and time-consuming work process and thereby, increase their productivity. Furthermore, vibration is a noisy and wearing work operation that is having a large impact on the working environment due to the reduced physical impact on concrete workers.

In a Danish investigation from 1983[44] the risk of Raynaud's syndrome[dd] amongst concrete workers are reported to be almost twice of that of other workers. A Swedish investigation found that within 48 workers that worked at a precast plant vibrating concrete ½ - 2½ hours a day, 40 % suffered from Raynaud's syndrome. However, it should be kept in mind that concrete workers are also exposed to vibrations from chipping and cutting of concrete for instance when repairing existing structures.

The above-mentioned investigation[44] also considers the relationship between noise and hearing damage on concrete workers. There is a significantly greater risk of hearing damage if you are working with concrete and construction. The trend starts at early age and it increases until retirement. Apparently there is no connection between the various types of concrete work where you are exposed to noise and the degree of hearing damage.

Figure 3.11 shows the trend in SCC-application within the past decade. The use of SCC seems to be growing mainly for precast concrete production where Sweden and the Netherlands are leading the way. In Japan – the birthplace of SCC – the use of SCC is still below 1 % of the total concrete production.

The task of developing SCC has been going on for a decade or so, starting in Japan. According to the feedback from the members of Cluster 3 national projects have been carried out in many European countries since the mid-1990ies. All of the Nordic countries have performed or are performing national research projects. For instance in Denmark, a 3-year national research program has just been launched[ee] to prepare SCC for full-scale production and to document the improvements in the working environment and productivity.

[dd] Raynaud's syndrome is a circulatory disorder that affects hands and feet with numbness due to insufficient blood supply.
[ee] www.SCC-konsortiet.dk/english/ 2003-2006.

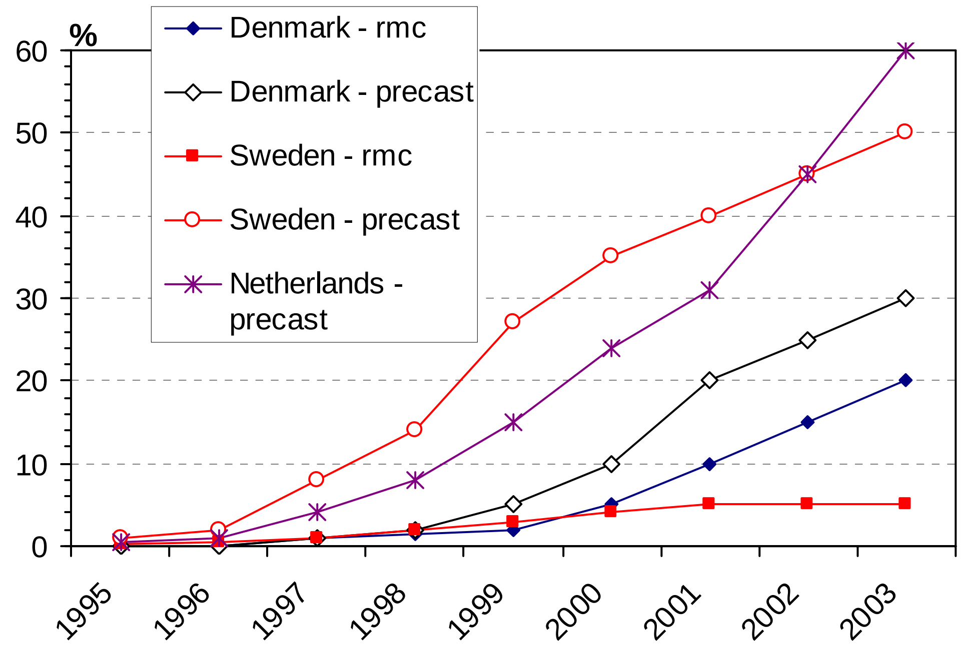

Figure 3.11 Trends for the application of SCC in ready-mixed concrete and precast concrete elements. The data are estimates collected from personal contacts by Danish Technological Institute.

Due to the need for new test methods to categorize and quantify the fresh properties of SCC a lot of work is currently being carried out on this subject both on a European level and on a Nordic level (Table 3.4).

Furthermore, RILEM[ff] hosts a technical committee TC 188-CSC on casting of SCC dealing with practical problems such as formwork pressure, finishing works and pumping/transportation.

There are still technical difficulties connected with SCC. For instance the finishing quality of the concrete surfaces seems to suffer from air voids and discolouring.

It is generally accepted that the use of SCC means an overall improved working environment at the concrete site. However, it has also been experienced that SCC means poorer material robustness and stability, for instance the time-window for finishing and protection works after casting is generally shorter than for conventional concrete. This again means higher demands on the contractor in terms of skills and education and an increased stress level on the contractor during concreting. These issues are difficult to quantify and measure but they also add up in the overall picture of the working environment.

[ff] www.RILEM.org

Admixtures

Another aspect of the working environment is the enhanced use of chemical substances in order to obtain certain performance improvements of the concrete mainly in its fresh state (e.g. retarded or accelerated hardening, reduced water need). Concrete admixtures are most often based on lignosulphonates, melamine sulphonates, naphthalene sulphonates and polycarboxylates. Some of these substances contain formaldehyde, which is normally considered a harmful substance, but the concentrations are generally low (compared to the limit value for labelling purposes).

The feedback from the Cluster 3 members clearly shows that admixtures are widely used in the concrete industry. Furthermore, no feedback indicated that the working environment is given any special focus around Europe.

These substances may cause problems when exposed to skin or inhaled. However, it is believed that admixtures are generally handled in a controlled manner so that the workers at the concrete plant are not exposed to them. Furthermore, the dosage of admixtures is rather limited meaning that for instance chromate eczema stemming from skin contact from cement paste may cause larger problems.

In 1999 the German body of producers of chemical substances for the building sector published a state-of-the-art report on admixtures for concrete with focus the environmental issues[45]. This report gives a good overview of the various products and their impact on the environment. The TESCOP project also looked into the environmental impact of admixtures concluding that the impact on working environment from admixtures seems small compared with other topics.

3.3.4 On-going and recent project summary

In Table 3.3 below a list is given regarding on-going and recent research projects and networks in the field of concrete and sustainability/recycling. The list is based on European activities reported from the members of Cluster 3 (see Table 1.1). Other sources of information have been the internet, particularly from databases at www.cordis.lu and www.e-core.org. It is recognised that such a list is bound to be incomplete and that relevant projects may be missing.

Table 3.3 Summary of on-going and recent projects involving concrete and sustainability.

Name of Project	Type of project Time period	Main Topic/Objectives *Publications*	Partners (project leader)	Web-links
TESCOP	Brite/Euram 3 1997-2000 4-year	Cleaner technologies in the life cycle of concrete products. Develop tools for assessing the environmental impact of concrete products and suggestion for cleaner technologies. *Glavind et al. (2001)*[46]	**Danish Technological Institute** Industry and research institutions from Denmark, Greece, Italy, The Netherlands. (See Cordis web site for details)	www.cordis.lu/search/ Search for Tescop
RESIBA (Recycled aggregate for construction)	National (NO) Budget 1 M Euros 1998-2002 3-year	Application of recycled aggregates in unbound use (road construction, drain layers) and as aggregate in concrete or asphalt production. The various applications are documented through demonstration projects. *English summary available from web site. Several reports in Norwegian.*	**Norwegian Building Research Institute**, building owners and contractors. See web site for project participants	www.byggforsk.no/prosjekter/resiba
Centre for Green Concrete	National (DK) Budget 3 M Euros 1998-2002 4-year	Production of environmentally friendly (green) concrete. Demonstrate the possibilities for producing and implementing green concrete including experimental documentation of its performance. *Articles and reports downloadable from web site. Project reports in Danish.*	**Danish Technological Institute** Concrete producers and contractors plus research institutions. See web site for project participants.	www.greenconcrete.dk

Name of Project	Type of project Time period	Main Topic/Objectives *Publications*	Partners (project leader)	Web-links
Concrete for the environment	Network funded by the Nordic Industrial Fund 2001-2003 3-year	Nordic consensus on sustainability in the concrete industry. Establish common understanding of concrete as a sustainable material and promote its use. *An ACI article is under preparation*	**Danish Technological Institute** See web site for project participants	www.nordicinnovation.net Search for project name
Concrete for the environment	Self-financed network 2004	Forum for exchanging experience and information. *Articles listed on web site*.	See web site for network participants	www.concretefortheenvironment.net
Eco-Concrete	Self-financed 2000-2002	To create a life-cycle tool (LCI and LCA) for use in cement and concrete evaluation. EcoConcrete created by INTRON on behalf of the Joint Project Group.	CEMBUREAU BIBM ERMCO EFCA EUROFER UEPG	
CO_2 uptake during the concrete life cycle	Funded by the Nordic Industrial Fund 2003-2005 2-year	Document the CO_2 uptake through carbonation and model its effect through a full life cycle. Guidelines for society in how to take the CO_2 uptake into account.	**Danish Technological Institute** Several Nordic participants	www.nordicinnovation.net Search for project name
Project for concrete products	National (DK) Funded by Danish Environmental Protection Agency 2003-2005	A plan of action for reducing environmental impact from concrete products has been formulated in close co-operation with the concrete industry. Several investigations have been initiated based on that plan: • hydrocarbons in slurry • recycling of crushed concrete waste • thermal properties and drying of concrete *Glavind et al. (2004)*[47] *(In Danish with short summary in English)*	**Danish Technological Institute** Aalborg Portland The council of the Danish concrete industry Support from various industrial partners	

Table 3.4 Summary of on-going and recent projects involving SCC.

SCC projects with emphasis on working environment				
Name of Project	**Type of project Time period**	**Main Topic/Objectives**	**Partners (project leader)**	**Web-links**
Rational production and improved working environment through using SCC	Brite/Euram 3 1997-2000 4-year	SCC for practical applications. Develop SCC including mix design, production methods and transportation aspects.	**NCC** (SE) Participants from Sweden, Belgium, France, Spain, U.K. See web site for details.	www.cordis.lu/search/ Search for project name
Testing-SCC	Growth-programme under FP 5 2001-2004 3-year	Appropriate test methods for SCC. Develop new test methods and asses the existing methods through round robin tests.	**University of Paisley** (UK) Participants from Sweden, The Netherlands, Denmark, Belgium, France, U.K., Iceland, Germany. See web site for details.	www.cordis.lu/search/ Search for project name
Danish SCC-Consortium	National (DK) Budget 3 M Euros 2003-2006 3-year	Increase productivity and working environment in the concrete industry. Make SCC the most common concrete material in DK.	**Danish Technological Institute** See web site for project participants	www.scc-konsortiet.dk
Nordic SCC network	Network funded by the Nordic Industrial Fund 2003-2006 3-year	Exchange results and experiences from SCC R&D activities in order to improve the knowledge of SCC.	**SINTEF** (NO) See web site for project participants	www.nordicinnovation.net Search for project name

4 RECYCLING AND USE OF RECYCLED AGGREGATES

4.1 Recycled aggregates from construction and demolition waste

The issue of recycling construction and demolition waste (C&DW) has been a subject for investigations and research worldwide for the last two decades. The generation of C&DW is increasing significantly creating major depositing problems. The development in re-use and recycling of C&DW in many European countries and other densely populated areas has been rapid over the past years, due to both lack of new building materials and increased restrictions on waste disposal. In some countries taxes have been implemented for C&DW disposal and others have legalized that all new constructions should use a certain amount of re-used or recycled material in new constructions. This type of action increases awareness of C&DW management and helps countries to focus on general planning of the issue. The progress of C&DW management, re-use and recycling is, however, still at different levels in the European countries.

Figure 4.1 illustrates the conflict between the societal and the economical issues of waste management. It is a well-known fact that most manufacturers only start recycling waste when the economical conditions dictate it. In the OECD (2003) report the political instruments for controlling the generation of C&DW are thoroughly discussed. Similar discussion is found in the Symonds report (see chapter 4.2) where it is stated that the primary non-technical barriers of re-use and recycling of C&DW are the cost of demolition, transport, crushing & sorting and disposal. The risk of illegal disposal increases with increasing cost of disposal in landfill sites.

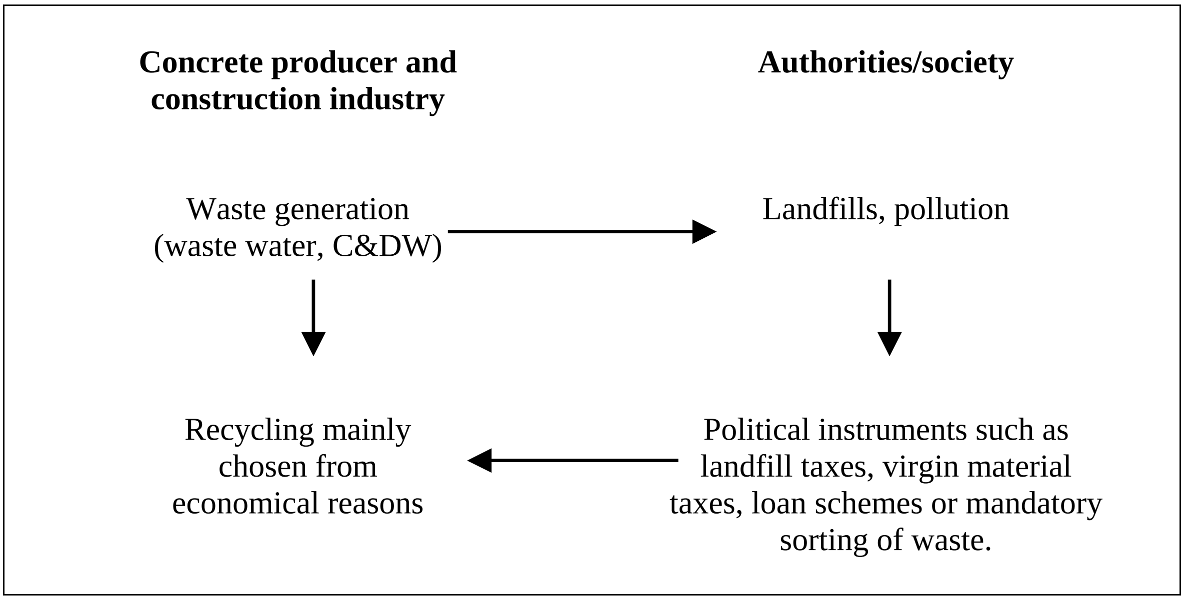

Figure 4.1 General environmental issues for waste problems in the construction sector.

4.2 Recycled aggregates in Europe

An extensive survey regarding Construction & Demolition Waste (C&DW) was carried out by Symonds (1999)[48]. Information available in that report forms the basis of the following account in Table 4.1, along with information from the first ETNRecy.net workshop on C&DW, held in 2000[49].

Country	Year of statistics (or estimate)	Concrete, brick, tiles etc (inert)	Other' Core C&DW	Sub-total ('Core'C&DW)	Population millions (1997)	'Core' C&DW (kg/ person/yr)	Country's 'Core' C&DW as % of EU-15	Cumulative %of EU-15 'Core' C&DW	Soil, stones etc.	Road planings (mainly asphalt)	Total
Germany	1994–96	45.0	14.0	59.0	82.0	720	32.8	32.8	215.0	26.0	300.0
UK	1996	n/a	n/a	30.0	58.9	509	16.7	49.5	29.5	(**)7.5	67.0
France	1990–92	15.6	8.0	(***)23.6	58.4	(***)404	13.2	62.7	n/a	(**)n/a	n/a
Italy	1995–97	n/a	n/a	20.0	57.5	348	11.1	73.8	n/a	n/a	n/a
Spain	1997	n/a	n/a	(*)12.8	39.3	325	7.1	80.9	n/a	n/a	n/a
Netherlands	1996	10.5	0.7	11.2	15.6	718	6.2	87.1	6.3	(**)2.7	20.2
Belgium	1990–92	6.4	0.3	6.8	10.2	666	3.8	90.9	27.0	(**)0.9	34.7
Austria	1997	3.6	1.1	4.7	8.1	580	2.6	93.5	20.0	1.7 (**)	26.4
Portugal	1997	n/a	n/a	(*)3.2	9.9	325	1.8	95.3	n/a	n/a	n/a
Denmark	1996	1.8	0.8	2.7	5.3	509	1.5	96.8	7.7	(**)0.4	10.7
Greece	1997	1.8	n/a	1.8	10.5	172	1.0	97.8	n/a	n/a	n/a
Sweden	1996	1.1	0.6	1.7	8.8	193	1.0	98.8	1.5	(**)2.7	5.9
Finland	1997	0.5	0.8	1.3	5.1	255	0.7	99.5	8.0	(**)0.1	9.4
Ireland	1995–97	0.4	0.2	0.6	3.7	162	0.3	99.8	1.3	0.0	1.9
Luxembourg	1997	n/a	n/a	(*)0.3	0.4	700	0.2	100.0	n/a	n/a	n/a
EU-15								100.0		- -	>450
Iceland***	**2000**	**0.11**	**0.06**	**0.17**	**0.29**	**600**			**3.5**	0.03	

Table 4.1 Estimate of the quantity of C&DW in Europe (million tonnes).

n/a Information not available.
(*) Estimated: Population times estimated quantity of C&DW.
(**) From an OECD-report
(***) Corrections have been made to the total amount of C&DW in France, from 8 million tonnes to 32 million tonnes, resulting in 548 kg /year per capita.
(***) Information from reference: Construction and demolition waste in Iceland.

The amount of C&DW is of great importance, of which a thorough account is given in the Symonds-report, which also discussed the importance of the classification and measurement techniques used on C&DW. Most countries use the European Waste Catalogue (EWC) for categorizing C&DW. The EU Member States rely on different building materials and these have also changed over the years, resulting in subtle differences when C&DW is categorized. As an example, material for road construction, excavated soil, outdoor-pipes and –cables, and vegetation are not considered C&DW, according to the classifications of many countries. This however is in contrast with the EWC, where road construction waste and excavated soil is classified in group 17 05 00, which is C&DW.

Of the main conclusions of the Symonds-report is the fact (in the year 1999); that on landfill sites, C&DW is equal to domestic waste; that the amount of C&DW, which may be re-used or recycled with today's technology, is only about one fifth of the amount of fresh aggregates used; that the road construction industry is the largest user of aggregates; that transport and the recycle processes are important factors in both cost and environmental assessments

Since concrete consists of about 75 % aggregate by volume a total European concrete production of almost 600 million m^3 corresponds to about 450 million m^3 of aggregates. In the EU it is roughly estimated that 180 million tonnes C&DW (excluding soil) are produced annually according to OECD. If we assume that 50 % of this waste material is plausible to crush, upgrade and recycle as aggregate in new concrete it corresponds to about 45 million m^3 (roughly 1 m^3 is equal to 2 tonne) i.e. one tenth of the concrete for aggregate consumption.

Furthermore, it is estimated that these 180 million tonnes C&DW will almost double in 2010. A recent Icelandic investigation[50] on classifying and quantifying C&DW in Iceland reports that the annual amount of C&DW in Iceland is about 600 kg per capita while in the EU-countries (before enlargement) it is on the average about 480 kg, according to the Symonds report.

This is far less than 10 % of the per capita consumption of primary aggregates.

Authorities in several countries in Europe are discussing to – or have already – imposed taxes on primary aggregates, partly in order to promote recycling of secondary aggregate. These taxes are of the order of 0.1 to 2.5 € per tonne (UK highest). For the motivation of a change into more recycled products this will hardly be a relevant tool, since the theoretical percentage of recycled aggregates can hardly exceed 10 % - unless one should start demolishing buildings solely for the purpose of "quarrying". The gradual transition from sand/gravel to crushed materials as discussed in chapter 2 would in this context be a more appropriate alternative.

Since the major part of C&DW consists of materials such as concrete, brick, stone and asphalt it would be advantageous if these materials could be recycled in the construction industry after demolition.

According to the Symonds report, 17 % of C&DW in Germany is recycled and 45 % in the UK. This proportion is 65 % in Germany and 80 % in the UK, according to the report following the first seminar on C&DW of the network ETNRecy.net/RILEM in 2000. These figures show that the overall proportion of recycled material in the Member States is increasing. They also highlight the need for a standardised and more accurate procedure for categorizing C&DW for a better sorting into what is recyclable and what is re-used.

4.3 The use of recycled materials in construction

4.3.1 Research and standardisation

Lack of standardisation has traditionally been an obstacle for the utilisation of recycled materials in construction, especially for the more demanding applications (like structural concrete) where the different and variable properties of the recycled aggregates as compared with mineral aggregates have been a challenge.

During the last more than 20 years much R&D has therefore been conducted in several countries worldwide to make up a basis for materials and production recommendations or standards.

The most comprehensive collection of research and knowledge on the subject has been collected in the auspices of RILEM[gg] through several technical committees:

- TC-37 Demolition and reuse of concrete, 1976-1989. Organised the 1st Symposium on Demolition and Reuse of Concrete in Rotterdam in 1985 and the 2nd in 1988 in Tokyo. The work of the committee is summed up in an extensive state-of-the-art-report in RILEM Report 6[51].

- TC-121 Guidance for demolition and reuse of concrete and masonry. Organised the 3rd RILEM Symposium on Demolition and Reuse of Concrete and Masonry in Odense, Denmark, October 1993. Published recommendation on specifications for recycled aggregate concrete[52].

- TC-165 SRM Sustainable application of mineral raw materials in construction. Published a state-of-the-art on "Sustainable Raw Materials – C&DW" in RILEM Report 22[53]

- TC-URM Use of recycled materials in construction.

These technical committees have gathered conference proceedings and produced state-of-the-art reports covering research and practical activities from all over the globe. Their work focuses on the demolition process itself, the sorting and processing of C&DW, as well as requirements for materials use. In RILEM TC-37 (1992) the state-of-the-art covers the period from 1945-1989 with references on the subject emerging in the mid-seventies. Thus, it is not a new idea to recycle C&DW in e.g. concrete in order to preserve the natural aggregates, or to minimise waste deposition.

The later RILEM committees cover activities and knowledge up to recent time, and the present one (TC-URM) which is chaired by professor Hendriks of Delft University and has been active a few years, will make an up-to-date publication next year following the international conference on recycled materials in buildings and structures, to be held in Barcelona in November 2004.

[gg] www.RILEM.org

Several European countries have produced National standards, norms and/or recommendations – much on the basis of the RILEM committees – covering production and environmental issues as well as the requirements for use in concrete and road construction respectively. This applies to e.g. Austria, Denmark, Germany, the Netherlands, Norway, UK and Ireland. The Dutch CUR recommendations were among the pioneering National guidelines on the subject, and in the early 1990ies a CEN TC 154 ad hoc committee led by Dr. Collins of BRE was given the task to draft an amendment on recycled aggregates to the new European aggregate standards.

The European thematic network ETNRECY.net – led by BBRI – joined at the turn of the millennium practitioners and researchers from most parts of Europe to share results and experience in an experience database, covering a broad range of recycling issues. It will reach too far to make an account of all relevant, recent and on-going research in this area. But it is fair to claim that the basic materials properties involving e.g. the workability, strength and durability of concrete are by far state-of-the-art knowledge. Most research is now focusing on different application areas, product development, local/regional implementation of technology, economy, environmental issues, legislative issues and effective production – to mention some.

4.3.2 Priorities for use

The existence of landfill taxes in many European countries mean that there is an obvious reason for finding alternative applications of C&DW. According to information from Cluster 3 members, the application today for C&DW is mostly in road constructions or landfills in the following countries: Norway, Denmark, Finland, France and Iceland. In Austria it is mostly used for producing concrete, in Britain and the Netherlands it is normal to recycle and use in both new concrete and sub base, and in Greece it is not allowed for use in new concrete.

The prioritising of area of use will naturally vary quite a lot between the countries, depending on e.g. the availability and quality of primary aggregate resources, as well as recycled ones, market location and transport distances, local price levels, National legislation and taxation – and probably several other factors as well.

One of the messages from the Cluster 3 members[hh] showed that the possibilities for using recycled aggregates as a substitute for natural aggregates in concrete production exist in several countries. Recycled aggregate from concrete and brick rubble may be implemented in new concrete according to standard recommendations from e.g. Norway, The Netherlands, Belgium, Germany, Austria and the U.K. In Denmark it is also possible to use recycled aggregate for concrete production but it is not allowed to use it for structural purposes (load-carrying beams, walls, columns). The use of recycled aggregates is also taken in as part of European standards (EN 12620).

At present the economical reasons for applying recycled aggregate into concrete production as compared to e.g. road construction, are limited in most European countries. One important economical issue is the storage facilities at a concrete plant. If new

[hh] Given during Workshop held at Danish Technological Institute, February 2004.

materials are added to the production the storage facilities need to be updated and extended. Another important issue is the consistency in supply and the transport distances. It seems most appropriate that C&DW is crushed and used locally and therefore a stable supply may only be maintained around major cities. In the Netherlands, a requirement for a minimum content of recycled aggregates in new concrete has been applied in some cities, first of all with an environmental argument, but also due to the supply situation of primary aggregates. In Norway, use of recycled concrete as aggregate has proved successful at precast factories, which can recycle their own wasted hollow core elements instead of transporting them to a waste deposit. Except for this, an alternative use as e.g. sub base is normally more feasible.

Most of the technologies needed to apply recycled aggregate into concrete production already exist, along with extensive reports on the documentation of mechanical as well as durability properties. However, such use depends either on extensive sorting and upgrading since the C&DW is often a mix of concrete, steel and bricks giving a rather poor (inhomogeneous) quality of aggregate. Or it requires a strict delivery control and quality assurance to limit and trace the origin of the materials – which will e.g. be the case in a prefab factory, but not in an urban receptory of C&DW.

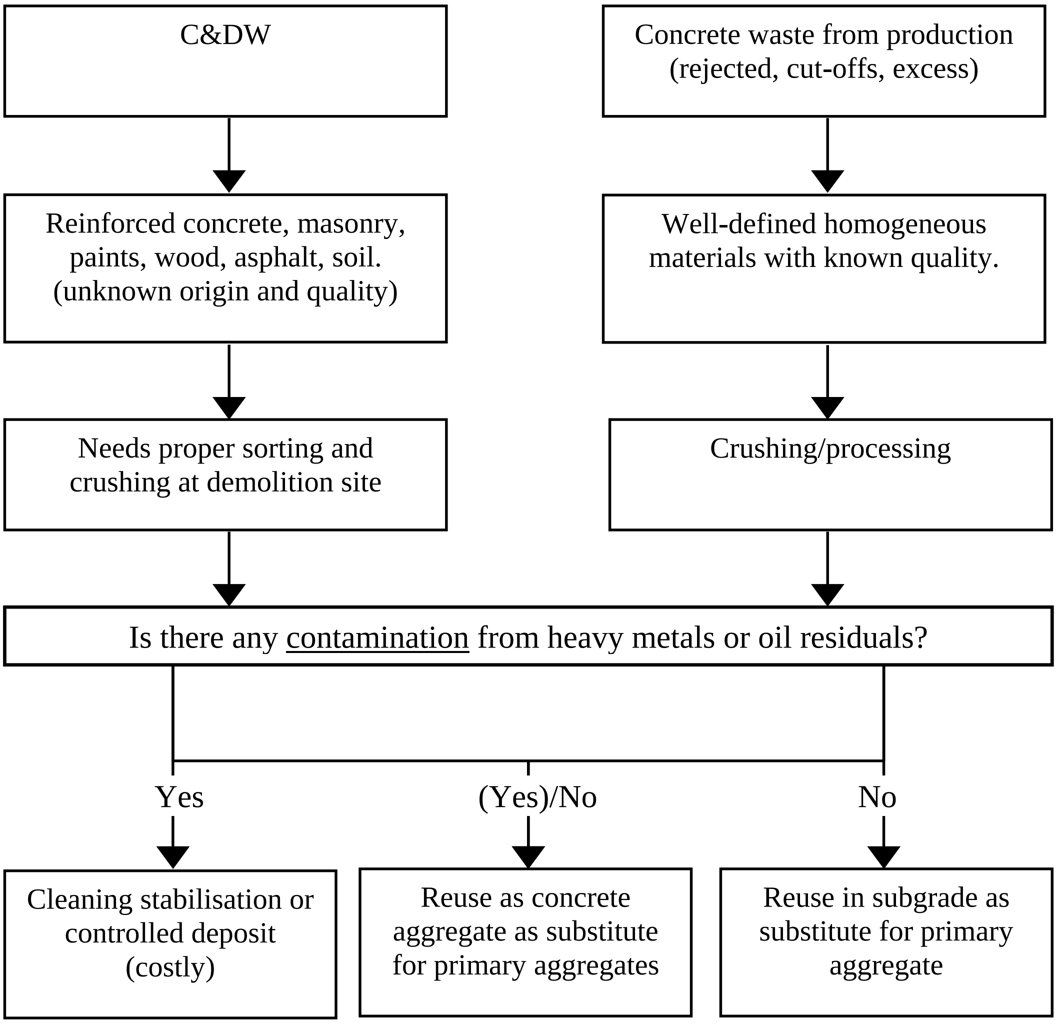

Figure 4.3 Treatments for hardened concrete waste

4.3.3 Recycled aggregates in concrete

Most of the research that has been carried out on the subject of recycling C&DW in concrete production concerns the technical aspects of:

- Crushing, grading and processing of the C&DW, i.e. production of recycled aggregate in order to obtain a sufficient quality and performance.
- Mixing and batching of recycled aggregate concrete, i.e. production of concrete based on recycled aggregate.
- The mechanical properties of recycled aggregate concrete and its durability performance compared with conventional concrete.

From the literature there seems to be a common agreement that the main technical problems facing further exploitation of recycled aggregate for concrete production are:

- Production aspects associated with the increased water absorption for recycled aggregate. This is particularly the case for the sand fraction.
- Slightly lower performance of recycled aggregate concrete. Depending on the degree of substitution and whether both coarse and fine aggregates are substituted.

It seems that most of the recommendations that exist are based strongly on the RILEM specifications published in 1994. Here recycled aggregates for concrete are basically categorised into:

I. Primarily produced from masonry rubble.
II. Primarily produced from concrete rubble.
III. Mix with minimum 80 % natural aggregates, maximum 10 % of type I and the remaining part of type II.

The same categorisation is applied by the BRE in their digest on recycled aggregates.[54] When using recycled aggregates of type III where only a part of the natural aggregates are substituted it is assumed that the mechanical properties are unchanged from those of a conventional concrete based on natural aggregates. When a full substitution is performed strength, stiffness, creep and shrinkage properties are expected to change, which needs to be taken into account in the structural design.

Typically it is recommended that only the coarse fraction be substituted by recycled aggregates. Furthermore, the specifications set limits for the amounts of foreign materials in the recycled aggregates. Typically up to 1 - 1½ % by weight is allowed to consist of steel, glass, wood, plastics, and clay, which should be controlled by the producer.

5 EUROPEAN LEGISLATION AND STANDARDISATION

In the concrete and aggregate industry and in many other industries the level of how environmentally friendly the industries are able to act is to a high degree determined by the legislation the industries are forced to fulfil. In addition to that the environmental friendliness is determined by the financial situation. In other words if environmentally friendly technologies at the same time lead to a financial benefit it is easy to convince the industry to act environmentally friendly, but the opposite situation is more or less unrealistic.

The European standardisation body, CEN, has published a guide for the inclusion of environmental aspects in product standards[ii]. Its scope is e.g. to raise awareness that provisions in product standards can affect the environment and to recommend the use of life-cycle thinking and recognized scientific techniques when addressing environmental issues of a product being standardised.

The European situation with regard to standardisation within the building area is characterised by the fact that requirements for building products are being harmonised as a consequence of the Construction Product Directive[jj]. The main purpose of the CPD is to improve the free market in Europe in the building industry. The idea is to have similar requirements to the products all over Europe in order to contribute to free mobility of products throughout Europe and thereby improve the competitiveness in the building trade. Products fulfilling a harmonised standard[kk] will be CE marked. Cement is the first building product which has been CE marked.

CE marking of aggregates is optional in the different CEN countries – some of them have decided that aggregates shall be CE marked and others have not. But all of them must use the CEN standards for aggregates, including the factory production control and comply with Annex ZA to fulfil requirements for CE-marking.

For some products it is difficult to specify harmonised requirements because the materials (geologic origin etc.) and climate is different in various regions throughout Europe. That means that each country has to specify their own additional requirements to the common EN standards in order to make them operational in the place of use.

These national requirements are specified taking into account previous expertise, national traditions, local climate conditions, level of technology etc. Therefore the ability of environmental awareness will also be reflected in the national standards, and extensive information on environmental performance on the aggregate and concrete industry can be obtained by studying the national legislation.

[ii] Guide 4, edition 1998, http://www.cenorm.be/boss/supporting/reference+documents/cen+guide+4.asp
[jj] Council Directive 89/106/CE
[kk] For more information on the harmonised European standards, see www.cenorm.be

5.1 Standardisation in the aggregate industry

Technical committee TC 154 within CEN deals with aggregates. Most of the TC 154 standards have been issued as formal EN-standards. The transition period started in March 2003 and as of June 1st 2004 all the test standards as well as the product standards have replaced all conflicting standards, which have been in use in European Economic Area.

Several different test standards as well as production standards for the different applications of aggregates belong to TC 154 and a comprehensive list can be found at the web site of CEN[ll].

Aggregate production has to comply with Annex ZA of the product standards to fulfil requirements for CE-marking. The Annex gives information about essential characteristics that have to be declared. It also presents procedures for attestation of conformity of aggregate production as well as the systems, which lead to the CE-marking of the product. There is an option between two attestation systems for aggregate production, 2+ and 4. The difference between the two systems is that when using 2+ a third party (Notified body) carries out an initial inspection of factory and factory production control, FPC, as well as continuous surveillance and approval of FPC. System 4 on the other hand does not require a third party to be involved in any conformity tasks as the producer himself carries out all the necessary inspections.

The levels of attestation vary between countries, for example, Germany has chosen 2+ for all aggregates, Sweden has 2+ for aggregates in concrete, asphalt, railway ballast and unbound road base and Denmark has 2+ for aggregates in mortar and concrete.

Although there are some uncertainties concerning the implementation of the package of European standards for aggregates, it seems clear that it is anticipated that National Guidance Documents (NGD) are to be produced by each participating country to help with the implementation of the new European standards.

The National Guidance Document can give information on how the transition to CEN standards should take place. They can also give information on the CEN test methods that will be used and which national test methods will be withdrawn. The documents can state the relationship between the traditional methods and the new CEN methods in some cases. Additionally, the NGD documents can give recommendations for requirements for each end use selected from the relevant product standard categories to clarify the transition. In any case the NGD should be guidance only and it should not present any additional requirements to the CEN product standard. The requirements shall be chosen from the relevant product standard categories. The BSI of UK has already published national guidance documents that are thought to constitute a suitable model for providing such guidance. The formulation of a national guidance paper is each individual Member Bodies' responsibility and not a matter for CEN.

[ll] www.cenorm.be

The CEN Commission Services recommend that the “guidance” for the use of harmonised standards should be developed as a “CEN-report”, or as a “report” or “guidance for good practice” elaborated and published by a National Standardisation Body. Such documents cannot change or alter any provision included in the harmonised European standards.

The package CEN TC 154 of standards was implemented on 1st of June 2004 and all co-existing standards are withdrawn. In the coming years individual test standards as well as product standards will be due for the 5-year revision.

5.2 Standardisation in the concrete industry

There is no mandate for ready mixed concrete, which means that there is not a harmonised standard for ready mixed concrete. Ready mixed concrete shall therefore not be CE marked. This is due to the fact that it was not possible to agree on the harmonised durability requirements within Europe and also because it is unrealistic to imagine that ready mixed concrete will be produced e.g. in Spain and sold in Germany. In contradiction to that the standards for prefab concrete are harmonised which means that concrete panels in the future shall be CE marked.

The European standard for concrete is EN 206-1 Concrete – Part 1: Specification, performance, production and conformity. This is a voluntary standard in the member states, but the member states have to implement it anyway because as a member of CEN the European national standardisation bodies are forced to withdraw conflicting national standards and replace them with the EN standards.

In fact the EN 206-1 contains very few specific requirements for concrete. Most of the specified requirements are optional in the place of use, which means that each member state shall consider the specifications and make them normative or not in a national application document.

This is being done right know throughout Europe and it appears that the requirements to concrete will still be very different from one part of Europe to another.

In the next phase of the work in Cluster 3 in ECO-SERVE it is decided to look into the different national application documents in order to evaluate the requirements from an environmental point of view.

5.3 Standardisation and sustainable production

Legislation and standardisation need to be addressed as prerequisites for obtaining a more sustainable production: Economic incentives for the industry will by far be based on standards and regulations – and without economic incentives behind the environmental issues, there will be no development in a sustainable direction.

As per today, however, it is fair to say that EU standards and most national standards hold very little incentives that can promote a more environmentally friendly and sustainable production and use of aggregates and concrete. There are requirements mostly to purely engineering properties, like (for aggregates) strength and abrasion resistance, putting the economic incentives specifically on materials quality parameters and not on environment related factors like transport distance/energy use, content of secondary materials and optimum use of resources. The often-experienced long transport of mechanically "better" aggregates to obtain a marginal improvement as to standardized strength parameters is one example. The tendency with e.g. public specifiers to require more narrow fractions that lead to more surplus and waste depositing is another one.

It has been predicted that the next revision of materials standards will be more influenced by people advocating environmental viewpoints, and not solely by traditional technocrats. Probably this could be the most important single event to promote a development towards more sustainable production in these industries.

6 RESEARCH NEEDS

6.1 Technological foresight – what lies in the future

The aggregate and concrete industries can be designated so called "mature industries"; mineral resources have been exploited during most of our known civilisation, and concrete has been produced and developed more or less since Roman time. Thus, technologically, these industries have come into a mature stage of slow, gradual improvement, rather than a stage where major leaps in development can be expected. Still, however, being sectors with great influence on economy, infrastructure, employment and environment, there is a need to continuously consider new options and challenges, and any major research result will have a great societal impact.

As already discussed in this report, the probably most urgent needs for these industries in the near future will be to comply with the increasing requirements from society to sustainability and environmental profile. A real challenge will be to merge the environmental issues – and demands – with the normal industrial requirements; to create industrial plants and products which are at the same time environmentally friendly and economically profitable. Guidance documents, national ones as well as from EU, clearly state the necessity of planning from a viewpoint of sustainability – which incorporates the minimizing of waste depositing, energy use and emissions, as well as the management of natural resources.

In the next generation of European standards, pure technological requirements may be gradually changed with environmental priorities. And in the future, probably only those branches and companies will survive, who can earn their public acceptance from an active use of environmental parameters in their planning and execution of own activities.

Some specific future prospects to be expected, and that will rule our need for research:

- There will be an on-coming shortage of sand/gravel resources, especially near populated areas; in many countries this will become critical within the next ten years.
- Still more countries will apply taxation of resource exploitation to regulate their resources, and of waste depositing to encourage recycling.
- There will be (even more) strict regulations on
  - Land-use and area preservation.
  - Waste deposits – for all purposes.
  - Protection of the neighbourhoods of quarries and plants as to noise, emissions and traffic.
  - The documentation of the health effect of materials produced.
  - Requirements for using substitute materials to reduce emissions (e.g. CO_2) and to save resources.
- But at the same time, there will be an increasing understanding in society for the general need for these materials, and thus a willingness to create new solutions.

Permissions to open new quarries will be linked to acceptable end-use plans after completed quarry period, to concepts for integrated plants (quarry/concrete plant/asphalt plant/recycling), and in densely populated areas even to sub-surface "aggregate mining".

6.2 Challenges for research – how do we meet the needs?

Research activities to meet these needs may be considered in e.g. four groups. Some of the most urgent areas will be:

Concept development

- Further development of "integrated plant" concepts to increase profitability while keeping up an environmental profile: See how over-all concepts of resource management – quarrying as an integral part of short term industry development as well as long term land use planning – can put the aggregate industry stronger into the value-chain, to meet environmental and societal needs. This will involve the development of fully integrated production units combining aggregate production and end-use production in the same plant, quarry planning based on long term land-use perspectives and restoration purposes like e.g. housing, recreation or waste deposits, and finally transport logistics that minimise pollution and traffic loading in utilising local alternatives
- Develop economically feasible sub-surface solutions for hard rock quarrying in combination with industrial activities (especially waste handling – deposition and recycling) in urban areas.

Production technology

- Develop reliable production systems (crushing, sorting) to make high consistent quality aggregates in all sizes from hard rock, with less energy consumption.
- See how alternative techniques for quarrying and refining marginal natural resources influence their properties as concrete aggregates.
- Development of a new technology for obtaining and refining industry filler from sludge.
- Develop towards less errors and reclamation from production and execution of concrete.
- Develop a technology towards zero waste at concrete plants.
- Eliminate substances harmful to health and safety, e.g. reduce amount of carbon hydroxide in concrete wastewater and crushed concrete

Basic materials knowledge

- Study whether and how, alkali reactive fillers can replace/supplement conventional pozzolanic materials in concrete.
- Study how aggregates from assorted rocks and minerals can be utilised to control concrete properties regarding durability, strength, elasticity and density.
- Research to be able to utilise concrete's potential for reducing the heating/cooling need in buildings (its thermal capacity). In the total life cycle of a concrete building, the thermal properties have a major impact on the total energy consumption of the structure.

- Continue the work with finding alternative, environmentally neutral products for concrete as a substitution for cement and utilise the guideline for how to implement new alternative constituents in concrete.
- Investigation on CO_2 uptake (Carbonation of concrete surfaces)

Application technology of materials

- Establish a relation between how various rocks and minerals are extracted, crushed and further refined, and the properties of the end products (especially crushed fine aggregates and filler) when used in concrete, with emphasis on water demand (concrete economy) and workability.
- Develop mix design concepts that optimise the cost/performance of different sorts of concrete with new kinds (local sources) of aggregates, especially filler and sand.
- Develop exact models, which make it possible to tailor-make concrete for its specific use.
- Create the technical basis for utilising self-compacting concrete as a contribution to improved working environment.

7 REFERENCES

[1] COM (2001) 94 final, 21.1.2001: "Proposal for a council decision concerning the multiannual framework programme 2002-2006 of the European community for research, technological development and demonstration activities aimed at contributing towards the creation of the European research area"

[2] OECD (2001): Report on sustainable development: *Policies to enhance sustainable development* (Draft policy report presented to the meeting of the ad hoc group of national officials on sustainable development in Paris 19-20 Feb. 2001)

[3] Danielsen S.W. & Ørbog A., 2000: Sustainable Use of Aggregate Resources through Manufactured Sand Technology. *Quarry Management*, July 2000, 27(7), 19-28.

[4] Geological Survey of North Rhine-Westphalia, 2002: Third European Conference on Mineral Planning. Raw materials Planning in Europe. Change of Conditions ! New Perspectives? http://www.gd.nrw.de/ecmp/ 211 pages.

[5] Department of the Environment, HMSO, 1995: Minerals Planning Policy and Supply Practices in Europe, Main Report 96 pp, with Technical Appendices.

[6] Chapman, G.R., taylor, L.E., Bonel, K.A., Hillier, J.A. & White, R., 2003: The European Mineral Statistics 1997–2001. A product of the World Mineral Statistics database, British Geological Survey. http://www.bgs.ac.uk/bookshop/product.cfm?id=WMS01EUR 296 pages.

[7] Norwegian Geological Survey, 2003: Mineralressurser i Norge. Bergindustrien i 2002. NGU rapport 2003.040, 23 pp. (In Norwegian).

[8] Norwegian Geological Survey, 2003: Norway´s coastal aggregates. Production in 2002 and potential. NGU rapport 2003.042, 30 pp.

[9] British geological Survey (BGS), 2003: Collation of the results of the 2001 aggregate minerals survey for England and Wales. Commissioned Report CR/0353N (www.mineralsuk.com/free_downloads.html#AM2001), 103 p.

[10] British geological Survey (BGS), 2003: United Kingdom Minerals Yearbook 2002 (http://www.bgs.ac.uk/mineralsuk/statistics/uk/ukmy.html)

[11] National Statistics, 2003: Mineral Extraction in Great Britain 2002 (www.statistics.gov.uk/STATBASE/Product.asp?vlnk=606)

[12] Lindgård, J., & Johansen, K., 1995_a: Maskinsandforedling og ny anvendelsesteknologi i betong. Delrapport I: Praktisk anvendelse av maskinsand. SINTEF Konstruksjoner og betong, rapport nr. STF70 A95085, 15 pp. (In Norwegian).

[13] Lindgård, J., & Johansen, K., 1995_b: Maskinsandforedling og ny anvendelsesteknologi i betong. Delrapport II: Dokumentasjon av materialegenskaper. SINTEF Konstruksjoner og betong, rapport nr. STF70 A95086, 45 pp. . (In Norwegian).

[14] Danielsen, S.W. & Ørbog, A., 2000: Sustainable Use of Aggregate Resources through Manufactured Sand Technology. *Quarry Management*, July 2000, 27(7), 19-28.

[15] Franzefoss Pukk AS 2001: *Production and use of manufactured sand in Norway*, Final report April 2001, Franzefoss Pukk AS.

[16] Heikkilä, P., 1991: *Improving the Quality of Crushed Rock Aggregate*. PhD. Helsinki University of Technology.

[17] Nordberg, 1999: SAND. Applications, Manufacturing, Classification, Requirements. Norberg Way of Sand making. Norberg-Lokomo 28.09.1999.

[18] Hudson, B. 1996_a: The Effect of manufactured Aggregate and Sand on Concrete Production and Placement. Svedala P437-1-8/96. 10 pp.

[19] Hudson, B., 1996_b: Flour Power. The influence of minus 75 micron material on concrete, as well as the importance of particle shape with manufactured sand.

[20] Hudson, B, 1998_a: Impact of manufactured sand in concrete. *Quarry*, December 1998, pp 1-4.

[21] Hudson, B., 1998_b: Aggregate Shape Affects Concrete Cost. *Quarry*, November 1998, pp 1-4.

[22] Hudson, B., 1999_a: Concrete Workability With High Fines Content Sands. *Quarry*, February 1999, pp 1-4.

[23] Hudson, B., 1999_b: Crushers affect product quality. *Quarry* April 1999. pp 1-5.

[24] Wigum, B.J., Hólmgeirsdóttir, Th., Danielsen, S.W. & Andersen, O.V., 2004: *Production and Utilisation of Manufactured Sand for Concrete Purposes*. Hönnun, Iceland, 47 pages.

[25] The Mining, Minerals and Sustainable Development (MMSD) Project (http://www.iied.org/mmsd/)

[26] fib (2003a) *Environmental effects of concrete*, fib bulletin 23, Federation International du Beton, Lausanne, Switzerland, 63 pp.

[27] Liu, T & Meyer, C. (editors) (2004) *Recycling concrete and other materials for sustainable development*, SP-219, ACI.

[28] ICIP, (2000) *State of the Art on Concrete – formwork - reinforcement - sustainable concrete - new concrete*, Intron, The Netherlands.

[29] fib (2003b) *Environmental issues in prefabrication*, fib bulletin 21, Federation International du Beton, Lausanne, Switzerland, 49 pp.

[30] OECD (2003) *Environmentally sustainable buildings*, OECD Publications, Paris, France, 195 pp.

[31] Josa, A., Aguado, A., Heino, A., Byers, E. & Cardim, A. (2004) "Comparative analysis of available life cycle inventories of cement in the EU", *Cement and Concrete Research*, Accepted for publication.

[32] EN 197-1:2001, *Cement – Part 1: Composition, specifications and conformity criteria for common cements*, CEN, Brussels.

[33] Jahren, P. (2003) *Greener Concrete – What are the options? – the CO_2 case*; SINTEF Civil and Environmental Engineering, 84 pp.

[34] Vissers, J.L.J; 2001; Fly ash obtained from co-combustion: A state of the art report on the situation in Europe.

[35] Piscaer, B (2003) "Limestone Fillers or Calcium Carbonate Fillers (CCF), a welcome CO2 reducer", Presentation on the Nordic Seminar *Concrete- the sustainable construction material*, November 11-12, 2003, Oslo.

[36] Hasholt, M.T., Mathiesen, D., Hansen, H. & Thøgersen, F. (2004) *Metoder til genanvendelse af farvede glasskår til produktion af tegl og beton og til vejbygning – fase 2*. (In Danish). The Danish Environmental Protection Agency; Copenhagen, 116 pp.

[37] Sveinsdottir, E.L., Wallevik, O. & Gunnarsson, G. (1998): *Recycled fines in concrete – Icelandic materials*, The Icelandic Building Research Institute, 98-10, 52 pp.

[38] Glavind, M., Olsen, G.S. & Munch-Petersen, C. (1993) "Packing Calculations and Concrete Mix Design", *Nordic Concrete Research*, Publication no. 13.

[39] Larrard, F. (1999) *Concrete Mixture Proportioning – A scientific approach*, E&FN Spon, London, pp. 1-73.

[40] Gram, H.E. (2002) "Concrete Mix Design – A software-based system for mix design of concrete", Proceedings XVIII *Nordic Concrete Research* Meeting, Elsinore, Denmark, pp. 89-92.

[41] Tølløse, K.; 2002; *Miljøscreening af Betonbro* (In Danish); Centre for Resource Saving Concrete Structures, Danish Technological Institute, 18 pp.

[42] EN 206-1:2000, *Concrete – Part 1: Specification, performance, conformity*, CEN, Brussels.

[43] EN 1008:2002, *Mixing water for concrete*, CEN, Brussels.

[44] Damlund, et al. (1983) *Nedslidning i jord- og betonarbejdet* (in Danish), Arbejdsmiljøfondet, Copenhagen, 214 pp.

[45] Deutsche Bauchemie (1999) *Concrete admixtures and the environment*, State-of-the-art-report, Deutsche-Bauchemie, Frankfurt, 35 pp.

[46] Glavind, M., Damtoft, J.S. & Rottig, S. (2001) "Cleaner technology solutions in the life cycle of concrete products", in *Proceedings of CANMET/ACI International Symposium for Sustainable Development of Cement and Concrete*, San Francisco, September 2001.

[47] Glavind, M., Bødker, J., Mathiesen, D. & Pommer, K. (2004) *Produktområdeprojekt vedr. betonprodukter – Handlingsplan* (in Danish), Danish Environmental Protection Agency, Copenhagen.

[48] Symonds, in association with ARGUS, COWI and PRC Bouwcentrum, (1999): Report to DGXI, European Commission – Construction and Demolition Waste Management Practices, and Their Economic Impacts.

[49] 1st ETNRecy.net/RILEM Workshop, (2000) Proceedings – *Use of recycled materials as Aggregates in the Construction Industry*.

[50] Edda Lilja Sveinsdottir et.al., (2002) "Construction and demolition waste in Iceland – part I: Classification and quantity". IBRI-report no. 02-03, March 2002, 48 pp

[51] RILEM TC-37 (1992) *Recycling of demolished concrete and masonry* (Ed. T.C. Hansen) Report 6, E&FN Spon, London, 305 pp.

[52] RILEM TC-121 (1994) "Specifications for concrete with recycled aggregates", *Materials and Structures*, Vol. 27, pp. 557-559.

[53] RILEM TC-165 (2001) *Sustainable raw materials – Construction and demolition waste* (Eds. Hendriks & Pietersen) Report 22, RILEM Publications, Paris.

[54] BRE (1998) *Recycled aggregates*, Digest 433, Building Research Establishment, Watford, UK, 6 pp.